

TECHNICAL PAPERS

THE ORIGIN AND DEVELOPMENT OF RADIOTELEPHONY*

By

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Summary—Upon this, the Silver Anniversary of the Institute of Radio Engineers, it is appropriate to recall how there came into being the art of radiotelephony and, in turn, such services as overseas telephony and broadcasting. The Institute has seen the entire evolution within its relatively short life, with radiotelephony an unsolved problem in 1912 and today an accomplished fact of world-wide application.

The pages of the Institute PROCEEDINGS testify to much of the building of the art, but nowhere has there been given a unified account of the structure as a whole and the relation of its technical substance to electric communications generally. To do this objectively and while the development is still fresh in mind is the purpose of the present paper. Naturally, the story is limited by space and by the information available to the writer. † Most of the account pertains to America. If the contributions of other countries are not adequately presented, it is because the limitations of time, space, and language have not yet been entirely overcome.

BACKGROUND IN THE PHYSICAL SCIENCES

IT IS well to acknowledge, in the first place, the debt which radio owes to the more fundamental contributions from the physical sciences, the more pertinent ones of which, underlying as they do the entire art of electric communications, may be epitomized as three major waves of advance:

The great transition which occurred in the early 1800's from the electrostatic to the electric current and electromagnetic state of electrical science, which led to the telegraph and later to the telephone (to say nothing of electric power).

The conception and demonstration of electromagnetic wave propagation and electric oscillations, notably by Maxwell and Hertz. This advance applied to guided as well as unguided wave propagation, and is the basis of the transmission art of both wire and wireless communication.

The proof of the corpuscular nature of electricity and its identity with matter, the basis of twentieth century physics and of electronics.

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† The story is told from the background of one who became acquainted with radio as an amateur wireless telegraphist, was associated with the founding of the Institute and, since then, as an engineer of the Bell System, has taken an active part in the development of both wire and radiotelephony.

EARLY EXPERIMENTS

It happens that an early attempt at transmitting speech without wires was made by the inventor of the telephone himself, Alexander Graham Bell. Back in the 1880's he sent speech over a beam of light, using reflectors in much the same way that ultra-short waves are directed today.¹ He called the system the "photophone." Mercardier² rechristened it the "radiophone" because it employed frequencies not limited to the visible range, and here we have the earliest use of the word "radio" in the sense employed today.

Of course, the more direct forerunners of radiotelephony were wire telephony and wireless telegraphy. The transmission side of both these arts came out of the early work of Maxwell and Hertz, but they developed for many years quite independently, because of the great difference in the transmission frequencies involved. Early attempts at carrier-current telephony and telegraphy over wires,²⁹ involving frequencies of tens of thousands of cycles and utilizing modulation, frequency selecting circuits and detection, were unsuccessful because of the lack of suitable technique even for those frequencies, and were in general unknown to later wireless telegraph experimenters. The devices with which Marconi initiated practical wireless telegraphy were adapted to frequencies of the order of a million cycles, generated discontinuously by means of sparks. In time wireless telegraphy evolved toward the use of continuous waves and, by such means as the high-frequency alternator and the oscillating arc, bridged the gap between the radio and the wire frequency ranges.

In the period of 1806-1912 radiotelephony was an experimental fact but a practical nonreality. Many were the early experimenters who had succeeded in transmitting speech over distances of some miles, notably Fessenden and De Forest in America, and Majorana, Vanni, and Poulsen in Europe. In 1911 General Squier,¹² of the United States Signal Corps, brought widespread attention to the possible application of the then wireless instrumentalities to high-frequency transmission over wires.

But, 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. The story which follows of the successful meeting of these problems, principally by means of the vacuum tube, is broken by the incidence of the Great War into three periods.

¹ Numbers refer to bibliography.

THE FORMATIVE PERIOD OF 1912-1916

In retrospect, it is now apparent that by about the time of the formation of the Institute the general front of technical advance had reached the point of almost inevitably yielding the solution of the radiotelephone problem. The two-element^{4,5} and three-element^{7,9,13} vacuum tubes existed, knowledge of thermionics and means for attaining higher vacuua were accumulating, coupled tuned circuits were well-known, and in wire telephony the basis had been laid in the loaded-line theory for the electric wave filter^{20,21} and circuit network philosophy. But lest the attainment of radiotelephony seemed too easy, let us follow in a little more detail how the structure of the art was built. The scene is placed in America principally, for it was here that De Forest was experimenting with his three-element audion tube, that telephony generally was developing apace, and that certain research laboratories were working upon problems which needed the tube.

The High-Vacuum Tube

Dr. Lee De Forest invented the three-element tube in 1906-1907, but it was not until about 1912 that he succeeded in adapting it under some circuit conditions to operate as a true amplifier. In the Fall of that year he and an associate, John Stone Stone, demonstrated the audion to engineers of the telephone company* in the role of an audio amplifier, a candidate for the solution of the telephone repeater problem. The device was still a weak and imperfect thing, had in the grid circuit the familiar blocking condenser of the audion detector, and was incapable of carrying any considerable voice load without blue hazing; yet, it was capable of amplifying speech.

Among those in the telephone laboratory who witnessed De Forest's demonstration was one H. D. Arnold, then fresh from the study of electron physics in Dr. Millikan's laboratory of the University of Chicago. Whereas there had always been confusion of thought concerning the effect of gas upon the operation of the audion, Arnold immediately recognized that what was wanted was a pure thermionic effect, free of gas complications. He set to work to produce a higher vacuum tube, using evacuation methods then only recently available. He succeeded and, once and for all, took the three-element tube out of the realm of uncertainty and unreliability and made of it a definite, reliable, amplifying tool.

About the same time that Arnold was doing this in the laboratories

* By "telephone company" is meant the American Telephone and Telegraph Company and Associated Companies, including the Western Electric Company, and now also the Bell Telephone Laboratories, which comprise the Bell System.

of the telephone company, principally in 1913, Langmuir, in the laboratories of the General Electric Company, studying the problem of X-ray tubes and power rectifiers, arrived at substantially the same result.¹⁷ In a patent contest lasting many years the Supreme Court of the United States gave to Arnold the credit of having been the first to attain the truly high-vacuum tube and agreed with Arnold's original viewpoint that this step, important though it was, did not constitute invention over the prior art.

By the time the high-vacuum tube was obtained several gaseous forms of tubes had appeared. One of these was of the mercury-vapor

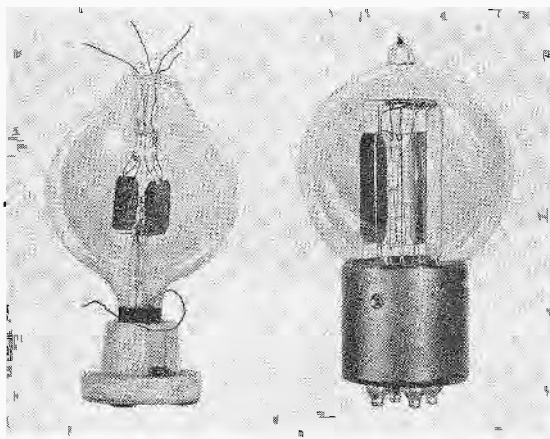


Fig. 1—Early De Forest audion and telephone repeater tube—about 1914.

type, employing magnetic control, which was being worked upon by Arnold as a telephone repeater at the time the audion was first called to his attention. Another was the tube of von Lieben and Reisz, of Austria and Germany, which employed a grid element. All such gaseous devices were soon eclipsed by the high-vacuum tube.

The high-vacuum tube was further improved in 1913 by the application to it of Wehnelt's oxide-coated cathode.^{6,27} The filament electron emission was thereby increased, producing the dull-emitter type of long-life tube. The vacuum tube in this form, stable, with adequate filament emission and long life, set the pace in the amplifier art from that time forward, and was the practical basis of the succession of further developments which resulted in practical radiotelephony. One of De Forest's audions and one of the early high-vacuum telephone repeater tubes are pictured in Fig. 1.

Oscillator

One of the next developments was, of course, the conversion of the vacuum tube amplifier into a generator of high-frequency currents. This was accomplished first by De Forest in 1912, according to a decision of the United States Supreme Court. Others did it independently about the same time, notably Armstrong here and Meissner in Germany. Particular forms of oscillating vacuum tube circuits were developed by other investigators, including C. S. Franklin and H. J. Round, of the British Marconi Company, and Colpitts and Hartley, in the United States. Armstrong's 1915 I.R.E. paper¹⁸ upon the subject was a notable one, as was evidenced by the demand for the issue of the PROCEEDINGS in which it appeared.

The earliest uses known to have been made of the oscillator in radiotelephony are the experiments of Meissner,^{14,32} in Germany in 1913, between Berlin and Nauen, using the von Lieben-Reisz tube, and of H. J. Round,¹⁹ of England, early in 1914 in experimental transmission between two ships.

Modulator

Another major step, the invention of the vacuum tube modulator, soon followed. This solved the problem of enabling low power voice energy to control the considerably higher power waves required for radiotelephone transmitting, and enabled this control to be exercised remotely over a telephone line, thereby giving through-transmission between wire and radio circuits. The earlier attempts at radiotelephony had depended for modulation upon the carbon microphone, usually worked directly in the antenna ground circuit. Here, again, we have a case of several investigators arriving at the invention at about the same time, 1913-1914, with Alexanderson, of the General Electric Company, and Colpitts, of the telephone laboratories, sharing the honors. Other modulating circuits followed. The telephone engineers had in mind doing the modulating at low power and then amplifying the modulated current by means of a high-frequency amplifier.

High-Frequency Vacuum-Tube Telephony

By the latter half of 1914 there was within grasp in the laboratories sufficient of the high-frequency technique, based upon the high-vacuum tube, to cause the telephone engineers to set about the development of high-frequency telephone systems. The first attempt was at the wire carrier-current problem. A two-channel multiplex system was set up using vacuum-tube oscillators, modulators, amplifiers, and detectors. The result was decidedly encouraging. Since the same instru-

mentalities were applicable to radiotelephony there was next undertaken the development of a vacuum-tube radiotelephone system.

These early wire carrier-current and experimental systems proved to be the precursors of our modern art. They mark a climax in what is perhaps the most rapid accretion of technique known in modern electric communications, from the condition, in the fore part of 1912, of there being no suitable generator nor modulator, to that of 1914-1915 where these essentials had become available and were being synthesized into operative high-frequency telephone systems.

Long-Distance Tests of 1915

Vacuum-tube radiotelephony was now to be taken out of the laboratory for a field trial. A vacuum-tube transmitter of a few watts output was developed and installed at Montauk Point, Long Island, and an amplifying receiver was located at Wilmington, Delaware, 200-odd miles distant. The distance was then stretched to some 600 miles by receiving the Montauk transmitter at St. Simons Island, off the coast of Georgia. These were one-way transmissions. For some of them the reception was brought back to New York by wire lines. The speech was itself clear, but was sometimes buried in noise due to the small transmitting power and the fact that it was the spring of the year. Wave lengths of 800 to 1800 meters were employed.

The success of these preliminary tests, together with the promise of laboratory developments for higher-power transmitting tubes, now led to a bold attempt on the part of the telephone engineers to overcome that great natural barrier of telephony, the oceans. Through the cooperation of the United States Navy Department, on the one hand, and the French Administration, on the other, appropriate field stations were made available for the tests. The large antenna of the naval station at Arlington, Virginia, was used for transmitting. A new vacuum-tube radiotelephone transmitter was developed, employing hundreds of tubes, each having a capacity of the order of fifteen watts, and installed at Arlington. For reception the Navy Department made available their stations at the Canal Zone, on the Pacific Coast, and in Hawaii. Through the kindness of General Ferrié, of the French Administration, use of the Eiffel Tower station was permitted the American telephone engineers for receiving purposes. Thus did the French collaborate in the interest of technical advance and international good will by accepting foreign engineers in their most important military station during the life-and-death struggle of the Great War.

By June all the distant receiving points were covered by engineers who had been dispatched from New York provided with the then latest receiving apparatus; the new telephone transmitter had been installed at Arlington; a great effort was being made in the laboratories to produce the necessary quantity and quality of power tubes. The tests continued on and off during the entire Summer on a reduced power basis, during which the difficult atmospheric conditions were studied by the receiving engineers. As the transmitting power was built up, and as the conditions improved with the coming of Fall, results began to be obtained, first, from Panama; next, from the Pacific Coast, representing transmission across the continent; then, from more distant Hawaii; and, finally, in November from Paris, where the receiving conditions had proven to be most difficult.

These were, of course, one-way transmissions. The reception was so uncertain and so subject to noise as to make it evident that the art would need to be advanced greatly before the requirements of a service could be met over such long distances.

Some of the technical features of the apparatus of these early tests were:

In the transmitting station, the use of the master-oscillator, power-amplifier type of circuit, operating in the 30 to 100-kilocycle range, with circuits designed to accommodate the "carrier and sideband" aspect of the modulated wave.

The development of power tubes of the order of fifteen watts, requiring new designs and more thorough pumping and degassing.

The operation of large numbers of tubes in parallel (as many as 500), in order to build up the necessary transmitting power. The problem of operating these tubes in parallel and preventing singing can well be imagined. An average power of two or three kilowatts was obtained in the antenna. A photograph of two banks of 250 tubes each is reproduced in Fig. 2, the tips of some of the tubes showing on the right.

Receivers employing a radio-frequency amplifying stage, plus two audio-frequency stages. Heterodyne detection was employed to find the carrier. Homodyne reception of the telephone signals was used at some of the receiving points.

The following year, 1916, tests of radiotelephony were made for the United States Navy, which included what is believed to have been

the first attempt at tying together radio and wire lines for through two-way radiotelephony. The Secretary of the Navy, Josephus Daniels, talked from his desk in Washington, D. C., with the commanding officer of the *U.S.S. New Hampshire*, off the Chesapeake Capes. During this year the important subject of modulation was advanced and Heising devised his well-known "constant current" system of modulation.³⁰ The simplicity of this system led to its use in the radio-



Fig. 2—Power amplifier of the Arlington, Virginia, experimental transmitter, 1915.

telephone sets which were produced during the war and in the early radio-broadcast transmitters. Incidentally, early in this same year there was undertaken anew the problem of carrier-current telephony and telegraphy, this time looking toward commercial designs, utilizing the newly acquired instrumentalities of the vacuum-tube and the electric wave filter. The application of the vacuum tube amplifier to voice-frequency telephone circuits was also proceeding apace.

Radiotelephony was now progressing rapidly, building upon and, in turn, stimulating its antecedent and contemporary arts of wire telephony, wireless telegraphy, and electronics. Something of the content of these related arts is indicated below:

ARTS UNDERLYING RADIOTELEPHONY

Wire Telephony	Wireless Telegraphy	Electronics
Electroacoustics Transmitters, receivers, characteristics of sound, high-quality reproduction	Generators and receivers of high-frequency currents; selective circuits	Discovery and study of the electron (Crookes, J. J. Thomson and others)
Wire Transmission Propagation constant, characteristic impedance, transmission measurement, interference, carrier, wave filters, and network theory	Antennas Dipole (Hertz), grounded (Marconi), directive	Thermionics (Richardson, Wehnelt and others)
Amplification Microphone, repeaters	Wave Propagation Spreading and absorption, ground and sky waves, effects of solar and meteorological phenomena	The Edison effect and the Fleming valve De Forest 3-electrode tube High-vacuum, high-power, and multielectrode tubes

THE WAR PERIOD

The war came to Europe before the new vacuum-tube art and radiotelephony had been fully born. Vacuum tubes were employed in the war by the European countries for radiotelegraphy, but radiotelephony is not known to have played a part on the Continent. This may have been due in part to the lack of secrecy of this form of communication.

In the United States the normal development of radiotelephony continued, as we have seen, up to the time of this country's entry into the war. The new vacuum-tube radiotelephony had by then assumed real promise. The United States Government undertook to develop two-way radiotelephone sets on a large scale for dispatch purposes on submarine chasers and airplanes. In the short space of a year or so hundreds of thousands of tubes and thousands of sets were developed and manufactured. Several of the larger laboratories of the country were in effect taken over by the government for this purpose. The apparatus was featured technically²³ by:

The general use of the high-vacuum, oxide-coated filament type of tube.

Employment of the constant-current type of modulation.

The attempt to make the operation of the sets simple and fool-proof, as by the elimination of filament rheostat and the standardizing of tubes and circuits to permit of ready interchangeability.

Such apparatus was used in some quantity on submarine chasers of the Navy, but the large production program for airplanes was not completed in time to enable radiotelephony to come into play in the Army on the battle front. From the technical standpoint the program

stimulated apparatus design and gave a useful experience in the standardization and quantity production of tubes.

Through the many military training schools in the United States the new vacuum tube radiotelephone art was "broadcast" to the most likely young men of the country, many of whom developed a real interest and after the war helped to swell the peacetime development.

POST-WAR DEVELOPMENTS

The peacetime development of the art was now immediately renewed, especially in the United States where the technical effort had been sustained throughout the war. It became evident to the several large companies, particularly the American Telephone and Telegraph Company and the General Electric Company, which were pursuing the vacuum tube art, that their inventions so interleaved as to require an exchange of patent rights. This took the form of an interlicensing agreement, entered into by these two companies in 1920. It enabled the telephone company to use tubes on its lines and to proceed with the development of two-way radiotelephony. The General Electric Company and its affiliates, including the R.C.A., were free to proceed in other fields, principally radiotelegraphy, and, as it turned out, in broadcasting.

Early Ship-to-Shore Telephone Experiments

The telephone company had by this time undertaken development work in marine radiotelephony, partly as a means of advancing the art and partly with an eye toward the eventual establishment of a mobile public telephone service connecting with the land line system. Experimental shore stations were provided (one of which, that at Deal Beach, New Jersey, is shown in Fig. 3), and ship apparatus capable of duplex operation was devised and tested on coastal vessels and on one of the transatlantic liners. This work was done in the frequency range then most available, that of the order of a million cycles. Shortly thereafter broadcasting preempted this range and because of this and of the post-war depression in shipping, these experiments did not then materialize into a service. Trial connections with the landline network extending across the Continent and to Catalina Island served to demonstrate the possibilities of combined wire and radio. Some of the technical attainments in this work³⁴ were:

The development of duplex systems for ship use.

The development of superheterodyne receivers.

Progress in placing radio transmission upon a quantitative basis by the measurement of received field strengths and the

overall circuit equivalent of radio links, and in the setting up of radio links as integral parts of long landline connections.

The beginning of the volume indicator, used to insure the voice loading of the radio transmitter and later employed extensively on wires, as well as in radio.

First Public Telephone Service by Radio

Another pioneering undertaking about this time, 1920, was the development of what has proven to be the first use of radiotelephony for public service, in the form of a point-to-point link on the Pacific

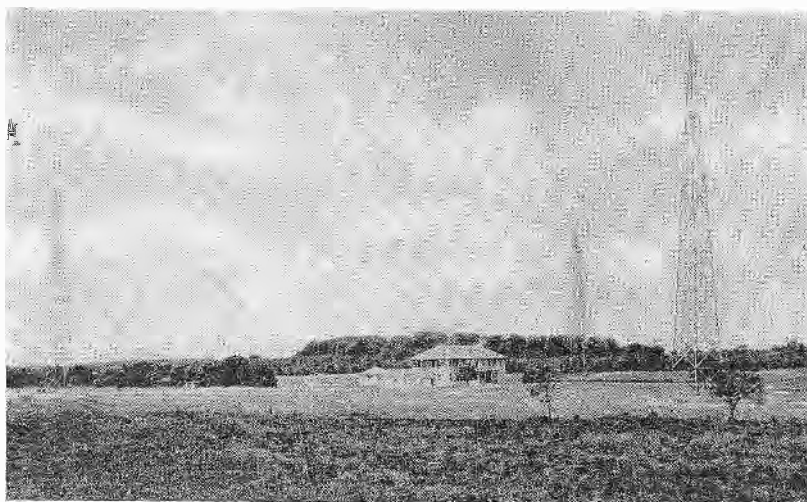


Fig. 3—Experimental Radiotelephone Station, Deal Beach, New Jersey

Coast between Catalina Island and Long Beach on the mainland, connecting thence to Los Angeles.³¹ Service was given over this link for about a year, when the frequency band being used was wanted for the then newly developing service of broadcasting. The telephone service itself came near being a broadcast one, so extensively were the conversations listened to by amateur radio enthusiasts. The system was replaced by a submarine cable.

From the standpoint of technical progress, this installation included a number of interesting features:

Full-duplex operation in the sense of separate channels for the two directions of transmission, joined at the terminals to the two-wire telephone network by means of hybrid coils.

Through voice-frequency ringing, the first application to radio. Superheterodyne receiving sets, incorporating wave filters in the intermediate-frequency stages which separated out:



Fig. 4—Long Beach, California, receiving terminal of the Catalina Island radiotelephone link, 1920.

A telegraph channel which was superimposed upon; i.e., multiplexed with, the telephone channel and used independently for telegraph service with the Island.

The provision toward the end of the period of means for rendering the telephone transmission private, comprising voice inverters, plus carrier-frequency wobbling, the first installation of this combination to have been made.

The picture of the Long Beach receiver in Fig. 4 shows at the top a portion of the loop receiving antenna; in center foreground, the cir-

cuit control desk; above, to the right, the speech inverter for privacy; and, in the left background, the apparatus of the superimposed telegraph channel.

Broadcasting

By 1920-1921 the stage was set in the United States for radio broadcasting. A radiotelephone technique was becoming available in the relatively empty portion of the frequency range centering about one megacycle. Something of an audience existed in the thousands of amateur radiotelegraphists spread throughout the country, a lively public interest in radiotelephony had been aroused during the war, and all that was needed to excite the public generally into providing itself with receiving apparatus was to have the experience of hearing speech and music on the air. These essential elements of an appropriate technique and of a widespread audience were lacking in the earlier years when De Forest and others broadcast speech and music upon a number of occasions with considerable success.

Public interest was first fanned by amateur listening to the experimental telephone transmissions being conducted by various people, amateur and professional. Engineers in making tests frequently availed themselves of reports written in by listeners, as a means of checking in a general way the effectiveness of their transmitters. For example, in the Fall of 1919, tests made between New York and Cliffwood, New Jersey, of a pair of 500-watt transmitters intended for shipment to China, were reported by many amateur listeners. Tests of ship-to-shore radiotelephony, which were being made on more or less regular schedules from Deal Beach, New Jersey, were listened to and reported by hundreds of amateurs throughout the eastern part of the country. In the vicinity of Los Angeles, California, listening to the radiotelephone link to Catalina Island was becoming enough of an indoor sport to be embarrassing to the public telephone service, as has been mentioned.

Of all the experimental activity at the time, it happened to fall to the personal efforts of Frank Conrad, an engineer of the Westinghouse Electric and Manufacturing Company, Pittsburgh, Pennsylvania, to give rise to broadcasting of a continuing nature. Starting with transmissions from his home, the activity was taken up by his company, which had been engaged during the war in making radio apparatus for the government, and the experimental emissions were evolved into a continuing program, accompanied by the entering of the company into the business of supplying receiving sets. The original transmitter of the now well-known station of KDKA is pictured in Fig. 5 as it

appeared on the occasion of its first broadcasting, when it sent out the returns of the presidential election on November 2, 1920. Note that the room which housed the transmitter served also as the studio. Public interest mounted rapidly and within a few years transmitting stations were growing up throughout the country⁴¹ and a boom was on in receiving sets. So great was the demand for transmitting station equipment that the telephone company was called upon to provide what proved to be most of the installations in these earlier days.³⁶

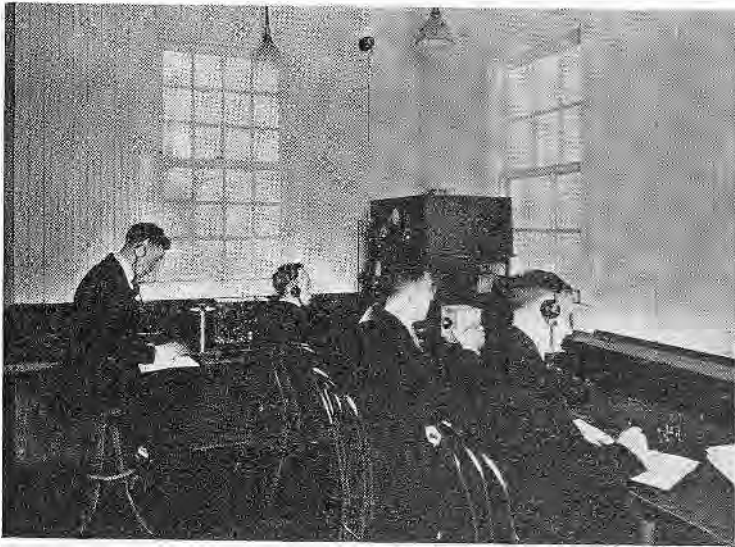


Fig. 5—First KDKA Transmitter, Pittsburgh, Pennsylvania, 1920.

This great burst of activity brought with it real concern as to the character which broadcasting might assume and as to how it could be supported as a continuing service. It being a form of telephony, the telephone company undertook to explore the field from the sending end by engaging in broadcast transmitting. There evolved the idea of putting the transmitter at the disposal of others for hire (toll broadcasting), the sponsored program, and arrangements for the syndication of programs over the wire telephone network. Thus was demonstrated the ability to support broadcasting from the sending end.

One of the first five-kilowatt, water-cooled transmitters, that used in Station WEAf of the telephone company in 1924, is shown in Fig. 6. Aside from representing an advanced design at the time, this transmitter is associated with an interesting bit of technical history. A 500-watt transmitter, which had been used just before it, had shown

bad quality when received in certain outlying sections of the city on the far side of groups of skyscrapers. This gave rise to the making of one of the first studies of the broadcast transmission medium, including the element of fading and of coverage.³⁷ The trouble proved to be due to the effect of the tall buildings in attenuating the direct transmission and making apparent interference between multiple paths. The effect of the interference upon quality proved to be exaggerated by a degree of frequency modulation occurring in the transmitter. The latter

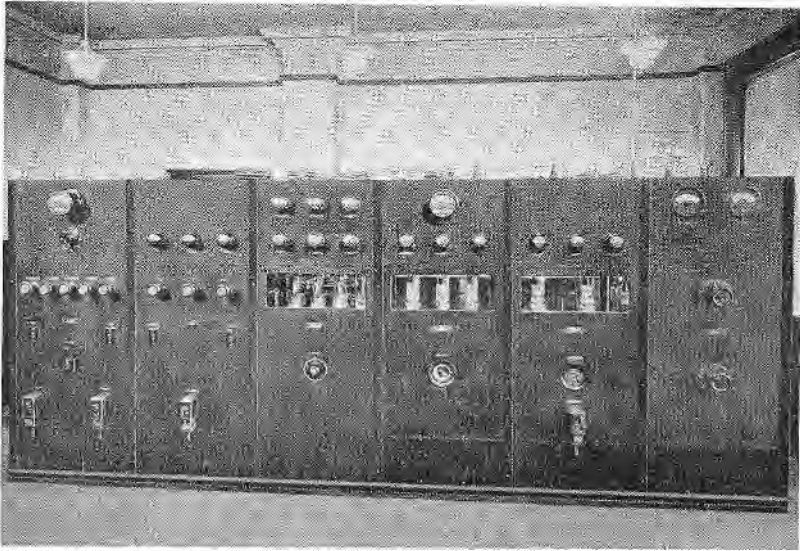


Fig. 6—Early Five-Kilowatts Transmitter of WEAf, Crystal Controlled, 1924.

trouble was removed by the adoption in the five-kilowatt transmitter of the master-oscillator type of circuit, employing piezoelectric crystal control, one of the first transmitters so provided.

The intimate interplay which existed technically between telephony broadly and broadcasting is shown also in the high quality side of broadcasting, involving studio acoustics, high-quality microphone pickup and high quality amplifiers. In the beginning of broadcasting the pickup and amplifying means were taken more or less bodily from the high-quality speech study work which had been going on in the telephone laboratories,³⁸ and from public address systems. In 1919 a great public address demonstration had been made in New York upon the occasion of a Liberty Loan; and in the Summer of 1920 such systems had played a prominent part in the two national political con-

ventions. Addresses delivered over such systems from a distance emphasized the need for high quality lines. As a result of such experience and the considerable amplifier network technique which had been built up in the long-distance telephone field, it was possible at an early stage of broadcasting to adapt telephone lines to handle as wide a sound-frequency band as the economics of the situation justified.

Broadcast Receivers

A realization of the progress which has been made in broadcast receivers is had by contrasting the modern, stable, and selective loud-speaker set with the ticklish crystal or regenerative battery set with which listeners first heard whispers in headphones. One of the first advances was to the high-frequency amplifying set, whereby sensitivity was achieved together with simplicity of adjustment. The stabilizing of these sets against singing stimulated the art of tube-balancing circuits and is remembered by Hazeltine's neutrodyne. The superheterodyne, the indirectly-heated cathode tube permitting operation from the alternating-current supply mains, the screen-grid tube, automatic gain control, featured the rapidly evolving receiving-set technique. Loud speakers progressed from the old horn type to the armature driven cone, to the electrodynamic, and multiple-unit system. While many of these advances had their origin elsewhere than in broadcasting, certainly the quantity production of broadcast receiving sets has been a powerful leaven in advancing the weak-current technique generally.

Transoceanic Telephony

As broadcasting was getting started, continuing research in the laboratory gave promise of considerably greater transmitting powers, in the form of the copper-anode, water-cooled tube. This and the other advances which had occurred since the original transoceanic experiments of 1915 indicated that it might be timely again to undertake the problem of extending telephony overseas.

A powerful water-cooled amplifier, the first of its kind, was developed and in 1922, in cooperation with the R.C.A., was installed at the transatlantic transmitting station at Rocky Point, Long Island. It is pictured in Fig. 7. Success attended the first objective of developing an antenna power of the order of 100 kilowatts and the transatlantic project was vigorously pushed. This work being in the then relatively low frequencies, it was possible to adopt single-side-band, carrier-suppressed transmission by borrowing that feature more or less bodily from the wire art, whereby the transmitting effectiveness was multiplied by a factor of about ten. The transmitting path to England

was studied by making measurements there, in collaboration with the engineers of the British Post Office, of the diurnal and seasonal variations received and of the noise levels. A further improvement was obtained by borrowing from the wireless telegraph art the newly-developed directive antenna known as the Beverage wave antenna.³³ There were, of course, other problems in getting started, and these and the manner in which service was established, beginning in 1927, and, in

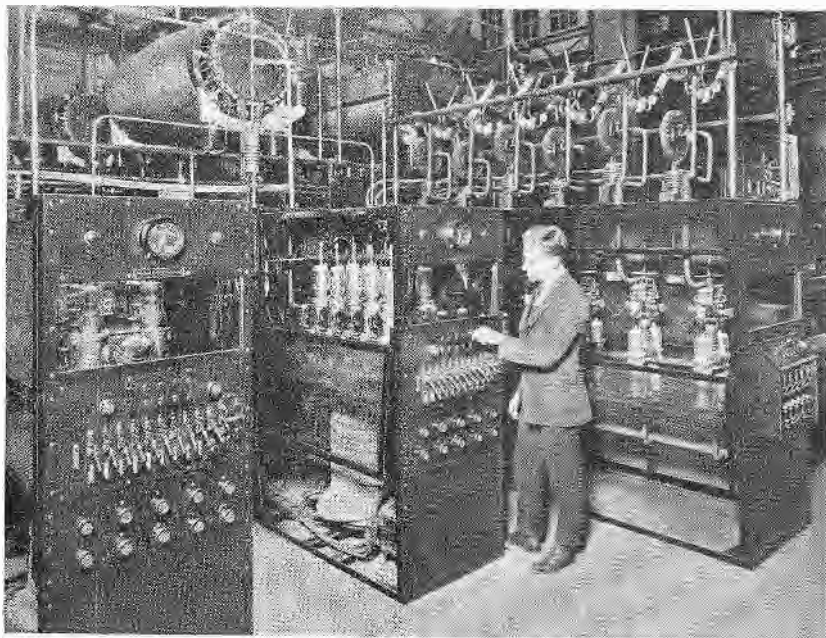


Fig. 7—Power Stage, in two units, with rectifier, of the first transatlantic radiotelephone transmitter at Rocky Point, Long Island, 1923.

time, extended by the use of high frequencies, are told in a companion paper entitled "Transoceanic telephone development," by Ralph Bown.

Higher Frequencies and Mobile Services

The extension of radio to the higher frequencies, or shorter waves, gave new opportunity for the development of radiotelephone services because of the greater message-carrying capacity of the higher frequencies and the greater transmission range.

Following the introduction of short waves to transatlantic telephony, the ship-to-shore problem was undertaken anew on a short-wave basis⁴⁰ and service was initiated on the North Atlantic in 1929. On the

shore end the essential facilities comprised a duplicate of one of the transatlantic point-to-point installations, including directive antennas pointing out along the transatlantic shipping route, and means for effecting two-way operation and for connecting into the wire network. The ship installation included a transmitter of 500 watts capacity, employing a new screen-grid power tube. As a result of "stay noise," there was adopted the "cut carrier" method of transmission. As it has³⁸ turned out, no American ships yet have been equipped permanently for service, but most of the larger foreign vessels are so equipped and marine telephone service is being given from both sides of the Atlantic.

A related form of marine telephone service is that to small boats. In the United States this started somewhat as a continuance by the Coast Guard of the submarine chaser installations of the war. In Europe fishing trawlers have been provided with simple radiotelephone sets in considerable numbers. In these installations the intention has been to enable the boats to talk with each other and with certain land stations; not with the landline telephone users. Small-boat telephony linked with the landline network is a more difficult matter. It is now under active development in the United States on both the East⁴⁴ and West Coasts, and on the Great Lakes, and in some countries in Europe. The installations in the United States are of crystal-controlled sets, designed to be used directly by the officer of the ship without technical attendance. Many of the ships are equipped to be "rung" individually as wanted by the shore station. The small boat telephony works generally in the medium-frequency range of two to three megacycles.

Another type of mobile service is that being used throughout the airways of the United States in maintaining contact between the planes and the ground stations. Telephony has proven particularly useful here because of the facility it offers the pilots of communicating directly on a two-way basis with ground stations. The service is operated generally in the three to six megacycle portion of the spectrum. The apparatus is crystal controlled, of special design for lightness, simplicity of operation, and reliability. This type of service was well started about 1929.^{38,39}

A third type of mobile radiotelephone service, and one which has become quite important in the United States, is that of the various city and state police departments, used to direct patrol cars. Most of these services are limited to one-way talking to the cars, and operate on intermediate frequencies. Now that ultra-high frequencies are becoming available, some of these systems are being extended to two-way service. The apparatus is generally similar to that employed in the aviation service.

Ultra-High Frequencies

The recent extension of the radio technique to ultra-high frequencies brings new opportunities and also new problems for radiotelephony. One of the earliest practical trials of these frequencies for telephony, and one representing at the time a very large jump in frequency, was the seventeen-centimeter wave propagation across the English Channel in 1931, accomplished by the system developed by the laboratory of Le Matériel Téléphonique of Paris, using the Barkhausen type of oscillator.⁴² Further experience has shown frequencies as high as this to be susceptible under some circumstances to rather serious transmission instability, resulting, it has been suggested, from changing moisture content of the air or from turbulent atmospheric conditions. A number of short radiotelephone links are now being operated in various parts of the world on somewhat lower frequencies, generally in the range of 40 to 100 megacycles.

It appears that as rapidly as the message-carrying capacity of radio is enlarged by extension to the ultra-high frequencies, the demand increases on the part of older services and of entirely new services, such as television. How much of the spectrum may be available for telephony will naturally be influenced by relative usefulness and economics. One problem is how to obtain radiotelephony sufficiently economically to "prove it in" for the shorter distances which characterize the useful range of these waves. Another is the one of preserving the privacy of communication by relatively simple means. It may be that the principle use of these waves for telephony will be for mobile services, thereby helping telephony keep pace with our increasingly mobile way of living.

Leaven of the Art

In describing the rise of radiotelephony we have spoken principally of physical things such as the vacuum tube, the filter circuit, etc. Another cross section of the art would be the leaven of ideas which gave rise to it, the analyses and the reductions to measurement which enabled results to be obtained by design. That radiotelephony is particularly rich in this respect will be evident from the following citation of some of the more outstanding analytical contributions.

One of the first is that of van der Bijl's early study of the operation of the vacuum tube. In 1913-1914 he derived approximate expressions for the plate current in terms of plate and grid voltage, and presented the concept of the amplification factor μ . This work was published²² toward the end of the war and was the forerunner of his 1920 book²⁸ on the vacuum tube, an authority for many years.

One of the earliest elucidations to be published of the operation of the audion as detector was the 1914 paper of Armstrong.¹⁵

Next, there is the more exact mathematical solution of the plate current in terms of the tube constants and grid voltage variations, given in an I.R.E. paper in 1919;²⁴ and the treatment of the vacuum tube as a part of a circuit network published the same year.²⁵

A potent factor has been the growing appreciation throughout the

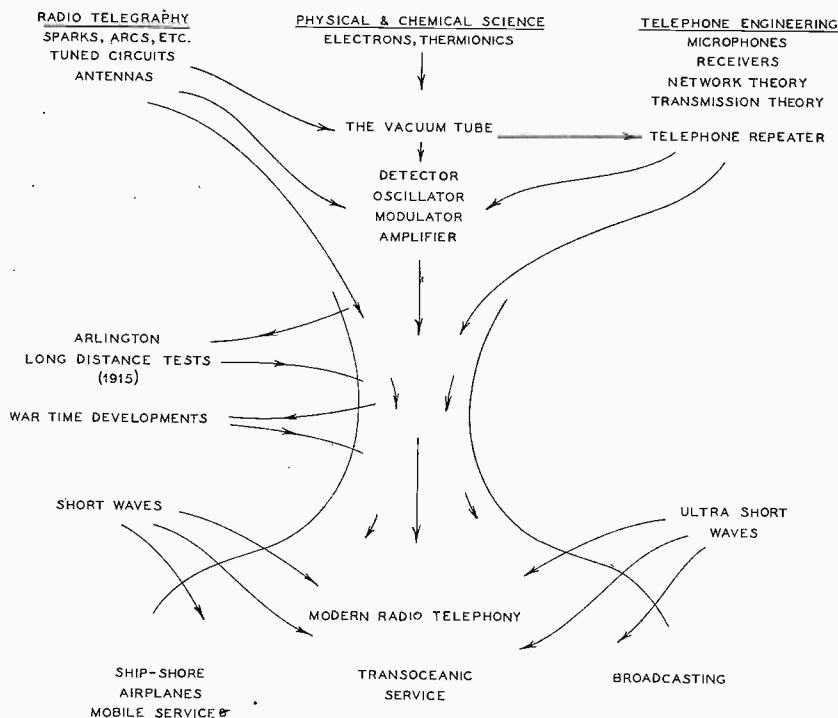


Fig. 8—An attempt to diagram the flow of the art.

electric communication art generally of Fourier's theorem and the steady-state concept of transient phenomena. Related thereto is the band idea of wire telephone transmission which developed out of the frequency-band nature of speech itself, the characteristics of lines, and the necessity of suppressing reflections at circuit junctions. Campbell, using the loaded-line theory, combined the band idea of telephony with the sharp selectivity feature of radiotelegraphy to secure the wave-filter characteristic of a uniform transmission band, plus a sharp cutoff. This was a milestone in the development of circuit network theory.

Related to both vacuum tubes and the band conception were Carson's analysis of the modulated wave into the component carrier and sidebands and his invention of single-side-band transmission,¹⁸ made as far back as 1915, and the general extension of the signal-band idea to high frequencies, which has meant so much to both wire carrier-current telephony and radiotelephony.

In the field of measurement and standardization there are the technique of making single-frequency measurements throughout a band, the decibel unit of attenuation, the volume indicator and the concept of volume range, and the measurements of the field strength of desired signals and of noise.

Fig. 8 represents an attempt to diagram the flow of the art as a whole.

FUTURE

Radiotelephony may be said to have "arrived" and to still be young. Looking toward the future, the writer likes to think of radio and wire telephony as increasingly dovetailing together to form one general front of advance. The principles and technical tools being fundamentally the same for both, a technical advance in one is likely to help the other. Thus radio has led the way to the higher frequencies and this has benefited wire communication, as we see in the carrier-current and wide-band coaxial cable development. As regards services, we observe that radio and wire telephony are one and the same thing in respect to the over-all result, that of the delivery of sound messages. Where one or the other is to be used will be a matter of natural adaptability of the medium of transmission and of the economics of the situation, with the meeting line shifting from time to time, but with the main emphasis upon integration rather than differentiation. Thus does radiotelephony become an integral part of telephony and of the whole field of electric communications.

Bibliography

1. A. G. Bell, "On the production and reproduction of sound by light," *Am. Jour. Sci.*, vol. 20, pp. 305-324; October, (1880).
2. E. Mercadier, "Sur la radiophone," ("The radiophone,") *Comp. Rend.*, vol. 91, pp. 929-931; December 6, (1880).
3. Thomas A. Edison, "Electrical indicator," U.S. Patent No. 307,031; filed November 15, (1883), issued October 21, (1884). (Application of the "Edison effect").
4. J. A. Fleming, "Improvements in instruments for detecting and measuring alternating electric currents," British Patent No. 24,850; filed November 16, (1904), issued September 21, (1905). (U.S. Patent No. 803,684; filed April 19, (1905), issued November 7, (1905).)
5. J. A. Fleming, "On the conversion of electric oscillations into continuous currents by means of a vacuum valve," *Proc. Roy. Soc. Lond.*, vol. 74, pp. 476-487; March, (1905).

6. A. Wehnelt, "On the discharge of negative ions by glowing metallic oxides, and allied phenomena," *Phil. Mag.*, vol. 10, pp. 80-90; July, (1905).
7. Lee De Forest, "Device for amplifying feeble electrical currents," U.S. Patent No. 841,387; filed October 25, (1906), issued January 15, (1907). (Audion with control electrode in the form of a plate.)
8. Lee De Forest, "The audion: a new receiver for wireless telegraphy," *Trans. A.I.E.E.*, vol. 25, pp. 735-763; October 26, (1906).
9. Lee De Forest, "Space telegraphy," U.S. Patent No. 879,532; filed January 29, (1907), issued February 18, (1908). (Audion with control electrode in the form of a grid.)
10. E. Ruhmer, "Wireless telephony in theory and practice," Translated from the German by James Erskine-Murray. D. Van Nostrand Co., New York, pp. 224+xii; (1908).
11. C. D. Child, "Discharge from hot CaO," *Phys. Rev.*, vol. 32, pp. 492-511; May, (1911). (Derivation of the $3/2$ -power law.)
12. G. O. Squier, "Multiplex telephony and telegraphy by means of electric waves guided by wires," *Proc. A.I.E.E.*, vol. 30, pp. 857-905; May, (1911).
13. Lee De Forest, "The audion,—detector and amplifier," *Proc. I.R.E.*, vol. 2, pp. 15-29; March, (1914).
14. A. Meissner, "The audion as a generator of high-frequency currents," *Electrician*, vol. 73, p. 702; July 31, (1914).
15. E. H. Armstrong, "Operating features of the audion," *Elec. World*, vol. 64, pp. 1149-1152; December 12, (1914).
16. E. H. Armstrong, "Some recent developments in the audion receiver," *Proc. I.R.E.*, vol. 3, pp. 215-238; September, (1915).
17. I. Langmuir, "The pure electron discharge and its applications in radio-telegraphy and telephony," *Proc. I.R.E.*, vol. 3, pp. 261-293; September, (1915).
18. J. R. Carson, "Method and means for signaling with high-frequency waves," U.S. Patent No. 1,449,382; filed December 1, (1915), issued March 27, (1923).
19. H. J. Round, "Wireless telephony," in Year Book of *Wireless Tel. and Tel.*, Wireless Press, Ltd., London, pp. 572-582, (1915).
20. G. A. Campbell, "Electric wave-filter," U.S. Patent No. 1,227, 113; filed July 15, (1915), issued May 22, (1917).
21. G. A. Campbell, "Electrical receiving, translating, or repeating circuit," U.S. Patent No. 1,227,114; filed June 5, (1916), issued May 22, (1917).
22. H. J. van der Bijl, "Theory of the thermionic amplifier," *Phys. Rev.*, vol. 12, pp. 171-198; September, (1918).
23. E. B. Craft, and E. H. Colpitts, "Radiotelephony," *Trans. A.I.E.E.*, vol. 38, pp. 305-343; February, (1919). *Proc. A.I.E.E.*, vol. 38, pp. 337-375; March, (1919).
24. J. R. Carson, "A theoretical study of the three-element vacuum tube," *Proc. I.R.E.*, vol. 7, pp. 187-200; April, (1919).
25. H. W. Nichols, "The audion as a circuit element," *Phys. Rev.*, vol. 13, pp. 404-414; June, (1919).
26. B. Gherardi, and F. B. Jewett, "Telephone repeaters," *Proc. A.I.E.E.*, vol. 38, pp. 1255-1313; November, (1919).
27. H. D. Arnold, "Phenomena in oxide-coated filament electron tubes," *Phys. Rev.*, vol. 16, pp. 70-81; July, (1920).
28. H. J. van der Bijl, "The thermionic vacuum tube and its applications," McGraw-Hill Book Co., pp. 391+x; (1920).
29. Colpitts and Blackwell, "Carrier current telephony and telegraphy," *Jour. A.I.E.E.*, vol. 40, pp. 301-315, 410-421, 517-526; April, May, June, (1921). (Bibliography.)
30. R. A. Heising, "Modulation in radiotelephony," *Proc. I.R.E.*, vol. 6, pp. 305-352; August, (1921).
31. L. M. Clement, F. M. Ryan, and D. K. Martin, "The Avalon-Los Angeles radio toll circuit," *Proc. I.R.E.*, vol. 9, pp. 469-505; December, (1921).
32. A. Meissner, "The development of tube transmitters by the Telefunken Company," *Proc. I.R.E.*, vol. 10, pp. 3-32; February, (1922).
33. H. H. Beverage, C. W. Rice, and E. W. Kellogg, "The wave antenna. A new type of highly directive antenna," *Jour. A.I.E.E.*, vol. 42, pp. 258-269, 372-381, 510-519, 636-644, 728-738; March-July, (1923). (Bibliography.)

34. H. W. Nichols, and L. Espenschied, "Radio extension of the telephone system to ships at sea," *Proc. I.R.E.*, vol. 11, pp. 193-242; June, (1923).
35. W. H. Martin, and H. Fletcher, "High quality transmission and reproduction of speech and music," *Trans. A.I.E.E.*, vol. 43, pp. 384-392; February, (1924). *Jour. A.I.E.E.*, vol. 43, pp. 230-238; March, (1924).
36. E. L. Nelson, "Transmitting equipment for radiotelephone broadcasting," *Proc. I.R.E.*, vol. 12, pp. 553-577; October, (1924).
37. R. Bown, D. K. Martin, and R. K. Potter, "Some studies in radio broadcast transmission," *Bell. Sys. Tech. Jour.*, vol. 5, pp. 143-213; January, (1926). *Proc. I.R.E.*, vol. 14, pp. 57-131; February, (1926).
38. R. L. Jones, and F. M. Ryan, "Air transport communication," *Trans. A.I.E.E.*, vol. 49, pp. 187-197; January, (1930).
39. E. L. Nelson, and F. M. Ryan, "Radio facilities for aircraft communication," *S.A.E. Jour.*, vol. 26, pp. 326-334, 340; March, (1930).
40. W. Wilson and L. Espenschied, "Radiotelephone service to ships at sea," *Bell. Sys. Tech. Jour.*, vol. 9, pp. 407-428; July, (1930).
41. C. W. Horn, "Ten years of broadcasting," *Proc. I.R.E.*, vol. 19, pp. 356-376; March, (1931).
42. "Micro-ray wireless," *Elec.*, vol. 106, pp. 507-510; April 3, (1931).
43. H. H. Beverage, H. O. Peterson, and C. W. Hansell, "Application of frequencies above 30,000 kilocycles to communication problems," *Proc. I.R.E.*, vol. 19, pp. 1313-1333; August, (1931).
44. F. A. Gifford and R. B. Meader, "Marine radiotelephone service," *Comm. and Broad. Eng.*, vol. 2, pp. 9-11, 15; October, (1935).
45. N. F. Schlaack, and F. A. Polkinghorn, "An unattended ultra-short-wave radiotelephone system," *Proc. I.R.E.*, vol. 23, pp. 1275-1285; November, (1935).

