# THE WONDERFUL ACHIEVEMENTS OF RADIOTELEGRAPHY IN WAR AND PEACE



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NEW YORK CITY
1919

# The wonderful achievements of radiotelegrap... in war and ...

William Dubilier, Dubilier Condenser Company

# Early Development

WHEN Hertz, over thirty years ago, proved experimentally that electromagnetic waves are radiated into space with the speed of light by the electric discharge that takes place between the electrodes of a spark-gap, and when, in 1895, Guglielmo Marconi showed that telegraph signals can be sent and received by means of these waves, who could have foreseen that a new era in communication had dawned? Even now it may be questioned if electrical engineers as well as the technically untrained public fully realize what it means to transmit intelligible pulsations through space with something like telepathic speed. It is hard enough even for a scientist to conceive such a medium as the all-pervading ether—harder still to imagine a message invisibly rippling through that subtle medium. Only the mathematical physicist can appreciate the full significance of what may well be regarded as the most magnificent achievement in the annals of electricity.

If we judge it merely by its practical success it is astonishing that radiotelegraphy had not made greater strides before the great European war than those with which it must be credited. A means of communication which made it possible to save many thousand lives at sea up to 1914 was surely worth applying on the broadest practicable scale.

On the eve of President Taft's inauguration in 1909 a destructive blizzard leveled the telephone and telegraph wires between Washington and other eastern cities. Had it not been for the radio station of the New Willard Hotel, the capital of the United States would have been as completely cut off from the outer world as if it had been at the North Pole. That single hotel station transmitted an immense volume of news to New York, Baltimore and the Atlantic seaboard. During the severe winter storms of 1917-1918 telephone and telegraph communication between New York and Washington was interrupted for hours. Radiotelegraphy at once met the pressing need of the Government. And yet despite many such demonstrations of its dependability radiotelegraphy was an aid chiefly to the mariner, and this because civilized countries had made it compulsory to install radio apparatus on passenger vessels.

## Some Applications of Radio Communications

Airplanes, big guns, submarines, "tanks," and poisonous gasses played so dramatic a part in the great war that even electrical engineers rarely think of the indispensable aid that was rendered by radio communication in saving lives in war and in fighting battles. Indeed, the modern mechanism of warfare was operated at full efficiency largely because of radiotelegraphy. It was radiotelegraphy that made it possible in a large measure to cope successfully with the submarine. Without it, England and France would have found it more difficult to beat off bomb-dropping aircraft. The destruction in 1917 of a whole fleet of Zeppelins in France, after an unsuccessful raid on England, was made possible by timely radio warnings. Every British dirigible that patroled the waters of Great Britain, ceaselessly watching for German submarines, every submarine chaser in the Atlantic ocean and the North sea increased its effectiveness with the aid of radiotelegraphic devices. Battles were fought at sea with modern ironclads before the days of practical radiotelegraphy. But what admiral of our time would dispense with radio equipment that enables him not only to give orders with instantaneous rapidity to a fleet stretching out for twenty miles and more, but also to summon reinforcements from some distant port hundreds of miles away? And what a debt the United States owes to the pioneers of radio communication—men who made it possible to send millions of soldiers to the battlefields of Europe in transports which were able to keep in constant communication with one another, with their protecting warships, and with shore solely by means of ethereal electric waves!

In every critical situation of the war radio communication proved itself invaluable. Telegraph cables were cut, but the waves that were sent into the ether by the radio operator could not be interrupted. Thus, ships were warned to change their courses in order to avoid danger. Night and day Washington was in radio communication with Paris and with the commanders of the American forces. Batteries of great guns fired at targets, ten, even twenty miles distant after the range had been indicated by radiotelegraphy from an airplane high in the air. Indeed, without radio apparatus modern artillery would have lost much in effectiveness; optical range-finding equipment alone could not meet the demands of artillerists. Without the aid of radiotelegraphic apparatus installed in the airplane the great German gun that bombarded Paris from a distance of seventy-five miles might not have been so quickly silenced.

In the trenches, too, radio communication played its part. Telegraph and telephone wires were easily broken by artillery fire, by a wagon wheel, or by a foot that stumbles in the dark. Fixed as they were, they could not be easily removed in an advance or in an enforced retirement. But the small portable trench set, the radio wagon, or the motor truck was always ready whether the army advanced or retreated; it took up a new position as easily as a field gun; it kept a general in contact with regiments that were battling on a front of more than one hundred and fifty miles.

Radiotelegraphy was not thus marvelously applied to the winning of battles in a night. Astonishing improvements have been made since 1914 as the result of military exigencies. Before the war, for example, radio communication from airplanes had not been highly developed. Messages could be sent only for a short distance; but not much success had been attained in receiving in the air because of the deafening roar of the engine and because of the crude character of the receiving apparatus employed. At the outbreak of the war, the first attempts at controlling artillery fire from airplanes were made with visual signals—puffs of smoke, disks moved about according to a code, etc. On many a cloudy day there could be no signalling from the air at all. In the last years of the war every gun was fired after the target had been radiotelegraphically indicated by a watchful man in the air. Every artillery control machine was in constant communication with some battery commander. It sent not only the range but it received his instructions.

Before the art of receiving messages high in the air had been perfected every officer sent aloft in a reconnaissance machine to study the enemy's position and movements had to return to headquarters in order to report; much valuable time was lost. Later the observer watched the enemy continuously for several hours at a time, telegraphing back important information without leaving the particular sector of the line that he was ordered to patrol.

War became more than ever like the game of chess to which it was often likened; opposing generals knew the disposition of each other's forces and moved regiments about exactly as if they were knights, rooks or pawns. So refined did radiotelegraphy from the air become, that two aviators could send messages simultaneously without interference, the one message revealing some tactical maneuver undertaken by the enemy, the other directing some battery how to train its guns. Yet one message might be transmitted twenty-five miles to staff headquarters, and the other only five miles to an artillery colonel. More wonderful still, the men in two machines could communicate with each other.

Radiotelegraphy owes its recent astonishingly rapid development entirely to the war. Before 1914 but few companies were engaged in the manufacture of radiotelegraphic apparatus; not one of them numbered its factory employees by the hundred. At present many companies are manufacturing radio apparatus, and the employees of a single factory may number a thousand. Radio apparatus was made and sold before the war; but there was no real, flourishing industry for the making of radio devices until the warring nations discovered how magically radio communication could aid generals and admirals, and how great was its commercial value.

Throw a pebble into a pool of water. Waves ripple out in every direction and gradually die away. The sun, the electric lamp on your desk, a lighted candle also sends out waves—waves that affect the eye so that you say that you "see" the light. Something must be made to undulate if light is the result of wave action, just as water is made to undulate in order to produce waves after a pebble is tossed in. What is that something in the case of light? Not air, because light will travel through a vacuum. The transmitting medium must be infinitely more persuasive, infinitely subtler than air. That medium is assumed to be the ether. It is supposed to fill everything in space—the abyss that separates us from the stars and the inconceivably small gaps between the atoms of a block of wood or a brick.

The ether transmits not only waves that we can see, but waves that we cannot see. When lightning flashes through the air invisible waves are sent through the ether. They are the very waves that are employed to send signals by radiotelegraphy. A primary requisite, then, in every radiotelegraphic apparatus is some device for creating little lightning flashes—a device to send waves through the ether.

Every radio installation usually includes:

1. A motor generator for supplying current.
2. A transformer for raising the voltage or potential of the current.
3. A condenser for changing frequencies.
4. Oscillating circuits containing a discharge gap, a condenser and an inductance.

Of these necessary parts one of the most important is the condenser. Until Dubilier's invention was widely introduced by the United States and its Allies the condenser was the most primitive of devices—a glass vessel which is called the Leyden jar for historical reasons and which is one of the oldest pieces of electrical apparatus.

## Early History of Condensers

On October 11, 1745, Dean von Kleist of the cathedral of Camin, Germany, made an experiment, the importance of which he himself did not grasp, but which was so strange that he thought it worth while to write about it to Dr. Leberkuhn. Said von Kleist:

"When a nail or a piece of brass wire is put into a small apothecaries' vial and electrified, remarkable effects follow; but the vial must be very dry and warm. I commonly rub it over beforehand with a finger on which I put some powdered chalk. If a little mercury or a few drops of spirits of wine can be put into it the experiment succeeds the better. As soon as this vial and nail are removed from the electrifying glass, or the prime conductor to which it hath been exposed is taken away, it throws out a pencil of flame so long that with this burning machine in my hand I have taken about sixty steps in walking about my room; when it is electrified strongly I can take it into another room, and then fire spirits of wine with it. If while it is electrifying I put my finger or a piece of gold which I hold in my hand to the nail, I receive a shock which stuns my arms and shoulders."

Thus was the Leyden jar invented.

In January, 1746, Peter van Musschenbroeck made the same discovery independently. It was he who thoroughly studied the phenomena observed. Von Kleist had no explanation of scientific value to offer. Because van Musschenbroeck was a professor in the University of Leyden the apparatus came fittingly to be called a "Leyden jar."

The Leyden jar was a puzzle and a delight to polite society of the eighteenth century. Just as we talked about the X-ray and radium when they were discovered, so Paris and London in their time discussed the Leyden jar over the dinner table. But the old experimenters were unconscionable exaggerators. Gralath, one of them, maintained that the discharge gave some people the nose bleed. Even van Musschenbroeck, when he first wrote about his observations to Réaumur referred to "a new but terrible experiment," and said that his arm and body "were effected in a manner more terrible than I can express." The Abbé Nollet, in France, used to kill birds with the discharge to entertain the ladies of the court. Gralath tried to emulate him but succeeded in killing only beetles and worms. In his effort to obtain still stronger effects he hit on the plan of grouping several jars together and then succeeded in killing birds easily.

The most daring and imaginative of all these experimenters was certainly the Abbé Nollet. To amuse the French king he sent a discharge through one hundred and eighty soldiers and later through a line of Carthusian monks nine hundred feet long "by means of iron wires of proportionable length between every two, and consequently far exceeding the line of the one hundred and eighty guards. The effect was such that when the two extremities of this long line met in contact with the electrified vial, the whole company at the same instant gave a sudden spring, and all equally felt the shock." He electrified seeds, vegetables and animals, and noted the effect with painstaking accuracy and thus anticipated modern electroculture researches.

Even scientists were so entertained by such experiments that no one seemed to realize that here was an apparatus which actually stored up electric charges—still the only one of its kind, if we consider the so-called storage battery as a chemical rectifier, as we should. But as the novelty of electrically shocking unsuspecting innocents and of killing birds and insects wore off, serious study began. To Benjamin Franklin we owe the first scientific research that threw any light on the Leyden jar's strange properties. It was he who conceived the idea of connecting the outer coatings of a number of Leyden jars to produce his famous "cascade battery," in which the strength of the shock was enormously increased; and it was he who proved that the charges reside not on the surface of the glass but on the metallic coatings.

In 1746 Dr. Bevis gave the jar its conventional modern form of a glass bottle which is coated part way up inside and outside with tinfoil and which has a metal chain suspended from its cover so as to touch the inner tinfoil coating. The only change made from that day to this is the employment of electrically deposited copper instead of tinfoil. It still remains primarily the old glass Leyden jar.

What happens in the Leyden jar or condenser? According to the older physicists, who believed in the "two-fluid" theory of electricity, a positive charge is given to the inner coating and an equal negative charge is induced simultaneously on the outer coating; the two charges unite when the two coatings are connected.

Franklin, who formulated the "one fluid" theory, referred all electrical phenomena to the accumulation of electricity in bodies in quantities more than their natural share, or to its being withdrawn from them so as to leave them minus their proper portion. On this theory the discharge of a Leyden jar consists in the passage of the excess through the conductor from one coating of the jar to the other.

Faraday, at a later date, realized that there is a peculiar state of strain in the glass and called the non-conductor that separated the metal coating, whether it be glass or some other suitable substance, a dielectric. Indeed, to such an extent is the glass of a Leyden jar electrically strained or squeezed, because of the tension along the lines of electric force, that, if it is made of very thin glass, it may actually give way under the stress.

"A good vacuum is a good dielectric," says Professor Sylvanus Thomson. Hence the material particles of the glass or other dielectric cannot be affected to produce the phenomena of the Leyden jar. When it became necessary to presuppose the existence of an all pervading ether to explain the transmission of light and other forms of energy through airless space it was easier to explain what happens when a Leyden jar or condenser is charged and discharged. It is the ether that is primarily strained, and the particles of the dielectric are affected because the ether communicates its strain to them. What is really stored up in a Leyden jar is not electricity, but energy. We must regard all electrical phenomena as the result of the stresses and strains to which the ether is subjected. Electricity is pushed against the forces that oppose it.

Negative electricity is nowadays regarded as a collective name for "electrons"—particles so minute that they fill the spaces between invisible atoms. These electrons—far, far smaller than atoms—have a speed of sixty miles a second. We must imagine them darting from atom to atom with almost unthinkable quickness. In an electric conductor these electrons are conceived to be pushed all in one direction with little opposition when they are acted upon by an electromotive force, so that we have what we call an "electric current." In a non-conductor or a dielectric, such as glass or mica, the electrons are not so free. As Professor Fleming puts it, "they are, so to speak, tethered by an elastic leash, which permits a little movement in every direction, but drags them back to their place when the displacing force is removed * * *. If, then, as in the Leyden jar, we place a sheet of glass between two sheets of tinfoil, or other metal, we have three regions to consider. In the outer or metal portions the electrons are free to move in any direction. In the inner or glass portion the electrons can be displaced from their mean position, but fly back like a spring released when the stretching force is removed."

We must then consider the dielectric not merely as a non-conductor, but as something that takes part in the propagation of electric forces. The ability of a dielectric to transmit the influence of an electrified body across it is called its inductivity.

Faraday showed that negative and positive electricity have no independent existence. When positive electricity is created an equal quantity of negative electricity is also created. In a charged Leyden jar we have an excess of negative electrons, for example, on the inner metal coating and a corresponding deficit on the outer metal coating. The electrons in the glass try to make up the deficiency in the outer coating; they cannot move freely enough to do so; they are displaced elastically from their normal position. When the inner and outer coatings are connected and we discharge the jar the electrons on the inner coating rush through the conducting medium and supply the deficiency on the outer coating. At the same time the strained electrons in the glass return to their normal positions.

But the discharge takes place not in a single movement in one direction, but with an oscillating movement that gradually dies away. Professor Fleming explains the oscillation thus:

"Suppose we take a thin strip of steel, like that used to stiffen a lady's corset, and fix one end to a vise. Then let us displace the top end and strain the elastic steel. On releasing the steel strip it will return to its vertical position, but as it possesses mass as well as elasticity, and has stored up energy on being bent it will overshoot the mark and continue to vibrate for some time like a pendulum."

What becomes of the energy that thus expends itself in vibrations? In the case of the steel spring they create heat in the surrounding air and in the bending steel; in the case of the Leyden jar they set up in the ether the electric waves that are used in radiotelegraphy. These waves travel with the speed of light—186,000 miles a second. By means of a telegraph key the waves are interrupted so as to obtain impulses of long and short duration corresponding with the familiar dots and dashes of the code.

It is evident that without a condenser or some other means of producing waves it would be impossible to signal across space without wires. And yet the condenser, the most important element in the most potent apparatus thus far invented for saving human life at sea and for communicating over vast distances with the speed of light, remained for one hundred and seventy years the simple Leyden jar of Franklin's day. Even Moscicki's radiotelegraphic jar—a long cylinder of glass thickened somewhat at the top—is but a slight mechanical improvement designed to prevent the piercing by a spark of the top edges of the metal coatings—the weakest spot.

The Leyden jar remained unchanged for the simple reason that there was little incentive to improve it and adapt it to the peculiar needs of radiotelegraphy; for radiotelegraphy, indispensable as it had become, found but limited application. With other parts of the radio set it was otherwise. They had varied commercial uses. Motor generators had been developed to a high pitch of perfection and manufactured for years in large quantities by efficient organizations. The transformer, which changes the low-tension current of the generator into a high-tension current to be discharged by the spark-gap in order to set up waves in the ether, was older than radiotelegraphy and had become an article of commerce. The discharge gap consists merely of two metal or other surfaces in close proximity. Provision must be made for quickly radiating the heat; but the dissipation of heat is not an electrical but a mechanical problem.

If we consider the functions that it has to perform the condenser is the most important element in any radiotelegraphic apparatus. It serves the purpose of transforming high-tension, low-frequency current into high-tension, high-frequency current. No other part of the radio set can thus change frequencies.

How does a condenser control the frequency? Suppose that a surface of given thickness is to be coated on both sides with a given amount of paint. Clearly, it takes a certain time to coat each square foot of that surface with a certain quantity of paint. The larger the surface the longer will be the time required to coat the entire surface; if one square foot can be coated in one second then two seconds will be required to coat two square feet. Similarly it takes a certain time to coat the metal surface of a condenser with a certain amount of electricity. The larger the surface to be electrically coated, the longer will be the time required. Thus it is that the condenser regulates the time of charging and recharging, and hence the frequency of the radiations from the aerial. In ordinary electrical engineering practice we have only sixty cycles per second to deal with; in radiotelegraphy with hundreds of thousands cycles per second. If it takes one-half of a millionth of a second to charge a condenser and one-half of a millionth of a second to discharge it, one million oscillations per second are produced—the standard fixed by the International Radiotelegraphic Convention for transmitting messages from ships. Thus we transform our five hundred cycles into one million. It is evident that the number of cycles bears a direct relation to the size of the condenser.

## Defects of the Leyden Jar

Glass is fragile. Because the Leyden jar, so long used in radiotelegraphy, is of glass, it is easily broken. Its life is scarcely a year. Why not make a jar of thick glass so that it will not break? Because its electrical capacity is dependent, among other factors, on the thinness of the dielectric between the metal coatings—the glass. Hence a Leyden jar must be as thin, and therefore, as fragile as the electrical demands made upon it and the rough usage to which it is subjected on a pitching, rolling ship, will permit.

In the early days of radiotelegraphy the battery of Leyden jars, with other parts of the set, was placed on the top deck of a battleship. When it became evident that radio signals were bound to supplant semaphores, flags and lights, particularly for communication in fogs and in black, stormy nights, and between vessels that could not see each other, the top deck was considered much too exposed a place. Often the concussion of a ship's own guns broke the jars. What might not happen in a battle? When a jar breaks the apparatus is immediately short-circuited; no message can set. In the very heat of an action, at a critical moment when it becomes vitally necessary to communicate an order to the ships of a fleet, an admiral may literally be stricken dumb, for a time, because a Leyden jar breaks.

Soon the radio apparatus was installed in a more protected room in the hold. Here a new difficulty was presented. The tremendous energy wasted in the form of a brush discharge by a Leyden jar after contiuued use generates ozone in large quantities. No operator can sit in an ozone-laden atmosphere without endangering his health; he is sure to complain at least of headaches. Consider what is demanded of the operator. He hears signals. He must mentally translate these signals into letters of the alphabet. And lastly, he must group these letters into words and sentences. And all this at the rate of forty or fifty words a minute. The man's brain must be clear. In an atmosphere saturated with ozone his mind is dulled. Receiving a radio message is at best never as easy as receiving a wire-sent message on land not only because the telegrapher on land is never troubled by ozone, but because radio signals are often blurred by electrical atmospheric disturbances technically called "static." The radio operator listens to the signals with a telephone receiver. Because the diaphragm of the receiver vibrates very rapidly he hears high-pitched musical notes. These high-pitched notes can be heard when lower notes would probably be swamped by other noises, particularly the sound produced in the telephone by those atmospheric discharges called "static." The effect is much the same as if two persons were speaking at the same time, one spasmodically in a low bass voice and the other regularly in a high-pitched treble.

Expensive and elaborate blower and exhaust systems were installed in an effort to provide better ventilation and to enable the operator to remain longer at his post. But these were but makeshifts at best; the operator still complained of headaches and of mental torpor. Finaly it was found necessary to enclose the Leyden jars in a large box from which the air was exhausted. The ozone and the brush discharge were accepted as necessary evils; no one thought of devising a practical condenser which would have no brush discharge, which would not generate ozone, and which would, therefore perform its functions without extraneous safeguards.

Despite all its complicated auxiliaries the Leyden jar battery was untrustworthy. When messages are sent continuously, which happens when a "Titanic" sinks, or when a battle is fought, on the outcome of which not only the lives of a thousand sailors, but perhaps the destinies of nations depend, the jars become hotter and hotter. A puncture by a spark is not only possible but probable. Until a new jar is mounted—an operation which consumes much time—the ship must depend on flags and semaphores in order to relay an important message to a long line of fighting ships.

The best Leyden jars have always been made of glass imported from Germany. German glass has a smaller resistance than other glass, for which reason a Leyden jar made of German glass generates the least heat. When war came in 1914 no more German glass was obtainable. The United States Government was compelled to specify American glass for its Leyden jars—glass so far inferior that the risks always entailed by using the best imported glass were multiplied, and that defects had to be accepted, which prior to the war, would not have been tolerated. Moreover, only a few manufacturers in the United States knew how to make an acceptable Leyden jar. They would have been incapable of filling the orders that the Government would have placed with them when the United States declared war, had no other form of condenser been devised.

There must have been about one hundred and fifty thousand Leyden jars in use before the war, chiefly in radio installations, if we may judge by the number in American hands. And yet beyond Moscicki's slight improvement and beyond the immersion of the jar in oil to make it more difficult for high-tension currents to "brush over" and break the Leyden jar, as we have pointed out, remained essentially unchanged for one hundred and seventy years.

After Franklin showed that condensers need not be made in the form of jars it was evident that a condenser could be made, which consisted of nothing more than sheets of alternating glass and metal. Such "parallel plate" condensers are sometimes used in radio transmitting systems; but always leakage discharges and punctures, due to the breaking down of the dielectric, occur. Condensers have also been made, which consist of alternate conducting plates enclosed in containers filled with compressed air or other gases, or with oil. Hard rubber, paper, bakelite, mica and other dielectrics have also been used in condensers; but these attempts to do away with the Leyden jar resulted in nothing practical.

Every condenser has what is called "capacity," which means that it can hold a certain quantity of electricity. In other words, it is just as if we pumped air into an automobile tire to raise the pressure to a definite number of pounds per square inch. The capacity of a condenser depends on (1) the size and form of the metal plates or coatings, (2) the thinness of the layer of dielectric between them, and (3) the dielectric constant of the material.

All condensers have this property: As the amount of electricity stored in them increased, the electrical pressure between the two conductors or metal surfaces also increased in exact proportion. If the metal surfaces are small and some distance apart, a large difference of pressure is required to store up a small charge. Such a condenser is said to have a small capacity. If the plates are large and near together, the condenser has a large capacity. The amount of electricity that can be stored up in any condenser is limited to the maximum electrical pressure that can exist between the two conducting bodies before a spark jumps between them—a spark which is a miniature flash of lightning.

All dielectrics are insulators—this much is clear from a study of the Leyden jar or of any other condenser. But it does not follow that equally good insulators are necessarily equally good dielectrics. Glass is theoretically a better dielectric than hard rubber, paraffin or air because it has a higher inductive capacity. But the best practical dielectric is mica. In an official monograph, published long before the war by the Bureau of Standards, mica condensers were specified as standards for the measurement of capacities. In almost every elementary textbook on electricity mica is credited with a high dielectric capacity The best practical condenser ought to be one in which the dielectric is mica. Glass and nearly all dielectrics vary in capacity as the frequency changes, because of their physical imperfections. Large phase differences or losses occur which may be attributed to leakage and to the conduction of the charge through and on the dielectric. Such losses inevitably shorten the distance to which a message can be sent and make it difficult to insure continuous and certain operation of the radio set.

Before the war a mica condenser with the capacity of a Leyden jar could have been made and sold for about the same price as a Leyden jar. Yet up to the outbreak of the war, the mica condenser was scarcely known to radio operators. Engineers were not blind to the advantages of mica; but they reasoned that it was impossible with mica to obtain, in a given space, a sufficiently large surface, and hence capacity enough to work under the strains imposed by high tensions. And yet, before the war mica was available in lots of many tons to test these theories by actual experiment. Perhaps it is because the condenser is so very simple—merely two metal surfaces separated by a thin dielectric—that it seemed beyond further engineering development; perhaps it was the apparently insuperable difficulty of coping with the brush discharge and with the heat generated by the discharge that checked the experimenter. At all events it was evident that the ideal condenser must be free from brush discharge and other losses, and therefore from heat, and that the enormous electrical strains imposed on the widely accepted Leyden jar must be avoided. It was to the solution of this problem that William Dubilier, an American radio engineer addressed himself.

## Development of the Mica Condenser

When Dubilier first began his researches, about ten years ago, his primary object was to design a radio set which would be so small, light and compact that it could be readily stowed away in an airplane. On a machine constantly shaken in flight by a powerful engine and subjected to severe shocks in landing at high speed, Leyden jars could not be used. A mica condenser suggested itself. In 1910 Dubilier made one which he tested with sufficient success to convince him that it could supplant Leyden jars for small powers. But he was still so far impressed by the brush discharges and strains to overcome in large condensers that at first he thought it impracticable to substitute mica sheets for glass Leyden jars in large installations. In 1910, however, he did submit a mica condenser to the United States Government. It was tested at the Brooklyn Navy Yard and broke down, but it convinced him that his conception was fundamentally sound. The adverse report made upon the test impelled him to take his invention to Europe. On March 18, 1913, while in England, he was invited to testify before the British War Office Wireless Committee, which was composed of Sir Henry Norman, Capt. Louis Vaughn, Commander Silvertop and others, and which was appointed by Parliament to investigate the status of radiotelegraphy. Dubilier's small mica condenser had attracted attention. In the presence of the Committee he substituted his little portable condenser, made for small sets, for the Leyden jar condenser of a large set, with results that astonished everyone. It seemed incredible to these well-informed men that a little box should be able to take the place of a whole battery of Leyden jars. As a result of the demonstration Dubilier was encouraged to begin the development and manufacture of mica condensers in England.

In 1915 Dubilier went to Europe again for the purpose of intensively studying the part that radiotelegraphy was playing in the war. As a consulting radio advisor of officials of the allied governments he spent eight months in an exhaustive investigation which convinced him that the Leyden jar needlessly restricted the military applications of radiotelegraphy, because of its fragility and clumsiness. When he returned to the United States in the same year he found that despite the lessons taught by the war the mica condenser had not yet found favor with American radio engineers. At the request of the Navy Department twelve mica condensers were made and subjected to test in the Brooklyn Navy Yard. The result was an order to form part of 5-kw Lowenstein service sets. Dubilier has every reason to believe that these first sets are still in use; for all broken condensers are returned to the company in accordance with its guarantee of performance.

A Dubilier condenser is composed of several sections or units enclosed in a common casing of aluminum. Each of these sections or units comprises alternating sheets of mica and foil, thousands in number. The sections or units thus constituted are piled on top of one another in the aluminium casing, and each section or unit is separated from the next by a sheet of mica. The sheets of mica are larger than the sheets of foil so as to avoid any brush discharge at the edges.

Air, moisture and small vacuum pockets must be eliminated from each section or unit. Hence an insulating adhesive of special composition, having the required dielectric properties is forced through the entire condenser. The moisture and air are expelled, and the vacuum pockets are filled with this adhesive, which is deposited in a thin layer on each of the thousands of sheets of mica. Next a melted wax compound is poured into the aluminium casing, so as to fill any empty spaces between the condenser sections or units and the aluminium case.

Before the wax has hardened a pressure plate is placed on the end section or unit. After the cover is screwed on, this plate presses all the sections together. Because they are tightly pressed together the sections cannot expand. It is highly important that the spacing between the metal foil and the mica be kept constant—an end secured by the use of the pressure-plate. A post passes up through the cover of the aluminium case to the outer atmosphere and serves as one terminal, the aluminium case serving as the other. Both terminals, therefore, have the greatest possible surface and the least possible mass.

Because it consists of thousands of sheets of mica and foil the full voltage across the transformer is minutely subdivided. Hence the potential that does act across a single unit is so very small that there is practically no destructive brush discharge. As soon as the current is applied it is subdivided by the sections of the condenser into fractions at tensions so low that the brush discharge practically disappears. The losses in the dielectric increase as the square of the voltage. Hence if the voltage of each section in the condenser is reduced markedly the problem of preventing the brush discharge is simplified. It is easier to control seven hundred volts in this manner than twenty thousand volts individually.

It is evident that in a Dubilier condenser we have not simply two metal surfaces separated by a dielectric, but literally thousands of metal and dielectric surfaces. Here we have the secret of the Dubilier condenser's remarkable efficiency. The condenser may be likened to a cable of a suspension bridge—a cable composed of many strands. Suppose a wire in a strand should break. The cable still supports its load; there is scarcely a measurable loss in tensile strength. So it is with a Dubilier condenser. In a single condenser unit there are hundreds of small condensers. What if one of the small condensers does break down? The condenser as a whole will not be markedly affected; there need be no interruption in the sending of a message. Imagine what this trustworthiness means at a critical moment in a battle at sea! It is indeed practically impossible to break down the condenser as a whole. This was the fundamental idea that Dubilier kept constantly before him from the very beginning. Moreover, unlike the broken wire in the cable of a suspension bridge, a weak spot in the condenser heals itself automatically. A Leyden jar, under similar circumstances, is useless; it must be renewed with much loss of time and with not a little difficulty.

## Mica Protective Devices

Protective devices must be used on shipboard and land stations to prevent stray high-frequency currents, induced in the leads of dynamos and motors, from burning out the machines. Paper condensers have been widely adopted to meet that protective purpose. The paper is thickly coated with wax, so that when it burns out, the wax melts and flows into the hole. Thus the condenser still continues to serve its purpose, but not with its original positive action. Very often the radio operator removes the condenser which broke down too often and leaves the line unprotected, either because he has no other condenser or because there is no time in which to make the connection.

Dubilier was requested by the Navy to make his condenser similarly self-healing, so that it could take the place of the paper condenser. At first the task seemed hopeless. When a mica sheet burns out it ceases to be a dielectric and becomes a conductor. A hole is left, and there is nothing to fill it. The spark jumps through the hole. Wax cannot be relied on to seal the hole; for but an imperceptible amount of wax can be utilized to fill the space between the metal surface, if an efficient condenser is to be produced. Finally Dubilier devised a condenser of such construction that, after a breakdown, there will always be a space between the mica and the metal foil. The condenser is truly self-healing, and there is rarely a short circuit. In unofficial tests made by the Government it transpired that these mica condensers often seal themselves twenty-five and even thirty times before they become useless. It is no longer necessary to run the risk formerly incurred when a burnt-out paper condenser was left in a line for lack of time. The adoption of the Dubilier condenser as a protector of generators effected an enormous saving on shipboard and prevented the burning out of many machines.

## Standardizing for Production

The Dubilier condenser was the first element in a radio set that was standardized. It is obviously convenient to use one type of condenser on all radio sets. Hence, in its contract for radio sets, by whomever made, the United States Government now specifies mica condensers. When it found that mica condensers were interchangeable because they were standardized the Government proceeded to standardize other parts of the radio set. Thus it became possible to introduce quantity production methods in the manufacture of radio apparatus.

Dubilier is probably the first who has confined himself to the making of only a single piece of radio apparatus. Its example and its success convince one that it is technically and economically wrong for one firm to make all parts of a radio set. Specialization, after standardization was established, had its evident advantages, particularly in time of war when quickness of delivery is all essential. Manufacturers of complete radio sets were at a disadvantage in competing with specialists who made but one piece of apparatus. So it happened that Dubilier supplied practically all the condensers used by the United States and Allied Governments.

The first Dubilier condensers were tested under conditions that would have spelled destruction to a battery of Leyden jars. They were operated not intermittently, as in actual practice, but continuously. Although it was evident that the familiar destructive brush discharge and the overheating that accompanied it had been overcome, and evident, too, that the condensers saved valuable space and that they did not generate ozone, they were expected to excel Leyden jars by some large, unexpressed margin. And they did. Brushes, inches long, were not uncommon phenomena when Leyden jars were but slightly overstrained. But in the tests of the first Dubilier condensers the Radio Division actually tried to detect microscopic internal discharges.

No doubt this excessive caution was to be traced to the faith that had so long been placed in the Leyden jar. The adoption of the Dubilier condenser meant the "scrapping" of large numbers of Leyden jars on which implicit reliance was placed, despite their admitted faults. No wonder that the officers of the Navy demanded the most unshakeable proof of the new condenser's merits.

By one five kilowatt ship set, the energy radiated with Dubilier condensers, was actually 253 watts more than could be obtained with a set of good Leyden jars. With the newer and more improved Dubilier mica condensers, 300 more watts could have been radiated with the same set. On the basis of the energy radiated by an antenna, the Dubilier mica condenser is able to effect an increase of fourteen per cent. over the best type of Leyden jar. This means that messages can be sent a hundred miles farther.

The advantages of the Dubilier mica condenser may be thus summarized:

1. It increases efficiency.
2. It does away with the brush discharge.
3. It is not fragile.
4. It's life is probably ten times as long as that of a Leyden jar.
5. It avoids the generation of ozone, and, therefore, renders unnecessary the complicated system required to exhaust Leyden jar cases.
6. It economizes space where space is valuable.
7. It is simple, and, therefore, reduces the cost of constructing a radio equipment.

While mica condensers cost slightly more than Leyden jars of equal capacity, any one of the advantages enumerated would in itself justify their adoption. Many a radio operator maintains that the introduction of the Dubilier condenser has vastly increased his personal efficiency. He is no longer subject to headaches, for which reason it is no longer necessary for him to leave his post after a short period of duty.

To the designing radio engineer the Dubilier mica condenser commends itself at once because it can be made in standard units; its capacity can be varied by small fractions, an impossibility in the manufacture of Leyden jars. Formerly the Navy Department specified five per cent. as the variation tolerable for Leyden jars; two per cent. is the maximum permited for Dubilier mica condenser. Often it has been found that a desired capacity could not be obtained with Leyden jars, and that only Dubilier condensers would meet the requirements. We have in mind a very important set in the designing and making of which it was found impracticable to employ Leyden jars because of the inordinate space that would have been occupied. Because of the experience gained by Dubilier in the manufacture of his unique product, the special condensers required were made in twenty-four hours. Yet it takes twelve hours to cool a condenser in one stage of its manufacture.

Frequently messengers have come to the company, bearing orders from the Government for special condensers. The orders were filled while the messengers were waiting. Before the war weeks would have elapsd before a single such special order for Leyden jars could have been filled.

Sometimes it is found that the oscillating circuits cannot be conveniently attuned to the waves which are to be transmitted where special capacities are required. The adjustment becomes possible, thanks to the refinement with which mica condensers can be constructed. In such circumstances it is not practicable to use Leyden jars. When condensers are used for shortening the antenna circuit so as to make it possible to send short waves with a large antenna the losses in the condensers are great. Actual tests show that Leyden jars under these conditions lose sixteen times as much as mica condensers of equal capacity.

Thus, instance could be piled on instance to demonstrate the immeasurable superiority of the Dubilier condenser over the Leyden jar and other condensers.

It is conceded by many Government officers and radio engineers that the introduction of the Dubilier mica condenser marks the greatest improvement in radio apparatus made in years. It would be difficult, if not impossible, to match the drastic sudden change made from Leyden jars to Dubilier condensers. The officers of the Navy deserve the greatest credit for having adopted an apparatus of revolutionary design at a critical time when it would have been but natural to retain the familiar, well-established Leyden jar.

It seemed incredible to the best-informed men in the Government service that the Leyden jar had been definitely supplanted. Dubilier had to prove that his condenser was not only as good as a Leyden jar, but almost infinitely better, before substantial numbers were ordered. Even when the condenser withstood the severest laboratory tests doubt was cast on its durability. Not until the apparatus had been in actual service for years were radio engineers convinced that Dubilier had solved his problem.

When an engineer designs a new automobile, a new steam engine or a new dynamo, his task is far from ended. So it proved with the invention of the Dubilier condenser. New tools, new manufacturing processes, new testing machines had also to be devised, as well as machines and methods for testing mica, for stacking the sheets, for vacuum impregnation, etc. Wax compounds had to be discovered which could be employed as fillers. Finally a new metal container had to be evolved which was light yet strong enough to protect the sensitive internal structure from mechanical injury. This in turn meant the solution of a difficult problem in handling high tensions. Indeed, not a single standardized commercial product or machine on the market could be used. In order that the Government might adopt the condenser with as little expense and trouble as possible after many experiments, a metal container of such size that it would fit existing Leyden jar racks on ships was designed. But it was the problem presented by mica that was solved with the great difficulty.

Mica occurs in layers with a definite cleavage. It must be mined and then split into sheets, each a few thousandths of an inch thick; but the thickness of the sheets must not vary more than half a thousandth of an inch. Sheets must be rejected if they contain air bubbles and pin holes; if they reveal vegetable and metal stains; if they exhibit waves and other inequalities; if they are of amber mica; if there is oil between the layers; if they are even slightly cracked or otherwise defective; and if they are too small. A rapid method of detecting these defects had to be devised, so that several hundred thousand sheets could be tested in a day.

Mica sheets must be of even thickness; otherwise the capacity will vary. Hence, it is necessary to gauge about a hundred thousand sheets per day in the Dubilier plant. After having been gauged, the sheets must be electrically tested for slight defects which are not obvious. Pinholes, for example, are scarcely to be detected with the naked eye, and yet a sheet with a pinhole is useless.

Mica has long been tested electrically by passing a wire from an induction coil over its surface. The spark seeks out the crevices and other defects and thus reveals them. Instead of using a single spark, in accordance with this old and well-known method, Dubilier devised a way of applying to a sheet, a whole spray of sparks at several million cycles frequency, so that any weakness is instantly revealed. In the past mica has been tested by low-frequency current. To get surer results it should be tested with high frequency currents, for nearly all insulators break down more easily under high than under low frequency. Machines were developed, each of which tests about twenty thousand sheets a day and reveals even the slightest defect. So impressed were the Government inspectors with this accurate and rapid method of testing that they asked and obtained the company's consent to the installation of similar machines in factories engaged in the making of low tension condensers for magnetos.

It would be tedious to recount at length the nature of the experiments that were conducted. Air bubbles are perhaps the commonest defect. A long study was begun to determine if the air could not be exhausted. When that proved impracticable, the attempt was made to squeeze it out. And always comparative tests of efficiency were conducted of condensers made of sheets so treated. Thus two condensers were tested, similar in every respect, save the mica of which they were in part composed, the one made of sheets containing air bubbles, the other of perfect sheets. Both were tested for eight hours in radio sets under exactly the same electrical conditions, and the losses indicated by increasing temperature carefully plotted. Similarly, sheets with defects other than air bubbles were comparatively tested with similar care.

Since the object was to devise a method of utilizing the best possible mica without impairing the efficiency of the condenser, Dubilier had to analyze the operating conditions in order to discover the cause of hysteresis losses, eddy current losses, ohmic resistance losses, losses due to imperfect contact, not to mention many losses which had long been considered negligible, but which proved to be of extreme importance. After hundreds of models had been built and hundreds of tests made, each of two to eight hours' duration in one hundred per cent. over-loaded service, Dubilier finally weeded out and so far reduced losses, such as those due to hysteresis etc., that they could not be measured with instruments used for that purpose.

How these numerous perplexing problems were solved, one after another, is well exemplified by Dubilier's success in overcoming the "edge effect." As every radio engineer knows, the highest potential is ordinarily found along the edges of the surfaces of a mica condenser, as well as the greatest electrical strain. Hence, the condenser is more likely to break down at the edges than elsewhere. Dubilier succeeded in producing a condenser wherein the largest potential is to be found at a spot where there is no edge.

After considerable experimental work involving the expenditure of large sums of money, the losses which previously occurred in condensers were to a great extent eliminated, and finally a product was manufactured where the defects in mica were less important than losses usually found in ordinary condensers. As a result, sufficient material was obtained to fill the Government's constantly increasing orders. Dubilier is probably now the largest consumer of clear flat mica in the world. No two mines, much less a single mine anywhere, could supply sufficient amount of closely trimmed sheets.

Before the Dubilier Condenser Company became contractors to the United States Government, mica was bought in large quantities chiefly for stove manufacturers. But no stove manufacturer ever had occasion to scour the world for mica. Condensers were made for the army and navy in such huge numbers that the Company soon absorbed all the available mica. It was found that nowhere was there one organization which could supply mica in large enough quantities.

Stove mica need not be more than reasonably transparent and heat-resisting. Condenser mica must fulfill certain very rigorous requirements. Books on mica were few in number and nearly worthless as a guide in judging the quality of mica as a dielectric. Dubilier had to become a self-taught mica expert—self-taught because there were no authorities on mica to whom he could turn with any hope of assistance. He had to familiarize himself not only with the product of the principal mica mines of the world, but also with the properties of the different kinds of mica—green, ruby, white, amber, etc.

Many varieties of mica could not be electrically tested in the laboratory as other materials are tested. Full-sized service condensers had to be made, and used in actual radio sets in order to determine which varieties had the best dielectric properties. Besides, there were no workmen who knew how to handle mica in making a condenser. A whole factory force had to be trained.

Before the war mica could be purchased cheaply. As soon as the United States entered the European conflict its price advanced rapidly until it rose to almost four times as much as in 1913. Dubilier made preparations to supply the United States Government with a large number of condensers and at a considerable financial risk ordered large quantities of mica. He felt that it was his duty in a national emergency to prepare for any contingency. His foresightedness saved not only weeks and even months of time when days were precious, but a fortune; by securing two years' supply in advance, he was able to maintain a constant price and thus prevent mica profiteering. He made no attempt to profit by his policy. The United States Government received the full benefit, both in prompt deliveries and in price. In a single year the Dubilier Company used 50,000,000 sheets of mica, which, placed end to end, would measure 2,300 miles, the distance between New York and Porto Rico.

In addition his Company requires annually fifty thousand pounds of aluminium castings; thirty thousand pounds of brass castings; millions of screws; fifty thousand pounds of foil; twenty-five thousand pounds of insulating wax. Only by investing hundreds of thousands of dollars in the business of making condensers would it be possible to utilize manufacturing material on so vast a scale for making a single piece of radio apparatus. In less than two years the Dubilier Company supplied condensers for over 50,000 radio installations with an aggregate energy of about twenty thousand kilowatts.

Such is the company's recognition of its responsibility that the utmost caution is exercised to select the best material obtainable. In the whole United States only a comparatively small amount of fine split mica sheets were purchasable at any time; Dubilier needed hundreds of thousands of pounds. A mica expert was sent to India to buy all that he could and even established a factory there to cut and split mica in order to save shipping space. South America was exploited through dealers with a result that a new supply of mica was opened in Brazil. Despite this ransacking of two hemispheres, difficulty was encountered in obtaining from dealers mica sheets of the desired quality, chiefly because they found it unprofitable to meet the standards of the Company. Endless discussions and disputes arose, because of the Company's seemingly unreasonable demands. After months of effort many tons of clear, perfect sheets finally reached the Company. By far the largest amount shipped from the Far East was seized by British and American Governments for their use in Dubilier condensers made by the Dubilier Companies of London and New York for the Allies. The General Electric Company unselfishly furnished to the Dubilier Condenser Company what mica it had on hand when it realized the Government's pressing need for mica condensers.

In the making of his condensers Dubilier feels that he assumes a grave responsibility. A poor condenser is like a poor shell, which refuses to explode at a moment when a telling hit must be scored; or like a badly built airplane in which a brave man risks his life. Never does he permit himself to forget that his product plays a vitally important part in the air, at sea and on land. Human lives are dependent on the reliability of the condenser. It has become a point of honor to produce only an absolutely trustworthy piece of apparatus.

Despite the increasing scarcity of mica, the Dubilier Condenser Company sees to it that it always has on hand a full year's supply. Only by adopting this policy has it been possible to furnish the Dubilier condenser at the Government's own price in the face of the rising cost of mica (worth now about three times more than it was two years ago) and of labor and material. Indeed, by improving manufacturing methods the Company actually reduced its price to the Government and Government contractors voluntarily, despite adverse conditions during the war.