HISTORY OF BROADCASTING:

RADIO TO TELEVISION

INVENTION and INNOVATION in the RADIO INDUSTRY

With a Foreword by KARL T. COMPTON

W. Rupert Maclaurin

$6.00

This book is a study of great technological innovations in the radio industry—tracing the development of radio from its scientific origins in the 19th century to its accomplishments of today, including FM and television. Attention is focused on key inventors and innovators to determine what personality requirements are needed for successful innovation. The role of new firms in introducing technical innovations is explained. The strengths and weaknesses of the large corporation in bridging the gap between scientific research and the introduction of new commercial products is examined. The book provides also an opportunity to see how the patent system has been working. Has it been an inducement to invention—to investment in research? Are there patent abuses that retard progress and, if so, how should they be corrected?

The result is a basic descriptive analysis of a major American industry, written in terms easily understandable to the layman. It should provide an important document for the formulation of public policy. It should also contribute to an organized and systematic theory of economic development based on observation and experiment.

The book is the first volume in a series of studies on the economics of innovation being undertaken—under the direction of Professor Maclaurin—at the Massachusetts Institute of Technology.

Jacket design by Meyer Wagman

W. RUPERT MACLAURIN

Dr. Maclaurin is Director of the Industrial Relations Section, Massachusetts Institute of Technology. He has had a distinguished career as university professor, industrial analyst, consultant to a considerable number of business concerns and as Secretary, Bowman Committee on Science and the Public Welfare, Office of Scientific Research and Development. He is author of *Economic Planning in Australia* and *The Movement of Factory Workers.*

Important Dates in the History of Radio Invention and Technology

1887—Hertz transmits and detects wireless signals in his laboratory

1896—Marconi receives a radio message over a distance of two miles

1907—De Forest applies for patent on the triode, revolutionizing radio art

1915—American Telephone and Telegraph transmits wireless telephone signals from Arlington, Virginia, to Eiffel Tower, Paris

1920—First regular broadcasting programs received on modern vacuum tube sets

1928—Vladimir K. Zworykin produces photo-electric tube for television transmittal

1933—Introduction of small sets opens new market for receivers; Edwin Armstrong announces system of FM

1936—RCA opens experimental television station on top of Empire State Building

1941—FCC fixes standards for full commercial operation of television broadcasting

The story of these innovators and their inventions, together with the "perennial gale of competition" and patent litigation which followed most of the advances, makes a revealing and fascinating history of a great industry.

Massachusetts Institute of Technology
Studies of Innovation

INVENTION & INNOVATION IN THE RADIO INDUSTRY

By W. RUPERT MACLAURIN *with the Technical Assistance of* R. JOYCE HARMAN

With a Foreword by KARL T. COMPTON

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THE original exploration for this monograph and its companion studies of invention and innovation in this series was made possible by the Rockefeller Foundation through a grant for which I am greatly indebted.

I am indebted, too, for suggestions and criticism to many scientists and engineers, who, from their close association with radio history and the underlying electronic arts, have generously contributed material and ideas which have helped to round out the story of radio communication. Two "pioneers" especially, George Clark and Lloyd Espenschied, deserve individual mention; their personal recollections and collections of unique radioana have proved invaluable.

My right arm in this study has been Miss R. Joyce Harman, who has rendered invaluable assistance in all phases of the investigation. In particular, she has helped me to assemble the mass of technical material involved and to interpret it to the reader.

I should like to express my personal appreciation to the various members of my office staff, especially to Miss Beatrice A. Rogers for her patience, understanding and her kindly efforts to keep me hewing to the grammarian line when I was tempted to go astray.

I have been privileged to discuss this work with many of the individuals mentioned within the book. To them and to the firms they represent I wish to express my gratitude for ready cooperation. I should add, of course, that the opinions expressed in interpretation of the facts connected with the development of the industry are entirely my own.

W.R.M.

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FOREWORD

When my colleague, Professor Maclaurin, first discussed with me the desirability of studying the history of technological change in a number of different American industries, I had no hesitation in urging him to do so. I felt then, as I do now, that such studies would not only provide useful educational material for M.I.T., but that businessmen, scientists and the general public needed a deeper understanding of the economic factors which have influenced technological change. I felt also that Professor Maclaurin would be well qualified as an economist to make such studies because of his technological associations at M.I.T. and his services as secretary of the committee of scientists which assisted Dr. Vannevar Bush in preparation of material for his report to the President—a report which led to the proposal for a National Science Foundation.

I think my original judgment has been vindicated by the quality of the studies now completed—and by external events. In this period of postwar reconstruction it should be clearer than ever that the potentialities and limitations of further technological advance are of pre-eminent significance to industrial development, both in this country and abroad.

The progress of science and the progress of technology may go hand in hand, but they have not always done so. Until the middle of the last century, science lagged behind industrial development in most fields. Gradually the increasing command over Nature which organized science was able to achieve, shifted this balance until today, in many cases, it is industry which lags.

Professor Maclaurin takes pains to point out the important distinction between advances in fundamental science and their practical applications in new or improved products. His choice of industries for initial study in this series—radio, lighting, paper, and glass—provides some interesting contrasts in this respect.

Paper and glass are both venerable industries in which extraordinary advances occurred without the assistance of modern science. Several hundred years before Christ, the Egyptians had produced papyrus and the Phoenicians had manufactured glass of a quality which in many respects cannot be surpassed today, although modern technology has added many new types of specil quality glass to meet desired specifications of thermal expansion, spectrum transmission, solubility, etc. The technological revolution that has occurred in the intervening centuries has been principally in the methods of manufacture. I have been told by the curator of the paper museum at M.I.T., Dr. Dard Hunter, that in the pre-Christian era it would have taken two men about eight hours to produce a dozen sheets of papyrus twelve inches square. Today newsprint can be produced in sheets twenty-five feet in width at the rate of over a quarter of a mile a minute.

Yet the forward march of science has not been primarily responsible for this spectacular achievement. The modern papermaking machine has evolved slowly through mechanical advances which were made largely by inventors who had little or no knowledge of science as such.

By contrast, the revolution that has taken place in the lighting industry was much more intimately connected with the progress of the science of physics than the introduction of either the Fourdrinier paper machine, or the high-speed Owens machines which in the last quarter of the nineteenth century converted the glass industry from its hand processes to mass production. To illustrate, Mike Owens, the inventor of the famous bottle-making machine, was an untutored mechanic who rose to be the factory superintendent and later the president of the Libbey-Owens Glass Company. He had no training beyond grade school, read very little and made his contribution primarily through the application of Yankee mechanical ingenuity of a high order. Thomas Edison, by contrast, although more an inventor than a scientist, made a definite effort to keep himself *au courant* with the progress of science. He did so by intensive study of the literature pertaining to any problem in which he was interested. As I once worked for him as a young man, I know that he was not just a "cut and try" experimenter but knew quite definitely in advance what he wanted to do. He did not single-handedly invent the electric lamp but forged instead an exceedingly important link in a chain of inventions which translated the fundamental scientific discoveries of Volta, Ampère, Humphry Davy, and Faraday into practical commercial products.

The case that is presented in this first volume of the series describes the origins of radio communications. This field represents the opposite extreme from the development of the glass and paper industries. There was no prior art or even prior conception to build on here, such as existed in the evolution of incandescent lighting from the arc lamp. The work of inventors like Marconi had to be primarily based on a careful study of the experiments that scientists had made in the laboratory in producing and detecting ether waves.

In the development of industry today, one of the major problems is a smooth and rapid transition from advances in science to their application in technology. Dr. Maclaurin tackles his analysis of the radio industry by focussing on the key inventors and innovators who have influenced this transition. The distinction that he draws between the scientist, the inventor, and the business innovator is of major significance to an understanding of the process of technological change. Probably the most inchoate of the three activities is the function of business innovation. I am particularly happy to see studies made of the innovator because the findings can later be translated into our educational process. Engineers may be trained as scientists in college, but in subsequent practice they are concerned with solving problems through action. I have known many engineers and inventors of distinction who have failed to achieve their objectives largely because they never acquired an understanding of how to carry their inventions successfully through to the commercial stage. It is curious also that, in spite of the general recognition by American industry of the importance of technological improvement, our schools of business have given very little attention to the problems of the management of research and invention. Far more thought has been given to marketing, accounting, and finance.

In my view, therefore, Professor Maclaurin and his associates have opened up a very important field of inquiry. I hope that they will continue to explore this area, and that over a period of years these and other studies will contribute to the emergence of a corps of scientifically trained innovators who will be continually alert to the possibilities of applying advances in the natural and social sciences to the practical problems of industry. I also venture to hope that, as in physics and chemistry science has profited greatly from the progress of the practical arts, so in economics, psychology, and sociology, the evolution of a science of human behavior will gain from intimate observational studies of the process of invention and innovation in American industry.

KARL T. COMPTON

PREFACE

In this modern age more than ever before, pure research is the pacemaker of technological progress.—VANNEVAR BUSH, *Science: The Endless Frontier.*

THE vital role played by science and technology in modern economic life is apparent to all. We are largely dependent on science and technology for the development of new industries, for the creation of new jobs and for improvement in our public health standards. It is therefore exceedingly important that we should understand the process of technological change—from fundamental scientific research to its practical applications in new or improved products and techniques.

Critical examination is needed of our sources of scientific advance.[1] Why, for example, has the United States been largely dependent on the older European countries for fundamental developments in so many scientific fields? Why, also, does the process of transition from pure research to practical applications take place much more rapidly and effectively in some industries than in others? Are there ways of speeding up this transition in the industries where it has lagged?

Advances in science are not automatically translated into advances in the practical arts. Far from it. Despite our engineering accomplishments, we have scarcely begun to put the latest advances in science to work in many industries.[2]

One of the most significant lessons of the war, one which apparently has been more consciously understood in England than in the United States, is the possibility of speeding up the process

[1] For this purpose I should strongly recommend President Conant's excellent little book, *On Understanding Science* (New Haven, Yale University Press, 1946).

[2] Some indication of this can be obtained from the fact that our total expenditures for scientific research (including industrial research) in the United States in 1940 were only $345,000,000—less than half of one per cent of our national income in that year—and that this research was concentrated primarily in a few industries.

of technological advance in industry by the use of carefully selected *teams* of research scientists. Termed *operational research*, this development has been carried on by the British through the use of teams composed of natural and social scientists, to tackle such problems as the nationalization of the coal industry and the revolution of the housing industry.[3] In housing, for example, the British have found that the physicist, the economist and the psychologist have much to offer in finding new solutions to old problems which had never been tackled before in this way. This development is only in the beginning stages, but results already achieved show great promise.

My own belief is that, if we are to progress to a standard and content of living as yet undreamed of in this country and abroad, it will be essential to make science penetrate every aspect of industrial life. Our international obligations require us to bend our energies to the furthering of an industrial renaissance throughout the world. Our internal economy, with its high level of individual and corporate savings, needs increasing outlets for new investment to avoid stagnation. And the development of a large number of industrial centers of initiative, each imbued with the creative spirit of science, is surely a goal worth achieving in itself.

Before the war, Lancelot Hogben threw a challenge to the economists to contribute to this task. "In Britain," he wrote, "a realistic study of how social institutions assist or impede the satisfaction of human needs, united to an inventory of scientific instruments now available for satisfying them, will not come from our universities, where the teaching on current social problems is dominated by the dreary futilities of deductive economics."[4]

Although I believe it to be the task of the economist to analyze the role of science and engineering in economic development, this is far from easy. We have carried specialization of knowledge to the point where interdisciplinary understanding is exceedingly difficult. *L'uomo universale*, as Leonardo da Vinci was

[3] For a discussion of this development, see J. D. Bernal, *Lessons of the War for Science* (Discourse at Royal Institution, Nov. 1945). Although the British have pioneered in this type of operational research, our own *backward* industries, like coal and housing, are still much further "advanced" than the British.

[4] Reprinted from *Science for the Citizen*, by permission of W. W. Norton, 1938.

called, cannot be discovered in the twentieth century. There is far too much to learn, and the specialists themselves make the obstacles even more overwhelming by their insistence on technical jargon and their lack of interest in popularization. Such lack of interest was not present in the last century; men like Huxley, Tyndall and Faraday made great efforts to explain science to the intelligent layman.

It is unfortunate that in our college training science and engineering have not been regarded as cultural subjects and that many educated men have been almost proud of their lack of even a rudimentary knowledge of these subjects. I was told recently of a group of prominent businessmen (all college graduates) who were eager to finance new enterprises of a technical character. "None of them, however," so my informant said, "has the least idea how even such a simple apparatus as an electric doorbell operates. *Nor do they care to know*." Much has been said, and rightly said, about the necessity of humanizing the scientist and engineer. It is equally important for the humanist to understand the strategy and tactics of science. This is one of the assignments that President Conant has set himself at Harvard University, and I hope it will be duplicated elsewhere.

I have tried in this study to emphasize the necessity of a *continuum* between pure science and engineering applications. The radio industry is of particular interest in this connection because it arose directly out of advances made in pure science. In the industries which employ the majority of American workmen—textiles, boots and shoes, iron and steel, coal mining, paper manufacturing—present-day procedures are based on an old art in which fundamental research has played an insignificant part. Many scientists now believe we are on the threshold of an era in which revolutionary discoveries will shift the balance of power to new types of industries that maintain a much more intimate relation with science.

The Bowman Committee on Science and the Public Welfare stated this point as follows:

In this modern age more than ever before, pure research is the pacemaker of technological progress. In the nineteenth century, Yankee mechanical ingenuity, building upon the basic discoveries of European science, could greatly advance the technical arts. Today the situation is different. Future progress will be most striking in those highly complex fields—electronics, aerodynamics, chemistry—which are based directly upon the foundations of modern science.[5]

In studying the radio industry, I have tried to focus attention on the following types of questions:

What has been the relationship between fundamental scientific research and invention?—between invention and innovation?

What are the strengths and weaknesses of the large corporation in bridging the gap between scientific research and the introduction of new commercial products?

What is the role of new firms in introducing technical innovations? Does our economy require a stream of new concerns to pioneer in the untried and the speculative?

What generalizations can we make concerning the personality requirements for successful invention and innovation? Are inventive talent and entrepreneurial skill rarely found in one man? If so, what kind of team management is likely to be most effective?

How is the patent system working? Does it provide an effective inducement to invention?—to investment in research? Are there patent abuses that retard economic progress?

And, finally, is there a discernible relationship between technological innovation and the business cycle?

I hope that our studies of the economic development of the radio and other industries will lead to more definitive work on the economics and sociology of technological change. Further inquiry will necessitate sharper questions and access to more complete data on individual inventors and innovators. I should like to be able to go through the classic stages of modern scientific method: observation, hypothesis, deduction and experimental verification. Eventually I hope to persuade one or two industrial companies to set up experimental procedures for investigating the process of invention and innovation; but this is a later step in the evolution of a science of economic development. Observa-

[5] Vannevar Bush, *Science: The Endless Frontier* (Washington, Supt. Docs., 1945), p. 72.

tional studies are needed before anything more ambitious can be attempted.

Stages in the Process of Technological Change and Some Definitions

Science and technology can be broken down into five distinct stages: (1) fundamental research, (2) applied research, (3) engineering development, (4) production engineering, and (5) service engineering.

Fundamental research can perhaps best be understood by an example. In 1899 Ernest Rutherford, while studying radioactivity at the Cavendish Laboratories in Cambridge, found that uranium emitted at least two distinct types of radiation. One type he named the alpha particles; later he found that he was able to deflect these magnetically and to measure the ratio of their charge to their mass. Continuing his experiments in yet another direction, Rutherford discovered that when these particles passed through very thin sheets of mica they were slightly deviated or "scattered." A few years later, Geiger, who was working in Rutherford's laboratory as a graduate assistant, made a detailed study of the scattering of alpha particles in films of gold. Geiger reported that a very small number of these particles, about one in ten thousand, were deviated by a surprisingly large amount. Rutherford asked his assistants, Geiger and Marsden, to investigate this further. A few days later they reported that some of the particles turned around in the foil and emerged from the same side at which they had entered. Speaking of his reactions to this information, Rutherford said:

> It was quite the most incredible event that has ever happened to me in my life. It was almost as incredible as if you fired a 15-inch shell at a piece of tissue paper and it came back and hit you. On consideration I realized that this scattering backwards must be the result of a single collision, and when I made the calculations I saw that it was impossible to get anything of that order of magnitude unless you took a system in which the greater part of the mass of the atom was concentrated in a minute nucleus. It was then that I had the idea of an atom with a minute massive center carrying a charge. I worked out mathematically what laws the scattering should obey, and I found that the num-

ber of particles scattered through a given angle should be proportional to the thickness of the scattering foil, the square of the nuclear charge, and inversely proportional to the fourth power of the velocity.[6]

Based on these and further experiments, Rutherford devised in 1911 a new model for the structure of the atom. He envisaged the atom as consisting of a minute, positively charged nucleus surrounded by electrons—a different number for the atoms of different chemical elements, but the same for each atom of a given element. This concept of the nuclear model of the atom is now the foundation of modern physics and chemistry.

The significance of fundamental research depends on the capacity of the scientist to ask original and important questions which have far-reaching implications, and to find answers to them. Rutherford demonstrated what I think is generally true: this type of research is conducted best in an atmosphere where the scientist has intellectual freedom and sufficient time available to explore basic long-range problems with no pressure for immediate results. By and large, it has been the great universities that have provided the environment, the freedom and the incentives for pure research. Such institutions have attracted and encouraged the more unconventional scientific minds, permitting the best of them to explore the unknown with a minimum of direction and control.

Fundamental research is not usually directed at immediate practical objectives. It does not follow, however, that scientists who have the fundamental approach are indifferent as to whether their results will be useful to society. "A society facing new practical tasks," Hogben writes, "forces new problems on the attention of scientists who are capable of solving them."[7] We find scientists with an inventive flair and inventors with broad scientific interests. And this has been particularly true in the United States, where materialism has reached its highest pitch. For example, Benjamin Franklin, whom we think of as typifying many of the best American qualities, was both an amateur scientist and an inventor. Franklin's contribution to electrical knowledge was through fundamental research; he had the disinterested curiosity

[6] Joseph Needham and Walter Pagel, editors, *The Background to Modern Science* (New York, Macmillan, 1938), p. 68.
[7] *Op. cit.*, p. 726.

to study electricity without any immediate practical objective in mind, and the creative imagination to conceive new hypotheses in explanation of electrical phenomena. He was one of the first to describe electricity as a flow of current from a positive to a negative terminal, and to identify lightning with electricity which could be generated in a Leyden jar.[8] But on the practical side, he invented the Franklin stove and adapted the lightning rod to commercial use.

The division of labor between fundamental and applied research is not clear-cut. Some scientists, like Oliver Lodge, who figure in this study of the radio industry were sufficiently interested in possible, practical applications to take out patents on their work. Others, like Maxwell and Hertz, did not concern themselves with the commercial fruits of their discoveries.

In the early history of radio communications, the physicist, as soon as he had acquired a basic understanding of the phenomenon that he was studying, turned to new fields, leaving unsolved the problem of translating his discoveries into useful devices. As a result, there was a substantial gap between the advances made in physics and their applications in industry. Although the rise of industrial research laboratories has narrowed this gap, much still remains to be done.

Fundamental discoveries usually usher in a host of new developments. *Applied research* is conducted for the direct purpose of exploring such applications. Characteristically, the applied research worker has a practical objective in mind when he starts his investigation. He may hope to eliminate static by the design of a new type of radio circuit, such as frequency modulation; or to perfect an electronic camera tube for television, like Farnsworth's image dissector, which will make it possible to break down a moving picture into its component elements. This type of research responds much more effectively to direction than does fundamental research, and can usually be carried further in industry than in a university.

[8] Mr. Lloyd Espenschied of the Bell Telephone Laboratories tells me that, after studying Franklin's work and especially the literature prior to his entry into the field, he has found that most of it was anticipated on the Continent. However, Franklin himself was unaware of this, partly because he was an amateur and partly because of the inadequate facilities for scientific communication in that period.

Engineering development is normally associated with the erection of a pilot plant or with the construction of complete functioning models. The development engineer takes the original design for a new or improved product from the industrial research laboratory to the stage of a preliminary commercial product. Measurement and detailed design are now important, and cost considerations are carefully evaluated. Effective development work calls for ingenuity and originality of a high order. Applying the test of "how-to-make-it-work-economically" frequently produces substantial changes between the laboratory and production stages.

Through *production engineering*, additional improvements are made in the new product in line with factory experience. The quality is standardized, design and material changes are made to fit factory processes, and the cost is lowered. And lastly, through *service engineering* the product undergoes further modification to meet the actual needs of the customer.

A distinction should be drawn also between a scientific discovery and a patentable *invention*. To make a scientific discovery is to reveal a manifestation of Nature or to explain a phenomenon not previously understood. An invention, on the other hand, discloses a new method of achieving some technical objective. Scientific discoveries stem from both fundamental and applied research, but the most far-reaching and important discoveries usually come from fundamental research. The scientist who makes an important discovery may see and be interested in its commercial applications; if he can devise an operational method of producing some useful new material or process, his discovery becomes an invention. However, applied scientists are much more likely to make patentable inventions than are pure scientists.

I can illustrate this from the development in the nineteenth century of photo-telegraphy—the precursor of modern television. The pure scientist, Becquerel, *discovered* in 1839 that certain chemicals, when charged with electricity, gave off light. He did not suggest any methods of putting this discovery to practical use. Twenty-three years later the Abbé Caselli, having read of Becquerel's work, *invented* a crude system of photo-telegraphy by which he was able for the first time to transmit drawings over telegraph lines. It was many years, however, before a practical system of photo-telegraphy was developed.

By stressing the importance of fundamental research, I do not mean to indicate that it far outshadows in significance the other phases of the process of technological change. I agree with J. G. Crowther when he suggests that a rigid separation of "pure science, applied science and invention prevents a true understanding of the history of science. Faraday, Henry and Maxwell would have had little influence in the world without Bell, Edison and Marconi."[9] Both types of scientific contribution are equally needed. Moreover, it is important to cultivate a free interchange of experience among pure scientists, applied researchers, engineers and inventors.[10]

Finally, the difference between invention and innovation requires emphasis. When an invention is introduced commercially as a new or improved product or process, it becomes an innovation. Usually, the innovator is an entrepreneur—not an inventor. And innovations cover a much wider sphere of possible new developments than inventions. The conception of a new use for an old product, such as *entertainment* broadcasting, or an organizational innovation like the formation of the Radio Corporation of America, is frequently a more important turning point in the evolution of an industry than the commercialization of a new invention.

These tools of analysis are unfortunately blunt. The more subtle distinctions can be obtained only by steeping ourselves in the subject matter.

[9] James Gerald Crowther, *Famous American Men of Science* (New York, Norton, 1937), p. xii.

[10] E. H. Land, the scientist-inventor-president of the Polaroid Corporation, suggests: "Industry can provide a much larger field of inquiry for pure science and much greater human stimulus to many of the young scientists than are now provided by the university. In short, a continuum between pure science in the university and pure science in industry should stimulate and enrich our social system." *The Future of Industrial Research* (New York, Standard Oil Development Company, 1945), p. 85.

Chapter I: THE SCIENTIFIC PIONEERS OF RADIO

We should fittingly honour Maxwell as the great pioneer of radio communication, for he not only had the genius to foresee that electric waves must be produced, but had given (in 1864) the complete theory of their generation and propagation long before their existence had been suspected by science.

—LORD RUTHERFORD.[1]

1. The Scientific Environment in the Nineteenth Century

THE PIONEER exploration of wireless waves came largely from the work of trained scientists with little *direct* stimulus from a pre-existing technology.[2] This is unusual. Most of the industries with which we are acquainted in every-day life have evolved slowly over the centuries, the original contributions coming primarily from men of the artisan class.

In the great inventions of former ages we see the needs of practical life stimulating the craftsman to further achievement: the need precedes and calls forth the invention, unless the invention be the result of accidental discovery. But during the nineteenth century we see scientific investigation, undertaken in a search for pure knowledge, beginning to precede and to suggest practical applications and inventions.[3]

Though scientists from many different nations contributed to the birth of the radio industry, the focal points of development were in England and Germany. It is important, therefore, to understand the spirit of inquiry that led to the scientific leadership of these two countries and to contrast it with that which prevailed in the United States.

[1] See Rutherford in tribute to Maxwell in *The Times*, A. S. Eve, *Rutherford* (Cambridge, Cambridge University Press, 1939), pp. 348–349.

[2] Hogben, *op. cit.*, p. 619.

[3] William Cecil Whetham, *A History of Science* (Cambridge, Cambridge University Press, 1929), p. 217.

(a) ENGLAND

James Clerk Maxwell, whom Rutherford called the scientific father of wireless, was a professor of natural philosophy at London University and later at Cambridge, where he presided over the newly established Cavendish Laboratory.[4] His appointment to Cambridge in the 1870's was made in response to the demand from a group of industrial leaders that the teaching of science be modernized in English universities.[5] Beginning with Maxwell, the Cavendish Laboratory was to have a profound effect on British physics through such leaders as Lord Rayleigh, J. J. Thomson, and Ernest Rutherford.

The establishment of the Cavendish Laboratory represented the beginning of a new era for university science in Great Britain. Though a few exceptional professors, like Isaac Newton, had previously applied their mathematical training to the study of Nature, the predominant influence had been scholastic. For example, under the Laudian statutes at Oxford which remained in force until 1858, "the importance of dialectics and the authority of Aristotle were to be strenuously inculcated."[6] Experiment was not encouraged, and the main function of the professors was to read "prescribed texts with such comments and explanation as they chose to add."[7]

During the seventeenth and eighteenth centuries British science had received its principal encouragement from extramural associations, particularly the Royal Society,[8] which was a "union

[4] The Cavendish Chair of Experimental Physics was founded in 1871 and the Laboratory in 1874. The funds for the Laboratory in which "practical researches could be conducted" were provided by the Duke of Devonshire—a capable mathematician who was a relative of James Henry Cavendish. The cost of the new Laboratory was £8,450.

[5] Hogben, *op. cit.*, p. 726.

[6] M. Ornstein, *The Role of Scientific Societies in the Seventeenth Century* (Chicago, University of Chicago Press, 1928), p. 237.

[7] *Ibid.*, p. 214.

[8] The Royal Society received its charter from Charles II in 1662. The Preamble of this charter reads as follows:

> And whereas we are informed that a competent number of persons of eminent learning, ingenuity and honour, concording in their inclinations and studies towards this employment, have for some time accustomed themselves to meet weekly and orderly to confer about the hidden causes of things, with a design to establish certain and correct uncertain theories in philosophy, and by their labour in the disquisition of nature to prove themselves real benefactors to man-

of the most diverse types of men—businessmen, divines, nobles, scholars and physicians."[9]

Of equal importance to the Royal Society as a stimulus to scientific exploration during the nineteenth century was the Royal Institution of London, founded in 1800 by the American scientist and adventurer, Count Rumford. This institution became one of the world's principal centers of scientific research and made possible the career of the leading figure in the electrical revolution, Michael Faraday.

Science has advanced most rapidly when there has been a combination of diverse types of talent at work on a particular problem, the theorist and philosopher positing the basic concepts, the experimentalist testing reality with the use of these theoretical tools, and the inventor or artisan converting the results to practical achievements for the use of mankind.

Conditions combined during the nineteenth century in England[10] to encourage such men to study electricity and its multifarious practical applications. The Industrial Revolution had brought manufacturers into a position of prominence, largely displacing the previous influence of the mercantilist class. The soul of British industrialism was expressed in its struggle to subject natural forces to commercial ends.[11] Under mercantilism the pressure for scientific exploration was concerned with navigation. With the rise of industry, scientific interest shifted from astronomy to electricity and chemistry and their applications to manufacturing.

The British scientific performance in the nineteenth century was characterized more by the brilliance of a few star performers than by the founding of highly organized scientific schools. In

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kind; and that they have already made a considerable progress by divers useful and remarkable discoveries, inventions and experiments in the improvement of Mathematics, Mechanics, Astronomy, Navigation, Physics and Chemistry, we have determined to grant our Royal favour, patronage and all due encouragement to this illustrious assembly, and so beneficial and laudable an enterprise.—Quoted from Ornstein, *op. cit.*, pp. 104–105.

[9] *Ibid.*, p. 135.

[10] The British were also spurred on by the important work being done on the Continent by such men as Oersted, Ampère, Ohm, Gauss and Weber.

[11] James Gerald Crowther, *British Scientists of the Nineteenth Century* (London, K. Paul, Trench, Trubner, 1935), p. 124.

this respect, there was a striking contrast with their great industrial rivals in Germany.

(b) GERMANY

German science received its first substantial encouragement from a group of statesmen who, in the late eighteenth century, determined to transform an aggregation of agricultural states into an industrial empire. To promote this end, they sought to advance scientific investigation within the universities; but, as in England, the ruling academic class refused to admit the sciences, regarding them as alien to the traditions of disinterested learning. Accordingly, in the early part of the nineteenth century, the state authorities created both technical schools and scientific institutes: to train engineers for industry, to train persons for scientific investigation, and to promote explorations in the fundamental sciences.[12] These purposes were achieved so successfully that by the close of the century the gulf between the traditional universities and the new scientific institutions had been bridged. The universities themselves joined in the movement to create scientific laboratories and to encourage the research spirit.

The domination of science by the State could have been disastrous; yet such control actually had the effect of strengthening the educational system and of providing uniformity of curricula and degree requirements.[13] Teachers could thus move frequently from one university or science institute to another, and students followed freely in the wake of the great scientists.

The secret of German supremacy in science was not that the country produced a greater proportion of chemists or physicists of genius than any other nation; rather, these gifted scientists

[12] W. E. Wickenden, *A Comparative Study of Engineering Education in the United States and in Europe* (Society for the Promotion of Engineering Education, 1929), p. 45. Karlsruhe, founded in 1825, was the first of the great polytechnic institutions. It was here that Hertz, while professor of physics, did some of his early work on electro-magnetic waves, which led to his famous experiments of 1887.

[13] Two direct contributions that State domination engendered were government subsidies to research laboratories and the foundation of national research organizations, such as the Prussian Ministry for Science. Supervision by the State also tended to encourage greater attention to the practical problems of German industry, and gave the country a high proportion of teachers interested in modern science.

(when they appeared) became professors and spent far more energy than British or French scientists in training a body of men, who, though often without genius, were yet capable of learning.[14] Crowther suggests that this large reserve of competent men was a decisive factor: "For while men of genius could always find a track, the conversion of the track into a smooth highway of progress could be accomplished only by the tramping of a large body of followers."[15]

As a result of all these determinants, Germany had a large, well-trained corps of scientific workers under a succession of leaders, such as von Helmholtz, Liebig, Siemens, Kirchhoff and Haber.[16] Nowhere else in the world was the scientist accorded such distinction as in Germany. Nowhere else was his opinion valued so highly in the political, economic and industrial phases of national life. Germany made science a business where other countries gave it the status of a hobby for rich men or an extracurricular activity for college professors.

The outstanding strength of German science in the nineteenth century was in chemistry. However, contributions made in physics were of profound importance to the growth of the radio industry, particularly in the fields of gaseous discharges, thermionic emission and electro-magnetic radiation.

In 1880 Julius Elster and Hans Geitel began a series of investigations which laid the basis for the development of the vacuum tube. Experimenting with glass bulbs, either exhausted or filled with various gases, containing an electrically heated wire and a metal plate, they observed that "electrified particles" were thrown off from the glowing wire in every direction.[17] Even before this, William Hittorf had been working on gaseous conduction, using high voltages and superior vacua; and within a few years Dr. Arthur Wehnelt had begun the research which led to his invention of the oxide-coated cathode.[18]

[14] James Gerald Crowther, *Social Relations of Science* (New York, Macmillan, 1941), p. 502.

[15] *Ibid.*

[16] The preponderance of German scientists on the Nobel Prize lists is confirmation of the effectiveness of their training.

[17] G. F. Tyne, "The Saga of the Vacuum Tube," *Radio News*, Pt. 3, May 1943, p. 28.

[18] This was later to be used by Western Electric in its development of the

In 1895 the discovery by Roentgen of "X" rays, set in motion a wave of exploration not only in Germany but throughout the scientific world, leading to such developments as the Braun cathode-ray tube of 1897 and the von Lieben amplifying relay of 1906.

(c) THE UNITED STATES

Compared with England and Germany in the field of science, the United States occupied an essentially colonial status in the nineteenth century. The slow development of original scientific research was due in part to the agricultural complexion of early American life and to the voluntary dependence of the colonists on European sources for culture and education.

> Our forefathers in colonial times had their national universities beyond the sea, and all of the young colonists who were able to do so went to Oxford or Cambridge for their classical degrees, and to Edinburgh and London for training in medicine, for admission to the bar or for clerical orders. Local colleges seemed as unnecessary as did local scientific societies.[19]

In 1743 Franklin issued his circular entitled *A Proposal for Promoting Useful Knowledge among the British Plantations in America*, in which he urged that "a society should be formed of 'virtuosi' or ingenious men residing in the several colonies, to be called the 'American Philosophical Society.'" But the society did not flourish with the same vigor as the Royal Society, despite the fact that it had the interest and support of the leading Americans of the day.

George Washington, Vice-President Adams and Secretary of State Jefferson were members of the Philosophical Society; and the entire official family was in sympathy with the chief executive's aim to "promote as objects of primary importance institutions for the general diffusion of knowledge." Washington himself was particularly interested in the application of science to

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triode. Wehnelt applied for a patent on his tube in 1904, claiming it as a rectifier for transforming alternating into direct current, but he made no mention of the tube's application to high-frequency oscillations or to wireless telegraphy.

[19] G. B. Goode, *Origin of the National Scientific and Educational Institutions of the United States* (New York, Putnam, 1890), p. 113.

agriculture;[20] and his ambition to found a national university is manifest in his last will. Among other things, Washington was active in the foundation of West Point as a way of providing educated engineers for national and state projects; and the Patent Office was set up during his term. In his first message to Congress he said:

> I cannot forbear intimating to you the expediency of giving effectual encouragement, as well to the introduction of new and useful inventions from abroad, as to the exertions of skill and genius in producing them at home.

Under Thomas Jefferson, and at his personal expense, American governmental work in paleontology began with the exploration of Big Bone Lick for fossils.[21] In other circumstances, Jefferson's natural bent for science might have encouraged investigations of more fundamental physical problems; but the times channeled that bent into more obvious ends. Vast areas of the country between the Atlantic and the Pacific were unexplored; and general curiosity was felt about the potentialities of these regions. It was logical, then, that explorations and government support should go to such uses as the Lewis and Clark Expedition. With similar motives, Jefferson organized the Coast and Geodetic Survey.

Yet progress in training scientists was slow, and the total of important research remained negligible. In 1801 Priestley, who was in this country, wrote to Humphry Davy that he was "perfectly insulated" from scientific news and developments, owing to the small and scattered number of scientists in the country.[22]

Though the United States produced several scientists of international distinction during the nineteenth century, such as Joseph Henry and Willard Gibbs, it developed no laboratories comparable to the Cavendish Laboratory in Cambridge or the German

[20] Crowther explains the American pre-eminence in biology and agricultural chemistry as resulting from the vast problems posed in the colonization of America. The early settlers knew how to cultivate crops under European conditions of soil and climate, but they had to learn by experimentation how to adapt them to the new world. *Famous American Men of Science*, *op. cit.*, pp. 29, 35.

[21] Goode, *op. cit.*, p. 25.

[22] Crowther, *op. cit.*, pp. 29–30.

university laboratories. Henry and Gibbs received much less recognition in this country than they would have, had they worked in Europe; and they created no followers.

The major educational contribution of the United States during the nineteenth century was in providing college training for a much higher proportion of the population than any other country in the world. Many new universities were founded, and there was great expansion in existing institutions. The challenge of offering advanced training to large groups of students absorbed the energies of the most vigorous leaders in American education; and scientific research suffered in competition. This condition led Tyndall to declare in 1873:

> If great scientific results are not achieved in America, it is not to the small agitations of society that I should be disposed to ascribe the defect but to the fact that the men among you who possess the endowments necessary for profound scientific enquiry, are laden with duties of administration so heavy as to be utterly incompatible with the conditions and tranquil meditation which original investigation demands.[23]

As long as the principal emphasis in the United States was laid on mass production education, there was relatively little radical experimentation with the curriculum. The liberal arts universities were dominated longer by the classical tradition than were either the British or German universities. The American engineering school broke away from the classical tradition after the Civil War, but until the twentieth century these schools were inadequately financed and considerably less scientific than their German counterparts.

When the department of electrical engineering was started in 1889 at the School of Mines of Columbia University, Professor Michael Pupin wrote:

> A small brick shed, a temporary structure, had been built to accommodate the new department. The students called it the "cowshed" without any stretching of the imagination. The laboratory equipment consisted of a dynamo, a motor and an alternator, with some so-called practical measuring instruments. . . . When I compared the facilities of the new department of electrical engineering

23 John Tyndall, *Lectures on Light* (New York, Appleton, 1873), p. 182.

at Columbia College with those of the Polytechnic School in Berlin, I felt somewhat humbled.[24]

It is not surprising, in these circumstances, that the basic contributions to the understanding of electricity came from Europe. And it was these European advances that gave rise to the radio industry.

2. *The Early Explorers of Electro-Magnetic Waves*[25]

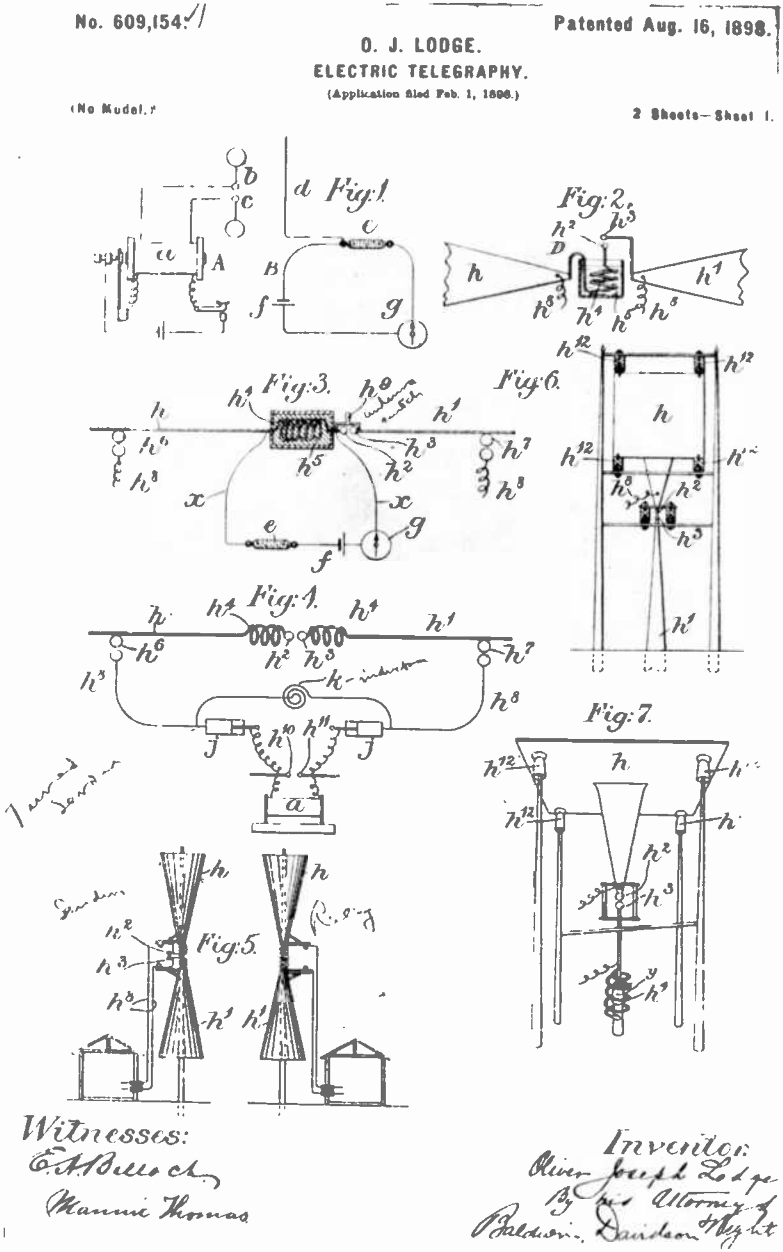
Until the nineteenth century, no means had been discovered for maintaining a continuous flow of electric current; and all the applications of electricity in modern life are dependent on having such a source of energy under complete control.[26] Just as, early in the twentieth century, atomic energy was recognized as a potential source of power of great importance if its secret could be unlocked, so a hundred years previously the inherent significance of electricity was widely understood by scientists, but the major task of bringing this new force under control had just begun.

The first device for producing a continuous flow of current through a wire was the electrical battery, designed by Volta in 1790. From then on, new developments came rapidly. Sir Humphrey Davy found that a spark from a powerful battery could be maintained between two sticks of charcoal, producing a brilliantly luminous arc lamp. Oersted discovered that an electric current produces magnetism, and he was the first to demonstrate mechanical interaction between an electric current and a magnet. Ampère, in 1821, "revealed the interaction between two electric circuits by virtue of what we now call electro-magnetic induc-

[24] *From Immigrant to Inventor* (New York, Scribner's, 1923), p. 280. In a discussion of the American reluctance to build proper laboratories for research, Pupin tells of an encounter in the 1890's with a famous lawyer, a trustee of a great educational institution, who believed that universities "should be built on the top of a heap of chalk, sponges, and books," and that laboratories were unnecessary. *Ibid.*, p. 283.

[25] I have singled out Faraday, Maxwell and Hertz to give the flavor of the nineteenth-century scientific exploration. From the standpoint of the history of science, however, there were many other contributors to the stream of development which culminated in Hertz's work, notably Ampère, Gauss, Weber and von Helmholtz.

[26] Malcolm MacLaren, *Rise of the Electrical Industry during the Nineteenth Century* (Princeton, Princeton University Press, 1943), p. 5.



One of the most famous patents in radio history, that on Sir Oliver Lodge's tuning apparatus.

tained at the age of twenty-one, he progressively rose to the directorship of the Royal Institution.

Faraday, throughout his scientific career, devoted his energies to chemical and electrical experiments which had immense practical importance. But he was a scientist rather than an inventor, and consistently refused to press forward his electrical studies to the point of practical commercialization. He "devised a variety of primitive dynamos, but he did not try to develop any of them."[33] "I have rather," he wrote in his diary, "been desirous of discovering new facts and relations dependent on magnetic-electric induction, than of exalting the force of those already obtained; being assured that the latter would find their full development thereafter."

The time lag between scientific discovery and invention did not concern him. Instead, he fastened his sights on the single goal of contributing to the advancement of "pure science." Faraday's role in the discovery of radio grew out of his work on electromagnetism. He was concerned with trying to explain how electricity in motion produces magnetic force and how a change in magnetic force produces an electric current.

In Faraday's time magnetic force was believed to act along the straight line joining two particles, thus following Newtonian gravitational theory. Faraday found this explanation unsatisfactory.

> He showed experimentally that an insulated sphere could be charged by induction even when screened from the direct action of the charge. He found too that the induced charge could be increased by disposing the sphere, screen and charge in certain positions which left the sphere and the charge farther apart than before. This increase of charge with increase of distance could be paralleled from gravitational phenomena.[34]

In a lecture entitled "Thoughts on Ray-Vibrations," Faraday suggested that "a line of force which ends on a vibrating particle might be set in a vibrating motion by the vibrating particle, and that a line of gravitational force or a line of magnetic force might be an effective vibratory agent of this sort."[35]

[33] *Ibid.*, p. 106.
[34] *Ibid.*, p. 115.
[35] *Ibid.*, pp. 121–122.

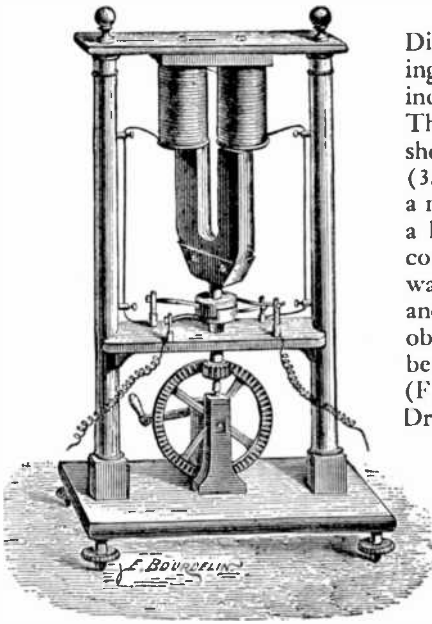


Diagram of Pixii apparatus embodying the principles of magneto-electric induction enunciated by Faraday. The machine, constructed in 1832, shows a double coil of insulated wire (3,000 feet in length) wound around a massive soft iron core and fixed to a horizontal cross piece; below is a compound permanent magnet which was moveable about a vertical axis, and a rapid rotation of this could be obtained by the handle and a pair of bevel wheels shown above the base. (From *Electric Illumination*, James Dredge, 1882, courtesy *Engineering*)

(b) MAXWELL

It was on these hypotheses and the earlier laws of Ampère that Maxwell developed his "Dynamical Theory of the Electro-Magnetic Field."[36] Concerning this theory he wrote a letter to a friend: "I have a paper afloat, with an electro-magnetic theory of light, which, till I am convinced to the contrary, I hold to be great guns."

It was great guns. Maxwell is now generally conceded to be the greatest theoretical physicist of the nineteenth century.[37] In contrast to Faraday, he had the advantage of being the son of a minor Scotch laird of adequate means who gave his boy every opportunity and encouragement to pursue a scholarly career. He received an excellent education at the Edinburgh Academy and while still a schoolboy was taken regularly by his father to the Edinburgh Royal Society. Before he was fifteen, his first paper was presented to this Society. "When he was sixteen, he entered Edinburgh University and attended the courses there for three

[36] Published in 1864, eighteen years after Faraday's lecture.
[37] Crowther, *op. cit.*, p. 261.

years. He worked under very little supervision."[38] He then went to Cambridge and later became a fellow of Trinity College; at twenty-six he was made professor of natural philosophy at Marischal College, Aberdeen; and after three years he was appointed to a similar chair at King's College, London. There, between the ages of twenty-nine and thirty-four (1860–1865), Maxwell first worked out his great contributions to the dynamical theory of gases and the electro-magnetic theory of light.

The example of Maxwell demonstrates one of the most important features of the university atmosphere at its best: it provides opportunities for untrammelled scientific exploration which are not present when there is too great day-to-day pressure for immediate results. As Crowther states:

> Maxwell was fortunate to live during a cultured period that was healthy and powerful enough to provide scope to his splendid genius. Though his contemporaries could apprehend only a half of his qualities, they did not fail in what was reasonably within their power and unconsciously helped their successors besides themselves.[39]

Maxwell was much more of a trained mathematician than Faraday. The kind of imagination that made him the forefather of the modern theory of matter—which does not employ the engineer's mode of thought—was implicit in his scientific work.

His great contribution to an understanding of electro-magnetism came from this imaginative insight and his ability to express his results in mathematical form. His series of equations placed the previous speculations concerning electro-magnetism in definitive terms and enabled others to build on the solid foundations that he had laid. Briefly, Maxwell showed that:

> . . . electro-magnetic action must travel through space at a definite rate in waves, and that these waves must consist of disturbances that are transverse to the direction in which the waves are propagated. In the course of his work he made the remarkable statement that the ether must be able to transmit electrical waves with a speed exactly equal to that of light [186,000 miles per second], and that therefore any medium explaining electrical action could also be held to explain light.[40]

[38] *Ibid.*, p. 273. [39] *Ibid.*, p. 265.

[40] Ellison Hawks, *Pioneers of Wireless* (London, Methuen and Company, 1927), p. 177.

The revolutionary importance of Faraday's and Maxwell's contributions is based on the fact that, according to Newtonian principles, electric waves could not exist, while on Maxwell's theory "all changes in electric and magnetic forces sent waves spreading through space."[41]

Maxwell was a theoretical physicist and not an experimentalist. Twenty-two years after his formulation of the theory of electro-magnetic induction, and forty years after Faraday's original suggestion that ether waves existed, Professor Heinrich Hertz in Germany proved their existence by experiment.[42]

$$\nabla \times E = -\frac{1}{c}\frac{dB}{dt}$$

$$\nabla \times B = \frac{\mu}{c}\left(4\pi i + \frac{dD}{dt}\right)$$

$$\nabla \cdot D = 4\pi\rho$$

$$\nabla \cdot B = 0$$

Maxwell's set of electro-magnetic equations, bearing his name, based on the experimental work of Ampère, Henry, Faraday, and others. The solution of these differential equations led Maxwell to predict the properties of electro-magnetic waves long before their existence was suspected. (Courtesy *Technology Review*)

(c) HERTZ

Hertz, like Faraday and Maxwell, was a pure scientist concerned with exploring new manifestations of Nature. Brought up in Hamburg in a family of moderate means, he left school at fifteen

[41] J. J. Thomson, quoted in Crowther, *op. cit.*, p. 308.

[42] Hertz was acquainted with the work of Faraday and Maxwell, but he was also influenced by the parallel continental explorations in electricity of Ampère, Gauss, Weber, von Helmholtz and others.

and had a private tutor every day for an hour. "During the remainder of each day he studied by himself and it was at this period that he fitted out a room at home with bench and lathe to make simple apparatus for experiments in physics and chemistry."[43]

Deciding to become an engineer, he obtained a year of practical training in the engineering school of the University of Munich. But he soon concluded that his real interest was in science. He therefore transferred to Berlin to study under von Helmholtz. On receiving his doctor's degree, he was selected by von Helmholtz as demonstrator in physics.

Hertz's historic researches in electro-magnetism were made from 1884 to 1893, between the ages of twenty-six and thirty-six. During these years Hertz worked at the University of Kiel, the Technische Hochschule at Karlsruhe and the University of Bonn. He died prematurely on January 1, 1894. Beginning at Kiel, Hertz set himself the task of attempting to show experimentally the nature of electro-magnetic waves. He conceived of this as a basic task required for the advancement of science rather than of any direct practical importance: "His decision to follow pure science instead of a technical career was faithfuly kept. . . ."[44] There is no evidence, moreover, that he had any premonitions concerning the future employment of Hertzian waves for telegraphy and telephony. After some of his early demonstrations of the propagation and reception of waves through space, he was asked whether his discoveries had any practical value for telegraphy. His answer is preserved in the Deutsche Museum in Munich:

TRANSLATION [45]

BONN, DEC. 3rd, 1889

DEAR SIR:

Replying to your kind letter of 1st, I have pleasure in giving you the following particulars:

Magnetic lines of force may be propagated just as well as electric, as rays, if their vibrations are sufficiently rapid; in this case they pro-

[43] Rollo Appleyard, *Pioneers of Electrical Communications* (London, Macmillan, 1930), p. 112.

[44] *Ibid.*, p. 140.

[45] *Ibid.*, pp. 138–139.

ceed together, and the rays and waves dealt with in my experiments could be designated magnetic as well as electric.

However, the vibrations of a "transformator" or telegraph are far too slow; take, for example, a thousand in a second, which is a high figure, then the wave length in the ether would be 300 kilometres, and the focal length of the mirror must be of the same magnitude. If you could construct a mirror as large as a continent, you might succeed with such experiments but it is impracticable to do anything with ordinary mirrors, as there would not be the least effect observable.

With kind regards,

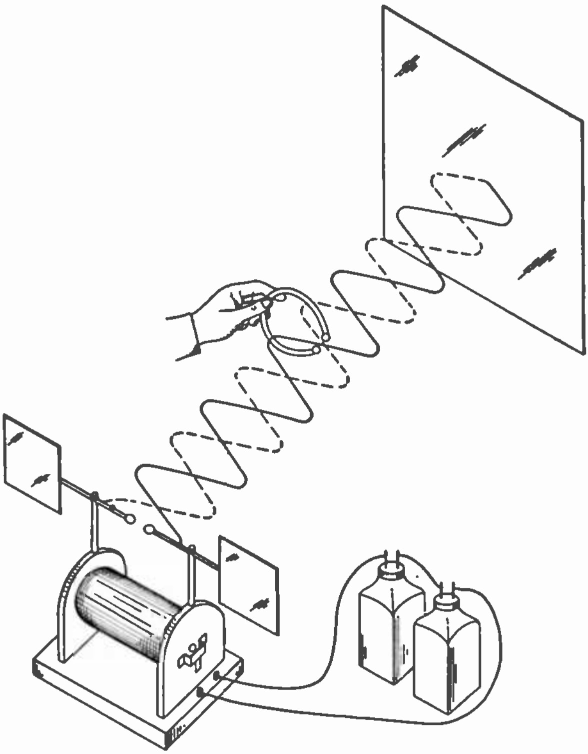
Yours
HERTZ

Since Hertz was the first scientist to produce and detect wireless waves, it is interesting to study just what he did. First, he had to create the waves, by oscillatory electricity. It was known at the time that electrical oscillations could be produced by the discharge of a Leyden jar or other types of condenser.[46] Hertz started his experiments with an electrical oscillator that gave powerful radiations and very high-frequency oscillations, and thus he enhanced his chances of detecting the waves at a distance.

A typical oscillator used by Hertz consisted of two metal balls a few inches in diameter, fastened to the ends of a thin metal rod about a yard long. In order to charge the balls electrically like a condenser, the rod was cut at its mid-point to make an air gap, and each half was connected to the secondary winding of a sparking coil.[47] When the high voltage from this coil was applied, one ball of the oscillator became strongly charged positively, the other negatively, and if the space between the ends of the rods were made small enough, the air gap became filled with a spark. The spark caused the two balls to become electrically connected by a space of hot conducting air, and one ball dis-

[46] Joseph Henry, in 1832, had suspected this oscillatory discharge; and in 1847 von Helmholtz had discussed it in great detail. Six years later William Thomson (Lord Kelvin) had given the formula for the discharge; and other scientists had demonstrated its existence. The British physicist, G. F. Fitzgerald, had even suggested that waves were created by the discharge oscillations.

[47] Sparking coils are transformers which generate a very high voltage in the secondary winding when the current in the primary winding is interrupted periodically.



Representation of Hertz's experiments with electro-magnetic waves, showing his procedures for creating, detecting, and reflecting the waves. (Courtesy *Technology Review*)

charged into the other. But since an electric current possesses momentum, during discharge it will overshoot the mark far enough to recharge the condenser partially. This action is analogous to the action of a pendulum. When the original energy is exhausted, the oscillations will cease. Hertz calculated that this cessation occurred in less than a millionth of a second, and that the periodicity of the oscillations was on the order of 100,000,000 per second.

The most difficult task was to detect the waves as they sped away from the oscillator. His basic detector Hertz termed a "resonator." He took a piece of wire about seven feet long, capped the ends with small balls, then bent the wire into a ring, with the balls nearly touching. By soldering small pieces of metal to the balls, he could increase their area (thus adding to their electrical capacitance) until a spark jumped the gap in the loop whenever the near-by oscillator sparked.[48]

By further variations in his experiments, Hertz went on to calculate the velocity of these waves, and arrived at a speed of 186,000 miles per second, which is the velocity of light—further confirming Maxwell's theory. He also proved that the waves with which he was working obeyed many of the laws of optics. For example, he discovered that electro-magnetic waves could be focussed in a beam by reflecting metal surfaces, his apparatus being the precursor of beam transmission of wireless and present-day radar.

(d) LODGE AND POPOFF

About the time of Hertz's work, Oliver Lodge, a physicist at the University of Liverpool, designed an effective system of wireless reception which he demonstrated at the meeting of the British Association for the Advancement of Science in 1894. Lodge's receiving station, sketched in Appendix, comprised a spark gap for collecting the waves, a coherer for detecting them, a relay for magnifying the currents, an inker for registering Morse dots and dashes, and a trembler for tapping back the coherer.[49]

Lodge's coherer proved more sensitive to feeble signals than Hertz's loop, and made it possible to detect wireless waves at greater distances. The principle of the coherer had been known before; but it had not been thought of as a detector.[50] When loose metallic filings are placed in a glass tube and connected in a circuit, electrical discharges in the neighborhood of the tube will

[48] W. H. Eccles, *Wireless* (London, Oxford University Press, Home University Library No. 160, 1933), pp. 28–29. In this way the ring was brought into resonance with the oscillator, or, in later terminology, was "tuned" to it. By adjusting the capacitance of the balls Hertz made his resonator sensitive enough to spark at distances of 20-25 feet from the oscillator.

[49] *Ibid.*, pp. 53–54.

[50] The coherer had been invented by Professor Edouard Branly in 1892. He did not consider this device in connection with the detection of electro-magnetic waves. Lodge conceived the idea of substituting it for Hertz's loop.

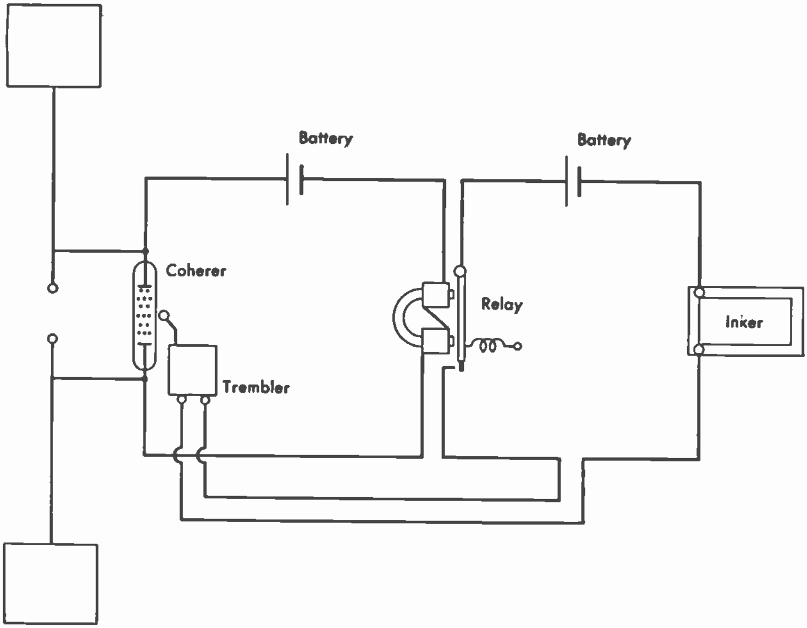


Diagram of the receiving station constructed by Oliver Lodge in 1894. (Courtesy Eccles, *Wireless*, Oxford University Press)

decrease the resistance of the filings, causing them to cohere and permit a flow of current from a local battery. A coherer, once it has responded to the voltage rise produced by the first few waves, afterwards behaves as a good conductor and does not respond to the waves that follow. To restore its resistance, a trembler is used to shake up the filings again. Like Hertz, Lodge was a scientist, not an engineer; and his original interest was in obtaining a clearer understanding of electro-magnetism. Of his work on the coherer, Lodge wrote:

When I had discovered the means of detecting electric waves by means of the coherer, the late Lord Rayleigh said to me, "Well, now you can go ahead; there is your life work!" But I didn't; I was engaged in teaching, and neglected the prelude to what has now developed into wireless telegraphy, though I went on with it more or less at intervals; but I attended to many other things as well, and the results were that Maxwell's ether waves, which had aroused my enthusiasm ever since I had heard about them in the early seventies, were mainly worked out and developed practically by others.[51]

In 1895 Professor A. S. Popoff of the University of Kronstadt improved further on Lodge's system of reception. He protected "the coherer from the effects of local sparks at the relay contact by inserting 'choking coils' in the wires along which the waves from such sparks could run."[52] For an antenna he used a long vertical wire, insulated at its upper end and connected to earth through the coherer at its lower end.[53] This was superior to Hertz's loop of wire.

It was on these scientific activities that Marconi and other inventors built. Marconi, lacking the background in experimental physics which led to the discoveries of Hertz, contributed mainly to improving the crude laboratory-type apparatus of his predecessors and making it perform much more consistently. In the stages that we have identified in the process of technological advance, Marconi's contributions can be classified as applied research and engineering development rather than fundamental research. Until the founding of the British Marconi company in 1897, the major contributions to radio had come from university laboratories, or extramural foundations like the Royal Institution. Maxwell, Hertz, Lodge and Popoff turned to other fields of investigation rather than attempting to perfect radio communications. But without the pioneer work of the scientists, commercial wireless would have been impossible.

[51] Oliver Lodge, *Past Years: An Autobiography* (New York, Scribner's, 1932), p. 113.

[52] Eccles, *op. cit.*, pp. 53–54.

[53] Popoff's purpose in constructing this apparatus was to further the study of atmospheric electricity. He employed Branly's coherer and a Morse printer connected to a conductor as a means of recording distant lightning flashes. Hawks, *op. cit.*, p. 202.

Chapter II: THE IMPACT OF NEW SCIENTIFIC ADVANCES ON ESTABLISHED INDUSTRY

Any two friends living within a radius of sensitivity of their receiving instruments, having first decided on their special wave length and attuned their respective receiving instruments to mutual receptivity, could thus communicate as long and as often as they wished by timing the impulses to produce long and short intervals on the ordinary Morse code.—William Crookes, 1892.

Two main streams of exploration made the modern radio industry possible. The first of these was the work, just described, on electro-magnetic waves. The other consisted of the experiments of Hittorf, Crookes, Elster and Geitel, J. J. Thomson, Roentgen and Braun on "electrified particles" and the theory of the electron; this line of investigation led at a later stage to the development of the most powerful tool of the radio industry—the vacuum tube.

The translation of these scientific advances into commercial applications did not take place smoothly and efficiently. And neither in the case of the vacuum tube, nor in that of the transmission and reception of wireless waves by the methods of Hertz and Lodge, was it established enterprise that created the first commercial products.

Why was this so? Were the scientists not speaking in a language that could be understood by the businessman?

Although some of the leading scientists who first explored wireless waves did not realize their practical implications, there were others with more vision. The British physicist William Crookes wrote in 1892:

> Here is unfolded to us a new and astonishing world, one which is hard to conceive should contain no possibilities of transmitting and receiving intelligence.

Rays of light will not pierce through a wall, nor as we know only too well, through a London fog. But the electrical vibrations of a yard or more in wavelength . . . will easily pierce such mediums, which to them will be transparent. Here, then, is revealed the bewildering possibility of telegraphy without wires, posts, cables or any of our present costly appliances.

This is no mere dream of a visionary philosopher. All the requisites needed to bring it within grasp of daily life are well within the possibilities of discovery, and are so reasonable and so clearly in the path of researches which are now being actively prosecuted in every capital of Europe that we may any day expect to hear that they have emerged from the realms of speculation to those of sober fact. . . .

What remains to be discovered is . . . firstly, a simpler and more certain means of generating electrical waves of any desired wavelength. . . . Secondly, more delicate receivers which will respond to wavelengths between certain defined limits and be silent to all others. Thirdly, means of darting the sheaf of rays in any desired direction, whether by lenses or reflectors. . . .[1]

If Crookes' predictions were to come true, they would have a profound effect on the telegraph, cable and telephone industries and on electrical manufacturing. Yet the established companies in electrical communications failed to envisage this new field.[2]

It is difficult today to conceive of the principal concerns in electrical communications being as oblivious to the possibilities of wireless telegraphy as most of them were in 1900. It should have been clear, for example, that if the scientists' predictions came true, the tremendous investment that had been made and was still being made in submarine cables might be jeopardized. Since then, the rise of the industrial research laboratories has placed the electrical industries in a position where they can much more effectively bridge the gap between the advances made in pure science and the practical applications in new or improved products. Many, though not all, of our leading industrial concerns have

[1] William Crookes, "Some Possibilities in Electricity," *London Fortnightly Review*, Feb., 1892, Vol. LI, p. 173.

[2] However, in the Boston laboratory of the Telephone company, John Stone Stone did set to work in 1892 to see if the Hertzian or Tesla oscillations could be used for telephony. Lacking adequate means to generate the waves and especially to detect them as voice signals, he failed. Thereafter the Telephone company followed the progress of radio but did not undertake any development work until the advent of the vacuum tube.

learned the value of long-range research and are prepared to make investments which may not bear fruit for years.

Such conditions did not exist at the turn of the century. Practical wireless telegraphy seemed and was a long way off. It was therefore left to a group of new entrepreneurs, none of them associated with existing electrical enterprises, to develop wireless telegraphy in its early stages. This was true, both in England and in America.

What were the leading American companies in the electrical field doing at the turn of the century when Marconi launched his first wireless company, and why did they not, in fact, take part in this new development? In 1900 Western Union, Postal Telegraph and the American Telephone and Telegraph Company were all flourishing enterprises in electrical communications; and General Electric, Western Electric and Westinghouse were important producers of electrical equipment.

1. The Telegraph and Cable Industry

The most powerful of all the electrical companies was Western Union. The telegraph industry had experienced a spectacular rise since the Morse company was founded in 1845. The early commercial success of the first telegraph company led to the establishment of a host of small telegraph firms to capitalize on this important innovation. These firms, many of which had gone through bankruptcy, were later consolidated into the Western Union and Postal systems, with telegraph networks throughout the United States and with transoceanic cables abroad. In 1902 [3] Western Union, operating over 1,000,000 miles of telegraph lines and two international cables, reported gross revenues of $29,000,000. Postal, though considerably smaller, had 266,000 miles of telegraph lines; and its affiliate, Commercial Cable, owned four cables with gross earnings of $10,000,000.

The telegraph industry, however, had failed to visualize sufficiently the potential importance of the telephone, and by 1900 was already beginning to feel the competition of this alternative

[3] Figures taken from *Statistical Abstract of the United States: 1902* (Washington, Supt. Docs., 1903), pp. 418–420.

method of communication. Alexander Graham Bell and his backers had tried first to interest Western Union in buying his patents for $100,000. When they were turned down, they promoted a company of their own in 1877 to license new groups which wished to construct telephone lines. The Bell Company manufactured telephone instruments which it leased to these companies. In the meantime Western Union organized a telephone subsidiary, acquired patents from Elisha Gray, Thomas A. Edison, Amos E. Dolbear and others, and entered into competition with the struggling Bell interests.[4]

The new Western Union subsidiary, the American Speaking Telephone Company, started to develop exchanges throughout the country. In some cities it competed directly with Bell licensees; in others it purchased a controlling interest in the existing Bell exchanges.[5] But this competition proved short-lived. In 1878 the Bell system made a counter-move by purchasing the patents on the Blake transmitter, which was considerably superior to the Edison type of transmitter.[6] And in the following year Western Union signed an agreement with the Bell company to withdraw from the telephone industry.

The managements of both Western Union and Postal were apparently more interested in buying up competitors and making protective agreements than in the long-range development of communications. Western Union was willing to withdraw from the telephone field in 1879 in exchange for Bell's promise to keep out of the telegraph business. And in the case of radio, it was not until the new industry was thoroughly established that the telegraph companies gave serious consideration to this method of communication. Like most other industries in 1900, neither Western Union nor Postal employed many trained engineers; they had no plans for the development of a separate research department to keep them abreast of scientific advances.[7] As a onetime Postal Telegraph executive of this period expressed it, "We

[4] *Report* of the Federal Communications Commission on the Investigation of the Telephone Industry in the United States (Washington, Supt. Docs., 1939), p. 3.

[5] *Ibid.*, p. 123.

[6] *Ibid.*, p. 124.

[7] Interview with E. J. Nally, Nov. 1946. Western Union did not establish its first real "laboratory" until 1916.

were *telegraph* men, and we did not think about alternative methods of communication."[8]

A similar attitude prevailed in the Anglo-American Telegraph Company,[9] which had four cables in operation between Ireland and Newfoundland in 1900, with a gross annual traffic of several million dollars. The Anglo-American company, originally promoted by Cyrus Field, had laid the first cables across the Atlantic. This had been extraordinarily difficult, and its final accomplishment was regarded as the last word in scientific progress. At the turn of the century the company did not conduct any research on communications and was not interested in exploring the new field of wireless. Lord Kelvin, who had been a director of Anglo-American at the time of its formation in 1866, had done some research on cable communications in the first years,[10] but, once the initial physical expansion and traffic problems had been overcome, this research relationship had been discontinued.

The executives of all the cable companies were primarily concerned with operating difficulties. Much remained to be done in improving the quality of cable construction. Moreover, it was to prove many years before wireless telegraphy offered a means of handling world-wide telegraph traffic with equal efficiency. Yet the fact remains that the telegraph and cable companies made no effort to explore "the wireless," and therefore were not in a position to capitalize on this new field.

2. *The Telephone Industry*

The American Bell Telephone Company was probably the most research-minded concern in the communications industry and the best equipped to appreciate "the new and astonishing world" that William Crookes saw unfolding. Alexander Graham Bell had started an experimental workshop or laboratory in Boston in 1876; and when he ceased working actively on the telephone, the laboratory was continued as a center for research and the devel-

[8] Nally interview. Mr. Nally later became general manager of American Marconi.

[9] Western Union leased the Anglo-American system of five transatlantic cables in 1911, for a period of 99 years.

[10] Kelvin invented his form of mirror galvanometer and the syphon recorder during this connection.

opment of patents, under the direction of his original assistant, Mr. Watson and, in turn, Hammond V. Hayes. Technically trained men were also added in other divisions of the company; and by 1901 there were 125 engineers and technicians employed in the various technical departments of the telephone system.[11]

However, wire telephony was in such an early and vigorous growth period that it kept all the technical talent of the company fully occupied. The basic Bell patents had expired in 1893 and 1894; and a number of small concerns had begun to expand telephone service into new regions not yet reached by the Bell system. Although the American Bell Telephone Company continued to control the most densely populated and lucrative sections of the country, it was facing vigorous competition from the independents.[12] At the close of 1902 there were 1,317,000 Bell-owned stations and 1,054,000 independently-owned stations.[13] In these circumstances, the Telephone company was primarily concerned with acquiring undisputed national supremacy. Its scientific energies were absorbed in developing central switchboards and increasing the distances that might be covered by its long-lines division. Only after these aims were accomplished and wireless methods themselves looked more promising, could it afford to explore this new field.

3. The Electrical Manufacturing Industry

Just as Western Union, Postal Telegraph, and the American Bell Telephone Company were the principal concerns in the communications industry in the United States in 1900, so also a few firms produced the major portion of electrical apparatus. The electrical-goods industry was expanding rapidly. The Edison Electric Illuminating Company, formed in 1880, marked the beginnings of the electric light and power industry. In the next twenty years electric power gradually came into use in manufacturing, especially in the cotton mills. Even more important as an

[11] F.C.C. *Proposed Report*, Telephone Investigation, 74th Congress, Pursuant to Public Resolution No. 8 (Washington, Supt. Docs., 1938), p. 206.

[12] No less than 508 new independent telephone systems were established in the year 1900.

[13] F.C.C. *Report, op. cit.*, p. 130.

outlet for electric apparatus was the development of the electric street railway which was expanding rapidly in the last decade of the century.[14] Although the electrification of the household had only just begun, the electrical-equipment industry had a volume of sales of nearly $100,000,000 in 1900.

The largest concern was General Electric, formed in 1892 as a merger of the Thomson-Houston and Edison companies. General Electric dominated the lighting industry. It was also active in the building of central-station equipment, though it lagged in the adoption of alternating current. GE controlled practically all of the important early patents in electric railways and took a leading part in the introduction of trolley systems throughout the country.[15] In electric motors, GE was the principal supplier, though it faced considerably more competition than in the other fields mentioned.[16]

The Westinghouse company was also an important factor in the manufacture of electrical apparatus. George Westinghouse was responsible for the vigorous exploitation of the alternating current system,[17] and installed the first a-c central station in Buffalo during the winter of 1886–1887. GE and Westinghouse, after years of expensive patent litigation, had in 1896 entered into an agreement to share their patents "on the basis of the General Electric Company handling 62½ per cent of their combined business."[18] In 1900 Westinghouse was doing a substantial business in central-station equipment, trolley systems, small electric motors and electric lamps. It was also selling steam turbines which were just coming into commercial use.

The third large manufacturing firm, Western Electric, had been purchased by the American Bell Telephone Company in 1881. Backed by a strong patent position in telephone equipment, it was by far the largest factor in that field; and it also had an im-

[14] E. S. Mason, *The Street Railway in Massachusetts* (Cambridge, Harvard University Press, 1932).

[15] MacLaren, *op. cit.*, p. 103.

[16] As early as 1887 it is reported that "there were fifteen well-known manufacturers of small electric motors in the country." *Ibid.*, p. 92.

[17] Direct current transmission was limited to about two miles. Stanley, working for Westinghouse, was primarily responsible for designing an effective a-c system that gave the central station its large radius and made power transmission a reality.

[18] MacLaren, *op. cit.*, p. 105.

portant business in industrial power apparatus,[19] including arc lamps, motors, generators and switchboard equipment.

None of these concerns, however, was in a strong position to gamble on new frontiers in 1900. GE, as a merger of two competing lighting companies, had been functioning for only eight years and was just beginning to get on its feet after the serious financial troubles engendered by the Panic of 1893.[20] Westinghouse's promotion of the Tesla polyphase patents,[21] and its championship of alternating current against the stubborn opposition of the Edison and the Thomson-Houston interests,[22] had left it in a precarious financial position which had necessitated recent reorganization. And Western Electric was devoting its major energies to improving telephone equipment.

All three electrical manufacturing companies employed trained electrical engineers in 1900. Although the work done was primarily advanced engineering development and production engineering, there was also some research. Steinmetz, for example, was brought to the General Electric Company in 1893. The focus of research attention at GE and Westinghouse was on alternating and direct currents,[23] motors, dynamos and lamps. There was so much to be accomplished in these fields in which the companies had a substantial stake that no consideration was given to radio and electronics. This was to come later when broad research programs had been established in all three companies. And even today in the best industrial research laboratories, it is not possible to cover all aspects of knowledge relevant to a company's inter-

[19] Western Electric's business in power equipment was sold to General Electric and Westinghouse in 1910. F.C.C. *Proposed Report*, *op. cit.*, p. 36.

[20] The policy of President Coffin had been to sell GE's products directly to the local electric lighting companies, taking a large proportion of the payment in securities of the local firms. As a result of this General Electric found itself greatly overextended in the Panic.

[21] George Westinghouse had paid $1,000,000 for the Tesla patents, plus $1 per horsepower royalty.

[22] Alternating current was used for the first time in America in a commercial system of lighting in 1886. This precipitated the "War of the Currents" with the Edison and Thomson-Houston interests battling for the retention of low-voltage direct current and the Westinghouse group for high-voltage alternating current with its promise of making long-distance transmission possible. It was nearly a decade before the industry accepted alternating current without reservations.

[23] Steinmetz, for example, formulated a mathematical system for solving problems of alternating current distribution.

ests; new approaches are often neglected for want of a sponsor, either in the laboratory or among the operating executives.

For these various reasons the established electrical companies played no part in the earliest developmental phases of the American radio industry. This advance was to come from new concerns and new capital.

Chapter III: THE PROCESS OF INVENTION AND INNOVATION—MARCONI AND THE WIRELESS TELEGRAPH: 1896–1920

Marconi was eminently utilitarian. His predominant interest was not in purely scientific knowledge per se, but in its practical application for useful purposes.—Sir Ambrose Fleming.

The scientific pioneers of wireless—Maxwell, Hertz and Lodge[1]—were university scientists working in an environment where the goals were largely non-commercial. There is a strong similarity between personal dedication to science and dedication of one's life to the church; as in the church, a cardinal or a bishop may have both materialistic and spiritual interests, so in science a professor may develop the commercial application of his work. But usually, the major goal of the university professor has been contribution to pure science. And this desire has been re-enforced in modern times by the growing importance of professional pride and professional recognition.

The strength of this tradition can be observed today in the lives of our senior physicists—Einstein, Niels Bohr, Fermi, etc.—whose motivation has been the creative intellectual urge to extend the boundaries of our understanding of Nature. The application of

[1] In focussing attention on Maxwell, Hertz and Lodge, and later Marconi, de Forest and Fessenden, I do not wish to build up the heroic theory of invention. Science and invention rarely progress in discontinuous spurts. On the other hand the process of invention and innovation is comprised of the sum total of the work of many *individuals*, each of whom has the opportunity during his lifetime of maximizing or minimizing his own creative response to his environment. I believe that the economic problems confronting Marconi, de Forest and Fessenden, and the way in which they responded, were typical of the period in which they operated.

these advances, except under the special pressure of wartime service, they have left entirely to others.

In the story of the process of technological development in the radio industry, there was a clear-cut division of labor between the university physicist and the inventor who came later. The university scientists were not interested in inventions or in patents. Hertz had no intuitive conception of the commercial possibilities of wireless. Had he had such a conception, the tradition of pure science would have been against his taking out patents.[2] Michael Faraday designed the first electric motors and dynamos, but he never applied for a patent. By contrast, Marconi, who was almost exclusively interested in making wireless work, applied for patents on everything that he did.

1. *Marconi, the Innovator*

Guglielmo Marconi was not a highly trained scientist.[3] Educated in Italy primarily by tutors, Marconi early developed an absorbing interest in physics and chemistry. When he was twenty (1894), he read for the first time in an Italian electrical journal of the work and experiments of Hertz.[4] Marconi's imagination was stirred by the possibility of making wireless communication a practical reality. Two large rooms at the top of his parents' villa were set aside for experiments, and there young Marconi worked almost constantly on perfecting home-made radio equipment. He improved on the Hertzian oscillator by constructing transmitting apparatus which, from an elevated aerial, discharged

[2] The tradition persists today. Dr. Rabi, in his recent testimony on science legislation, declares: "University scientists in general are not patent-minded. At Columbia University the policy has been that anyone can patent whatever he pleases, and even though the research has been supported by the university, the university makes no claim on that patent. Very few have availed themselves of this privilege. A patent-minded colleague in our department would in time find that he has few scientific friends. We like to discuss matters freely, and it gives us the jitters to feel that someone is going to rush off and patent some idea which came up." Senate Sub-Committee on War Mobilization, Hearings on Kilgore and Magnusson Bills, 1945, p. 976.

[3] Sir Ambrose Fleming, "Guglielmo Marconi and the Development of Radio Communication," *Journal of the Royal Society of Arts*, Nov. 26, 1937, p. 57.

[4] B. L. Jacot and D. M. B. Collier, *Marconi, Master of Space* (London, Hutchinson, 1935), p. 24.

across a spark gap to earth.[5] He also improved on Lodge's coherer by choosing the metal more carefully, grading the plugs and evacuating the tube.[6] By the beginning of 1896 Marconi was receiving Morse code messages over a distance of nearly two miles.[7]

As Marconi's family had wealth, there was no practical necessity for him to earn a living. He was swept into wireless experimentation with an irresistible inner compulsion, and his persistence, to the exclusion of almost all other interests, was perhaps the principal reason for his outstanding success. His career bears out a conclusion of Benjamin Franklin:

> I have always thought that a man of tolerable abilities may work great changes, and accomplish great affairs among mankind, if he first forms a good plan, and, cutting off all amusements or other employments that would divert his attention, makes the execution of that same plan his sole study and business.

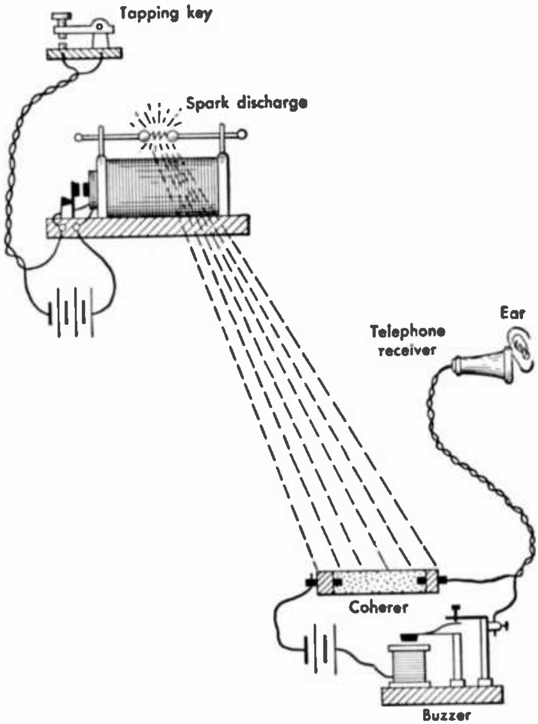
Marconi was also greatly aided by his family connections. His mother was of the Irish aristocracy and moved in the "best circles" in England. The family concluded that Guglielmo would have a better chance to commercialize his inventions there than in Italy. A visit was arranged in 1896, and the young inventor (then twenty-two) was introduced to government officials and capitalists who might be interested in the radio field. Among these officials was William Preece, engineer-in-chief of the British Post Office. Preece himself was an inventor of distinction who had worked on inductive wireless telegraphy.[8] He took a keen interest in Marconi, and planned a demonstration for the post office engineers. Marconi, who had been steadily improving the

[5] Sir Oliver Lodge has commented on this discovery in the following terms: "His (Marconi's) novelty was that he employed a high aerial and an earth connection as the effective radiator. In the achievement of actual telegraphy the earth connection was an assistance; but in my experiments on the demonstration of the waves I had avoided earth connection (1894) as giving an unfair advantage from the point of view of theory. If a disturbance was detected through the earth that wasn't the same thing as detecting it through waves in space. But for practical telegraphy, any and every method was legitimate; and no one now had any serious doubt about the waves." *Past Years, An Autobiography, op. cit.*, pp. 232–233.

[6] Eccles, *op. cit.*, p. 61.

[7] The reader who is not familiar with the way in which wireless operates may wish to refer to Appendix I at this point as background for subsequent discussion.

[8] Preece had succeeded in telegraphing by induction a distance of four and one-half miles.



Representation of the fundamental features of wireless signalling, showing the spark gap of an induction coil which can be switched on and off by a tapping key in the circuit. Oscillatory currents from the spark gap excite the coherer, causing it to become a good conductor. If the coherer is placed in series with a battery and a telephone receiver, it will switch the current in the telephone on and off in synchronization with the tapping key of the transmitter. The coherer may also be used to actuate recording mechanisms. (Courtesy, Horrabin, illustrator. Reprinted from *Science for the Citizen*, by Lancelot Hogben, by permission of W. W. Norton & Company, Inc. Copyright 1944 by the publishers.)

workmanship of every part of his equipment, showed that messages could be sent up to eight miles. This success and the interest displayed by Preece led to the formation of the British Marconi company in 1897.

Two years later an American subsidiary was launched. From then until the formation of the Radio Corporation of America in 1919, the Marconi companies were the dominant concerns in British and American wireless.

The original capital of the British Marconi company (£100,000) was subscribed largely by wealthy individuals who wanted a speculative investment in the new wireless venture. The company had a distinguished directorate; and, considering the fact that Marconi himself was only twenty-three at the time, the terms were exceptionally favorable. Marconi obtained £15,000 in cash and 60 per cent of the original stock in exchange for almost all of his patent rights.[9]

(a) EXPERIMENTS WITH LONG-DISTANCE COMMUNICATIONS

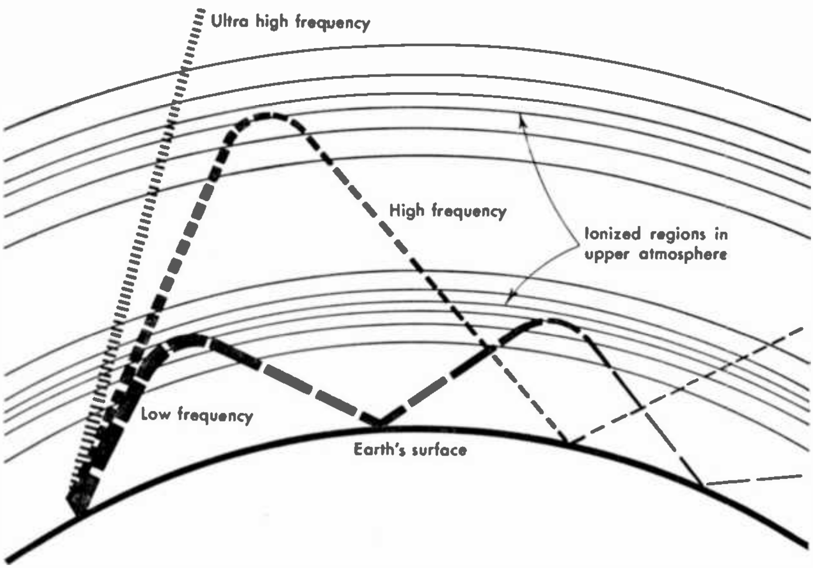
The ease with which the company was launched reflected the public interest in the new electrical developments emerging on every hand. Here was a young inventor, Marconi, who had already succeeded in sending messages eight miles. Wasn't this case likely to be comparable to the telephone? Wasn't wireless going to absorb most of the lucrative transmarine cable business in a few years? Marconi assured investors that it would.[10]

The technical obstacles to the commercial transmission of wireless messages proved much more difficult than Marconi anticipated. Here the analogy with the telephone proved fallacious. Wireless did not become profitable until the difficulties of long-distance communication were overcome; while in the telephone industry substantial profits were earned many years before long-distance telephony became a reality. The early investors in wireless, therefore, were doomed to disappointment. The British Marconi company did not pay dividends from 1897 to 1910.

Immediately after his company was formed, Marconi began experimenting with long-distance communications. The scientists

[9] He reserved to himself his patents in Italy and her dependencies. Marconi testimony, Marconi Wireless Telegraph Company of America *vs.* De Forest Radio Telephone and Telegraph Company, U.S.D.C., S.D.N.Y., in Equity 8211.

[10] He gave his reasons to a representative of Dow, Jones and Company in 1903: whereas a transatlantic cable cost $4,000,000, with an annual maintenance and operating cost of $400,000, the cost of installing a wireless station capable of doing the same amount of business would be only $200,000, with yearly costs of $50,000. "Estimating the present average at but ten words per minute, and the average price of transmission but seven cents per word, the revenue would be $42 per hour, or $1,008 per day, or over $365,000 per year for each station." *Electrical World*, Feb. 28, 1903, p. 361.



Representation of the methods in which radio waves are propagated. Ionized layers of the atmosphere reflect the waves back to earth, the area of return differing with the frequencies used. (Courtesy Dunning and Paxton, *Matter, Energy, and Radiation*, McGraw-Hill)

of the day did not agree on how electro-magnetic waves were conducted around the earth's surface. Nikola Tesla declared as early as 1893 that the upper strata of atmosphere (today called the ionosphere) were conductive and that waves could be sent long distances in the narrow space between the surface of the globe and the conducting strata.[11] But Tesla's actual experiments in long-distance transmission proved a failure. And many scientists believed that wireless waves behaved like light waves and that one could not hope for greater distance than could be achieved by diffraction.

[11] Eccles, *op. cit.*, p. 76. The scientific theories for this phenomenon were later expounded by Oliver Heaviside and A. E. Kennelly, in whose honor the reflecting layer is named the Kennelly-Heaviside Layer. In 1902 Heaviside, writing in the tenth edition of the *Encyclopedia Britannica*, said: "The irregularities make confusion, no doubt, but the main waves are pulled round by the curvature of the earth, and do not jump off. There is another consideration. There may possibly be a sufficiently conducting layer in the upper air. If so, the waves will, so to speak, catch on to it more or less. Then the guidance will be by the sea on one side and the upper layer on the other."

Marconi, nevertheless, decided to erect an experimental station in England and one in Newfoundland, 1,700 miles away.[12] On December 6, 1901, Marconi landed in Newfoundland, to determine whether he could receive a wireless signal transmitted across the Atlantic Ocean. His receiving station was on a high bluff beside the ocean. On the twelfth of December he flew a kite with wires connecting it to the receiving station, and was able to hear faintly a signal of the Morse telegraphic letter "S" transmitted from England.[13]

Despite this initial success and the excellent backing that Marconi received, the Marconi enterprises were to go through a very trying period. The company soon began to feel the opposition of the vested interests in the cable and the telegraph lines. When Marconi started to erect a permanent receiving station in Newfoundland, the Anglo-American Telegraph Company, whose cables terminated there, contended that such action violated its franchise.[14] Marconi finally succeeded in persuading the Dominion Government of Canada to give him a franchise and to appropriate £16,000 for the erection of a station at Glace Bay.[15] This was done only after Marconi promised wireless telegraph rates from England to Canada of 10 cents a word, compared with 25 cents for the cable.[16]

The opposition of the British Post Office also had to be overcome. Although William Preece had been very encouraging to Marconi, Austen Chamberlain, as Postmaster-General, took quite a different attitude. He saw the Marconi company as a potential competitor of the government-controlled telegraph industry, and adamantly refused to connect the Marconi overseas service with the post office telegraph lines. If someone in London wished to send a Marconigram to Paris, he had to go to a local Marconi office; the office would send a mesenger to the post office to telegraph the Marconi broadcasting station in Dover. The message was then relayed across the Channel and sent to its final destination through the French telegraph offices—in all, a slow and ex-

12 Jacot and Collier, *op. cit.*, p. 68.

13 R. N. Vyvyan, *Wireless over Thirty Years* (London, Routledge, 1933), p. 29.

14 *Ibid.*, p. 31.

15 *Ibid.*

16 *Electrical World*, March 29, 1902, pp. 543–544.

pensive procedure. The cross-channel cable companies, by contrast, had a direct connection with the post office.[17] Marconi could compete only by substantial rate cutting; and, as wireless was much more subject to interruption by atmospheric conditions than the cable, the volume of traffic remained small.

(b) DEVELOPMENT OF SHIP COMMUNICATIONS

Marconi soon realized that his company would not survive if it relied primarily on international communications. The most promising field for immediate exploitation seemed to be communication with ships.

Marconi's plans for marine wireless were large and ambitious. He hoped to control the basic patents in the art, and to equip ships of all nations with wireless apparatus. He hoped also to erect shore stations at key points around the world, through which all ship messages would be sent. In the pursuit of these objectives, Marconi was determined to obtain a monopolistic position. Although he succeeded, his aggressive tactics created great antagonism.

Two important ship contracts were secured at the outset—one with Lloyd's and one with the British Admiralty. The Lloyd's contract called for the erection of a series of wireless stations on the coast of England, and the Admiralty contract, for the equipping of thirty-two ships of the British fleet with Marconi apparatus.[18] Lloyd's agreed that for a period of fourteen years from 1901, Marconi apparatus would be used exclusively in equipping the ships it insured.[19] But the Marconi management was too grasping, and Lloyd's brought suit over the interpretation of the contract. Lloyd's contended that the Marconi company had refused to equip its shore stations if these were in the same locality as Marconi installations. Marconi lost the case. In a new contract,

[17] An agreement between the post office and the Marconi company was finally signed on August 11, 1904, by which the Postmaster-General undertook to give facilities for wireless telegraphic traffic. Testimony, H. B. Smith, *Report* to Select Committee on Radiotelegraphic Convention, House of Commons (London, H. M. Stationery Office, 1907), p. 7.

[18] The Admiralty paid £20,000 down, £1,600 for each of 32 installations and £5,000 yearly during continuation of agreement, for a period of eleven years beginning in 1903. Testimony, Col. Daniell, Assistant Director of Naval Intelligence, *Report* to Select Committee, *op. cit.*, p. 50.

[19] *Electrical World*, Nov. 9, 1901, pp. 785–786.

signed in 1905, these points of difference were resolved and both firms agreed to use their "best endeavors" to induce British and foreign governments to grant no wireless licenses to any companies except Lloyd's and Marconi.

Marconi had decided in 1900 that he would not sell apparatus outright, but only lease it.[20] This decision covered all types of wireless equipment. When Fleming wrote Marconi to ask if his valve could be put on sale, Marconi replied:

> . . . . your valve is likely to become a very valuable receiver for long distance wireless, and I wish if possible to keep the monopoly of these experiments to ourselves.[21]

Marconi's leasing arrangements to ships provided for a certain number of messages per month without charge, plus a standard rate per word above this maximum. The company trained and furnished wireless operators who remained on the Marconi payroll. Marconi reasoned that, if the equipment were sold outright, the price charged could not be large enough to support any effective research and engineering. And he was determined to perfect his system of radio communications by continuing his experiments.

Competition, however, developed from Germany and from the United States. The Germans were engaged in a commercial struggle to break into international markets on equal terms with the British and were anxious to challenge the incipient Marconi monopoly. Marconi had applied for and obtained patents on his inventions in Germany; but the Germans developed through the Telefunken Corporation a rival system to Marconi's based on the inventions of Professor Ferdinand Braun, Dr. Rudolf Slaby and Count George von Arco.[22] Shore stations were erected in Ger-

[20] An exception was made in the case of the British Navy which insisted on purchase.

[21] Fleming deposition, Marconi Wireless Telegraph Company of America *vs.* De Forest Radio Telephone and Telegraph Company, *op. cit.*, p. 127.

[22] Prior to 1903 the Braun-Siemens and Halske system had been developed by the Gesellschaft für Drahtlose Telegraphie, while Slaby-Arco was the system of the Allgemeine Electricitäts-Gesellschaft. The patents of the two groups came into conflict in the courts; and on May 30, 1902, a Berlin court handed down a decision for Braun and Siemens and Halske. The Kaiser ordered a halt to the rivalry, and accordingly the two systems were amalgamated in 1903 under Gesellschaft für Drahtlose Telegraphie, known as the Telefunken System.

many; and key ships of the German Navy were equipped with Telefunken apparatus. An American subsidiary was established in 1905 with a powerful station in New York City.[23] In addition, the parent company manufactured and sold transmitting and receiving apparatus noted for high quality.

In the United States the American De Forest Wireless Telegraph Company and its successor, United Wireless,[24] began to invade Marconi's market by leasing and selling radio apparatus at a price that was considerably cheaper than the Marconi arrangements.

Marconi found himself compelled to sell rather than lease wireless apparatus to the navies of various countries, but he retained numerous restrictions. A navy had to pay a substantial flat royalty each year; equipment was to be purchased at current market prices, including duty; messages must be accepted for relay from Marconi-equipped merchant vessels and commercial Marconi stations; and Marconi equipment was not to be used for communication with any rival system except in an emergency or when working with another naval vessel. In return, the navy was granted certain privileges at Marconi stations in the way of rates, time, etc., that would make unnecessary the building of many expensive shore stations of its own.[25]

Marconi had a sufficient head-start over his rivals so that several navies signed such contracts. The American Navy, however, refused to make any such agreements, and insisted that all apparatus be purchased by competitive bidding. Since at first the Marconi company would not agree to this, the United States Navy turned to German companies—Slaby-Arco and Telefunken—and to American companies such as De Forest, for its wireless apparatus.

Merchant shipping companies in many cases would also have preferred outright purchase of Telefunken or De Forest equipment. But here the Marconi company remained at a substantial advantage over its competitors, since English stations all over the world refused to communicate with ships having other than Mar-

23 *Electrical World*, Dec. 9, 1905, p. 1005.
24 This will be described in detail in the next chapter.
25 Paul Schubert, *The Electric Word* (New York, Macmillan, 1928), pp. 33–34.

coni equipment. This policy aroused so much antagonism that it ultimately had to be changed. In 1903 the German government called a special international wireless conference in Berlin at which Germany proposed that coastal stations be required to accept messages regardless of their system of origin. The Marconi strongholds, England and Italy, steadfastly opposed this; and, although a Convention was drawn up, it lacked ratification by a sufficient number of governments to make it significant.

Five years later, as a result of constant agitation, international coastal stations were opened to all senders.[26] The British Marconi company acquiesced only after the British government agreed to make good by a three-year subsidy any loss the company might suffer as a consequence of the new plan.

Despite the aggressive nature of Marconi's campaign to control ship-to-shore communications, his companies remained in financial difficulties until about 1910. Wireless was still regarded as a luxury for most ships and the volume of traffic was scarcely sufficient to yield a return on the large capital investment involved. The sinking of the *Republic* in 1909 and the *Titanic* in 1912 brought dramatic attention to the practical importance of wireless for safety of life at sea. The *Carpathia*, which responded to the *Titanic's* SOS signal and rescued 700 survivors, was 58 miles away and did not reach the scene for several hours. Later it was discovered that a "dead ship"—a freighter without wireless—had passed within 25 miles at the time the *Titanic* sank, and that the *California* was less than 20 miles away but her wireless operator had retired for the night. The public was aroused; and from 1910 to 1912 laws were passed in the United States,[27] England and other maritime countries requiring all ships above a certain size to carry wireless.

[26] July 1, 1908.

[27] In the United States, the Radio Act of 1910 had made it unlawful, after July 1, 1911, for any passenger vessel carrying 50 or more persons, including passengers and crew, plying between ports more than 200 miles apart, to leave any port in the United States unless equipped with "an efficient apparatus for radio communication, in good working order" with a skilled operator in attendance. Following the *Titanic* disaster, the 1910 Act was amended to require two operators and a constant watch, as well as an auxiliary source of power capable of operating the wireless for four hours. In addition, the scope of the Act was extended to cover cargo vessels.

This legislation gave a substantial boost to radio. The position of the Marconi company was also materially strengthened by the fact that its principal American rival—United Wireless—went into bankruptcy in 1912, and its assets were acquired by the British and American Marconi companies. A contributing factor to the bankruptcy was that United Wireless was found guilty of infringing the Marconi "four sevens" patent and the Lodge tuning patent.[28] American Marconi thus gained control of the 400 ship installations and 17 land stations belonging to its competitor. This gave it almost "all the coast stations of importance on the Atlantic and Pacific coasts, besides practically the whole of the American Mercantile Marine at present fitted with wireless installation." [29] The result was that the company carried on about 90 per cent of the American ship-to-shore business between 1912 and the outbreak of war in 1917.[30]

Immediately after acquiring United Wireless, American Marconi increased its minimum charge for merchant ships to $1,000 a year, claiming that the previous charges had "not satisfactorily recompensed the company for the work and labor entailed in operating the stations. . . . It is impossible for the company to do business profitably at the low rates hitherto prevailing." [31] From this time on, the company began to enjoy increasing prosperity.

As may be seen from the following table and chart, it thus took many years for Marconi's wireless innovations to develop into a profitable and secure system of interlocking companies handling ship-to-shore communications over a large portion of the world.

[28] See Annual Report of the American Marconi company for the Year Ending January 31, 1912, pp. 4–5.

[29] Annual Report, 1913, p. 5.

[30] Testimony of Vice-President Nally in 1918 before the Committee on Merchant Marine and Fisheries in the House hearings held on HR13159 for government control of radio.

[31] Annual Report, 1914. The new arrangements were as follows: the contract allowed the shipowners 6,000 words per year to Marconi coastal stations without charge, above which regular coastal rates would be paid. The company furnished the operators, and the shipowner paid their wages and maintenance. The company also maintained the apparatus and added improvements to the ship sets as they were developed. Testimony of Sarnoff on HR13159.

TABLE I: MARCONI WIRELESS TELEGRAPH COMPANY OF AMERICA INCOME AND EXPENSES
1903–1918

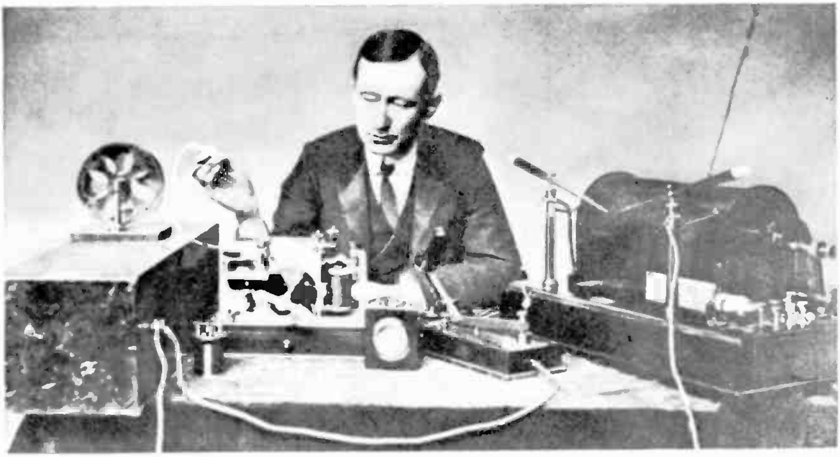
Year Ending	*Organization Expenses and Deficit Acct.*	*Net Income after Taxes*	*Depreciation and Reserves*	*Net Profit*
Jan. 31, 1903	$ 35,468	Deficit	——	——
Jan. 31, 1904	85,183	Deficit	——	——
Jan. 31, 1905	168,843	Deficit	——	——
Jan. 31, 1906	257,475	Deficit	——	——
Jan. 31, 1907	384,804	Deficit	——	——
Jan. 31, 1908	422,422	Deficit	——	——
Jan. 31, 1909	448,803	Deficit	——	——
Jan. 31, 1910	445,102*	$ 16,637	$ 12,936	$ 3,701
Jan. 31, 1911	——	9,405	11,126	1,721(d)
Jan. 31, 1912	——	26,499	11,261	15,238
Jan. 31, 1913	——	242,235	30,989	211,246
Dec. 31, 1913†	——	211,484	33,233	178,251
Dec. 31, 1914	——	271,889	122,011	149,877
Dec. 31, 1915	——	288,995	111,678	177,317
Dec. 31, 1916	——	336,041	76,152	259,889
Dec. 31, 1917	——	780,592	162,820	617,773
Dec. 31, 1918	——	897,325	286,516	711,842‡

* The cumulative deficit was written off in 1911 and 1912.
† For 11 months.
‡ Includes $101,033 described as "other income."
Source: Annual Reports, Marconi Wireless Telegraph Company of America.

2. *Marconi, the Inventor*

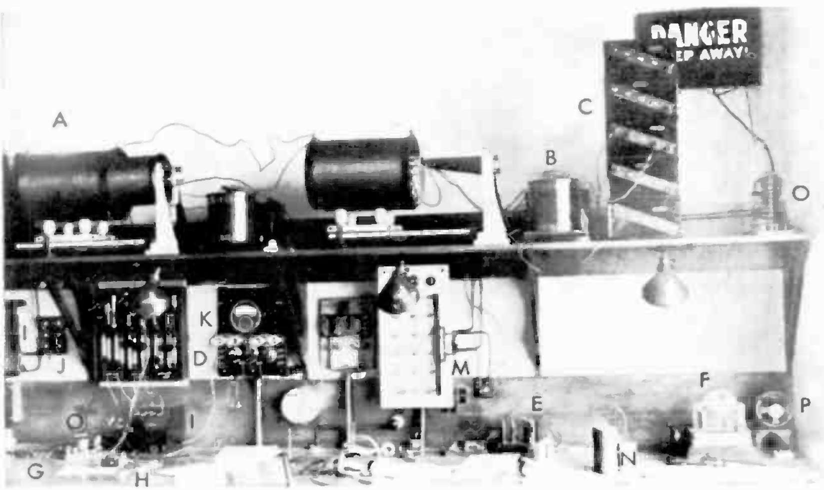
Professor Ambrose Fleming, who joined the Marconi research staff in 1899, has described the inventor in the following terms:

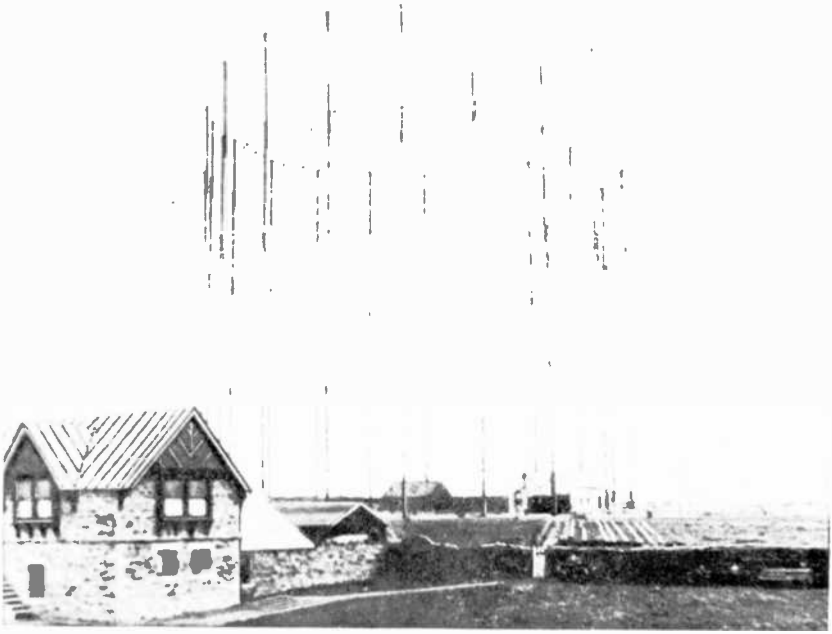
> In the first place, he was eminently utilitarian. His predominant interest was not in purely scientific knowledge *per se*, but in its practical application for useful purposes. He had a very keen appreciation of the subjects on which it was worth while to expend labour in the above respect. . . .
>
> He had enormous perseverance and powers of work. He was not discouraged by initial failures or adverse criticisms of his work. He had great power of influencing others to assist him in the ends he had in view. He had remarkable gifts of invention and ready insight into



Marconi with receiving apparatus, approximately 1898. (Courtesy G. H. Clark Radio Collection)

Receiving and control apparatus used in Marconi high-power station at Bolinas, California, for transpacific working with Hawaii and Japan, about 1912. (Courtesy G. H. Clark Radio Collection) A. Coupler; B. Variable condenser; C. Inductance coils in wooden boxes; D. Balanced crystal system; E. Brown relay; F. Wheatstone transmitter; G. Variable condenser; I. Battery box; J. Switch; K. Charging panel; L. Power control switch; M. Transfer switch (to either of two receivers); N. Test buzzer; O. Antenna switch; P. Motor for Wheatstone transmitter.





Marconi station at Poldhu, Wales, 1900, from which first signals were received in Newfoundland. (Courtesy G. H. Clark Radio Collection)

Marconi at transatlantic station at Glace Bay, Canada, about 1903. (Courtesy G. H. Clark Radio Collection)

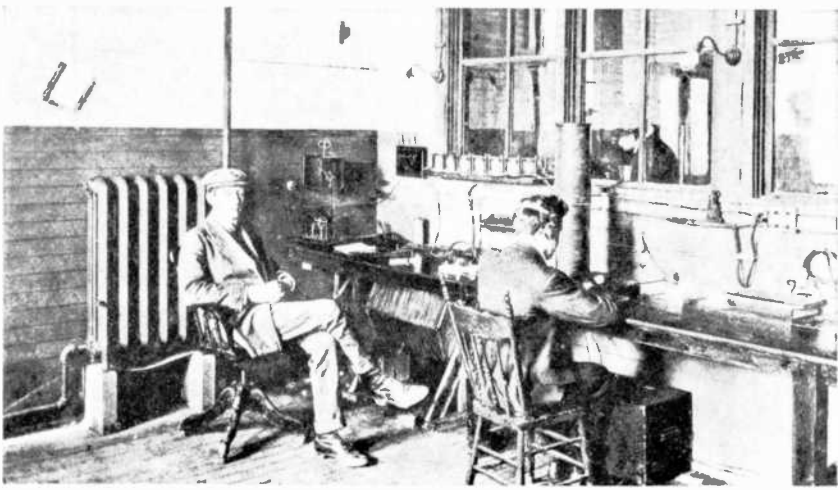
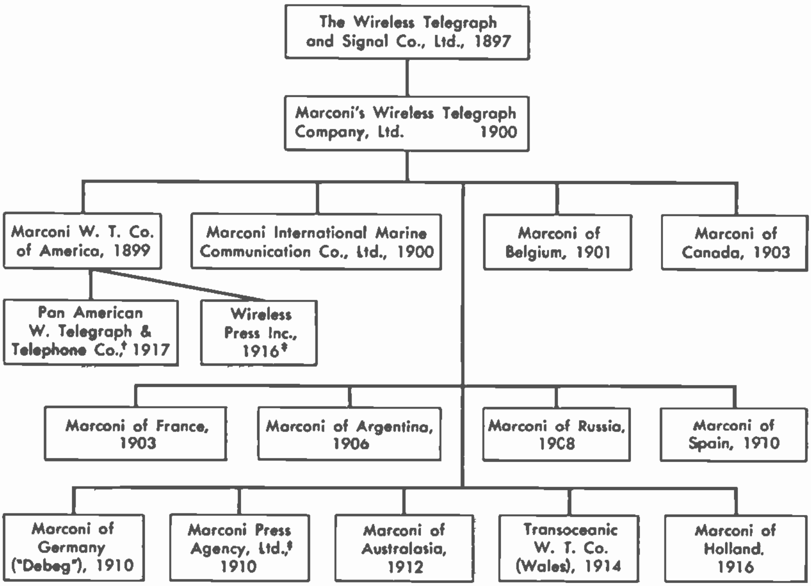


TABLE II
PRINCIPAL MARCONI ENTERPRISES *
1897–1917



* In a number of foreign subsidiaries, the full titles are not given.
† This was organized jointly by British Marconi, American Marconi, and Federal Telegraph, to develop radio communication in South America.
‡ These subsidiaries operated a general printing and publishing business for wireless books and periodicals.

the causes of failure and means of remedy. He was also of equable temperament and never seemed to give way to impatience or anger, but he did not suffer fools gladly or continue to employ incompetent men. He also owed a good deal to the loyal and efficient work of those who assisted him.[32]

Marconi's contributions to the commercialization of wireless made him more important as an innovator than as an inventor. But his company succeeded in getting possession of many of the principal patents in the radio art, despite the fact that the most important wireless discoveries and inventions were not made by

[32] *Journal of the Royal Society of Arts*, Nov. 26, 1937, pp. 57–62.

him or his associates. Hertz was the first man to produce wireless waves experimentally; Lodge invented selective tuning; Edison first noted the phenomenon associated with electron emission from heated filaments, and Thomson and Richardson explained it theoretically; de Forest through his invention of the triode showed how to control the flow of electrons; Langmuir and Arnold developed the high-vacuum tube; Dunwoody and Pickard produced the first crystal detectors; Tesla pioneered in continuous-wave transmission; Poulsen invented the high-frequency transmitting arc; Fessenden and Alexanderson perfected the high-frequency alternator; de Forest and Armstrong invented the regenerative circuit.

Yet the Marconi company acquired, in wireless patents, a dominant position which far exceeded any of its rivals. Although Marconi's own technical contributions were not revolutionary, he applied for patents on everything that he did; and he was the first worker in the field whose interest was in *practical* wireless telegraphy. The principal patents in Marconi's name were on improved types of vertical antennas, on the improved coherer, on the magnetic detector and on methods of selective tuning. The patents on the coherer illustrate the way Marconi was able to obtain a strong position without doing the fundamental work. Branly patented the coherer but did not conceive of its use for wireless.[33] Lodge used it first for radio reception but did not feel that he had made an invention and did not apply for a patent. Marconi improved the coherer and was able to get the basic patents for its use in wireless.

Marconi's coherer, although practical for distances up to 100 or 200 miles, had the disadvantage of being "easily upset by the stray electric waves called 'atmospherics,' which are produced mostly by distant thunderstorms and also by any near-by electric sparks." [34] To overcome atmospheric interference, Marconi in 1902 developed the magnetic detector "based on a discovery by Lord Rutherford that very rapid electric currents can knock the

[33] Lodge first conceived of using the Branly coherer as a wireless detector and is credited with giving it the name "coherer." O. E. Dunlap, *Radio's 100 Men of Science* (New York, Harper, 1944), p. 76.

[34] Ambrose Fleming, *Memories of a Scientific Life* (London and Edinburgh, Marshall, Morgan and Scott, 1934), p. 139.

magnetic state out of an iron wire." [35] This detector was "more certain in its action than the coherer but had the disadvantage that the signals could only be heard as sounds in a telephone and could not be recorded on a tape." [36] For the succeeding ten years, however, the magnetic detector was standard receiving equipment on English and most other European vessels.[37]

The two inventions that were to prove of outstanding importance to the Marconi patent structure were the Lodge tuning patent[38] and the patent on the Fleming valve.

One of the major problems to be solved in the early days of wireless was how to make a receiver select messages from those that were sent out simultaneously from different stations. The pioneering work was done by Oliver Lodge, who through his studies of selective resonance, showed that, by adding an inductance coil to an antenna, selectivity was greatly increased. This was a very significant contribution, and Lodge applied for a patent on the method. Marconi realized that Lodge had discovered the basic principles of tuning. He set to work immediately to make Lodge's method more practical in a number of ways, including the addition of what is known today as a tuning dial.[39] Marconi's patent on tuning (British No. 7777, filed in 1900) became one of the most famous in wireless history. Marconi brought a series of successful suits against most of his early rivals on this patent; but in 1911 the prior Lodge patent was upheld against Marconi. It was then purchased by the Marconi company on condition that the Lodge-Muirhead syndicate,[40] which had been

35 *Ibid.*

36 *Ibid.*, p. 140.

37 A. F. Harlow, *Old Wires and New Waves* (New York, Appleton-Century, 1946), p. 448.

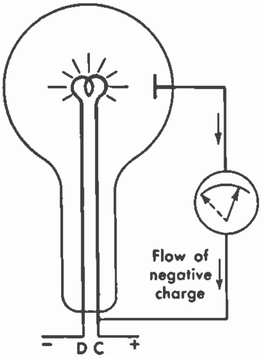
38 U. S. Patent No. 609,154, application Feb. 1898, issued August, 1898. This was the only one of the three principal Marconi company patents which was completely upheld by the Supreme Court in 1943, when the Marconi four-circuit tuning patent was held invalid.

39 Douglas Coe, *Marconi, Pioneer of Radio* (New York, J. Messner, Inc., 1943), p. 111.

40 The Lodge-Muirhead Syndicate had been formed in 1901 with £50,000 capital. It was unable to obtain a commercial license in England, and was therefore forced to do business with Colonial governments, particularly in Burma and India. Colonel F. J. Davies testified before the House of Commons in 1907 that the Lodge-Muirhead sets had "given the most satisfactory results so far" in competition with Telefunken and Marconi. *Report* to Select Committee, *op. cit.*, p. 47.

formed to develop Lodge's radio patents, cease its operations.

The second most important patent in the Marconi structure was on the Fleming valve. Fleming's invention was declared by the courts to be basic to the whole vacuum-tube art,[41] and its history is therefore of particular importance. In 1883 Thomas Edison, investigating the blackening of lamps, had noticed that under certain conditions of vacuum and voltage a lamp would give off a blue glow. Experimenting, he found this to be caused by an unexplained current that flowed directly across the space between the two legs of the lamp filament. The flow took place in the opposite direction to the regular current passing through the filament—that is, from the cathode or negative terminal to the anode or positive terminal. Edison recorded his observations on this phenomenon but was not able to explain it. It became known as the "Edison Effect," and the inventor secured a patent on an "electrical indicator" based on the effect in October 1884.[42]



The Edison Effect. The current flows from the hot filament to a plate inside the bulb, causing an indication on the galvanometer when the plate is made positive. When the plate is connected to the negative wire, no current flows. (Courtesy Dunning and Paxton, *Matter, Energy, and Radiation*, McGraw-Hill)

From then on, the Edison Effect was studied in both its theoretical and practical aspects. Scientists linked this phenomenon with similar manifestations from other sources, such as x-rays. And in 1897 the British physicist, J. J. Thomson of the Cavendish Laboratory, published his theory of the electron, in which he suggested that atoms of a metal are made up of negative charges

[41] In 1943 the U.S. Supreme Court upheld a decision of the Court of Claims declaring that the Fleming patent was invalid. The patent, however, had long since expired and was not successfully challenged during its life. Marconi *vs.* U.S., 320 U.S. 1.

[42] U.S. Patent No. 307,031.

imbedded in a sphere of positive charges. When a metallic electrode is heated to an extremely high temperature, these negative charges, or electrons, boil out of the metal and are drawn across to the anode. This electron flow, he thought, manifested itself in the blue glow of the Edison Effect.

Ambrose Fleming, who had been scientific adviser to the Edison Electric Light Company of London and who had seen Edison's experiments, conceived the idea of using a vacuum lamp of the Edison type as a detector for wireless signals. The ether waves sent out from a radio station are at such a high frequency that they are inaudible to an instrument like the telephone. To produce audible sounds in a wireless head phone, which was a standard method of reception in the early days, it was necessary that the signals be rectified—that is, passed through a device that allows the current to flow in one direction only and suppresses any flow in the other direction.[43]

Fleming decided to utilize the Edison Effect in a wireless valve. He constructed a vacuum tube with a cathode and an anode, and attached a battery to the cathode, enabling him to heat it to incandescence so that electrons would be continuously emitted. Fleming then inserted the tube in the aerial circuit of his receiver. The alternating character of an incoming wireless signal made the anode successively positive and negative. During the negative half of the signal wave, the anode repelled the electrons given off from the cathode, and no current flowed. But during the positive phase, the anode was positively charged, and drew the electrons across the tube, causing a flow of current that operated a telephone receiver or a recording device. Fleming's invention, patented in 1904, went automatically to the British Marconi company under his consulting contract.

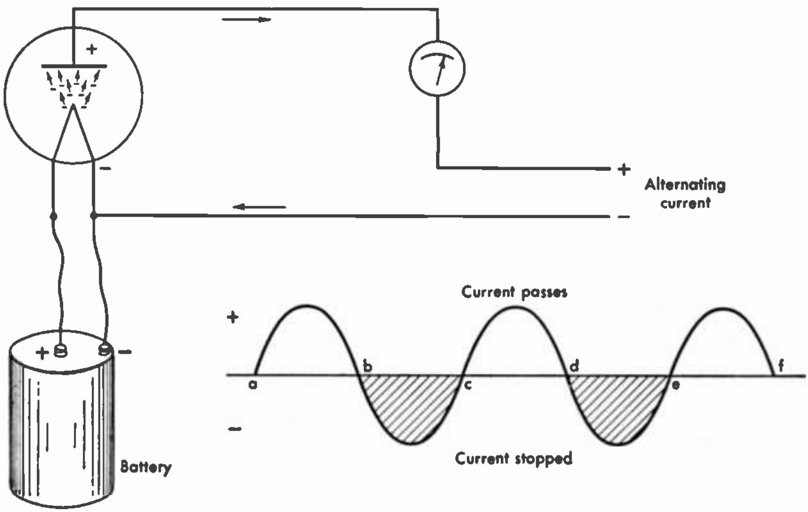
In its original form the Fleming two-element tube or diode was not as satisfactory[44] as the crystal detector which was invented about the same time. It was not until de Forest added the plate battery and grid control, and Arnold and Langmuir showed the

[43] Arnold *vs.* Langmuir, Interference No. 40,380, Brief on Behalf of Irving Langmuir, p. 25.

[44] In initial operation, the diodes were superior to crystal detectors, but they soon became unstable and erratic. They were, therefore, never really used in practical wireless telegraphy.

necessity of very high vacuum that the valve became the keystone of modern radio communications.

Marconi himself made no important inventions after 1902. The character of his work changed from inventing to the initiation of research to be carried out by subordinates. Although he became increasingly involved as a promoter of his world-wide enterprises, he remained for many years the dominant *technical* figure in the company. He had considerable imagination about possible



Operation of a diode or two-element tube, showing a valve action which will allow passage of current in one direction only. (Courtesy Stokley, *Electrons in Action*, Whittlesey House)

new improvements in wireless telegraphy, and was primarily responsible for setting others to work on most of the problems that were investigated.

But he does not rank with Edison, Cartwright, Watt, Bell or de Forest in the originality of his technical contributions.

Taussig, in *Inventors and Money Makers*, concluded from a review of the lives of inventors that:

> We are misled by the fact that the names of most inventors are associated with one device, at most two. Watt, with the steam engine, Cartwright, with the power loom and the combing machine, Fulton,

with the steamboat, Howe, with the sewing machine, Ericcson, with the screw propeller and the monitor, Bell, with the telephone, Edison, with the incandescent light and the moving picture. Their biographies show that they were constantly experimenting on all sorts of schemes, promising and unpromising; sometimes with money-making intent, sometimes in the spirit of scientific research, and sometimes merely in sport. Werner Siemens, one of the few who combined a strictly scientific temper with the genius for contrivance, began with the telegraph, proceeded to the metallurgy of iron and copper, closed with devotion to the field of pure science.[45]

This description does not fit Marconi. He devoted his life exclusively to the one purpose of perfecting and promoting wireless telegraphy and his inventions were entirely confined to that field.

3. Marconi as Research Director and Manager

Marconi surrounded himself from the beginning with a group of able technical assistants. In 1900 there were seventeen professional engineers in the Marconi company in England, many of whom later became well known in electrical engineering circles.[46] In addition, Marconi sought out some of the most promising university scientists who were interested in wireless and employed them as consultants, among them Lord Kelvin. Marconi was not afraid, as many inventors have been, of hiring men with greater technical competence than his own.

The selection as a consultant of Ambrose Fleming, who was then a promising young professor of electrical engineering at University College, London, illustrates Marconi's practice when special technical obstacles were met. With the apparatus used from 1896 to 1898, Marconi had found that, if he doubled the height of the aerial, the range of possible communication would be four times greater. But the practicable economic height of wooden masts for supporting the aerial was at that time believed to be about 200 feet. Marconi concluded that he would have to

[45] F. W. Taussig, *Inventors and Money Makers* (New York, Macmillan, 1915), pp. 22–23.

[46] This original group included Dr. W. H. Eccles, Dr. Erskine Murray, W. W. Bradfield, Andrew Gray, C. S. Franklin and H. J. Round. Vyvyan, *op. cit.*, p. 24.

design a transmitter of much greater power than had been used hitherto. Fleming, he learned, had gained considerable experience in the electric lighting field with extra-high tension alternating currents. He therefore appointed him as scientific adviser to the company.

In the United States the American Marconi company engaged Michael Pupin as a consultant for a number of years.[47] Pupin, a professor of physics at Columbia, was one of the leading contributors to electrical engineering development of the period.[48] His most important invention was that of the loading coil—of great importance in long-distance telephony. The connection with the Marconi company did not prove fruitful; but the selection of Pupin was characteristic of the company's high standards in searching for scientific assistance.

Marconi had considerably greater capacity for directing research than for managing a business. An early associate stated that he "detested routine business and legal conflicts." [49] The Marconi enterprises did not become a financial success until Godfrey Isaacs was appointed managing director in 1910. Marconi was enough of a salesman to interest William Preece in his work and to acquire the all-important contracts with the British Admiralty and Lloyd's. Yet much of the good will toward the young inventor was dissipated later by the company's tactics. The quarrel with Lloyd's, which resulted in a suit, could easily have been avoided. And in 1907, Sir William Preece, the erstwhile champion of Marconi, declared: "I have formed the opinion that the Marconi company is the worst managed company I have ever had anything to do with. . . . Its organization is chiefly indicated by the fact that they quarrel with everybody." [50]

As Marconi's friends and contemporaries declare that he had a very equable temperament and got along extremely well with his technical associates, this is difficult to explain. Apparently he had no intuitive sense of how to develop smooth business relations.

[47] *Electrical World*, June 6, 1903, p. 961.

[48] Pupin made a fortune from his inventions which he subsequently gave to Columbia University for science buildings.

[49] James C. H. Macbeth, quoted in Dunlap, *Marconi, the Man and His Wireless* (New York, Macmillan, 1937), pp. 204–205.

[50] *Report* to Select Committee, *op. cit.*, pp. 232–234.

This was, perhaps, because of his fervid interest in the technical phases of wireless. After several difficult business years, the directors of the company decided that they must bring in a man of exceptional promotional skill and influential connections to take charge of the broad business policy of the far-flung Marconi enterprises. Accordingly, in 1910, Godfrey Isaacs was appointed managing director. Isaacs was a brother of Rufus Reading, the Lord Chief Justice, and a close friend of Herbert Samuel, the British Postmaster-General. Such government connections were particularly important when it came to competing with Germany, which also was trying to develop a world-wide system of wireless communication. In South America and other countries, where International Marconi was expanding, British ambassadors were enlisted to help the company secure concessions. And when in 1912 the British Post Office decided to build a series of radio stations throughout the Empire, it gave the contract to the Marconi company.[51] (The Marconi company then began construction of the Imperial Chain on a spark basis, which was largely outmoded.)

Godfrey Isaacs, in the minds of those who knew the company well, became "the king-pin of the organization." [52] An associate described him as "the salesman of wireless with the business strategy and enthusiasm necessary to promote such a radically new communication system. He revelled in acquiring telephone and electrical instrument companies to link them as subsidiaries of wireless. Marconi entrusted the business end of wireless and its promotion to Mr. Isaacs, who presided at the company's meetings and usually at public functions." [53]

The research and advanced engineering development for the Marconi enterprises was conducted primarily in England.[54] The company was sufficiently well financed, so that it was able to sup-

[51] Marconi stock jumped from £2 per share in August, 1911, to £9 in April, 1912—less than a month after the government accepted the formal Marconi tender. The contract later proved lucrative in an unexpected fashion. The post office cancelled it during the war and was sued for damages. The courts awarded the Marconi company £600,000 for this breach. Dunlap, *op. cit.*, p. 207.

[52] James C. H. Macbeth, early member of the company, quoted in Dunlap, *op. cit.*, pp. 204, 205.

[53] *Ibid.*

[54] The American Marconi company, however, did have some very competent engineers, including Roy Weagant, Ralph Langley and Harold Beverage.

port a research organization from the beginning. This remained on a much more modest scale than in companies like General Electric and American Telephone and Telegraph.

Marconi's principal weakness as a director of research was that he emphasized the perfecting of existing methods instead of reaching out for radically new discoveries in wireless. Although this may occur in any research organization, there is more danger of it where the director takes a restricted scientific view of the functions of his company. Marconi's intense drive for the rapid commercialization of wireless produced a number of blind spots, the most serious of which was his failure to visualize continuous-wave operation in transatlantic working, and in turn the significance of radio *telephony*. No one, of course, foresaw the development of the radio broadcasting industry, but there were many of Marconi's contemporary inventors who believed in the wireless telephone. Marconi did not share their optimism. He thought that the Morse code was adequate for communication with ships and for transoceanic messages and saw no clear need for voice transmission. Since his approach was pragmatic, he was not interested in the scientific investigation of a field whose commercial possibilities seemed remote. This was unfortunate both for the Marconi company and for the advancement of the art. The early experimentation with the radio telephone was left almost entirely to Marconi's American rivals, Lee de Forest and Reginald Fessenden, neither of whom had at his disposal financial resources or engineering skill comparable to the Marconi enterprises.

On the other hand, within the limitations of spark wireless telegraphy, Marconi's research organization made substantial advances—by attaining greater distances, by achieving better tuning and by partially overcoming static and interference.

In the early years, interference from other stations was so serious that "there were only two sure ways of getting a message through: wait till no one else happened to be sending, or boost up the power of your transmitter in an attempt to drown out the other fellow and allow your own signal to be deciphered by sheer brute power. The second method was the usual one." [55]

[55] G. H. Clark, unpublished ms., *John Stone Stone*, p. 79.

Marconi's attempts to eliminate interference centered in the development and improvement of the coupled circuit.[56] His controlling patent on the coupled circuit (the 7777 British patent) was issued in 1900, but variations in closer or looser coupling were made by the company for many years afterward in attempts to lengthen the train of waves and to increase selectivity. Marconi himself continually encouraged his research engineers to make improvements in the sharpness of tuning.[57]

Another important advance in spark telegraphy was duplex working. Until 1913 it was the practice to have transmitting and receiving aerials on one site, the transmitter being stopped at intervals and the receiver switched on so that the distant station could acknowledge receipt or ask for repetitions.[58] As a result, each plant was in use only half the time. This was very difficult to correct because of the lion-and-lamb characteristic of a transmitter and a receiver. The transmitter was brutally powerful in contrast with its receiver, the energy received being only an infinitesimal part of that sent. Detectors of the period were notoriously delicate and were readily upset by any surge of high power.

Marconi ultimately evolved a plan of duplex working, first introduced on the Ireland–Canada link, by which the sending and receiving stations were separated by a number of miles. Two directive aerials were employed for each receiver, one getting optimum reception from the remote station, the other from the local transmitter. The transatlantic aerial received the distant signal, plus a local interfering signal, while the other received only the local station. When the two aerials were coupled in opposition, the local signals were balanced out, leaving a transatlantic signal free from interference.

Even these ingenious measures were not sufficient to provide reliable transatlantic wireless communication. Spark telegraphy

[56] In this circuit the spark gap was not directly connected in series with the antenna, but was placed in an "exciting" circuit of its own.

[57] Vyvyan, *op. cit.*, p. 56. In 1911 H. J. Round invented a balanced crystal circuit for reception. He employed two crystals working in opposition, and so set that one was sensitive to the signal whereas the other only operated when a disturbance exceeded the value to which it had been adjusted. This gave relief to the operator, and yet produced stronger signals.

[58] *Ibid.*, p. 58.

was inevitably doomed by the rapid progress of continuous-wave transmission, and in this development Marconi's research organization did not participate. By 1916 the Poulsen arc and the Fessenden-Alexanderson alternator, both of which produced continuous waves, had been improved to a point where they were more reliable than spark apparatus. The patents on the Poulsen arc were held by enterprises that were competing with Marconi. The Marconi company tried to buy rights to the alternator from General Electric but was unable to reach an agreement before the war terminated negotiations.

Marconi did develop a semi-continuous "timed disc" transmitting apparatus that was installed at Carnarvon in June 1916. It was technically a success, though so noisy that it was known as the "Rock Crusher." The first wireless message sent directly from England to Australia was transmitted by this apparatus.[59] In the meantime, the Germans in 1914 had inaugurated machine-generated continuous-wave transmission across the North Atlantic. And three years later General Electric, using the Alexanderson high-frequency alternator, perfected a system of continuous-wave telegraphy superior to any other existing apparatus for long-distance communication.[60]

Marconi engineers played no pioneer roles in the development of the three-element vacuum tube, the feedback circuit and the heterodyne. These were the most revolutionary advances in the science of wireless communications between 1900 and the first World War. Although Marconi's research organization made some contributions beyond the two-element tube of Fleming, they were, from a patent point of view, "too little and too late." [61]

The most significant contribution of Marconi engineers after

[59] Vyvyan, *op. cit.*, pp. 65–66.

[60] Two other companies were competing with Marconi for transatlantic traffic—Telefunken with its station at Sayville, Long Island, communicating with Nauen, Germany; and a station at Tuckerton, New Jersey, communicating with Eilvese, Germany. Tuckerton, using the alternator of Dr. Rudolph Goldschmidt, was the first American high-power station to use machine-generated continuous waves.

[61] C. S. Franklin of British Marconi devised a feedback circuit which greatly increased the amplification powers of receiving tubes, but priority of invention in the United States was awarded successively to Armstrong and de Forest. H. J. Round of British Marconi also did some early experimental work on the oscillatory feedback.

the invention of the Fleming valve was the development of beam transmission and short-wave propagation. In the progress of wireless telegraphy since Hertz's time, experiments had indicated that increasing the wave-length to as much as 20,000 meters produced steadily better results for *long distance* communication. Radio engineers had assumed, therefore, that very short waves would simply not carry over long distances, although Hertz, using concave mirrors, had demonstrated that very short waves could be focussed in a beam, obeying the ordinary optical laws of reflection.

In 1916 Marconi asked Franklin to re-explore the use of the short waves which had been the basis for the original experiments of Hertz.

> I could not help feeling [Marconi said] that we had perhaps got rather into a rut by confining practically all our researches and tests to waves of some thousands of feet in length.[62]

Marconi was concerned with the military problem of sending messages which would not be readily intercepted by the enemy. Franklin, using vacuum-tube techniques, duplicated Hertz's experiments, and carried them through to a carefully engineered system of beam transmission. It came as a surprise to everyone, when, after the war, Franklin in England, Frank Conrad of the Westinghouse company, and various groups of amateurs independently found that they could communicate over very long distances by the use of short waves. Marconi and Franklin persisted in their tests, and reached the conclusion that a commercial system of short-wave beam stations throughout the British Empire would give much more reliable and effective service than was possible with long-wave apparatus. The Marconi company succeeded in 1924 in securing a contract with the British Post Office to erect such stations in Canada, India, South Africa and Australia.

These installations proved extremely successful and forced all wireless organizations to enter this new field of development.[63] With the inauguration of beam services, the radio began for the

[62] G. Marconi, "Radio Telegraphy," *Proc.* I.R.E., Vol. 10, No. 4, August 1922, p. 215.

[63] Vyvyan, *op. cit.*, p. 92.

first time to compete seriously with the cable in transoceanic communications.

Marconi himself continued throughout his life to experiment with wireless. A large portion of his time from the years 1919 to 1934 was spent on board the yacht *Elettra*—which was his research laboratory at that time—testing and perfecting new types of apparatus. Most of this work could be described as advanced engineering development. He was concerned with "next year's model," rather than with a radically new approach.

Sir Ambrose Fleming may have had Marconi in mind when he wrote:

> Invention consists in overcoming the practical difficulties of the new advance, not merely talking or writing about the new thing, but in *doing it*, and doing it so that those who come after have had real obstacles cleared out of their way, and have a process or appliance at their disposal which was not there before the inventor entered the field. In most cases, however, the removal of the obstacles which block the way is not entirely the work of one person. The fort is captured only after a series of attacks, each conducted under a different leader. In these cases the inventor who breaks down the last obstruction or leads the final assault is more particularly associated in the public mind with the victory than are his predecessors, though his intrinsic contribution may not actually be of great importance.[64]

Yet, despite his limitations, Marconi was truly the midwife of radio. Hertz's discoveries lay in embryo, as it were, for nearly ten years, unheeded by entrepreneurs and inventors alike, a source of academic interest only. It required a man of exceptional vision to seize upon these scientific discoveries, relate them to an imperative need and translate them into a workable and effective method of communication.

Besides Marconi's personal capacities as an inventor and more particularly as an innovator, the birth of wireless was abetted by two fortuitous circumstances. The first of these was that Marconi could afford, in the literal sense, to spend time and money on experiments. No economic pressure forced him to abandon his deep-seated convictions that wireless would work. Marconi was once asked what he would have done had he been very poor. "In

[64] J. Ambrose Fleming, *Principles of Electric Wave Telegraphy* (London, Longmans, Green, 1906).

these circumstances," he replied, "I do not know whether I should have invented anything at all. If so, I am not at all sure I should have persevered." [65]

The other adventitious circumstance was Marconi's introduction in England. Had he remained in Italy, it is probable that he would eventually have abandoned his ideas for lack of stimulation, or that they would have been slow to develop because of the absence of a ready market in that country. The warm welcome accorded Marconi by British authorities and the active interest in a device which would strengthen England's maritime "life-line of Empire," gave him a sympathetic environment and a motivating drive that was of paramount importance.

[65] Jacot and Collier, *op. cit.*, p. 117. *Cf.* Edward Gibbon, "Wretched is the author and wretched will be the work where daily diligence is stimulated by daily hunger." *Autobiography* (New York, Fred De Fau and Company, 1907), p. 248.

Chapter IV: THE PROCESS OF INVENTION AND INNOVATION: FESSENDEN, DE FOREST AND THE EARLY WIRELESS TELEPHONE

De Forest would sweep down on a problem with a hungry rush and his imagination had an astonishing faculty for leaping difficulties. If the quarry snagged or proved elusive, however, he had to hop to something else.—SAMUEL LUBELL.

THE United States played a much more important role in radio invention than in the scientific discoveries underlying radio. Two of the principal early radio inventors—de Forest and Fessenden—were Americans, and the most important single invention in the history of wireless was made by an American—Lee de Forest. Freedom from tradition, the attraction of the "finest of youth to industry," and the burst of energetic activity, which have characterized the economic development of America, provided a magnificent environment for the exercise of "Yankee ingenuity." Scientific research, in contrast, required more sober, persistent, scholarly effort than American youth was willing to offer.

The foregoing story of the early technological development of radio has stressed the vital contribution of fundamental research in laying the foundations for the industry, and the significance of new companies like the Marconi enterprises in translating this research into practical commercial products. The most difficult ingredient to supply proved to be effective management rather than capital. Marconi, de Forest and Fessenden—all succeeded in obtaining venture capital in substantial quantities to back their wireless enterprises. All three had exceptional inventive skill. But only the Marconi companies were well managed, and only they survived.

1. Reginald Fessenden

(a) THE INVENTOR

Professor Reginald Fessenden of the University of Pittsburgh was the first important American inventor to experiment with wireless. In 1900 he left the university to assist the United States Weather Bureau in working out a means of wireless transmission of weather forecasts. Several wireless telegraph stations were erected and underwent successful tests. And in December, 1900, Fessenden gave a demonstration for the Weather Bureau in which he transmitted *speech* by electro-magnetic waves using two masts 50 feet high and one mile apart. He used spark apparatus which was not really satisfactory for voice transmission; but the Weather Bureau was so interested that work on a larger scale was planned and some of it completed. However, Fessenden had a choleric personality, and his relations with the Bureau soon became so strained that he resigned, the final break being precipitated by a quarrel over patent rights.

Fessenden then succeeded in interesting two Pittsburgh capitalists—Hay Walker, Jr., and Thomas H. Given—in forming the National Electric Signaling Company to support his work on wireless telegraphy and telephony. It was now clear to the inventor that speech transmission would require a train of continuous waves, on which the voice currents could be superimposed, rather than the spark apparatus which he had used hitherto.

Nikola Tesla, a Yugoslav physicist, had first conceived the idea of transmitting continuous waves and had pioneered in high-frequency alternators in the 1890's, but he was not successful in his radio experiments. Fessenden took up where Tesla left off and was more persistent. He believed he could design equipment to transmit and receive Morse code signals across the Atlantic by the continuous-wave method much more effectively than Marconi could with spark apparatus. He was also convinced that eventually he could design apparatus capable of carrying telephone conversations between America and Europe. His first high-frequency alternator was built to his specifications by Steinmetz of the General Electric Company in 1903. This was a 10,000 cycle machine and did not prove sufficiently powerful to transmit over long distances. Thereafter, Fessenden pressed for apparatus of higher and higher power. In 1906 he obtained a second alternator that could operate at 80,000 cycles; and on Christmas Eve he broadcast a program of music and speech with a request that listeners report the results. Operators from ships in various parts of the North Atlantic responded to this first voice broadcast.

It was to take years before an alternator capable of regular voice broadcasts across the Atlantic was developed by Alexanderson of the General Electric Company. In the end, however, the continuous-wave methods were to triumph over the spark.[1] But many of the leading engineers in the industry, especially those associated with the Marconi enterprises, remained skeptical until they actually saw the demonstrations of the Alexanderson equipment.

Fessenden also worked on continuous-wave reception. The Marconi coherer was limited to receiving dots and dashes because the tapper, which shook up the filings and restored its sensitivity, prevented continuous reception. Fessenden sought a detector which would follow the undulations of the voice. After various attempts, he developed in 1903 a new receiving mechanism—the "electrolytic detector"[2]—consisting of a fine platinum wire, coated with silver and dipped into a dilute acid solution. After the acid had destroyed a short length of the silver coating, the platinum wire was withdrawn from the acid, allowing surface tension to form a meniscus between the acid and the wire. A flow of current from a battery to which the detector was connected would cause gas to form at the end of the wire. An incoming

[1] There were also parallel developments of high-frequency alternators by the Germans. Powerful Goldschmidt alternators for transatlantic communication were installed at Sayville, Long Island, in 1912 and at Tuckerton, New Jersey, in 1914. On the West Coast the Federal Telegraph of California began installing a series of high-power Poulsen arcs in 1911. The Poulsen arc had been invented in Denmark in 1903.

[2] This was also developed independently in Germany by Schloemilch. S. M. Kintner, one of Fessenden's associates and later director of research for Westinghouse, described the electrolytic detector as "the standard of sensitivity for years, in fact until it was displaced by the vacuum tube about 1913." "Pittsburgh's Contributions to Radio," *Proc.* I.R.E., Vol. 20, Dec. 1932, p. 1851.

The U.S. Navy used many of these detectors; in fact, it was the Navy's standard detector from 1908 to 1913. The United Fruit fleet carried them, and United Wireless used them until prohibited from doing so by court injunction. Interview with J. V. L. Hogan, May 1946.

wireless wave would explode the bubble, dissipate the gas and allow the passage of the impulse to a local circuit containing a telephone receiver. The delicacy of the device made for extreme sensitivity, but its use at sea was limited because of the ship's roll in heavy weather.

Another of Fessenden's major achievements was his work on heterodyne reception, often called "the second greatest thing in the radio art."[3] This also arose from his quest for a type of receiver more effective than the coherer.[4] The coherer, like the electrolytic detector, was operated with an auxiliary battery which provided the source of local energy to make audible signals. When the iron filings of the coherer became conductive under the influence of received electro-magnetic waves, the energy from the battery was used to ring a bell or sound a buzzer. Attempts to improve the sensitivity of these receivers beyond a certain point met with little success, because when they were made very sensitive, they responded to static as well as to wireless waves.

In his search for a more satisfactory receiver, Fessenden evolved the heterodyne system. Previous receivers had acted like valves, turning on and off a direct current in amounts proportional to the received impulse; the heterodyne acted by the joint operation of two alternating currents. One wave originated from the transmitter, and the other was generated at the receiving station. An inaudible transmitted frequency of 200,000 cycles, for instance, combined with a frequency of 201,000 cycles at the receiver, would produce an audible "beat" note of 1,000 cycles, the difference of the two former frequencies.

Tests in 1913 between the Navy's "Fessenden equipped" station at Arlington and the cruiser *Salem*, as well as earlier Navy tests in 1910, showed the superiority of the heterodyne, as to both sensitivity and static control. The Navy was very much interested in the heterodyne, but the cumbersome apparatus which was necessary for its use in the early years prevented its wide-

[3] Next to the de Forest triode. Both the triode and the heterodyne were unused for many years after their invention, because they were ahead of the times and had faulty construction.

[4] See article by John V. L. Hogan on the heterodyne principle in *Proc.* I.R.E., Vol. I, Pt. 3, 1913, p. 75 *et seq.*

spread adoption. Fessenden produced the heterodyning frequency with an arc generator, which was noisy, difficult to adjust, and costly. It was many years, therefore, before the heterodyne principle came into its own.[5]

Fessenden as a personality was in many respects the antithesis of Marconi. Where Marconi was content to build a better model on the same principles as the old one, Fessenden was eager to pioneer, to build something new on revolutionary principles, with little regard to the *status quo* and not much regard to its practicability. His ideas were so far ahead of contemporary practice that they were frequently inapplicable until the engineering art had caught up with him; yet he stubbornly refused to abandon them in the face of overwhelming opposition from the "experts." At a time when the coherer was "the very heart of the wireless system," Fessenden insisted that the successful detector of the future must be continually receptive. On Fessenden's death, J. V. L. Hogan commented that radio had gone through a "Lost Decade" because Fessenden stood alone so long in support of his continuous-wave theories.[6]

Unfortunately, much of Fessenden's creative imagination was marred by his temperament. Fessenden apparently had considerable charm and was a stimulating companion. But he was hot-tempered and intolerant, seldom suffered fools and was distressingly vain. Most of his quarrels with his associates probably came about through clash of personality; and people did not like being overridden.

Fessenden's refusal to be guided by anyone else's ideas was clearly demonstrated in his relationship with Alexanderson during the development of the alternator. Fessenden wanted an alternator designed without iron, and arbitrarily overrode the objections of Alexanderson, who was a highly trained engineer with a long experience in power problems. Alexanderson says of this:

> I submitted a design of an alternator without iron but reiterated my opinion that iron is preferable (to wood). . . . I did the work contrary to my own opinion, hoping to ultimately persuade Fessenden to go back to my early designs. On October 16, 1905, I re-

[5] Heterodyne reception reached its maximum value only when the oscillating triode was devised as a means of generating the local frequency.

[6] Editorial in *Electronics*, Sept. 1932, p. 294.

ported to Fessenden on the test of one of his models and pointed out the great difficulties and suggested the abandonment of this line of designs and the adoption of one which is a compromise between his design and my early one.[7]

But Fessenden was adamant. That Alexanderson was right was proven later by the success of the General Electric alternator made of iron.

However, this much is clear about Fessenden as an inventor: in the period from 1905 to 1913 he succeeded, in competition with the better organized and aggressive Marconi enterprises, in developing a wireless system which, from a patent point of view, was completely self-sustaining.[8]

(b) THE INNOVATOR

Fessenden was much more effective as an inventor than as an innovator. The National Electric Signaling Company never proved successful as a business venture. This concern was launched as an inventor's laboratory. Neither manufacturing nor commercial communications were contemplated. Fessenden was to be given an opportunity to experiment with wireless and to make inventions which it was hoped would be sufficiently basic and sweeping so that the Fessenden system could be sold at a substantial profit to a wireless operating company.

The establishment of an inventor's laboratory, with relatively broad scientific objectives and somewhat remote commercial prospects, was not a rare occurrence at this time. It was the era of the individual inventor; and wealthy businessmen in the United States were surprisingly willing to finance the research of talented inventors even when these inventors showed very little business judgment. The imagination of the business community had been stirred by the possibilities in an age of electricity. The American courts were particularly generous in their interpretation of the patent rights of inventors, and the rewards for backing an Edison or a Graham Bell had proved spectacular. The fact

[7] Gleason Archer, *History of Radio to 1926* (New York, American Historical Co., 1938), p. 85.

[8] Despite Fessenden's lack of commercial success, his radio patents were to enable him to live in comfort the later years of his life. He received $500,000 in settlement of a suit brought by him against the Radio Group in 1926. (See Chap. VIII.)

that a high percentage of these scientific ventures were failures did not seem to discourage capitalists from underwriting new inventors, nor investors from buying stocks in what would now be regarded as wildcat promotions.

The backers of Fessenden—Walker and Given—were men of substantial means who believed that wireless was on the verge of a great development and that an investment in a laboratory and experimental stations would prove highly profitable.

Three stations were built initially at Washington, Brooklyn, and Jersey City, and later experimental stations were erected at Machrihanish, Scotland, and Brant Rock, Massachusetts, for transatlantic communication. In January, 1906, Fessenden succeeded in sending and receiving two-way wireless telegraph messages across the Atlantic. But the results obtained were little or no better than those of the competing Marconi system, and it was clear that considerable further technical progress was necessary before transoceanic wireless transmission would be commercially practical. In 1907 a gale blew down the antenna on the Machrihanish station in Scotland, causing such great damage that no attempts were made to reconstruct the station.

In the meantime, Fessenden had been continuing his work on the wireless telephone. Goldsmith writes that on December 11, 1906, a demonstration of radio telephony was given from Brant Rock to Plymouth, Massachusetts—a distance of eleven miles. And in July, 1907, speech was transmitted between Brant Rock and Jamaica, Long Island, a distance of 180 miles.

Yet radio telephony was a field which showed more promise than immediate practical value. Chief Engineer J. J. Carty of the Telephone company wrote in July, 1909:

> I have personally talked by the Fessenden wireless method from Brant Rock in Massachusetts across Plymouth Bay to Plymouth. . . . The talk was very faint indeed. Mr. Fessenden tells me that he has talked from Brant Rock in Massachusetts to Jamaica, Long Island. . . . I am told that the transmission was very faint indeed. . . . Rather exhaustive experiments . . . are being undertaken by the Navy and we expect to get the results of this work, which I think will represent the most advanced information. . . .[9]

[9] Letter to the president of Central Union Telegraph Company, Indianapolis, Indiana, July 16, 1909 (files of Telephone company).

For overland communication, the wire telephone was to remain more reliable for many years—the principal weakness of the radio telephone being that it was often subject to complete interruption from "atmospherics." It was, moreover, competing against a huge investment in wire telephony all over the country.

Following the Brant Rock tests, Walker and Given tried hard to sell the National Electric Signaling Company to some existing firm. American Telephone and Telegraph, Western Union, and Postal were approached. The Telephone executives showed considerable interest, and an engineering investigation was ordered. The report by E. H. Colpitts was favorable and optimistic. Chief Engineer Hayes in transmitting it to President Fish concluded:

> I feel that there is such a reasonable probability of wireless telegraphy and telephony being of commercial value to our company that I would advise taking steps to associate ourselves with Mr. Fessenden if some satisfactory arrangement can be made.[10]

On receipt of this report Mr. Fish, according to Fessenden, "had reached the decision to buy." [11]

> At this point in the company's negotiation with Professor Fessenden [writes Lloyd Espenschied of the Bell Laboratories] there occurred one of those events of fate which we can now see was destined to change technical history as to the development of radio telephony. The financial panic of 1907 precipitated a change of banking control of the Bell Telephone Company from Boston to J. P. Morgan Company of New York, with the resulting change of the headquarters from Boston to New York and the replacement of President Fish by Theodore N. Vail. Similarly, the chief engineer, Hammond V. Hayes, was replaced by the then chief engineer of the New York Telephone company, John J. Carty. . . . The study of the Fessenden wireless matter was continued now under the new regime, and on the basis of a more realistic and critical analysis of the possibilities.[12]

On July 8, 1907, Thomas D. Lockwood, the patent counsel of the company, wrote a twenty-six page report on the subject to President Vail. In reviewing the Fessenden patents at some length, he says: "No. 706,747 is the first patent issued for voice

[10] Memorandum of April 2, 1907 (files of Telephone company).

[11] Fessenden testimony, F.T.C. *vs.* GE, AT&T, Westinghouse, RCA, *et al.*, Docket 1115, *Hearings*, pp. 3896–97.

[12] Memorandum of Oct. 28, 1947, sent to the author by Lloyd Espenschied.

transmission by electro-magnetic waves." But he writes in conclusion:

> Nevertheless, the field of commercial operation in sight is relatively so small; there are so many systems competing for it; and there are apparently so many ways of performing every requisite function, that as stated at the beginning of this section, it is difficult to see where the business can ever be successful or profitable unless the several systems can unite, and be operated and managed as a single concern. Even under these conditions, it is hard to see from whence sufficient business can be derived for many years to come.[13]

And on July 9 Lockwood summarizes his report with the following conclusion:

> If an individual or a corporation is desirous of becoming interested in wireless telephony for the sake of keeping in touch with progress in electrical transmission work, based on recent scientific research, this would seem to be an excellent opportunity; but for a telephone company, the possibility of substituting a wireless system for a system of toll lines is the most attractive feature of the proposition, and I have a strong conviction that this feature cannot and will not reach any practical realization within the term of years yet remaining to Fessenden's fundamental patents.[14]

President Vail expressed the new attitude of the Telephone company toward the wireless telephone in a letter to a large English investment house which was disturbed about the possible impact of wireless on Telephone stock.

> As to the "wireless": I can only refer you to the success of the wireless telegraph and the [negligible] inroad made by it upon the general telegraphic situation as compared with the promises and prophecies. The difficulties of the wireless telegraph are as nothing compared with the difficulties in the way of the wireless telephone.[15]

When the negotiations with the Telephone company broke down, Fessenden urged the wisdom and necessity of selling apparatus in large lots to selected customers. The inventor had for several years favored manufacturing and selling wireless sets.

[13] Report by Thomas D. Lockwood to President T. N. Vail, July 8, 1907 (files of Telephone company).

[14] *Ibid.*

[15] F.C.C. *Proposed Report*, p. 210.

However, the policy of Given and Walker was to develop a patent structure for a complete system of wireless communication and then sell the whole company. When Fessenden had previously suggested, in July, 1905, submitting bids for apparatus for the Navy, Walker wrote as follows:

Dear Professor:

. . . We had thought this matter of the Navy or anyone else being offered or furnished anything of ours had been settled in the negative—and we do not wish to complicate any deal we may be able to make for the whole of all we have.[16]

However, in 1908 the "no-sale" policy was modified and permission given by Walker and Given to sell by contract to the United States Navy and the United Fruit Company.[17] In the meantime, the relations between Fessenden and his backers had been steadily deteriorating. Fessenden, as we have said, was an exceedingly difficult person to deal with. And from what evidence is available, neither Walker nor Given possessed a great amount of tact or managerial skill. Quarrels were continuous, and finally an open break occurred over the question of transatlantic communications. Fessenden wished to develop a company which could compete with British Marconi, and for this purpose he formed on his own initiative the Fessenden Wireless Company of Canada. A Canadian by birth, Fessenden took the position that a British company would have a much better opportunity to get concessions from the British Postmaster-General, who was in charge of imperial wireless communications, than would an American company. The relationship between Fessenden's Canadian company, in which Walker and Given were not represented, and the National Electric Signaling Company was not clearly defined. The Pittsburgh capitalists came to feel that Fessenden was no longer working for their interests. As they had put in all the money, they notified Fessenden in January, 1911, of his dismissal. Fessenden then brought suit for breach of contract, won his case in the lower court and was awarded dam-

[16] Helen M. Fessenden, *Fessenden—Builder of Tomorrows* (New York, Coward-McCann, 1940), pp. 124–125. Walker and Given also opposed any suggestion to sell stock to the public.

[17] *Ibid.*, pp. 155–162.

ages of $400,000. To conserve assets pending an appeal, receivers were appointed for NESCO in 1912.[18]

National Electric continued with its developmental work during the receivership, with a curtailed technical force. In 1912 the company employed about ten professional engineers, several of them of considerable prominence in the radio world. Samuel Kintner, general manager of NESCO during its receivership, described the work of the company's leading engineers in the following terms:

> Kroger was responsible for eight to twelve patents or applications, several of which were very important. Hogan had eight to ten, one of which was "particularly important." [This was his patent on unituning—the tuning of separate circuits by one control shaft and dial.] . . . With the exception of those of Kroger and Hogan, the patents were more of detail than fundamental.[19]

NESCO engineers at this time were regarded as more outstanding than the research engineers maintained by American Marconi, which relied primarily on the British company for its new developments. NESCO was also a more prominent group than United Wireless, which had lost its most distinguished inventor, de Forest.

Walker and Given, who remained the sole financial backers of the company, continued to hope that, with the perfection of NESCO's system of radio communications, the concern could be sold at a profit. This ultimately occurred, but not until they both had died.

The most profitable deal that National Electric made during the period of its receivership was a cross-licensing agreement on patents with the Marconi company in 1914. NESCO had been sued by Marconi for infringing the "four sevens" patent and the Lodge patent. National Electric, in turn, had sued Marconi for infringing Fessenden's patents on continuous-wave transmission. Injunctions were granted by the court in both cases, and the Marconi company decided that a settlement was necessary. Through this agreement, National Electric received about $300,-

[18] Interview with J. V. L. Hogan, May 1946.
[19] Kintner testimony, F.T.C. *Hearings*, *op. cit.*, pp. 588ff.

000 in royalties from Marconi and paid to the latter approximately $30,000.[20]

The sale of the patent assets of National Electric, which its backers had long hoped to achieve, finally took place after the war, through purchase by Westinghouse.[21] From the formation of NESCO in 1902 to the disposal of their stock interests in 1921, Walker and Given and their estates had spent over $2,500,000 on engineering development.[22] In the final settlement, the Given estate, which had bought out Walker's interest, received 450,000 shares of RCA preferred and 450,000 shares of RCA common.[23] This stock, if held, could have been sold at very substantial prices.[24] But, considering the amount of time and money which Walker and Given devoted to the enterprise, and the many years in which there were no returns at all, the financing of Fessenden was far from a satisfactory investment.

Walker and Given were wealthy businessmen, with an interest in new technical developments but with no scientific training. They had the vision to see the potentialities in wireless telegraphy and to recognize Fessenden as an exceptionally capable inventor. They also had the persistence to back the enterprise through all its vicissitudes. Yet the team was not an ideal combination of capitalist and inventor, such as, for example, that of Boulton and Watt.

"Given and Walker," writes Helen Fessenden, "each had his own highly profitable business. Fessenden's output as an inventor was for them a 'flier.'"[25] If National Electric Signaling had started from the outset to manufacture radio apparatus, sales

[20] Kintner testimony, F.T.C. *Hearings, op. cit.*, pp. 645, 652. Of the gross selling price, 20 per cent was to be paid by each to the other on every set sold. The agreement caused Marconi to raise ship rentals from $1,000 to $1,200 a year. F.T.C. Exhibit.

[21] Given and Walker had formed the International Signal Company in 1917 and had transferred NESCO's patent assets to that company. Westinghouse obtained majority control by purchasing $2,500,000 of stock and the company was reincorporated as The International Radio Telegraph. In 1921, when the Westinghouse-RCA agreements were signed, the assets of International were transferred to RCA.

[22] Given, who had purchased Walker's interest during the war, died about a year before the advent of radio broadcasting.

[23] F.T.C. *Hearings, op. cit.*, Exhibit.

[24] RCA common sold as high as 114 in 1929.

[25] *Fessenden—Builder of Tomorrows*, *op. cit.*, p. 162.

would have partially supported research. Walker and Given reasoned instead that, if they gave Fessenden generous financial backing, he could develop a system of radio communications so superior to all rivals that the patents could be sold at a handsome price. They overrated the commercial potentialities of Fessenden's inventions, failing to recognize that there were many alternative methods of perfecting radio communications. They also made the common mistake of underestimating the time required to develop a new industry to the point of mass production. No one was willing to pay large sums for patents as long as the manufacture of radio apparatus remained primarily a specialized engineering job in which very few standard units were produced. It was not until after the first World War that the Fessenden system could be sold for a price at all commensurate with research and developmental expenses incurred.

The experiences of Walker, Given and Fessenden illustrate the difficulties inherent in launching a scientific enterprise when the men who put up the money do not understand the technical problems with which the company is dealing and when, as is so frequently the case, the key inventor has a troublesome personality.

2. *Lee de Forest*

(a) THE INVENTOR

Lee de Forest, the most prominent American inventor of the pre-war period, is primarily distinguished for the three-element vacuum tube or triode. Dr. Rabi, who recently won the Nobel Prize in physics, has described the three-element vacuum tube as "so outstanding in its consequences that it almost ranks with the greatest inventions of all time."[26]

The Triode

Lee de Forest was one of the first Americans to write a Ph.D. thesis on wireless telegraphy.[27] On graduation in 1899 he got a

[26] I. I. Rabi, "The Physicist Returns from the War," *Atlantic Monthly*, Oct. 1945, p. 109.

[27] "The Reflection of Short Hertzian Waves from the Ends of Parallel Wires," Yale University, 1899. Georgette Carneal, *A Conqueror of Space* (New York, Horace Liveright, 1930), p. 83.

job with the Western Electric Company in Chicago. His vicissitudes during the next two years are described vividly in his diary:*

August 12, 1899. Away to Chicago. . . . The third place I applied for a job, the Western Electric Company, . . . took me into their Dynamo Department. I work like a nigger from 7 a.m. to 5:15 p.m. Too much chasing of parts and mopping grease for me to learn much. $8 a week. . . .

October 15, promoted to the telephone laboratory, goal of my hopes. . . .

There is one free private library here, the Crerar, cozy, with dark wood tables and shaded lamps, where the chairs just seem to fit. I take great comfort in reading there. I have begun a systematic search through Science Abstracts, Wiedemann's *Annalen*, etc., for some hint or suggestion of an idea for a new form of detector for wireless signals. I had built a Branly coherer at Yale and used it. Marconi's coherer, and tapping-back, did not appeal to me. It was too slow and complicated. . . .

November 5, 1899. Finally, in the April number (1899) of Wiedemann's *Annalen* in an article by Aschkinass, I found a brief description of a phenomenon newly discovered which promised to be the solution to my problem . . . which, in a previous page of my diary, I had stated to be: "What wireless telegraphy requires is a self-restoring detector, which would permit the operator to hear in the headphones the sound, as it were, of the transmitter spark. . . ."

Dean and Smythe, co-workers of mine in the Western Electric Laboratory, began to take casual interest in what I was doing, although neither knew much about wireless telegraphy or Hertzian waves, nor shared my enthusiastic belief as to the enormous developments in electrical science which awaited further perfection of the crude transmitting and receiving apparatus which was then in use in Europe. . . .

March 18, 1900. Experiments on my new wireless "Responder," as I then called it, began to occupy more and more of my time. My work on telephone tests and devices was never brilliant, to speak charitably, for my thoughts were ever elsewhere. Dean became progressively more impatient with my work, but was too considerate to fire me, although he saw little of merit or promise in the experiments I was wrapped up in. Certainly he saw no possibility that the great

* From an unpublished diary. By permission of the author.

Western Electric Company would ever become interested in Wireless Communication!

One day he exclaimed: "Look here, de Forest. You'll never make a telephone engineer. As far as I am concerned you can go to hell, in your own way. Do as you damn please!" With typical recklessness I took him at his word, turned to my little corner where I had my spark gap and responder parts, and thereafter spent eight hours a day at my own delectable tests, totally oblivious to the telephone work going on about me and for which I was supposed to be paid. . . .

Following the German idea, which was obviously impractical as a wireless detector, I sought to overcome the pernicious tendency of the Responder to stop responding after a few seconds or minutes of operation. . . .

Now it was that Ed Smythe proved himself to be a practical, modern, electrically-minded engineer. He was swift to grab the significance of my experiments, watched my work with interest, discussed the problems with me, and occasionally contributed helpful practical criticism and advice.

April 8, 1900. At last I have the opportunity to do experimental work in wireless telegraphy. This came as the result of my having written to Professor Johnson of Milwaukee, president of the newly organized American Wireless Telegraph Company. Not long after, he came to see me in Chicago and asked me to join his concern.

Milwaukee, May 1, 1900. Started on my wireless telegraphy work at 809 Grand Avenue. Professor Johnson and his assistant, Fournier, were working on an impractical system of wireless reception, employing a coherer with iron filings (of all possible materials!) . . .

Becoming disgusted with the Johnson-Fournier "non-receiving set," I brought out my Chicago responder and a telephone receiver, and within an hour was receiving signals from Johnson's "plop-plop" transmitter. Lyman, slyly watching over my shoulder, soon grasped the idea of what I was doing. . . .

The work continued for three months. Lyman then begged me to give my responder to the company and when I refused he told about it to Johnson and I was called up on the carpet before him. I told him that the responder was my invention and would be used in no company but my own. So I was fired and took the night boat back to Chicago.

August, 1900. Smythe and I applied for our first patent, directed to our various improvements which would distinguish our invention from the Aschkinass disclosure and claim as broadly as possible what we considered would be practical and patentable. Of necessity Smythe became my financier. Notebook entries:

August 29.	Lent de Forest, patent application	$22.50
	Lent de Forest, personal	1.00

September 3, 1900. I am starting in a new job with poor pay. But I am on the right track and feel that it is destined to make me independent.

Nights I worked with partner Smythe in my room, on the Responder. Without much delay I got a job as assistant editor on the staff of the *Western Electrician.* Salary was $10 a week. Every night not spent in the library was devoted to experimenting with the electrolytic anti-coherer. Smythe was comparatively rich, earning $30 a week. Naturally, our budget for experimental work was very limited. . . .

October 28, 1900. I have begun to hazard my job with the *Western Electrician* by working half-time in the laboratory of Armour Institute, teaching two nights weekly at Lewis Institute. I am risking mediocricy and weak contentment for a chance of great success. . . .

Soon the experiments became so engrossing that it was impracticable for me to continue to work even half time for the *Western Electrician.* So once more I crossed the Rubicon, burned my bridges, and with only the amount of $5 paid by Lewis Institute per week, and an equal amount advanced by Smythe, determined to continue my life as an inventor. . . .

December 23, 1900. Smythe has been cautious, diffident, lacking confidence, as he well might. Time is short and Marconi sails fine and weather-worthy boats, and these boats already headed toward America. If our craft cannot meet him next spring it might as well sink now.

De Forest's first chance to demonstrate his wireless apparatus came in 1901 with an offer from the Publishers' Press Association, which was willing to pay him $800 if he could successfully report the International Yacht Races. The trial was a failure.

De Forest had been able to borrow $1,000 to manufacture his equipment for the races, and later that year, through the sale of stock to the public, he got an opportunity to set up a laboratory of his own. He proved a prolific inventor. Between 1902 and 1906, he took out 34 patents on all phases of wireless telegraphy, including loop antennas, receiver tuning, generators and antenna de-icers.[28]

His major search, however, was for a detector which would not infringe the Marconi or Fessenden patents. In this he was unsuccessful. The responder, on which he pinned so much hope in his diary, never proved satisfactory. His next attempt, the Wollaston wire electrode, was adjudged to have infringed the Fessenden electrolytic detector; and a further effort, the Spade electrode, involved only such minor changes that it was attached for contempt of court by Fessenden's company. De Forest then decided to return to some earlier experiments he had made, in an effort to devise an entirely new form of detector.

In 1900, while working with Smythe on the responder, he had noticed that the gas light in the laboratory dimmed while his spark equipment was operating, and that it returned to full strength when the apparatus stopped. This suggested that a gas flame might be used to detect wireless signals (later the dimming of the flame was shown to have been caused by sound waves from the spark gap). De Forest, therefore, tried to make a detector consisting of a bulb filled with gas and containing two electrodes intended to be heated by a dynamo. This gas detector was later described by the courts as "utterly useless."[29]

However, it led to the invention that was to revolutionize the radio art.[30] Continuing to experiment with gas-filled and partially evacuated two-element tubes, de Forest placed a third electrode, called a grid (because it was shaped like a gridiron), between the incandescent electrode (the cathode) and the cold electrode (the anode). He then attached a battery; and, by changing the voltage on the grid, he was able to control the flow of current across the space between the hot and cold electrodes. By making the grid negative, all the electrons could be forced back into the cathode; by making the grid positive, the electrons could be drawn from

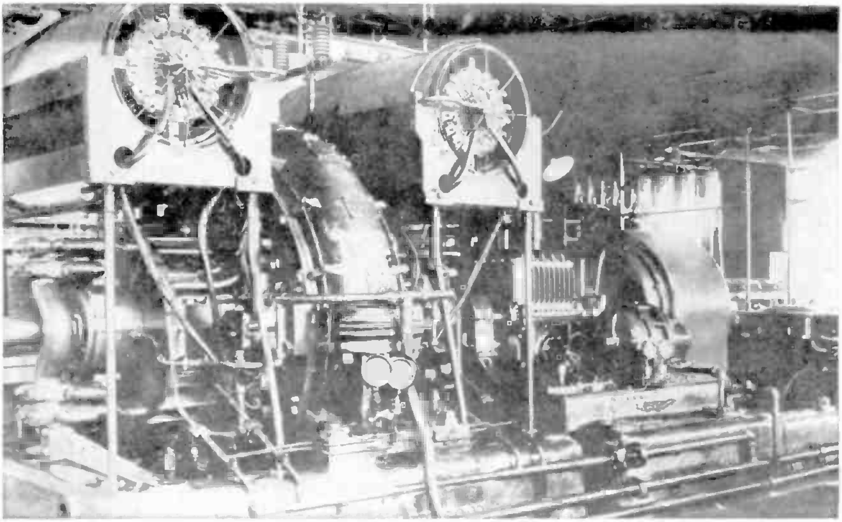
[28] Carneal, *op. cit.*, p. 165.

[29] Decision of the District Court, Marconi Wireless Telegraph Company of America *vs.* De Forest Radio Telephone and Telegraph Company, *op. cit.*, Sept. 20, 1916.

[30] U.S. Patent No. 879,532 was applied for January 29, 1907, and issued February 18, 1908. Lubell reports that it took de Forest three weeks to raise the $15 necessary for the patent application. Samuel Lubell, "Magnificent Failure," *Saturday Evening Post*, Jan. 24, 1942, p. 36.

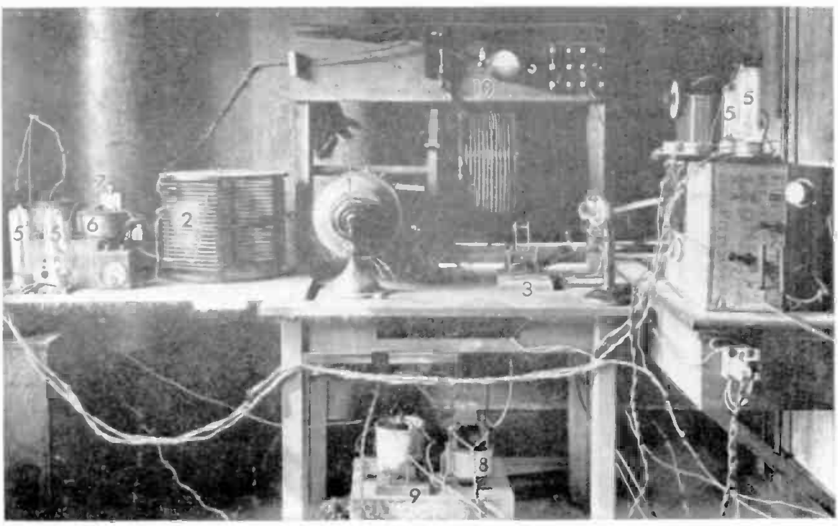
Transmitting equipment for the American Telephone & Telegraph Company's transatlantic radio telephone tests with the Eiffel Tower, 1915. The antenna towers at the Naval Station, Arlington, Virginia, were loaned for these experiments. Five hundred tubes were mounted on racks and connected in series to constitute the high-frequency amplifier. (Courtesy American Telephone & Telegraph Company)

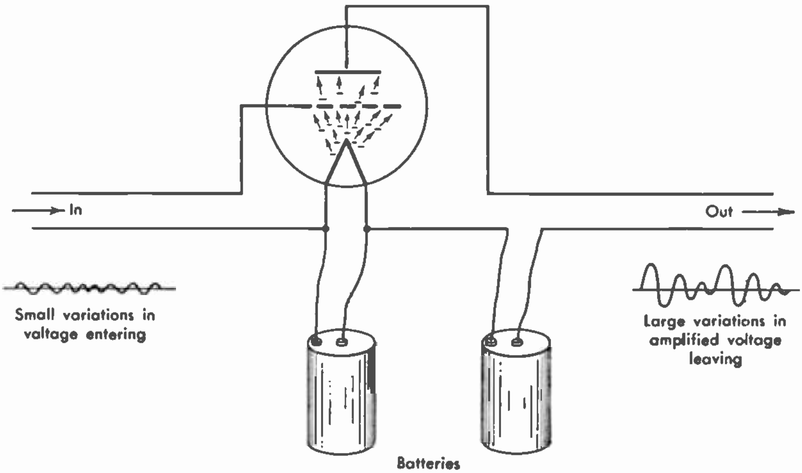
The New York control room of the Bell System overseas radio-telephone service, 1947. The technicians are making necessary adjustments to obtain maximum efficiency on these channels. (Courtesy American Telephone & Telegraph Company)



200 kw. Alexanderson high-frequency alternator installed in Naval Radio Station, New Brunswick, New Jersey, 1918. (Courtesy General Electric)

Equipment used by Dr. Frank Conrad for amateur broadcasting, prior to the establishment of KDKA. This was station 8XK. 1, Rotary spark gap; 2, Antenna tuning coil; 3, Antenna change-over switch; 4, Microphone; 5, Vacuum tubes; 6, Variable condenser; 7, Fixed condenser; 8, High voltage transformer; 9, Keying relay, and 10, Antenna ammeter. (Courtesy Westinghouse Electric Corporation)





Operation of a triode. With the addition of a grid, minute currents may be amplified considerably. (Courtesy Stokley, *Electrons in Action*, Whittlesey House)

the cathode as fast as they were emitted.[31] De Forest then connected the aerial of a receiver to the grid. The alternating current of the incoming electro-magnetic waves would successively affect the grid with positive and negative charges. When the negative half of the received wave reached the grid, the grid would repel the electrons being emitted from the hot cathode. At the same time the positive phase of the incoming signal would act on the grid to reinforce the positive charge of the cold electrode and thus help to draw electrons across the tube. This provided a much more effective method of control than could be obtained in the Fleming diode, where the emission of electrons was controlled by the degree of heat applied to the cathode.

De Forest himself did not fully understand the principles of the triode. Despite his doctoral training, he was much more an inventor than a scientist. According to some of his former associates, de Forest read intensively in the scientific literature, with the

[31] Eccles, *op. cit.*, p. 141. The principle of grid control had been used previously by the German physicist Lenard, for "studying the motion and nature of the electrons liberated from a zinc cathode by ultra-violet light," but Lenard had not conceived of its use for the detection or amplification of wireless signals.

object of discovering new principles which would enable him to invent devices rather than to understand or improve inventions he had already made. He did not attempt to relate his experiments to the general literature of physics, and consequently overlooked clues which might have assisted him in making a more useful electronic device. At first he believed that the presence of some residual gas was essential to the operation of his triode. A knowledge of Richardson's theory of thermionic emission might have suggested the possibilities of developing a detector with a pure electron discharge in a high vacuum—which was what Arnold and Langmuir later accomplished.

Another of de Forest's handicaps was his lack of adequate manufacturing facilities for producing tubes. In consequence, his triodes were not uniform in performance and proved less satisfactory than other competing devices, such as the electrolytic, magnetic and crystal detectors.[32]

Between 1907 and 1912 de Forest made few scientific experiments with the triode. He turned his attention primarily to wireless telephony, giving his first demonstration in the spring of 1907, between a Lackawanna Ferry and the Hoboken and Manhattan terminals. Within a short time, the Navy installed radio telephone sets on a number of ships; and, in the tests that followed, communication over twenty miles was achieved. But the company was inadequately financed, and the volume of radio sales was not large enough to sustain an effective program of development. When his laboratory was destroyed by fire in 1908, he took a year to re-equip it.[33] Finally, in 1911, the plight of the company became so desperate that de Forest went to Palo Alto to work for Federal Telegraph at a salary of $300 a month while waiting for some miracle to lift his firm from the economic doldrums.

De Forest worked in the Federal laboratories for nearly two years. For the first time he was relieved of commercial pressure and of the necessity of dividing his talents between inventing and

[32] While inherently superior to other detectors, de Forest's triodes needed such constant attention and such frequent adjustment of plate potential and filament current that commercial users found them too bothersome.

[33] All his records were destroyed in this fire. The loss of his notebooks proved a serious handicap during the lengthy vacuum-tube litigation that was to follow.

financing. He has described his tenure at Federal as among his "happiest and most useful years." [34] The research team of de Forest, Herbert Van Etten and Charles Logwood worked successfully on problems of high-speed telegraphy, static reduction and long-range transmission. One of de Forest's principal achievements during this period was the construction of transmitters and receivers, which would allow speeds of 90 words per minute between Los Angeles and San Francisco.

In 1912 de Forest undertook some new experiments with the triode. He connected first two, then three, audions in cascade; and, by feeding the output of the first tube into the input of the second, and the output of the second into the input of the third, he was able to obtain amplification far greater than that of a single tube. He used these cascades as telephone repeaters and described their effectiveness for the purpose in a letter to his friend John Stone Stone, a consulting engineer in New York. Stone, who knew of the Telephone company's search for such a repeater, brought the triode to the attention of Chief Engineer J. J. Carty; and de Forest was invited to demonstrate his device. The demonstration took place in October, 1912, and in the following spring the Telephone company purchased telephone repeater rights in the triode for $50,000.[35]

Back in Palo Alto, de Forest continued his investigations of the triode. He discovered that not only could the triode act as a detector and amplifier, but it could also be used as an oscillator to *generate* electro-magnetic waves.[36] This was a discovery that was to prove of great significance. The Marconi spark apparatus, the Poulsen arc and the Alexanderson alternator were all expensive and cumbersome. They have since been displaced by power tubes which had their origin in de Forest's work.

De Forest first put his new discovery to use for heterodyne reception of continuous-wave signals. The Fessenden heterodyne system used an arc to generate the high-frequency current which

[34] Carneal, *op. cit.*, p. 239.

[35] The research of the Telephone company on the triode will be discussed in Chapter V. AT&T subsequently paid $90,000 for the radio rights to the triode.

[36] The use of the triode as an oscillator was later to become involved in a four-party interference among Langmuir, Meissner, Armstrong and de Forest. De Forest eventually won the contest and was awarded the covering patents in 1924.

was combined with the incoming signal. De Forest, in competition, devised a compact, oscillating triode circuit, called the "ultraudion," for installation in Federal Telegraph stations The Navy became a large customer for these circuits.[37]

The Feedback Circuit

After the triode, the other principal invention with which de Forest's name is associated, is the feedback circuit, which could be used either to generate oscillations or to increase the sensitivity of the audion as a detector. Priority of invention here was claimed by both de Forest and Edwin Armstrong, and this dual claim produced the most controversial litigation in radio history. Armstrong, a graduate assistant at Columbia University, had delivered a paper before the Institute of Radio Engineers in 1913 in which he described a new "regenerative circuit." This circuit, he stated, made the triode a much more effective and sensitive detector of wireless signals. Five months later, de Forest applied for a patent on the same principle. Since the invention soon proved to be of great commercial importance, the question of whether de Forest or Armstrong had first made the discovery became crucial. De Forest produced notebooks to prove that, while working in his laboratory in Palo Alto, he and his associate, Van Etten, had observed that when they connected the output circuit back into the input circuit of the same tube, the amplification of the triode was increased. He was unable to show that he had made any use of this discovery, or had explained its operation technically. His opponents contended that, if he had understood it, his cascade amplifier, using several tubes, would have been superfluous.

Armstrong won the first round;[38] and in 1917 de Forest sold

[37] The Navy by this time had completely switched to continuous-wave apparatus. The "tikker" receivers developed by Federal Telegraph for use with Poulsen arcs were constantly getting out of order. And, while the Navy was anxious to use heterodyne reception, the small arcs supplied by the Fessenden company were subject to frequent breakdowns. The ultraudion circuit was thus a lifesaver to the Navy.

[38] The Supreme Court in 1928 reversed the decisions of the lower courts and awarded priority to de Forest. Six years later, when the issue again reached this court, a similar decision was rendered. However, the Franklin Institute, in its report awarding the Franklin Medal to Armstrong in 1941, said that this decision was made "much to the astonishment of radio engineers . . . It is generally con-

the feedback patents, all his remaining radio telephone patents and all vacuum-tube inventions that he might make in the next seven years to the Telephone company for $250,000.[39] This point marked the decline of de Forest's interest in radio. He turned his attention to talking movies, reviving his earlier interest in sound-on-film,[40] and from that time on made no further contributions to the radio art.

De Forest as an inventor lacked the persistence to carry any one project through to a completely successful conclusion. Like many highly creative individuals, he had far more ideas than he was capable of handling. And his restless mind was always seeking new fields to explore, demonstrating what Taussig has described as "the irresistible urge to invent."[41]

> He would sweep down on a problem with a hungry rush and his imagination had an astonishing faculty for leaping difficulties. If the quarry snagged or proved elusive, however, he had to hop to something else. When necessity did compel him to work at something without respite, his nerves rebelled. "The jumpies" de Forest called these attacks.[42]

(b) THE INNOVATOR

De Forest, like his American rival, Fessenden, had little of the entrepreneurial ability displayed by Marconi. De Forest's high inventive skill enabled him to launch a large number of com-

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ceded by the radio engineering fraternity that de Forest was endeavoring to suppress the unwanted oscillations which occurred in his apparatus, while Armstrong, understanding the nature of the phenomena, was working to control and make use of these continuous oscillations. This view was reflected in the presentation to Armstrong in 1918 of the first Medal of Honor awarded by the Institute of Radio Engineers. When the final decision of the Supreme Court was handed down, Armstrong, in 1934, returned the Medal to the Institute. The Institute thereupon gave it back to him, re-affirming the award and indicating their conviction of his priority of invention." The Franklin Institute of the State of Pennsylvania for the Promotion of the Mechanic Arts, Committee on Science and the Arts, Report No. 3087, Jan. 8, 1941, pp. 3–4.

39 Archer, *History of Radio*, *op. cit.*, p. 135. De Forest's share amounted to about $175,000. Lubell, *op. cit.*, Jan. 31, 1942, p. 40.

40 His phonofilm was patented in 1904.

41 See Taussig, *op. cit.*, pp. 23–24. "The instinct of contrivance in man unlike the corresponding instinct in animals, is not directed to one specific end. . . . It is directed to all sorts of contrivances no longer restricted to those immediately serviceable. . . . There seems to develop an erratic streak."

42 Lubell, *op. cit.*, p. 41.

panies, but none of these survived long. He seemed incapable of building on solid foundations an enterprise in which stable customer relations were cultivated. The first of his promotional ventures was the De Forest Wireless Telegraph Company, started in 1901 with an investment of $1,000 obtained from a business acquaintance.[43] De Forest rented a small machine shop in Jersey City to make equipment for reporting the international yacht races. When this proved a failure, he set out for Wall Street in quest of additional funds. Reputable capitalists were not interested. After countless rebuffs, he found an over-the-counter broker who helped him to raise a few hundred dollars.[44] With this amount he built a trial transmitting station in Jersey City.[45] Then in the fall of 1901, de Forest met a stock promoter, Abraham White, who became very much interested in the financial possibilities of a radio company.

At White's suggestion the American de Forest Wireless Telegraph Company was incorporated, with an authorized capital of $3,000,000.[46] This new venture had some initial success.[47] In 1902 de Forest received an order from the War Department to install his receiving apparatus on one of the Army tugboats and to erect two land stations for the Signal Corps.[48] When these were completed and tested, he was asked to build two land installations for the Navy. Hitherto the Navy had purchased most of its wireless apparatus from the German Slaby-Arco corporation.[49] In 1904 de Forest's company built a radio link for the United Fruit Company between Costa Rica and Panama.[50] In 1905 the Navy awarded the De Forest company its largest con-

[43] Carneal, *op. cit.*, p. 125.

[44] *Ibid.*, p. 141.

[45] This was the first transmitter to use alternating current as a source of supply.

[46] During this period the de Forest system was demonstrated to George Westinghouse, who professed not to be interested in this new development. Carneal, *op. cit.*, p. 147.

[47] *Electrical World*, March 8, 1902, p. 458.

[48] Carneal, *op. cit.*, p. 148.

[49] This later became Telefunken (see Chap. III). *Ibid.*, p. 149.

[50] The Fruit company was to become an important purchaser of radio apparatus. The company's early interest in wireless stemmed from the need for rapid communication between ports and ships carrying a perishable commodity. Much of de Forest's early work on improving ground connections and eliminating static resulted from the special difficulties of wireless working in the tropics, which he encountered at United Fruit stations.

tract to date—an order to construct five transmitting and receiving stations along the Gulf of Mexico.[51]

It was in 1906 that de Forest invented the three-electrode vacuum tube. This historic invention was not used at all by his original company, which was soon to experience serious financial difficulties. White, as promoter and president of the company, had grandiose ideas for expansion which de Forest apparently shared. They planned to erect a network of wireless land stations to rival Western Union and Postal. As described by Lubell:

> Off the printing presses poured prospectuses predicting that telegraph rates would be slashed to less than a cent a word and cable costs from twenty-five to two and a half cents a word. Wireless towers mushroomed over the United States, while glib salesmen told how "$100 invested in Bell Telephone stock rolled into $2,000,000" and promised that de Forest stocks will do the same.[52]

Over ninety stations were erected by the company, and more were projected. Many never sent a message.[53] Static interference proved so bad that reliable communication was impossible. White hoped to stave off bankruptcy by various devices. Typical was his newspaper announcement of 1906 that he had obtained control of American Marconi and planned to amalgamate these two companies. White succeeded in selling a substantial amount of stock before American Marconi was able to deny the rumor. In the late summer of 1907 two Denver speculators in the de Forest enterprises—Christopher Columbus Wilson and W. A. Debold[54] —interceded on behalf of the De Forest shareholders (they themselves having large De Forest holdings), put the company out of business and sold its assets to the United Wireless Telegraph Company which they organized. De Forest was forced to resign. He took with him, however, the patents pending to the triode, which nobody regarded as of much significance.

De Forest then joined with one of White's star stock salesmen, James Dunlop Smith, and together with his patent attorney, Samuel Darby, they formed a new corporation in 1907—the De

[51] *Electrical World*, March 31, 1906, p. 655.

[52] Lubell, *op. cit.*, Jan. 24, 1942, p. 35.

[53] *Ibid.*

[54] These two men and some of their associates were later sent to jail for stock frauds.

Forest Radio Telephone Company[55]—with a capitalization of $2,000,000.[56]

This concern set out to develop wireless communication by means of the radio telephone, a field which Fessenden had also been exploring. The Navy was the first customer and ordered twenty-seven sets to be used on fleet maneuvers in the Pacific.[57] The sets were hastily made; and, with no time to train operators before the fleet sailed round the world during the winter of 1907–1908, the results were disappointing, though not a complete failure. De Forest arc transmitters were employed in these sets and both crystal and vacuum-tube receivers. One wireless operator, Meneratti, developed the practice of broadcasting daily to the fleet, using phonograph records.[58]

In the meantime, de Forest's funds began to run low again; and he tried desperately to raise some more money by sales of stock. The methods that were followed have been described by an employee of this period:

> In 1908, I was night operator at the Atlantic City station of the American De Forest Wireless Telegraph Company on Young's Million Dollar Pier. This station had been designed largely for advertising. It was a glass house about the middle of the pier, and in the evenings I worked surrounded by a crowd of resort visitors, attracted by the noise of the spark.
>
> When I went on watch one evening late in August, I was told by Bob Miller, the day man, that a broker from Philadelphia would be in later on with a customer, and presently he appeared with a prosperous looking old lady. I showed them how things worked and let her listen to some signals from a ship, and then he started explaining what a wonderful opportunity to get rich he was offering.
>
> I listened in amazement and silence for about fifteen minutes, but finally he told her that the average amount collected monthly on each ship for messages sent was $500. Unfortunately, he turned to me. "You have been out on several ships, haven't you?"—"Yes."—"Didn't you take in about five hundred a month?"—"No, I never took as much

[55] Carneal, *op. cit.*, p. 198. This concern was aided by the acquisition of the assets and the especially important tuned-circuit patents of John Stone Stone. Since the De Forest company had insufficient funds for development, a subsidiary, the Radio Telephone Company, was formed.

[56] De Forest owned 50 per cent of the stock of this company.

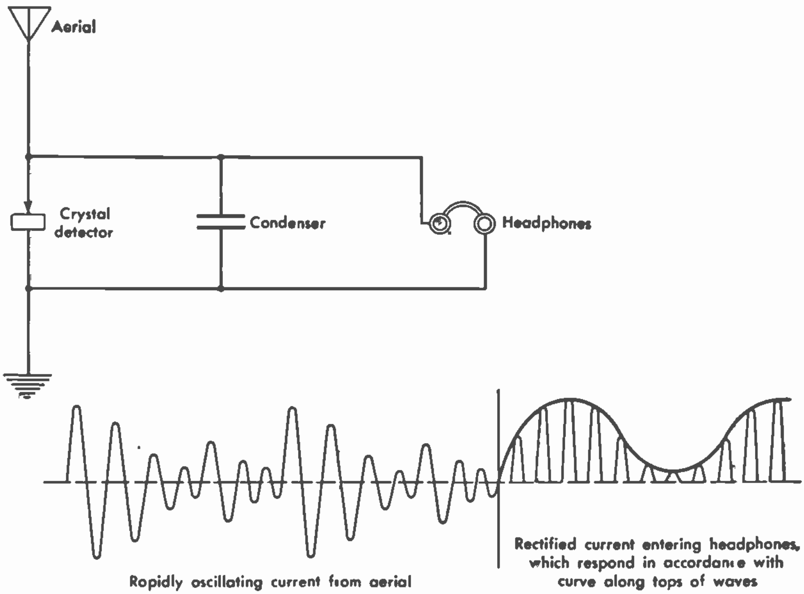
[57] Lubell, *op. cit.*, p. 38.

[58] Interview with George Clark, August, 1946.

as $50, and ten dollars would be about the average!"—He sputtered and stuttered, and finally took his prospect away.

Next morning at 9:00 a.m. I received a telegram ordering me to come to New York and sail for England on the *Tagus* at 3:00 p.m. I was tired of working 12 hours every day and Sunday for $80 a month anyway.[59]

In another type of salesmanship stunt, de Forest journeyed to France and obtained permission to use the Eiffel Tower. From there he broadcast in the summer of 1908, some of his messages being received as far as Marseilles. While in Europe, de Forest also demonstrated his apparatus to the British Admiralty, achieving transmission over sixty miles. Several sets were ordered by the Admiralty, but the Marconi company insisted on a literal interpretation of its exclusive contract, thereby forcing a cancella-



Operation of a crystal detector. The crystal rectifies the oscillations of current from the antenna, giving an output similar to that of a diode. (Courtesy Stokley, *Electrons in Action*, Whittlesey House)

[59] Witnessed statement of Austin M. Curtis from the files of Lloyd Espenschied.

tion of the order.[60] The following year de Forest planned communication between New York and Paris, but a severe sleet storm destroyed his wires and antennas.

Although sales of de Forest apparatus remained limited, with the Navy as the best customer, the company did become moderately successful for a short period. The high-power stations constructed for the Navy were excellent. De Forest knew how to get power into his equipment; his transmitters were characterized by a "good carrying spark"; and he was one of the few to realize the importance of good ground connections. By 1909 de Forest, with a new laboratory and seven assistants, declared: "Never until this year have I had the proper backing." [61] Had he been content to improve and perfect his apparatus progressively, he would have had a greater measure of commercial success. Instead, he was too ambitious and too impatient.

Always a showman, de Forest in January, 1910, staged the first opera broadcast in history, with Caruso singing in *Cavalleria Rusticana* and *Il Pagliacci.* The voices were hardly recognizable. More serious disappointments were to follow. The government was beginning a crusade against wireless stock promoters, and the plans to obtain more funds by stock and bond sales had to be abandoned. The Radio Telephone Company went into bankruptcy in 1911, following an unsuccessful merger into a $10,000,000 North American Wireless Corporation; [62] and de Forest went to California to work for Federal Telegraph.

In May, 1912, de Forest and his associates were charged with using the mails to defraud. During the course of the trial, the government prosecutor showed how little understanding there was of the significance of de Forest's inventions when he accused the defendants of selling stock "in a company incorporated for $2,000,000, whose only assets were de Forest's patents chiefly directed to a strange device like an incandescent lamp which he called an Audion and which device had proven worthless." [63] But the government proved conclusively that unscrupulous methods

[60] Carneal, *op. cit.*, p. 226.

[61] From a speech by de Forest, as reported in the *New York Times*, Feb. 14, 1909.

[62] According to Lubell, de Forest was given $1,000,000 stock and $250,000 cash in this company. Lubell, *op. cit.*, Jan. 24, p. 38.

[63] Archer, *History of Radio, op. cit.*, p. 110.

had been employed in promoting the Radio Telephone company. De Forest himself was exonerated on the grounds that he had not been responsible for the unlawful practices used, though two of his associates were sent to jail.

Undaunted, de Forest used the $50,000 obtained from the sale of repeater rights in the triode to reorganize his old company, changing its name to The Radio Telephone and Telegraph Company.[64]

The following year, 1914, de Forest sold further triode rights for radio, to AT&T, and with the $90,000 began to manufacture triodes under the limited rights he had retained for "amateur and experimental use." The company centered its efforts on the production of tubes for oscillating circuits, which would give high-frequency output in useful quantities for heterodyning. New equipment was installed in de Forest's laboratory and modern machinery and pumps purchased for the factory. By then the triode had become easier to use and less expensive because better and cheaper batteries and charging equipment had been placed on the market.

In the meantime, the Marconi company brought a patent suit, claiming that the triode infringed the Fleming valve. De Forest immediately filed countersuit, averring that the Marconi company had infringed his patent by its use of the third element. In September, 1916, the court decided that de Forest had infringed the two-element Fleming valve, while Marconi had infringed the three-element de Forest patent.[65] Neither company could manufacture the triode.

During the war, however, de Forest manufactured triodes under government immunity;[66] but at the conclusion of hostilities some sort of working compromise with the Marconi company was essential. For a brief period the two companies tried to work together. A lamp manufacturer named Moorehead assem-

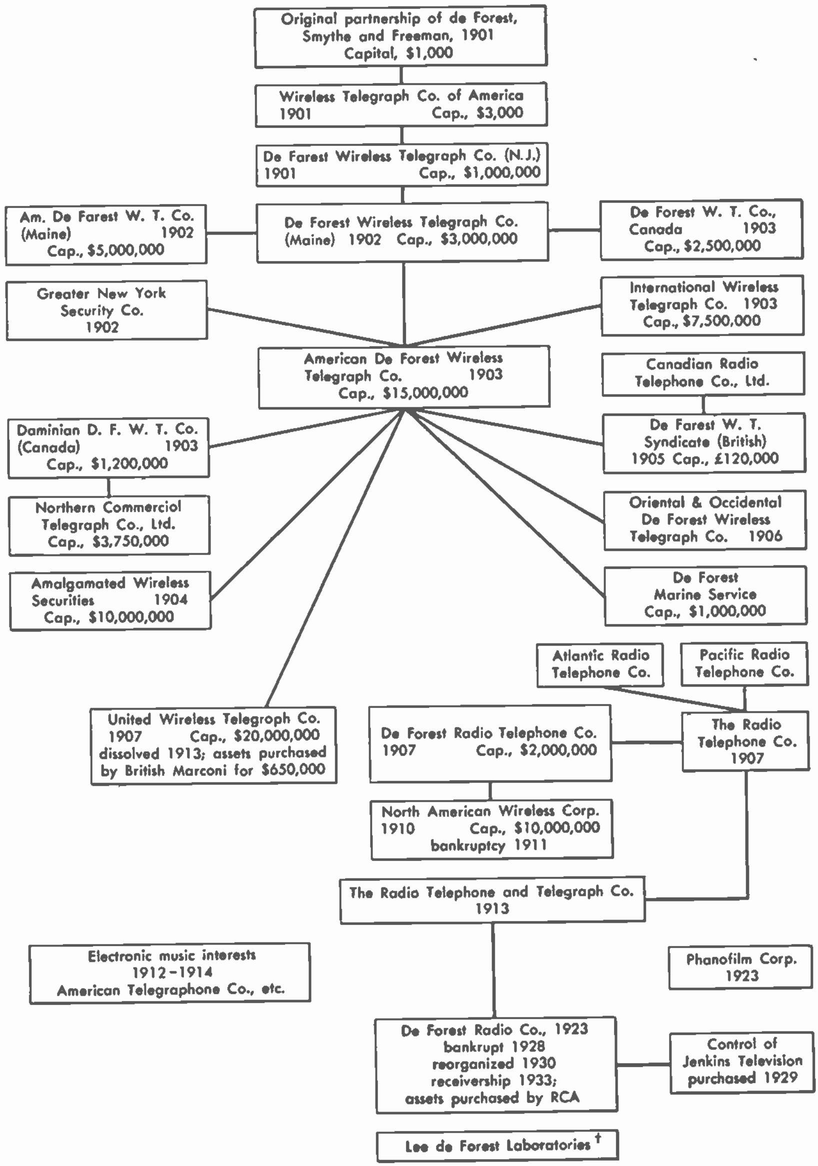
[64] De Forest owned about 80 per cent of the stock of this company.

[65] The Marconi company had first used three-element tubes at the United Fruit Company's station in New Orleans in order to fulfil a $100,000 contract which was in jeopardy due to unsatisfactory performance of magnetic and carborundum detectors. 236 F. 942, affirmed 243 F. 560.

[66] His triodes were not uniform or standardized, and the entry of such firms as Western Electric and General Electric into tube manufacturing pointed up the deficiencies of the de Forest product.

TABLE III

THE DE FOREST COMPANIES *



bled triodes for de Forest, who passed them on to the Marconi company for exclusive distribution in the United States. The first order for 150,000 tubes brought in substantial revenue. But quarrels soon developed. And when in 1920 RCA acquired rights to the triode through cross-licensing agreements with the Telephone company, it was no longer necessary to deal with de Forest. In the competitive struggle that ensued, de Forest's company was no match for GE, Westinghouse and RCA.

Thus, although de Forest was perhaps the most imaginative inventor in the history of the radio industry, and had the opportunity to create a great radio enterprise, he failed entirely to do so. His career, when compared with Marconi's, effectively illustrates that an inventor, to achieve commercial success, must associate himself with men of exceptional business judgment.

* This is not a complete table of de Forest's companies but only those on which we have been able to find a record. De Forest himself did not remain associated with all the companies that bore his name. Almost all the de Forest companies were capitalized for much more than the company ever received in cash or tangible assets. Indicative of de Forest's attitude toward financial matters is an entry in his diary, made during his student days: "I always seem lost in the financial woods."

† This is de Forest's present venture. The Laboratories are located in Hollywood and produce principally diathermy machines.

Chapter V: THE ROLE OF THE LARGE ELECTRICAL FIRMS IN WIRELESS: 1912–1921

Fifteen years is about the average period of probation, and during that time the inventor, the promoter and the investor, who see a great future for the invention, generally lose their shirts. . . . This is why the wise capitalist keeps out of exploiting new inventions and comes in only when the public is ready for mass demand.—Owen D. Young.

In wireless, as in most new fields, the number of important contributors remained small during the initial exploratory years. A coherent account of the technological development of radio communications until about 1912 can therefore be given by focussing attention on Marconi, Fessenden and de Forest. The passage of legislation requiring ships to carry wireless apparatus produced a substantial change so that from 1912 on, there were many more contributors to radio technology. And, with the outbreak of war, the large, well-established electrical companies began the manufacture of radio apparatus—a development which was to alter significantly the postwar structure of the industry.

The three large companies which entered the radio field were AT&T, General Electric, and Westinghouse. These were the firms which later joined together their extensive patent interests in radio, in the newly created Radio Corporation of America.

1. American Telephone and Telegraph Company

The American Telephone and Telegraph Company first became seriously interested in radio telephony in 1906,[1] when Fessenden

[1] The company had earlier investigated wireless telegraphy. In 1892 Mr. Hammond V. Hayes, who was then in charge of the telephone laboratory, suggested to John Stone Stone that "it might be possible to signal vessels at sea by means of

conducted a series of demonstrations of his apparatus. President Fish of the Telephone company was particularly interested, and a contract was drawn up by which Fessenden's firm was to install a wireless telephone link between New London and Martha's Vineyard. Fish's plans for wireless telephony fitted in with his policy of providing for "thirty years in advance," as exemplified by his installation in 1906 of underground telephone lines between New York and Philadelphia. He was, however, overenthusiastic about expansion, and the directors of the company insisted on a new policy of retrenchment which caused Fish to resign. His successor, President Vail, cancelled plans for the wireless telephone links,[2] regarding them as too visionary.

Radiotelephony remained for the radio experimenter a golden goal of attainment, for there were wanting practicable means for generating the high-frequency currents, for controlling them in accordance with the relatively weak waves of speech, and for renewing at the receiving end the waves so greatly weakened in transit.[3]

All these deficiencies were ultimately to be satisfied by the vacuum tube. The de Forest three-element tube was utilized for generating radio waves, for modulating them, and for amplifying the received waves. But the vacuum tube, more than any other single feature in the progress of radio, required a mass attack on its theory, its mathematics, its construction and its behavior; and this was not made until the laboratories of the great corporations had turned their attention to the problem.

After the Fessenden episode, AT&T did not again become actively interested in radio telephony until it investigated the de Forest triode[4] for transcontinental wire telephony. The tube

electrical oscillations of high frequency, transmitted to them through space without wires." Stone was delegated to investigate this possibility. He was unsuccessful, however, for he lacked an appropriate continuous-wave, high-frequency generator and even a detector for telephony. He had entertained the idea of high frequency multiplex telephony on wires but that too required instrumentalities not yet known to the art. (U.S. Patent Interferences of 1896, Stone and Pupin, No. 17196; Stone and Hutin and Leblanc, No. 17197; also Telephone company files.)

[2] Fessenden testimony, F.T.C. *Hearings*, *op. cit.*, p. 3897.

[3] Lloyd Espenschied, "The Origin and Development of Radio Telephony," *Proc.* I.R.E., Vol. 25, No. 9, Sept. 1937, p. 1102.

[4] Even before 1912 the Telephone company had been considering what methods might be used in establishing public service transoceanic telephony by means

which de Forest demonstrated to AT&T engineers in 1912 was a weak device. It choked and distorted when a loud speech current was applied, but it seemed to have potentialities for amplifying weak signals. The problem of adapting this device to telephone requirements fell to Dr. Harold D. Arnold, a young physicist who had recently joined the staff.[5] Arnold suspected that the instability of de Forest's tube was caused by gas ionization, and that this defect could be removed by increasing the vacuum. In addition, Arnold believed that the tube could be improved by using a cathode of the oxide-coated type, rather than the tantalum filament of de Forest's tube.[6] The first improvements effected by AT&T were in the circuits used by de Forest; later the mechanical structure was redesigned, and the plate area was increased.[7] A very high vacuum was obtained by a Gaede molecular pump imported from Germany.[8] By the middle of 1913, a filament had been made with a laboratory life of 1,000 hours—a vast improvement over that of de Forest's triode, which had averaged about 50 hours.[9]

During the next two years, research workers in the telephone laboratories continued to improve the filaments and grid structures of the vacuum tube. This phase of development culminated in the use of tubes as repeaters when the transcontinental line between New York and San Francisco was opened in January, 1915.

The high-vacuum tube brought the wireless telephone within the realms of practical accomplishment. Accordingly, in January,

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of radio. Prior to de Forest's demonstration of the triode, Bell System engineers had seriously investigated the possibilities of using arcs, but they, like all previous inventors, had encountered the problems of getting enough power and finding a means of modulating it. Interview with Lloyd Espenschied, Aug. 1947.

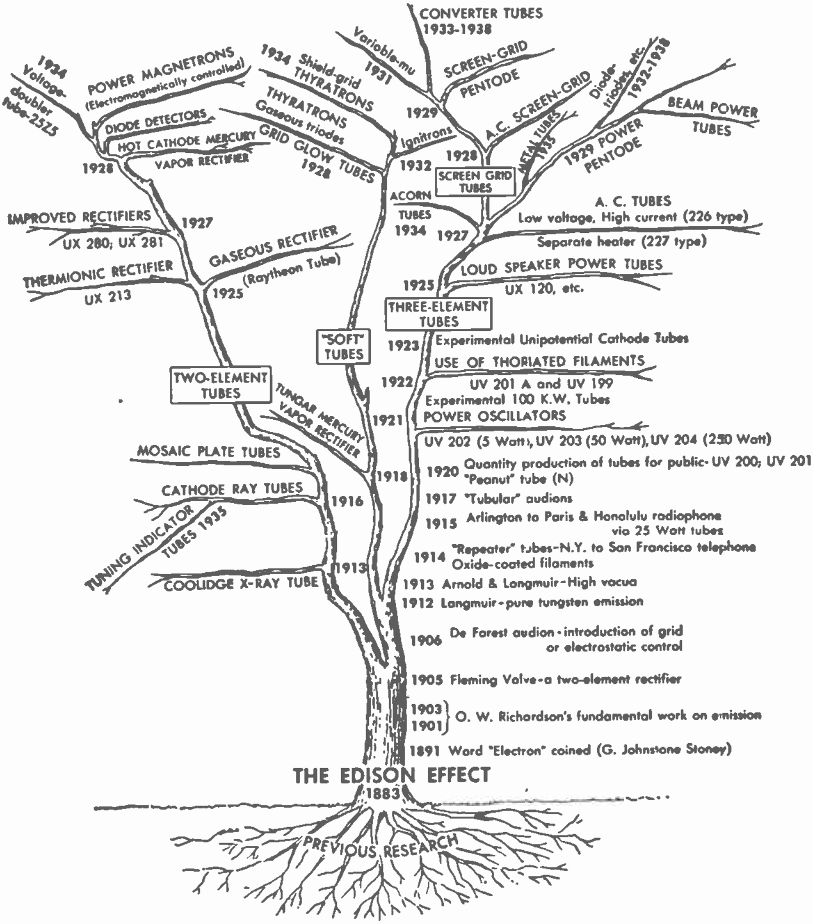
[5] Arnold had previously been working under Professor R. A. Millikan at the University of Chicago.

[6] Tyne, *op. cit.*, p. 56. This type of cathode, invented by Wehnelt in Germany, was a more copious generator of electrons, would operate at comparatively low temperatures, and give greater stability and longer life.

[7] *Ibid.*, p. 58.

[8] The invention of the Gaede molecular pump in Germany in 1910 gave GE and AT&T scientists the means for obtaining higher vacua than had previously been possible.

[9] Trial installation of the tube as a telephone repeater was made at Philadelphia on a toll circuit between New York and Washington in October 1913. (*Ibid.*, p. 58.)



The Family Tree of the Thermionic Tubes. From the early work of Edison and previous research men, many types of vacuum or thermionic tubes have come. The words on this chart describing these new devices may sound like Greek to the uninitiated reader, but each new tube has proved to be of vast technical importance. Whole new systems of communication have been based upon them. There is no end in sight to the production of still further tools of this sort—provided the research laboratories keep going. Similarly, there is no end in sight to the new uses for the tubes already produced. (Courtesy *Electronics*)

1914, the telephone laboratories instituted a one-year program to determine the technical possibilities of transatlantic radiotelephony and the chances of its ultimate success.[10] By August, 1915, speech had been sent by land wire to the Navy's radio station at Arlington, Virginia, picked up automatically there, connected to a newly developed vacuum-tube transmitter, and received at Darien, in the Canal Zone, 2,100 miles distant.[11] Reporting on these tests Chief Engineer Carty of the Telephone company declared: "Overcoming atmospheric disturbance is the greatest problem we have. During the conversation with New York, there was sometimes a roar like the sound of distant musketry, which was recognized as static disturbance." [12]

The next step was to try to communicate with Europe. General Ferrié of the French Army was so interested that he permitted the Eiffel Tower to be used as a listening post even though France was at war. At the transmitting station in Arlington, a bank of 500 tubes was used, each having a capacity of 15 watts.[13] The tubes kept burning out, and men from the Bell Laboratories in New York City had to make frequent trips to Arlington with suitcases full of replacements. Only a few faint words could be distinguished in the tests. Much more remained to be done before long-distance radio telephony was perfected.

AT&T did not claim to have made any momentous discoveries in these various tests. Its contribution was described by President Vail:

> So far as the perfection of the wireless telephone goes, there has been no new basic invention, merely a perfection of the sending and receiving instruments.[14]

The company's conception of the future role of the radio telephone was given by Mr. Carty in 1915. "The results of long-

[10] F.C.C. *Proposed Report*, pp. 213–215.

[11] Signals were also transmitted in a later test to the California coast and to Honolulu.

[12] *Electrical World*, Oct. 9, 1915, p. 789.

[13] Espenschied, I.R.E., *op. cit.*, p. 1106. High-power transmitting tubes were then only a laboratory promise and were not to be a reality until after the war.

[14] *Electrical World*, Oct. 9, 1915, p. 790. But we know today that this was an understatement, for actually there were involved many developments that proved to be of first-rate importance to the newly budding technique of high-frequency vacuum-tube telephony, both by radio and wires.

distance tests," he said, "show clearly that the function of the wireless telephone is primarily to reach inaccessible places where wires cannot be strung. It will act mainly as an extension of the wire system and a feeder to it." [15]

From 1917 to 1918 long-distance telephony research was discontinued. Efforts in the war years centered on the development of two-way radio telephone sets for dispatch purposes on subchasers and airplanes.[16] In 1919 AT&T resumed its former program: an expenditure of $500,000 was authorized for wireless development, including $360,000 for a marine transmitter at Deal Beach, New Jersey, and a receiving station at Cliffwood.[17]

Through this development program and through its purchased rights to the de Forest triode and feedback circuit, the Telephone company had, by 1920, acquired an important stake in radio technology. Although the company did not, itself, dominate the radio industry, it was in a strong enough position to prevent any other company from doing so.

2. *General Electric Company*

While AT&T had been secretly conducting its transatlantic tests with vacuum-tube transmission, General Electric had been focussing attention on the Alexanderson alternator and on vacuum-tube equipment for continuous-wave telegraph transmission.

(a) THE ALTERNATOR

The alternator, originally, had been the brain-child of Tesla and Fessenden. When in 1904 Fessenden gave to the General Electric Company his second order for an alternator capable of 100,000 cycles, the work was assigned to Alexanderson, a brilliant engineer who was a newcomer at Schenectady.[18] Fessenden, it will be recalled, was adamant in insisting that wooden armatures be

[15] *Ibid.*

[16] Espenschied, *op. cit.*, p. 1109.

[17] F.C.C. *Proposed Report*, p. 215.

[18] Ernst F. W. Alexanderson, a native of Sweden, had graduated as an electrical and mechanical engineer from the Royal Technical University in Stockholm. Later he studied under Professor Slaby in Berlin and decided to come to America to work under Steinmetz at GE. He was only twenty-six when he began working with Fessenden.

used, despite Alexanderson's advice to the contrary. Several years later Alexanderson succeeded in getting Fessenden to change his specifications, but by the time the machines were ready for operation, NESCO was on the verge of bankruptcy and in no position to purchase new equipment.

GE decided that since so much money had been spent on the alternator, Alexanderson should be encouraged to continue with its development. Patents were taken out on the young inventor's ideas, and work was continued in the expectation of finding another customer. Alexanderson himself investigated the problem of modulating the powerful currents of the alternator by the minute energies of the voice. Fessenden had used a water-cooled microphone for his ½ kilowatt machine, but as this was totally unsuited for high-power apparatus Alexanderson turned to other methods, producing his form of magnetic amplifier in 1912. Later, after consultation with Coolidge and Langmuir, he obtained a patent for an electronic amplifier,[19] a highly evacuated audion which was capable of stepping up the power enormously. Then, in 1916, Alexanderson perfected his multiple-tuned antenna,[20] which materially increased the efficiency of the radiation, and in 1918 he and his assistant, Harold Beverage, devised a "barrage receiver"[21] which later led to the Alexanderson-Beverage static eliminator. The use of this receiver led to an accidental discovery of the directional character of static, an important clue for the scientific study of the phenomenon.

The work of Alexanderson, together with that of Langmuir, Coolidge and others in the General Electric Research Laboratories, had by 1915 given General Electric a complete system of continuous-wave transmission and reception. But at that time the company had no desire to start a communications company of its own in competition with such firms as AT&T and the Marconi company.

[19] Patent No. 1,042,069.

[20] Marconi was so impressed by this invention that he invited Alexanderson to demonstrate it at the New Brunswick station early in 1917. It proved so successful that the Marconi company made plans to equip all its world-wide stations with the apparatus. (Archer, *History of Radio*, *op. cit.*, p. 121.)

[21] This was an ingenious mechanism which could be used to neutralize German blanketing signals, allowing Allied wireless messages to come through. It also cut off interfering signals from powerful stations in the vicinity of the receiver.

Accordingly, GE sought a customer for its perfected alternator. The Marconi companies were the obvious choice. Marconi, who was in the United States in connection with patent litigation, was invited to inspect the alternator in May, 1915. He was so intrigued by the demonstration that a conference of British Marconi and General Electric executives drew up a tentative agreement by which the Marconi companies were to have exclusive rights to use the alternator while General Electric retained exclusive rights to its manufacture.[22]

The consummation of this agreement was postponed because of the war. However, General Electric did arrange to install a 50 kilowatt alternator at the New Brunswick station of the American Marconi company. Transatlantic tests in July, 1917, demonstrated the superiority of the new alternator over other types of transmitting apparatus. General Electric also began the construction of a 200 kilowatt alternator, which on the Navy's request was similarly installed at New Brunswick. This station became the most powerful transmitter in the world, communicating not only directly with the A.E.F. in Europe but with battleships in all waters.

(b) VACUUM-TUBE RESEARCH

General Electric's contributions to the vacuum tube were just as important as its work on the alternator. The company's original interest in vacuum tubes stemmed from motives quite different from those of AT&T. The Telephone company urgently needed a relay device for transcontinental telephony. General Electric was under no such coercion. Instead, it entered tube research through its interest in the progenitor of the vacuum tube, the incandescent lamp and the x-ray tube. Lamps had been a major item of production since General Electric was formed; and one of the primary objectives of its research laboratories had been the investigation of the fundamental principles of lamp technology.

By 1912 General Electric lamp research was being conducted by such notable scientists as Willis R. Whitney, William D. Coolidge, Irving Langmuir, and A. W. Hull. The company had

22 Archer, *History of Radio, op. cit.*, p. 130. In this connection it should be recalled that German competitors of the Marconi company by 1915 were working continuous-wave alternators across the Atlantic.

purchased the Just and Hanaman patents on tungsten filaments,[23] and Dr. Coolidge had filed application for his important ductile tungsten patent. These patents gave General Electric airtight control of the tungsten filament. Coincidentally Dr. Coolidge had been working with x-ray tubes, A. W. Hull had begun the project which was to result in the *pliotron* in 1913 and Irving Langmuir, General Electric's theoretical chemist, was investigating fundamental considerations in all phases of lamp and tube behavior.[24] Concerning his work at this time, Langmuir has written:

> My active interest in thermionic currents began in connection with some experiments on electrical discharges occurring within tungsten lamps. . . . As a result of this work, we became firmly convinced that the electron emission from heated metals was a true property of the metals themselves and was not, as has so often been thought, a secondary effect, due to the presence of gas.[25]

Quite independently of the Telephone company scientists, therefore, Langmuir concluded that an approach to a pure electron discharge was necessary to make the de Forest triode an effective device, and this required the use of a high vacuum in the tube.

The development of the high-vacuum tube represented a far greater advance than the name alone would suggest. Although Fleming and de Forest had used "vacuum" tubes, they had neither an adequate pump nor other techniques necessary to produce a vacuum free of ionization. At the time when Langmuir and Arnold first produced tubes with an almost perfect vacuum, there had been no conclusive proof that a tube would operate if all residual gas were eliminated. Richardson's theory of thermionic emission had suggested that the discharge of electrons was independent of residual gas,[26] but his theory was not immediately

[23] "Incandescent Bodies for Electric Lamps," U.S. Patent No. 1,108,502. Filed 1905, granted 1912.

[24] Langmuir's measurements of the effects of various gases on filament deterioration led to the gas-filled lamp in 1914.

[25] Irving Langmuir, "The Pure Electron Discharge," *Proc.* I.R.E., Vol. 3, No. 3, Sept. 1915, pp. 266–269.

[26] O. W. Richardson, "The Electrical Conductivity Imparted to a Vacuum by Hot Conductors," *Phil. Trans.*, Vol. 201, 1903, p. 497. At p. 546 Richardson stated: ". . . Both these points of view lead to the conclusion that the corpuscles

accepted, and, in fact, certain experiments tended to discredit it. For instance, in 1907 Professor Soddy, of the University of Glasgow, conducted some experiments on thermionic emission in a tube from which all gases had been removed, and found that the current stopped completely. He concluded that, in the absence of all gas, the cathode was unable to emit electrons.[27] Several other prominent scientists confirmed his conclusions.

Arnold and Langmuir, on the other hand, believed and demonstrated that if a *high enough* vacuum could be obtained, a pure electron discharge would result.

To maintain a very high degree of vacuum, it was necessary for the tube to be subjected in manufacture to a most rigorous treatment. A vacuum tube could be pumped out effectively to give a high initial vacuum; but in operation the walls and other components of the tube, when heated would give off gas in large quantities. Pre-heating and other processes to prevent this took care and time, as well as special apparatus which was not generally available.[28]

The fact that GE and AT&T were each devoting major research attention to the vacuum tube led to no less than twenty important patent interferences between the two companies from 1912 to 1926.[29] These interferences became so numerous and so

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are not produced by a dynamical action between the molecules of the surrounding gas and the surface of the metal. In fact, all the experimental results seem to point to the view that the corpuscles are produced from the metal by a process similar to evaporation. The effects of the surrounding gas, of impurities in the wire, and of its previous history are to be regarded as due to alterations in the property of the metal which corresponds to latent heat in the theory of evaporation."

[27] Work of later experimenters showed that the result obtained by Soddy and others was "not due to any failure of the filament to emit electrons but was due to the inability of the space around the filaments to carry the currents with the potential available in the lamp." Langmuir, *op. cit.*, pp. 266-267.

[28] Langmuir filed a patent application for a type of high-vacuum furnace which he invented for this work. See Patent No. 994,010, issued May 30, 1911.

[29] These interferences included the following: (1) Modulating high-frequency currents by means of tubes; Nichols and de Forest (AT&T) and White and Alexanderson (GE)—three interferences.

(2) Use of the feedback circuit for producing oscillations; Langmuir (GE), Lee de Forest (AT&T), Armstrong and Meissner—two interferences. Meissner was one of Telefunken's top scientists. His patents, along with others of the German company, had been seized by the Alien Property Custodian on the outbreak of war. The government became a member of the famous four-party interference on behalf of this patent. (Meissner had been one of the earliest

serious that some cross-licensing agreements on patents had to be arranged.

3. Westinghouse Electric & Manufacturing Company

The third large electrical firm, Westinghouse, had done very little work in the radio field prior to World War I. In 1916 a Westinghouse engineer, Frank Conrad, had asked permission to start a small development program on radio transmitters and receivers. An experimental station was erected at the factory in East Pittsburgh, and Conrad built another station of his own, four or five miles away in the upper story of his garage. The results from Conrad's early experiments were sufficiently promising so that in the following year, the executives of the company decided to make this a permanent field of development.

During the war, Westinghouse manufactured considerable quantities of radio apparatus for the United States and European governments, as well as auxiliary equipment such as motors, generators and rectifiers.

Westinghouse, however, lacked in its own right a strategic position in wireless comparable to that of GE and the Telephone company. That it ultimately became a full partner in the Radio Corporation of America was due primarily to some imaginative postwar moves which will be described in the next section.

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to use a vacuum-tube oscillator for radiotelephony, employing a Lieben-Reisz tube for communication between Berlin and Nauen in 1913.—Lloyd Espenschied, *op. cit.*, p. 1105.)

(3) Structural features of tubes; Langmuir (GE) and Nicholson (AT&T)—two interferences.

(4) Suppression of carrier wave; Alexanderson and White (GE) and Arnold and Carson (AT&T)—two interferences.

(5) Use of tubes for modulating high frequencies; Alexanderson (GE) and Colpitts (AT&T).

(6) Use of tubes for current limiting purposes; Langmuir (GE) and Espenschied (AT&T).

(7) Plate modulation of output of tube oscillator (extremely important in broadcasting); White (GE) and Hartley (AT&T).

(8) Suppression of carrier frequency and transmission of one or both sidebands; Alexanderson (GE) and Englund (AT&T).

(9) High-vacuum; Langmuir (GE) and Arnold (AT&T).

(10) Use of alternating current for lighting tube filaments; White (GE) and Heising (AT&T).

From the testimony of A. G. Davis before the F.T.C. *Hearings, op. cit.*

4. The Formation of the Radio Corporation of America

At the end of the war each of the three large American electrical companies had some significant stake in wireless. They were blocked, however, by the fact that in international communications the British Marconi company dominated the field. And in the United States, the control of key patents by opposing interests contributed to a stalemate that retarded the best utilization of radio. Major Armstrong, testifying before the Federal Trade Commission, declared: "It was absolutely impossible to manufacture any kind of workable apparatus without using practically all the inventions which were then known." [30]

(a) OWEN D. YOUNG, THE INNOVATOR

It was Owen D. Young of General Electric who, at the suggestion of the Navy, carried through the plan that broke this bottleneck. Young was a man with a broader background and outlook than the inventor-entrepreneurs whom we have previously discussed. Trained in a liberal arts university and a graduate school of law,[31] he served his apprenticeship as legal counsel, first for Stone and Webster and then for General Electric in the era when public utilities were in the flood of their expansion. Young developed a strong interest in new technical developments and a drive for accomplishment which were essential elements in his very successful career.

His capacity as an organizational innovator came from his keen intuitive imagination and his sense of strategy. It was his practice to surround himself with a very able staff who would prepare analyses on all the major phases of a program in advance of taking action. Legal habits of precise thinking enabled him to

[30] *The Radio Industry*, *op. cit.*, p. 24. During the war, manufacturers of military equipment were permitted to use any U.S. patents and were held harmless for damages. This later led to protracted infringement suits in the U.S. Court of Claims.

[31] He graduated in an era before schools of business administration had been established and when a legal training was regarded as one of the best methods of embarking on a business career. Young first came to the attention of GE when he won a case against them which they had expected to win. Charles A. Coffin, chairman of the board of General Electric, was so impressed by the skill with which Young handled this case that he followed his career for two years and, when the company's counsel died, offered the position to him.

work out such plans in detail so that, once the strategy was determined, the subsequent steps followed effectively and smoothly. His entrepreneurial ability was in sharp contrast to that of Fessenden, de Forest, and to a lesser extent Marconi, who were continually jumping from one business crisis to another.

Young's first contact with wireless came in 1915, when the Marconi company was negotiating for the purchase of a considerable number of Alexanderson alternators. The question was referred to Young, but the negotiations were discontinued because of wartime pressure on British foreign exchange. Following the Armistice, the British Marconi company reopened the discussions, suggesting the outright purchase of 24 alternators at $127,000 each. Young proposed instead, that alternators be supplied on a royalty basis—having in mind the success of the rental policy in telephones and shoe machinery. The Marconi representatives then suggested an additional payment over the original purchase price of a million dollar bonus in lieu of royalty[32] which would have adequately compensated for the expenses of the development work that had been incurred.[33] But the offer was coupled with the requirement that the Marconi companies be given *exclusive* rights to the alternator.

News of these negotiations soon reached the Navy, which was vitally interested in the alternator for world-wide communication with its ships and bases. In a letter to Franklin Roosevelt, then Acting Secretary of the Navy, Mr. Young disclosed the full details of the impending deal with the Marconi interests. This information was referred to Commander Hooper, head of the radio division of the Bureau of Engineering. Hooper had been alarmed for years over the manner in which all transoceanic communications in the United States were being conducted by companies of foreign domination. Hooper believed that the solution lay in an all-American company; and in a memorandum to the chief of the Bureau of Engineering he wrote: "Of all the American concerns in business of such a nature that it could be induced

[32] Archer, *History of Radio*, *op. cit.*, p. 160.

[33] Various authorities have estimated that GE spent between 1 and 1½ million dollars on the development of the alternator. The latter figure was used by Owen D. Young in a conference with Admiral Bullard. George Clark, unpublished manuscript on the history of radio in the Navy, Chap. XII, "Formation of RCA," p. 45.

to organize and capitalize such an organization, none is known to fulfil the requirements as well as the General Electric Company." [34]

Mr. Young has given a personal account[35] of the next steps:

Following the offer from British Marconi. I received a call from Admiral Bullard.

When Admiral Bullard arrived in my office, he said that the President, whom he had just seen in Paris, was concerned about the postwar international position of the United States and had concluded that three of the key areas on which international influence would be based were shipping, petroleum and radio. In shipping, England was supreme and the United States could not rival her position. On the other hand, in petroleum, England could not challenge America's position. But in radio, the British were now dominant and the United States, with her technical proficiency, had an opportunity to achieve at least a position of equality.

Admiral Bullard has independently reported on his own thinking at this time:

In early April, 1919, the writer had just returned from a war detail in Europe, and had assumed the duties of Director of Naval Communications. . . . The fact that the General Electric Company was negotiating with the English Marconi Company for a sale of a number of Alexanderson machines was brought to my official notice a few days after my arrival in my office, and immediately sensing the great advantage that would be placed in the hands of foreigners by the successful conclusion of this transaction, I tried at once to prevent it. I had continually in mind the cable situation, and its control by foreign interests and was determined that if possible this new form of international communication should remain in the hands of American citizens, particularly so as so many American engineers had provided the most valuable inventions in the radio world.[36]

Bullard's visit came at an opportune time. GE had manufactured large quantities of radio equipment for the Army and Navy during the war. Great strides had been made in perfecting the wireless telephone; and its potentialities for international com-

[34] *Ibid.*, p. 37.

[35] In an interview with the author, August 1944. See also testimony of Admiral Grayson in Hearings before the Committee on Interstate Commerce, Dec. 10, 1929. Public Doc. No. 89624.

[36] *U.S. Naval Institute Proceedings*, Oct. 1923.

munications were generally recognized. The possibilities for entertainment broadcasting, however, were only dimly appreciated.

Young was aware of the importance of timing in the exploitation of a new invention.

> Fifteen years [he has declared] is about the average period of probation, and during that time the inventor, the promoter and the investor, who see a great future for the invention, generally lose their shirts. Public demand even for a great invention is always slow in developing. That is why the wise capitalist keeps out of exploiting new inventions.[37]

By 1919, many people were convinced that there were substantial business opportunities in international radio communications. The problem that confronted GE was how to enter the industry. The Marconi companies had emerged from the war with their international monopoly stronger than ever and with no important competitor in ship-to-shore communications. During the war the American subsidiary had erected a very powerful modern transmitting station at New Brunswick and had built an important radio manufacturing plant at Aldene, New Jersey. Though Marconi's patent position was less strong than it had been, the Fleming patent was still basic to the vacuum-tube art. Moreover, the Telephone company controlled the all-important de Forest patents on the triode and feedback circuits. And in the high-vacuum case, General Electric had not succeeded, as it hoped, in obtaining undisputed control of the field. The Arnold-Langmuir litigation was to last for years and to result finally in a Supreme Court decision that there had been no invention. This, of course, could not have been predicted, but GE knew that the Telephone company was determined to fight the case vigorously with the support of some of the leading physicists of the day.

To buy out the Marconi interest and create a unified American wireless company which would bring together all the major conflicting interests called for diplomatic strategy of a high order. Young believed that the directors of British Marconi could be persuaded to sell their American subsidiary to General Electric, because of the intense opposition of United States government officials toward British domination of American wireless. His-

[37] Archer, *History of Radio, op. cit.*, p. 94.

torically, this feeling dated from the early rental policy of the Marconi company. The American Navy, which was the largest customer for wireless equipment, had objected strenuously to the company's refusal to sell any of the apparatus on which it had patent control. The antipathy toward British control of wireless was greatly increased in 1914 when the English cut the cables linking America with Germany. During the war, in an effort to defeat various congressional bills for government ownership of wireless, the American Marconi company attempted to promote the idea that a substantial proportion of its stock was in American hands. Although these particular bills were not passed, the company's efforts to prove itself free of foreign control were unsuccessful. The United States Shipping Board, early in 1919, refused to allow American Marconi to equip shipping board vessels unless the company could furnish an affidavit showing that over 50 per cent of its stock was owned by American citizens. This the company could not do.[38] After the war, a new wave of proposed legislation, giving the government various degrees of peacetime control of wireless, further jeopardized the future of American Marconi.

In Washington, Franklin Roosevelt, as Assistant Secretary of the Navy, and other Navy officials in the communications field were strongly in favor of establishing an "All-American" company.[39] Secretary of the Navy, Josephus Daniels, preferred government ownership of overseas communications service; but his influence was not great enough to obtain legislation to this effect.

Stimulated by the Navy, Young persuaded the directors of the General Electric Company to purchase a controlling interest in American Marconi. The British finally agreed to terms; the Radio Corporation of America was formed; and the assets of the Ameri-

[38] Testimony of Lewis MacConnach, F.T.C. *Hearings*, *op. cit.*, p. 885.

[39] Mr. Young has commented on the part that particular officers in the Navy played in the formation of RCA as follows: ". . . The facts are that the initiative which brought into being our American radio policy and resulted in preventing us from being outdistanced by other nations started with Hooper. It was he who spurred on Admiral Bullard in his negotiations with the General Electric Company, and he was always ready to help overcome every kind of difficulty. I don't want to detract in any way from the able work of Admiral Bullard; Commander Hooper could not have accomplished what he did without the Admiral's assistance. The original thought, the initiative and the persistent pushing were Hooper's, and he should have full credit for them." Clark, *op. cit.*, p. 69.

can Marconi company were transferred to the new corporation. GE contributed something over $3,000,000 to set up the new enterprise.[40]

There was not unanimous enthusiasm for this step in the top management of GE. Mr. E. W. Rice, president of General Electric, with a record of wise selection of new activities in the engineering field, had grave doubts. But Charles A. Coffin, chairman of the board and dominant figure in the company, with a history of successful creative ventures, was stirred by the potentialities of radio. Concerning this difference of opinion between the two chief executives of General Electric, Mr. Young has written:

> Here again one sees that the engineer as distinguished from the inventor may in the field of responsible business be more conservative than the man of business who is less well informed about technical difficulties but who may have a more correct appraisal of the possibilities of a new art.[41]

Of his own feelings, Young has said:

> My interest in promoting the project was twofold—a feeling that I was performing a useful service to the country and to my company in undertaking the task, and a personal interest in radio. This interest was increased later when I learned from engineers of its possibilities for entertainment. I had been brought up on an isolated New York farm and felt very strongly that any service which would bring the outside world to rural communities, especially in the long winter months, was a service well worth performing.[42]

The relative parts played by the government and the General Electric Company in the initiation of what was later termed "the radio trust" were to become the subject of heated controversy[43] when RCA was being attacked in Congress as an unlawful monopoly. There is no doubt, however, that there were many officials in the Navy who favored the formation of a single American company in international wireless communications. The opposition to RCA, which developed in the 1920's, grew out of the animosity arising from its dominant patent position in radio sets

[40] F.T.C., *The Radio Industry, op. cit.*, p. 17.

[41] Letter to the author, Oct. 1947.

[42] Interview, Aug. 1944.

[43] See testimony of Oswald F. Schuette, executive secretary of the Radio Protective Association, before the Committee on Interstate Commerce hearings of the U.S. Senate, 71st Congress, 1st sess., on S.6 (Washington, Supt. Docs., 1930), p. 12.

and tubes rather than from its position in international communications.

Young was made chairman of the board of RCA, and Edwin J. Nally and David Sarnoff of the old American Marconi company were appointed president and commercial manager respectively. It was planned from the outset that the Radio Corporation of America would not manufacture radio sets and tubes; these would be supplied by the General Electric Company and sold through RCA.[44]

The newly formed company was immediately faced with a difficult patent situation and some agreement between the principal patent holders was *essential*. The Navy, in a patent investigation in 1919, had "found that there was not a single company among those making radio sets for the Navy which possessed basic patents sufficient to enable them to supply, without infringement, . . . a complete transmitter or receiver." [45]

Young was anxious to create an industry in which competition would be "orderly and stabilized." This, he believed, could best be accomplished through an accord with the Telephone company which was the other principal patent-holding concern. Since the Telephone company proved equally interested in reaching a satisfactory solution, a cross-licensing agreement was signed on July 1, 1920;[46] and the Telephone company purchased 500,000 shares each of RCA common and preferred stock for $2,500,000.[47] All current and future radio patents of the two companies were to be available to each other, royalty free, for ten years. AT&T was given exclusive licenses in wire telegraphy and telephony and certain rights to radio telephony in conjunction with the telephone network. In its turn GE was granted wireless telegraphy and, rather secondarily, "an exclusive license to make, use, lease and sell all wireless telephone apparatus for amateur purposes." [48] Many provisions of the agreements, however, were ambiguous, leading to subsequent disputes among RCA's partners.

[44] GE was to sell to RCA for cost, plus 20 per cent, or a negotiated price. License agreement, GE–RCA, Art. IV, par. 3.

[45] Memorandum of Commander Loftin as quoted in Clark, *op. cit.*, p. 82.

[46] The Navy, through Commander Hooper, again helped in the negotiations.

[47] F.T.C., *The Radio Industry*, Exhibit Q, p. 21.

[48] License agreement, GE and AT&T, July 1, 1920, Art. V, par. 4 (d) (3).

In the meantime, General Electric's rival, the Westinghouse company, had not been standing still. Westinghouse had an efficient radio manufacturing organization which had specialized in military equipment during the war, and was anxious to enter the industry. The management decided to establish a competitive position in radio through the purchase of strategic patents.

In May, 1920, Westinghouse formed an alliance with the International Radio and Telegraph Company—the successor of Fessenden's National Electric Signaling Company. Part ownership of International Radio[49] gave Westinghouse control of the Fessenden inventions, including his patents on continuous-wave transmission and heterodyne reception. Westinghouse then made an even more important move by purchasing for $335,000 the Armstrong patents[50] on the regenerative and superheterodyne circuits. The Armstrong regenerative patent was in interference with de Forest, and an additional $200,000 was to be paid if the regenerative litigation were decided in Armstrong's favor. De Forest had sold his feedback patent along with other patent rights to AT&T for $250,000. Fourteen years later, the Supreme Court was to award priority conclusively to de Forest.

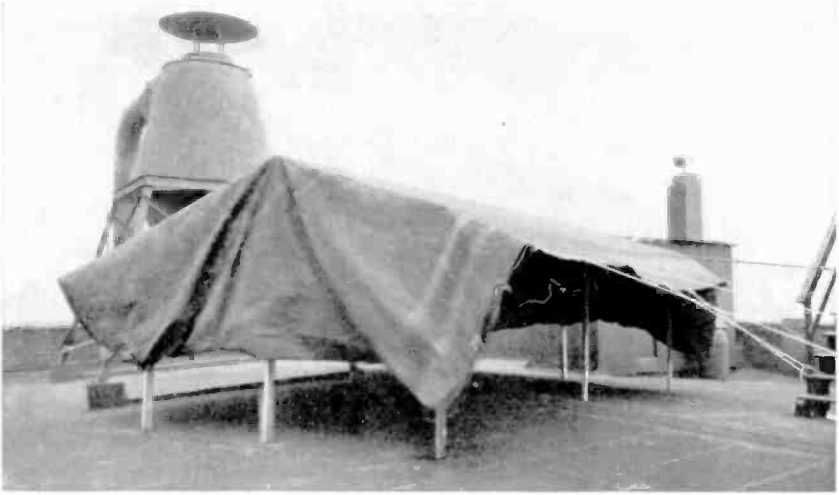
The high price paid to Armstrong was an indication of the eagerness with which Westinghouse was attempting to strengthen its position. General Electric had considered purchasing the Armstrong patents, but had not acted quickly enough. Its general counsel, L. F. H. Betts, had suggested to Armstrong's attorney that GE was interested, but Betts happened to be out of town and could not be reached when the Westinghouse offer was made. William H. Davis, as Armstrong's attorney, believed it was too dangerous to wait for a competitive bid; he thought any delay might encourage GE and Westinghouse to get together.[51] The offer was, therefore, accepted with alacrity.

In this case Owen Young had failed to protect himself from a flank attack—the counter-moves had come too rapidly. But, while

[49] The agreement was signed May 22, 1920. Westinghouse undertook to purchase 125,000 shares of International Radio stock for $2,500,000, payment to be made within two years.

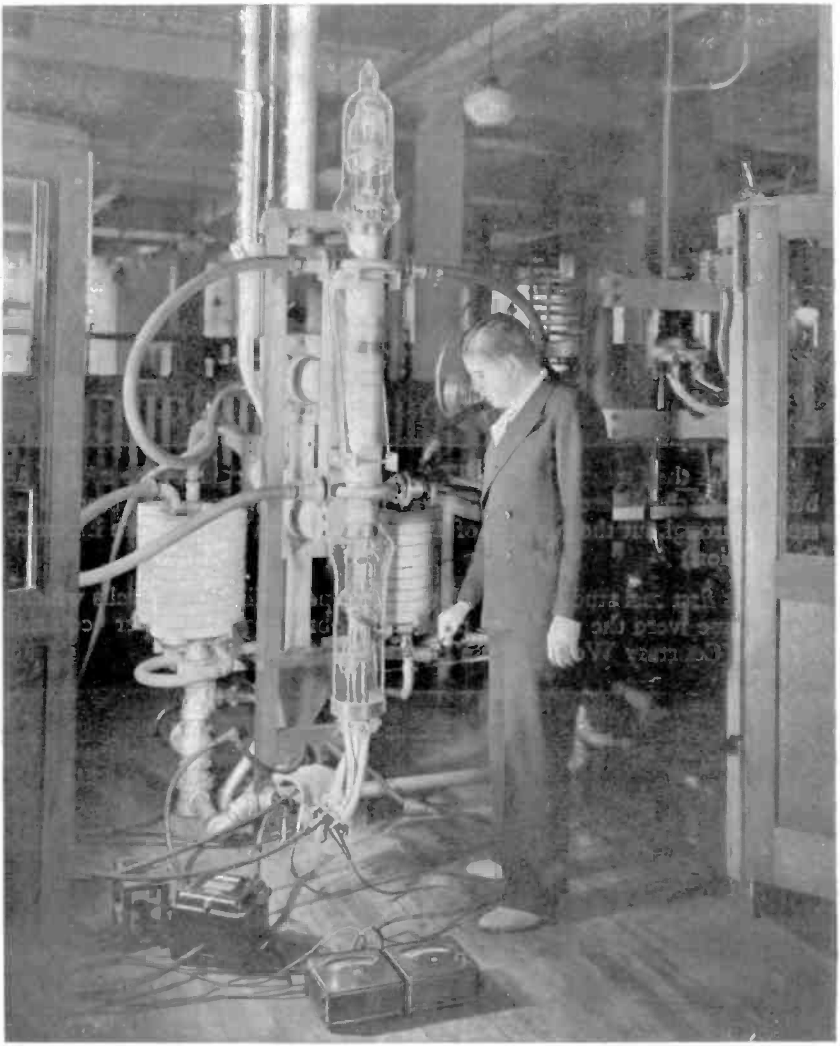
[50] Purchased Oct. 5, 1920. The group of patents included also several of Professor Michael Pupin's. Armstrong had done much of his work in Pupin's laboratory at Columbia, and Pupin had helped to finance some of his experiments.

[51] Interview with Armstrong, Fall of 1943.



This shows the first studio at KDKA. A tent was erected on the roof of a building at the Westinghouse Works in East Pittsburgh and used as a studio throughout the summer of 1921. (Courtesy Westinghouse Electric Corporation)

KDKA's first real studio, 1922. Note the draped ceilings and walls which at the time were the approved method of obtaining the proper acoustic effects. (Courtesy Westinghouse Electric Corporation)



250 kw. tube—largest ever made in the United States—developed by the Bell Laboratories and manufactured by Western Electric Co. (Courtesy American Telephone & Telegraph Company)

he had lost a skirmish, he had not lost the battle. Westinghouse soon found that it was seriously handicapped in building up an international system of radio communications. RCA had already concluded watertight agreements with the British Marconi company and other foreign groups that made it exceedingly difficult for International Radio to develop a competing system.[52]

Nevertheless, Westinghouse was now in a strong bargaining position on patents, and Owen Young was anxious to have it join RCA. His strategy was to avoid cut-throat competition. Negotiations were initiated and a settlement was reached whereby rights under the patents of International Radio were granted to the Radio Corporation, and Westinghouse joined the "radio group" on June 30, 1921. Thereafter, RCA was to purchase 40 per cent of its radio apparatus from Westinghouse and 60 per cent from General Electric.

As a result of these and other agreements,[53] RCA obtained rights to over 2,000 issued patents,[54] including practically all the patents of importance in the radio science of that day.

RCA's most important agreements in the international sphere were with the British Marconi company, the Compagnie Générale de Télégraphie sans Fil, and the Telefunken Corporation. These three companies were the dominant concerns in radio communications in their respective countries. The agreements entered into in 1919 were to run until January 1, 1945. Each corporation was to have the *exclusive* right to the use of the other company's patents within its respective territories, as well as for "mutual traffic arrangements wherever possible throughout the world."[55] Thus was organized the first international radio cartel.[56]

[52] Archer, *History of Radio*, *op. cit.*, p. 196.

[53] The United Fruit Company and Wireless Specialty Apparatus were also brought into the cross-licensing arrangements.

[54] F.T.C., *The Radio Industry*, *op. cit.*, p. 3.

[55] Exhibit DD, Traffic Agreement, Radio Corporation of America and Marconi's Wireless Telegraph Company, Ltd., F.T.C., *The Radio Industry, op. cit.*, p. 239.

[56] *Ibid.*, pp. 51–59. Later in 1925 an agreement was reached with the Philips company in Holland in which RCA obtained exclusive rights under Philips company patents in the United States and Canada, and Philips obtained exclusive patent rights from RCA in Holland, Czechoslovakia, Denmark, Esthonia, Finland, Latvia, Lithuania, Norway, Sweden and Switzerland, together with their respective colonies and dependencies.

The position of RCA in 1923 was described by the Federal Trade Commission in the following terms: ". . . the Radio Corporation has acquired all the high-power stations in this country with the exception of those owned by the government, and it has practically no competition in the radio communication field."[57] Had radio continued to be confined primarily to international communications, the plan might have worked smoothly. The growth of entertainment broadcasting, however, radically altered the nature of the industry. In the competitive scramble that resulted, the operating arrangements under which GE and Westinghouse did the manufacturing and RCA the selling, proved too cumbersome. Mr. Young's genius lay in the formulation of policy rather than in operational detail, which he delegated largely to

TABLE IV: RADIO CORPORATION OF AMERICA—SALES, LICENSE, AND TRAFFIC AGREEMENTS
1919–1923

Party	*Scope*	*Date*	*Termination* *
General Electric Co.	Cross-licensing	1919	1945
British Marconi	Traffic and cross-licensing	1919	1945
Extension of GE–AT&T agreement	Cross-licensing	1920	1930
Imperial Japanese Government	Traffic	1920	——
Reichspostministerium	Traffic	1920	1930
Government of Norway (assignment from American Marconi)	Traffic	1920	——
AT&T	Traffic	1920	1930
Elmer T. Cunningham † (Audio Tron Mfg. Co.)	License	1920	90 days
Elmer T. Cunningham	Sales	1920	——
GE & Wireless Specialty Apparatus Co.	Cross-licensing	1921	1945
United Fruit Co.	Cross-licensing	1921	1945

[57] *Ibid.*, p. 52. Competition was to develop later from such firms as Mackay, IT&T. and Federal Telegraph.

TABLE IV (*cont'd*)

Party	*Scope*	*Date*	*Termination* *
The International Radio Telegraph Co.	Sale of I.R.T. Co.	1921	——
GE and Westinghouse	Cross-licensing	1921	1945
Drahtloser Uebersee-Verkehr A.G.	Traffic	1921	1951
Telefunken	License and traffic	1921	1945
Compagnie Générale de Télégraphie sans Fil and Radio France	Traffic	1921	1945
Republic of Poland	Traffic	1921	1951
Compagnie Générale, Brit. Marconi, and Telefunken (South American Consortium)	Traffic and cross-licensing	1921	1945
Federal Telegraph Co. of California	Formation of Federal Telegraph of Delaware	1922	——
Federal Telegraph Co. of California	License to Fed. on heterodyne patents	1922	1930
Postal Telegraph-Cable Co.	Traffic	1922	1927
Kingdom of Sweden	Traffic	1922	1947
Radio Engineering Co. of N.Y. and John Hays Hammond	Cross-license	1923	——
Republic of China (through Federal Telegraph Co. of Delaware)	Traffic and construction	1923	——

* The termination dates given are the dates fixed at the time the agreements were made; in some cases, these dates were subsequently changed. Agreements with parties in enemy countries were terminated by the outbreak of World War II.

† F. T. Cunningham was a tube manufacturer on the Pacific Coast who had developed a substantial tube business. The 90-day license was to allow him to liquidate his stock, with the understanding that he cease manufacturing. He then became a sales agent for RCA tubes. In 1924, RCA purchased a controlling interest in the firm, paying $1,000,000 for "good-will."

Source: Federal Trade Commission, *The Radio Industry*, *op. cit.*, Exhibits.

others. In the years that followed, much of Mr. Young's energy as chairman of the board of RCA was absorbed in straightening out its international agreements and in negotiating with the Telephone company over the respective roles that AT&T and RCA were to perform in entertainment broadcasting.

The difficulty with any organization that is put together from the top is that it lacks a solid operational base. To David Sarnoff, who became general manager and then president of RCA, fell the task of converting the company into a soundly managed operating concern. As the subsequent chapters will reveal, this took twenty years to achieve.

Chapter VI: THE STRUGGLE OVER PATENTS: 1921–1928

I can state emphatically that it would be most unfortunate for the people of this country to whom broadcasting has become an important incident of life if its control should come into the hands of any single corporation, individual or combination.— HERBERT HOOVER.

1. The Contest over Patents in Radio Broadcasting

"THE study of the history of technology," writes J. D. Bernal, "shows that the application of a scientific idea has usually come in a field of immediate profitability, which may often not be the one in which it is ultimately most valuable." [1]

So it has been in the radio industry. Marconi focussed his attention on wireless communication with ships and foreign countries, failing entirely to envisage entertainment broadcasting. Lee de Forest, by contrast, made several attempts at public broadcasting before the war, but his equipment was not sufficiently perfected to give satisfactory results. In the period of postwar reconversion there were many radio engineers who speculated on the possibility of broadcasting for amusement purposes.[2] But when in 1920 the *Detroit Daily News* purchased a radio telephone transmitter from the De Forest company to send out

[1] J. D. Bernal, *The Social Function of Science* (London, Macmillan, 1939), p. 133.

[2] See memorandum of David Sarnoff to Mr. Nally, vice-president of American Marconi, in which he originally suggested in 1916 "a plan of development which would make radio a household utility in the same sense as a piano or phonograph. The idea is to bring music into the home by wireless." In March, 1920, Sarnoff wrote to Owen D. Young repeating his suggestion of 1916 and predicting that "it would seem reasonable to expect sales of 1,000,000 'Radio Music Boxes' at $75 each within a period of three years." Statement issued by Department of Information, RCA, April 1945. See also Lloyd Espenschied as quoted in William Peck Banning, *Commercial Broadcasting Pioneer, the WEAF Experiment, 1922–1926* (Cambridge, Harvard University Press, 1946).

regular news bulletins, and Frank Conrad of the Westinghouse company started nightly broadcasts of news and music for amateurs, the interest aroused exceeded the expectations of almost everybody in the industry.

By the 1920's wireless had become the hobby of thousands of young Americans. No other modern industry has been supported by so many ardent participants. It is hard today to recapture the spirit of this period: amateur clubs were started in every state, comprising all types and classes—schoolboys, professors, electricians and ex-servicemen who had operated radios during the war. Radio was a new toy, not only technically interesting, but the means by which people could reach out into unknown regions and communicate with new-found friends.

In Pittsburgh, H. P. Davis, the driving force in the Westinghouse management of the period, was one of the first to capitalize on the imaginative possibilities of radio broadcasting. At the conclusion of the war a Westinghouse engineer, Frank Conrad, reopened the amateur wireless telegraph station which he had built in 1916. He changed over to radio telephony and transmitted many programs which were picked up by widely scattered radio "hams." So much interest was aroused that Conrad announced a regular two-hour broadcast on Wednesday and Saturday nights. The response of the local amateurs in Pittsburgh was so enthusiastic that a department store, the Joseph Horne Company, bought a supply of crystal sets and advertised their sale to the "amateur" public at "$10.00 up." The sets were sold in a few weeks and more were ordered. Observing this response, Vice-President Davis became convinced that regular broadcasting would offer a new and extremely effective method of spreading information and entertainment, and that Conrad's station should be made a regular operating division of the company. Various members of the Westinghouse management set to work immediately to plan what should be done. It was decided to develop, make and sell radio transmitting and receiving equipment—the receivers to be so simple that they could be operated by any housewife.

Westinghouse Station KDKA was officially opened on November 2, 1920. Its initial broadcast of the Harding-Cox election created a sensation.

From then on, radio broadcasting showed a spectacular mushroom growth. Some of the new wireless manufacturing companies which had supplied military equipment started to produce "amateur" sets; and newspapers, department stores, educational institutions, churches and other groups opened their own broadcasting stations.[3] At the end of 1922 there were 30 licensed broadcasting stations in the United States; by 1924, over 500.[4]

Many rushed to establish broadcasting stations because of the widespread belief that the early comers would pre-empt the best positions in the wave spectrum. And when in 1924 Secretary Hoover decided to prevent further overcrowding by refusing to issue new licenses, the established stations did have a definite advantage. The only recourse for a group wishing to broadcast was to buy a station that already possessed a license. Many stations were sold in this way, in some cases at a substantial profit; but most of the early starters met with failure.

Broadcasting grew so rapidly and so unexpectedly that it created many unanticipated problems. The officers of the Telephone company decided that, since broadcasting for entertainment was closely related to radio telephony, they had an important stake in its development.[5] Under the GE cross-licensing agreements, AT&T contended that it had received the exclusive rights to manufacture radio-telephone transmitting equipment.[6] After some internal debating, the Telephone executives decided that this clause covered broadcasting equipment, and that all broadcasting stations should be required to take out licenses under the company's patents.

A royalty rate was fixed at $4.00 per watt of power, with a minimum fee of $500 and a maximum of $3,000.[7] And beginning in 1923 the Telephone company started a campaign to force all

[3] Archer, *History of Radio to 1926*, *op. cit.*, p. 241.

[4] *Broadcasting Yearbook*, 1946, p. 19.

[5] For an interesting account of the Telephone company's early part in broadcasting and the beginning of network broadcasting, see Banning, *op. cit.*

[6] License agreement, GE–AT&T, Art. V, par. 4, cl. 2, reads: "For the protection of the Telephone company under the licenses herein below granted to it, it is agreed that the General Company has no license to equip wireless telephone receiving apparatus sold under this paragraph with transmitting apparatus, or to sell, lease or otherwise dispose of transmitting apparatus for use in connection with receiving apparatus sold under this paragraph."

[7] F.C.C. *Proposed Report*, p. 459.

broadcasting stations to take out licenses. A test suit, brought in 1924 against an unlicensed station, WHN (Ridgewood, New York), was settled out of court by the signing of an agreement.

This drive for licensing caused great opposition. The strongest feeling was not against paying royalties, but against the license restriction which prohibited the sale of broadcasting time. The broadcasters feared that the Telephone company would attempt to obtain a monopoly of entertainment broadcasting, after an initial experimental period, as it had done in telephone communications.

Political agitation against the Telephone company became so intense that it led Secretary of Commerce Hoover to declare:

> I can state emphatically that it would be most unfortunate for the people of this country to whom broadcasting has become an important incident of life if its control should come into the hands of any single corporation, individual or combination.[8]

The aggressive attitude of the Telephone executives toward entertainment broadcasting was causing grave concern to the Radio Group. David Sarnoff, as commercial manager of RCA, saw clearly the potentialities of entertainment broadcasting, and was as eager to make his company a leader in this field as Young was to make RCA supreme in international communications.

No actual skirmish between the Radio and Telephone groups occurred until AT&T opened station WEAF in New York in 1922. The management of the Telephone company thereafter refused to permit wire connections to be made with a radio station competing directly with a Bell System installation.[9] This meant that other broadcasters could not cover special events through an on-the-spot telephone connection with their studios. The first broadcasting station affected was WJZ (Westinghouse). RCA, GE and Westinghouse turned, in consequence, to Western Union for assistance, and received permission to use its telegraph lines for special broadcasts.[10]

[8] *Radio Broadcast*, June, 1924, p. 128.

[9] Archer, *Big Business and Radio* (New York, American Historical Co., 1939), p. 58. The Telephone management disposed of all its RCA stock holdings in 1922–23. F.T.C., *The Radio Industry*, *op. cit.*, p. 21.

[10] These telegraph lines were not too satisfactory, since they were not designed to transmit the whole frequency range of speech and music. Occasionally, too,

From then on, keen rivalry developed. RCA stations circumvented the Telephone company's clause prohibiting the sale of broadcasting time by offering time free if advertisers furnished talent and material.[11] And the president of RCA charged the Telephone company with violating the 1920 cross-licensing agreement by engaging in wireless broadcasting on a commercial basis.[12]

An arbitrator had to be appointed, and after lengthy hearings he concluded that AT&T had rights only for radio telephone transmission and not for entertainment broadcasting.[13] The Telephone executives managed to checkmate this decision by getting an opinion from John W. Davis that such an iron-clad construction would violate the anti-trust laws. The negotiations dragged on and on. Finally, in 1926, the Telephone management agreed to sell Station WEAF to RCA for $1,000,000. The effect of the new cross-licensing agreement was to give AT&T exclusive patent rights in the field of public service telephony and to give GE, Westinghouse and RCA exclusive patent rights in the areas covered by wireless telegraphy, entertainment broadcasting and the manufacture of receiving tubes and sets for public sale.[14] AT&T was also given the exclusive rights to furnish wire telephone service for radio.[15]

When RCA actually took over the Telephone broadcasting stations, the rivalry had been so intense that many employees were reluctant at first to serve under their former competitor.

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programs would be interrupted by the dots and dashes of regular telegraph business.

[11] Archer, *Big Business and Radio*, *op. cit.*, p. 89.

[12] The principal disputed clauses in the agreement were as follows: Art. V, par. 4(d), "The Telephone Company grants to the General Company: . . . (3) Exclusive license to make, use, lease and sell all wireless telephone apparatus for amateur purposes." Art. V, par. 4(e), "The General Company grants to the Telephone Company . . . exclusive licenses in the field of wireless telephony to make use, lease and sell all wireless telephone apparatus connected to or operated as a part of public service telephone communication system whether wire or wireless."

[13] Archer, *Big Business and Radio*, *op. cit.*, pp. 171–172.

[14] The Telephone company was permitted to manufacture a limited quantity of tubes and sets for public sale, but it never exercised this privilege.

[15] This was to become an important source of revenue for the Telephone company since much of the distribution of radio programs occurs by wire connecting the broadcast stations.

Although there was some difference of opinion in the Telephone management as to the wisdom of this settlement, the majority held that the company would be subject to public censure if it tried any longer to exercise monopolistic power outside the telephone field.[16] This conclusion was undoubtedly based in part on the adverse political reactions to the company's licensing policy on broadcasting.

Following the 1926 agreements, RCA, GE, and Westinghouse joined forces to establish the National Broadcasting Company, a plan in which David Sarnoff again was the prime mover. Fifty per cent of the stock went to RCA, 30 per cent to GE and 20 per cent to Westinghouse. NBC was divided into three divisions —the Red, Blue and Pacific networks. In their first full year of operation—1927—the forty-eight stations in these networks did a gross business of nearly $4,000,000.[17] NBC's success stimulated the formation of other chains. Columbia Broadcasting had its origins in 1927,[18] and the Mutual Broadcasting System in 1934.

[16] This attitude was consistent with other actions that the company had taken and was to take. Western Electric's large electrical supply business had been sold to General Electric and Westinghouse in 1910, its wholesale supply business was turned over to the employees in that division as the Graybar Electric Company in 1928, and the company's export business was sold to the International Telephone and Telegraph Corporation in 1925. The Telephone company still retained Electrical Research Products Incorporated (ERPI), which had charge of the manufacture and sale of various products outside the telephone art that were developed in the company's laboratories. These were later to include patents on sound motion-picture equipment. But the activities of this division were also ultimately to be curtailed drastically.

[17] *Broadcasting Yearbook.* By 1928 gross time sales had reached nearly $10,000,000.

[18] This was sponsored by the Columbia Phonograph Corporation in a somewhat desperate gamble to regain the losses that it had been experiencing from competition with the radio. After a few months of substantial losses, the phonograph company withdrew its support. The broadcasting business was purchased in 1928 by William S. Paley and his family, and the title changed to the Columbia Broadcasting System. Ironically enough, CBS was later able to purchase the Columbia Phonograph Corporation after that company had gone bankrupt.

The other leading phonograph concern—the Victor Talking Machine Company—was purchased by RCA in 1929. Both Columbia and Victor had been long established companies which were profitable for many years. However, they did almost no research, and fell seriously behind on technical developments. The advent of the radio found them unprepared to meet the new rival. It was soon apparent that better tone quality could be obtained from a radio receiving set than from the conventional home mechanical phonograph. When the radio companies finally took over the phonograph companies, they introduced electric reproduction of records and made important engineering changes in the sound

TABLE V: RADIO NETWORKS
1926–1941

	NBC			CBS			MUTUAL		
Year	*Outlets*	*% of Total Outlets*	*Gross Time Sales (in thousands)*	*Outlets*	*% of Total Outlets*	*Gross Time Sales (in thousands)*	*Outlets*	*% of Total Outlets*	*Gross Time Sales (in thousands)*
1926	19	2.6	—	—	—	—	—	—	—
1927	48	6.9	3,760	15	2.2	73	—	—	—
1928	56	8.3	8,789	28	4.1	1,447	—	—	—
1929	69	11.2	14,310	47	7.6	4,786	—	—	—
1930	72	11.9	20,089	69	11.4	7,605	—	—	—
1931	83	13.8	25,607	82	13.6	11,895	—	—	—
1932	85	14.2	26,505	92	15.4	12,602	—	—	—
1933	85	14.6	21,453	92	15.8	10,064	—	—	—
1934	86	14.7	27,834	97	16.6	14,826	4	.7	—
1935	87	14.1	31,149	97	15.7	17,638	3	.5	529
1936	103	15.9	34,524	93	14.4	23,168	39	6.0	1,979
1937	138	20.0	38,651	110	16.0	28,722	80	11.6	1,455
1938	161	22.3	41,463	113	15.7	27,345	107	14.8	2,920
1939	178	23.3	45,245	117	15.3	34,540	116	15.2	3,330
1940	214	25.8	50,663	121	14.6	41,026	160	19.3	4,767
1941	220	24.9	—	—	—	44,584	—	—	7,301

Sources: for 1926–1940, T. P. Robinson, *Radio Networks and the Federal Government*, New York, Columbia University Press, 1943; for 1941, *Broadcasting Yearbook*, 1946, p. 20.

By the mid-1930's most of the commercial radio business in the country was conducted by chain networks. Broadcasting had become a large-scale industry with gross time sales of over $50,000,000.[19]

2. *The Contest over Patents in the Set-Manufacturing Industry*

The contest in the broadcasting industry was duplicated in set manufacturing from 1921 to 1928. Until America's entry into the first World War, radio manufacturing in the United States was concentrated in a few companies of which American Marconi was by far the most important. Young's original plan was to unite and develop the radio resources of the United States in order to challenge the dominant position of England in international com-

chamber of the phonograph greatly improving the quality. (See A. N. Goldsmith and A. C. Lescarboura, *This Thing Called Broadcasting* (New York, Holt, 1930), pp. 323–324.

[19] In the year 1936. In 1945 gross time sales were over $300,000,000.

munications. Entertainment broadcasting was not then envisaged as an important business. After the war, GE and Westinghouse began to make receiving sets for sale to the general public, but they were not prepared for the tremendous interest aroused and were therefore not able to keep up with the demand for sets. By 1924, there were 300 companies manufacturing radio sets. Many of these were fly-by-night concerns having no patent rights; others were reputable companies which believed they had certain rights. Although the RCA partners controlled the major patents on vacuum-tube sets, it would obviously not have been possible, had they wished to do so, to force all competitive companies out of business. GE, Westinghouse and RCA did succeed, after a lengthy struggle in the 1920's, in substantially reducing the number of manufacturers during these years and requiring those remaining in business to take a license from them. How this was accomplished is an interesting story of the use of patents to dominate an industry.[20]

The majority of the new radio companies started with the production of crystal sets. Such sets were simple to produce and could be manufactured with a small capital investment. Moreover, patents did not represent any serious obstacle.

The first crystal detector had been designed in 1906 by H. H. Dunwoody of the De Forest Wireless Company.[21] It consisted of a crystal of carborundum clamped between two electrodes. About this same time another American inventor, G. W. Pickard, patented a detector of silicon in which a wire was suspended above the crystal and kept in light contact with it. To tune in on different stations the wire could be moved by turning a knob to which it was attached. The patents on the particular crystal combinations of Dunwoody and Pickard found their way into the RCA patent group; but because of the variety of other substances that could be used, the crystal-set manufacturers were not afraid of infringing RCA's patent position.

The Garod Company, one of the first to manufacture these

20 The relaxation of license control will be described in the next chapter.

21 Dunwoody had been formerly with the United States Signal Corps and at the time was a vice-president of the De Forest company. His invention was stimulated by the injunction obtained by NESCO against the de Forest electrolytic detector.

crystal sets, may be cited as an illustration. It was started in 1922 by two partners, Gardiner and Rodman. Gardiner had been in the jewelry business; and Rodman was an electrical engineer who had worked with Edison. Under the name "Heliphone" they marketed a small crystal set which was cleverly designed. The set contained two small, compact coils; the tuning was accomplished by sliding one coil over the other. The "cabinet" was a flat wooden box which could be slipped into a coat pocket; it retailed as a novelty for $5.00 and sold very well.[22]

Radio manufacturers soon realized, however, that the future lay in vacuum-tube sets.[23] And here, patent rights proved exceedingly important. The RCA group succeeded in obtaining a key position on all major aspects of the vacuum-tube set—the circuit design, the tube itself, loud speakers and other parts.

The concerns which were later to become household names in radio—Philco, Zenith, Emerson, etc.—did not manufacture the principal parts of the radio sets bearing their brand name. They bought these from outside suppliers and assembled them into a finished product. The only significant patentable item in this process was the design of the circuit connecting the vacuum tubes to the other parts of the set.

In the early stages of vacuum-tube reception, radio engineers had to solve two major circuit problems. The first was to increase the sensitivity of reception through the circuit itself; the second was to prevent continuous oscillation in the circuit, which produced loud squealing noises. A considerable number of inventors worked on these two problems; and the patents on the solutions they offered became the subject of bitter and extensive litigation.

The most important of these circuit designs were the feedback circuit, the neutrodyne circuit and the superheterodyne circuit.

(a) THE FEEDBACK CIRCUIT

There were four inventors—Armstrong, de Forest, and Langmuir in the United States, and Meissner in Germany[24]—who inde-

[22] *The Radio Industry* (New York, Cornell, Linder and Co., mimeographed, 1928), p. 72.

[23] One of the major weaknesses of crystal detectors was that they had no power of amplification.

[24] This resulted in a four-party interference proceeding in the United States. Round and Franklin in England were also working on this type of circuit.

pendently discovered how to increase the sensitivity of reception of a vacuum-tube set through a new type of circuit. Perhaps the reader can visualize this best in terms of an analogy.

> If a pendulum is set swinging with a push of the hand, its oscillations will gradually cease; but the motion may be sustained or augmented with the right amount of push at the right time. To keep the same amplitude and the same frequency—that is, the same number of swings per second and the same arc—the force applied by the hand must equal the frictional force, and the timing of the push must be perfect.
>
> A radio circuit made up of an inductance and a condenser oscillates like a pendulum with a definite frequency of its own. If an arrangement is made to have some small voltage from the oscillating circuit reach the grid of the triode and to have the amplified voltage in the anode or output circuit applied to the electrical pendulum in the direction to encourage the electrical movements, the triode may be employed for *generating oscillations*. . . .[25]
>
> The method of regeneration "lies in arranging the coils so that the alternating current in the anode coil shall act inductively on the grid coil and generate an alternating voltage in it. Now this new voltage may assist or may oppose the voltage induced in the grid coil by the input circuit. . . . If then the anode coil is so turned as to assist the input coil, the amplification is obviously increased. And by pushing the anode coil gradually closer to the grid coil, the amplification can be increased enormously.[26]

At the time of the first exploratory work on the vacuum-tube feedback circuit, the radio stations on this continent which were capable of receiving transoceanic messages from Europe[27] had found it necessary to erect bulky and costly apparatus for reception. And even with this equipment the reception was far from

[25] Adapted from Eccles, *Wireless*, *op. cit.*, pp. 164–165.

[26] *Ibid.*, p. 156.

[27] These were the Marconi company station in Newfoundland, the Telefunken station at Sayville, Long Island, and the Goldschmidt station at Tuckerton, New Jersey.

satisfactory. Typical antennas were 1,000 to 6,000 feet long and 400 to 850 feet high. They were placed on the seashore away from the cities to avoid interference. The feedback circuit made it possible to design small sets with comparatively low antennas which could receive transatlantic signals in the heart of a city—an unheard-of feat hitherto.

Radio experts quickly recognized that the feedback circuit was to be of great commercial importance. The four rival claimants came into interference in the Patent Office, and litigation costs began to mount.

The Meissner patent belonged to the Telefunken company,[28] Langmuir's to General Electric and the American Telephone company had purchased the de Forest patent in 1917. These concerns could all afford expensive patent proceedings. The fourth patent belonged to Edwin Armstrong, who was an almost penniless graduate student at Columbia when he made his invention, and was not able to afford the costs of litigation. He had previously offered to sell the patent to American Marconi; its chief engineer urged the company to acquire it, but the British management turned it down.[29] However, the Telefunken station, the Goldschmidt station and, later, the American Marconi company all took out licenses from Armstrong. Then the heavy litigation began. The case was to drag on for twenty years; and when it was finally settled in de Forest's favor by the Supreme Court in 1934, legal expenses had reached huge totals.[30] An editorial in *Electronics* following the ultimate decision reflected the widespread attitude of the radio engineering profession.

> The amount of money that has gone into this fight must run to several millions of dollars; so far as the art was concerned, wasted, gone to attorneys and patent lawyers instead of being reinvested in further research to the benefit of the art. . . . So far as recognition goes, both de Forest and Armstrong are appreciated as inventors of the first rank—the only regret is that their energies could not have

[28] On the outbreak of the war this patent was seized by the Alien Property Custodian and carried by the government in the suit.

[29] See testimony of Roy Weagant, chief engineer of American Marconi, F.T.C. *Hearings*, *op. cit.*, p. 2989.

[30] This legal battle also represented a bitter personal quarrel between Armstrong and de Forest.

been spent exclusively in invention and not futilely dissipated in litigation.[31]

Armstrong had asked a prominent firm of patent attorneys—Pennie, Davis, Marvin and Edmonds[32]—to handle his case. Litigation costs were heavy, but the firm did not press Armstrong for immediate payment. However, it was decided to put the feedback circuit patents on a paying basis by licensing a number of companies to manufacture radio sets for "amateurs only."

By November, 1920, seventeen companies had agreed to take an Armstrong license and pay royalties of 5 per cent of net sales. These concerns, all of them small, operated by purchasing the principal parts and assembling them into a set. The A. H. Grebe Company, for example, reported that it purchased "batteries, outside moulded bakelite parts, transformer coils, wood cabinets, wire, sheet bakelite and, of course, all the semi-finished material which is required to make up a complete apparatus." [33]

The patent attorneys believed that Armstrong should eventually sell his patents to some large and substantial industrial enterprise; and the patent rights were granted with this in mind. The license gave a "non-exclusive" and "non-transferrable" right to manufacture and sell to "radio amateurs" and to "radio experimenters" only.[34] Licenses were also confined, except in two cases, to the feedback circuit patents which arose from work done by

[31] *Electronics*, June 1934, p. 192. I have received an interesting letter from Professor Armstrong about this editorial: "There is one comment that might be made with respect to the editorial in *Electronics* and that is in respect to the words 'not futilely dissipated in litigation.' The whole proceeding may appear on the surface to have been a futile one but a man's destiny sometimes moves in a very strange way. Because of the circumstance that a patent attorney on the other side made a statement in the regenerative circuit case that wasn't true, and because I had the burden of setting up apparatus to prove what the truth was, I accidentally ran into the phenomenon of super-regeneration. The sale of that invention a year later was to net me more of a return than the sale of the regenerative circuit and the superheterodyne combined. It was that invention (super-regeneration) which furnished, in fact, the resources by which I was able to continue my investigation of the problem of static that was to lead to the development of frequency modulation. I would never have made the super-regenerative invention had I not been engaged in the regenerative circuit litigation." Letter to the author, October 12, 1947.

[32] Now Pennie, Edmonds, Morton and Barrows.

[33] Testimony of A. H. Grebe, U.S. Circuit Court, *op. cit.*, p. 235; see also testimony of Adams-Morgan Co., *ibid.*, p. 249.

[34] *Ibid.*, p. 9.

Armstrong in 1912 and 1913. Subsequently, the inventor had conceived of a much more effective circuit design not yet fully worked out in practice—the superheterodyne circuit.

(b) THE SUPERHETERODYNE CIRCUIT

Armstrong's work on the superheterodyne was done in France during World War I.

> I happened [he writes] to be watching a night bombing raid and wondering at the ineffectiveness of the anti-aircraft fire. I may say that night bombing was not very dangerous in those days, either for the man on the ground or the man in the airplane. Thinking of some way of improving the methods of locating the position of the airplanes, I conceived the idea that perhaps the very short waves sent out from them by the motor ignition system might be used. The unique nature of the problem, involving the amplification of waves shorter than any ever even contemplated and quite insoluble by any conventional means of reception, demanded a radical solution.[35]

Working on this problem Armstrong succeeded in designing a receiver which was more sensitive than any wireless apparatus that had been previously invented.[36] It was never used for anti-aircraft detection, but became important for radio reception.

The vacuum tubes of this period were not effective for receiving weak signals. In the superheterodyne or *double detection* circuit, the heterodyne principle (developed by Fessenden) was used to change the frequency of the incoming signal to a lower but super-audible frequency which could be readily amplified. The amplified signal was then transformed again to an audible signal.

In this type of receiver as originally designed, tuning adjustments were required by a number of different circuits. To get a particular transmitting station, four or five tuning knobs had to

[35] Armstrong, "Vagaries and Elusiveness of Invention," *Electrical Engineering*, April, 1943, p. 150.

[36] Armstrong patent No. 1,342,885 issued June 1920. The original claims of this patent were subsequently greatly reduced through interference proceedings. Despite this, the Franklin Institute stated: "The evidence clearly indicates that Armstrong understood the difficult problem and its pitfalls. His solution resulted in the invention of a most valuable contribution to the art of communication—the superheterodyne circuit, which is found in about 98 per cent of the millions of broadcast receivers in use today." *Report, op. cit.*, pp. 7–8.

be manipulated; and one of these—that controlling the local oscillator—had to be moved at a *constant difference* from the others, or the signals would not be heard.[37] Such complicated tuning was far too much to expect of the general public. Considerable further development work was necessary before superheterodyne sets could be commercially practical; but the circuit was immediately recognized as having great potentialities.

Armstrong was a commissioned officer in the Signal Corps when he made his invention; and it was the practice at that time for anyone in the service to retain rights in any invention he might make while there. His attorneys advised that the superheterodyne and feedback circuit patents be sold together, and these were the patents that Westinghouse purchased when building up its competitive position in relation to General Electric. When Westinghouse joined the Radio Group, the inventions became part of the cross-licensing agreements of the Big Four.

The problem then became one of handling the seventeen original "amateur set" licensees of Armstrong. When these licenses had been granted, the ultimate importance of entertainment broadcasting was not generally foreseen, and the amateur market was regarded as unimportant. But with the rapid growth of broadcasting in 1922 and 1923, a number of these companies began to manufacture sets on a substantial scale, and to undercut the RCA price structure. More embarrassing still, some of these concerns were bringing out up-to-the-minute improvements ahead of RCA. The process of getting agreement on specifications between the RCA sales department and the autonomous manufacturing divisions of GE and Westinghouse was sufficiently slow so that orders had to be placed months in advance. As set design was evolving rapidly RCA often found itself saddled with outmoded sets which were difficult to dispose of in competition with the newer models of the small companies.

The policy that the RCA partners adopted toward the Armstrong licensees was formulated in a patent policy committee meeting held August 3, 1922:

Mr. Sarnoff reported to the committee that he had been in negotiation with Mr. Watrous, who represented all of the present Arm-

[37] Eccles, *op. cit.*, pp. 211–212.

strong licensees, and Mr. W. H. Davis, who is counsel for the Armstrong licensees. . . .

During the course of the patent committee meeting, Mr. Watrous informed Mr. Sarnoff that the Armstrong licensees . . . *will not agree to the principle of a limitation of business. If they are not limited as to the volume of business, the licensees agree to pay a royalty of 15 per cent.* Mr. Sarnoff stated that as to the remaining questions involved in the trade, he felt that they could be satisfactorily disposed of with the single exception of the principle of limitation on the volume of business. . . .

The patent committee recommends to the board that negotiation with the Armstrong licensees be terminated. . . .

The committee recommends to the board the following policy: that suits be brought, as the counsel may think best, on any of the patents of the Radio Corporation which are believed to be good and valid patents and which are infringed, but that great pains be taken not to have a multiplicity of suits. Pains should, however, be taken to bring enough suits so that if one defendant goes out of business, time will not be lost. The choice of the defendants should be left to the counsel and the general manager. It is felt that these suits should be instituted at the earliest possible moment.[38]

An early test case was against the Tri-City Electric Company of Davenport, Iowa.[39] The suit was for the cancellation of the license and an injunction against further manufacture of radio sets. Tri-City—originally a partnership—had begun by assembling a small number of amateur radio sets in the cellar of the home of one of the partners. The partners later invested $3,000 in a "manufacturing building in the back yard."[40] They started selling radios to Montgomery Ward, and soon their expanded facilities were not large enough to meet the demand. Arrangements were made with the Briggs and Stratton Manufacturing Company in Chicago to manufacture sets for Tri-City and to ship them directly to Montgomery Ward and other customers. The type of enterprise that developed is suggested by the testimony of one of the partners:

38 F.T.C., *The Radio Industry*, *op. cit.*, p. 90. (Italics added.)

39 See also Westinghouse *vs.* Cutting and Washington Corporation, 294 F 671 at 673 (1923) and Radio Craft Company *et al. vs.* Westinghouse, 7 F. (2d) 432 (1925).

40 Westinghouse *vs.* A. H. Grebe Co., U.S. Circuit Court, Testimony, p. 183.

In the beginning, Montgomery Ward paid this (Davenport, Iowa) office direct for sets manufactured by Briggs and Stratton. They sent down thousands of dollars for sets that had been shipped. They followed that up with hundreds of dollars of credit, red slips for sets that had been refused and sent back, and in about three weeks I was in a maze that no one in the world could ever have crawled out of. I went to Chicago and saw the vice-president and told him it was absolutely imperative to make some other arrangements for payment as I was lost entirely, and we did make arrangements for Montgomery Ward to relieve me of the bookkeeping and send such payments as were due the factory on our order direct to them with the statement and such payments as were due me direct. . . .

I didn't know how to keep a book. I never was a bookkeeper.[41]

In the suit, Westinghouse contended that selling to distributors and jobbers could not be construed as selling to "amateurs," and that a sub-contracting arrangement such as that with Briggs and Stratton was illegal, even though, as was the case, royalties were paid to Westinghouse *on all sets sold*. Tri-City replied that it had been customary to sell to distributors and jobbers since the licenses were first taken out, that Major Armstrong had encouraged this in order to increase the royalty receipts,[42] and that sub-contracting of manufacturing was a general practice in the industry. Both the District Court and the Circuit Court of Appeals upheld Tri-City's rights to sell to distributors and jobbers on the grounds that the original licensor, Armstrong, had in fact encouraged the licensees to sell sets widely to the public and that the Westinghouse company had not even admonished the licensees for their practices from the time the patents were purchased in 1920 until suit was brought in 1923.[43] On the other hand, the court held that the sub-contracting arrangements were beyond the scope of the license agreement.

[41] *Ibid.*, p. 125.

[42] See testimony of Alfred P. Morgan of Adams-Morgan Co., U.S. Circuit Court, *op. cit.*, p. 255. According to Morgan's testimony, his company's arrangements were as follows: "When we sold a set at retail, we were to receive 5 per cent of the retail price and when we sold a set at wholesale, it was to be 5 per cent of the wholesale price." Apparently, at least in the case of this contract, it was clear to both parties from the beginning that as long as the sets were to be sold ultimately to the general public, sales to wholesalers were considered sales to amateurs. *Ibid.*, p. 256.

[43] See oral opinion of the Court. *Ibid.*, pp. 450–451.

When the District Court decision was rendered, however, RCA was ready to release the superheterodyne receiver which eliminated one of the most unsatisfactory features of the feedback circuit—the occasional loud squeals caused by interference from other sets in the neighborhood. It was expected, therefore, that the competition from the Armstrong licensees would be much less significant in the future. In the meantime, a new threat to RCA had developed from a group of radio set manufacturers who believed that they had found a way to circumvent RCA's patent position through the use of the Hazeltine neutrodyne circuit.

(c) THE NEUTRODYNE CIRCUIT

The neutrodyne was the invention of Professor L. A. Hazeltine of Stevens Institute of Technology. A professor of electrical engineering who had become interested in radio problems, he was retained by the Navy as a consultant to develop wireless equipment during the war. He designed for the Navy a new type of vacuum-tube receiver (SE 1420) which was an advance over existing circuit designs.

This receiver was so successful that it appeared to have significant peacetime applications. Hazeltine's patent attorneys were Pennie, Davis, Marvin and Edmonds, who also represented Edwin Armstrong. In addition, this important patent firm was counsel for a group of small radio concerns making crystal sets. Recognizing that the vacuum tube was going to displace the crystal set very shortly, these companies had formed the "Independent Radio Manufacturers, Inc.," to consider ways in which they might get around the apparently iron-clad patent position of the RCA group. They were primarily interested in circuit patents for *tube sets*, since the advent of the feedback receiver had by 1922 brought the business of the crystal manufacturers practically to a standstill.[44]

Willis H. Taylor, Jr., of Pennie, Davis suggested that the Independents might find a solution of their problem through Hazeltine's work. Following this lead, three of the Independents—F. A. D. Andrea (Fada), Freed-Eisemann, and Garod—asked

[44] See testimony of Walter Russ, Independent Radio Manufacturers, Inc. *vs.* Freed-Eisemann, U.S.D.C., E.D.N.Y., Equity 1485.

Professor Hazeltine to design a model radio receiver for commercial use. Later they called at Hazeltine's laboratory to see a demonstration of his new circuit. They were "very favorably impressed and decided to make a deal with the professor." [45]

When, in the spring of 1923, Fada brought out the first commercial "neutrodyne," [46] it proved an immediate success. Many other companies wanted to join the Independents, and the group decided to charge an admission fee of $6,000. The association soon had fourteen members. No more were admitted. For about two years any set carrying the name "neutrodyne" would sell, and any firm having "neutrodyne" printed on its letterhead was sure of orders. The name was registered as a trademark by Hazeltine and made the subject of skillful publicity in the technical press.[47] The set was so popular that the fourteen members of the association were not able to keep up with orders.

A serious defect of the standard "regenerative" sets, which GE and Westinghouse were manufacturing in competition, was that they could be unwittingly manipulated so as to cause the tubes to oscillate. This made the receiver into a transmitter, and the generated oscillations caused squeals and howls on other sets in the neighborhood. The early regenerative sets were also hard to keep in adjustment. It took an expert to obtain satisfactory results, because there was no way of getting the same station regularly by setting the dials to a predetermined position. In contrast, the neutrodyne would always receive the same station at a particular dial position.

The Independents therefore were becoming a serious threat to RCA. The superheterodyne was not developed commercially until 1924, and by that time a great many people had come to accept the neutrodyne as the last word in radio. The Radio Corporation decided to challenge Hazeltine's patent position.[48] Prior to Hazeltine's work, Chester Rice of the General Electric Company and Ralph Hartley of the Telephone company had worked on methods of controlling oscillation and had taken out patents

[45] Interview with Frank Andrea, Sept. 1943.

[46] The term "neutrodyne" was coined by Willis H. Taylor, Jr.

[47] *The Radio Industry* (Cornell, Linder), *op. cit.*, pp. 81–82.

[48] By the time of the trial it was estimated that $50 million worth of neutrodyne sets had been sold. RCA, GE, Westinghouse, and AT&T *vs.* Twentieth Century Radio Corp., U.S.D.C., E.D.N.Y., Equity 1610, March 1924, pp. 310–311.

on their developments. According to Hartley's testimony, his work on the "electrical circuits patent No. 1,183,875 described in notebooks between September, 1913, and June, 1914," was concerned with the use of vacuum tubes in apparatus for submarine cable telegraph reception. "Shortly after the date of June 26 [1914], I became actively engaged on the problem of developing circuits for radio telephony." [49]

RCA contended that this work was basic to the later Hazeltine developments. The validity of the Hazeltine patents was not questioned—only the breadth of their coverage. RCA won in the Court of Appeals in 1927, after losing the district court case. The final court decision meant that in future any manufacturer of neutrodyne sets must, in addition to a Hazeltine license, also obtain a license under the Rice and Hartley patents, which RCA controlled. The activity of the Independent Radio Manufacturers association, therefore, declined and its members took out licenses from RCA.

3. *The Contest over Patents in the Tube and Loud-Speaker Industries*

With the favorable decision on the neutrodyne, RCA's patent position in the set-manufacturing industry had been convincingly established. There remained the problem of gaining a key patent position on the principal patent components, vacuum tubes and loud speakers. RCA had acquired the rights to the Fleming two-element tube through the purchase of the American Marconi company. It also obtained rights to the de Forest three-element tube for "commercial" radio communication through its cross-licensing agreements with the Telephone company.

On the other hand, de Forest's reservation for himself of rights to manufacture tubes for sale to amateurs[50] precipitated a major battle. The De Forest Company was not able to sell receiving tubes until the Fleming patent expired in 1922, but thereafter the company began to manufacture them in substantial quantities.

[49] *Ibid.*

[50] It was characteristic of de Forest that he was continually selling rights under his inventions, reserving other rights for himself, and then getting into legal battles over the status of his activities.

RCA believed that the De Forest Company was selling these tubes to others beside amateurs, and asked the company to obtain from purchasers an agreement that the apparatus would not be used for commercial radio communication. When the De Forest management refused, RCA brought suit.

In awarding the decision to the De Forest Company, Vice-Chancellor Lewis stated:

> The clear purpose of the provision and the agreement of March 16, 1917, requiring the De Forest Company to obtain from purchasers of this apparatus an agreement that the apparatus should not be used in the transmission or reception of messages for pay, or by others than the original purchasers or for purposes other than radio communication, was to protect the exclusive right of the American Telephone and Telegraph Company in the field of transmission and reception of messages either by wire or radio for pay. The complainant, the Radio Corporation, is not entitled to enforce the covenant for the purpose of protecting the "pay" field. . . .
>
> To compel the De Forest Company to obey the strict letter of the covenant would, in effect, prevent it from doing business at a profit. It would make the investment of the De Forest Company worthless.
>
> And to go back to the first proposition, the covenant will have to be used for a purpose not contemplated by it. It will have to be used to reduce competition in the "amateur" field, whereas the purpose was to prevent competition in the "pay" field.[51]

This decision, however, did not save the De Forest company, which went into bankruptcy in 1926.[52] The receiver in bankruptcy then sued RCA for violating the Clayton Act through a clause in its license contract requiring all set licensees to buy tubes for initial installation from the Radio Corporation. He claimed, further, that the apparatus covered by RCA patents was so extensive that the license agreements prevented the sale of tubes for many other purposes besides radio. Both the district and the circuit courts sustained the claim.[53] As a result of the loss of

[51] Quoted from the testimony of William Priess, F.T.C. *Hearings*, p. 3008 *et seq.*

[52] The receivership was ended shortly, when other interests acquired the company. Later in 1933 RCA purchased its assets for $400,000.

[53] Arthur D. Lord *et al. vs.* Radio Corporation of America *et al.*, 24 F. (2d) 565.

this case, damage suits totalling $47,000,000[54] were filed against GE, Westinghouse and RCA. In settlement, $1,000,000 was paid to the De Forest company in 1931, and smaller amounts to other companies.

After this adverse decision, RCA started to offer licenses for the manufacture of tubes. A considerable number of tube companies besides De Forest had entered the industry after the Fleming patent expired. By 1928 the original patents on the de Forest triode had also expired, and the General Electric and Telephone company patents on high-vacuum had been declared invalid by the district court (1928).[55] But the Telephone company, GE and Westinghouse were the leading centers of research on the vacuum tube, and new types were being developed steadily. The tube companies, of which there were fourteen at this time, therefore decided to take out licenses from RCA. They were primarily small concerns, and only Raytheon had any patent position of its own.

The story of loud speakers was similar. A number of small manufacturers entered the industry in the early 1920's. None of these companies conducted research, and the speakers which they produced were based on a prior art on which the patents had expired. In 1925, however, the General Electric Company brought out a new type of cone loud speaker based on research done by Rice and Kellogg of the Schenectady Laboratories. This represented a very substantial improvement. The seven principal loudspeaker companies therefore applied for licenses from RCA, and these were granted.

By 1928, the RCA group had thus established a strong patent position in all the major branches of the radio industry, and an RCA license was considered essential for the manufacture of any up-to-date set or modern vacuum tube. No one was to challenge this for many years to come.

[54] An amount of $30,000,000 of this was asked in a triple damages suit under the Clayton Act, filed by Grigsby-Grunow in 1930. *Electronics*, July, 1930, p. 163.

[55] This decision was subsequently affirmed by the Supreme Court (1931).

Chapter VII: THE PERENNIAL GALE OF COMPETITION: 1928–1941[1]

The engineer was too often at the mercy of the whims and profit considerations of the management and the opinionated instructions of the sales department. . . . There was no great urgency and little encouragement for radical technical innovations.

—BENJAMIN ABRAMS of Emerson Radio.

WE ARE all painfully aware of the waves of business optimism and pessimism that sweep across the country in periods of prosperity and depression. The ebullient optimism of the 1920's in this country was nowhere more noticeable than in the burst of activity in the radio industry. In seeking a basic explanation for such wavelike movements in business, one of our most distinguished modern economists, Professor Schumpeter, has suggested that the clustering of strategic innovations is a major causal factor. Why, he then asks, do innovators appear in clusters?

> If one or a few have advanced with success, many of the difficulties disappear. Others can then follow these pioneers, as they will clearly do under the stimulus of the success now attainable. . . . The pioneers remove the obstacles for the others, not only in the branch in which they first appear but, owing to the nature of these obstacles, *ipso facto* in other branches too.[2]

In the 1920's the organizational innovation of the Radio Corporation of America and the later development of the National Broadcasting Company was followed by a host of imitative

[1] This monograph discusses the process of invention and innovation up to our entry into World War II. I have made occasional references to subsequent developments but have not attempted to analyze the war and postwar periods, as I regard them as a separate story in themselves.

[2] Joseph A. Schumpeter, *Theory of Economic Development* (Cambridge, Harvard University Press, 1934), pp. 228–229.

developments by other concerns. This movement was so overwhelmingly strong that the original conception of GE and Westinghouse of supplying almost all the radio-set demand was impossible of execution. And although in this period RCA succeeded in obtaining an almost complete patent monopoly on all phases of radio broadcast receivers, it was ultimately forced to offer licenses to a large number of applicants. In the 1930's the strenuous competition of these licensees, together with the onset of the depression, forced RCA's profits nearly to the vanishing point.

1. RCA's Licensing Policies

The managements of RCA, General Electric and Westinghouse must have been aware that *unrestricted* licensing would lead to "excessive" competition.[3] The assembling of radio sets involved a relatively small capital investment, and the technological "know-how" of manufacture was not difficult to acquire. Except for patents, the industry was easy to enter and the profit margins of 1924, 1925 and 1926 were sufficiently high to be tempting to new firms. Nevertheless, the officers of RCA were in a difficult dilemma in 1927, when they succeeded through court action in obtaining a dominant patent position in the industry. The radio companies that had become established since the war were clamoring for licenses.

The question of a suitable licensing policy had been under discussion almost from the inception of RCA.[4] One alternative was to offer licenses with restrictions on output and price. The GE-Westinghouse cross-licensing agreements on lamps offered a precedent: General Electric, controlling the principal lamp patents, offered licenses only for certain types of lamps and limited the licensee to a fixed percentage of General Electric sales. Al-

[3] It was, I assume, to avoid such competition that Westinghouse had brought court action to curb the sales activities of the original Armstrong licensees (since the royalties that Westinghouse was receiving from these licensees were substantial).

[4] See letter of Dec. 7, 1921, from David Sarnoff to President Nally, stating that he regarded the formulation of an industry-licensing policy as one of the most important subjects with which RCA had to deal. From then on various committees of the board of directors studied the problem.

TABLE VI: TURNOVER OF RADIO MANUFACTURING ESTABLISHMENTS 1923–1934

	Existing Firms			New Firms		
		Mortality				
Year	*No.*	*No.*	*Per Cent*	*Established*	*Surviving in 1934*	*Per Cent Surviving*
1923	129	56	43.4	185	11	5.950
1924	172	101	58.6	144	1	0.007
1925	215	215	100.0	258	5	0.019
1926	115	261	227.0	161	1	0.006
1927	72	69	96.0	26	0	0.000
1928	70	18	25.7	16	6	37.500
1929	65	31	47.7	26	5	19.200
1930	83	21	25.3	39	5	12.800
1931	82	87	106.0	86	14	16.300
1932	90	45	50.0	53	8	15.100
1933	75	56	74.8	41	19	46.400
1934	110	0	0.0	35	35	100.000
		960		1,070		

Source: Ralph H. Langley, consulting engineer, New York.

though this practice had been challenged by the Department of Justice, it was upheld by the Supreme Court in 1926.[5]

But there were difficulties in adopting a similar licensing policy on radios. Radio sets were not a homogeneous product on which quotas and prices could be established with the same ease as on lamps. Moreover, the RCA management was perhaps afraid that any such plan would not receive as favorable treatment from the courts as the lamp decision. Quota and price control of lamps had been established since 1912; and General Electric owned outright the major patents. RCA's patent position, by contrast, resulted from cross-licensing agreements among General Electric, Westinghouse, the Telephone company and other groups. The important patents were thus contributed by several companies. In addition, the agreements covered future inventions as well as contemporary patents. These arrangements were currently under

[5] "A patentee in granting a license to another to make and sell the patented article may limit the method of sale and the price, provided the conditions of sale are normally and reasonably adapted to secure pecuniary reward for the patentee's monopoly." U. S. *vs.* General Electric Co., 272 U.S. 476.

attack by the Federal Trade Commission, and RCA was threatened with an anti-trust suit as a result of the practices disclosed.[6] In 1926 also, the RCA group had been sued by Fessenden for alleged violation of the Clayton Act in its use of patents originally issued to him, and the companies had deemed it expedient to settle the case out of court through the payment of $500,000 damages.

The policy that the RCA group adopted in 1927 was to offer licenses to "$100,000 customers," but without quota or price agreements. The royalty rate was fixed at 7½ per cent of the net selling price. The first licenses were for tuned radio frequency receivers only, excluding the much more efficient superheterodyne set which RCA had recently developed and which it reserved to itself. However, RCA was selling less than half of the total sets in the country in 1927, and since its relations with its dealers were not very satisfactory, the licensees were able to persuade the majority of the dealers to push tuned radio frequency and not superheterodyne receivers. By 1928, therefore, RCA was forced to change this particular policy; and in a very short time tuned radio frequency sets disappeared from the market.

Nor did the policy of attempting to restrict licenses to "$100,000 customers" last for long. This minimum royalty rate was never actually assessed, but it had the effect of restricting licenses to the larger companies. Almost immediately the smaller concerns responded by political action. A story is told that Senator Jim Reed of Missouri called one day at the office of Mr. Sarnoff, who was then general manager of RCA, and brought with him the president of a Missouri radio company who had been denied a license.

> "I am going to sit in this office until my friend here is given a license," Mr. Reed is reported to have said.

Sarnoff arranged an appointment with General Harboard, president of RCA, and a license was granted.

RCA in fact was faced with a number of difficult problems. The desire to maintain a "healthy industry" free from "cutthroat competition" was not confined to RCA; new licensees,

[6] The Federal Trade Commission dismissed the complaint but the anti-trust suit materialized in 1930 and resulted in a consent decree in 1932.

once having obtained a license, wanted other companies kept out. And RCA itself was suffering from internal growing pains. The idea of forming a company which would concentrate entirely on selling, while its two large and somewhat cumbersome partners, GE and Westinghouse, did all the manufacturing, was not working well. The smaller integrated licensees were much more flexible and able to outmaneuver their big rival in bringing out new models and in salesmanship.

The management of RCA finally decided in 1929 to grant licenses freely to all reputable companies. RCA, according to a *Fortune* "guesstimate," had collected nearly $3,000,000 in royalties in 1927 and over $6,000,000 in 1928.[7] Whatever the exact figures, it soon became clear that, through licensing, the company could obtain very substantial revenues from its investment in patents. The royalty rate, however, was regarded by many companies in the industry as too high, and created considerable antagonism. The rate was reduced in 1932 from 7½ per cent to 5 per cent and a license bureau was established to assist the licensees in their technical performance. The minimum royalty was also reduced to $10,000. The number of licensees rose steadily from 25 in 1928 to 55 in 1941.[8]

Even with the liberalization of its policy, RCA's license control of the industry continued to meet opposition. Manufacturers resented paying a substantial fee to a competitor. They claimed, moreover, that RCA was a "patent octopus" and that the license bureau did not provide adequate service in return.

There was, consequently, a constant struggle between RCA and some of its principal licensees over the question of fees. The most drawn-out and bitter of these took place between RCA and Philco and resulted in a lengthy court suit over the method of calculating royalty rates. Philco finally won in 1939.

This case illustrates the difficulties of RCA's licensing policy.

[7] "Blue Chip," *Fortune*, Sept., 1932, pp. 142–146. According to the government brief in the anti-trust suit of 1930, RCA's royalty receipts were $7,000,000 in 1929. U. S. *vs.* Radio Corp. of America *et al.*, U.S.D.C., Dist. Del., Equity 793, *Petition*, p. 11.

[8] In 1947 the number of set licenses had risen to 186. The royalty rate for domestic receivers was reduced to 2¼ per cent in 1939. And in 1946 the minimum royalty provision was removed.

The Philadelphia Storage Battery Company, founded in 1892,[9] began making battery eliminators for the radio industry in 1924. When the a-c tube made it possible to operate a radio directly from an electric light socket, there was no further demand for battery eliminators. Since RCA was restricting the total number of licenses granted in 1927, the only way to enter the industry was to purchase an existing concern that already had a license. This was done in February, 1928, through the acquisition for $100,000 of the William J. Murdock Company; RCA then accepted the transfer of the license.

There was no open quarrel concerning the initial royalty arrangements. The Philadelphia Storage Battery Company manufactured a receiving set, complete with cabinet, and packaged in a carton for direct sale to the consumer. Original terms called for the payment by the licensees of 7½ per cent of the price of the entire package. Only tuned radio receivers could be manufactured, and the company was required to purchase tubes for its sets from RCA.[10]

As time passed, these restrictive clauses were relaxed. The royalty on the cabinet was also substantially reduced. RCA had no patents covering cabinets as such, but it was anxious to establish a royalty base on the complete package. One difficulty, however, was that many sets were sold to amateurs without a cabinet. In May, 1929, RCA permitted its licensees to subtract the cost and profits on the cabinet from its rate base and "to add $2.00 in lieu of the deduction for the useful value of the cabinet."[11]

In 1932 RCA reduced the royalty rate to 5 per cent on receivers for domestic use (and 2½ per cent for export products). Yet the royalty payments were still regarded as excessive by most of the licensees and the Philadelphia Storage Battery Company conceived of an ingenious method of reducing them further. Two separate companies were formed in 1932—a manufacturing concern and an engineering and selling organization, the latter under the title of Philco Radio and Television Company. Physi-

[9] As the Helios Electric Company. The name was changed to Philadelphia Storage Battery Company in 1906.

[10] Supreme Court of the State of Delaware, Radio Corporation of America *vs.* Philadelphia Storage Battery Company, *Opinion*, May 13, 1939, pp. 11-12.

[11] *Ibid.*, p. 18.

cally, they continued to occupy the same building. The manufacturing company confined its operations to the production of certain components and their assembly into a chassis. The cost of the cabinet and the dials and their assemblage and packaging as a complete radio set was charged to selling. The original engineering force was divided in two. Routine production engineering was charged to the manufacturing company, and all other engineering expenses, including research and advanced development, were charged to the selling company. The latter amount was stated by the court as being about $500,000 in 1937.[12] The Philco officers claimed that the activities of their engineering department were directed toward improving their present radio products and investigating new products such as television, and that there was no reason why they should pay royalties on these costs.

In justifying this technique of reducing royalties, Philco argued before the court that it had to meet competitors who were selling radios in large quantities to chain stores such as Sears Roebuck and Montgomery Ward at a price which just covered manufacturing cost. These competitors had no advertising and distributing expenses, did almost no advanced engineering development and cut corners wherever possible. Their selling price, therefore, on which they paid royalties, was much lower than Philco's.

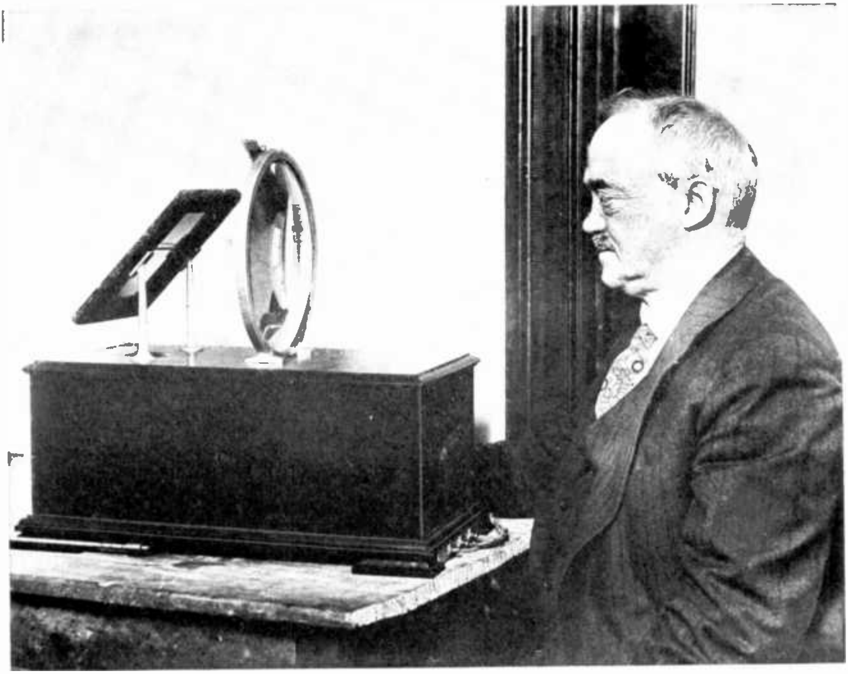
The difference between the royalty receipts under the two standards was very substantial, so that by 1939, when the judgment was finally rendered in the Supreme Court of Delaware, it amounted to $450,000.[13]

Philco's victory placed RCA in an embarrassing position. Although Philco was the largest licensee and spent more on engineering than any other company, Zenith, Emerson, Galvin, and Sylvania were all rising concerns and RCA did not wish to encourage them to adopt the Philco subterfuge. The management therefore decided to reduce its royalty rates for the entire industry from 5 per cent to 2¼ per cent of the net selling price. This

[12] Court of Chancery for New Castle County of the State of Delaware, Philadelphia Storage Battery Company *vs.* Radio Corporation of America, *Opinion*, 1937, p. 26.

[13] Supreme Court of the State of Delaware, *op. cit.*, pp. 2, 4.

Dr. V. K. Zworykin, inventor of the iconoscope, shown with the present-day picture tube, the RCA Image Orthicon. This pick-up tube was developed by Drs. Rose, Weimer, and Law of the RCA research staff. (Courtesy Radio Corporation of America)



C. Francis Jenkins with his Radiovisor, 1929. This was the first television receiver for home use. Jenkins' system employed a pair of bevel-edged glass dises whose angle bevel changed continuously around the circumferences. The bevelled edges formed prisms which deflected a beam of light as the dises rotated. By spinning the dises so that one rotated many times faster than the other, the entire surface of an image could be scanned successively by the beam of light. At the receiver, the same prism dises were used. A glow lamp projected a light beam, the brightness of which was modulated by electromagnetic waves sent from the photoelectric cell of the transmitter. (Courtesy G. H. Clark Radio Collection)

TABLE VII: SALES OF HOME RADIO APPARATUS IN THE UNITED STATES
1922–1941

(000 omitted in Number and Value)

	Broadcast Receiving Sets			Radio Broadcast Tubes			
Year	*Number*	*Value*	*Average Unit Price*	*Number*	*Value*	*Average Unit Price*	*Total Sales for Broadcast Reception* *
1922	100	$ 5,000	$ 50	1,000	$ 6,000	$6.00	$ 60,000
1923	550	15,000	27	4,500	12,000	2.67	136,000
1924	1,500	100,000	67	12,000	36,000	3.00	358,000
1925	2,000	165,000	83	20,000	48,000	2.40	430,000
1926	1,750	200,000	114	30,000	58,000	1.93	506,000
1927	1,350	168,000	124	41,200	67,300	1.63	425,600
1928	3,281	400,000	122	50,200	110,250	2.20	690,550
1929	4,428	600,000	136	69,000	172,500	2.50	842,548
1930	3,827	300,000	78	52,000	119,600	2.30	496,432
1931	3,420	225,000	66	53,000	69,550	1.31	300,000
1932	3,000	140,000	47	44,300	48,730	1.10	200,000
1933	3,806	230,099	61	59,000	49,000	.83	300,000
1934	4,084	270,000	66	58,000	36,600	.63	350,000
1935 †	6,027	330,193	55	71,000	50,000	.70	370,000
1936	8,248	450,000	55	98,000	69,000	.70	500,000
1937	8,065	450,000	56	91,000	85,000	.93	537,000
1938	6,000	210,000	35	75,000	93,000	1.00	350,000
1939	10,500	354,000		91,000	114,000		375,000
1940	11,800	450,000		115,000	115,000		584,000
1941	13,000	460,000		130,000	143,000 ‡		610,000

* Includes receiving sets and tubes and such supplementary apparatus as aerials and batteries.

† Figures for value of sets since 1935 include the value of tubes in the receivers.

‡ In recent years, tubes for replacement purposes constitute about 40% of total tube sales.

Sources: *Radio Today*, Jan. 1939, p. 12, and *Broadcasting Yearbook*, 1946, p. 20.

had the desired effect of quieting the opposition, at least for a time.

2. *The Growth of the Licensees*

By the early 1930's the type of competition which, I believe, RCA had hoped to avoid by a restrictive licensing policy had nevertheless emerged. The RCA–GE–Westinghouse axis was too unwieldly a giant to maintain a dominant position. The new capitalists who entered the industry, in such companies as Philco, Zenith and Emerson, were hard-hitting and aggressive. The managements of these firms were quite different from those in the corporate giants of electrical communications. GE and Westinghouse in the 1920's and 1930's had developed large empires in which stable customer relations were being cultivated. Research and quality were stressed and price competition was avoided. Philco, Zenith and Emerson, by contrast, were dominated by entrepreneurs who were primarily sales-minded. And from 1928 to 1941, sales promotion and production engineering were much more important than research in stimulating demand for the ordinary home radio.[14] The industry had reached a stage where, for a time at least, the major technical developments had taken place. The progress that had occurred in vacuum-tube and circuit designs made it possible to achieve very satisfactory results with known technology. In these circumstances the immediate rewards went to those companies who were most effective in bringing down costs and prices, and in developing a consumer preference for their particular lines based largely on advertising. The next major advances in the industry were frequency modulation and television, but these were not introduced on a significant scale until after World War II.

Under the type of competition that developed in the 1930's, minor "gadgety" improvements were stressed rather than basic engineering innovations. Benjamin Abrams of Emerson Radio has characterized the 1930's in the following terms:

> Each year the advertising and sales departments wanted something new to talk about and each year the engineers obliged. . . . The engineer was too often at the mercy of the whims and profit considerations of the management and the opinionated instructions of the sales department. So long as the public was willing to buy the goods thus

[14] The emphasis has shifted since World War II, and companies like Philco, which had developed a taste for research during the war, have become much more seriously interested in it now than previously. In 1946 RCA signed a license agreement, covering Philco's present and future patents through 1954. At the same time, Philco renewed its license with RCA, extending to the same date.

devised and manufactured, there was no great urgency and little encouragement for radical technical innovations.[15]

The largest and most successful of the new companies, as we have seen, was Philco. The Philadelphia Storage Battery Company had built up an exceedingly effective merchandising organization in the battery industry, with excellent dealer outlets all over the country. These proved of great assistance when the company entered the radio-set business in 1928. The executives were energetic salesmen and promoters, who made Philco into an important household trade name. By designing sets that appealed to the American public and by skillful advertising, the company was able by 1940 to equal RCA in set volume, in spite of RCA's tremendous head start. Philco's development of the portable set added a new and untapped source of customer demand and proved very popular almost immediately. Philco also pioneered in the sale of battery sets for farms not equipped with electricity, and was one of the earliest promoters of automobile radios. And Philco expanded aggressively into other products to offset the seasonality of its radio sales. In 1938 it began to sell "Philco-York" portable air conditioners; within four years it sold as many units as all other manufacturers combined. Later in 1938 it entered the refrigerator field, and in three years it was in sixth place there. Philco's total sales volume in 1941 was in excess of $75,000,000. This was accomplished in part by substantial promotional expenditures. In five years the company spent $11,000,000 on advertising and an equal amount was spent by dealers. Philco was also the first of the set licensees to place an increased emphasis on research.[16]

Next in importance to Philco was the Zenith Manufacturing Company, formed soon after World War I to assemble amateur radio sets. Gene McDonald, its owner, had been an enthusiastic

[15] *Small Radio* (New York, Emerson Radio and Phonograph Corp., 1943), pp. 51–52. It should be pointed out that, while I think this characterization of the 1930's gives a correct impression, other executives in the industry do not agree with Abrams. Philco, for example, feels that there were many more important contributions to improved radio reception and performance by the set licensees than this statement implies.

[16] This is bearing fruit, particularly in the postwar period. Though not an important pioneer in television, Philco has done a great deal to help perfect a workable commercial system.

TABLE VIII: PHILCO CORPORATION SALES AND EARNINGS CALENDAR YEARS 1928–1941

(000 omitted)

Year	*Net Sales* *	*Net Income after Taxes*
1928	$12,472	——
1929	32,737	——
1930	32,034	——
1931	34,697	——
1932	16,607	——
1933	23,207	——
1934	37,492	$1,941
1935	46,740	2,348
1936	56,675	833
1937	51,904	110 (d)
1938	30,528	222 (d)
1939	45,421	1,899
1940	52,311	2,249
1941	* 77,074	2,514

* In 1941, Philco's dollar sales (except sales for export and tube sales of National Union) were divided as follows:

Home radio receiving sets	47.4%
Automobile radio receiving sets	15.0
Household electric refrigerators	23.0
Single-room air conditioners	1.8
Miscellaneous sales including batteries, radio receiving tubes and parts	12.8
	100.0%

radio amateur. He had a dynamic personality and a flair for promotion. On an Arctic expedition in 1925 he provided one of the first demonstrations of the effectiveness of short-wave communication for great distances by establishing contact with the United States fleet which was then in the South Pacific, 12,000 miles away. McDonald also organized and became the first president of the National Association of Broadcasters. By 1927 Zenith was recognized as a rising company and was the first major concern to obtain a license from RCA. Zenith gradually extended its line until it became one of the principal producers of combination radio and phonograph sets. It was particularly successful in appealing to a large section of American taste by the design of cabinets which fitted into living-room schemes. In the 1930's Zenith began to invade the low-price field with characteristic aggressiveness. It was quick to discern the possibilities of the portable set, and it has been especially skillful in designing tuning dials that are easy to work and that appeal to the public.[17] The company has also gone extensively into the non-electrified farm market for radio sets. Zenith has confined itself primarily to the radio field, with the exception of hearing aids in which it has become by far the largest producer. From a sales volume of $10,000,000 in 1929 Zenith had expanded to nearly $25,000,000 by 1941.

The quality of Zenith entrepreneurship is suggested in the following excerpt from a *Fortune* article.

> The secret of Zenith's success "can be epitomized by a simple story. One Saturday it occurred to McDonald that hand controls for auto radios were dangerous, and he dictated a memo to his engineering department suggesting ideas for a foot control. On Monday he started a patent search and had his engineers build a rough working model for his own car. On Tuesday he tried it and on Wednesday he sent it to Detroit. On Thursday he went to Detroit and talked up the device to Edsel Ford and George Mason (Nash–Kelvinator). That night he was back in Chicago with Ford and Nash in the bag. Several people doubtless thought of foot controls before McDonald; the point is that McDonald saw its possibilities and lost no time in using them." [18]

The radio company which perhaps more than any other has been responsible for bringing down prices is Emerson. Under the leadership of the Abrams brothers, Emerson has been responsible for the development and promotion of the small table set, an important innovation in the industry. Although Benjamin and Max Abrams started selling radios in 1924, their position in the industry remained insignificant until 1932, when they reached the conclusion that there was an untapped potential demand for the

[17] "Back in 1935 McDonald insisted on building radios with dials the size of school clocks because he was sure that people would go for them." "Commander McDonald of Zenith," *Fortune*, June, 1945, p. 214.

[18] *Ibid.*, p. 141.

TABLE IX: ZENITH RADIO CORPORATION SALES * AND EARNINGS 1929–1942

(000 omitted)

Year Ending April 30	*Net Sales* *	*Net Income after Taxes*
1929	——	$1,110
1930	——	258 (d)
1931	——	483 (d)
1932	——	399 (d)
1933	——	578 (d)
1934	——	50
1935	——	11
1936	$ 8,538	1,213
1937	16,967	1,904
1938	17,299	701
1939	17,980	1,075
1940	20,381	738
1941	23,877	1,236
1942	34,228	1,394

* The company's sales during this period were almost exclusively confined to radio receivers and radio-phonograph combinations.

small, low-priced set.[19] Benjamin Abrams has described this development as follows:

> In 1932, when the fortunes of small radios were at their lowest ebb, I found what I was looking for and what later pointed the way to a successful operation. It was a clock, or rather a clock case—handsomely styled as style was understood in those days, and only ten inches wide, six and a half inches high and four inches deep. A few attempts had previously been made to produce a small set . . . but nothing quite so small as that clock case. There were no "standard" speakers, condensers, coils, dials, or tube complements for such a miniature unit and skeptical suppliers showed little enthusiasm about making them. It was a pioneering job.[20]

[19] Price competition and the introduction of "small sets" brought the average set price down from $133 in 1929 to $35 in 1933.

[20] *Small Radio, op. cit.*, p. 31.

The set was offered, when completed, at $25 and proved an immediate success. "For more than a year the demand was far greater than our ability to manufacture. It was not until the latter part of 1933 that production and sales of that one model alone came within balance." [21] Since then the small radio has increased steadily in popularity. By 1941 about 80 per cent of the home sets sold were small radios. Emerson continued to be in the vanguard in producing low-priced models—culminating in a set for $6.95 in 1939. Such prices encouraged the purchase of more than one radio for the home and contributed to the phenomenal growth of the radio listening audience from approximately 12,000,000 people in 1932 to 55,000,000 in 1941. Emerson has shown remarkable skill in production engineering, which has made it possible to manufacture low-priced sets at a profit. Its sales volume in 1941 was $14,000,000.

Another pioneering company which contributed to opening new markets for radios was the Galvin Radio Company [22] of Chicago. This concern was started by Paul Galvin in 1928. Galvin was out of work at the time and looking for something to do. He decided to try to make radios, starting his company with an original investment of $500. The first few years were very difficult, but in the 1930's the company engineered a receiver that would function effectively in an automobile, and merchandised it so successfully that a large demand was created. In the year 1941, there were 2,500,000 radios sold for automobiles, of which Galvin was the largest single producer, with sales of 600,000 sets. In addition, the company sold nearly 400,000 household sets.

Because of the effective competition of these various concerns, RCA gradually lost its major lead in the set industry. It remained clearly the largest producer of radio tubes; but Sylvania, Raytheon and National Union gradually absorbed an increasing proportion of this business. And in loud speakers and other parts, RCA also declined relative to such concerns as Magnavox and Utah Radio Products.

The comparative position of the leading firms in the industry in 1940 is indicated in the following figures:

[21] *Ibid.*, p. 34.

[22] The name was changed to the Motorola Corporation in 1947.

TABLE X: SALES OF SETS BY MAJOR COMPANIES *
1940

RCA	1,700,000
Philco	1,675,000
Zenith	1,050,000
Emerson (mostly midget sets)	1,050,000
Galvin	950,000
Colonial (for Sears Roebuck)	650,000
Belmont	550,000
Noblitt Sparks	400,000
GE	350,000
Crosley	350,000
Stewart-Warner	250,000
Simplex	250,000
Electrical Research Laboratories	250,000
Sonora	200,000
Wells Gardiner (for Montgomery Ward)	200,000
Detrola	175,000
Farnsworth	100,000
Sparks Withington	100,000
All others	1,584,000
Total	11,834,000

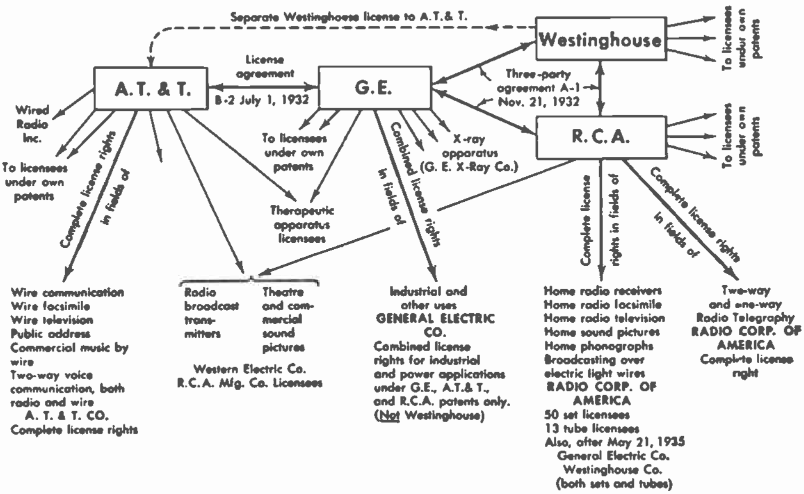
* I believe these figures are approximately correct, but there are no official statistics published. The estimates include exports, and I believe that RCA had larger exports than Philco and that Philco outsold RCA in the domestic market.

The appearance of General Electric as a separate seller of sets was a result of anti-trust action instituted by the Department of Justice against RCA, GE and Westinghouse in 1930,[23] alleging unlawful combination and conspiracy in restraint of trade in both domestic and foreign commerce. The defendants were said to control more than 4,000 patents on radio apparatus, which enabled them to "dictate by agreement among themselves the terms upon which any competitor or potential competitor may use the patents." [24] After eighteen months of negotiations, and without

[23] United States *vs.* Radio Corp. of America *et al., op. cit.* The original complaint named AT&T and General Motors and their subsidiaries among the defendants, but the case was later dismissed as to these parties.
[24] *Ibid.*, pp. 5, 6.

taking testimony or making any adjudications, the parties accepted a consent decree, by which General Electric and Westinghouse agreed to dispose of their stockholdings and managerial direction of RCA. All of the cross-licensing agreements, as well as foreign traffic and licensing contracts, were made non-ex-

LICENSING ARRANGEMENT UNDER
Patents Applicable to Electron Tubes and Circuits
as of May 21, 1935



Cross licensing of patents relating to circuits and electron tubes among AT&T, GE, RCA, and Westinghouse, following the consent decree. (Courtesy *Electronics*)

clusive.[25] GE and Westinghouse were to refrain from the manufacture and sale of radio apparatus for two and one-half years in order to give RCA time to establish itself independently.[26]

General Electric began in 1935 to sell radio sets, having them manufactured at first by RCA. This proved an unsatisfactory arrangement for GE; and its radio operations were conducted at a loss for several years until it began to manufacture for itself.

[25] U.S. *vs.* Radio Corp. of America *et al., op. cit.*, consent decree, Nov. 21, 1932.

[26] RCA had itself begun manufacturing in 1930, when it acquired the Camden and Harrison plants formerly owned by GE and Westinghouse.

Since World War II, General Electric has entered all phases of the radio manufacturing industry. In recent years Westinghouse has also begun to manufacture home radio receivers.

While Philco, Zenith, Emerson and Galvin were rapidly increasing in importance from 1930 to 1940, other concerns with less efficient sales departments were losing their positions. The three leading radio set manufacturers of 1930, other than RCA, were Atwater Kent, Grigsby-Grunow and Crosley. Grigsby-Grunow had a spectacular rise and fall. It began to manufacture sets in 1928, became the industry leader in 1929 and failed in 1934. Atwater Kent was in the top position in 1930 and withdrew in 1932 because of the depressed economic conditions.[27] Crosley gradually lost ground until its radio manufacturing division was thoroughly reorganized in 1937. After that it expanded again, but by 1940 it was still a much less important factor than in 1930.[28]

A significant development in radio merchandising methods was the rise to prominence, as major sales outlets, of Montgomery Ward, Sears Roebuck and the automobile chain stores—Western Auto and Firestone. Sears Roebuck and Montgomery Ward, in particular, provided a challenge to the growth of the nationally advertised radios like Philco, and forced the pace in bringing down prices and costs.

On the basis of the somewhat scanty information that is available, I have attempted to estimate, as shown below, the sales of some of the major chain outlets in 1941:

Table XI: estimate of sales of radio sets by major chain-store outlets—1941

Montgomery Ward	900,000
Sears Roebuck	700,000
Firestone	375,000
Western Auto	350,000
Gamble's	250,000
Goodyear	150,000
Total	2,725,000

[27] The company had been extremely prosperous prior to the depression and Mr. Atwater Kent retired a multi-millionaire.

[28] Since World War II it has become increasingly important again.

Although these stores sold radios under their own trade names, they did no manufacturing themselves. A number of the RCA licensees specialized in supplying the chains. Colonial,[29] Continental and Belmont all did a substantial chain-store business as did Noblitt Sparks, Stewart Warner, Farnsworth and Wells Gardiner. RCA, Philco, Zenith, Emerson and Galvin, by contrast, sold primarily under their own trademarks and made no sales to chain stores.

Many chain-store manufacturers produced radios which compared very favorably in quality with the nationally advertised product. But with the exception of Farnsworth, whose major interest was in television, none of the companies which manufactured primarily for the chains undertook research. Profit margins were narrow; and the technical contributions were confined to production engineering.

The emergence of a limited number of major competitors was also taking place in the tube division of the industry. In 1930 there were fifteen tube companies licensed by RCA. Thereafter, the number of tube licensees gradually declined through bankruptcy or merger until there were only eight in 1941.[30]

Next to RCA in importance in the tube industry was Sylvania Electric Products. Sylvania owed its rise primarily to manufacturing skill and low-cost production. Its plants were located in small towns in Pennsylvania and Massachusetts, where labor supply was adequate and not expensive. Sylvania was able to undercut RCA's prices and still sell at a profit, despite substantial royalty payments. Philco and Zenith became its largest customers, both of them being glad to buy from a non-competitor rather than from RCA, as long as the product was well engineered. Although Sylvania carried on relatively little creative research prior

[29] Colonial was controlled by Sears Roebuck until purchased by Sylvania Electric in 1944.

[30] The war brought a great many new companies into the electronics industry for the manufacture of such important war products as radar. Some of these, like Sperry and Bendix, were very large concerns; many others were small. The tremendous increase in the productive capacity of the industry has created a highly competitive postwar condition. In 1947 RCA reported 32 tube and 186 broadcast-receiver licensees. The royalty rate on tubes in effect in mid-1947 was 4 per cent and on sets 2¼ per cent. The royalty rate on tubes was reduced, in November, 1946, from 4 per cent to 2½ per cent.

Table XII: SYLVANIA ELECTRIC PRODUCTS INC.
SALES AND EARNINGS
1928–1941

(000 omitted)

Year	*Net Sales*	*Net Earnings*
1928	——	$ 607
1929	——	600
1930	——	818
1931	——	1,414
1932	——	852
1933	$ 7,081	655
1934	7,950	874
1935	7,914	777
1936	10,234	1,035
1937	9,417	868
1938	7,957	439
1939	11,022	857
1940	14,359	881
1941	20,561 *	1,067

* In 1941, the company estimated that its total net sales were divided as follows: incandescent lamps, 23 per cent; fluorescent lamps, fixtures and apparatus, 32 per cent; radio tubes, 45 per cent.

to World War II, the company's engineering performance was extremely good.

None of the other tube licensees was so successful in growth or profit record as Sylvania. National Union showed deficits in almost every year from 1930 to 1939 until it was purchased by Philco in 1940.[31] Raytheon was on the verge of bankruptcy for a number of years.[32] Ken-Rad, with low-cost plants, did better, but not so well as Sylvania; and Hytron was only a small factor in the industry.

We have seen in this chapter that the RCA group, to protect its position in the early years, adopted a restrictive attitude on

[31] By acquiring a controlling interest in National Union, Philco became the first company besides RCA to manufacture both tubes and sets. Later Sylvania purchased Colonial, General Electric bought out Ken-Rad, and Raytheon purchased Belmont. Philco sold its interest in National Union to Detrola in 1947.

[32] Raytheon became a very important company during the war, and its post-war position is quite different from that of the 1930's.

TABLE XIII: RAYTHEON MANUFACTURING COMPANY SALES AND EARNINGS 1927–1942

(000 omitted)

Year Ending	*Net Sales* *	*Net Income after Taxes*
Dec. 31, 1927	——	$216
May 31, 1929	——	not stated
1930	——	$329 (d)
1931	——	250 (d)
1932	——	166 (d)
1933	——	324 (d)
1934	——	175 (d)
1935	——	—
1936	——	81 (d)
1937	——	151
1938	$3,471	427
1939	3,177	79 (d)
1940	3,483	60 (d)
1941	4,483	151
1942	6,306	220

* The company's *sales* up to the war were almost exclusively confined to radio tubes. However, Raytheon was spending substantial sums on the *development* of electronic equipment, which has borne fruit since.

licensing but was gradually forced by competitive pressure and legal action to liberalize this policy. With the rise of the licensees during the thirties, emphasis in the industry was laid on achieving volume through aggressive promotion and price competition. While unit sales of sets inevitably declined under the onslaught of the depression, they fell below the 1928 level in only one year —1932. Profit margins, however, were low and, on the average, approached close to zero.

One of the most challenging questions concerning the *rationale* of the RCA patent cross licensing was whether it in fact led to the protection of research budgets and the development of important new products in this "perennial gale of competition." In the next two chapters I propose to discuss the rise of industrial research in radio and television, and to consider in detail the rela-

TABLE XIV: RADIO CORPORATION OF AMERICA *
SALES AND EARNINGS
1928–1941

(000 omitted)

Year Ending Dec. 31	*Gross Revenues*	*Net Sales*	*Net Income after Taxes*
1928	$101,852	——	$19,835
1929	182,138	——	15,893
1930	137,038	——	5,526
1931	102,645	——	769
1932	67,361	——	1,134 (d)
1933	62,333	——	582 (d)
1934	77,303	——	4,249
1935	87,647	$41,593	5,127
1936	100,230	49,721	6,156
1937	111,853	57,090	9,025
1938	99,201	49,568	7,412
1939	109,844	56,569	8,083
1940	127,846	68,289	9,113
1941	157,691 †	92,224	10,193

* Includes the following principal subsidiaries, in which Radio Corporation of America had 100 per cent voting power as of Dec. 31, 1940:

RCA Manufacturing Company (RCA Victor of Canada, Argentina, Mexico, etc.);

RCA Communications, Inc. (operates international radiotelegraphic service, direct radiophoto transmission, etc.);

Radiomarine Corporation of America (manufactures, sells, rents, maintains and operates radio equipment on ships, maintains marine coastal stations for ship communications);

National Broadcasting Company, Inc.;

RCA Institutes, Inc. (gives instruction in fields of radio equipment, sound motion pictures, television, and other electrical apparatus).

† In 1941, the gross income from manufacturing was $88,850,589; the remainder was from broadcasting and other sources.

tionship between the competitive organization of the industry and the nature of the research contribution.

Chapter VIII: THE RISE OF INDUSTRIAL RESEARCH—RADIO: 1900–1941

I am not just interested in practical results. The [General Electric] Laboratory will have to pay for itself, but in addition it should make a contribution to the advancement of science and knowledge.—WILLIS R. WHITNEY.

IN THE precommercial period of wireless exploration, research was carried on largely by university scientists. The conversion of the fundamental discoveries of Maxwell and Hertz into engineering practice was undertaken by young inventors like Marconi and de Forest, who founded the earliest wireless companies. Industrial research in this period was a haphazard undertaking, inadequately financed and dominated by the personalities of key inventors. In the United States it was not until the large and well-established electrical companies turned their attention to radio that research became more business-like and more co-ordinated. At the same time, it lost some of its spark of originality.

In the thirty years from 1910 to 1940, industrial radio research in the United States was concentrated primarily in the American Telephone and Telegraph Company, General Electric, Westinghouse and more recently RCA. These firms maintained a dominant position through their research and through the patents which they produced or acquired. The industry has, therefore, been operating under monopolistic conditions; [1] and one significant question is whether these have been conducive to rapid technological progress.

[1] In using the term *monopoly* in this study I am obviously speaking in economic, not legal, language. Most industries, practically speaking, exhibit a fusion of monopolistic and competitive elements. Varying degrees of monopoly can be obtained by patents, by advertising, by price leadership or in other ways. The significant issue to the economist is not the degree of monopoly but the way in which the monopoly power is exercised. See Edward S. Mason, "Monopoly in Law and Economics," *Yale Law Journal*, Vol. 47, No. 1, Nov. 1937.

The economics and sociology of business behavior have given us conflicting theories as to what to expect of the monopolist. Professor Schumpeter, in a discussion of large-scale enterprise, has written:

> In capitalist reality, the competition which counts is the competition from the new commodity, the new technology, the new source of supply, the new type of organization. . . .
>
> The first thing a modern [large-scale] concern does as soon as it feels that it can afford it is to establish a research department every member of which knows that his bread and butter depend on his success in devising improvements. . . .
>
> . . . there are superior methods available to the monopolist which either are not available at all to a crowd of competitors or are not available to them so readily. . . . There cannot be any reasonable doubt that under the conditions of our epoch such superiority is as a matter of fact the outstanding feature of the typical large-scale unit of control, though mere size is neither necessary nor sufficient for it. These units not only arise in the process of creative destruction . . . but in many cases of decisive importance they provide the necessary form for the achievement. *They largely create what they exploit.*[2]

Schumpeter in these passages is stressing the creative side of the monopolist's behavior which he believes, and I think rightly, has been underestimated in economic discussions. Perhaps because he wants to right the balance, he brushes aside the serious restrictions that do occur and the resistance to innovation that is not infrequently found in large units. These aspects of monopoly, in so far as they appear in the history of radio, are dealt with in other parts of this monograph. But the rise of industrial research in wireless does conform closely to Schumpeter's picture of the monopolist in the role of creator.

Radio research has been carried on primarily by the large companies, a fact that should give pause to those who believe that "*perfect competition* is the life of trade." With few exceptions, the smaller concerns have not had either the financial resources or the imagination to support a vigorous and effective research organization. It is somewhat surprising that during the rapid rise

[2] Joseph A. Schumpeter, *Capitalism, Socialism and Democracy* (New York, Harper, 1942), pp. 84, 96, 101 (italics added).

of the radio industry in the 1920's, more companies were not started with a research conception. Most of the new companies were run by amateur radio enthusiasts who had some engineering training, but were not "scientist-entrepreneurs." The new entrepreneurs of the 1920's were much less interested in the science of wireless than Marconi, Fessenden or de Forest; an exception, in television, was the Farnsworth Company, established in 1926 to support the research of Philo Farnsworth. For the most part, however, men with a strong scientific interest who wanted to enter the radio industry joined the large established concerns.

The concentration of patents and research talent in the Telephone company, General Electric, Westinghouse and RCA constituted a formidable challenge for any group considering a policy of intensive research and patent accumulation. RCA in its license contracts insisted on an option to acquire rights under any radio patents developed by its licensees at a price to be agreed upon by both parties.[3] This, I believe, together with the wide patent coverage of RCA and its partners, weakened the incentive for original research in many of the licensees in the prewar period.[4]

The story of industrial research in radio up to World War II is, therefore, mainly a story of the big company; and the contributions of the large concerns to radio technology have been very great indeed.

1. American Telephone and Telegraph Company

By far the largest industrial research organization in the United States is that maintained by the Telephone company,[5] which also has spent considerably more money on radio research than any other concern.

[3] This policy of requiring an option was abandoned in 1946.

[4] Since the war and the growth in stature of many of the licensees, this situation has altered.

[5] By 1940 there were 4,600 people in the Bell Telephone Laboratories. About 2,000 of these were professionally trained members of the technical staff. This trained personnel covered development and engineering, as well as research. "Somewhere between a fifth and a half of the personnel would be designated as 'research' according to the interpretation of that somewhat indefinite term." *Research—A National Resource*. Part II, *Industrial Research*, National Resources Committee (Washington, Supt. Docs., 1938), p. 50.

Emphasis on scientific research dates from the origin of the company. Following his invention of the telephone in 1875–76, Alexander Graham Bell took little part in the commercial development of telephone service, but the nucleus of a laboratory which he had founded in Boston was continued and expanded by his assistant, Thomas A. Watson. It developed into what became a headquarters laboratory and engineering department, led by Hammond V. Hayes around the turn of the century.

In 1907 the headquarters laboratory of the parent Bell company was moved from Boston to New York, and Theodore N. Vail became president, with J. J. Carty chief engineer. In the meantime the manufacturing branch of the Bell System—the Western Electric Company—had also developed an engineering department and two laboratories, one in Chicago and one in New York.

Dr. Frank Jewett, who later became president of the Bell Telephone Laboratories, has described [6] the conditions in the Western Electric laboratories as he found them in 1912:

> Mr. Vail was not satisfied with the kind of service the parent company was getting from its laboratories in the Western Electric Company, and asked me to find out where the trouble lay. I soon discovered that the method that was being followed in rewarding engineers for their technical accomplishments was not satisfactory. The situation was an outgrowth of the conditions in the telephone industry in the 1880's and 1890's. This had been the "era of the inventor" when it was vital to the future of the company to control the basic patents in the telephone art. In order to stimulate invention, the Western Electric Company had offered a reward of $100 for every patent issued. And this practice had continued into a period when the Bell Telephone System had become firmly established ahead of all rivals and the need for patents was no longer acute. The engineers would get together from time to time to discuss some new development in which they were all interested. Each man would then go off by himself and try to develop the idea in secrecy to the point where a patent application could be made. Moreover, wherever it was possible to make a number of divisional patent claims, instead of one broad claim, this was done, even though a patent on one broad claim would usually be more valuable to the company.

[6] In a personal interview, August 1944.

This method of remuneration was therefore abandoned and any special rewards that were given thereafter were in the form of a bonus for exceptional inventive accomplishment.

From their inception, and especially since 1912, the research activities of the Telephone company have grown steadily in importance and influence.[7] A separate research department was formed in 1912, and in 1925 the Bell Telephone Laboratories were incorporated as a non-profit corporation owned jointly by AT&T and Western Electric. Research expenditures for the twenty-year period from 1916 to 1935 are given in Table XV. Expenditures in 1930 reached a peak of $23,000,000, from which they declined to $14,000,000 in 1933; they rose again to about $21,000,000 in 1940. Five to ten per cent of total research expenditures have been in the radio field.[8]

The management of the company has, almost from its inception, taken a broad view of its field of interest. We have already seen the important part that the Telephone company played in the development of transatlantic wireless communication. After the first World War, the Telephone engineers pressed vigorously forward with this work until they had finally perfected an international radio telephone service. In 1927 the first overseas commercial service was opened from New York to London, and ship-to-shore telephone service was established in 1929.[9] From then on, the use of the radio telephone grew rapidly in importance.

As of January 1, 1935, the Federal Communications Commission reported that the Bell System owned 875 patents in the radio field—about 15 per cent of the total United States radio patents.[10] These included some of the most important patents in radio. "In its suits against patent infringers," the FCC declared, "RCA has placed the greatest reliance upon Bell System patents. In the

[7] Something of the earlier days of these laboratories is sketched in the article "Hammond V. Hayes: 1860–1947," by Roger B. Hill and Thomas Shaw, *Bell Telephone Magazine*, Vol. XXVI, No. 3, Autumn, 1947.

[8] In 1932 Dr. Jewett reported that, to date, the Bell interests had spent $11,000,000 in radio. In addition, between $5,000,000 and $6,000,000 had been spent on radio circuits then in use for commercial telephone work. *Electronics*, Aug. 1932, p. 266.

[9] F.C.C. *Report*, p. 376.

[10] *Ibid.*, App. 12, p. 644.

TABLE XV: DEVELOPMENT AND RESEARCH EXPENDITURES OF THE BELL TELEPHONE SYSTEM*

1916	$ 2,229,173
1917	3,234,915
1918	3,327,302
1919	5,403,545
1920	7,276,529
1921	7,222,840
1922	7,113,886
1923	8,267,778
1924	9,206,018
1925	11,666,281
1926	13,568,675
1927	15,154,014
1928	15,912,911
1929	18,610,767
1930	23,241,590
1931	21,803,502
1932	16,757,143
1933	13,562,458
1934	15,234,480
1935	15,372,678
1936	17,196,768
1937	18,615,470
1938	19,756,036
1939	20,508,658
1940	20,943,341
	$331,186,758

* 1925–1940 from Report of NARUC Joint Subcommittee, Sept., 1945, Table No. 5, p. 28; 1916–1924 from Bell Telephone Laboratories, Inc.

majority of cases, the patents have been held to be valid and infringed." [11]

Detailed figures on radio research expenditures have been furnished by the Telephone company for the period from 1925 to 1940, as shown in Tables XVI and XVII.

[11] F.C.C. *Proposed Report*, p. 235.

TABLE XVI: DEVELOPMENT AND RESEARCH EXPENDITURES OF THE BELL TELEPHONE SYSTEM ON RADIO *

	1925–1940 Inclusive
Short wave—general	$ 5,928,693
Transoceanic radio	3,457,930
Aircraft communication	3,647,220
Other radio transmitting and receiving	2,090,508
Ship-to-shore	1,079,223
Miscellaneous	5,161,620
	$21,365,194

* Source: Bell Telephone Laboratories, Inc.

In addition, many millions were spent on research that had some bearing on radio. The principal items were as follows:

TABLE XVII: DEVELOPMENT AND RESEARCH EXPENDITURES OF THE BELL SYSTEM WHICH HAVE A BEARING ON RADIO, AS WELL AS ON WIRE CIRCUITS *

	1925–1940 Inclusive
Television	$ 3,389,527
Photo-electric cell	397,839
Coaxial conductor system	4,487,827
Transatlantic radio telephone and transatlantic submarine cable (connecting equipment)	1,552,499
Vacuum tubes	8,816,649
Fundamental studies	6,100,525
	$24,744,866

* Source: Bell Telephone Laboratories, Inc.

When research expenditures have been so substantial over a period of many years, it is difficult to single out the major contributions. One reason for this is that AT&T research, while excellent in its over-all character, has not produced startling individual inventive achievements such as, for example, the de Forest triode. This is perhaps partly because, as a public service monopoly, AT&T is not subject to keen competitive pressures. But while there has been little stimulus for the research laboratories to produce something new and different as a spur to sales, the incentive to develop for public *service* has been great and most productive.

The cumulative contributions of the Telephone company have been of vital significance to radio technology. Some of its best research efforts have been centered in the keystone of modern wireless—the vacuum tube. The company's experimentation with vacuum tubes dates back to 1912. The Telephone company built up a wealth of research talent to open a field which gave promise of revolutionizing communications technology. Its physicists—Arnold, Van der Bijl and others—evolved from de Forest's audion the important *high*-vacuum tube and adapted the oxide-coated cathode for use in the triode. Colpitts studied its practical potentialities for long-distance telephone circuits and high-frequency operation; he also devised a system of vacuum-tube modulation. And in 1915 Arnold undertook the building of large triodes for transmission purposes, and produced the first "all vacuum tube" transmitter. Other researchers developed a multi-stage vacuum-tube receiver employing radio-frequency as well as audio-frequency amplification and homodyne detection which worked remarkably well for the period. These advances enabled speech to be transmitted overseas for the first time that same year—1915.

Little was known about this tube research until many years later. The transatlantic tests were conducted in wartime and under great secrecy, and not until 1919 was the lid lifted to show the progress made in five years. In the intervening period AT&T research had been utilized to provide new types of radio equipment for the armed forces. The demand of the military for sets for airplanes, sub-chasers and patrol vessels, together with the need for frequency space, caused the company to investigate the possibilities of shorter waves. From 1916 to 1918, sets were being produced in the 150–300 meter range, as compared with the 5,000–8,000 meter wave-length used in the Arlington to Paris experiments a few years previously. This exploration of the 300 meter range (the present entertainment broadcasting region) contributed significantly to the rapid development of home wireless in the early 1920's.

In the development of transmitting tubes the three major firms —AT&T, GE and Westinghouse—worked on parallel stages. In 1920 tubes of 500 watts represented a major achievement; by 1925 research and development had produced water-cooled tubes of 5,000 watts, used for broadcasting purposes. One of AT&T's contributions here was the work of Housekeeper, who devised an important process for sealing copper into glass, yielding in the early 1920's the water-cooled power tube.

After the withdrawal of the Telephone company in 1926 from entertainment broadcasting, the Bell Laboratories concentrated their radio research on transmitters for broadcasting, including frequency control by piezo-electric crystals, and upon studio acoustics, microphones and connecting lines for the pick-up and network distribution of programs. In 1918 Nicolson had invented the piezo-electric oscillator, and a few years later AT&T acquired rights under the patents of Professors Cady and Pierce which were directed more specifically at frequency stabilization. With the broadcasting spectrum so crowded, stabilization of a transmitter on its assigned frequency was of the utmost importance; and AT&T's contributions in this field have been invaluable.

Also of significance, particularly in transoceanic communication, has been the work of the Laboratories on antennas. One of the first of these was the short-wave stacked antenna of John Stone Stone, which achieved a powerful directive effect. Another was the Musa antenna, designed to pull out of space a sharply directive, steerable beam. The laboratory scientists have also originated rhombic antennas and, just before World War II, the wave guide and micro-wave antennas.

Still another area of research conducted for radio in the 1920's was that on the physical media of transmission. Little was known about the behavior of ether waves under varying climatic and geographical conditions, including the effects of magnetic storms and sun-spots on transmission. With the ultimate aim of achieving transoceanic telephony, AT&T research workers decided to investigate these conditions themselves. For several years they undertook intensive studies of the ionosphere, involving hundreds of different tests and measurements of transmission conditions in order to build up a knowledge of the factors encountered in long-distance radio communication. The officers of the Laboratories later recognized that this type of work should be carried out by more centralized bodies for the benefit of the whole industry. Such research is now conducted primarily by organizations like the Carnegie Institution of Terrestrial Magnetism and the United States Bureau of Standards.

In the 1930's the work of the Telephone Laboratories in tube technology was directed in large measure toward increasing the efficiency and lengthening the life of *existing types* of tubes. The Telephone company could afford to develop expensive but extremely reliable tubes which could be put in a circuit and then forgotten. Service is all-important; if a tube fails in a home receiver, little damage is done; but if a tube fails in a long-distance circuit, it may disrupt the circuits servicing a large area.

AT&T has also continued to do pioneering work in *new types* of tubes. During the thirties the Laboratories produced tubes in the range of one meter down to tens of centimeters—the predecessors of present-day micro-wave tubes. In the thirties also, high-power, short-wave transmitting tubes were developed for transoceanic telephony and a beginning was made in short-wave multiplexing.

In the field of acoustics, AT&T's radio interest has been related to public-address systems and microphones rather than to home receiver speakers. Yet much of what has been accomplished here has had direct application to sets. By 1915 the Laboratories were using speakers in conjunction with wireless experiments, the first field application having been made by AT&T with the Victory Way speaker in 1919. By 1922 and 1923 Western Electric was producing the first cone speakers as a result of acoustics research, and since that time the work on dynamic speakers (for long lines and talking movies) has produced some outstanding results.

The important fundamental research carried on today by the Laboratories includes the physics of the solid state, or matter, in electrical terms. This ultimately has the value of affecting the materials that the company uses, but the projects also contribute original information to the store of knowledge on the physics of matter, affecting all fields and industries. Such projects include investigations of barrier layers, semi-conductors, changes of matter with stresses, etc.

Some of the "fundamental studies," especially those of the qualities of music, speech and hearing, and of noise, have had an important effect on the science of radio communication. An example is Johnson's discovery that conductors generate thermal noise; his work determined the limit of faintness of a signal which can be amplified without the noise from the conductor drowning out reception.

In the emphasis placed on fundamental research, the Bell Telephone Laboratories resemble some of our leading university research centers. Until World War II, however, the Laboratories were far bigger and had a much larger budget for scientific research than any single university in the country.

One of the chief differences from a university environment lies in the fact that the research motivation is less wide as to field of application and deeper in development. "A large industrial laboratory may be likened to a spearhead. At the forefront edge are those having the widest latitude for penetrating Nature's secrets and, fanning out behind them, those who work in greater depth in developing and designing the projects that begin to materialize." [12]

In the case of the Bell Telephone Laboratories, the need for co-operation between individuals and the co-ordination of groups working on related problems was recognized in 1907 under J. J. Carty's leadership, and has been an integral part of the Laboratories' organization since 1912, when research was made a department unto itself under Dr. Jewett. Young men entering the Laboratories were urged to join a group which was working on some important problem such as transcontinental telephone communication; and, as the organization grew with expansion of the field, co-operation and over-all integration have developed correspondingly.

In contrast to a university, the Bell Telephone Laboratories have no large number of professional scientists pursuing their own inquiries in an independent and largely unco-ordinated man-

[12] Lloyd Espenschied, Bell Telephone Laboratories, in a letter to the author, Sept. 1947.

ner; yet there is a certain latitude for the more original and individualistic effort. One mathematician was permitted to work at his home in Pennsylvania and come to the Laboratories for a day every few weeks. The physicist Davisson, who won the Nobel Prize for research on electron diffraction, has pursued lines of inquiry of his own choice much wider than the field of telephone communications. His later work lay closer to the interests of the Telephone company, yet continued to be broad. There are cases in which individuals have literally made their own jobs by originating ideas which they were permitted to pursue. However, the majority of the personnel of the Laboratories are working on assigned projects under general direction. The degree of freedom of inquiry achieved by Davisson and the "mathematician who worked primarily at home" is the exception.

In consequence, the type of scientist who seeks a career in the Bell Laboratories differs somewhat from his colleague in the large university. There is a much higher percentage of men with practical interests and, conversely, a much smaller percentage of research workers with wide speculative interests.

The best telephone performance requires infinite attention to detail. In the realm of weak current technique and careful measurement studies and designs bearing on electrical communications, the Bell Laboratories have had the incentives and the capacities to do more intensive work than any other laboratory in the world. In contrast to some of the leading universities, the Bell Laboratories have perhaps not attained the same peaks of brilliant intuitive research performance, but their contributions to the technical development of radio communications have been unique and brilliant.

2. *General Electric Company*

Next in size and also of great importance as a contributor to radio technology has been the General Electric Company. The original works laboratory at General Electric, as described by Elihu Thomson, was "a space set aside from a portion of the manufacturing and testing department, where with a few tools and perhaps one or two workmen, devices and new appliances were constructed in the form of working models, which were there to be refined and immediately put into manufacture." [13]

In 1900 E. W. Rice, the company's director of engineering, urged the management to establish a research department devoted exclusively to scientific advancement in the electrical field. Charles A. Coffin, the president of the General Electric Company, was one of the most far-sighted business geniuses in the country during the formative period of the electrical industry. He was in reality the founder and creator of the General Electric Company, with insight to see the potential value of a research department at a time when this was a novel conception. The next annual report of the General Electric Company carried the announcement to stockholders that "although our engineers have always been liberally supplied with every facility for the development of new and original designs and improvement of existing standards, it has been deemed wise during the past year to establish a laboratory to be devoted exclusively to original research. It is hoped that by this means many profitable fields may be discovered." [14]

Although subsequent results have justified this decision many times over, the competitive advantages to be obtained from "original research" were by no means obvious to industrialists in 1900. Thus, about the turn of the century, a prominent financier told Elihu Thomson that he "thought the electrical industry was rapidly becoming standardized and getting to the point where new research and experimentation were hardly necessary." [15]

Rice's idea from the first was to develop a laboratory for research in pure science. Willis R. Whitney, then an instructor at the Massachusetts Institute of Technology, was put in charge of the new laboratory; and in 1905 Dr. Coolidge, an assistant professor at M.I.T., was brought to Schenectady to assist Whitney.

Whitney created an environment which was apparently unique for an industrial laboratory of that period. It was this spirit which made the laboratory attractive to a man like Irving Langmuir, who was later to receive the Nobel Prize for work

[13] Elihu Thomson, as reported in *Research–A National Resource*, *op. cit.*, p. 51.

[14] *Ibid.*, p. 52.

[15] *Ibid.*

which he did at General Electric. "I am not just interested in practical results," Whitney told Langmuir when he joined the laboratory in 1909. "The laboratory will have to pay for itself, but in addition it should make a contribution to the advancement of science and knowledge."[16] And later, when Langmuir had been working on high-vacuum phenomena for some time and reported that he was not getting any results that were useful for the company, Whitney replied,

> I don't care. We are learning a lot about high vacuum and, even if the company gets nothing out of it, I want some men in our laboratory who are contributing to fundamental scientific discovery.[17]

The growth of the Research Laboratory is shown in Table XVIII, giving personnel figures from 1901 to 1941. These figures are for the Schenectady laboratories only. GE also conducts its specific product research in twenty-one different division laboratories, each of which is responsible for its own products. Very little fundamental research is done at the division laboratories. The work there is mostly advanced engineering development. It is the responsibility of the Schenectady laboratories to undertake fundamental studies of interest to the whole company; and these laboratories are not responsible for any particular product. As one of the scientists in the Schenectady laboratories said:

> It is our privilege to investigate any particular product that we want to, but we have no obligation to do so. That is not to say, of course, that the central laboratories will not co-operate on engineering problems, but this is not our regular function.[18]

It is up to the division laboratories to maintain a continuous program of research on the products in their field. If the manager of an operating division has an important question in which he would like help from the central laboratories, he will try to interest them in the problem; but if he cannot do so, he must arrange to have it done in his own division or take it to some group outside the company.

[16] Interview with Dr. Langmuir and Dr. Whitney, May 1944.
[17] *Ibid.*
[18] Interview with Dr. A. W. Hull, May 1944. This does not imply that the central research laboratory sometimes refuses to give help which a works laboratory requests.

TABLE XVIII: TOTAL PERSONNEL OF GENERAL ELECTRIC LABORATORIES, SCHENECTADY *
1901–1941

Year	Salaried	Labor	Total	Year	Salaried	Labor	Total
1901	5	3	8	1922	133	123	256
1902	14	8	22	1923	144	135	279
1903	19	26	45	1924	165	143	308
1904	20	21	41	1925	174	156	330
1905	36	21	57	1926	183	169	352
1906	44	58	102	1927	196	196	392
1907	40	55	95	1928	223	234	457
1908	31	47	78	1929	265	290	555
1909	39	50	89	1930	202	230	432
1910	47	59	106	1931	172	202	374
1911	51	63	114	1932	137	135	272
1912	62	72	134	1933	135	139	274
1913	65	89	154	1934	138	134	272
1914	66	89	155	1935	140	140	280
1915	68	124	192	1936	136	140	276
1916	78	168	246	1937	153	148	301
1917	98	200	298	1938	156	130	286
1918	112	176	288	1939	162	135	297
1919	134	139	273	1940	168	154	322
1920	159	142	301	1941	182	174	356
1921	128	125	253				

* Source: General Electric Company.

Because electric lamps were such a vital part of General Electric's business, much of the research in the early years was concentrated on light sources. From this work came the important Coolidge drawn-tungsten filament and the Langmuir gas-filled lamp.

Contributions to radio science became increasingly significant as radio came into commercial prominence. Langmuir's work on the high-vacuum tube has already been cited, and this was followed by many further vacuum-tube developments by Langmuir and other General Electric scientists.

For example, Langmuir developed the thoriated tungsten cathode which is still used extensively in high-power tubes. The way this happened is an illustration of how "accidents favor the well-prepared mind." [19] Langmuir, measuring electron emission under various conditions with no reference to tube research as such, obtained with one particular filament an emission hundreds of times greater than with anything heretofore. Investigating, he found he had used by chance a thoriated filament made by Dr. Coolidge for another purpose in the laboratory. Langmuir subsequently carried on various experiments with thoriated wire, discovering that there was a long trail between knowing that thorium was good for increased emission and getting exactly the type of filament he wanted. What he needed was a thin film of the metal over the tungsten of the filament; and after thorough study he was able to file a patent application. In the final formula he added about three-quarters of one per cent of thorium oxide to the tungsten, heated the filament to the correct temperature (which would leave a thin film on the filament), and then dropped the temperature sharply.

This proved a significant scientific advance. Since the time of Richardson's law it had been known that raising the temperature of the tungsten wire in vacuum increased the rate of emission. But in practical use it was impossible to raise the temperature above 3100° Centigrade, since above that point the tungsten evaporates so rapidly that tube life is short. It had also been discovered that there were many substances such as thorium which are very good emitters but which likewise evaporate too rapidly at such temperatures. General Electric research workers found that these alkaline earth metals have one peculiar property: they can be absorbed on the surface of a metal such as tungsten in a layer one molecule thick, and will not evaporate to any appreciable extent up to and, in many cases, well beyond the melting point of the core metal. This meant that one of the high-emitting metals could be absorbed onto tungsten and used as the cathode with far superior properties to a cathode made with either the absorbed or the core metal.

Thus Langmuir's discovery made possible an improved tube with longer life; and the studies of the laboratories in connection

[19] Pasteur's dictum was: "Dans les champs de l'observation, le hasard ne favorise que les esprits preparés."

with these features of thoriated tungsten, and the means of making the process work, led to important discoveries in surface chemistry and electron emission.

By the late 1920's, Langmuir's interest had shifted away from research applying directly to radio. He became engrossed in surface chemistry relating to films: this was "pure" research, unrelated to GE's commercial interests. In fact, the only industrial group to benefit by his work has been the mining interests. Langmuir's research opened up a whole new field, from which sprang a revolutionary change in the flotation process of ore separation.

An important contribution of the 1920's was a form of screen-grid tube of Dr. A. W. Hull. When Armstrong's superheterodyne receiving set was first introduced, it gave out a peculiar noise which interfered with reception. Parasitic sounds seemed to be made by all receivers, and designers had a difficult task trying to identify and catalogue them. Hull undertook the task of investigating these noises in 1923. The tube which he developed effectively eliminated oscillations due to feedback. When the screen-grid tube was reduced to commercial practice in 1932,[20] it became standard equipment in almost all receiving sets.[21] It also acted as a much more efficient amplifier; and therefore fewer tubes were needed, and the size of the set could be reduced.

In loud speakers, the General Electric Company has also made significant progress. All the early loud speakers used horns for amplification, and the reverberations inherent in horns gave a "tinny" quality to both speech and music. In 1925 C. W. Rice and E. W. Kellogg of the Schenectady laboratories developed the electro-dynamic loud speaker which delivered a high output of sound with no reverberation or distortion, and thus made possible high-fidelity reproduction. Although this type of speaker is now universally used, its perfection had to await the discovery of some method of reducing the size of the magnet used in the speaker. This came with the development of the *alnico* magnet.

Alnico alloy (aluminum, nickel, cobalt and iron) had been developed as a resistance material some years previously for the industrial heating department of General Electric. It gave high

[20] The screen-grid tube was also invented abroad. Schottky, U.S. Patent No. 1,537,708, filed 1919.

[21] Dunlap, *op. cit.*, p. 200.

specific resistance and was non-oxidizing, but it was too brittle for commercial use. Later the Japanese brought out a patent on a magnet which utilized this material. GE bought the patent and its research workers went back to investigate their discarded alloy. They found that, suitably treated, this alloy had three times the strength of earlier alloys and this allowed the reduction in size of the magnet.

The pioneering work on the Alexanderson alternator has already been described. It operated so satisfactorily that the Navy in 1918 declared it to be "the most efficient transmitting system for international communication developed to date." [22] Although now generally displaced by the high-power transmission tube, the alternator is still used (1947) for overseas transmission when short waves cannot get through. Alexanderson's work on antennas, both for transmission and reception, has also been notable.

Still another General Electric development (of significance in obtaining and maintaining a very high vacuum) was the introduction of "getters" into vacuum tubes. Their first application was made by Dr. Langmuir in a patent applied for in 1915,[23] and his original methods were subsequently greatly improved by a number of General Electric research workers.

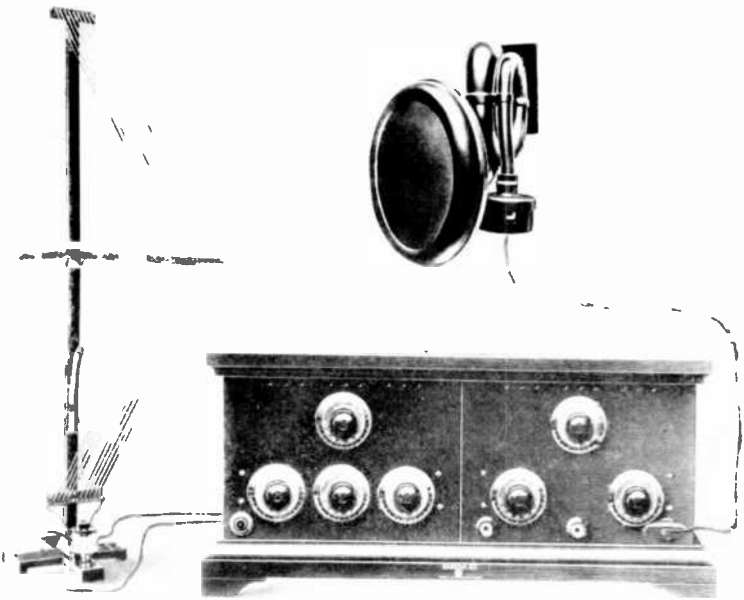
The metal tube was also a General Electric development initially. The vacuum tube took many years to break away from its lamp progenitor: it originally took on the shape, size, mechanical structure and the glass envelope of the lamp. And although all workers in the field admitted that glass had many disadvantages, especially for large tubes, the ways and means of breaking away from the lamp model were not apparent.

The immediate stimulus for the metal tube was not for radio application, but for power uses. Late in the 1920's Dr. W. C. White of the Schenectady laboratories began to explore the application of tubes to industrial purposes. In radio, there was no known substitute for vacuum tubes; they had to be used despite certain drawbacks of cost, structure and fragility. In industry, on the other hand, any use of tubes had to compete with other

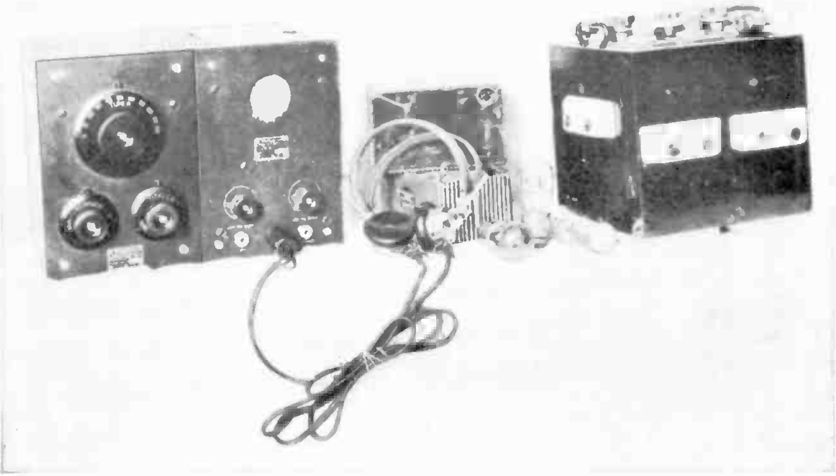
[22] Glover and Cornell, eds., *The Development of American Industries*, "The Radio Industry," by E. E. Bucher (New York, Prentice-Hall, rev. ed., 1941), p. 837.

[23] Patent No. 1,244,217 issued Oct. 23, 1917.

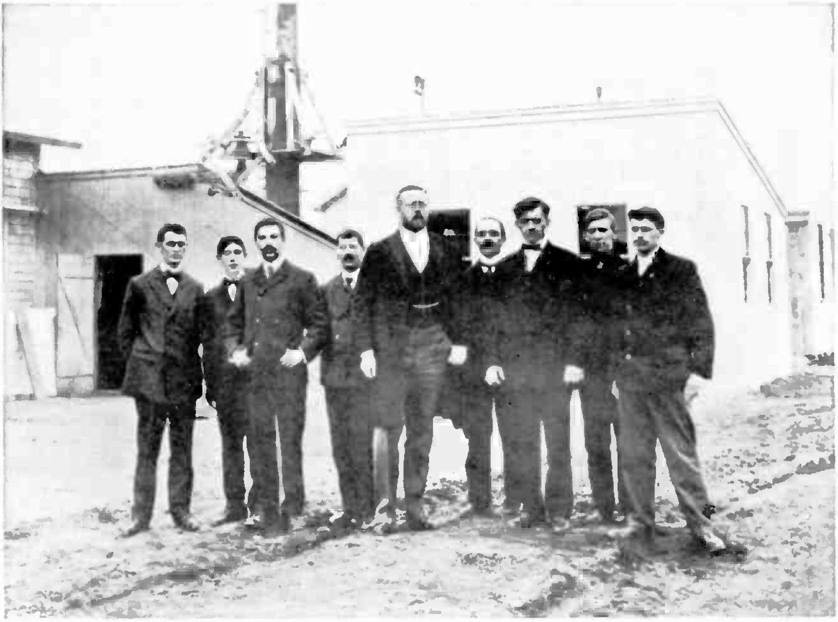
Lee de Forest in his Highbridge Laboratory, adjusting his oscillion transmitter. This was an early form of radio transmitter, using vacuum tubes as generators of oscillations. At the right is an ultraudion receiver, using detecting and amplifying tubes, and the calibration dials popularized by the U. S. Navy. (Courtesy G. H. Clark Radio Collection)



Radiola Model VI, introduced by RCA late in 1922. Sales were 17 units in 1922, 670 in 1923 and 2087 in 1924. This set sold for $162.50, less batteries, speaker and antenna. Three stages of radio frequency and two stages of audio frequency amplification were provided, and the range was 200-5000 meters. 6 tubes and 6 batteries were used. The Radiola Loop Antenna and the Vocarola speaker are shown. (Courtesy Radio Corporation of America)



Picture of 1922 Radiola (tuned radio receiver type), manufactured by Westinghouse, showing battery-type tubes and the wet and dry cells required to operate the set. (Courtesy Radio Corporation of America)



The Fessenden engineering and research staff outside the Brant Rock station, 1906. Fessenden is fifth from the left. Others are H. R. Hadfield, J. W. Lee. F. P. Mansbendel, G. Davis. M. L. Wesco. A. Stein, Jr., H. Sparks, and Guy Hill. (Courtesy G. H. Clark Radio Collection) devices, and the cost and fragility features were a distinct handicap.

White reasoned that the principal mistake had been in not realizing, for years, that opposite conditions prevailed in lamps and tubes. With a lamp, the object was to get light *out;* with a tube, the object was to keep the electron stream *in*. In fact, in this latter case an actual shield was usually needed around the tube's glass envelope. Therefore, why not combine the envelope and shield and make them one and the same? A further economic reason, from GE's point of view, was that its working personnel covered a wide field in metal working–it had a thousand workers in metal to every man skilled in glass technology.

Two of White's assistants were assigned to the initial exploratory work; many difficulties were encountered, though none of a fundamental nature. After a year, this work proceeded more vigorously. Two more men were started on a parallel development along somewhat different lines, and in a few months had reached a stage which would justify proceeding with a commercial design. About this time also GE research workers decided that the metal tube, which up to then had been considered only for industrial purposes, would be equally effective in radio reception. A year's further development brought the all-metal radio tube to the point where manufacture was discussed with the lamp department, and help was obtained in setting up methods of producing these tubes in quantity. Some six months later similar assistance was given to RCA.[24] Thus, the radio tube phase required about one and a half years of development by itself.

This work was particularly important because it allowed the manufacture of much larger tubes than was possible with glass. In the meantime activity in industrial all-metal tubes had been continuing. The first such tube was completed a little more than two years after the exploratory work was started, and a little less than a year after the commercial design was undertaken.

Two parallel developments in General Electric laboratories made the metal tube practical. One was the discovery by Dr. Hull of the sealing alloy, *fernico* (a combination of iron, nickel and cobalt), also discovered independently by Scott of the West-

[24] Westinghouse produced an all-metal tube simultaneously, but the GE design was adopted by the industry.

inghouse company. This made it possible to seal ferrous metals to glass—until then one of the most bothersome problems in tube technology. The other was the development of vacuum-tight seam welding—an interesting example of the necessity of having a tube to make a tube. Before this type of welding could be used, it was necessary to develop electronic controls to make vacuum-tight line welds.

The success of the Schenectady laboratories can be attributed to the foresight of the management in establishing a laboratory center for fundamental research as early as 1900, in picking such an exceptional leader as Willis R. Whitney, and in giving him full backing and encouragement. Whitney was not only an able and devoted scientist, but he had an infectious enthusiasm and a lovable nature which produced deep loyalty in his associates. He also proved very successful in engaging men with exceptional scientific ability.

In consequence, it is my impression that the General Electric Company has obtained greater returns per dollar invested in research than any other laboratory in the country. There was, however, some let-down in the 1930's. Research expenditures were cut drastically in the Great Depression, and new staff appointments were not of comparable stature to Langmuir, Coolidge and Hull. This, however, was probably true of most research laboratories in this period.

Contrasting General Electric with Telephone company research, there has been greater emphasis on individual initiative and less on directed projects than in the Bell Laboratories. This is perhaps because the objectives of telephone research have been more sharply focussed on the development of a nation-wide communications system for public service.

3. *Westinghouse Electric Corporation*

The Westinghouse company was much slower than General Electric in integrating its research activities. Although George Westinghouse was a brilliant inventor and a great engineer, he had little understanding of commercial and organizational problems; and he did not surround himself with men of business insight. During the period of his presidency—from 1886 to 1910

—he struggled continuously to raise adequate funds for his engineering projects, but neglected to build an effective commercial organization which would have made that possible.[25]

Nor was the situation corrected upon Westinghouse's death. In the period from 1911 to 1929 the Westinghouse company had two presidents, neither of whom showed marked entrepreneurial ability. The second of these presidents, in fact, was quite ill for about the last ten years in which he was the chief executive. During this time, Westinghouse let General Electric carry the banner of commercial leadership without offering as much effective competition as it might. Not until 1928, when Mr. A. W. Robertson was brought in from outside the firm to be chairman of the board, did the company have a chief executive of comparable stature to that of its big rival.

The situation in the top management was reflected in the uncertain policy that the company adopted on research. Although a separate research department was established in Pittsburgh in 1902, there was no centralized laboratory, and the experimental work was conducted in laboratories scattered throughout the East Pittsburgh works. In order to free the scientists and engineers from daily manufacturing problems, a separate group of laboratory buildings was erected in 1916 and placed under the directorship of C. E. Skinner.[26] From 1916 to 1920 Skinner attempted to build a large and important organization. The new laboratories were to be devoted *exclusively* to fundamental research. All applied research was to be kept in the manufacturing laboratories. The idea was to approach the goal of a university environment in which investigators of exceptional caliber[27] would be free to explore new problems in electricity with little

[25] The Westinghouse empire was not as cohesive and unified as that of GE. George Westinghouse founded and directed (in addition to Westinghouse Electric) the Union Switch and Signal Company, the Westinghouse Air Brake Company, the Philadelphia Company (exploitation of natural gas), the Westinghouse Machine Company and several other smaller organizations. Westinghouse Electric and Manufacturing Company in 1907 included the Westinghouse Lamp Company, the Bryant Electric Company, the Perkins Electric Switch Manufacturing Company and the R. D. Nuttall Company.

[26] *Research—A National Resource, op. cit.*, p. 54.

[27] Dr. Arthur Compton, who later received the Nobel Prize in physics at the University of Chicago, was among the young men brought to the laboratories at that time.

or no pressure for immediate results. The conception, however, was too ambitious both for Skinner to handle and for the company to absorb financially. Skinner had been with the company many years and was not a research scientist himself. Moreover, he had a large number of interests in the company, in addition to the administration of research. The staff of the laboratories grew very rapidly, expenses mounted and the management began to get impatient for *results*.

In the postwar period of readjustment, the top management concluded that the activities of the laboratories were not closely enough related to the operations of the company, and a new director, S. M. Kintner, was chosen in 1920. During the 1920's much more progress was made. The contributions of the laboratories to radio technology date primarily from this later period.

One of the most far-reaching contributions of the Westinghouse company was the early experimental broadcasting work of Dr. Frank Conrad. Besides his original efforts at entertainment broadcasting, which proved outstandingly successful, Conrad did pioneering work on short-wave transmission. Subsequently, practically all high-power, long-wave commercial stations for point to point communication have been abandoned in favor of the more economical and more reliable short-wave system. For his pioneering work Conrad was awarded the Edison medal[28] with the following citation: "By painstaking observation and investigation in a discarded field, Conrad discovered the characteristics of the short wave for extra long-distance transmission, and has made radio communication and broadcasting world-wide."

Also of great significance to the broadcasting art was the invention in 1928 of a form of a-c tube by Freeman and Wade.[29] In designing a radio to be operated from an electric-light socket, the difficulty to be overcome was that alternating current made a loud hum in a receiver. The Westinghouse laboratories attacked this problem with vigor and imagination. Freeman and Wade succeeded in evolving a method of operating the filament

[28] The Edison medal is the highest award of the American Institute of Electrical Engineers.

[29] U.S. Patent No. 1,909,051. The indirectly heated cathode for a-c operation was invented by Nicholson of Bell Telephone Laboratories, U.S. Patent No. 1,459,412, filed 1915, issued 1923.

and the plate in such a way as to avoid hum. They designed a tube in which the cathode temperature was indirectly raised by a heater placed inside a cylinder, the outer surface of which was coated with a good electron-emitting material. This outer surface constitutes the cathode, and all points of this surface are at a substantially constant potential regardless of whether direct or alternating currents are supplied to the heater.[30] Following this invention, there was an almost universal change to the socket-power set.

Another outstanding research worker at Westinghouse was Dr. Ilia Mouromtseff, who joined the research laboratories in East Pittsburgh in 1923 to take charge of radio transmitter tube development. Dr. Mouromtseff pioneered in the design of ultra-high power and ultra-high frequency tubes. In later years he conducted research on micro-waves and their application to radio and other phases of industry.

Westinghouse also made other important advances in radio tubes. Howard Scott in the late 1920's developed the kovar alloy of cobalt, nickel and iron which was to prove very important for sealing glass radio tubes. Housekeeper of the Telephone company had previously developed a method of sealing copper to glass, but the method was very expensive and not applicable to all types of tubes.[31] Among other developments, Charles Upp in the 1920's found a way to immunize grids and other electrodes in radio tubes by carbonizing their surfaces. This stopped secondary emission and thus eliminated some background noise. Dr. Lowry developed konal as a substitute for platinum in a vacuum tube. Konal was a strong alloy at high temperature and gave excellent electron emission.

The Westinghouse laboratories also did important pioneering work in electronic television under Dr. Zworykin. This research was started in the 1920's at Westinghouse and transferred to the Radio Corporation of America in 1930. It will be described in detail in the next chapter on television.

Statistics are not available on Westinghouse research expendi-

[30] This form of cathode is shown in a Westinghouse patent No. 2,000,695, issued May 7, 1935, on an application filed Jan. 8, 1923.

[31] In particular, it could not be used with mercury, which made kovar especially important in radar.

TABLE XIX: TOTAL PERSONNEL OF WESTINGHOUSE LABORATORIES, EAST PITTSBURGH *

1924	122	1930	191	1936	102
1925	118	1931	223	1937	120
1926	108	1932	180	1938	130
1927	124	1933	170	1939	132
1928	142	1934	148	1940	146
1929	148	1935	118	1941	170

* On June 1, 1944, the personnel of the laboratories had risen to 433, divided as follows: engineers, 126; junior engineers (professionally trained), 88; laboratory assistants, 48; clerks, 51; draftsmen, 23; shipping and maintenance, 97.
Source: Westinghouse Electric Corporation.

tures. They have not been as large as General Electric's, but the company itself is smaller. Figures on the personnel of the laboratories from 1924 to 1941 show a substantial rise to a peak in 1931, an exceptionally drastic decline to 1936 and a steady increase thereafter.

4. Radio Corporation of America

When the Radio Corporation of America was formed in 1919, the General Electric Company was very active in radio technology, and the directors expected that GE would remain the principal center of research for RCA. In 1921, when Westinghouse became associated, the facilities of its research laboratories and the work they had done and were doing became likewise available to RCA.

In addition, there was in 1919 a small group active at the College of the City of New York, under Dr. A. N. Goldsmith, doing research in radio; and "this activity became in a sense a research branch for the Radio Corporation."[32] This relationship continued until 1924, when RCA established a technical and test department in New York. Members who had earlier been active in the C.C.N.Y. group were transferred to this Van Courtlandt Park laboratory, continuing research work, quality control and the establishment of a specification center for apparatus for enter-

32 Memorandum of E. W. Engstrom, Director, RCA Laboratories Division, August 21, 1947, p. 1.

tainment broadcasting sold by RCA and manufactured by GE and Westinghouse. Also in 1919 RCA established research facilities on Long Island to conduct work in the field of radio transmission, propagation and reception.

In 1929 the personnel of the technical and test laboratory was transferred to the Victor Talking Machine Company at Camden, which had been acquired by RCA. The next year, General Electric and Westinghouse transferred the engineering development, design and manufacture of most radio apparatus to this Camden plant; and the principal radio technicians of GE and Westinghouse were also moved to RCA.

A laboratory to render service to the licensees was set up in 1930. Its aim was "to assist radio manufacturers in solving technical problems and in deriving the maximum benefits from rights obtained through the licensing arrangement." [33] Today (1947) there are two branches of the RCA Industry Service Laboratory, one in New York and one in Chicago; and part of the staff travels frequently to the West Coast to assist manufacturers there. During seventeen years these laboratories have published more than seven hundred technical bulletins covering such subjects as automobile radio, facsimile, television techniques and new types of circuits. They have undertaken the systematizing of measurement procedures for the benefit of radio manufacturers, and have developed a variety of new testing devices.

The laboratory work of this service division is primarily development engineering and trouble-shooting. Research—in such fields as television, frequency modulation, circuits, etc.—also engages a certain percentage of the laboratory's staff. While this research is not of a fundamental nature, some significant contributions to the radio engineering art have been made.[34]

The service laboratories hold "clinics" on new developments, issue pamphlets describing the problems involved and the methods of solving them, and stand ready to place their knowledge at the disposal of the licensees. The service rendered is principally of

[33] Engstrom memorandum, *ibid.*

[34] For instance, Stuart W. Seeley, the Director of the Industry Service Laboratory, was awarded the 1948 Morris Liebmann Memorial Prize of the Institute of Radio Engineers, for "his development of ingenious circuits related to frequency modulation."

assistance to the smaller manufacturers who have no important engineering staffs of their own. For example, if a licensee plans to manufacture a certain radio set, he may encounter difficulties in engineering design or performance. He can then send the set to the laboratories, where some expert in that particular field will analyze it and make suggestions for correction of the difficulty. Or the licensee may send his own engineers to the laboratories to work there on the problem in conjunction with the RCA staff and with the facilities provided there.[35]

Another type of trouble-shooting involves defects in sets already on the production line. A typical case occurred recently after a manufacturer had distributed several thousand units of a new model. In some areas customers were returning the receivers because of a persistent whistle encountered in tuning. The task for the Industry Service Laboratory was to find out what caused the trouble; to devise some means of correcting the fault so that those sets already manufactured could be altered without adding extra parts; and, lastly, to analyze the circuit so that future sets could be made without trouble from this source.

When, following the consent decree of 1932, RCA was officially separated from GE and Westinghouse, its research activities were further expanded. In a short time it had five research groups in operation: Harrison and Camden, New Jersey, Riverhead and Rocky Point on Long Island, and New York City. And since the cross-licensing agreements with its former partners were extended until 1954, RCA continued to enjoy royalty-free rights to the radio inventions of these companies.

About 1939, the research officers of the company began to press strenuously for a separation of research from developmental and engineering activities. This led to the present Princeton Laboratory, opened in 1942, and still in an expanding state.[36] (War pressures made it necessary to avoid uprooting too many people until research problems were less a matter of military

[35] With the passage of time, the radio industry has become increasingly dependent on instruments for testing and analyzing. Many of these are complex and expensive, and the small licensee is in no position to maintain such equipment for his own use.

[36] In 1942 RCA reported 428 persons engaged in research activities. The number had increased to 579 in 1947, 75 to 80 per cent of these being in the Princeton laboratories.

necessity.) Today there is a definite separation of research from other activities. Princeton gives RCA for the first time a laboratory working strictly on research problems.

It is in television that RCA has developed its most significant long-range research program. This will be discussed in the next chapter.

5. Hazeltine Electronics Corporation

By no means equal in size and importance to the big corporate laboratories, but nonetheless making a significant contribution to radio technology, is the Hazeltine Corporation.

It will be recalled that the impetus for the formation of this company came from several small radio manufacturers who were impressed with the possibilities of Professor Hazeltine's neutrodyne system and saw in it a way of circumventing the patent position of RCA. The company was incorporated in 1924 with assets of slightly over $4,000,000, of which patents, patent rights and trademarks were valued at $3,600,000.[37] This valuation was extremely high in relation to the actual cost of Hazeltine's research and patents at that time; yet the corporation was able to earn a good percentage return on its declared assets.

The adverse circuit court decision of 1927, declaring that the neutrodyne principle was broadly covered by patents of General Electric and AT&T, necessitated a drastic reorganization of Hazeltine's commercial arrangements. The exclusive license to the Independent Radio Manufacturers was cancelled and royalties were reduced from 5 to 2½ per cent.[38] At the same time, the officers started an aggressive campaign to get additional licensees. In doing so, they declared their intention to expand research and provide competent engineering service for licensees. In this they were successful. Neutrodyne sets were still in considerable demand and could not be manufactured without a Hazeltine license. Moreover, the promise of research and engineering assistance meant a good deal to the small struggling companies which

[37] The Annual Report of the Hazeltine Corporation, 1924, states: "Your company is primarily a patent holding corporation and is particularly interested in the development of the radio art, through the purchase, commercialization, and improvement of patents."

[38] Annual Report, 1927.

were trying to get a foothold in the industry and had no effective developmental facilities of their own. The establishment of such a service was one of the principal innovations made by the Hazeltine Corporation. By 1929, two years after the court decision, the number of active licensees had been expanded from fourteen to twenty, and about 40 per cent of the total radio set sales in the country were manufactured under Hazeltine license. This compared with 23 per cent in 1927. From then on, with some minor reverses during the Great Depression, the proportion of sets sold under Hazeltine licenses gradually increased until it represented perhaps 70 per cent [39] of the total industry just before World War II.[40]

Hazeltine's income and expenses from 1926 to 1941 are shown in Table XX.

The total royalties collected for the sixteen prewar years from 1926 through 1941 amounted to $15,243,000. The figures also reveal the high cost of establishing an important patent position in the industry, with nearly $4,000,000 spent on patent applications and patent litigation.[41]

The other main items of expense have been research and engineering service.[42] Research expenses are not reported separately, but total salaries, fees and laboratory expenses amounted to $2,618,000, a large part of which was for service and research.

The "service" which the Hazeltine company has offered has been of material benefit to the industry. For example, Hazeltine engineers have been helpful to licensees in designing new radio models, such as the small sets which became the fashion in the early 1930's. Even a large concern like Philco has relied to a very considerable extent on Hazeltine's research and engineering assistance.

The Hazeltine Corporation has not been in a position to sup-

[39] This included RCA, Philco and Zenith, but not Emerson, Crosley or Colonial.

[40] This percentage was considerably smaller in 1947.

[41] The 1927 annual report says: "The cost in connection with patent litigation and protection constitutes the largest item of expense." Purchased patents were charged to the capital account and do not appear as an expense item.

[42] In 1930 a separate research laboratory was established in Long Island, and the original laboratory in New York City was given over to rendering direct service to the company's licensees. In 1937 these services were further expanded by establishing an engineering laboratory in Chicago to service that area.

TABLE XX: HAZELTINE CORPORATION INCOME AND EXPENSES
1926–1941 (000 omitted)

	1926	1927	1928	1929	1930	1931	1932	1933	1934
Income:									
Royalties	$433	$350	$609	$920	$1,172	$585	$383	$406	$1,319
Other income	10	15	16	28	33	38	25	18	17
Total income	$443	$365	$625	$948	$1,205	$623	$408	$424	$1,336
Expenses:									
Salaries, fees and laboratory expenses	$ 60	$ 65	$ 71	$ 84	$119	$144	$116	$106	$135
Legal fees and other expenses	85	101	153	351	414	379	307	226	336
Total expenses (excl. of amortization of patents)	$145	$166	$224	$435	$533	$523	$423	$332	$471

	1935	1936	1937	1938	1939	1940	1941	Totals
Income:								
Royalties	$961	$1,136	$1,113	$1,193	$1,342	$1,450	$1,871	$15,243
Other income	7	6	3	219	2	1	1	439
Total income	$968	$1,142	$1,116	$1,412	$1,344	$1,451	$1,872	$15,682
Expenses:								
Salaries, fees and laboratory expenses	$155	$204	$213	$242	$257	$268	$379	$ 2,618
Legal fees and other expenses	211	234	196	182	255	305	232	3,967
Total expenses (excl. of amortization of patents)	$366	$438	$409	$424	$512	$573	$611	$ 6,585

port the type of fundamental research that was possible in the Bell Telephone or General Electric laboratories. Patent applications have been based on specific engineering improvements rather than on fundamental advances. One such contribution was the introduction of automatic volume control. A serious defect of home receivers in the 1920's was that, in turning from a station with a weak signal to one with a strong signal, the potential frequently built up in the last amplifying tube and produced a "blast" in the loud speaker. Often, also, the same signal varied in intensity, requiring constant attention to the volume dial.

A young graduate student at Johns Hopkins, Harold A. Wheeler, conceived a method of overcoming these deficiencies. Willis Taylor, Hazeltine's patent attorney, had heard of Wheeler's work and arranged to have any radio inventions he might make assigned to Hazeltine. The company subsequently developed the principle of automatic volume control for commercial use; Wheeler, also, joined the staff. The patent, however, was finally declared invalid by the Supreme Court in 1941.[43] Following a noticeable trend of insisting that an invention must represent a "flash of genius,"[44] the court stated:

> . . . We conclude that Wheeler accomplished an old result by a combination of means which, singly or in similar combination, were disclosed by the prior art and that, notwithstanding the fact he was ignorant of the pending applications which antedated his claimed date of invention and eventuated into patents, he was not in fact the first inventor, since his advance over the prior art, if any, required only the exercise of the skill of the art.[45]

The decision was a serious blow to the Hazeltine Corporation. Emerson and Crosley subsequently brought suit against Hazel-

[43] The original patent, No. 1,879,863, issued in 1932. It was the object of suit against the Emerson Company, and was declared invalid and not infringed by the district and circuit courts. The Hazeltine company applied for a reissue patent and the claims were redrafted. This new patent, Re-19,744, granted in 1935, was declared invalid by the Supreme Court. The pioneer invention of automatic volume control proved to be the Espenschied-Bowen, Patent No. 1,447,773, filed 1921, issued 1923, held by the Bell Telephone Laboratories.

[44] It should be noted that relatively few patent cases reach the Supreme Court; and if all patents were adjudicated there, the number of valid patents would be greatly reduced on the basis of the standards applied in recent years.

[45] Justice Roberts, Detrola Radio and Television Corp. *vs.* Hazeltine Corp., 313 U.S. 269.

tine for a declaratory judgment on Hazeltine's major patents. In this type of suit the court examines all the patents of the defendant which are questioned, and makes a judgment on their validity. The procedure was designed to protect a company from harassing suits in different jurisdictions and on different patents. The case has not yet been settled (1947).

Hazeltine's experience shows the difficulties in store for a corporation whose sole revenue comes from license fees. To begin with, it becomes increasingly difficult to secure new basic patents as an industry gets older. Secondly, no well-established industry likes to pay an annual toll for research and engineering service. The attempt is inevitably made to break down the license structure by contesting patent suits.[46] If the company grows large enough to undertake pioneering studies in new fields, it may be able to perpetuate its patent position and maintain its research. But this is not easy for a firm which is in competition with such large corporations as RCA, General Electric and the Bell Telephone Laboratories.

So far we have been discussing industrial research on a company basis and have confined our attention to the perfection of standard radio broadcasting and reception. In recent years, however, two very important innovations have been introduced—FM and television—which are having a profound impact on the structure of the industry. These innovations, and the scientific work which preceded them, deserve separate treatment.

6. Research in Frequency Modulation

Up to World War II, organized research in the radio industry was concentrated primarily in the set-manufacturing concerns and in the Telephone company. The broadcasters as such have done relatively little research. Possibly for this reason the most radical innovation in sound broadcasting that has occurred since the 1920's—FM—did not arise from within the radio industry, but from the work of a university professor.[47]

[46] Over a period of 23 years (1924–1947) Hazeltine has had 14 different patents involved in litigation against persistent infringers, and of these only 3 have been held valid and infringed by courts of final jurisdiction.

[47] The subject, however, was coming naturally to the fore as the radio art expanded to the higher frequencies. See, for example, Balth van der Pol, "Fre-

Edwin Armstrong, the most significant inventor in frequency modulation broadcasting, combined exceptional gifts with a passionate interest in radio. Unlike his older rival, de Forest, Armstrong has devoted his entire life to radio engineering, and has been equally effective as an innovator and an inventor. His shrewd business judgment, creative originality and dogged persistence have kept him working on "insoluble" radio problems like static elimination long after most of his contemporaries have given up the task. There is a stubborn quality in Armstrong's personality which, coupled with great physical vitality, has enabled him to accomplish in the end most of the objectives that he has set for himself.

Armstrong's interest in radio technology began during his student days at Columbia. He early won recognition through his work on the regenerative circuit; and the subsequent sale of this and the superregenerative and superheterodyne patents gave him a small fortune. Armstrong became one of the leading authorities in the world on radio technology. His appointment to a professorship at Columbia in 1934 provided a stimulating environment and freedom for further pursuit of research.

One of the major problems which Armstrong had been eager to solve was the elimination of static. His first work with Pupin had been in this field, and for eight years (1914–1922) he had wrestled with the task without making any significant progress.

> My early failures here [Armstrong has reported] were a chastening experience and it was two years before I regained sufficient confidence to tackle this particular problem once more.[48]

In 1924, however, Armstrong again set to work to overcome static. Previous experimentation had shown that natural static could not be filtered out by a receiver, since it was practically identical in nature with the radio waves used for broadcasting. Armstrong determined to make an attack from another angle. He worked to produce a new kind of wave for broadcasting—differ-

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quency Modulation," *Proc.* I.R.E., Vol. 18, July 1930, pp. 1194–1205; Hans Roder, "Amplitude, Phase and Frequency Modulation," *Proc.* I.R.E., Vol. 19, Dec. 1931, pp. 2145–2176; and J. G. Chaffee, "The Detection of Frequency Modulated Waves," *Proc.* I.R.E., Vol. 23, May 1935, pp. 517–540.

48 Interview with the author, July 1945.

ent in character from that of static. This led him to re-examine frequency modulation as a possible solution.

Frequency modulation was not a new principle. It had its origin shortly after the invention of the Poulsen arc, when inability to key the arc in accordance with spark transmitter practice made a new method of modulation necessary. In the early 1920's Westinghouse engineers had advocated frequency modulation as a means of reducing the band width of broadcast stations and thus gaining more channel assignments.[49] Dr. Carson of the Bell laboratories published[50] a very thorough analysis of FM, in which he showed the fallacy of this particular proposal. But he went too far in discounting the method, and subsequent investigators accepted his conclusions as a general discrediting of frequency modulation.

Armstrong was not so inhibited. The vigor and originality of his experiments ultimately brought results. Toward the end of 1933 he had perfected a system of frequency modulation which seemed to overcome natural and many forms of man-made static.[51] He then set out to put his invention to work. He was a large stockholder in RCA and turned naturally to it for tests. Some laboratory demonstrations were arranged at the end of 1933, but RCA engineers were not sufficiently convinced to recommend its adoption without further trial and development work. In 1934, the apparatus was moved to an NBC low-power[52] television station in the Empire State Building, and tests were continued. Successful results over a distance of 65 miles were achieved. However, disturbing factors such as fading and interference from automobile ignition systems were apparent. Armstrong was convinced that these could be overcome by higher power, and tried unsuccessfully to persuade the RCA officers to

[49] *FM and Television*, Nov. 1944, p. 29.

[50] John R. Carson, "Notes on the Theory of Modulation," *Proc.* I.R.E., Vol. 10, Feb. 1922, pp. 57–64.

[51] Natural static can be differentiated from man-made static caused by automobile ignition systems, power lines, electrical machinery, etc. Previous exploration had shown that natural static became less of a problem in high and ultra-high frequencies, although these in turn created other problems. Armstrong was the first to produce a commercially workable system of overcoming natural static in these higher frequencies.

[52] This was the highest-power television transmitter in operation, although it was only 2 kilowatts.

raise the power of the transmitter to 20 kilowatts. According to Armstrong:

> The Radio Corporation declined to undertake the task of putting the system into public use. Various reasons were advanced to prove the impracticability of the system, such as its alleged inability to work beyond the horizon, the necessity of constructing new transmitting stations, and the high cost of new receivers. The proposition was also advanced that if amplitude modulation was used in the ultra-high frequency range, substantially the same freedom from noise could be secured, as well as the same quality of reproduction. Subsequently, when the better quality of frequency modulation was demonstrated, the proposition was advanced that the public would not appreciate it and did not want it.[53]

Armstrong felt that this attitude left him with the alternative of either abandoning his work or building the high-power transmitter himself. He determined to go ahead with FM. Building a transmitter of his own would not normally have been possible for a university professor; but Armstrong was a man of wealth. He also had the engineer's desire to "make things work." Convinced that the public could be made to see the real advantages of FM, he undertook the ambitious task of promoting frequency modulation independently of the large established firms.[54] Their seeming indifference merely intensified his determination to put across his invention.

First, he found a small manufacturing firm in New York—Radio Engineering Laboratories—to build his modulator.[55] Then he embarked on a lecture tour throughout the United States in which he gave dozens of FM demonstrations. Unable at first to obtain a construction permit from the FCC, he stormed until he got one. Single-handedly, also, he battled for space on the spectrum. He found a valuable ally in John Shepard,[56] owner of the

[53] Edwin H. Armstrong, "Frequency Modulation and Its Future Uses," *Annals of Am. Acad. of Pol. and Soc. Sci.*, Jan., 1941, p. 4.

[54] General Electric was the first of the large manufacturing firms to show keen interest in Armstrong's system. It asked for and obtained a license under his patents and instituted a broad program of investigation resulting in FM stations in the Schenectady area and the installation of relay links for FM program transmissions.

[55] He purchased his transmitter from RCA and erected his station in Alpine, New Jersey, just outside New York City.

[56] And also in the company's chief engineer, Paul deMars, whom Armstrong

Yankee network. The static problem was particularly acute in New England, and Shepard decided to erect an FM station in the vicinity of Boston.[57] Since Shepard was regarded as an extremely shrewd businessman, his decision had a dynamic effect on the rest of the industry.[58]

Soon applications for broadcasting licenses began to flood the FCC. By January, 1940, 150 applications had been filed with the Commission, and 20 stations were operating or about to function.

All this activity was very expensive for the inventor. Armstrong has testified that, up to 1940, it cost him personally "between $700,000 and $800,000" [59] to promote his FM system and he had received no revenues in return. However, by March, 1940, 10 concerns had been licensed by Armstrong to manufacture FM receivers at a royalty rate of 3 per cent of the net selling price.

Frequency modulation differs from amplitude modulation in the following respects. In standard broadcasting, an electrical pump at the base of the antenna pumps electricity into the antenna and sucks it back again a great many times per second. The current is modulated by superimposing a voice current which changes the signal strength in accordance with the fluctuations of the voice. Throughout this process, the electrical pump continues to operate at a constant speed. In frequency modulation, on the other hand, the strength of the antenna current does not vary, but the *speed of the electrical pump is changed* in response to fluctuations in the voice.

When FM waves enter the receiver, they are combined with vibrations from the oscillator to produce an intermediate frequency. They then pass through a part of the set not found in AM receivers, a "limiter," which is a combination of tubes that chops off the tops and bottoms of the waves, so that they are now all of the same amplitude or height. Since the FM receiver is designed to be responsive to changes in frequency of the in-

describes as "a man of great vision and courage." Letter to the author, October 12, 1947.

[57] Subsequently he erected a station on Mt. Washington, New Hampshire.

[58] John Shepard became the first president of FM Broadcasters, Inc., an organization of stations having licenses, construction permits or applications for FM. By 1940 membership had reached 55.

[59] F.C.C. *Hearings*, March, 1940, reported in *Electronics*, April, 1940, p. 14.

coming signals rather than changes in amplitude, and since most static is predominantly amplitude modulated, the static signals are eliminated. The waves still have their varying spacing, as determined by the original sounds, and when they pass into the final detector, these differences in frequency are converted back into sound again.

FM today has clearly demonstrated certain of its advantages. It is superior to standard AM against *natural static* (though much of this is due to the use of ultra-high frequencies, *per se*). Moreover, no one has yet succeeded in devising an AM system which is as effective as FM at overcoming man-made static at high frequencies. In addition, FM reduces noise and increases selectivity. And, despite the increased band-width[60] required, the comparative lack of interference between two FM stations on the same frequency allow the placing of more FM stations in the same region.

FM has been making steady progress as an innovation. Up to April, 1946, more than 800 FM applications had been filed with the FCC. Of this number, 70 per cent were from standard broadcast licensees. Newspapers account for half of the remaining applications. Twenty channels have been reserved for noncommercial and educational stations. Thousands of FM receiving sets are in use for police and fire department work, railroad signalling and emergency services, all of which FM is ideally suited to serve.

A significant feature of FM's introduction is the bitterness and animosity which have been aroused between its sponsors and RCA. FM advocates are convinced that RCA, either by its apathy or by a carefully planned resistance to FM, was opposed to this new system of broadcasting. This opposition, if it existed, has had less substance in recent years, since NBC in 1940 put into operation the first FM station in the New York area, and since RCA actively pushed the production of FM receivers in the low-priced field.[61]

[60] FM requires a band-width of 200 kilocycles; an AM transmitter of equal fidelity would require 40 kilocycles.

[61] Murray G. Crosby in 1943 received the Fellow Award of the Institute of Radio Engineers "for his contributions to the development of high frequency radio communications, including a careful study of frequency modulation."

The controversy raged about the 1935–1939 period, when RCA did little that the public could perceive to exploit FM.[62] And Armstrong shows no tendency to let sleeping dogs lie. His brief before the FCC, filed in October, 1947, repeats in detail the story of his early struggles.

As the acknowledged leader of the radio industry in 1935, RCA showed an indifference to Armstrong's system that was tantamount to a denial of the merits of the scheme. There may have been various reasons for this. RCA was beginning in 1935 to reach pay-dirt in its electronic television research—a program which culminated a decade of work and the expenditure of large sums. It was apparent that both FM and television would require several years of additional experimental and engineering work, with commensurately large budgets. It was likewise clear to both engineers and management of RCA that television and FM would be competitive for channel space in the same region of a crowded spectrum, and that allocations to one service would necessarily be given only at the expense of the other. RCA may have chosen then to put its money on what was clearly the more important innovation.

Yet it seems obvious that RCA, whatever its merits in this controversy, was at fault in its handling of the situation. It should have better understood the caliber of the man it was thwarting, and should have been able to commit itself and its energies to television at that time without antagonizing Armstrong and the group which favored FM. RCA's appearances before the FCC *for* television space were certainly construed as a movement *against* FM. Regardless of RCA's wish for "more time to explore" FM—which may have been reasonable from one point of view—the public and the radio industry saw only that RCA did not endorse Armstrong's system, made no plans to put it to commercial use, and on various occasions damned FM with faint praise.

On the other hand, some blame may accrue to Armstrong. The temperament, stubbornness and determination which character-

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And in 1945, the invention of the "ratio detector" by Seeley of RCA provided a more efficient and economical circuit than had been available before.

62 However, RCA engineers were engaged in research on frequency modulation, during this period, and between 1933 and 1939 RCA engineers made 66 patent applications for inventions relating to frequency modulation.

TABLE XXI: GROWTH OF FM BROADCASTING *

YEAR	STATIONS				RECEIVERS
	Experi-mental	*Non-commercial*	*Commercial*	*Total*	
1938	1			1	
1939	7			7	
1940	11			11	
1941	14	2	18	34	
1942	9	3	36	48	
1944	3	5	44	52	500,000 †

* *FM and Television*, Nov., 1944, p. 29.
† Includes receivers capable of receiving both FM and AM.

ized his encounters with de Forest over patents, and which spurred him on in the contest against static, also militated against a smooth campaign to win the support of RCA for his system. Armstrong undoubtedly has the type of rugged personality which counts anyone not enthusiastically for him on the side against him; and he carried the campaign for FM as though it were a personal crusade against the unbelievers.[63]

Nevertheless, it is Armstrong's conviction that RCA's initial decision was to stall, or resist the introduction of FM—either on the ground that early tests did not prove its commercial superiority, or that its foreseeable advantages were not such as to justify tossing standard AM overboard—and that only since 1939 has the company had any change of heart.

It is my own belief that the large receiving-set companies were not responsible for the pioneering work on FM and reacted to its introduction with varying degrees of stubbornness or apathy. The imagination of an independent inventor like Armstrong and a small but aggressive broadcasting concern like the Yankee Network were, I think, *essential*, both for the original research and for the subsequent adoption of this important innovation. Thus, although the record of this chapter shows that the most significant contributions to advancing radio technology have come from the large industrial research laboratories, it is also of prime importance to encourage other competitive sources of new ideas.

[63] Armstrong also levels the charge of disinterest against CBS.

Chapter IX: THE RISE OF INDUSTRIAL RESEARCH—TELEVISION

I had considerable difficulty in securing patent protection. . . . My experience in this regard has impressed me tremendously with the importance of a good patent lawyer in the process of invention.—VLADIMIR K. ZWORYKIN.

WE ARE discussing television in a separate chapter because of its importance as an innovation. As in radio, the basic conception of electronic television was evolved many years ago by university scientists. But the developmental problems have proved so difficult and expensive that the principal burden of translating these concepts into an operational product has had to be carried by the large industrial research laboratory. This affords us an opportunity to assess further the strengths and weaknesses of the great corporation in bridging the gap between fundamental research and invention.

1. European Origins of Television

The early exploration of television was carried on primarily in Europe and largely by university scientists. The progress in electrical communications that took place in the first half of the nineteenth century, culminating in the invention of the Morse telegraph and comparable developments in the field of photography, had led scientists to conceive of the possibility of transmitting images over wires. While photo-telegraphy should not be confused with television, the techniques are sufficiently similar so that this early work was of considerable assistance in the subsequent development of television.

In 1862 the Abbé Caselli devised a crude system of photo-telegraphy which made possible the first long-distance transmission of images by electricity: his process involved transmitting small portions of a photograph until a complete picture was constructed at the receiving end. Caselli, an Italian-born priest whose work and experiments were aided by Napoleon III, opened several commercial stations in France where messages could be sent over the telegraph lines in the sender's own handwriting.[1] This had more curiosity value than anything else. It was not practical to stop all telegraph traffic during the lengthy process of sending a picture; and the received image frequently had dots and dashes all over it.

Not until 1884 was a mechanism designed which made it possible to transmit a reproduction of live moving objects.[2] A German engineer, Paul Nipkow, in that year invented what has come to be known as the scanning disc. Television depends on a peculiarity of the human eye known as "persistence of vision." Both television and the movies make use of this characteristic to present successive scenes at such a speed that the observer thinks he is seeing continuous action. Nipkow's scanning disc, the first attempt to create this impression, was perforated with a single spiral of holes, each hole a little nearer the center than the preceding one. When the disc was placed directly between a light source and an object and slowly rotated, the light shone through one hole at a time. After one complete turn every element of the object had been illuminated by the narrow beam of light from the lamp.[3] Passing through the holes in the scanning disc and striking the object to be televised, the light next encountered a selenium cell.[4] Each element of the picture was received there separately, and a stream of current variations was sent along a wire to a receiver. At the receiving end Nipkow attempted to reconstruct the picture on a screen by means of a synchronized disc. But he was never able to do so.

Professor Lazare Weiller in 1889 originated another scanning system similar to that of Nipkow. The disc was replaced by a

[1] Harlow, *op. cit.*, pp. 203–204.

[2] Nipkow-German patent No. 30,105, 1884, known as the "electrical telescope." His patent lapsed because he was unable to pay the costs of extending it. For the next thirty-two years he worked as an engineer for a railway signal company in Germany.

[3] Lee de Forest, *Television Today and Tomorrow* (New York, Dial Press, 1942), pp. 23–24.

[4] The discovery of the light-sensitive properties of selenium had been made accidentally in 1873.

revolving drum mounted with small mirrors which reflected on a selenium screen the image to be televised.

Such methods of mechanical scanning were later to prove of considerable developmental importance; the receivers which were marketed in the early days of English and German television used either the Nipkow disc or the mirror drum. These methods, however, were merely exploratory stages leading to the practical reality of electronic television.

The experimental work of Nipkow, Weiller and others was done with selenium cells; but selenium has a serious defect in that it reacts slowly to variations in light. Although it could be used for photo-telegraphy which did not require instantaneous recording of the elements of the picture, it was not suitable for moving objects. For television some substitute was necessary. This came eventually through the application of the discovery made by Hertz that electrons are emitted from alkaline metals negatively electrified under the effect of light.[5] In 1905 Julius Elster and Hans Geitel of the Gymnasium at Wolfenbüttel developed a photo-electric cell based on Hertz's pioneer work.[6]

While work was being done on photo-electricity,[7] scientists were also devising an alternate system of scanning which ultimately was to prove more effective than the Nipkow disc. The foundation of the principles of scanning by electronic rather than mechanical means was laid by Rosing in Russia about 1907. His contribution, in turn, rested on the earlier evolution of the cathode-ray tube.

In 1897 Ferdinand Braun[8] of the University of Strassburg made his important development of the cathode-ray oscilloscope, carrying considerably further the previous work that had been done on the cathode-ray tube by Hittorf, Crookes and others.[9]

[5] Hertz, *Ann. d. Physik*, Vol. 31, 1887, p. 983.

[6] Elster and Geitel, *Ann. d. Physik*, Vol. 41, 1890, p. 161; *Phys. Z.*, Vol. 14, 1913, p. 741.

[7] In 1905 Albert Einstein showed that the quantum theory would explain the photo-electric effect. He proposed an equation stating the way in which energy is transferred from the light quantum (also called a "photon") to the electron. For this Einstein received the Nobel Prize in physics in 1921.

[8] Braun, whose wireless inventions were incorporated in the Telefunken system, shared with Marconi the Nobel Prize in physics in 1909.

[9] For an account of this early and very important cathode-ray work, see Stark, *Die Elektrizität in Gasen* (Leipzig, Barth, 1902).

When a cathode and an anode were placed at opposite extremes in a tube and made a part of an electric circuit, the cathode emitted a stream of electrons which flowed across the gap to the positively charged anode. Braun found that he could deflect this stream by allowing a magnetic field to cut across the path of the electrons. He placed two sets of electro-magnets around the neck of the tube through which the electron beam traveled. One pair of energized magnets could sweep the beam from side to side, the other pair directed it up and down. Since certain chemicals glow under the impact of electrons, Braun placed a fluorescent screen at the end of the tube to indicate the changing electron paths caused by magnetic deflection.

Professor Boris Rosing of the St. Petersburg Technological Institute conceived the idea of using a Braun tube for television by inserting into it a screen of photo-electric cells. On this he was able to receive very faint images from a mechanical transmitter near by.[10]

There were still many obstacles to overcome. First, someone had to design a television camera which would break down the picture into its smallest elements and bring out a sharp distinction between light and shade. (Zworykin accomplished this ultimately by his iconoscope, and Farnsworth with his image dissector; but neither of these developments was possible until more fundamental work had been done on the photo-electric cell.) Next, the video current had to be amplified to assure sufficient signal strength for reception. The high-vacuum tube made this possible. And there was the problem of designing reception apparatus sufficiently sensitive to reconstruct the original image in a form that could be recognized. Further developments in the cathode-ray tube were to solve this. It was also necessary to devise methods of accurate synchronization between the transmitting and receiving apparatus which would not be affected by interference. And, lastly, if television were to achieve widespread use, some method of relaying the signal had to be devised

[10] Rosing took out a British patent on his device in 1907 (No. 27,570). Shortly afterwards, A. A. Campbell-Swinton of London University suggested in a letter to *Nature* (June 18, 1908) that the television problem might be solved by using two cathode-ray tubes, one at the receiver and one at the transmitter, but he never tried out such a system.

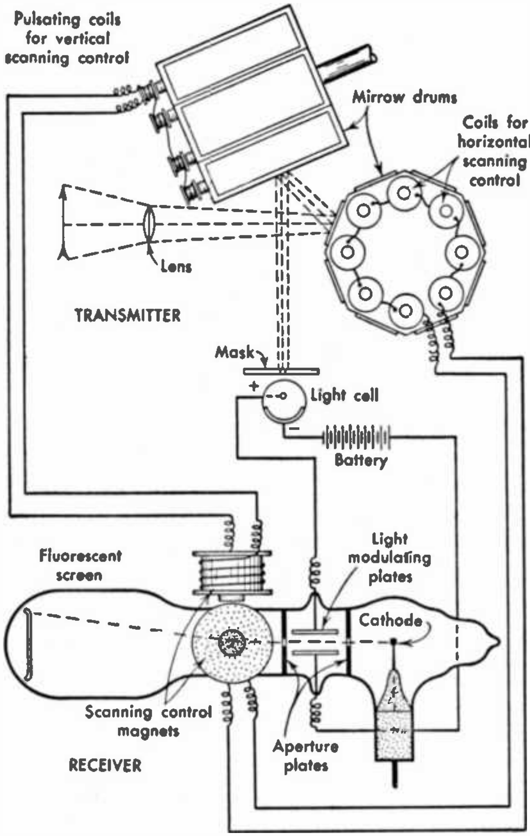


Diagram of the television system developed by Boris Rosing in 1907, utilizing mechanical scanning in the transmitter and an electronic receiver. (Courtesy Hylander and Harding, *An Introduction to Television*, The Macmillan Company)

to overcome the "line of sight" limitation on transmission.[11]

The original exploration of the field of television took place almost entirely in Europe. American inventors, however, were primarily responsible for translating this early work into commercial electronic television.

[11] The ultra-short waves necessary to high-definition television behave in many respects like light waves. This limits their effective range to the visual horizon from a transmitter. This same feature causes television waves to be cut off or reflected by obstructions, producing multiple images at the receiver.

2. The Major American Developments

Few products can progress from the university laboratory to large-scale commercial use without substantial and sustained expenditures for advanced engineering development. The time lag between fundamental discoveries and their practical applications is due primarily to this fact.

Television provides an interesting illustration of the way in which some degree of monopoly can shorten this time lag. As in radio, the basic discoveries in television were made by university scientists, studying new phenomena of Nature. But, even more than in radio, university research could only point the way for further work which was to require developmental expenditures entirely beyond the reach of any group of university scientists. Indeed, the expenditures were such that competitive companies with small profit margins were in no position to assume them.

Until recently, therefore, the magnitude of the technical problems to be overcome discouraged most radio manufacturing companies in the United States from undertaking television research. In an industry in which total sales were expanding rapidly every year, most radio companies did not feel any necessity to divert their energies to a costly new product as long as its commercial development did not seem imminent.

The major research contributions to television in this country before World War II came from the Bell Telephone Laboratories, General Electric, Westinghouse, RCA and Farnsworth. And RCA, more than any other company, was responsible for the development of a modern electronic system of television.

Television was ready for commercial introduction in this country by the outbreak of the war. A few hundred sets were sold in 1941, and regular broadcasting programs were started in New York, Philadelphia and Chicago. The war then put a stop to further direct development work; yet television inevitably profited by wartime research in related fields such as radar and guided missiles. This, however, is a special study in itself, and our treatment here will be confined chiefly to the prewar story.

(a) MECHANICAL TELEVISION

The earliest significant American research on a complete system of television transmission and reception was undertaken by Dr.

Herbert E. Ives of the Bell Laboratories.[12] His work developed from research on telephoto transmittal in 1923 and 1924—a project which led to the wire-photo service now in use throughout the country. Ives's exploration of television was designed "to keep the Bell System abreast of the general advances in the art of television and to perform such work in connection with new ideas and suggestions as to methods, apparatus and field of service as may be necessary to properly evaluate them." [13]

In 1924 mechanical scanning showed greater promise for immediate commercial operation than electronic methods. Ives worked, therefore, on a mechanical scanning system.[14] He had a sizable research staff assigned to him, and the project, over a period of years, cost about $250,000. Through this research, mechanical scanning was significantly advanced. In 1927 Ives was able to report in his log book, "This afternoon at about three o'clock connection was made by wire [from New York] to Washington. . . . The first viewing of human beings at a distance of hundreds of miles was completely successful." [15] Ten days later Herbert Hoover broadcast from Washington to the Bell Laboratories auditorium in New York. As he spoke his face was shown on a "large" neon tube screen, 2 by 2½ feet in size. Reporting on the event, the *New York Times* wrote: "At times the face of the Secretary could not be clearly distinguished. He looked down as he read his speech and held the telephone receiver up so that it covered most of the lower part of his countenance. There was too much illumination also in the background of the screen. When he moved his face his features became clearly distinguishable. Near the close of the talk he turned his head to one

12 Early photo-emissive cells had a thick layer of metal as the emitting surface. In 1924, Ives started work on a "thin-film cathode." In cells of this type, the emitting layer is so thin as to be of atomic dimensions, and a great increase in sensitivity can be obtained by depositing this thin film on specially treated metal surfaces. See *Journal of Astro-Physics*, Ives, Vol. 60, 1924, p. 290.

13 F.C.C. *Report*, p. 200.

14 The Bell Laboratories have not contributed directly to developing a system of electronic television, that work having been done primarily in this country by RCA and Farnsworth. But in the years immediately preceding the war, the Telephone company undertook extensive developmental work on the coaxial cable and on relay systems for network broadcasting of television.

15 Herbert E. Ives, "Television: Twentieth Anniversary," *Bell Laboratories Record*, May, 1947, p. 190.

side and in profile his features became clear and full of detail." [16]

Of the television work of the Bell Laboratories in the next few years, Ives writes: "In 1928 the development of large-dimension apparatus of great light-gathering power permitted outdoor scenes to be televised by daylight. In 1929 television in color by a three-color, three-channel method was shown. In 1930 a complete two-way telephone-television system was set up between the Laboratories and 195 Broadway. It was maintained for over a year and was used by more than 10,000 people." [17]

Yet despite these advances, the images remained crude and the interest aroused was primarily that of curiosity. The inadequacies of mechanical systems were brought out sharply by the experience of the Jenkins Television Company, which attempted to commercialize broadcasting programs. While Ives was conducting his experiments on television in the mid-twenties, an independent American inventor, C. F. Jenkins, gave the first public demonstration of mechanical television in the United States. His apparatus was not so well engineered as that of Ives, and the demonstrations were far from satisfactory. The basic difficulty was in the scanning process. The clearness of a television picture depends in part on the number of lines into which it can be broken by scanning. Ives produced a picture of 48 lines and Jenkins's experiments varied from 30 to 60. (Compared with this, the standards set for electronic television in 1941 were 525 lines.) It was possible, by mechanical scanning, to produce the Mickey Mouse type of cartoon with some success, but the interest of the audience flagged rapidly after the initial novelty had worn off. Nevertheless, in 1929 the Jenkins Television Company was formed to manufacture both transmitting and receiving apparatus. Commercial programs were announced for 1930, and the Jenkins company licensed a number of manufacturers under its patents to make sets. However, before regular broadcasting was started, it became obvious that the company could not make a profit, and Jenkins Television went into receivership.[18]

The other important experimental work undertaken on a

[16] *Ibid.*, p. 192.

[17] *Ibid.*, p. 193.

[18] The De Forest Company acquired control of Jenkins Television in 1929 and later RCA purchased the patents along with the De Forest assets.

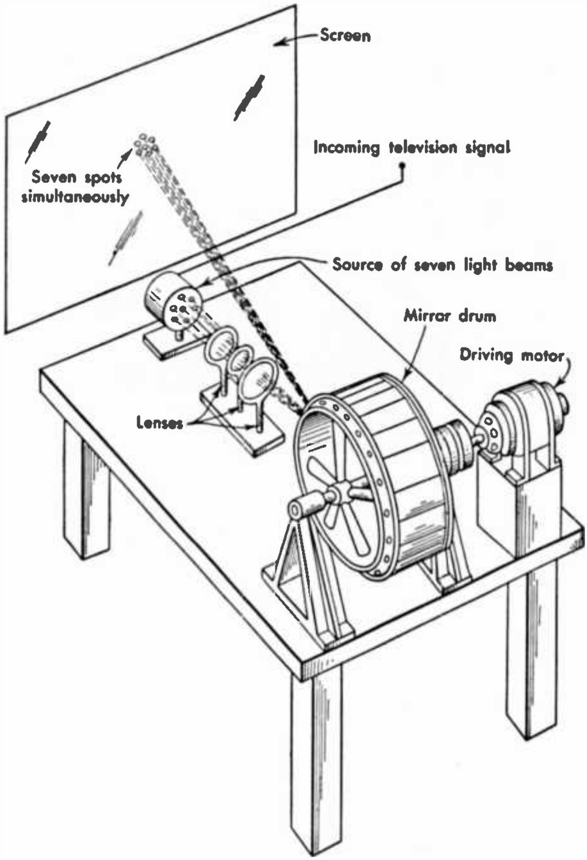


Diagram of the mechanical television system developed by Dr. E. F. W. Alexanderson in 1927. This system used a mirror drum for scanning. (Courtesy Hylander and Harding, *An Introduction to Television*, The Macmillan Company)

mechanical system of television in the United States was under the direction of Ernst F. W. Alexanderson of the General Electric Company's Schenectady laboratories.[19] Dr. Alexanderson made a number of original contributions to the development of a system of rotating mirrors for scanning. The mirrors were set

[19] Alexanderson was "lent" to RCA as chief engineer from 1920 to 1924, and did some of his television work there.

on a cylindrical drum and revolved at *high speed;* but even this did not permit sufficiently rapid scanning to break down the image into a great many lines. It gradually became apparent that this could be obtained only by electronic means.

(b) ELECTRONIC TELEVISION

1. Zworykin and RCA

The principal contributors to the original development of systems of electronic scanning in the United States were Zworykin and Farnsworth. Zworykin had received his basic training in electrical engineering at the Institute of Technology in St. Petersburg, and his advanced training at the Collège de France.[20] While a student at St. Petersburg, he became very much interested in Professor Rosing's work on television and asked permission to assist him in his private laboratory.[21] Rosing, who was using a Braun cathode-ray tube for reception and a mechanical mirror drum for scanning, was able to reproduce only a simple image—such as that of a cross—rather faintly on the receiving tube.

In 1917, when Zworykin was working for the Russian Wireless Telegraph and Telephone Company, he suggested to the chief engineer that he be given an opportunity to work on television. "This moment," he later said, "can be called 'the actual beginning' of my independent work in television." [22]

After the Russian revolution, Zworykin came to America (1919). By then he had already evolved in his mind a method of transmitting as well as receiving television signals by electronic means.[23]

The major difficulty in perfecting an electronic camera tube was the low light sensitivity of photo-electric cells. Since the time when the scanning beam paused on any one cell was extremely short, a very feeble signal resulted. Zworykin conceived a method whereby the light, as it struck the photo-cells, created

[20] In the laboratory of Professor Paul Langevin, where he studied x-rays and gaseous discharges. Testimony of Dr. Zworykin in the U.S. Patent Office Interference No. 64,027. Record for Vladimir K. Zworykin, p. 65.

[21] Zworykin Record, *op. cit.*, Testimony of Vladimir K. Zworykin, p. 66.

[22] *Ibid.*

[23] In the interference proceedings with Farnsworth, Zworykin stated that he conceived the idea in 1917 when he was working for the Russian Wireless Telegraph and Telephone Company. Zworykin Record, *op. cit.*, p. 65.

an electrical charge, which was stored temporarily;[24] by releasing this charge later, it was possible to increase the sensitivity of the electronic camera very considerably. But while Zworykin had conceived this idea in general terms in 1919, it was far from being an operative conception. He discussed with a Russian friend, Mouromtseff, the possibility of their working together and developing television apparatus; but Mouromtseff was convinced that without money it could not be done.[25] It was a number of years, therefore, before Zworykin had any opportunity to develop his ideas to the point of actual operation.

Zworykin joined the Westinghouse staff in 1920. At that time, the focus of attention in radio research was on sound broadcasting which was just coming into its own; and no research was being undertaken on television by any of the important laboratories. Zworykin's expressed desire to work on television fell on deaf ears, and he was assigned to other work. He resigned from the laboratories in October, 1921, to go to the C and C Development Company in Kansas, but returned to Westinghouse in February 1923. He made arrangements with the Westinghouse company to retain the rights to the television inventions which he had disclosed in 1919, and gave Westinghouse an exclusive option to purchase the patents for a certain price if it wished to do so later.[26]

After Zworykin rejoined the Westinghouse laboratories, he again asked for an opportunity to work on television.[27] This time the response was more favorable. The manager of the research department, Samuel Kintner, had decided independently that the company should undertake some study of television. Kintner made a thorough canvass of the laboratory and concluded that Dr. Zworykin was "the only one who was sufficiently interested

[24] This storage effect which made Zworykin's iconoscope potentially more sensitive than Farnsworth's image dissector had been proposed by Campbell-Swinton, of whose work Zworykin was not aware in 1919. Campbell-Swinton's work was purely theoretical and apparently did not receive much attention. He made no attempt to patent his methods. Moreover, having studied Campbell-Swinton's proposals subsequently, Dr. Zworykin does not believe that they were operative. Interview with Dr. Zworykin, Aug. 1, 1944.

[25] See testimony of Ilia E. Mouromtseff in the U.S. Patent Office Interference No. 64,027. Record for Vladimir K. Zworykin, p. 103.

[26] This option was not exercised until 1934.

[27] Testimony of Zworykin, *op. cit.*, p. 81.

to justify making an assignment of this work to him." [28] He was therefore encouraged by Kintner to prepare some demonstrations.

These proved disappointing, and Kintner concluded that it would be a long time before any practical success could be obtained. He suggested that the inventor work first on photo-electric cells, which had many different applications other than their important use in television. During the next few years Zworykin developed a caesium-magnesium photo-cell which was an advance on any previous photo-cell.[29] He also worked on sound movies. Finally, in 1928,[30] he succeeded in producing a practical photo-electric tube for television transmittal, which he called the "iconoscope." This was to prove a revolutionary invention.

The principle of the iconoscope will be described in detail in order that the process of television transmission may be more effectively understood.

In the iconoscope, the illuminated image to be transmitted is focussed through an optical lens onto a photo-sensitive mosaic plate. This plate is a mica sheet coated with tiny particles of silver. Each particle is in reality a small photo-cell, and is insulated from its neighbors. The reverse side of the mica sheet has a thin coating of metal and is called a signal plate. A signal wire leads from this plate to an amplifier tube.

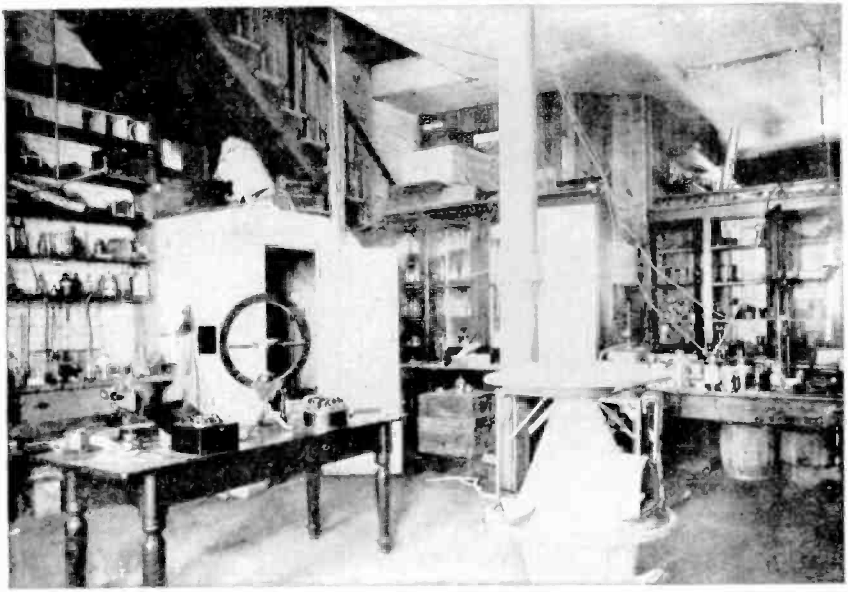
The iconoscope contains an electron gun, the function of which is to project a beam of electrons upon the mosaic plate. This beam is made to scan the mosaic, line by line from top to bottom, with the odd and even lines interlaced. When the electron beam passes over the individual photo-cells, each of which has been charged by the light rays falling thereon from the illuminated image, the electrons neutralize the positive charge and enable the metallic plate on the back of the mica sheet to discharge. This series of tiny discharges is then amplified and transmitted as a "video signal."

After each horizontal line of the picture has been scanned, the electron beam travels back to a lower line at the left-hand side of

[28] Testimony of Samuel M. Kintner in Zworykin Record, *op. cit.*, p. 112.

[29] The General Electric Company in England had developed a photo-cell of caesium and silver but this was not as sensitive.

[30] The date of his patent application.

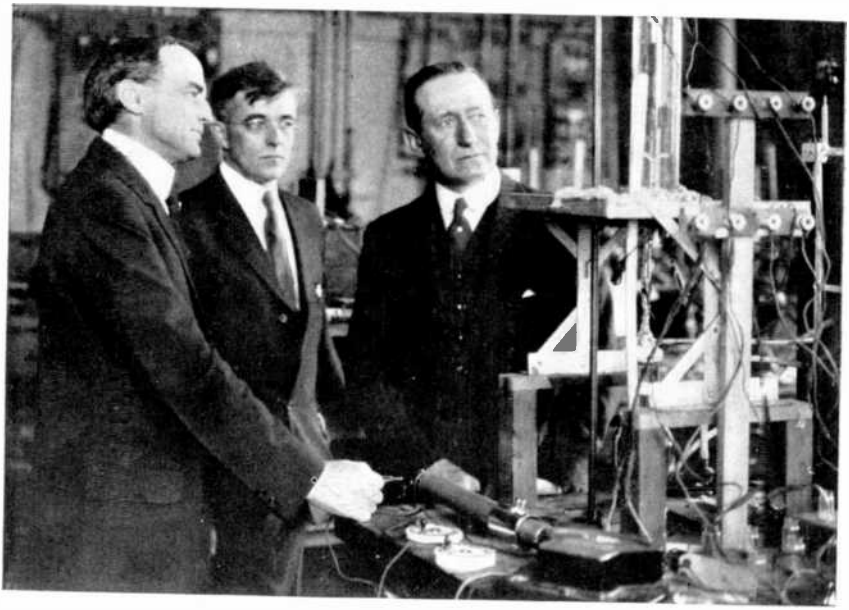


Laboratory of the American Bell Telephone Company in Boston, 1886. (Courtesy American Telephone & Telegraph Company)

Architect's conception of the new Bell Telephone Laboratories, Murray Hill, New Jersey. The unit to the right of the main driveway was completed in 1941. The other unit is now under construction. (Courtesy AT&T)

Barn in Schenectady used by Steinmetz as a laboratory in 1900, and by Whitney and his assistants when the GE research laboratory was formed. (Courtesy General Electric Company)

Owen D. Young, Irving Langmuir, and Guglielmo Marconi inspecting apparatus in Langmuir's laboratory in Schenectady. (Courtesy G. H. Clark Radio Collection)



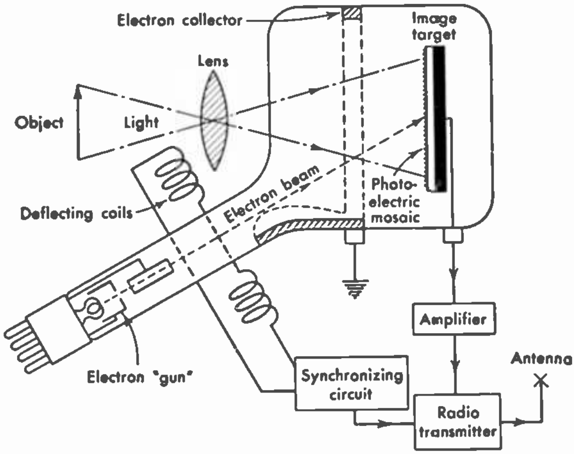


Diagram of the iconoscope showing the electron "gun," the deflecting coils, and the photoelectric mosaic. (Dunning and Paxton, *Matter, Energy, and Radiation*, McGraw-Hill)

the picture. In order to avoid producing a signal from this backsweep, a "blanking signal" is created to erase the effect.

Synchronizing signals have to be sent at the same time as the video signals in order to keep the scanning beam at the receiver in step with the scanning at the transmitter. The only time at which this can be done without mutilating the picture is during the blanking period.

The importance of the iconoscope was recognized almost immediately. Mr. Sarnoff, as vice-president and general manager of RCA, got in touch with Dr. Zworykin personally and asked him about his progress and the prospects for commercializing electronic television. Sarnoff, who had keen imaginative insight, was greatly impressed, and shortly thereafter Zworykin was told that he could have additional assistance. Up to that time he had been working with very little help. He was now given four or five assistants, and was able to push ahead rapidly with his experimental work. Dr. Zworykin dates the end of his struggle for recognition from this discussion with Mr. Sarnoff.

Sarnoff also made an effort to strengthen Zworykin's patent position. In 1923 the Westinghouse company had filed an application in Dr. Zworykin's name for a patent on a camera tube which disclosed the basic idea of the storage effect.[31] Concerning this application, Zworykin has said:

> I had considerable difficulty in securing patent protection. I didn't write English well and I was working at the beginning of a new art. My experience in this regard has impressed me tremendously with the importance of a good patent lawyer in the process of invention.[32]

Until 1928, Zworykin had worked primarily to perfect an electronic photo-tube which was sufficiently sensitive to transmit a satisfactory image. But a great deal of work also remained to be done on circuits and methods of synchronization. Zworykin and his research assistants, therefore, turned their attention to these other elements.

In the meantime, another inventor, Philo Farnsworth, working independently, had developed a camera tube which he called the "image dissector." Farnsworth had also been working on television circuits and methods of synchronization, with more assistance than Zworykin. Thus, when it came later to a showdown on patents, it appeared virtually impossible for RCA to manufacture electronic television apparatus without a Farnsworth license. This situation was to lead ultimately to cross-licensing agreements between RCA and Farnsworth.

The successful development of the iconoscope and the image dissector quickly convinced almost all television engineers that electronic methods were more promising.[33] In 1930, when RCA took over from GE and Westinghouse the research that was being done in radio, Dr. Zworykin was transferred to RCA. Zworykin's work expanded rapidly; by 1932 RCA had about sixty people working in television.[34] This proved to be the high tide of research in television for some years to come.

From 1929 to 1932 it had been generally expected that commercial television might be launched at any moment; and RCA wanted to be in the vanguard of television development. Commercial broadcasting on a limited scale was already taking place

[31] Patent application No. 683,337, Dec., 1923. Interference proceedings delayed the issue of this patent for 15 years, until Dec., 1938.

[32] Interview with Dr. Zworykin, May, 1944.

[33] Thereafter, Dr. Alexanderson of the General Electric, who had been working on mirror scanning methods, largely dropped out of television research.

[34] Interview with Dr. Zworykin.

in Germany and England[35] under mechanical scanning systems; and Jenkins had planned regular broadcasts in the United States. Dr. Zworykin and some of his research associates would have liked to see electronic television introduced to the public in the early 1930's. They believed that limited commercialization would help to push forward the technical developments more rapidly. But the RCA management, in reviewing the performance of television in 1932 and 1933, concluded that practical commercial operations were still a number of years away.[36]

Zworykin, therefore, was encouraged to continue with his research, but with less pressure for immediate results and with a smaller staff. During the succeeding years he had a group of about ten people associated with him, and steady progress was made. By May, 1935, Mr. Sarnoff could report at the annual meeting of stockholders that "upon a laboratory basis we have produced a 343-line picture as against the crude 40-line television picture of several years ago. The picture frequency of the earlier system was about 12 per second. This has now been raised to the equivalent of 60 per second."[37] Sarnoff also announced that RCA would begin work at once, preparatory to getting television out of the laboratory, by building a new transmitting station on the Empire State Building in New York City. And the next year he reported that RCA was successfully transmitting television signals over the air to a point forty-five miles from this new station. Extensive development work was also initiated on a radio relay system

[35] In England, the BBC started broadcasting mechanical television on an experimental basis in 1929, using the system developed by a British inventor, John L. Baird. Short, half-hour programs were sent out five days a week. Baird receiving sets were sold originally for about £40, and the price gradually came down to about £20 in 1931. Sets were also sold in kits and parts so that the amateur could assemble them at home. The simplicity of the mechanical receivers made amateur assembly possible in contrast to electronic television systems, which were very much more difficult of home construction. In 1932 the BBC announced the further extension of television facilities on a regular broadcasting schedule and guaranteed security to purchasers of existing receiving equipment by the freezing of transmission standards at 30 lines until March, 1934. But in spite of these promotional efforts, sales of receiving sets remained very limited.

[36] In 1932 a cathode-ray receiving tube with a useful life of 1,000 hours cost about $75. It was all handmade. If electronic television sets had been made for commercial use at this time, they would probably have cost between $500 and $1,000 and the picture reception would certainly have been very crude compared with 1947 standards.

[37] Quoted from Annual Report.

TABLE XXII: TELEVISION EXPENDITURES OF RCA AND SUBSIDIARIES 1930–1939 *

Cost and expense in connection with patents and patent rights †		$2,124,000
Research and advanced development		2,651,000
New York field test		
Plant and equipment, including pertinent engineering	$870,058	
Technical operations	624,367	1,494,425
Manufacturing operations, including plant and equipment items, pertinent engineering, and other manufacturing expense, less any income from sales applicable to such costs		2,170,547
Expense in connection with preparation for development and transmission of programs (exclusive of New York field test)		813,751
	Total	$9,253,723

* Data filed by RCA with Federal Communications Commission, Apr. 3, 1940.
† To obtain adequate protection in a new field like television, it was necessary to maintain a large patent department. The interference proceedings, especially with Farnsworth, were very long-drawn-out and expensive.

which would make it possible to establish television networks.[38]

Such a prolonged period of experimentation and engineering development proved very costly. From 1930 to 1939, when limited commercialization was first authorized, RCA's expenditures were over $9,000,000. (Table XXII)

2. *Philo Farnsworth and the Farnsworth Television and Radio Corporation*

Philo Farnsworth was a fifteen-year-old farm-boy in Rigby, Idaho, when he first became interested in television through reading "popular electrical and radio magazines." At high school he discussed television with his chemistry teacher and started reading about photo-electricity and the cathode-ray tube. His chance came

[38] At the same time the Bell Telephone Laboratories were perfecting the coaxial cable as an alternative method of network transmission.

at the age of nineteen, when he was a student at Brigham Young University. Through a community chest drive in Salt Lake City he met an influential San Francisco businessman, George Everson, who listened with keen interest to Farnsworth's enthusiastic predictions about what could be done with television. Everson asked an electronics specialist at the California Institute of Technology to review Farnsworth's work, and when the scientist reported favorably, Everson persuaded a group of California bankers, headed by J. B. McCargar of the Crocker First National Bank, to back the young inventor as a speculative investment. The investigation covered the work which Farnsworth had done in developing electronic television, but did not appraise his business judgment and organizational ability.

Farnsworth, established in a laboratory of his own in San Francisco, now tried to reduce his ideas to practice. Here he began to experience difficulties. He had only a few engineers working with him; organization on an industrial laboratory basis was not necessary or possible. He worked well enough with his few associates, but he was continually thinking up new ideas to try and found it very difficult to press any of them forward to practical results. And, like many young inventors, he greatly underestimated the difficulties of successful development work. This was a new field both for him and his assistants, and many aspects were unfamiliar to them, as they would have been to any engineer of the day other than a very few high-salaried technicians of the foremost laboratories. Farnsworth had originally expected that he could create a commercial television system in a comparatively short time and with only modest funds at his disposal. This proved an illusion. Developmental expenses from 1926 to March, 1929, amounted to nearly $140,000, which was considerably more than Farnsworth or the original backers had anticipated. On the other hand, Farnsworth achieved a system of electronic television which worked in the laboratory, even though crudely, and did this essentially single-handed.

As it became clear that Farnsworth was not going to produce a practical system of television in a short period, the financial backers decided early in 1929 to get public support to carry the venture. Television was then thought to be "just around the corner," and Farnsworth's work had received so much publicity that there was no great difficulty in selling stock in the new company.

Farnsworth continued for some time to be given a free rein to develop television as he saw fit. In 1930, however, the directors strongly urged him to accept an offer from Philco to transfer his work to Philadelphia under Philco financing. This came about in the following manner: Philco was concerned over the vulnerability of its position if commercial television were to come as rapidly as predicted. The company was particularly anxious to break away from its subservient position to RCA. Zworykin was with RCA and the only alternative system of electronic television was that of Farnsworth. Philco, therefore, offered to support Farnsworth in the Philco laboratories. His research expenditures were to be credited as prepaid royalties. Farnsworth would have preferred to stay in California; but the Philco proposal offered substantial financial support while still leaving Farnsworth in control of his inventions. The offer was therefore accepted.

The arrangement lasted for two years. The Philco management was by that time convinced that, although Farnsworth was an ingenious inventor, it would take him years to develop an operating *commercial* system of television. Farnsworth's research had cost $250,000 between 1930 and 1932 and there was no evidence that the rate would decline.

Thereafter Farnsworth continued in Philadelphia with California support only. Although the stockholders [39] were becoming increasingly impatient, they concluded that they had to give the inventor free rein and hope for the best. As with RCA, the television demonstrations that Farnsworth made in 1934 and 1935 were considerably superior to what had been possible before. But the undeniable fact remained that television was not yet good enough to show promise of successful commercial introduction. And a small research company under the direction of an inventor who had no commercial instincts was at a great disadvantage in competition with the large patent resources of the Radio Corporation of America. The stockholders finally decided to take action.

The Farnsworth patents were offered for sale to both RCA

[39] Jesse B. McCargar, a California banker and capitalist, was by far the largest stockholder. George Everson of San Francisco, who had "discovered" Farnsworth originally, was also a director and stockholder.

and Paramount. Neither company was willing to pay a price commensurate with the expenses that had been incurred, which in 1938 had reached nearly $1,000,000 (see Table XXIII).

Something had to be done to get ready for commercialization. Various alternatives were explored. One suggestion was to make the company into a patent-holding and service organization in television. But it was concluded that a purely patent-holding company would be in a vulnerable position: it would be more satisfactory to manufacture television receivers and to grant licenses for the support of further research. So, in December, 1938, a new Farnsworth Television and Radio Corporation was launched as a manufacturing concern. E. A. Nicholas, manager of the licensing division of RCA, was brought in as president and Philo Farnsworth was made vice-president and director of research. The Capehart Corporation of Fort Wayne, Indiana, as well as the former radio set manufacturing plant of the United States Radio and Television Company [40] in Marion, Indiana, were purchased.

The expectation was that the Federal Communications Commission would soon authorize commercial television, and that the new company could start to manufacture television receiving sets almost immediately. This did not prove to be the case. The company therefore decided to manufacture a regular line of radio sets and to continue production of the de luxe Capehart radio phonographs.

As was to be expected, there were losses in the first year. However, the formation of the Farnsworth company coincided with the beginning of the war boom. The years 1940 and 1941 were very profitable in the radio industry and Farnsworth radios found an effective outlet through the Firestone Company and through their own sales organization. In the year ended April 30, 1942, it sold over 150,000 radio sets and was making comfortable profits. With the complete conversion of the civilian radio industry to war production after Pearl Harbor, the Farnsworth company was given a substantial number of important government contracts, including some in the television field. By 1943 Farnsworth

[40] This company had failed. It had never done anything in the field of television but had adopted the name at a time when commercial television seemed imminent.

TABLE XXIII: EXPENDITURES OF FARNSWORTH TELEVISION, INC.* 1929–1938

		Expenses	Receipts
From Mar. 27, 1929, to Dec. 31, 1929			
Original acquisition	$ 139,759		
Development expenses	15,484		
Patent expenses and legal fees	1,561	$ 156,804	
Year ended Dec. 31, 1930			
Development expenses	$ 16,229		
Patent expenses and legal fees	3,104	19,333	
Year ended Dec. 31, 1931			
Development expenses	$ 59,287		
Patent expenses and legal fees	4,895	64,182	
Year ended Dec. 31, 1932			
Development expenses	$ 93,183		
Patent expenses and legal fees	6,951	100,134	
Year ended Dec. 31, 1933			
Development expenses	$ 54,525		
Patent expenses and legal fees	16,994	71,519	
Year ended Dec. 31, 1934			
Development expenses	$ 47,184		
Patent expenses and legal fees	14,364	61,548	
License fees received			$ 5,000
Year ended Dec. 31, 1935			
Development expenses	$ 70,632		
Patent expenses and legal fees	22,039	92,671	
License fees received			53,875
Year ended Dec. 31, 1936			
Development expenses	$ 126,871		
Patent expenses and legal fees	33,413	160,284	
License fees received			10,000

TABLE XXIII (*cont'd*)

		Expenses	*Receipts*
Year ended Dec. 31, 1937			
Development expenses	$ 143,299		
Patent expenses and legal fees	30,301	173,600	
11½ months ended Dec. 15, 1938			
Development expenses	$ 109,406		
Patent expenses and legal fees	24,314	133,720	
Totals	$1,033,795	$1,033,795	$68,875

[*] Source: Registration Statement, S.E.C., No. 2-3939.

had 4,000 employees, and both the inventor and his financial backers were at last in a position to obtain substantial financial rewards for the long-drawn-out period of research and experiment, with its combination of successes and failures.

Over a period of years Farnsworth had succeeded in building an important patent position in television. By 1938 research had resulted in 73 patents and 60 applications, of which Farnsworth himself was responsible for about 75 per cent.[41] The original backers of Farnsworth had recognized the importance of patent counsel to protect their investment, and one of their first moves in 1926 was to retain a very able patent attorney in San Francisco.[42] It is not, of course, possible to create important patents where there have been no significant inventions. But a patent attorney working closely with an inventor like Farnsworth, who was full of ideas and working in an unexplored field, can greatly enhance the strength of his patent position. The result was that RCA and AT&T [43] both felt it desirable to take out Farnsworth licenses.

To consolidate this patent position, the Farnsworth companies have been involved in a long series of extensive interference pro-

[41] Registration Statement, S.E.C., No. 2–3939.

[42] After Farnsworth Television was formed in 1938 the company appointed a new and equally able patent counsel as vice-president and secretary.

[43] The Telephone company wanted the use of Farnsworth's inventions for their application to telephone communication.

ceedings. Among the more important of these were two interferences with Zworykin. The question at issue was whether certain phases of Zworykin's early work on television, which antedated Farnsworth's, gave his patent applications priority over the image dissector.

The evidence presented before the Examiner of Interferences, and successive stages of the Patent Office proceedings, indicated that Farnsworth and Zworykin worked independently and that Farnsworth's image dissector operated on a quite different principle from the iconoscope. Zworykin was not able to prove that his early disclosures covered the Farnsworth method. The rival inventors, therefore, retained basic patents on two alternative methods of television transmission.

Later in 1941 Farnsworth won perhaps its most important interference case on the George and Heim patents which RCA also controlled. From 1929 to 1932 Professor George and an assistant, Dr. Heim, had worked on a complete electronic television system at Purdue University with initial financial support from one of the large radio manufacturing companies of that period—the Grigsby-Grunow-Hinds Company.[44] The scientists made a patent application on their work covering basic electronic television developments; and a broad patent was later issued to them. Their patent was subsequently purchased by RCA.[45] Had the patent remained in force, it would have been a very serious blow to Farnsworth. But the company instituted interference proceedings, and after a long-drawn-out case Farnsworth finally won the majority of the claims in 1941. The decision meant that the patents on synchronization and other important features of modern television will not expire until 1958 (seventeen years from 1941, and about thirty years after the original work was done).

Seven or eight other Farnsworth patents have also been the subject of interference suits (some of them still to be settled). The Farnsworth company has won most of these cases.

Of the persons who have made the most significant contribu-

[44] Grigsby-Grunow, like Philco, was worried about the possible impact that television might have on the radio industry. The company therefore made arrangements with Professor George of Purdue to undertake research on television. Grigsby-Grunow went bankrupt in Feb. 1934.

[45] As part of a move by RCA to strengthen its position in television.

tions to television Farnsworth alone has worked almost entirely outside the large corporation and the large university. His research experience illustrates the strengths and weaknesses of the methods of the lone inventor. He could have avoided many mistakes and progressed considerably more rapidly on certain aspects of his work had he been working in a large research laboratory with competent advice in various specialized fields. He was handicapped, especially at the beginning, by an amateurish approach, not only to electronics but to the problems involved in building laboratory equipment. Yet some of his originality may stem from having worked on his own.

The image dissector—which is one of Farnsworth's most notable inventions—is an ingenious device. Whereas the mechanical systems of Nipkow and others, and the electronic system of Zworykin, had scanned the object or its image in successive stages, Farnsworth moved the entire electron image past a scanning aperture, which dissected the image into as many segments as the number of picture elements required in the transmitted picture.[46] The camera tube is highly evacuated and contains a photocathode at one end on which the image is projected by an exterior lens. A field produced by an electrode causes the electron image to move along the length of the tube toward the aperture.

For high picture definition, the aperture must be extremely small, and this means that the signal output of the electrons passing through the aperture is also small. Farnsworth overcame this deficiency by building up the numbers of these electrons with his electron multiplier.

The electron multiplier is based on the phenomenon of secondary emission. When an accelerated electron bombards a suitable anode surface, several secondary electrons are dislodged, and these may in turn be directed to another anode of higher potential. Each of these secondary electrons will then dislodge more electrons from the second anode, and the process may be repeated.[47] Farnsworth arranged a number of anodes within a single

[46] See Farnsworth's article on his television system in the *Journal of the Franklin Institute*, Vol. 218, Oct. 1934, p. 411.

[47] The electron path is set up in a zigzag pattern, the electrons being directed from one electrode to the next by magnetic fields. The few original electrons will increase logarithmically. For a diagram of the image dissector, see Fink, *Principles of Television Engineering* (New York and London, McGraw-Hill, 1940).

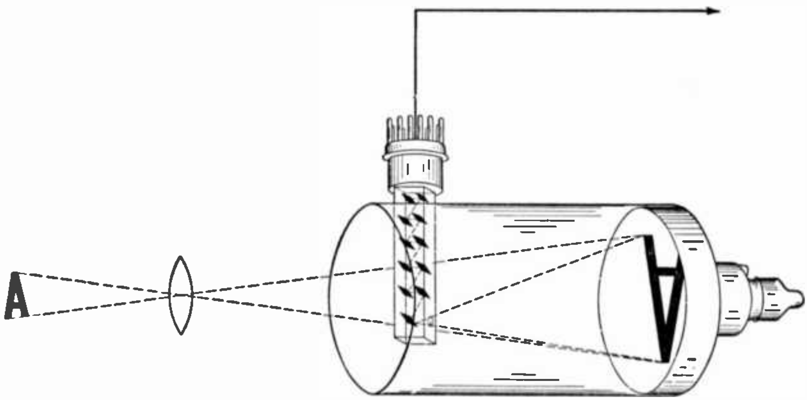


Diagram of the Farnsworth image dissector tube. Light from the image "A" at the left is focussed on the photo-electric material on the back of the tube. When light in the shape of the "A" strikes the surface, an identical "A" pattern of electrons is thrown off. This electron pattern travels back along the tube to the small opening shown. Focussing coils move the image back and forth over the aperture, feeding successive sections of the electronic pattern into the hole. This process takes place almost instantaneously—in fact, thirty electronic images per second are directed into this "optic nerve." At this point the weak electron stream is multiplied many times by the "electron multiplier," shown as a ladder of metal plates. (Courtesy Farnsworth Television and Radio Corporation)

tube so that the electron path progressed from one to the other, each succeeding anode being of higher voltage than the preceding one. Thus the few electrons entering the aperture in the image dissector at any one time would be passed through the multiplier, emerging with a multiplication factor of many thousand times that of the original.

Farnsworth's work in developing more effective synchronization between the transmitter and the receiver is also of considerable importance. His total contributions, therefore, have been very substantial.

Farnsworth withdrew from active participation in his company in 1940. The main reason for this was that he found the struggle for business development hard to bear. He did not enjoy his two years at Philco and was equally uncomfortable in the Farnsworth plant at Fort Wayne, Indiana, as vice-president in charge of research. The public relations aspect of such a position, including streams of visitors, bothered him particularly. He was much more content when isolated in his laboratory with a few close associates. And in the laboratory he liked to work on new ideas, but quickly lost interest when it came to reducing them to a usable device. It soon became clear that he was out of place as an operating vice-president of a manufacturing concern. He was a substantial stockholder and a director of the Farnsworth company and this gave him adequate financial resources to withdraw at the age of thirty-four to Fryeburg, Maine, where he bought a farm and set up a small laboratory. He has since maintained his connection with the company as a consultant and has carried on research at his Maine laboratory to the extent that his health would permit.

Farnsworth's decision to withdraw may have been influenced by the fact that television has proved one of the most difficult technical fields in which to operate, and the scientific requirements have become increasingly exacting. Television today, like radar, is an area in which the lone inventor is at a disadvantage. The field primarily needs a team attack by individuals who are highly trained in the different branches of science related to television and whose skills complement each other. This is not to say that the individual, working alone, cannot make important further contributions. Television *might* be advanced tremendously, for example, through a deeper understanding of the entire process involved in reception of light by the eye. But scientists capable of making such advances are rare.

3. Television Research in Other American Companies

(a) HAZELTINE ELECTRONICS CORPORATION

RCA's principal rival as a patent holding company, the Hazeltine Corporation, also had an important stake in television. But, in contrast to the Radio Corporation, it was not financially able to spend large sums on research years in advance of actual commercial operations. Hazeltine, therefore, did not begin intensive research on television until 1938. The company worked particularly on improving methods of synchronization.

For a television picture to be received clearly, the electron beam at the transmitting end, which scans the scene to be televised, must be kept in completely accurate phase with the scanning beam in the receiver. Otherwise, a distorted picture is received. The signal must also be shielded against interference. This proved one of the most difficult problems in cities, where automobile ignitions, diathermy machines and many other electrical devices caused interference. At worst, they prevented reception altogether or tore out part of the picture on the receiving screen. Shortly before the war Hazeltine, working in co-operation with Philco, produced the most satisfactory method of eliminating interference that had then been devised. Subsequently, however, RCA made significant improvements in its own system of synchronization and the Philco-Hazeltine method was never put into commercial operation.

(b) COLUMBIA BROADCASTING SYSTEM, INC.

Another of RCA's rivals contributing to the progress of television is the Columbia Broadcasting System, whose expenditures on television to December 30, 1939, are given in Table XXIV.

The principal item of expenditure was the construction of a transmitter on top of the Chrysler Building at a cost of $650,000. To experiment with television transmission from a research point of view, Columbia hired a young Hungarian television expert, Dr. Peter Goldmark, who came to the company in 1936. Until 1940 his television work was concerned primarily with engineering problems in connection with the erection of the transmitter, and then in experimenting with its operation.

In 1940 Goldmark began to experiment with color television. At that time, television was still far below the effectiveness of motion-picture entertainment. The picture, as viewed on a cathode-ray reception tube, was small and lacked vitality. Although the definition was quite good, it was difficult to maintain interest even with the best programs. Goldmark felt that color would help to overcome the deadness of the picture.

Preliminary results were achieved rapidly. Three months after Goldmark first conceived of using color, he gave to Columbia

TABLE XXIV: TELEVISION EXPENDITURES OF THE COLUMBIA BROADCASTING SYSTEM *
January 1, 1936 to December 30, 1939

Expenditures for transmitter, studio and other technical equipment, improvements to leased premises, etc.	$ 764,018.81
Materials, test equipment, etc., in connection with research and development activities	43,100.54
Salaries of full-time television employees (engineering, research and operations, program and maintenance)	213,091.10
Rent (Chrysler Building and Grand Central Terminal Building locations)	70,500.00
All other direct television expenses, including program experimentation (other than salaries), power and light, tube expense, miscellaneous supplies and repairs, insurance, taxes, traveling, outside attorney's fees, etc.	101,529.83
General administration, general overhead and expenses of other departments applicable to television activities	120,000.00
Total	$1,312,240.28

* In addition to the expenditures included in the above schedule, outlays covering the purchase or construction of new cameras, a mobile unit and other necessary technical equipment amounting to $209,500 have presently been authorized. Expenditures prior to Jan. 1, 1936, were absorbed in Columbia's general engineering department.

executives a demonstration in which he combined a regular electronic system of black and white television with a three-color spinning disc at the transmitter and at the receiver. The colored discs produced an impressive result for certain types of scenes. All observers seemed to agree on this. Color was particularly effective in bringing vitality into pictures of home cooking and flower arrangements.

Goldmark's contribution lay in demonstrating the advantages of color to engineers and others who were surprised by its effectiveness. Following the work of the Bell Telephone Laboratories in the 1920's, there had been very little progress made on color television,[48] the emphasis having been placed entirely on perfecting black and white methods. Since 1941 various research workers, principally at RCA, have developed methods of achieving color television entirely by electronic methods, which seemed a more promising approach.

(c) ALLEN B. DU MONT LABORATORIES, INC.[49]

In addition to the larger firms, one specialized company, the Allen B. Du Mont Laboratories, deserves to be mentioned, because it was the first concern in this country to manufacture and sell electronic television sets. Allen Du Mont, who had been chief engineer of the De Forest Company, first became interested in television when his firm purchased the Jenkins patents in 1929. Using the mechanical drum, the De Forest Company built several stations to broadcast sight and sound. Du Mont himself was involved in this program, and his work led to several patents on television apparatus. When the company got into serious financial difficulties, he decided to develop cathode-ray tubes on his own. Although the cathode-ray tube had originated in Europe in the 1890's, it was not used in significant quantities until the advent of electronic television. With a total capital investment of $500, he hired several glass-blowers, bought some equipment, and began operations in the basement of his home in 1931. Within three years his business had expanded to five buildings. Du Mont's early sales were largely cathode-ray oscillographs to college laboratories for experimental purposes. He then began to develop the oscillograph for commercial use. In 1932, the first full year of operation, net sales of the company were $1,600; in 1933, $16,000. Du Mont sales reached a total of $103,000 in 1937; $117,000 in 1939; $648,000 in 1940; and $2,000,000 in 1941.

It was not financially possible for a small company of this sort to develop a research organization in the early years, but in 1936 a modest research program was initiated which gradually expanded thereafter. The company began by bringing in young

[48] Jenkins in the United States and John L. Baird in England, as well as Ives, had experimented with color. But they, too, had worked entirely on mechanical systems.

[49] Du Mont expanded greatly during the war and has become a much more important factor in television in the postwar period.

men, just out of college, who were interested in television. In this way the struggling little company gradually improved its technical proficiency. And in 1939 Paramount, which was concerned over the possible impact of television on the movies, bought a 50 per cent interest in the Du Mont Laboratories.

Although Du Mont had neither the funds nor the facilities to carry on any very significant research before 1940, his development work on the cathode-ray tube contributed materially to the progress of television. The company also made some contributions to synchronization methods. Du Mont's major role in television was to question the system of standards which had been adopted by the Radio Manufacturers Association and to require the Radio Corporation of America to defend its proposals before the Federal Communications Commission and the industry. This struggle will be described in detail in the next chapter on government regulation. Whether or not there was merit in Du Mont's position, it forced a very thorough airing of television standards.[50]

The first Du Mont commercial television set was produced in 1939 and retailed for $295. It featured a 14-inch picture tube which was larger than any competitive unit at that time. In addition Du Mont manufactured less expensive television transmission equipment than had previously been available.

Du Mont operated without any licensing agreements on patents until 1940. The Radio Corporation had wanted him to take out an RCA license to manufacture cathode-ray tubes, but he argued that this was an old art and that his firm was not infringing RCA's patent position. Just before the war, Du Mont and RCA reached an agreement under which RCA paid approximately $100,000 in a lump sum for the use of Du Mont's patents, and Du Mont took an RCA license on television apparatus. The license, however, did not require the payment of royalties on oscilloscopes, oscillographs or on cathode-ray tubes used in this type of apparatus.[51]

50 The Du Mont proposals for synchronization before the National Television Systems Committee were not adopted. Yet the Du Mont objections to the Radio Manufacturers Association's standards led ultimately to better methods of synchronization being adopted.

51 One of his inventions, the cathode-ray tuning indicator or "Magic Eye," he sold to RCA for $20,000. Harold J. Wheelock, "Video Impresario," *Signals*, May-June 1947, p. 34.

Du Mont's total expenditures on television as reported to the Federal Communications Commission are given below:

TABLE XXV: TELEVISION EXPENDITURES OF ALLEN B. DU MONT LABORATORIES, INC.
1931–1939 *

General television experimental cost	$109,713
Development expense of receivers	148,584
Experimental transmitter costs	13,816
Option on transmitter site	3,355
Total	$275,468

* Data filed by Du Mont with the Federal Communications Commission, Jan. 29, 1940, F.C.C. Docket 5806.

TABLE XXVI: ALLEN B. DU MONT LABORATORIES, INC.—SALES AND EARNINGS
1936–1941

(000 omitted)

Year	*Net Sales* *	*Net Income after Taxes*
1936	$ 72	$ 0.3 (d)
1937	104	3
1938	94	9 (d)
1939	117	95 (d)
1940	176	79 (d)
1941	648	23 (d)

* The company's sales during these years were almost exclusively confined to cathode-ray tubes and cathode-ray oscillographs. In 1941 oscillographs accounted for approximately 80 per cent of sales, television apparatus for 20 per cent. In 1947 the percentages were reversed.

4. *Some Postwar Developments*

Although many of the major problems of television transmission and reception had been solved by the outbreak of the war, there were others that remained. The pictures were too small, antenna designs for large, multiple-set apartment buildings had not been perfected, and further development was required on the relaying of programs from one station to another.

In 1941 home television reception was limited to the face of the viewer tube. Of necessity, this was small[52] for technical (constructional) reasons, and because increasing the size of the tube not only added greatly to the expense of the set, but meant extending the dimensions of the enclosing cabinet beyond reasonable proportions.[53] This limitation restricted home reception to a small group huddled in close proximity to the screen. Until recently, too, pictures did not have enough brightness to be watched in anything but a darkened room. Both these defects have been eliminated by the development (first by RCA and later by both RCA and Philco) of projection receivers giving a screen brightness sufficient to allow viewing in daylight, with a size varying from 15 by 20 inches to 18 by 24 inches or more.

A much more serious obstacle to the widespread introduction of home receivers is the problem of receiving antennas. Compared with the ordinary wire aerial which suffices for sound reception, the antenna for a television home receiver is a complicated and expensive piece of apparatus.[54] And, while a specially designed antenna may allow optimum reception in individual houses in small towns, a completely new problem arises in densely populated areas and in the midst of tall buildings. Television waves are reflected from buildings in their paths—causing multiple images or ghosts. And, even in 1947, much still remained to be done on a method of distributing television signals in large apartment houses, where an antenna for every set would be an impossibility.

The other barrier to be surmounted has been that of country-wide coverage by television programs. Television waves because of their shortness have a range that corresponds to the visual horizon. In New York City, for example, no point further than

52 The models sold by RCA, Westinghouse and others in 1939 had 5-inch screens and retailed for $200 without sound receivers. *Electronics*, June 1939, pp. 13–15. Du Mont at that time offered a 14-inch picture tube, without sound, for $295, and a 20-inch tube for $575, with radio combination.

53 Very large vacuum tubes also created the danger of implosion.

54 The "dipole aerial" in use in 1947 consists of two rods—4 to 5 feet long—mounted horizontally on a wood or metal mast. The rods must be placed at right angles to the direction from which the signal emanates.

fifty miles from the Empire State Building could receive a program from the transmitter there; and in most cities the effective range would be only about twenty-five miles. Some means had to be found of relaying a television program in much the way that radio networks operate.[55] For this purpose, two lines of attack have been explored: coaxial cable and short-wave relay stations.

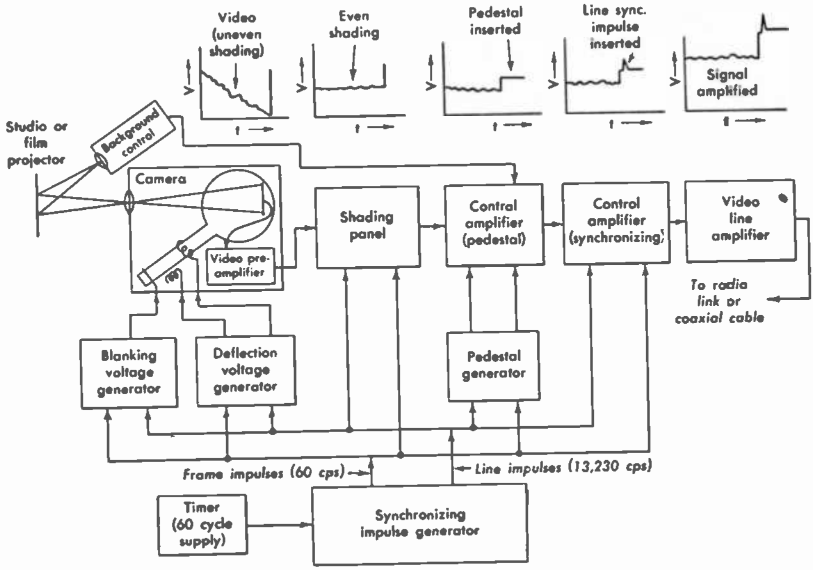
The coaxial cable resulted from efforts of AT&T engineers to produce a cable which could carry several hundred telephone conversations simultaneously. By 1936 the first installation, that between New York and Philadelphia, had been completed; it was capable of transmitting a band of frequencies more than a million cycles wide. Its possible use for television relaying thus became apparent. But its cost of between $10,000 and $12,000 per mile, plus the necessity for a "booster" station every few miles, makes it extremely expensive as a nation-wide solution for television networks. Nevertheless, in 1947 the coaxial cable was being used to transmit television programs between New York, Philadelphia and Washington.

The other approach intensively explored in 1947 was radio relaying of television programs. In this field RCA has done the pioneer work not only for television, but for facsimile, teletype and code telegraphy.[56] Using only a fraction of the power of the original transmitter, the relay is a small piece of apparatus mounted on poles fifteen to twenty miles apart. It picks up the incoming signal, amplifies it and sends it on to the next relay, using a directional antenna. RCA successfully demonstrated its system of automatic, unattended radio relaying in 1941, and has made many improvements since. In the meantime, AT&T and other companies have entered the field and have begun experiments in radio relaying between various cities.[57]

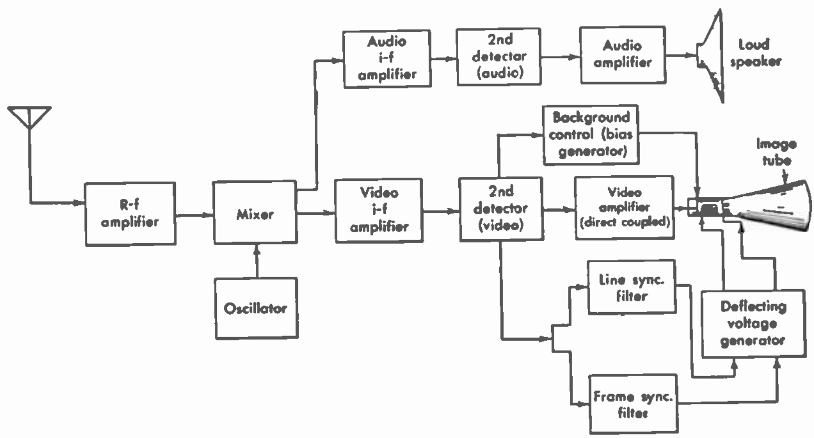
[55] Telephone circuits, such as interconnect a radio network, handle only 5,000 impulses or items of information per second, whereas in television broadcasting more than 6,000,000 such items must be conveyed every second. See Donald G. Fink in *We Present Television*, ed. W. Kaempffert (New York, W. W. Norton, 1940), p. 69.

[56] In 1945 Western Union announced a plan to spend $62,000,000 on the establishment of a radio relay system for multi-channel telegraphy using equipment developed by RCA engineers.

[57] FM as well as television will benefit from research into methods of relaying wide-band broadcasts.



Block diagram of typical pick-up and control equipment in television transmission. (Courtesy *Electronics*)



Block diagram of a typical television receiver, showing both video and audio channels. (Courtesy *Electronics*)

5. Summary

Television, as we have seen, is the type of product which has required long years of applied research and advanced engineering to bring it to the commercial stage. For the development of such a product, some degree of monopoly is essential. Research expenditures, as we have seen, have been enormous, and under conditions of *perfect competition* could not have been forthcoming. The technical obstacles to be overcome were exceedingly difficult, and there were many who believed that it would be years before sets could be sold in large volume. It is not surprising, therefore, to find that in the prewar period research contributions to television were made primarily by the very large and well-established companies. Philco, it is true, supported Farnsworth for two years and collaborated with Hazeltine in television synchronization. But the prewar contributions of Philco, Sylvania and Du Mont were not on a par with the contributions of the Telephone company, Westinghouse and RCA. These large companies could afford to support pioneering research years in advance of commercial operations. However, since commercialization has come closer to being realized, and especially since the war, companies like Philco and Du Mont have made significant contributions to perfecting the television receivers which they now manufacture.

Another conspicuous point is that Farnsworth would never have received the backing that he did, and the Farnsworth company would not have been launched, except under a patent system which was generous to the inventor. Moreover, once the company was launched as a manufacturing enterprise, the management had a strong incentive to collect royalties on its patents; and it recognized that there would be no possibility of holding this position unless it maintained a creative research department which would keep it in the forefront of new developments.

Chapter X: GOVERNMENT REGULATION AND TECHNICAL PROGRESS—FM AND TELEVISION: 1900–1941

Frequency modulation is "a visionary development years in advance of broadcasting's capacity to utilize it."—ANDREW D. RING, formerly assistant chief engineer, Federal Communications Commission.

THE earliest interest displayed in wireless by a department of the American government came from the Navy, which was quick to visualize the potential importance of this new method of communication. By its willingness to purchase experimental equipment on a generous basis, the Navy was largely responsible for encouraging inventors like de Forest to stay in the field at a time when the prospects of commercial success seemed very remote.[1]

The Congress did not become concerned with radio until its potentialities for the protection of safety of life at sea had been dramatically demonstrated. In 1910 the first Radio Act[2] was passed requiring the merchant marine to install radio transmitting and receiving apparatus. And in 1912 the executive branch of the government undertook a system of licensing which forbade radio transmission without a license from the Secretary of Commerce and Labor.

The problem of regulation was comparatively simple at first. The radio lanes were not congested. The interference difficulty, as it was known in the 1920's, had not arisen. There were only three main groups to be accommodated: the Navy Department,

[1] A special study could profitably be made of the role of the armed services in stimulating advances in radio technology and radio manufacturing. See, for example, the study of radar by Henry Guerlac, prepared for the Office of Scientific Research and Development (not yet published).

[2] 36 Stat. L., 629.

which was using radio very extensively; the commercial companies, which specialized primarily in ship-to-shore service; and the few amateurs. These difficulties were settled by giving the Navy and the commercial companies extensive wave bands and placing the amateurs in the shorter wave lengths which were regarded as being of no importance.[3]

When, after World War I, entertainment broadcasting began to develop, Herbert Hoover, as Secretary of Commerce, was faced with more difficult tasks. He assigned specific frequencies to stations, refused to grant licenses to those whom he did not consider qualified, and (because there were more stations than could operate simultaneously) he specified the time during which an individual broadcasting station could operate.

There were soon far more applicants than could be permitted to go on the air, and many stations were forced to take frequencies or times which they did not consider adequate. Complaints were bound to arise. Finally, in 1926, the Zenith Radio Corporation challenged the authority of Secretary Hoover in the courts. The court,[4] upholding Zenith, declared that the Department of Commerce, being without specific legislative authority, had no power to establish regulations on radio frequencies. This created an intervening period of chaos. Many new stations came on the air to crowd the existing broadcasters; stations broadcast from any frequency or on any power that suited them;[5] sales of sets dropped and it became clear to all concerned that some legislative action was necessary.

Congress, therefore, established the Federal Radio Commission in 1927 with broad powers of regulation. One of the first acts of the new Commission was to try to reduce the number of stations. In the year 1928, 162 broadcasters were challenged to show why their stations should not be discontinued.[6] Most of them

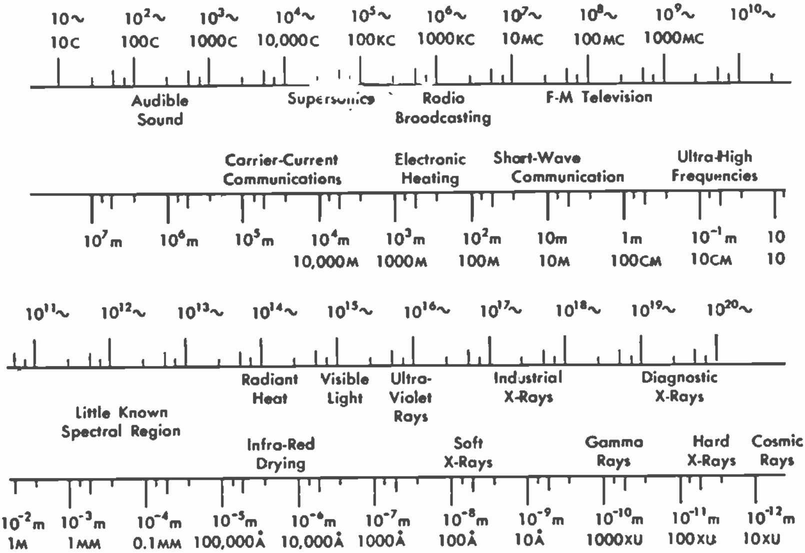
[3] Stephen B. Davis, "The Law of the Air," *The Radio Industry—the Story of Its Development* (Chicago, Shaw, 1928), p. 164.

[4] United States *vs.* Zenith Radio Corp., U.S.D.C., N.D. Ill., 12 F (2d) 616, April 1926.

[5] From July 1, 1926, when government radio control officially broke down, to December 1 of that same year, 102 new stations took to the air and 94 existing stations reported that they had changed their wave lengths. Department of Commerce Report, Dec., 1926, as quoted in Goldsmith and Lescarboura, *op. cit.*, p. 60.

[6] *Ibid.*, p. 66.

took their cases to court; but some went off the air. New licenses were also issued in such a way as to avoid interference between stations. The Commission asked the Institute of Radio Engineers to advise it concerning a scientific allocation of frequencies; and in 1928 it set up the basic principles of allocation which are still used today. It also issued the first rules and regulations for *all*



The electro-magnetic spectrum, showing the relationships among broadcasting, television, FM, and other frequencies. (Courtesy Stokley, *Electrons in Action*, Whittlesey House)

radio services, thus encouraging the orderly development of such important new services as police and aeronautical radio.

The Radio Act of 1927 was incorporated, with very minor changes, in the Communications Act of 1934. The new Federal Communications Commission was established to extend communications regulations to telegraph and telephone services and to centralize all such regulation in one government body.

The FCC has been called on to play a very significant role in regulating the broadcasting industry. The Commission has been investigated by a series of congressional committees, and has been both damned and praised in equally extravagant terms.[7]

The FCC has had an opportunity to affect technological progress in the industry on two very important new developments—frequency modulation and television. Describing these cases in some detail should help to visualize the nature of the regulatory problem. Both cases have involved the reallocation of space in the broadcasting wave spectrum.

1. Frequency Modulation

Frequency modulation first came to the attention of the FCC in 1935. When in that year Edwin Armstrong applied for permission to construct an FM transmitter, Andrew D. Ring, the FCC's assistant chief engineer, termed FM "a visionary development, years in advance of broadcasting's capacity to utilize it."[8] He therefore refused to recommend a construction permit. Armstrong could have appealed directly to the Commission for a final ruling; but he was afraid of being turned down and was determined to carry FM, as an innovation, through the commercial stage. Had Armstrong been content to remain in the role of inventor, the introduction of frequency modulation might have been delayed for many years. He proceeded, however, to conduct an extremely skillful promotional campaign to bring his new product to the attention of the public and the Commission. By persistent efforts and the presentation of vigorous arguments, he obtained an experimental permit and then attempted to persuade the Commission to give FM some broadcasting space. Here he collided with pressure groups in the radio industry who were interested in space for other services, particularly television.

The FCC had in 1936 asked the various interests in the industry to suggest their probable future needs for broadcasting space. The Commission also suggested that the Radio Manufacturers Association (RMA) obtain agreement among its members on

[7] Mr. Fly, its energetic chairman until 1944, was called by critics "the most ambitious bureaucrat in Washington," and by those who approved of his actions "one of the most far-sighted and shrewd members of the public service in Washington." "Federal Communications Commission," *Fortune*, May, 1938, p. 60.

[8] *Christian Science Monitor*, Nov. 18, 1935, *Hearings* before the Committee on Interstate Commerce, U.S. Senate, 78th Congress, 1st Sess., on S 814.

performance standards for television in order that "any receiver manufactured for the public would be capable of receiving any visual broadcasting transmitting station which may be licensed by the Commission." Several Committees of RMA immediately went into action.[9] One group took up the study of television standards, while another investigated allocations. Although the Commission had requested a general survey of all new needs for space, the principal focus was on television.

At the 1936 hearings, Armstrong asked that some of the space being considered for television be assigned to FM. The great majority of the industry, however, were skeptical about the significance of the new development, and the Commission reflected this attitude. The problem which confronted the Commission was that television required far wider bands than either FM or AM broadcasting. If, therefore, television were to be given the "green light" and a generous allocation of space, very little room would be left for frequency modulation. Initially in 1936, the Commission set aside four channels of 200 kilocycles each for FM exclusively, plus eight more channels for either FM or high-fidelity AM.[10] This was in the experimental period for FM, and was probably adequate.

The problem came later when expansion was needed. In April, 1939, television was judged to be nearly "ready," and nineteen six-megacycle channels[11] were set up for television. This tended to blanket the available space in the spectrum where FM wanted to be. FM allocations of that date—thirteen channels—were in different sections of the spectrum, and it was a serious engineering problem at that time to design receivers for both bands. Although these allocations were described as "experimental," the effect was to make the public believe that television was to be the next major innovation.

If the Commission and the industry had recognized the future

[9] The Radio Manufacturers Association had maintained a committee on television since 1929, and in 1935 the Board of Directors had charged its engineering department with the responsibility of determining what television standards should be adopted by the industry.

[10] According to Armstrong, only five of these were in "a workable part of the spectrum."

[11] Each television channel was wide enough to accommodate 30 FM stations.

importance of frequency modulation, the FM allocation would have been more generous. For it was FM rather than television which was on the verge of immediate commercial development. This initial mistake proved difficult to rectify. By 1940 FM needed more space. Many people believed, however, that the RCA broadcasting chains were opposed to frequency modulation.[12] The widespread adoption of FM was bound to involve the erection of many new stations serving local communities[13] and operated by new competitors. Opponents of FM argued that standard AM was giving adequate service to the country and that the technical advantages of FM did not warrant the additional investment.

In 1940 the controversy was brought to a head in extensive hearings before the Commission. RCA and one or two other television manufacturers opposed giving television space to FM. A number of the principal broadcasters had erected television transmitting stations which were equipped for particular channels. RCA was established in Television Channel No. 1, Columbia in Channel No. 2, Philco in Channel No. 3, etc. Moving them out of these spaces meant substantial engineering costs to each of these companies. On the other hand, the FM movement was spreading rapidly, new stations were being started all over the country and the association of FM broadcasters was pressing for action by the Commission. Finally, after the hearings, the Commission decided to push television higher up in the spectrum and give Television Channel No. 1 to FM.

By December 1, 1941, the FCC had granted sixty-seven commercial FM licenses and there were forty-three applications pending.[14] And it later announced a plan to set aside additional channels for distribution to small business units which could enter the field after more FM sets had reached the public.

In 1943 the FCC suggested to the radio industry that it set up a Radio Technical Planning Board (RTPB) to prepare for the

[12] See, for example, testimony of Paul deMars, U.S. Patent Office, Interference No. 79,216, Armstrong *vs.* Hansell, p. 192, ". . . Such an attitude I interpret to be antagonistic."

[13] FM uses shorter waves than standard AM, and, like television, obtains the best service when the receiver is in approximately "line-of-sight" with the transmitter.

[14] Seventh Annual Report of the F.C.C. for the year ending June 30, 1941, p. 30.

postwar period and to make recommendations as to standards and allocations for the various services. At FCC hearings beginning in 1944, Panel 5, which considered problems relating to FM, recommended that FM be given 75 channels between 41 and 56 megacycles. However, on the evidence of a Commission witness, which showed that FM should be moved to the bands above 100 megacycles,[15] FM broadcasting was moved from the low to the high band (88–108 megacycles). This meant that FM, although possessing 100 channels,[16] was faced with a serious conversion program, particularly in view of Chairman Porter's statement to the effect that broadcasting in the old band would be halted. No plans were available for the construction of transmitters on the new band, and censure of the FCC by the FM broadcasters became acrimonious. Nor was the situation alleviated when, in November 1947, Armstrong forced the Commission's expert, Mr. Norton, to admit that technical advice which he had given and which was the basis for "kicking FM upstairs," had been totally in error. At that time Armstrong urged that the FCC make a permanent assignment to FM of 44–90 megacycles, and, since it would be impractical to move FM broadcasting back to the lower bands, he asked that FM be given the 44–50 megacycle channel for relays.

FM has thus encountered a somewhat rough road in its fight for space on the spectrum. As Armstrong states:

> The regulation of its [FM] development to date has been administered under five different chairmen of the Federal Communications Commission. The personnel of the Commission and its engineering and legal staffs have changed so many times that today no one in the Commission has first-hand knowledge of the actions of the Commission which have affected, and in many instances retarded, FM development.[17]

[15] On the grounds that ionospheric disturbances in the lower bands would prevent the giving of a satisfactory broadcast service, and that a larger service area could be covered (for any transmitter power) in the vicinity of 100 megacycles than in the lower bands.

[16] Television received 13 channels, only three of which need not be shared with various mobile services. The situation is becoming so serious over this sharing that telecasters are considering a plan to give up one channel voluntarily in order to obtain 12 satisfactory free channels.

[17] F.C.C. Docket 8487, Brief of Edwin H. Armstrong, Oct. 7, 1947, p. 2.

2. *Television*

Determining engineering standards for television has proved an even more difficult task than the allocation of space for FM and television. If more than one type of transmission system were in commercial operation, receiving sets would have to be designed to receive different types of signals. This is much more complicated than in ordinary broadcasting because three separate transmission signals are required—sight, sound and synchronization. This creates a "lock and key" relationship between the transmitter and the receiver which has made television a unique and extremely difficult new product to launch.

Whenever it is necessary to get industry-wide agreement before the adoption of a new product, the process is usually slow. It is likely to be particularly slow where some companies have more to gain by delay than by immediate co-operation. Such was the case in television in the prewar period. The Radio Corporation of America had done most of the research and, together with Farnsworth, controlled the basic patents. It, therefore, had everything to gain by pushing aggressively for prompt commercialization. But the greater part of the industry was in a less favored position. Philco and Zenith, for example, had succeeded in building up a strong competitive position with RCA in radio receiving sets, making comfortable profits and doing very little basic research in television.[18] RCA's principal broadcasting rival, CBS, did not manufacture radio sets, had done little research on television and had no patents to speak of. Columbia did not share RCA's enthusiasm for rapid commercialization, particularly as it was expected that, in the initial years, television profits would come from the sale of sets, while the broadcasting would have to be conducted at a substantial loss. Immediate commercialization of television would mean the adoption of engineering methods on which RCA had patents and the technical know-how. If the decision were postponed, there would be a chance to catch up.

These conflicting views were reflected in the FCC hearings in

[18] Philco, however, in the late 1930's spent considerable sums on the engineering development of television receivers. And since the war both Philco and Zenith have made important contributions to television research.

1940. The Commission had no direct control over the sale of television sets, but it had authority to fix "standards for transmission" and to determine the degree of commercialization that should be permitted. Television broadcasts had been on a regular schedule since the opening of the New York World's Fair in May 1939, and some receivers were on the market and being sold. But only after "full commercialization" was authorized could the radio manufacturers promote the sale of television sets on as extensive a scale as they wished.

The first full-dress hearings on television were held in Washington in January, 1940. They were called by the Commission to obtain comments on the television regulations which it proposed. These regulations had been unanimously recommended for field tests by the Engineering Department of RMA. But the hearings brought to light a *substantial* disagreement among the manufacturers. The principal protagonists in the battle that followed were RCA, Philco, Du Mont, CBS and Zenith. The problem of "resistance to innovation" can be understood best by explaining the position which each of these companies took.

The proposed standards provided for a television picture of 441 lines and 30 frames per second. The system of synchronization had been developed by RCA engineers. Television was to be black and white, and the transmission system was to use horizontal polarization.

The first major objection came from the Du Mont company, which was not a member of RMA. Allen Du Mont declared that his concern had developed a television system which, with the use of a retentive screen, was capable of receiving a picture of 800 lines at 15 frames per second and that this high definition could be obtained without sacrificing other qualities. The retentive screen, he claimed, should make it possible to produce a clear, flickerless picture at the slow speed of 15 frames per second.

Du Mont's contentions were important because everyone agreed that more scanning lines gave a clearer impression. Most people also agreed that the ordinary moving picture was superior to the best television performance and that more scanning lines would help to correct this. Hitherto increases in the number of lines beyond 500 had not proved possible without an offsetting deterioration in other qualities of the picture. The Du Mont company was therefore asked to arrange a special demonstration for the Commission. It proved a complete failure.[19]

Du Mont was naturally anxious not to have accepted, as the standard for the industry, a television system in which his company had played no part. Moreover, most of the observers agreed that the synchronization between the transmitter and the receiver in the field tests of the RMA standards was not satisfactory. Du Mont claimed that his company had designed a method of synchronization which was at least equal to, if not an improvement on, the RMA proposal, and that before standards were frozen, opportunity should be given to test the Du Mont method in commercial practice.

The officers of the Zenith corporation chose a different line of attack. Their representatives maintained that television was not ready *at all*. The cost of effective programming, they argued, was so substantial that it would be many years before a service was provided sufficient to interest the public in buying a large number of sets. They concluded that a great deal more technical development work on television was necessary before full commercialization was justified. This was a tenable (though irritating) position to take, and was understandable in a company that had done no significant television research up to that time.

Philco, in turn, believed that serious deficiencies had shown up in the field-testing of the proposed RCA system. Philco argued that an additional six months' time should be allowed to complete tests on the alternatives which it and other companies were exploring, and that no standards should be set until this work had been completed. There were four major points on which it felt improvements could be made:

[19] *Chairman Fly:* "Did you see the demonstrations of the bowling that Mr. Du Mont gave with his retentive screen?"

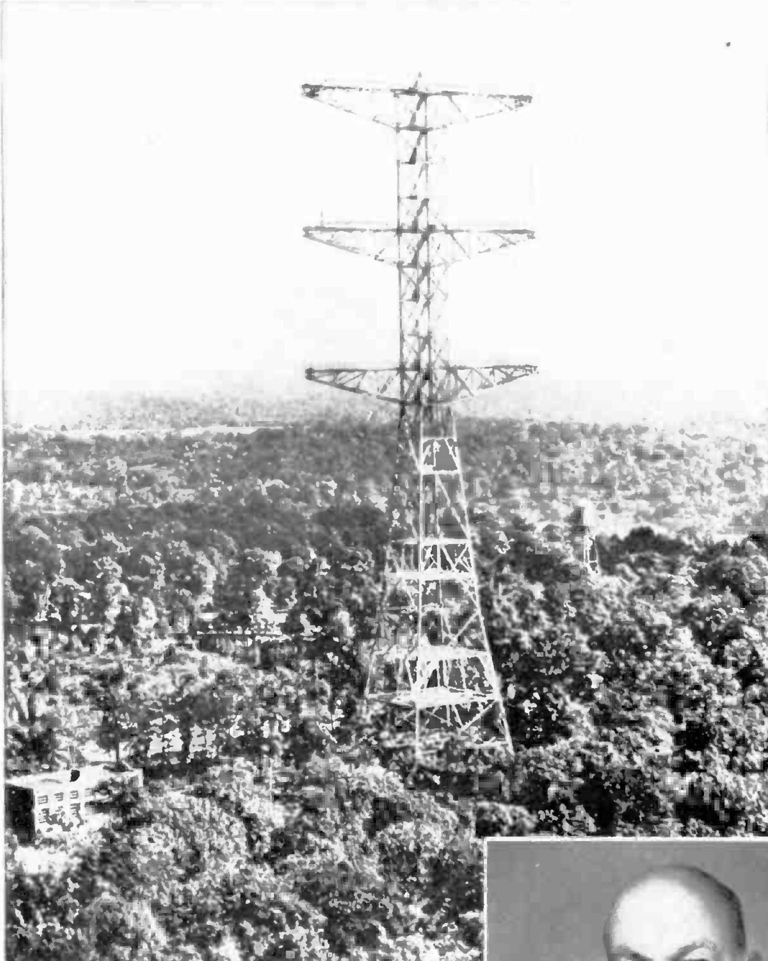
Witness: "I did not, but I was told that the ball and the motion went away from the camera instead of across it."

Chairman Fly: "The motion as I recall went in every direction."

Witness: "Sir, I stand on your observations."

Chairman Fly: "We saw quite a lot of bowling in that picture." (Official Report of Proceedings before the F.C.C., April 9, 1940, Vol. 9, p. 1540.)

Type of picture received with early sixty-line television apparatus. (Courtesy National Broadcasting Company)



Airplane view of Armstrong's FM station, W2XMN, at Alpine, New Jersey, with the laboratory at the left of the base. The antenna tower is 400 feet, and the top of the tower is 900 feet, above the Hudson River. Edwin H. Armstrong, the inventor of FM, is shown in the inset. (Courtesy E. H. Armstrong and Bachrach)

(a) The synchronization, Philco maintained, was not satisfactory. There were several alternatives:
   (1) The alternate carrier method, on which Philco was working with Hazeltine.
   (2) Narrow vertical pulse, on which Philco had several years of actual operating experience.
   (3) Serrated horizontal signal (proposed by Du Mont).

(b) Vertical polarization would be more effective than horizontal polarization, as experiments indicated that the vertical type antenna built inside a receiving set was practical and would eliminate the necessity of erecting antennas on the outside of the building.

(c) Twenty-four frames and 605 lines would be better than 30 frames and 441 lines.

(d) The sound should be improved and FM should be considered.

Columbia Broadcasting was later to join the opposition by advocating that color television be included in the standards, but it did not oppose the RMA standards at the first hearings. Paul Kesten, Vice-President of Columbia Broadcasting, summed up Columbia's position:

> We propose that these standards be set for 10 years. . . . Our most optimistic studies of the sale of sets indicate that the broadcaster continues to operate at a cumulative loss until some 30 per cent ownership of television sets in the areas in which he is broadcasting is achieved. We can't see that in less than 7 years, and we think that it is doubtful if it will be reached in 7 years. That would give the broadcaster at least a sporting chance to do programs good enough to hasten that date and thereby reach the period where he was at least operating in television without a cumulating annual loss.[20]

Faced with this division of opinion within the industry, the Federal Communications Commission had great difficulty in reaching a decision. Some members of the Commission felt that television should be permitted to go ahead immediately without any restrictions, while others considered that a further period of experimentation was desirable. The broad issue of policy in the debates was whether the Commission should "interfere with the

[20] Proceedings before the F.C.C., Jan. 17, 1940, Vol. 3, p. 488.

'free play' of private enterprise" or "protect the public against the persuasive advertising and promotion of an imperfect product."

The proponents of full commercialization contended that sales would not be extensive unless the product were good, and, if it were, there was nothing to worry about. They pointed out that the British, several years previously, had inaugurated public television broadcasting, which was far from perfect; yet set sales had remained small. Nothing, they maintained, would spur the industry to improve television so effectively as full commercialization.

On the other hand, those who favored waiting argued that the situation in the United States differed from that in England. American practice has been to press for volume production on a new product by intensive advertising and sales promotion. If, therefore, the Commission were to give the "green light" to television, sales of sets would be much more aggressively pushed than they had been in England. And against those who maintained that, after all, the customary American practice was to commercialize early and then bring out new and improved models frequently, they declared that for most new products the original purchasers still had something that they could use, even though great improvements were introduced later. In television, if the transmission standards were changed radically, the original sets would be of no use. Some members of the Commission were antagonistic to RCA for trying to monopolize television by securing the adoption of standards on which it had most of the patents,[21] while others felt that RCA had done most of the research and was entitled to the rewards. Finally, the Commission agreed in a compromise vote that "commercial television should be permitted beginning the first of September, 1940, and that broadcasters and manufacturers could prepare for *limited* commercialization at that time." No standards were to be fixed. The public was to be given the opportunity to determine which system it preferred.

RCA immediately launched a substantial advertising campaign stating that television was here, that the Commission had approved it, and that broadcasting would start on September 1.

[21] The opponents of RCA in the Commission also accused them at the hearings of dominating the Radio Manufacturers Association.

Chairman Fly and other members of the Commission took strenuous objections to the character of this advertising on the grounds that it gave a false impression of the "clear intent" of the Commission, and that the public would be a heavy loser in the purchase of expensive equipment actually useful for only a brief period. Further hearings were scheduled to determine whether, in the light of RCA's action, the order for limited commercialization should be rescinded.

By this time the issue had become in part a battle of the FCC *versus* RCA, and more particularly Fly *versus* Sarnoff. Mr. Sarnoff, appearing before a Senate Investigating Committee, complained of the Commission's action as being dictatorial and bureaucratic in the extreme. There was some question, in fact, as to whether it might become an issue in the presidential campaign of 1940.

Nevertheless, the Commission reversed its previous decision authorizing commercialization and requested a special engineering committee of the industry to review once more the whole question of standards. Dr. Baker of General Electric was made chairman of this National Television Systems Committee (NTSC). A series of subcommittees were established to investigate the major issues. By March 1941, after a great deal of intensive work, the industry was able to present a united front to the Commission.

And in May, 1941 [22] the FCC finally authorized full commercial operations to start July 1, on the standards recommended by the NTSC. These standards did not differ very materially from the original RMA proposals. The sound modulation was changed from AM to FM, and the number of scanning lines was raised from 441 to 525.

Another change concerned color television. The issue here was whether standards should be drawn up to permit color broadcasting. It was generally agreed that the simpler and the more foolproof the receivers, the better the public would be satisfied. One of the unsatisfactory features of color television was that the system proposed by Dr. Goldmark of Columbia involved

[22] See F.C.C. "Television Report, Order, Rules and Standards" dated May 3, 1941. This is the foundation for the development of commercial television and contains the fundamental rules and regulations for the service.

a mechanical color disc in each receiver. This it was felt might get out of order.

With the exception of the Columbia Broadcasting representatives, the National Television Systems Committee was unanimous in its opinion that color television was still in the laboratory stage and a long way from commercial development. One of the difficulties with color was that clear definition required more lines and therefore more space on the spectrum.

On the other hand Columbia Broadcasting had the backing of Chairman Fly, who was distinctly interested in color and had been very much impressed by the Columbia demonstration. The engineers of the NTSC finally agreed to the following recommendations:

(a) That a full test of color on the Group A channels be permitted and encouraged.

(b) That, after a successful field test, the early admission of color to the Group A channels on a commercial basis, coexistent with monochromatic television, be permitted.[23]

Still another modification concerned the method of synchronization. Tests showed that the Philco-Hazeltine pulse which involved adding a third carrier for synchronization was apparently more effective than the RMA standard. To overcome interference, it was essential that the transmitter and receiver be kept completely synchronized. Reporting on the tests made on the Philco-Hazeltine development, the NTSC engineers stated that "with the noise that we had available, we couldn't tear any of the Hazeltine picture out" but "we might tear the RMA picture all apart."[24] Stations therefore were to be permitted to use any one of three alternative methods—RMA, Du Mont or Philco-Hazeltine. Du Mont used his system for a while, but the Philco-Hazeltine system was not put into commercial operation. In the meantime the Radio Corporation made some significant improvements in the RMA system and experience showed that it was the best. This was later verified and made standard by the FCC.

[23] Report of the N.T.S.C. to the F.C.C., p. 97.
[24] Proceedings before the F.C.C., March 20, 1941, Vol. I, p. 2474.

The original recommendations of the NTSC were all adopted by the Federal Communications Commission in 1941, but the further development of commercial television had to be postponed until after the war. Since then there have been a number of additional changes in television standards and picture reception has been considerably improved.

Summary

In both FM and television the constant pressure of a group of effective promoters greatly speeded up the introduction of the new product. In FM it was Professor Armstrong who first interested some of the smaller broadcasting concerns, like the Yankee Network, in adopting his system. He also organized and directed the campaign to win over the industry. In television, on the other hand, RCA was the principal promoter using high pressure tactics to persuade the industry and the Commission to move from the laboratory to the commercial stage.

The presence of a government regulatory board with the power to determine the timing of the introduction of a new product inevitably has a retarding influence. Regulation in the two cases reviewed entailed endless arguments by lawyers, the filing of briefs and counterbriefs and a tremendous amount of time of skilled engineers in preparing testimony. Had there been no natural limitation of broadcasting space and therefore no necessity for a Federal Communications Commission both FM and television would have been introduced much more rapidly. Without regulation, however, the various competing systems would have lacked uniformity, and no single system is likely to contain all the best available methods. In the case of frequency modulation, the Commission, like the industry, was skeptical of its potentialities at first, and was slow to assign it adequate space in the spectrum. The top officers of the Radio Corporation of America were much more interested in television than in FM. Since there was competition for space in the spectrum, they urged that television be given first consideration. Their arguments prevailed for some time. But in 1940 the Commission finally gave frequency modulation a substantial allocation of space.

In the case of television, the delaying action of the Commission resulted in the adoption of somewhat better technical standards. The objections offered, at the 1940 hearings, to the television standards which had been agreed upon by the Radio Manufacturers Association did not appear at the time to warrant the intensive investigation which followed. But the discussion and debate did produce some improvement in standards. Moreover, insistence on uniform rules encouraged the more co-operative elements in the industry to work closely together on engineering standards.

I was very much impressed by the quality of co-operation achieved by the National Television Systems Committee. The FCC forced the engineers to work together in a way that would probably not have occurred otherwise. Perhaps because of this, it is my impression that the engineers in the industry were able to come much closer to unanimity of opinion on such matters as FM and television than were the top business executives in the industry.

Despite the various difficulties that I have outlined, there is every prospect that the public will soon have uniform and effective systems of television and FM broadcasting throughout the United States. Considering the technical obstacles that had to be overcome, this is a major achievement.

Chapter XI: CONCLUSIONS

1. The Process of Invention and Innovation

I SHOULD like now to review the steps which were required to bring the basic scientific concepts of "ether waves" from their theoretical origins to the development of the present great radio industry. This will give us an opportunity to analyze the stages in the process of technological development and consider what tentative generalizations can be reached.

The growth of the radio communications industry from its scientific origins to widespread commercial usage has not been a story of smooth and continuous development. Sir William Petty once wrote that "hindrance of the advancement of learning hath beene because thought, theory and practice hath beene always divided in severall persons; because the ways of learning are too tedious for them to be joyned."[1]

(a) THE ROLE OF FUNDAMENTAL RESEARCH

The pioneer exploration of electro-magnetic waves was made by European physicists during the latter part of the nineteenth century. It was Professor James Clerk Maxwell, a mathematical physicist, who laid the theoretical basis for the study of ether waves; and Professor Heinrich Hertz of the University of Bonn who first developed apparatus to transmit and receive such waves. Neither of these men was consciously thinking about the commercial possibilities of wireless. Their interests were in studying electro-magnetic waves as a new phenomenon of Nature that was not yet fully understood.

The other essential feature of modern radio—the thermionic vacuum tube—was a separate problem of physics, unrelated to electro-magnetic waves. Here there was a similar course of development in that there was a period of several decades of purely scientific research of a type which it would be exceedingly hard to describe as of any practical value. This research came to a

[1] Hogben, *op. cit.*, p. 1064.

climax with the work at the University of Cambridge of J. J. Thomson, and especially of his pupil, O. W. Richardson, who worked out the theory of thermionic emission of electrons from hot filaments, and correlated this emission with the temperature and the physical characteristics of the filament.

Those who made the scientific advances which gave rise to the radio industry were all Europeans, and this has been true in many other industries. Our genius in this country has lain more in applied research and advanced engineering development. With a skill and ingenuity that have been unrivalled elsewhere, we have taken the discoveries of the great European scientists and converted them into practical commercial products. Most of the senior physicists of today are Europeans—Einstein, Niels Bohr, Fermi, etc. It is these men and others who are responsible for the original exploration of the atomic nucleus. They have followed in the tradition of Maxwell and Hertz. Their motivation has been the creative intellectual urge to widen our understanding of natural phenomena. The application of these advances, except under the special pressure of wartime service, they have left entirely to others.

In recent years there has been a substantial improvement in our standards of fundamental research in this country. We have been producing more scientists of distinction, like E. O. Lawrence, I. I. Rabi, A. H. Compton and Irving Langmuir, most of them in our universities, but some like Langmuir, in industry. While fundamental research was conducted almost exclusively in universities and non-profit institutes during the nineteenth century, the rise of industrial research has shifted this balance to some degree. But even today there are comparatively few industrial companies which undertake fundamental research. In the radio industry up to World War II, such work was confined largely to General Electric, Westinghouse, the Telephone company, and RCA. Despite the outstanding contributions that some of the scientists in these companies have made, we cannot expect many industrial concerns to provide the proper environment for fundamental research. The pressure for immediate returns is too great.

And there are many areas of fundamental research which it is impractical for industry to finance because commercial applications are remote. Consider, for example, the work of Michael

Faraday. There was no electrical industry at the time of his original exploration of electro-magnetism. It is hard to conceive how any of the established industries of the day could have justified to their stockholders an investment in the kind of research which Faraday undertook; yet without this research it is very unlikely that the modern electrical industry, as we know it, would ever have developed. And today it is difficult to imagine any industrial concern in this country undertaking an intensive investigation of astro-physics, though from the exploration of variable stars and cosmic radiation may come some revolutionary new developments which will have profound effects on industry.

I should conclude, therefore, from this study of the origins of the radio industry that a flourishing program of fundamental research is vital to our future industrial progress.[2]

It is also essential that more effective mechanisms be developed to bridge the gap between advances in the boundaries of knowledge and their commercial application in new industries and products. This brings us to a consideration of another question that I raised in the preface: "Does our economy require a stream of new firms to pioneer in the untried and the speculative?"

(b) THE ROLE OF NEW FIRMS

New companies have been of critical importance in the history of radio. The electrical industry was well organized at the turn of the century when Marconi launched the first radio companies in England and the United States. The American Telephone and Telegraph Company was already an important concern. Western Union and Postal Telegraph had telegraph lines throughout the United States and cable connections abroad. The development of wireless communications was obviously a potential threat to the interests of these companies, particularly to the international cable system. Yet neither the Telephone company nor Western Union made any contributions to wireless in the early years. The same can be said of the General Electric and Westinghouse companies, both of which were important manufacturing enterprises at the time. All these companies had their

[2] See also V. Bush *Science: the Endless Frontier* and "Federal Support for Scientific Research," by the author, *Harvard Business Review,* Spring, 1947.

own fields of interest; and a new and highly speculative development such as wireless had very little appeal.

The three most important early American concerns were American Marconi, National Electric Signaling and De Forest Wireless. Each of these companies was organized around one outstanding inventor. Marconi, Fessenden and de Forest could perhaps have found an outlet for their wireless interests in established companies, but none of them did so; and it is probable that, had they been employed by some of the leading electrical companies of the day, they would not have been given much scope for wireless experimentation. The commercial potentialities of wireless seemed and were quite remote in 1900.

Through Marconi's pioneer work, however, ship-to-shore communication was developed. Reginald Fessenden of NESCO conducted the first wireless telephone experiments made by any commercial company. And it was while working for the American De Forest Wireless Telegraph Company that Lee de Forest made his revolutionary invention of the three-element vacuum tube. Very few of our modern developments in electronics would have been possible without de Forest's discovery of the tremendous increase in sensitivity that can be obtained by introducing a third element between the cathode and the anode of a vacuum tube.

Since the turn of the century our well-established industries have made great strides in their capacity to contribute to the advancement of science. The modern industrial research laboratory has materially altered the relationship between science and industry.

Yet it is only the very large companies in the radio industry which have first-rate scientists in their employ. And it will be unfortunate if the translation of scientific advances into new products and new industries is left entirely to the great corporations. Any large, well-established institution almost inevitably tends to become somewhat bureaucratic. It develops fields of special interest; and no matter how hard it tries to be receptive to new ideas, the radical notion and the new risk-taking approach are not always exploited. We can expect our great industrial corporations to take substantial risks and to be very forward-looking in many areas.[3] But some of the less obvious developments which are off the beaten track, and which are in the highly speculative stage where their potentialities cannot be visualized, are likely to be neglected.

I believe, therefore, that it is very important to have new firms arise to take risks in unexplored areas, but there are barriers which must be overcome. In the days when American Marconi and NESCO were launched, many wealthy individuals were willing and able to put capital into new ventures; with tremendous increases in taxation the number of such individuals has dwindled rapidly. At the same time, the large established corporation is in a much more dominant position to restrict entry into its field. This suggests that special efforts must be made to ensure a flow of capital into new enterprises.[4]

(c) THE ROLE OF THE INVENTOR

It was not only fundamental research, inventive talent, venture capital, and new firms that were needed to develop the radio industry, but entrepreneurial skill as well. De Forest's vacuum tube was more revolutionary in its ultimate impact than any invention of Marconi's, but the Marconi company was a success and the De Forest companies were failures.

The period in radio history up to the outbreak of the first World War can be characterized as the era of the "entrepreneur-inventor." Success was dependent not only on the ability of the inventor to make a significant technical advance, but on his capacity to carry through a successful innovation—a rare combination of skills. The three leading entrepreneur inventors whom we studied during this period were Marconi, de Forest and Fessenden. These men possessed high inventive talent, but they varied considerably in their entrepreneurial skill.[5]

[3] The current work being done by the General Electric Company in nuclear physics is an example of this. Yet the electrical industry did little in this field until the development of the atomic bomb.

[4] For a further discussion of this problem see "Investing in Science for the Future," by the author, *Technology Review*, May 1946.

[5] I am following Schumpeter here in implying that the entrepreneur should be judged primarily on his capacity to innovate. See his *Theory of Economic Development* and *Capitalism, Socialism and Democracy*.

Marconi, for example, was one of the first to foresee the commercial possibilities in radio, and he had the tenacity of purpose to devote his entire life to the development and extension of wireless communications. On the other hand, Marconi's primary interest was in the technical development of wireless. He knew very little about business and was impatient over operating details. During the early years of the Marconi company when he managed both its business and technical aspects, he got into considerable difficulty. The directors finally suggested that Godfrey Isaacs, who was a "born businessman," be brought in as managing director; and Marconi agreed enthusiastically. Thereafter, although he was chairman of the board, Marconi devoted his major attention to research and invention and left the business phases to Isaacs. Marconi was a well-adjusted person and worked easily with others; he and Isaacs made a very effective team, each respecting the other's skills; and it was under this joint management that the company prospered.

Marconi's principal rivals in the United States—Lee de Forest and Reginald Fessenden—while his equals if not his superiors in inventive capacity, were not so well adjusted personally as Marconi and did not succeed in teaming up with skillful innovators.

Lee de Forest had a keen intuitive sense of significant technical inventions. He was not only a pioneer in the development of the vacuum tube and the feedback circuit but also one of the early inventors of sound motion-picture apparatus. However, he remained always the lone type of inventor, totally unadapted to co-operate with others in organizing research. In consequence, he was never able to keep any research assistants for long. Nor did he have Marconi's tenacity of purpose. He was too impatient and volatile to stick with any one aspect of a field.

These characteristics applied equally to his business ventures. De Forest was responsible for a succession of companies, all ending in bankruptcy. He did not surround himself with able business associates, and had no sense of sound finance. In his business activities he was essentially a promoter, seeing the possibilities for a new commercial venture, eager to obtain funds for new technical experiments, but losing interest very quickly in the commercial aspects of his companies once they had been launched.

Reginald Fessenden had far more tenacity of purpose. But he too was a "rugged individualist," with very little toleration of other people's opinions. He received his financial support from two Pittsburgh capitalists, Walker and Given, neither of whom had a workable conception of how a wireless venture could be made to pay. Fessenden showed no tact in dealing with the men who supplied him generously with funds. And in the day-to-day conduct of the enterprise, he had no understanding of the principle of delegation of authority. He ran NESCO as a personal venture to support his experiments. A scientist and inventor with considerable imaginative powers, he nonetheless failed entirely when it came to organizing a business that could compete with the American Marconi company.

With the development of entertainment broadcasting after the first World War, the "inventor-entrepreneur" became less significant. In the 1920's the leaders of the large electrical corporations, the "older capitalists," played the decisive role in shaping the industry. General Electric, Westinghouse and the Telephone company combined their wireless interests to form the Radio Corporation of America, and Owen D. Young, stimulated by the Navy, was primarily responsible for carrying through this innovation. Young represented a new type of entrepreneur whose thinking was in broad and long-range terms. A lawyer, not an engineer, he was primarily interested in "organizational innovation." He created the company that dominated American wireless up to World War II. He was also largely responsible for America's leadership in a series of international radio telegraph agreements.

It was David Sarnoff, however, who converted Owen Young's brainchild into an effective working organization. This took years of painstaking operational effort, as well as aggressive tactics. Sarnoff, reared in the old American Marconi company, was thoroughly versed in radio problems. His task for many years was to consolidate and entrench his company's position. He also had the conviction and enthusiasm to stress entertainment broadcasting as the major opportunity for RCA rather than international communications, which had been the original conception when the company was formed. And Sarnoff, far more than other executives in the industry, pressed constantly for television development. The Television Broadcasters Association conferred on him the title of "Father of American Television" in 1944 for "his initial vision of television as a social force and the steadfastness of his leadership in the face of natural and human obstacles in bringing television to its present state of perfection." He strove constantly, using all the weapons at his command, to place RCA in a dominant position in the major branches of the industry—communications, broadcasting, receiving set and tube manufacturing. But he also tried to infuse life into a company which had been put together from the top instead of growing slowly from small beginnings.

During the 1930's a group of new capitalists emerged in the industry; the term "new capitalists" is appropriate because these men were the successful survivors of the new recruits[6] who had entered the industry in the 1920's. Most of them were self-made men who had started without adequate financial backing. They did not have hired managers to run their companies. In the case of Zenith, Galvin, Emerson and Sylvania, the top managerial officers were also the principal stockholders. Emphasis was on salesmanship, price competition and low-cost production. Very few of the manufacturing companies, started after 1920, emphasized research.

Most of these concerns were primarily imitative and were therefore not important "transmitters of newness."[7] An executive of one of these companies told me that when his company first entered the industry he said to his manufacturing superintendent, "I want you to copy RCA's product completely in every detail, even though you believe that you can improve on some of its features. When we have learned to do this successfully, we can then think about improvements." And he insisted that this be continued for some time, with efforts concentrated

[6] It is through new recruits that capitalism has developed up to this time—a fact noted with a sneer by Karl Marx: "That a man without wealth but with energy, solidity, ability and business sense may become a capitalist in this way, is very much admired by the apologists of the capitalist system—although this circumstance continually brings an unwelcome number of new soldiers of fortune into the field and into competition with the already existing individual capitalists, it also secures the supremacy of capital itself, expands its basis and enables it to recruit ever new forces for itself out of the lower layers of society." Marx, *Capital III*, pp. 705–706.

[7] The Farnsworth company, started in 1939, was an exception.

on bringing costs down, rather than on change. As the company grew in experience and demonstrated its capacity to manufacture at a profit, these copying rules were slowly relaxed and minor changes and improvements were introduced. Gradually the company began to build up its engineering force and bring in men with more technical originality.

The most successful of these new concerns were dominated by salesmen entrepreneurs such as Larry Gubb of Philco, Gene McDonald of Zenith and Benjamin Abrams of Emerson. Not that these men were similar in personality, but they represented a new type of influence in the industry. All were very conscious of market demand and knew how to offer radio sets to the public in an appealing way. They also saw clearly that the industry had reached a stage where a vast new market could be created by drastic lowering of costs and prices.

A thorough analysis of the role of management and entrepreneurship in translating the fundamental discoveries of Maxwell, Hertz and others into practical commercial products would require much more complete biographical information on the key figures than I have been able to assemble.[8] Nevertheless, certain elementary facts seem to emerge. The most successful companies have been dominated by strong personalities who were *innovators*. This applies to the Marconi companies, RCA, Philco, Zenith, Emerson and Sylvania. All of these concerns were efficiently administered; and *none* of them was dominated by an *inventor*. In the case of the British Marconi company, for example, it was Godfrey Isaacs who formulated the business policies of the company during its period of commercial success. The executives of these companies showed the same intensity of purpose as the pioneer inventors, but their interests and instincts were in commerce rather than in science.

[8] I hope that others will undertake biographical studies of some of the leading American inventors. Most of the studies that have been made are disappointing in the contribution they make to an understanding of the process of invention. There has been too much uncritical acceptance of the heroic theory of invention with little or no attempt to relate the contribution of the "hero" to others who have preceded him. In the field of invention, we need comparable studies to John Livingston Lowes's analysis of the process of Coleridge's creation in *The Road to Xanadu.*

No case has come to my attention in the history of the industry in which high inventive talent and the capacity for successful innovation were combined in one man.[9] There have been such cases, of course, in other industries; but it is apparently a rare phenomenon. Successful invention seems normally to require intensive application to the problem which is being tackled, to the temporary exclusion of all other considerations; it is an egocentric activity which, for those gripped by it, is all-absorbing. De Forest, Fessenden and Farnsworth were such men. When de Forest was working on a new invention, everything else was forgotten. He burned with an intense flame, and his success seems to have been a product of brilliant imagination and intense application. The pace was so energy-consuming that he could not maintain it for long. And during his periods of creative productivity the commercial aspects of his enterprises were completely neglected.

The majority of the inventors we have studied had difficult personalities. De Forest, Fessenden and Farnsworth were highly temperamental. And none of them had the judgment to recognize that it was essential to associate with men of exceptional managerial skill who would relieve him of commercial burdens. Marconi, by contrast, was willing to do this.

We can see, however, a distinct improvement in the process of innovation over the period studied. Marconi, de Forest and Fessenden were "rule-of-thumb innovators," who were more or less unconscious of the problems of entrepreneurship. Since the first World War, much more emphasis has been placed on the profession of management. Owen D. Young and David Sarnoff of RCA, J. T. Buckley and L. W. Gubb of Philco, and Walter Poor of Sylvania more nearly typify the "informed entrepreneurs." [10] They have been specifically conscious of the problems of administration and the necessity of building an integrated organization which will deal with all phases of the companies' responsibilities. The rise of industrial research has also brought more order into

[9] I suspect that Edwin Armstrong may have possessed the requisite skills, but he has never been engaged in manufacturing enterprise.

[10] I am indebted to Arthur Cole for this classification of "rule-of-thumb" and "informed" entrepreneurs. See his "An Approach to the Study of Entrepreneurship" in the *Journal of Economic History*, Suppl., 1946.

the innovation process; companies today can, to a considerable extent, plan for new developments. The director of research is becoming an important participant in the formulation of company policy. As in war, science is beginning to determine tactics in industry. But what is being done in this direction in the radio industry is still halting and sporadic. There has yet to emerge a "scientific entrepreneur" who will attempt to apply the latest advances in the physical and social sciences to the solution of his problems. I am hopeful that such leaders will arise in the years to come and that they will represent an even more significant advance than the transition from "rule-of-thumb" to "informed" entrepreneurship.

(d) THE ROLE OF MONOPOLY

No industry which was *perfectly* competitive [11] could conduct research. Some protection against competition is essential if there are to be profits; and profits in turn are required to sustain a research program concerned with new products. The realistic issue for any industry in which rapid technological progress is desired is: "What degree of monopoly should be permitted?" As modern science begins to have its full impact on all American industries, it will become increasingly important to consider the optimum organization of different industries in relation to their technological needs. I believe that this optimum will differ considerably between and within industries and at different stages in their technical development.

Between 1920 and 1940, outside of the larger patent holding companies—RCA, GE, Westinghouse and the Telephone company—conditions were so competitive in the radio manufacturing industry that most firms found it difficult to undertake research. The RCA licensees were primarily concerned with achieving volume production, lowering costs and obtaining brand preference for their radios through advertising and promotion. They acted on the principle that if some important new development arose from research in one of the large industrial laboratories, they would be able to follow this lead very rapidly. This attitude, of

[11] For the non-economist reader it should be explained that under conditions of perfect competition prices are driven down to the point where they just cover costs, and consequently there are no profits.

course, was partly the result of the license arrangements. Yet the fact remains that an entrepreneur with a research spirit and an absorbing interest in new technical developments did not arise in these companies.

Shortly before the war, in response to the awakening of a general interest in research, an increasing proportion of the RCA licensees started research departments. In studying their results, I have been impressed with the difficulty of getting first-rate work done in a cost-conscious company. It is an axiom of research that, in the day-to-day pressure for immediate accomplishment, applied research drives out pure. This need not happen if special measures are taken to nourish pure research, but a major effort must be made to accomplish this. The postwar period will show how many of these companies are able to develop first-rate research departments. I believe that only a few will succeed in doing so.

Practically all the research of the RCA licensees in the period under review was directed toward specific practical objectives—toward the improvement of existing products rather than toward the creation of new ones. They did not attempt to take scientists into their laboratories and give them a free hand in the selection and execution of a long-range project of inquiry. Yet it is the cultivation of the latter type of research which is vital to scientific productivity. The presence of a group of men who ask new and penetrating questions and are not inhibited by existing practices can have an extraordinarily stimulating effect on applied as well as on fundamental research.

Freedom of inquiry within the broad limits of the company's long-range objectives is essential to fundamental research. The best scientists will not stay in an industry unless they are convinced that the company knows what such research is, believes in it thoroughly, and has the financial resources to assure a fair trial for a research program, without pressure for immediate accomplishment.

The best research, therefore, is not directed from above but wells up from below in the proper environment. The RCA licensees, by and large, did not face this problem squarely. It was not the characteristic practice of Philco, Zenith, Sylvania, Galvin or Emerson to encourage men to plan a research career [12] and stay with it. The major rewards in these companies went to the administrators in manufacturing and engineering. I believe, therefore, that if the radio industry had been composed exclusively of such companies, the emphasis would have been on the engineering improvement of existing products rather than on longer-range exploration into new areas.

The most important research in radio was undertaken by the large corporations. It may be that we are dealing with an industry in which the large companies were exceptionally forward-looking in this respect. Certainly the original decision of the General Electric executives to establish a centralized research laboratory was a very progressive step. And the management had the courage and imagination to bring in men of outstanding ability, and to create a research environment which compared favorably, in freedom of long-range inquiry, with that of the best American universities of the day. Out of this environment came the Langmuir high-vacuum tube, the Alexanderson alternator, the Rice–Kellogg loud speaker, the Hull screen-grid tube and the Langmuir thoriated filament.

The Bell Telephone Laboratories is also a unique institution. Since before the first World War, the American Telephone and Telegraph Company has had a virtual monopoly of the telephone business in the United States. As monopolists, the officers of the company might have been indifferent to new developments outside their immediate field of wire telephony. Instead they built up a great industrial research laboratory with far-ranging interests over the whole area of electrical communications.

AT&T was the first concern to communicate with Europe by the wireless telephone, and since the Arlington–Eiffel-Tower experiments, the company has played a major role in perfecting radio telephony. It has also done very important work on power tubes for wireless transmission, and was responsible for the first sustained program of television research in this country under Dr. Herbert Ives.

12 I am making a distinction here between scientific research and engineering practice. An interesting career of active engineering practice was possible in these companies. Since the war, moreover, research careers have become much more possible.

The Westinghouse research laboratories did pioneering work on the a-c tube, which made it possible to plug a radio into a light-socket in the home. They also supported Zworykin in his early work on the photo-electric cell, the iconoscope and other vital aspects of electronic television. And when radio manufacturing was transferred from Westinghouse and GE to RCA in 1930, Dr. Zworykin's work was absorbed and expanded greatly. Since then, the Radio Corporation has carried the main burden of research in television, involving, as we have seen, very substantial expenditures.

Compared with these four companies, the research undertaken by the rest of the industry was far less significant.

On the other hand, I believe that more competition between the large patent-holding companies would have resulted in still greater technical progress from 1920 to 1940. Though I cannot prove this point, there seems some evidence to support it.

With the formation of the Radio Corporation of America in 1920, GE, Westinghouse and AT&T agreed that all their radio patents were to be available, royalty-free, to one another. At first, the field of radio broadcasting was sufficiently new and important so that all three companies made a major effort to exploit it. Each erected its own stations and each spent large sums on research. Had this competition continued, I think the industry would have remained healthier. But the officers and most of the directors of RCA were apparently afraid of competition; and in 1926 they persuaded the Telephone company to withdraw from entertainment broadcasting. This led Dr. Jewett, president of the Bell Laboratories, to write: "From the standpoint of the man who has a brilliant idea, an agreement in advance to hand over the results of all research work to another company without financial reward will tend to discourage the research workers of the laboratories from exploring that area." [13]

[13] F. C. Waldrop and J. Borkin, *Television—A Struggle for Power* (New York, Morrow, 1938), p. 194. Donald Wallace reached a similar conclusion in his study of the aluminum industry, in which he concluded that several large companies competing aggressively against one another would have advanced aluminum technology more rapidly than the Aluminum Company of America. See *Market Control of the Aluminum Industry* (Cambridge, Harvard University Press).

Thus, as it became increasingly clear that television would be primarily useful for entertainment purposes rather than for telephonic communication, the excellent research on mechanical systems of television was not continued for electronic television. I believe that, if the Bell Laboratories had been provided with a more direct incentive, the power of their research organization, and their very great skills, would have resulted in more important contributions to television.

Considering next the General Electric Company after its separation from RCA, the patent cross-licensing policy did not provide the maximum incentive for GE to press forward with original radio research. This perhaps explains why General Electric made no significant contributions to television or FM up to World War II.

And with Westinghouse, as GE's original *junior* partner in radio, there was a greater incentive for its officers to concentrate their research efforts in areas in which they had a hundred per cent financial interest and which contributed to the largest share of their profits, such as central-power stations and other heavy industrial equipment. Though the research directors of the Westinghouse laboratories took an early interest in television, Zworykin was given little support during a substantial part of the period that he was with the company. It was Mr. Sarnoff of RCA who saw clearly the commercial possibilities of television and made arrangements with the Westinghouse laboratories to have Zworykin's work pushed forward more rapidly.

Power is also subject to abuse. In the case of frequency modulation, it is my conviction that this important innovation would have been considerably delayed but for the zeal of Armstrong and the interest of the smaller broadcasting companies which had no large fixed investments in amplitude modulation stations. The Yankee Network was the first to erect a commercial FM station. And the rapid development of other new stations came primarily from the small broadcasting companies throughout the country which saw a way of improving their competitive positions.

I believe, therefore, that, although some degree of monopoly is desirable, it is equally important to have new firms and rising firms searching for technical developments that may have been overlooked or not pressed by the large companies.

(e) PATENTS AND MONOPOLY

The role of patents in stimulating or retarding technical progress is a special problem of monopoly. Recent public discussion has been focussed on the abuses of the patent system which tend to impede technological change. Many people believe that these weaknesses are sufficiently deep-seated to warrant abolishing the patent monopoly altogether, or drastically reducing patent life. It would be informative to consider the nature of these abuses as they have appeared in the history of the radio industry. But this is not the appropriate place for an exhaustive treatment of the patent problem, as evidence from one industry could scarcely be conclusive. I should like, however, to offer a few observational impressions on the workings of the patent system in the radio industry. I shall confine my remarks to patent litigation, patent cross-licensing and patent incentives.

Patent Litigation

In reviewing the role that patents have played in radio development, one cannot help being depressed by the excessive litigation involved. The high cost of patent suits has played into the hands of the large corporations: the great electrical firms have operated patent factories in which a field is blanketed with applications, and suits are pressed aggressively against infringers. Relief is certainly needed against the wastes of duplicate litigation in different jurisdictions where ultimate decisions are frequently delayed for many years. Nearly forty per cent of the total patent suits in the industry on which we could obtain information lasted over two years. On the regenerative circuit, Armstrong and de Forest submitted their patent applications in 1913 and 1914; but the final decision on priority of invention was not awarded by the Supreme Court until 1934. This is not unlike the famous inheritance case satirized in *Bleak House*, which was finally settled when the estate was used up in legal fees. By the time the de Forest patent was upheld, de Forest had long since sold his patent rights, had gone through several bankruptcies and had finally left the radio field entirely. Armstrong had also sold his regenerative circuit patents because, as he reported, "I was in danger of being litigated to death." [14]

There has been a good deal of discussion of a double standard of validity between the Patent Office and the courts, but actually the great majority of the radio patent cases pressed in the courts were declared valid and infringed (see Appendix II, Table V). The overwhelming percentage of cases was conclusively settled in the district court, and where an appeal was taken, the chances were only about one out of four that the district court would be reversed (see Appendix II, Table IV). Nevertheless, the fact that the courts are known to be more rigorous than the Patent Office in their interpretation of patent claims apparently encouraged many defendants to fight the case, even though statistically they proved to have very little chance of winning.

The course of litigation would also run more smoothly if expert technical assistance were available to the courts. Lay judges are distinctly handicapped in trying cases in such complicated technical fields as radio. The high-vacuum tube litigation, for example, included conflicting depositions by some of the leading physicists of the day. The case dragged on for eighteen years, with alternate victories for the disputants and a mounting volume of expert opinion which produced testimony running to thousands of pages, most of it highly technical.

The increasing pace of technological change raises the question whether patent life is not too long. Certainly, there can be little justification for permitting the life of a patent to be prolonged for years through interference proceedings. For example, in the Farnsworth—George and Heim interference case, when Farnsworth was ultimately given priority, his original patent applications—filed in 1926—obtained a twelve-year extension of life—to 1955.[15] The suggestion has been repeatedly made that over-all patent life be reduced to twenty years, but as yet no congressional action has been taken.

[14] Interview, July, 1944.

[15] The seventeen-year life of a patent commences on the date when the patent is *granted*, regardless of when the application was first made. If there is interference with another application, no patent is granted until the case is settled.

Patent Cross-Licensing

There are many cases where the cross-licensing of patents is necessary for the best engineering development of a product. I believe that this was so in 1920 when the RCA group was formed: neither General Electric, Westinghouse nor the Telephone company could have manufactured the best radio set without cross-licensing agreements on their major patents. Where this is permitted, however, there should be no license restrictions, and royalty rates should be low. This was not the case originally in the RCA group. The initial conception was apparently not to offer any licenses at all, and later when political pressure forced some licensing, the initial rates were high.

The principal disadvantage of the cross-licensing of both present and future patents among the major concerns in an industry is that new firms find it extremely difficult to acquire a significant patent position of their own and to obtain thereby some protection for their research budgets. Small companies generally find it difficult to develop patent bargaining power until they have made a substantial investment in research, in patent applications and in patent litigation. However, if the approach is sufficiently original, it is not impossible to create a patent position in competition with the great research laboratories of established enterprise. This was shown in the case of Farnsworth. Some of the original RCA licensees, too, such as Philco, Raytheon and Sylvania, have been gradually developing patent positions of their own. They were greatly handicapped in doing so, however, by the restrictionist practices that RCA maintained up to the end of the 1930's. Today the situation is different. All restrictions have been removed and royalty rates are reasonable.

Patent Incentives

When Hertz and Lodge did their original work in wireless, they were primarily interested in studying natural phenomena. Hertz made no patent applications; and, although Lodge did obtain some important patents, there is no evidence that this incentive stimulated his work. This was true also of Crookes, Braun and other nineteenth-century scientific pioneers of radio.

After 1900, the possible rewards to be obtained from radio patents provided a direct stimulus to inventors and those who financed them. Fessenden, for example, obtained two backers—Walker and Given—who advanced large sums of money to finance his experiments. They did so with the definite hope that this would prove a profitable speculative investment. They expected Fessenden's patent position [16] would enable him to develop a system of wireless communication which could be sold at a substantial profit to some competitor of the British Marconi company. De Forest raised his funds by stock promotion, and his patents were played up in the sales appeal. Edwin Armstrong, as a young and struggling inventor, had no private means or sources of capital to tap, and for a number of years was able to finance himself only by what he received from his patents. And later, in television, a group of California bankers supported Farnsworth in the expectation that his patents would be basic to the new television industry and more than compensate for the initial investment. Without the patent system, it is difficult to see how any of these inventors could have obtained adequate financial support except by joining established companies; and in the critical years when these men were beginning their experiments, none of the existing firms was interested in their inventions. The patent system, therefore, provided an important stimulus.

The role of patents as an incentive to research and invention in established concerns is in a different category. The nature of the incentive has varied with the circumstances of the company. It seems doubtful that patents served as a direct incentive to radio research in the Telephone company; its officers were interested primarily in the possible use of high-frequency methods for public communication service. The potential threat to its investment in wire telephony was sufficiently clear so that wireless research was given a high priority. The officers of the Telephone company also made strenuous efforts to prevent any other company from acquiring in radio a basic patent position to which they would not have access.

[16] Fessenden has been accused of obtaining patents in things which he did not intend himself to develop and was not ready to develop. Whether or not this was true, the fact that it is possible is a weakness in our patent system which needs correction.

General Electric and Westinghouse, on the other hand, were not compelled by the nature of their business to explore wireless communications; and if the industry had not offered significant financial rewards through the control of patents, I do not think they would have entered the field. Little capital investment was required to assemble radio sets. And there were many companies which possessed the "know-how" to manufacture the principal component parts. With no patent restrictions, competition would have been very keen. In these circumstances, it seems unlikely that GE and Westinghouse would have entered the radio manufacturing industry at all, or stayed in it long if they *had* entered. Both these companies have specialized on products that provide comfortable profit margins. And without GE and Westinghouse I think technical progress would have been considerably slower from 1920 to 1940. These companies brought to the industry large, well-equipped laboratories and a staff of technical experts which the small competitive concern could not afford.

The incentive for the smaller concerns to undertake research in order to obtain patents was weakened by the overwhelming nature of the RCA patent structure. Yet, in television, Philco's support of Farnsworth was undertaken primarily to build a patent position which would make the company less dependent on RCA. And the Philco executives, once they acquired some patents of their own, became more interested in spending money on research to protect their position. My own conclusion, therefore, is that the patent system, in spite of its weaknesses, did operate to encourage research and invention during the period under review.

2. *Technological Innovation and the Business Cycle*

Although we have not been directly concerned in this particular study with the relationship between invention, innovation and the business cycle, one of the motivations for studying the process of technological change is to assist in achieving a high and steady level of employment. It is tempting, therefore, to record some impressions on the relation of radio inventions and innovations to cyclical fluctuations in business.

(a) SCHUMPETER'S HYPOTHESIS

The role of technological change in the business cycle deserves further treatment by economic investigators. Professor Schumpeter has given innovations a key position in his analysis of the cycle, and has assembled some historical facts which lend support to his theoretical scheme. But much more needs to be done to test his hypothesis empirically. I wish that I had been able to carry this task forward significantly; but the period studied here is too short and a "single industry" analysis does not permit definitive conclusions. However, it may prove helpful for subsequent investigators to record the impressions that I did obtain.

Schumpeter believes that one can discover in the history of particular industries, major innovations which have carried long cycles of business activity, and other less important innovations which run their course on the back of the wave created by the principal break-through. The variation in the period of gestation and absorption of innovation by the economic system accounts, in Schumpeter's mind, for the fact that there is not a single wave-like movement in business fluctuations but several cycles superimposed one on another.

Schumpeter identifies the period covered by our study (1900–1940) as a long wave which was carried in large part by the electrical revolution.

> Soon after the turn of the century, long-distance transmission, the triphase current, the spread of the steam turbine, improvement of hydro-electric motors, construction of hydro-electric and thermo-electric plants of ever-increasing capacities, and the victory of the big power stations over the plants of individual industrial consumers became the leading features of the period. . . . Hydro-electric enterprise had started on a large scale in 1895 when the plant at Niagara Falls went into operation. . . .
>
> This new supply of power had tremendous repercussions in changing the location of industries and in making possible the expansion of existing plants. Gradually textiles, paper mills, metallurgical and chemical industries installed electricity. . . . In many cases—that of cotton mills, for instance—different types of factory buildings were necessary in order to take full advantage of the installation of power. . . . The expansion of electric tram (street-car) mileage was very substantial.[17]

[17] Joseph A. Schumpeter, *Business Cycles*, Vol. I (New York, McGraw-Hill, 1939), pp. 412, 413.

According to the wave hypothesis, each major break-through brings in its train a series of secondary waves of innovation which involve less capital investment but are still of considerable importance. The radio industry was such a secondary wave. It developed after many of the other major uses of electricity had been explored, and did not involve capital investment comparable to the construction of central-station power equipment.

By the late 1920's, the major construction period in the electrical industries was over. Elaborate and costly power stations had been built, all major industries had been re-equipped for use of electricity, and a very large percentage of American homes had been electrified and supplied with radios.

When a wave of new enterprise has extended for several decades, an increasing number of imitative entrepreneurs enter the industry and profit margins diminish because of this competition. The time comes when an additional wave of progress must await some new and important break-through which will again improve the prospects for profit.

(b) INNOVATION IN THE RADIO INDUSTRY

How does this conception fit the development of the radio industry? The major organizational innovation occurred in 1920 with the formation of the Radio Corporation of America; until then, radio had not been of great economic importance. The innovator firms sponsoring the development of RCA were General Electric, Westinghouse and the Telephone company. The first regular commercial broadcasting service was initiated by Westinghouse; and GE and Westinghouse were among the first companies to manufacture vacuum-tube sets for the general public. Their action was followed by the entry of a host of imitator firms, both in commercial broadcasting and in radio manufacturing. As more and more firms were drawn into the industry, profit margins were reduced; and by the end of the 1920's they had largely disappeared for many companies.

By 1929, the major investment in the radio industry had taken place. The first period of broadcasting-station construction was largely over, and the set-manufacturing industry had reached a capacity which was capable not only of filling replacement needs but of taking care of considerable expansion in demand. New investment at this stage was likely to come only from changing over to new types of transmission stations and from the reconstruction and relocation of manufacturing plants. Such a wave of industrial investment did not come until the development of FM and television in the late 1930's.

The danger, however, in "fitting these facts" so neatly into a broad conceptual scheme is that they by no means prove that technical and other types of innovation *cause* cyclical fluctuations. Assuming, for example, that there is some quite different causal factor, it is natural to expect that in periods of high business prosperity every effort will be made to capitalize on previous scientific break-throughs by pushing investment to the limit. Thus, one could argue that, had we not gone on such a temperamental building spree in the 1920's in the expansion of public-utility enterprises, and the high pressure development of such fields as radio (between 1923 and 1929, over 800 firms entered the industry, and almost 15,000,000 radio sets were sold), the "new investment" phase would have lasted until FM and television were ready.

Our present method of handling new products certainly accentuates cyclical swings. Aggressive competition and high-pressure selling drive business concerns to make an all-out effort to push a new product, once it is ready for mass commercialization. This means that a major portion of the energies of the engineers in the industry are absorbed on current projects. In such periods it is very difficult to carry on an important research program pointing to future products. Day-to-day needs are too pressing. Thus, in radio during the 1920's, the all-absorbing problem was the improvement of existing radio techniques so that everybody could own a set and get enjoyment from it. Only the Telephone company, which was in a monopolistic position, spent substantial sums of money on television before 1929.

When the depression of the 1930's swept over the industry, every concern retrenched. Even large, well-financed companies like General Electric and Westinghouse reduced their research staffs and budgets drastically. The Telephone company cut research from $22,000,000 to $12,000,000. And in a period in which the emphasis in the industry was on reducing costs, it was the research and development work on new products which suffered particularly. Some of the work on existing products had to be maintained to preserve a competitive position; but new developments, especially in the embryo stage, could be postponed.

3. Conclusions

Regardless, therefore, of the role of innovation as a cause of the cycle, fluctuations in business could probably be alleviated by a more rational handling of industrial research. It would certainly be desirable for corporations to plan their technological developments to take place in a more even fashion. The large modern corporation with substantial financial reserves is in a position to operate, in part, on three- and five-year budgets rather than on a strictly year-to-year basis.[18] Typically, American business enterprise has been slow to engage in long-range planning of research as well as of other activities; and the radio industry has been no exception.

However, I personally doubt that the basic problem of maintaining a steady stream of new industrial products is likely to be solved by industrial planning alone. I find myself in agreement with Schumpeter's observation that science tends to progress in spurts and that this results in a clustering of innovations. Important scientific break-throughs require men of exceptional mark. In the history of science there appear to be important turning points where, after a long period of experimentation by many individuals, a Newton or an Einstein creates a new conceptual scheme that brings a whole chain of subsequent discoveries in its track. Once the original and revealing scientific hypothesis has been suggested, a series of less important discoveries tends to follow rapidly.

If this is a fundamental phenomenon, it would be very difficult of alteration. It may, as Schumpeter implies, be the basic cause of the long, forty-year cycle which he sees in modern industrial history. But one thing which could be altered is the time-lag between basic scientific discoveries and their practical application in new products.

During World War II it was shown that, provided the funda-

[18] I believe we have greatly overdone our strict adherence to annual budgets in this country.

mental research had already been done, it was possible to develop radically new products, such as radar and the atomic bomb,[19] in a much shorter period than under peacetime conditions. To a very considerable extent, we can produce new products by forced draft. Working under such time-pressure is exceedingly expensive, both in manpower and in materials; and it would not be feasible in peacetime for an individual business enterprise to undertake new developments on so profligate a scale without subsidy.

However, I do not believe that in *normal peacetime*, industrial science should be organized to make a *mass attack* on a problem. Science does not flourish best under such conditions. Long-range speculative inquiry has to be abandoned for immediate objectives. But we are doing this now in the field of atomic energy, largely through motives of security. And since widespread unemployment *must* no longer be tolerated, I think we should also study possible methods of mobilizing our scientific resources as one of the key weapons to combat *a major depression*. For example, I believe that, if we had decided in 1928 to press forward in television research and development with the same all-out energy that we put into radar, it would have been technically possible to advance as far in two or three years as we have gone in twenty years. And this is also true of many other products and services. I see no valid reason why we, as a nation, should be willing to prepare to fight a war but not to fight a depression.

[19] The fundamental research in both these products was done before the war. The wartime contribution can be described as advanced engineering development of a high order.

Appendix I: THE ELEMENTS OF MODERN RADIO COMMUNICATIONS

When anybody "goes on the air" today in a broadcasting studio, he talks into a microphone, which is a sensitive electrical device capable of converting sounds into electrical equivalents. A microphone amplifier in the control room adjacent to the studio strengthens these electrical signals. From the amplifier, the electrical voice travels over wires to the transmitter. The electrical voice is then "turned over to the modulator, or electrical sculptor, which carves the sounds into the outgoing carrier waves. This is known as modulation, and depending upon how deeply these sounds are carved into the carrier waves, we have more or less modulation." [1]

Sound waves are vibratory in motion. The rattle which emanates from certain objects when loud sounds of suitable pitch are produced near them is well known. It was not until the last century that an experimenter fastened a straw pointer to a paper diaphragm and saw this vibratory motion magnified at the end of this straw. The next step was to move a smoked glass screen transversely in contact with the end of the pointer. The sound waves thus traced a wavy line, whose shape was found characteristic of the sound itself. For instance, a typical sound wave may resemble the heavy line in the Figure on page 267.

The higher the pitch of the sound, the closer together are crowded the crests of the line. When the sound becomes louder, the waves spread higher. Similarly, it may be shown that a combination of sounds, such as several notes played together, does not produce several lines, but merely another single line more complex than that produced by a solitary note. Thus, the sounds which are to be sent into space are produced before a microphone in a studio. This electrical ear creates an exact replica of their wave form and superimposes the sound waves on radio waves or radio oscillations. These sound waves, such as are produced by speech or music, oscillate or vibrate at low frequencies. In contrast, the radio waves, produced by large vacuum tubes, are of much higher frequency—that is, they vibrate many hundreds of times more rapidly.

[1] See Goldsmith and Lescarboura, *op. cit.*, p. 85.

The modulator which produces these composite waves controls the effective output of the transmitting oscillator. This oscillator produces a continual stream of electro-magnetic waves. Attached to the transmitting apparatus is an aerial which may consist of one or more elevated wires, supported from a tower. When this antenna is fed with high-frequency, alternating currents, the electro-magnetic waves are automatically sent into space to all points of the compass. These high-frequency currents flow to and fro in the circuit which connects the transmitter to the antenna at rates from 15,000 to 20,000,000 times per second, varying with the design of the transmitter. Currents of very high frequency—from 3,000,000 to 20,000,000 per second—radiate short waves, whereas currents from 3,000,000 down to 15,000 per second radiate what are termed long waves.

Radio waves travel with the speed of light (186,000 miles, or 300,000,000 meters, per second), and the frequency of the wave, or the number of vibrations per second, may be determined by dividing its wave length into the velocity. Thus, a wave-length of 600 meters will have a frequency of 500,000 cycles (or 500 kilocycles) per second. As the radio waves

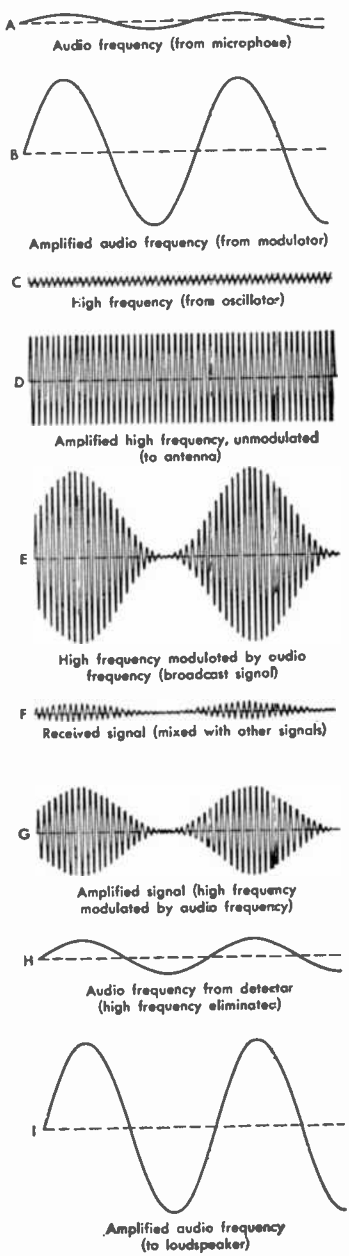
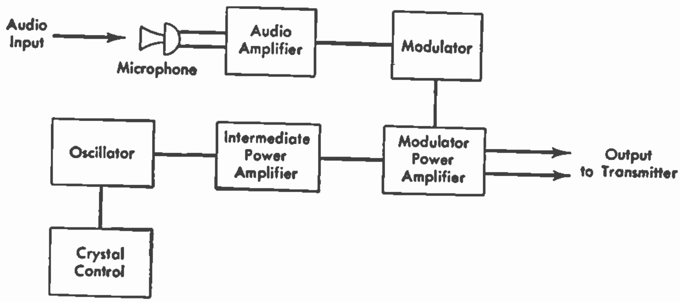


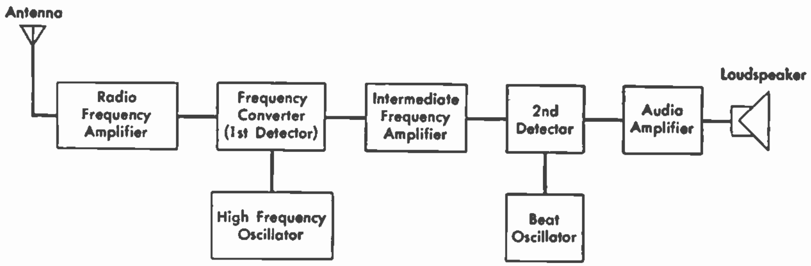
Diagram of the current changes produced in broadcasting and reception. (Courtesy Dunning and Paxton, *Matter, Energy, and Radiation*, McGraw-Hill) proceed through space, their amplitude continually diminishes, but their frequency and wave-length remain unchanged.

Therefore, by the time a radio wave has reached a distant destination, only a small fraction of the original energy remains. For this reason more "power" is required to receive a distant broadcasting station than a local one.

By referring to the block diagram, it may be seen that the receiving set repeats the process of the transmitter in reverse. The high frequency radio waves picked up by the aerial are amplified; these are then sent to the demodulator which separates the original sound waves from the original radio oscillations, and the low frequency audio waves are further amplified and delivered to the loud speaker to emerge as audible and recognizable speech or music.



Elements of a Typical Crystal-Controlled AM Transmitter



Elements of a Basic Superheterodyne Receiver

Appendix II: RADIO PATENT LITIGATION

Because of the extremely important role that patents have played in the radio industry, we have tried to obtain a body of statistical information on radio patent litigation. We were interested in finding out what patents have been principally involved in litigation, and how they fared in the courts. The majority of patent suits are listed in the *Patent Gazette*, published weekly by the United States Patent Office. The suits are recorded in this periodical, but the patents are not classified. To collect the data that appear in the following tables, we have therefore taken the following steps:

(1) Listed the suits in equity [1] recorded in the *Gazette*, involving a patent judged relevant to the radio industry [2] from January 1, 1900, to December 31, 1941;

(2) Obtained, where possible, from the district courts the subsequent history of the case in that particular jurisdiction;

(3) Compiled a record of cases which were appealed, and traced them through various legal records.

This compilation represents a very large sample of radio litigation during the period studied. Some cases were not reported at all in the *Gazette;* and about other cases we were not able to secure satisfactory information from the district courts. Moreover, what constitutes a "radio patent" is a matter of judgment in cases where the patent has an application in other industries. In general, we have followed the classification of Maxwell James, a patent attorney who made a series of compilations of United States radio patents and suits for the Radio Manufacturers Association between 1926 and 1931. His standard was to include patents "having some relation historically, structurally or functionally to the instrumentalities peculiarly employed in the radio receiving field . . . and which disclose structures adaptable, although not specifically intended for radio uses." For this reason we have included the General Electric patents on drawn tungsten filaments and on the tipless bulb, which were of primary importance to the lamp

[1] Today these are designated as civil suits.

[2] We have omitted from the record cases in equity involving the construction of license agreements or disputes over royalty rates. Suits against the government in the U.S. Court of Claims are likewise omitted, as are interference proceedings in the Patent Office.

industry;[3] but both of these patents were also used in suits against radio and tube companies.[4] However, in the table listing the patents on which there has been most litigation, we have indicated those patents in which a large number of suits were filed against firms outside the radio industry.

Some of our methods of classification and separation of suits may be open to criticism. For instance, we have considered as a separate suit every case in which the courts have assigned a separate equity number, even though, as frequently happened, suits on similar issues were filed simultaneously against the same firm by other members of the Radio Group.[5] These were counted as individual cases, although they were frequently handled as one piece of litigation in the courts. Since each suit required its own answer and entry of judgment, we felt this method of counting to be valid.

We have also felt justified in including cases against wholesalers and retailers selling an allegedly infringing product. For instance, in the case of Hazeltine Corporation *versus* E. A. Wildermuth (a dealer in Atwater Kent apparatus), the court stated that, while the retailer was the nominal defendant, "the suit is actually defended by the Atwater Kent Company." Since a plaintiff may file suit against any number of infringers of the same article,[6] and in any jurisdiction in which the defendant conducts a business, there is thus a great duplication of issues. But it must be remembered that the numbers and coverage of suits, in the early period of receiver manufacture, had as profound an effect on the industry as did the legality of the issues and the scope of the patents.

About half of the suits, as shown in the table, involved only one patent. The early suits tended to involve fewer patents than the later suits. Most of the radio suits involving more than five patents were instituted by RCA and its associates, GE, Westinghouse, and AT&T.

[3] The patents on amplification, modulation, and loud speakers were applicable to telephone and public address systems as well as to radio.

[4] For instance, the important Coolidge ductile tungsten invention was declared invalid in a suit instituted by GE against the De Forest Radio Company (17F (2d) 90, 1927).

[5] However, a suit instituted on several patents owned by one company, even where there is a non-uniform decision on patent validity, is treated as a single case.

[6] At one period the Hazeltine Corporation had brought 26 suits in New York against radio retailers, and contemplated filing others. The court was asked to enjoin this practice as having an *in terrorem* purpose. Judge Dickinson stated clearly that "a patentee has the undoubted right granted by law to ask for an injunction and damages against every maker, user or seller of what has been patented . . . a dealer who sells a patented thing may himself be an infringer."

TABLE I: PATENTS AFFECTING THE RADIO INDUSTRY ON WHICH INFRINGEMENT SUITS WERE RECORDED
1900 to 1941, inclusive *

Patents Involved in Each Suit	*Suits*	*Patents Involved in Each Suit*	*Suits*
1	832	11	3
2	250	12	4
3	151	13	3
4	81	14	1
5	82	15	0
6	54	16	1
7	60	17	0
8	24	18	1
9	16	19	1
10	3	20	0

Total number of suits, 1,567
Total number of different patents involved in suits, 684

* Infringement suits did not begin to multiply in the industry until the growth of entertainment broadcasting after 1920. Of the 1,567 suits recorded, fewer than 5 per cent were started before 1920.

TABLE II: LOCALE OF PATENT SUITS AFFECTING THE RADIO INDUSTRY

District Court	*Number*	*Percentage*
New York, Southern District	604	39
New York, Eastern District	201	13
Illinois, Northern District	181	11
New Jersey	114	07
California, Southern District	107	07
Thirty-four other districts	347	22
Insufficient information	13	1
Total suits filed	1,567	100

The radio manufacturing industry is located primarily in the New York and Chicago areas, with a growing activity around Los Angeles. Therefore, most of the suits are concentrated in the courts in these three regions.

TABLE III: COURT RECORD ON PATENT SUITS AFFECTING THE RADIO INDUSTRY
1900–1941

District Court		
Cases reaching settlement in district courts		1,381
Circuit Court of Appeals		
Cases reaching settlement in courts of appeal	154	
Cases in which certiorari was denied by Supreme Court	12	
Total settlements in circuit courts of appeal		166
Supreme Court		
Cases reaching final settlement in Supreme Court		20
Total suits		1,567
Circuit Court of Appeals		
Cases sustaining D.C.	114	
Cases reversing D.C.	34	
Cases dismissed or no information	18	
Total cases carried to Circuit Court		166
Supreme Court		
Cases sustaining D.C. and C.C.A.	8	
Cases reversing D.C. and C.C.A.	4	
Cases reversing C.C.A. and sustaining D.C.	4	
Cases sustaining C.C.A. and reversing D.C.	4	
Total cases carried to Supreme Court		20

The overwhelming percentage of cases is conclusively settled in the district court; and if an appeal is taken the chance is about one in four that the district court will be reversed.

In many of the 650 cases in the valid and infringed category obvious infringement was admitted by the defendant, once the patent holder pushed the suit. On the large number of cases dismissed, we have no information as to how many were settled out of court in a manner satisfactory to the defendant or to the plaintiff. However, the table does show that where prosecution was pushed, most patents were declared valid and infringed.

TABLE IV: PATENTS AFFECTING THE RADIO INDUSTRY—CLASSIFICATION OF DISTRICT COURT AND CIRCUIT COURT DISPOSITIONS

Patent Adjudications *	*Number*	*Percentage*
Valid but not infringed	99	3
Invalid	106	3
Valid and infringed	650	17
Decree Pro Confesso (validity not determined in the courts)	383	10
Dismissed (no prosecution, or settled out of court)	1,246	33
Consent decree (validity not determined in the courts)	1,241	32
Insufficient information	74	2
Total	3,799	100

* As is shown in Table I, many suits involved more than one patent. Since each patent in these cases was determined separately, we have listed the total number of individual patent adjudications.

TABLE V: PATENTS AFFECTING THE RADIO INDUSTRY—LENGTH OF TIME IN THE COURTS

Total Time in the Courts	*Number of Suits*	*Percentage*
Six months or less	524	33.4
Six to twelve months	178	11.4
One to two years	259	16.5
Two to four years	330	21.1
Four to six years	169	10.8
Six to ten years	69	4.4
More than ten years	7	.4
Insufficient information	31	2.0
Total suits	1,567	100.0

Of the total number of cases, 33 per cent were settled within six months of their filing dates. On the other hand, 37 per cent of the cases lasted more than two years. Some of these, however, were delayed through lack of desire by both parties to expedite final disposition.

TABLE VI: PATENTS AFFECTING THE RADIO INDUSTRY—COURT RECORD OF SUITS BROUGHT BY THE MAJOR COMPANIES

Plaintiff	*District Court*	*Circuit Court of Appeals*	*Supreme Court Certiorari Denied*	*Supreme Court Others*	*Total*
Radio Corporation of America	357	13	1	4	375
General Electric	176	18	2	2	198
Westinghouse	54	5	—	—	59
American Telephone and Telegraph	29	9	—	2	40
Hazeltine Corporation	170	12	1	1	184
Marconi W. T. A.	1	5	2	—	8
National Electric Signaling	3	3	—	—	6
Totals	790	65	6	9	870
All other firms	591	89	6	11	697
Totals	1,381	154	12	20	1,567

Table VI shows that RCA, GE and Hazeltine were the principal plaintiffs in the period under review. It also shows where each case was settled. The actual patents involved in these various suits are shown in the following tables.

Table VII includes patents on many of the famous inventions in the industry, such as the De Forest triode, the Armstrong regenerative circuit, and the Hazeltine neutrodyne circuit. It also includes the General Electric patents on the drawn tungsten filament and the tipless bulb, which were of vital importance to the lamp industry; but these were also used in the radio industry.

Patents on which many suits are brought are not necessarily the most important technical contributions to the industry. The Mitchell and White patent on the tipless bulb was not nearly so important as the work of Coolidge on drawn tungsten; but the General Electric Company used the tipless bulb patent extensively in suits against tube and lamp infringers.

On most of these patents RCA had rights to sublicense others under its cross-licensing agreements.

There were, of course, far fewer suits in the period in which the American Marconi company operated than there were after 1920. And there is a strong presumption that the record of patent suits in the *Gazette* was not so complete in this early period as it has been in

TABLE VII: PATENTS AFFECTING THE RADIO INDUSTRY—PATENTS INVOLVED IN FORTY OR MORE SUITS

Patent No.	*Inventor*	*Description of Patent*	*No. of Suits † in Which Patent Was Used*
879,532	De Forest	Triode	40
1,082,933*	Coolidge	Tungsten filament	64
1,113,149	Armstrong	Regenerative circuit	54
1,231,764	Lowenstein	Negative grid bias	75
1,251,377	Hull	Constant D.C. potentials	77
1,297,188	Langmuir	Variable currents	79
1,403,475	Arnold	Vacuum tube circuits	109
1,403,932	Wilson	Electron discharge	85
1,423,956*	Mitchell and White	Tipless bulb	73
1,465,332	Arnold	Vacuum tube	57
1,507,016–17	De Forest	Oscillating triode and feedback circuit	85
1,533,858	Hazeltine	Neutrodyne	59
1,573,374	Chamberlain	Radio condensers	107
1,618,017	Lowenstein	Straight line tuning condenser and circuit	97
1,702,833	Lemmon	Electrical condenser	75
1,707,617	Kellogg	Sound reproducing	57
1,728,879	Rice and Kellogg	Amplifying	74
1,795,214	Kellogg	Sound reproducing	56
1,811,095	Round	Thermionic amplifiers	88
1,855,168	Farrand	Loud Speaker	40
1,894,197	Rice and Kellogg	Sound reproducing	49
Re–18,579	Ballantine and Hull	Demodulator	92
	Total patent actions		1,592

* These patents had their primary application outside the radio industry. Several other patents—particularly those relating to sound reproducing and amplifying—had important applications in such fields as wire telephony, public address systems, and sound movies.

† This represents the number of times a particular patent was used as a cause of action. Since many cases involved more than one patent, the totals of these columns in all tables will be greater than the total numbers of suits filed.

recent years. Moreover, the tabulation in Table VIII is of suits actually *filed*. The position of American Marconi was such that the *threat* of suit was often sufficient to cause an infringing firm to halt its operations.

TABLE VIII: PATENTS AFFECTING THE RADIO INDUSTRY—RECORD OF SUITS BROUGHT BY AMERICAN MARCONI COMPANY 1900–1919

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
609,154	O. Lodge	1898	3
627,650	G. Marconi	1899	1
763,772	G. Marconi	1904	3
803,684	J. A. Fleming	1905	2
Re–11,913	G. Marconi	1901	2

DISPOSITION OF SUITS IN THE COURTS

American Marconi Company, Plaintiff

Judgment for plaintiff	4
Judgment for defendant	3
Discontinued	1
Total suits	8

American Marconi Company, Defendant

Judgment for plaintiff	1
Judgment for defendant	1
Total suits	2

TABLE IX: PATENTS AFFECTING THE RADIO INDUSTRY—RECORD OF SUITS BROUGHT BY NATIONAL ELECTRIC SIGNALING COMPANY 1900–1919

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
706,736	Fessenden	1902	2
706,744	Fessenden	1902	1
706,745	Fessenden	1902	1
918,306–07	Fessenden	1909	1
928,371	Fessenden	1909	1
1,050,441	Fessenden	1913	1
1,050,728	Fessenden	1913	1
Re–12,115	Fessenden	1903	1

DISPOSITION OF SUITS IN THE COURTS

National Electric Signaling Company, Plaintiff

Judgment for plaintiff	1½*
Judgment for defendant	2½
Dismissed	2
Total suits	6

National Electric Signaling Company, Defendant

Judgment for plaintiff	2
Total suits	2

* Fractional judgments have been given in cases involving more than one patent where the decree was not uniform; i.e., one patent was declared valid and infringed, another patent invalid.

The most important Fessenden patents from the standpoint of litigation were those on heterodyne reception, Nos. 1,050,441 and 1,050,728. Although NESCO brought few suits, these Fessenden patents were subsequently involved in extensive litigation by the Westinghouse Corporation (see Table XII–C).

TABLE X: PATENTS AFFECTING THE RADIO INDUSTRY—RECORD OF SUITS BROUGHT ON THE DE FOREST PATENTS BY DE FOREST COMPANIES
1900–1941

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
824,637	De Forest	1906	1
836,070	De Forest	1906	1
841,386	De Forest	1907	1
841,387	De Forest	1907	1
867,876	De Forest	1907	1
867,877	De Forest	1907	1
867,878	De Forest	1907	1
874,178	De Forest	1907	1
879,532	De Forest	1908	5
979,275	De Forest	1910	1
1,201,270	De Forest	1916	6
1,201,272	De Forest	1916	1

TABLE X (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,221,035	De Forest	1917	1
1,331,264	De Forest	1919	1
1,314,252	De Forest	1919	1
1,348,157	De Forest	1920	1
1,377,405	De Forest	1921	8
1,417,662	De Forest	1922	1
1,446,247*	De Forest	1923	1
1,466,701*	De Forest	1923	2
1,482,119*	De Forest	1924	1
1,489,314*	De Forest	1924	1
1,507,016	De Forest	1924	4
1,507,017	De Forest	1924	3
1,653,155*	De Forest	1927	1
1,680,207	De Forest and Logwood	1928	1
1,693,071*	De Forest	1928	2
1,693,072*	De Forest	1928	1
1,695,414*	De Forest	1928	2
1,695,415*	De Forest	1928	1
1,701,911*	De Forest and Reynolds	1929	1
1,716,033*	De Forest	1929	1
1,764,938	De Forest	1930	1

* Assigned to other than De Forest radio companies, i.e., Phonofilm, Inc., General Talking Pictures, etc.

DISPOSITION OF SUITS IN THE COURTS

De Forest Companies, Plaintiff

Judgment for plaintiff	3
Consent decree	1
Decree pro confesso	2
Dismissed or discontinued	13
Insufficient information	1
Total suits	20

De Forest Companies, Defendant

Judgment for plaintiff	3
Judgment for defendant	3
Dismissed or discontinued	4
Total suits	10

De Forest was a prolific inventor, and many of his patents were involved in suits. By far the most important of his inventions were his original patent No. 879,532 on the triode, and the later patents Nos. 1,507,016 and 1,507,017 on the feedback circuit and the triode as an oscillator. These were carried in suit primarily by AT&T and the Radio Group; and the suits brought by these companies are listed separately in Table XII.

TABLE XI: PATENTS AFFECTING THE RADIO INDUSTRY—RECORD OF PATENT SUITS BROUGHT BY THE HAZELTINE CORPORATION 1924–1941

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,450,080	Hazeltine	1923	16
1,489,228	Hazeltine	1924	11
1,533,858	Hazeltine	1925	59
1,605,411	C. O. Weber	1926	1
1,648,808	Hazeltine	1927	21
1,650,353	Hazeltine	1927	1
1,710,035	R. E. Thompson	1929	4
1,755,114–15	Hazeltine	1930	20
1,763,380	C. E. Trube	1930	11
1,798,962	C. E. Trube	1931	11
1,833,085	V. C. MacNabb	1931	1
1,845,306	W. A. MacDonald	1932	2
1,852,710	Hazeltine	1932	4
1,857,055	W. A. MacDonald	1932	2
1,869,894	Hazeltine	1932	1
1,879,861	H. A. Wheeler	1932	1
1,879,863	H. A. Wheeler	1932	15
1,890,426	V. C. MacNabb	1932	1
1,904,185	H. A. Wheeler	1933	1

TABLE XI (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,913,604	W. A. MacDonald	1933	10
1,934,940	J. M. Miller	1933	1
1,951,685	H. A. Wheeler	1934	6
1,962,104	D. E. Harnett	1934	1
2,007,253	W. A. MacDonald	1935	3
2,021,692	H. M. Lewis	1935	2
2,022,514	W. A. MacDonald	1935	6
2,041,273	Hazeltine	1936	5
2,048,528	H. A. Wheeler	1936	1
2,111,483	C. E. Trube	1938	5
Re–19,744	H. A. Wheeler	1935	6
Re–19,765	D. C. Harnett	1935	1
Re–20,400	H. M. Lewis	1937	2

DISPOSITION OF SUITS IN THE COURTS

Hazeltine Corporation, Plaintiff

Judgment for plaintiff	25½
Judgment for defendant	10½
Consent decree	22⅓
Decree pro confesso	5
Dismissed or discontinued	113⅔
Insufficient information	7
Total suits	184

Hazeltine Corporation, Defendant

Judgment for plaintiff	1
Dismissed or discontinued	3
Total suits	4

The fact that 184 suits were brought by the Hazeltine Corporation is an indication of the extent to which this company has had to rely on litigation to establish its position as a licensor for the industry.

TABLE XII: PATENTS AFFECTING THE RADIO INDUSTRY—RECORD OF SUITS BROUGHT BY GE, RCA, WESTINGHOUSE, AND AT&T 1920–1941

A—GENERAL ELECTRIC *

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
532,760	Howell	1895	1
665,582	Sargent	1901	2
726,293	Howell	1903	1
726,391	Armstrong and Woodbridge	1903	1
818,253	Jones	1906	1
883,725	Kuch	1908	1
955,459	P. Hewitt	1910	1
955,460	P. Hewitt	1910	1
996,936	J. Massey	1911	1
1,010,914	J. Howell	1911	1
1,011,523	A. Swan	1911	1
1,013,124	W. Burrows	1911	1
1,076,884	J. Hayden	1913	1
1,082,933	W. Coolidge	1913	64
1,086,106	E. Weintraub	1914	1
1,086,185	O. Krub	1914	1
1,090,992	Kuch	1914	1
1,110,847	E. Weintraub	1914	1
1,128,120	Fagan	1915	1
1,134,786	E. Weintraub	1915	1
1,140,134	B. Eldred		1
1,140,136	B. Eldred		1
1,173,079	Alexanderson	1916	2
1,182,290	G. Meikle	1916	4
1,208,597	G. MacKay	1916	4
1,220,836			1
1,244,216	I. Langmuir	1917	4
1,244,217	I. Langmuir	1917	5
1,251,377	A. Hull	1917	12
1,261,708	W. Coolidge	1918	1
1,266,517	G. Meikle	1918	6
1,282,439	I. Langmuir	1918	1
1,287,265	S. Dushman	1918	1

TABLE XII-A

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,297,188	I. Langmuir	1919	13
1,326,121	W. Kensen	1919	1
1,334,118	C. Rice	1920	2
1,374,679	J. Pratt	1921	1
1,393,520	E. Friederich	1921	6
1,410,499	A. Pacz	1922	17
1,423,956	Mitchell and White		72
1,423,957	Mitchell and White		21
1,453,594	Mitchell and White	1923	1
1,453,595	Mitchell and White	1923	1
1,475,192	J. Marshall	1923	1
1,477,898	C. Rice	1923	5
1,498,908	C. Fink	1924	1
1,501,831	E. Alexanderson	1924	1
1,522,221	E. Alexanderson	1925	1
1,529,597	I. Langmuir	1925	4
1,558,436	I. Langmuir	1925	1
1,558,437	I. Langmuir	1925	1
1,617,974	W. White	1927	1
1,621,360	R. Folge	1927	2
1,687,510	M. Pipkin	1928	19
1,707,617	E. Kellogg	1929	3
1,708,756	J. Fagan	1929	1
1,728,879	Rice and Kellogg	1929	1
1,738,420	E. Charlton	1929	1
1,758,803	O. Pike	1930	1
1,778,457	I. Langmuir	1930	1
1,790,153	A. Hull	1931	1
1,794,315	D. Mulloney	1931	1
1,795,214	E. Kellogg	1931	3
1,820,809	E. Kellogg	1931	1
1,855,885	A. Hull	1932	1
1,874,753	A. Hull	1932	1
1,880,092	A. Hull	1932	1
1,967,852	D. Wright	1934	1
2,054,030	Charlton and Whelan	1936	1
2,069,638	D. Wright	1937	1

TABLE XII-A (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
2,096,963	J. Cox	1937	1
2,182,732	F. Meyer	1939	1
2,185,832	E. Charlton	1940	1
Re-14,341	Jones	1917	1
Re-15,278	I. Langmuir	1922	4

* Includes all suits in which GE was the principal plaintiff.

DISPOSITION OF SUITS IN THE COURTS

General Electric Company, Plaintiff

Judgment for plaintiff	34
Judgment for defendant	14
Consent decree	111
Decree pro confesso	5
Dismissed	32
Incomplete information	1
Still pending	1
Total suits	198

General Electric Company, Defendant

Judgment for plaintiff	1
Judgment for defendant	1
Dismissed or discontinued	4
Total suits	6

B—RADIO CORPORATION OF AMERICA *

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
803,684	Fleming	1905	10
824,637	De Forest	1906	1
836,070	De Forest	1906	1
841,387	De Forest	1907	13

TABLE XII-B (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
879,532	De Forest	1908	33
1,050,441	R. Fessenden	1913	1
1,128,292	Colpitts	1915	1
1,129,942	H. Arnold	1915	1
1,158,123	R. Fessenden	1915	2
1,173,079	E. Alexanderson	1916	31
1,183,875	R. Hartley	1916	6
1,195,632	W. White	1916	28
1,203,190	Fritts and Fritts	1916	3
1,213,614	Fritts and Fritts	1917	3
1,223,496	I. Langmuir	1917	3
1,231,764	F. Lowenstein	1917	64
1,239,852	F. Vreeland	1917	13
1,244,217	I. Langmuir	1917	6
1,245,166	F. Vreeland		2
1,251,377	A. Hull	1917	65
1,273,627	I. Langmuir	1918	3
1,282,439	I. Langmuir	1918	8
1,297,188	I. Langmuir	1919	66
1,307,510	A. Nicolson	1919	4
1,313,094	I. Langmuir	1919	9
1,316,967	D. Moore	1919	3
1,334,118	C. Rice	1920	5
1,341,006	C. Babcock	1920	1
1,342,885	Armstrong		2
1,349,252	H. Arnold	1920	1
1,350,752	H. Van der Bijl	1920	1
1,353,976	E. Stockley	1920	2
1,354,939	H. Arnold	1920	9
1,356,763	R. Hartley		4
1,374,679	J. Pratt	1921	5
1,393,283			1
1,403,475	H. Arnold	1922	103
1,403,932	H. Wilson	1922	84
1,419,530	W. Wilson	1922	2
1,423,956	Mitchell and White		1
1,426,754	R. Mathes	1922	6

Table XII-B (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,432,022	R. Heising	1922	4
1,432,867	M. Kelly	1922	2
1,447,773	Espenschied and Bowen	1923	2
1,448,216	R. Heising	1923	1
1,448,550	H. Arnold	1923	1
1,456,528	H. Arnold	1923	13
1,459,412	A. Nicolson	1923	19
1,465,332	H. Arnold	1923	52
1,465,961	E. Alexanderson	1923	1
1,472,470	R. Hartley	1923	2
1,479,778	H. Van der Bijl	1924	10
1,483,273	Blattner	1924	1
1,491,772–74	T. H. Hammond, Jr.	1924	1
1,507,016–17	De Forest	1924	77
1,508,151	E. Alexanderson	1924	1
1,520,994	H. Arnold	1924	3
1,531,805	R. Mathes	1925	6
1,537,708	W. Schottky	1925	21
1,544,081	Vreeland	1925	13
1,558,437	I. Langmuir	1925	19
1,573,374	Chamberlain	1926	106
1,592,934	R. Hartley	1926	1
1,596,198	S. Loewe	1926	5
1,614,214	O. Steiner	1927	1
1,618,017	Lowenstein	1927	97
1,623,996	P. Carter	1927	1
1,631,646	E. Rice	1927	1
1,639,713	A. Sykes	1927	2
1,646,249	C. Hoxie	1927	1
1,658,346	R. Mathes	1928	4
1,666,163	Chamberlain	1928	2
1,672,233	W. Skinner	1928	5
1,696,103	G. Seibt	1928	13
1,702,833	W. Lemmon	1929	75
1,707,617	E. Kellogg	1929	54
1,718,206	I. Mouromtseff	1929	1
1,728,879	C. Rice	1929	73

TABLE XII-B (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,729,048	G. Myers	1929	3
1,734,038	L. Levy	1929	1
1,736,815	W. Albersheim	1929	2
1,738,269	H. Van der Bijl	1929	1
1,740,331	W. Carlson	1929	1
1,748,026	L. Mitchell	1930	6
1,756,863	C. Hoxie	1930	4
1,778,456	I. Langmuir	1930	1
1,795,214	E. Kellogg	1931	53
1,811,095	H. Round	1931	88
1,820,809	E. Kellogg	1931	2
1,823,322	R. Heising	1931	1
1,840,351	W. Douden	1932	2
1,850,981	H. Donle	1932	4
1,852,865	C. Upp	1932	2
1,854,159	L. Robinson	1932	2
1,855,885	A. Hull	1932	4
1,865,449	I. Wuertz	1932	2
1,869,323	P. Evans	1932	3
1,879,514	Round and Pisken	1932	1
1,880,937	H. Elsey	1932	1
1,884,006	N. Lindenblad	1932	1
1,885,001	H. Olson	1932	2
1,890,302	W. Runge	1932	1
1,893,466	R. Gowden	1933	4
1,894,197	C. Rice	1933	49
1,896,780	F. Llewellyn	1933	6
1,897,732	Olson and Krueger	1933	2
1,899,561	H. G. Dorsey	1933	1
1,907,555	A. B. Moulton	1933	1
1,909,051	Freeman and Wade	1933	1
1,909,610	P. Carter	1933	1
1,920,789	C. Heisler	1933	1
1,927,522	N. Lindenblad	1933	1
1,936,162	R. Heising	1933	23
1,947,514	J. Biquet	1934	1
1,966,065	R. Ginn	1934	1

TABLE XII-B (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,974,387	P. Carter	1934	1
2,052,316	R. Sagle	1936	7
Re-15,278	I. Langmuir	1922	17
Re-17,245	W. Cady	1929	6
Re-17,247	W. Cady	1929	6
Re-17,355	W. Cady	1929	6
Re-18,579	Ballantine and Hull	1932	92
Re-18,916	J. Aceves	1933	13
Re-20,307	A. Mavrogenis	1937	1

* Includes all suits in which RCA was the principal plaintiff.

DISPOSITION OF SUITS IN THE COURTS

Radio Corporation of America, Plaintiff*

Judgment for plaintiff	69
Consent decree	163
Decree pro confesso	55
Dismissed	56
Discontinued	32
Total suits	375

Radio Corporation of America, Defendant*

Judgment for plaintiff	1
Judgment for defendant	8
Consent decree	2
Dismissed or discontinued	21
Insufficient information	2
Total suits	34

* Includes RCA Photophone, Radio Victor Corporation, RCA Communication, RCA Manufacturing Company.

C—WESTINGHOUSE CORPORATION *

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,050,441	R. Fessenden	1913	24
1,050,728	R. Fessenden	1913	24
1,113,149	Armstrong	1914	52
1,180,264	A. Lederer	1916	1
1,239,852	F. Vreeland	1917	2
1,239,896	C. Fortescue	1917	1
1,245,166	F. Vreeland		2
1,342,885	E. Armstrong		8
1,734,038	L. Levy	1929	1
2,200,443	E. Deneb	1940	5
2,228,210	R. Hays, Jr.	1941	4
2,261,900	J. Cavanagh	1941	1

* Includes all suits in which Westinghouse was the principal plaintiff.

Westinghouse Corporation, Plaintiff

Judgment for plaintiff	13
Judgment for defendant	1
Consent decree	36
Decree pro confesso	1
Dismissed	7
Discontinuance	1
Total suits	59

Westinghouse Corporation, Defendant

Judgment for plaintiff	1
Consent decree	1
Dismissed or discontinued	8
Total suits	10

D—AMERICAN TELEPHONE AND TELEGRAPH COMPANY *

TABLE XII-D

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
841,387	De Forest	1907	3
879,532	De Forest	1908	2
1,128,292	Colpitts	1915	7
1,129,942	H. Arnold	1915	2
1,129,943	H. Arnold	1915	2
1,201,270	De Forest	1916	1
1,218,195	C. Logwood	1917	1
1,231,764	Lowenstein	1917	10
1,329,283	H. Arnold	1920	3
1,349,252	H. Arnold	1920	3
1,377,405	De Forest	1921	1
1,385,777	A. Clark	1921	1
1,388,450	Colpitts and Arnold	1921	1
1,398,665	H. Arnold	1921	3
1,403,475	H. Arnold	1922	4
1,403,932	H. Wilson	1922	1
1,426,754	R. Mathes	1922	7
1,432,022	R. Heising	1922	7
1,432,863	K. Johnson	1922	2
1,442,146–47	R. Heising	1923	2
1,442,439	R. Mathes	1923	3
1,448,550	H. Arnold	1923	10
1,453,982	B. Kendall	1923	1
1,465,332	H. Arnold	1923	4
1,483,273	D. Blattner	1923	7
1,493,217	R. Mathes	1924	2
1,493,595	D. Blattner	1924	8
1,504,537	H. Arnold	1924	7
1,507,016–17	De Forest	1924	5
1,520,994	H. Arnold	1924	3
1,530,981	D. Ceccarini	1925	1
1,544,921	R. Mathes	1925	1
1,544,943	E. Scriven	1925	2
1,638,555	E. Wente	1927	1
1,667,805	H. Ives	1928	1
1,707,544	A. Thuras	1929	2

Table XII-D (*cont'd*)

Patent No.	*Inventor*	*Date of Issue*	*No. of Suits in Which Patent Was Used*
1,707,545	E. Wente	1929	6
1,717,158	W. Jones	1929	2
1,730,425	H. Harrison	1929	1
1,734,624	H. Harrison	1929	5
1,799,189	D. Whiting	1931	1
1,921,037	K. Morgan	1933	1
1,923,757	H. Silent	1933	1
1,936,162	R. Heising	1933	2
1,936,176	R. Scoville	1933	1
1,952,861	J. Harley	1934	1
1,992,268	E. Wente	1935	1
1,993,795	R. Miller	1935	1
2,022,983	H. Silent	1935	1
2,037,187	H. Harrison	1936	1
2,086,595	S. Anderson	1937	1
2,212,845	A. Nicolson	1940	1
Re–14,380	E. Colpitts	1917	2

* Includes all suits in which AT&T was the principal plaintiff.

DISPOSITION OF SUITS IN THE COURTS

American Telephone and Telegraph Company, Plaintiff*

Judgment for plaintiff	13
Consent decree	7
Decree pro confesso	4
Dismissed	14
Default decree	1
Incomplete information	1
Total suits	40

American Telephone and Telegraph Company, Defendant*

Judgment for defendant	6
Consent decree	1
Dismissed or discontinued	5
Incomplete information	1
Total suits	13

* Includes Western Electric Company.

The suits listed in Table XII have been separated into four groups, depending on the principal plaintiff. We adopted this system of classification because many records do not list all the parties plaintiff; that is, certain cases are listed as having been brought by "RCA et al.," "General Electric et al.," and so forth, indicating that any or all of the other members of the cross-licensing structure might be parties to the suit.

Cross-licensing also engendered a duplication of certain actions. Since RCA in the early years was the owner of few patents and acquired its rights by agreement, it was obliged to file suits in conjunction with the patent owners. However, in several cases where RCA sued in combination with all its associates, the infringing firm set up the defense of misjoinder. To avoid disputing this legal technicality, it was customary for RCA to separate the complaint into several suits. For example, suppose a tube manufacturer were infringing the de Forest triode and the Coolidge tungsten patent; RCA would file two suits against the infringer, one in combination with AT&T, the other in combination with GE. Of the 375 suits listed under RCA in Table XII-B, 126 cases may be classified as this type of "duplicate" litigation. These suits, however, are not included elsewhere under GE, AT&T, or Westinghouse.

The high percentage of dismissals, discontinuances, and consent decrees—often signifying that the defendant had settled for past infringement and accepted a license—is an indication of the large number of cases which never went to trial. Once infringement was discovered and suit brought, the defendant usually admitted his lack of right to continue manufacturing without a license.

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