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The Radio Club of America, Inc.

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PROCEEDINGS
of the
RADIO CLUB OF AMERICA

Vol. 8 FEBRUARY, 1931 No. 2

Engineering Aspects of the Broadcast Antenna†

By HENRY E. HALLBORG*

Introductory

BROADCAST service has become inseparately a part of American life. We now cut it on or off with the throw of a switch. We normally give no more thought to the vast and complicated system behind it than we bestow on those other great services—power and the telephone. We expect it to be there, and seldom are we disappointed.

Broadcast service, however, differs fundamentally from power and telephone services in that there is no tangible medium, no copper wires connecting the service source and the home. The effectiveness of the medium that links the broadcast station and the home is subject to many influences. One of these influences is the design of the broadcast antenna. It will be the purpose of this paper to consider many of the engineering aspects of the broadcast antenna that influence its reliability, economics and service range.

†*Presented before the Club, December 10, 1930.*
**R.C.A. Communications, Inc., New York City*

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Technical Data of Antenna Design and Descriptions of Actual Broadcast Antenna Installations

Modes of Antenna Operation

The American broadcast waveband—200 to 600 meters—is intermediate between what is commonly referred to as the "short wave" and the "medium long wave" bands. It is consequently so placed in the frequency spectrum that physical dimensions do not prohibit the application of antennas longer than one-quarter of a wavelength. In fact, it has been found desirable to operate the broadcast antenna at lengths varying from one-quarter of a wavelength to five-eighths of a wavelength. The selection of the mode of operation in any particular case is determined by the best compromise of theoretical, practical and economic factors.

Three of the many possible modes of operation of the broadcast antenna are:

1. One-quarter wave, or 100 per cent fundamental.
2. One-third wave or 75 per cent fundamental.
3. Five-eighths wave, or 40 per cent fundamental.

These modes of operation are typical, and their characteristics will be considered. In Fig. 1 is shown the current and voltage relations which exist in the above three modes of operation. The full hatched portions represent the current distributions along the wire, and the dotted lines the voltage distributions from ground to open end of the antenna. The current at the ground decreases as the length of the antenna increases above one-quarter wavelength. The maximum of current, or the current loop, moves progressively up the antenna. Operation at an antenna length greater than one-quarter wavelength has two advantages:

(a) It reduces the current loading of the ground wires.

(b) It produces a more horizontal type of radiation.

These factors both affect the efficiency of the antenna system. It is at

POSSIBLE MODES OF OPERATION OF THE BROADCAST ANTENNA SHOWING THE RESULTING CURRENT AND VOLTAGE RELATIONS.

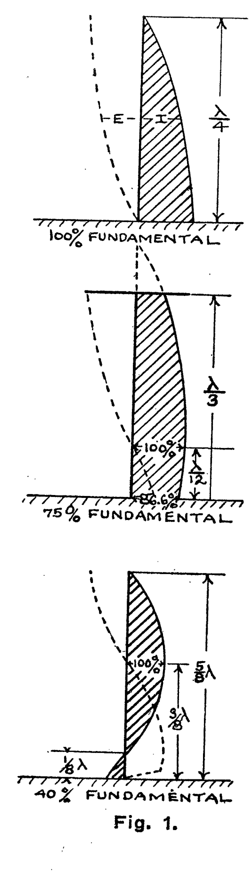

Fig. 1.

POWER DISTRIBUTION CHARACTERISTICS IN VERTICAL PLANE OF THE ONE THIRD WAVE AND FIVE EIGHTS WAVE T TYPE ANTENNAS.

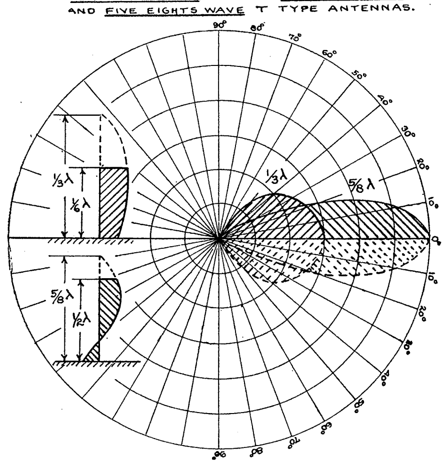

Fig. 2.

once apparent, that it is desirable to operate a broadcast antenna at a length greatly in excess of a quarter of the wavelength.

It is well to consider at this point the role played by physical limitations and economics. For example, a five-eighths wave vertical antenna designed for 480 meters would be 984 feet in height. However, the cause is still not hopeless. While the straight vertical antenna for this wavelength is impractical most of the benefits of the vertical current distribution may be retained by the adoption of the T type antenna.

The horizontal top of the T type antenna contributes nothing to the radiated field, but it is does permit of a better current distribution in the vertical, or radiating portion of the antenna. The middle diagram of Fig. 1 shows a T type antenna operating as a one-third wave system. It will be noted that the current maximum occurs one-twelfth wavelength above ground.

P. S. Carter of R. C. A. Communications, Inc., has calculated the power distribution in the vertical plane of a one-third wave, and a five-eighths wave, single wire, T type antenna. The diagrams of Fig. 2 illustrate graphically the results of these calculations. The small diagrams at the left of the figure illustrate the current distributions in the two antennas. The upper T antenna is assumed one-sixth wavelength high, and to have an electrical length of one-third wavelength. The lower T antenna is assumed one-half wavelength high, and to have an electrical length of five-eighths wavelength.

It will be observed from Fig. 2 that a considerable portion of the energy of the one-third wave antenna is projected at a vertical angle of approximately 35° while the corresponding angle of the five-eighths wave antenna is about 15°. The five-eighths wave antenna radiates twice the power in the horizontal plane that is obtained from the one-third wave antenna.

The graphs of Fig. 2 assume a perfectly conducting ground. The effect of imperfectly conducting soil is to raise the angle of radiation above the horizontal. The angle of elevation will be higher as the conductivity of the soil becomes lower. Not all of this theoretical gain in power radiation by use of

RELATION BETWEEN HEIGHT AND INSTALLED COST OF GALVANIZED STEEL SELF SUPPORTING TOWERS WITHOUT TOP STRUCTURES.

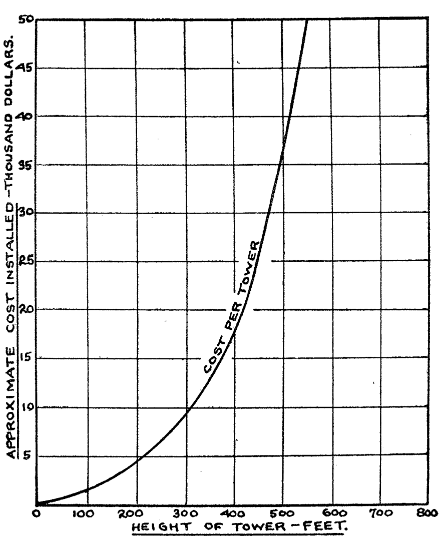

Fig. 4.

the five-eighths wave antenna can be obtained in practice. The theoretical gain is reduced by absorption in guys, and supports, even in the so-called tower type radiators. If the theoretical gain of 2 could be obtained, the signal increase will be $\sqrt{2}$ or 1.41, a theoretical signal increase of 41 per cent.

Typical Arrangement of RCA Broadcast Antenna

Reference has already been made to the single wire T type antenna. It is well to consider at this point why this type of antenna has been standardized for RCA broadcast service. The essential features of an antenna system for broadcast service may be summarized briefly as follows:

(a) Radiation efficiency.
(b) Uniform field pattern.
(c) Low angle radiation.
(d) Reliability under all weather conditions.
(e) Serviceability.
(f) Economy and simplicity.

If an antenna has all these characteristics it may be considered to be well engineered. In attempting to comply with all the above conditions many compromises between the theoretical and the practical must be resorted to. For instance, it may be possible to achieve conditions (a), (b) and (c) and to completely violate conditions (d), (e) and (f). On the other hand, conditions (d), (e) and (f) may be met, to the disparagement of conditions (a), (b) and (c). The compromise arrived at in the RCA broadcast antenna system is the single wire T type illustrated in Fig. 3.

The RCA single wire, T type broadcast antenna system is normally adjusted as a one-third wave antenna. The supports are standard, lattice type, self-supporting steel towers 165 feet, 200 feet, 250 feet and 300 feet in height depending upon the wavelength. The normal tower spacing is two and one-half times the tower height. The towers may be insulated or not depending upon frequency assignments.

The use of a single wire in the antenna system reduces the capacity of the antenna, and increases the insulation required; but the wires are readily kept below the corona point even with 100 per cent modulation. Such a single wire system is almost immune to damage by high winds, and by means of a counter-weight system, as indicated, is not rendered inoperative by sleet accumulation.

The high radiation resistance of an antenna of the one-third wave type allows for high radiation efficiency with a relatively simple ground system. A star ground system is provided for both antenna and towers. The required lengths of the ground wires are determined by local soil conditions. These conditions will herein be considered in greater detail.

TYPICAL ARRANGEMENT R.C.A. SINGLE WIRE T BROADCAST ANTENNA AND GROUND SYSTEM.

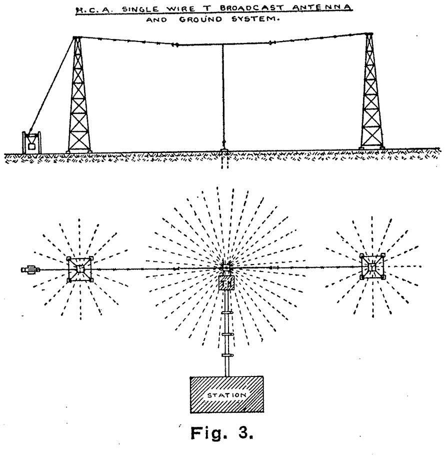

Fig. 3.

SINGLE WIRE "T" ANTENNA.
RELATION BETWEEN OVERALL LENGTH IN FEET - VERTICAL AND ONE HALF HORIZONTAL - AND FUNDAMENTAL IN METERS
λ_o = LENGTH x K
FOR OPERATION AT 75% OF THE FUNDAMENTAL THE FOLLOWING RELATIONS APPLY: $\lambda_o = \frac{\lambda}{.75}$ AND LENGTH = $\frac{\lambda_o}{K}$

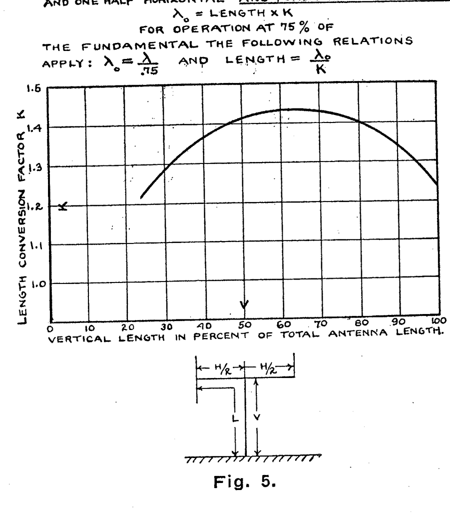

Fig. 5.

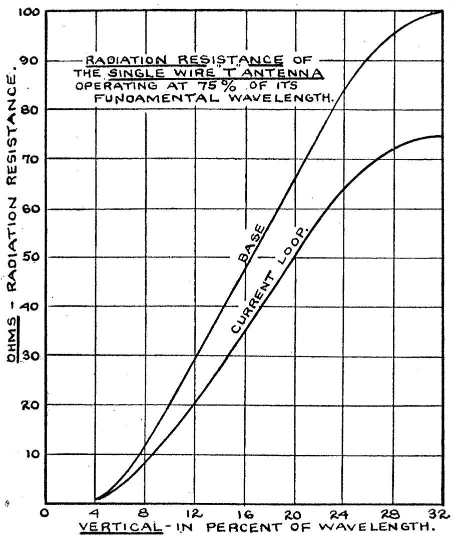

Fig. 6.

The distortion of the field pattern by secondary radiations from the towers may be corrected by detuning the towers either by the insertion of tower leg insulators, or by adjusting lengths of guy wires attached to the towers. Tower radiation may even be helpful under the condition in which it is desired to increase radiation in the direction of a certain important town; but usually it is desired to keep the radiated field pattern as nearly circular as practical.

The horizontal wire of the T type antenna produces no useful radiation, since the currents in the two sides flow in opposition. The top merely serves as a highly efficient loader and as a means for improving the current distribution in the vertical, or radiating portion of the antenna. Reference is again made to the middle diagram of Fig. 1.

The comparative costs of towers vary in a ratio roughly proportional to the square of their heights. A 400 ft. tower will cost about three times as much as a 250 foot tower. If a T type antenna supported by two 250 ft. towers is constructed of the same electrical length as a single vertical wire type supported by a single 400 foot tower, the electrical preference will be slight due to the detrimental effects of the supports of the 400 ft. tower, and the cost will favor the 250 foot T type in the ratio of nearly one and one-half to one.

The approximate relation between installed costs and heights of self supporting steel towers of the same general type is shown in Fig. 4. It will be understood, of course, that actual costs are a function of general market and labor conditions, as well as the accessibility of the station site. The graph is typical of average conditions only. The foregoing analysis briefly summarizes the reasons for the selection of the single wire, T type of antenna for broadcast service in installations made by the Radio Corporation of America and its subsidiaries.

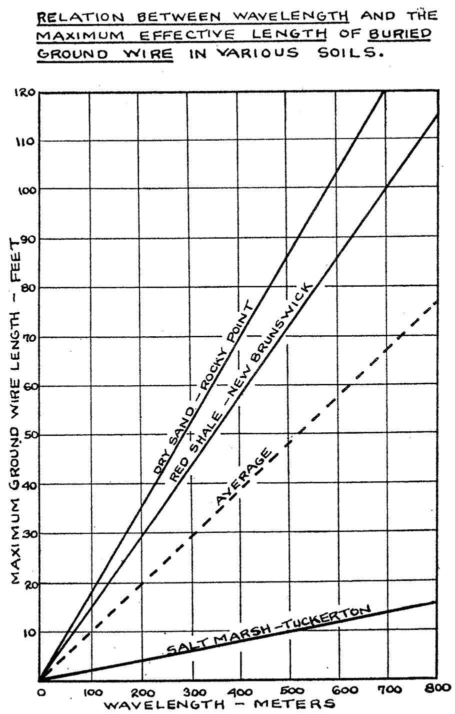

Fig. 8.

Determination of Fundamental Wavelength

It is necessary to know the relation that exists between the physical length of the T type single wire antenna and its fundamental wavelength in order to design for a particular mode of operation. This relation has been expressed in terms of a practical conversion factor from overall length in feet (vertical plus half horizontal) to fundamental in Fig. 5. Applying this figure, it will be observed that a vertical wire 100 feet long will have a fundamental of 123 meters. If the antenna has a total horizontal T top of 100 feet and is 50 feet high it will have a fundamental of 142 meters. It is thus possible to calculate the physical dimensions of the single wire T antenna for any practical mode of operation. This data is transcribed from theoretical calculations by Mr. Carter. The conversion factor K is subject in practice to a variation with the capacity of insulator end fittings, ground and tower effect and may run as high as 10 per cent above the theoretical value given in Fig. 5.

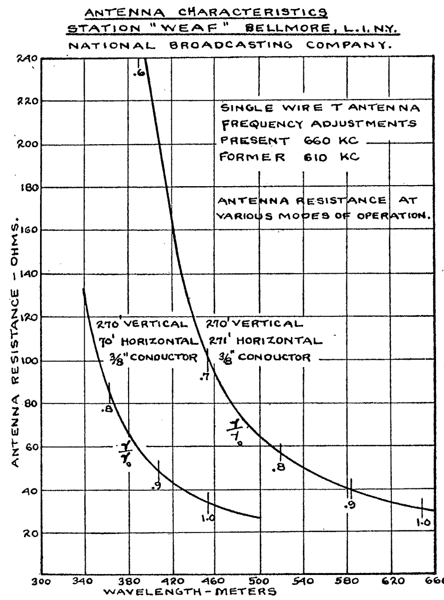

Fig. 7.

Radiation Resistance

The radiation resistance of an antenna is that portion of its total resistance that is useful in producing the radiated field. The efficiency of the antenna is the ratio of radiation resistance to total resistance.

The radiation resistance of the one-third wave single wire T type antenna (75 per cent operation) in terms of the height of the vertical has been calculated by Mr. Carter. The calculated values of radiation resistances at the base, and at the current loop of this antenna are shown in the graphs of Fig. 6. It was previously noted that the current loop of the one-third wave antenna occurs at one-twelfth of a wavelength above the ground.

I am indebted to Raymond F. Guy of the National Broadcasting Company

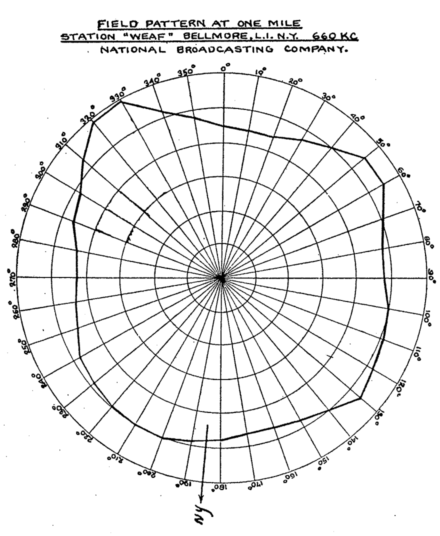

Fig. 9.

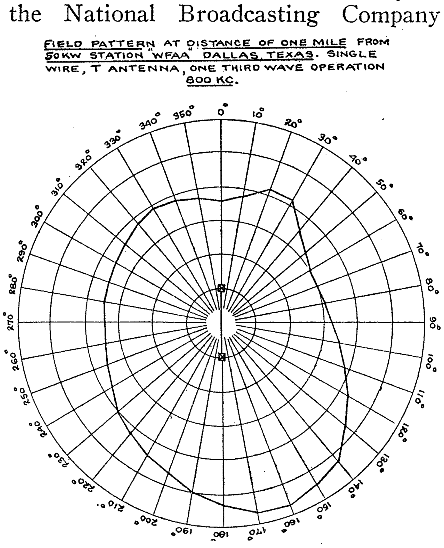

Fig. 10.

for the antenna resistance measurement of the WEAF antenna at Bellmore, L. I., with two different single wire, T type antennas, and for different modes of operation. These measurements are shown in Fig. 7. Bellmore is located in dry, sandy soil which plays an important part in the determination of the total resistance.

The efficiency of the WEAF antenna in soil of very high absorption averages about 60 per cent. The WJZ antenna efficiency in much better soil, averages about 80 per cent.

The Ground System

The efficiency of the broadcast antenna is largely determined by the relative conductivity of the soil upon which the station is located. The soil conductivity will be a maximum in salt, marshy ground and a minimum in loose, dry sand. Building a counterpoise system whose wires are clear of the ground will not eliminate the ground

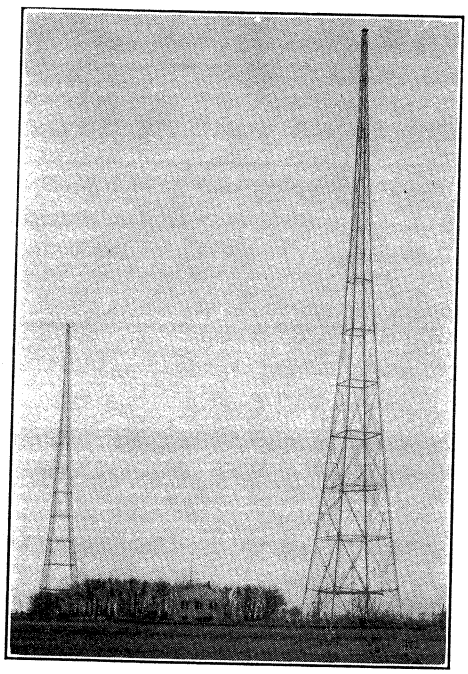

Fig. 12. View of 300 foot insulated towers, single T type antenna, WEAF, Bellmore, L. I., N. Y.

effect. Experiments on the effects of ground at short wavelengths has indicated that ground losses cannot be neglected until a height of two wavelengths above ground is obtained. It is obviously impractical to attain such a height at broadcast wavelengths. It is apparent, consequently, that ground losses must be given full consideration when selecting the location of a broadcast station.

An extensive series of ground system tests conducted by R. C. A. Communications, Inc., has indicated that the useful length of a ground wire is a function of soil conductivity and wavelength. The soil conductivity determines the rate of propagation of the current in the buried wire. The

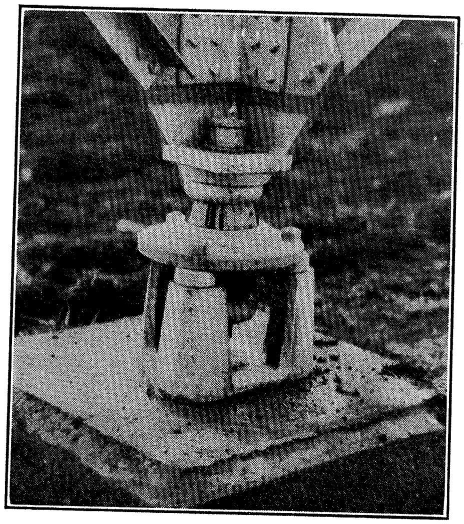

Fig. 13. Close-up view of insulated tower footing.

propagation is slower with high soil conductivity, consequently the length of wire that can be used effectively in such soil is shorter. Increase of the wire length above a critical length may increase the resistance since the added length of wire acts as a series reactance. Since the condition of a soil is a variable with diurnal and seasonal conditions, an average ground wire length for a typical kind of soil should be applied.

A typical relation which was found to exist in the broadcast waveband, between maximum ground wire length and various soils at Rocky Point, New Brunswick and Tuckerton, is shown in Fig. 8. It may be calculated from this data that there is no advantage in using a ground wire in the poorest soil longer than 5 per cent of a wavelength.

In salt, marshy soil a wire length of 1 per cent of the wavelength is all that is required.

In soils having a strata of high moisture content relatively close to the surface, a number of ground rods driven into this strata, and connected to the terminal of the wire ground forms a useful supplementary ground system.

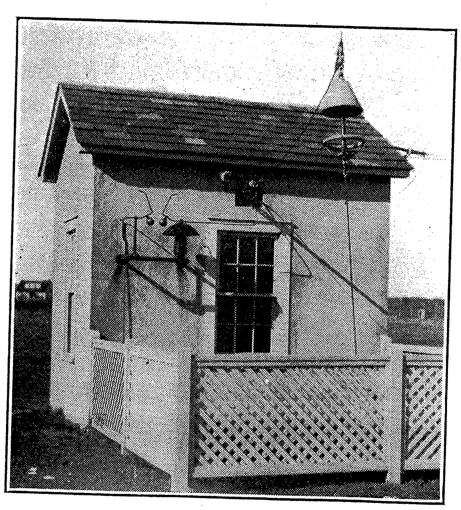

Fig. 14. Tuning house, antenna down lead and lead-in, WEAF.

This method is indicated in the typical ground system of Fig. 3.

Field Pattern and Coverage

The ideal field pattern of a broadcast station would consist of a series of concentric circles, each point representing the equisignal locus for that particular distance with respect to the transmitting station at the exact center. Such an ideal pattern is seldom obtained. This is partly because of the necessity for using supports, such as steel towers, which are in themselves in effect reradiating antennas, and partly because of the varying absorption of the terrain over which the wave passes. The first of these factors is, to a large extent, in the control of the engineer; the second factor is out of his control except for a judicious selection of the station site.

Recognizing that the supporting towers are sources of field distortion,

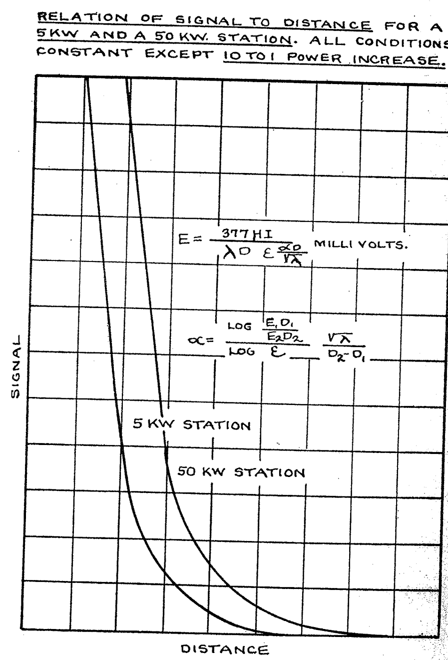

Fig. 11.

means may be applied for minimizing the effects of tower radiation. The most effective of these corrective means is to detune the towers. This procedure usually takes the form of insulation at the base for shortening the period of the tower, and the addition of stays without insulation to lengthen the tower period. It will also be recognized that a certain control of the field distribution is available by the relative spacing of the towers with respect to a definite assigned frequency, so that the radiation may favor the line of the tower array, or the broadside direction as in directive antenna design. Usually the effect of the tower radiation on field distortion is not a serious consideration.

The observed field pattern of station WEAF of the National Broadcasting Company, Bellmore, L. I., taken at a distance of 1 mile, is shown in Fig. 9. This station has a single wire, T type

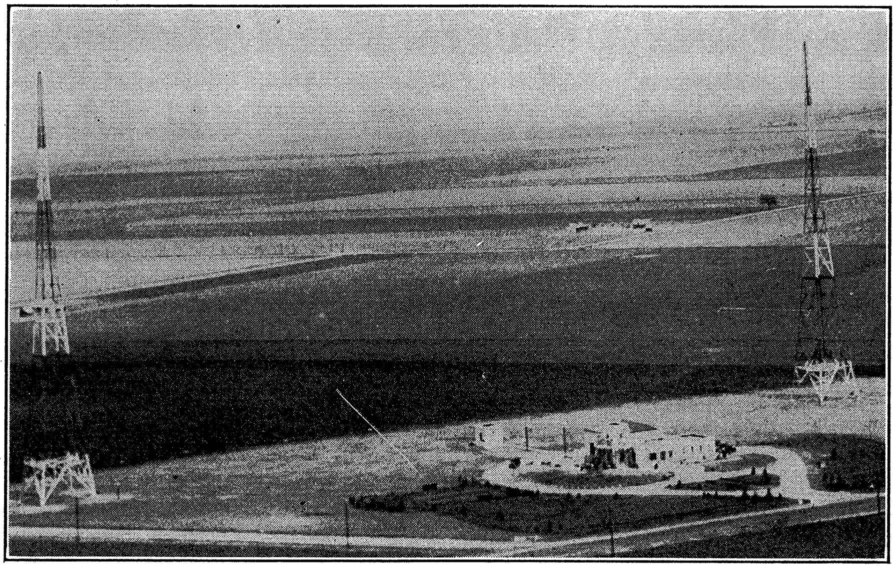

Fig. 15. General view of WFAA, Dallas, Texas.

antenna supported by two 300 foot, insulated steel towers. It operates on a frequency of 660 kc. (454 meters). The capacitive effect of the tower insulators reduces the period of the towers to approximately 60 per cent of their normal non insulated values. The difference in periods resulting between the antenna at 454 meters, and the towers is seen to result in a nearly circular type of field pattern.

The observed field pattern at a distance of one mile of 50 kw. station WFAA, Dallas, Texas, owned and operated by the *Dallas News* and *Dallas Journal* is shown in Fig. 10. The antenna of this station is also of the single wire, T type, supported by 300 foot, insulated steel towers. The operating frequency is 800 kc. (375 meters). The field pattern shows more distortion than WEAF, particularly on one side. This distortion is due in part to necessary attachments on one tower, and to nearby telegraph and power wires. The operating frequency 800 kc. approaches more nearly the natural frequency of the towers, than is the case at WEAF. The field pattern of Fig. 10 was obtained by the engineers of the RCA-Victor Company, Inc.

General field surveys made at many broadcast stations have indicated that prediction of the coverage of a given station is not a straightforward mathematical proposition. It depends principally upon topographical and geological conditions. The coverage obtainable from a given station is subject to variations in the attenuation of the wave as it passes over soils having different absorption factors, over lakes, bays and rivers, and is subject to high attenuation and local shadows in passing over large cities. Another very human variable encountered is the wide variation in the sensitivities of receivers in the homes of the broadcast listeners.

The writer has calculated the relation of signal to distance for a known daylight value of attenuation constant and an antenna power of 5 kw. and 50 kw. from the equations shown in Fig. 11. In these expressions the following legend applies:

E=Signal strength in millivolts.

α=Attenuation constant.

HI=Kilometer ampere antenna output.

λ=Wavelength in kilometers.

D=Distance in kilometers.

It will be observed that the distance covered between the 5 kw. and the 50 kw. station is much less than the ratio of the powers used; but that a considerably larger service area is covered satisfactorily by the 50 kw. station. Since the studio expenses, pickup outlay, program production costs and the like, are about equal in the two cases, the 50 kw. station will, in most instances, be a more economical investment in terms of cost of service per listener.

A power increase far in excess of what is now known as a super-power station, 50 kw. need cause no serious apprehension as to interference.

Typical Installation

A few typical illustrations of broadcast stations will be of interest. In Fig. 12 is shown a view of the 300 foot insulated towers and the single wire T type antenna of station WEAF of the National Broadcasting Company at Bellmore, L. I., N. Y. The simplicity of this antenna system is apparent.

A close up view of an insulated tower footing is shown in Fig. 13.

The tuning house, antenna down-lead and antenna lead-in arrangement of station WEAF is illustrated in Fig. 14. This picture also shows to the right the radio frequency transmission line, and to the left the lightning protection on the antenna.

The writer is indebted to George E. Chase, manager of station WFAA, Dallas, Texas, for the views of this 50 kw., 800 kc. station. Fig. 15 is a general view of the station showing the station building, tuning house and aircraft camouflaged towers supporting the single wire, T type antenna. The flatness of the immediately surrounding country is well illustrated.

In Fig. 16 is a general view of the transmitter room of station WFAA showing the general arrangement of the 50 kw. transmitter and the radio-frequency transmission line outlet to the antenna.

The line amplifier and control line

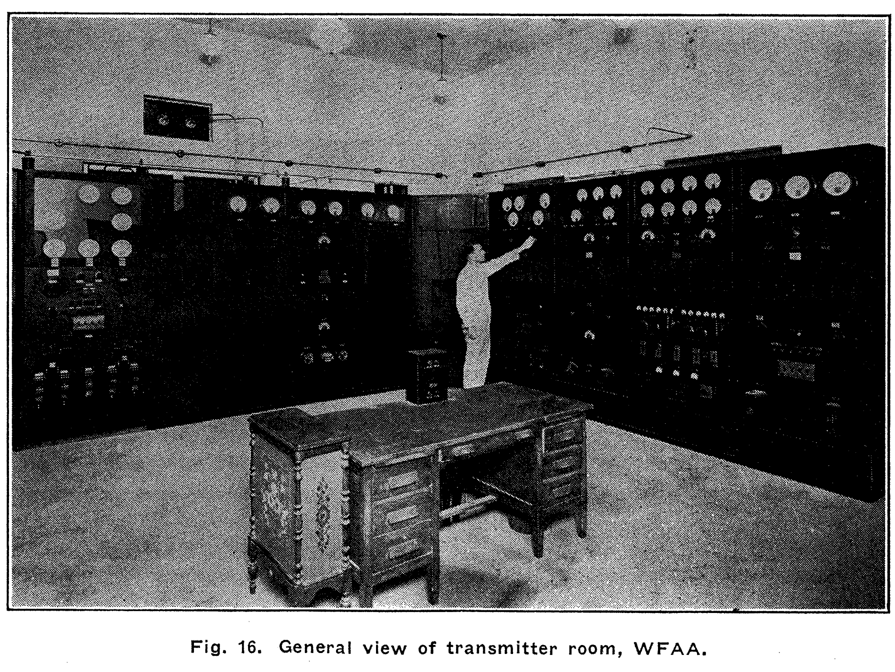

Fig. 16. General view of transmitter room, WFAA.

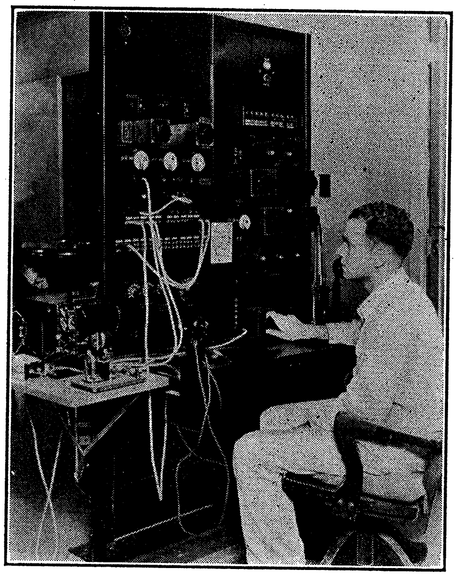

Fig. 17. Line amplifier and control line panels, WFAA.

panels at which the incoming voice signals from the Dallas studio of WFAA are manipulated, amplified and fed to the transmitter are shown in Fig. 17.

Radio Engineering and Public Service

No other public service gets so close to the hearts of the populace as radio broadcasting. In a little less than a decade it has become the oracle and sentinel of the nation. It has bridged that heretofore impassable void between the distant rural community and the great metropolitan centers, bringing the learning, music, sports and culture of the city to any urban fireside that has the will to listen. This indeed is service of an inestimable type.

The direct link between the broadcast listener and the broadcasting station is the transmitting and receiving antenna and the transmission medium. The effectiveness of the service rendered to the listener is largely determined, as has been demonstrated in the foregoing, by the skill and thoroughness of the work of the radio engineer. Success is due to his application of sound principles to the design of the broadcast antenna, as well as to his knowledge and understanding of the many factors that affect transmission through that cosmic and sometimes turbulent medium, which the broadcast listener familiarly refers to as "the air."

Acknowledgment

The writer wishes to express appreciation to those who have contributed directly, or indirectly; to the material of this paper. Engineering application has become so diversified that the accomplishments of any great projects are invariably the works of not one, but many men. Now, as always, the most lasting reward of the engineer is the satisfaction of a difficult job well done. The writer expresses appreciation to C. H. Taylor, vice-president of R.C.A. Communications, Inc., under whose supervision this work has been undertaken; to P. S. Carter of R.C.A. Communications, Inc., for theoretical calculations on the single wire, T type antenna; to R. F. Guy of the National Broadcasting Company for photographs and data of stations owned and operated by that company; to G. E. Chase, general manager of Station WFAA, Dallas, Texas, for photographs of that interesting station; and to RCA-Victor Company, Inc., engineers for the use of of data obtained by them at station WFAA Dallas, Texas.

CLUB NOTES

Following is a list of members recently elected

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Carmine Caruso
W. Howland Taubert
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Walter R. Jones
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R. C. Reinhardt
C. Hart Collins
Herbert B. Fischer
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Ralph B. Austrian
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Hollis S. Baird
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Nelson S. Tobey
Reginald W. Lowander
William E. Riecken
R. B. Steele
J. C. Burkholder

Joseph E. Olander

The February Meeting of the Club

IT MAY be of interest to the members who were unable to attend the February meeting of the Club to know that a very interesting paper entitled, "The Multicoupler Antenna System for Apartment Buildings," was delivered by J. G. Aceves, in cooperation with E. V. Amy and Frank King, co-inventors of the system.

Briefly, the system comprises a well-designed and suitably located common or group antenna provided with a downlead to which thirty or more radio receivers may be connected by means of specially designed coupling devices known as multicouplers. The reception of each radio set is claimed to be perfect regardless of the number of sets connected to the line, and it is also claimed that no interaction is noticeable between sets even if all tuned to the same station. This system has been developed for installation in conduit which makes it readily adaptable for concealed wiring in new apartment buildings. Mr. Aceves fully explained the theory and engineering background upon which this system is based and showed how the final and practical system was evolved. Lantern slides, illustrating the practical installation of this system in modern apartment buildings, were also shown.

The complete paper will appear in the April issue of the Proceedings.