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GENERAL INFORMATION

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INSTITUTE ACTIVITIES

September Board Meeting

At the September 1st Board meeting held at Institute headquarters, New York, the following were present: D. McNicol, president; R. Bown, vice-president; L. Espenschied, M. Eastham, A. N. Goldsmith, A. H. Grebe, R. H. Marriott, L. A. Hazeltine, L. E. Whittemore and A. E. Reoch.

The Board approved election to Associate grade of 179 applicants and to Junior grade 29. The following were approved for transfer to Member grade: O. K. Hovgaard, D. H. DeBurgh, H. W. Kitchin, James A. Dowie, A. A. Hebert, E. H. Smythe, R. K. Potter, R. H. Wood and N. E. Wunderlich. The following were approved for direct election to Member grade: T. Thorne Baker, Irving Vermilya, and J. B. Dow. F. A. Hinners was transferred to grade of Fellow.

The Liebmann Memorial Prize, consisting of $500 in cash, which is issued annually was this year awarded to Dr. Ralph Bown for his researches in "Wave Transmission Phenomena." The award will be presented to Dr. Bown at the annual convention early in 1927.

The addition of about 500 square feet of space for headquarters offices was approved by the Board.

The president was authorized to appoint a committee on Broadcast Engineering. This committee will consist of five members, three of them to be board members. The personnel of this committee will be announced in the next issue of the PROCEEDINGS.

There was preliminary discussion relative to the holding of the Annual Convention in 1927. A Convention Committee will be appointed at the October Board meeting. The Convention very likely will be held in January.

Rochester Section

The Rochester Section will hold a meeting on October 2nd at which Mr. John W. Million, Jr., of the King-Hinners Company, will deliver a talk on radio.

Membership Committee

The Membership Committee, H. F. Dart, chairman, held a meeting at Institute headquarters on the evening of September 7th. The Committee is planning a campaign for new and desirable members. The desire is to do all possible to make sure that every radio man may have an opportunity to make application for membership. Ordinarily, it is best even for experienced radio engineers to apply for Associate membership initially. After being admitted to the Institute, those enrolled as Associates, are in a position to study the requirements for the higher grades and to become acquainted with the required number of Fellows and Members so that they may use the names of these gentlemen as references.

Washington, D. C., Section

The new Section officers for the coming year are: Chairman, A. Hoyt Taylor; Secretary-Treasurer, F. P. Guthrie, 1112 Connecticut Ave., N. W., Washington. The Section officers are working on a schedule of important radio papers to be presented and discussed at meetings to be held during the next Fall and Winter months.

Chicago Section

The Chicago Section held a meeting on Friday, July 30th, in the rooms of the Western Society of Engineers. A paper was presented by Dr. E. W. Engle on the subject of "Characteristics of Electrolytic Rectifiers as Used in Radio Engineering."

A committee was appointed to serve as an Executive Committee, the members being G. A. Johnstone, three years; J. H. Miller, two years, and Montford Morrison, one year. These members will serve with the chairman of the Section.

Toronto Section

The officers of the Toronto Section to serve during the coming year are: D. Hepburn, Chairman; C. C. Meredith, Secretary; George F. Eaton, Vice-Chairman; C. I. Soucy, Assistant Secretary, and A. L. Ainsworth, Treasurer. Professor T. R. Rosebrugh was elected Honorary Chairman of the Section.

Diplomas for Fellows and Members

The diplomas authorized to be issued to Fellows and Members of the Institute are ready for distribution. Fellows and

Members who have not yet procured their diplomas may do so by making application to the Secretary.

Change of Address

Members, any grade, who change their place of employment or their residence address should advise the Secretary of the Institute relative to the new address. This is important in order that the PROCEEDINGS and other publications of the Institute may reach each member promptly and without being returned to Institute headquarters for remailing.

The 1927 Year Book, which will contain the names of all members, all grades, in good standing after the beginning of the year, is intended to be correct in all particulars. Members should notify the Secretary's office as to correct business connections and correct mailing address so that entries in the Year Book may be accurate.

Pictures of the Presidents

The Institute has procured and had framed pictures of all the past presidents of the Institute. These are displayed in one of the rooms at Institute headquarters.

Los Angeles Section

The Los Angeles Section at its last meeting had for consideration a paper on the subject of "Radio Interference," by Ralph W. Wright.

The officers of the Los Angeles Section are: Chairman, Lee Yount, 1220 Wall Street, Los Angeles, Calif.; Vice-Chairman, M. E. McCreery; Secretary-Treasurer, L. Elden Smith, 340 North Painter Ave., Whittier, Calif. The Executive Committee is made up of the officers and Les Taufenback, Dr. E. C. Waters and C. S. Pratt.

Advertising in the PROCEEDINGS

Members of the Institute in writing to the manufacturers of radio apparatus who advertise in our pages should not fail to mention that the advertisement was seen in the PROCEEDINGS. The Institute's income from advertising is used to help defray the cost of publishing the PROCEEDINGS. All possible support should be given to the concerns which advertise in these pages.

Entrance Fee

On page 15 of the 1926 Year Book, Article IV, Dues, the entrance fee payable on admission to the Institute, covering each grade is given. During the past three or four years the entrance fee has been waived, but is to be restored on January 1, 1927, as stated in Article IV. Those who join the Institute, any grade, after January 1, 1927, shall be required to pay the proper entrance fee, as well as the annual dues, as soon as they are notified of their election to membership.

PROCEEDINGS to be Issued Monthly

The present plan is to begin monthly publication of the PROCEEDINGS, beginning with the January, 1927 issue. All members will receive the monthly issues as heretofore they have received the bi-monthly issues, without any additional dues payment. This increase in the number of copies of the PROCEEDINGS, which members receive annually, will be of very great advantage and value.

Bound Volumes of the PROCEEDINGS

Bound volumes of the PROCEEDINGS are available from the year 1917 to 1925, inclusive. The price to members is $8.75 per volume. The price to non-members is $11.00 per volume.

Chicago Section

The new officers of the Chicago Section elected at the annual meeting held on July 30th, are: Chairman, G. M. Wilcox, Professor of Physics, Armour Institute; Secretary-Treasurer, H. E. Kranz, 703 North 5th Ave., Maywood, Ill. As stated in another paragraph in this issue, the officers for the year act with an Executive Committee which carries over from year to year in managing the affairs of the Section.

Membership

On August 1, 1926, the Institute had a membership enrollment as follows: Fellows, 80; Members, 415; Associates, 2,760; Juniors, 175—a total of 3,430. This is a gain of approximately 1,000 in the past year.

In the British Isles there are 255 members; in Canada, 135; n other foreign countries, 220.

Section Territories

Philadelphia—Philadelphia, Camden, Atlantic City.
Washington—District of Columbia, Annapolis.
Boston—60-mile radius.
Chicago—Chicago City, Aurora, Joliet, Ottawa, Elgin.
Toronto—Province of Ontario.
Rochester—Syracuse, Elmira, Oswego, Binghamton.
Seattle—State of Washington.
San Francisco—Oakland, Alameda, San Jose, Stockton, Sacramento, San Rafael.
Los Angeles—Santa Barbara, Pasadena, San Diego, San Pedro, Bakersfield.

Errata

In the paper by N. N. Tsiklinsky and V. A. Volynkin on "Choice of Power for a Radio Station," published in the PROCEEDINGS for June, the following changes should be noted:

Page 383, equation (2), e should be ϵ; equation (3), the exponent ξ should be δ.

Page 384, second equation, C should be $\mathscr{C}$; in formula (5a), A_{mA} should be a_{mA}; in formula (6a), C_{mA} should be $\mathscr{C}_{mA}$; eighth line from top, exponent -7 is inverted; in formula (4a), C should be $\mathscr{C}$.

Page 385, 13th line, consideron should be consideration.
Page 386, 10th line from bottom $\gg$ should be $\geqslant$.
Page 388, last line, power kw. should be power 20 kw.
Page 389, 5th line of summary, h^2 should be h^{-2}.

REDUCTION OF INTERFERENCE IN BROADCAST RECEPTION*

By

Alfred N. Goldsmith

(Chief Broadcast Engineer, Radio Corporation of America)

When, in addition to the desired program, there is released from the loud speaker of the receiving set employed by the broadcast listener a program or programs emanating from other and undesired stations, it is said that "interference" is present. The relative loudness of the interfering sound, as compared to that of the chosen program, will in part determine the usefulness of the radio receiver to its owner (at that time and for the rendition of the desired program). If the interference is extremely slight, it may be tolerable; yet if it is at all noticeable, even during silent pauses in the desired program, it will probably detract from the enjoyment of the listener to such an extent as to spoil his entertainment and the corresponding value of the radio broadcast service. High quality radio service requires inaudible (that is, psychologically non-existent) interference.

The discussion in this paper will be limited to interference caused by undesired broadcasting stations; although it should be kept in mind that the interference from damped wave marine transmitters (for example, of the spark type), harmonics of continuous wave transmitters or irregular variations in their radiation (such as "arc mush"), inductive interference from a number of electrical devices and systems, incidental to human activities, and electrical disturbances of atmospheric origin may all interfere with broadcast reception of feeble signals to a noticeable extent. The reduction of interference primarily involves technical factors, but it also carries the engineer and investigator into the realm of human relations. It is accordingly necessary in the following study of the reduction of interference to consider, as a practical proposition, certain non-technical matters.

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*Received by the Editor, July 30, 1926. Presented before The Institute of Radio Engineers, New York, October 6, 1926.

1. Factors in the Production of Interference

It is assumed that reception is being carried out, at a given frequency, using a vertical effectively non-directional antenna. It is also assumed that the incoming electromagnetic waves, carrying the broadcast program, are vertically polarized. It is also taken for granted (although unfortunately it is not universally the case in practice) that the frequencies of stations on adjacent channels are separated by 10 kilocycles per second and that, in consequence, their carrier waves will produce a practically inaudible beat-note with one another. It is to be noted, however, that the intelligence-carrying side bands of two signals will interfere with each other under such conditions unless the audio frequencies transmitted as carrier modulation from each station are limited to a maximum of 5,000 cycles per second, a value too low for entirely satisfactory reproduction of music or speech.

(*a*) *Field Strength.* The more intense or powerful the field of the incoming waves, the greater will be their capabilities in the production of interference. It is therefore to be expected that persons in the immediate vicinity of powerful broadcasting stations, which are capable of laying down high field strengths over considerable areas, may experience interference.

(*b*) *Receiver Selectivity.* Selectivity is that characteristic of a receiver which enables it to discriminate between two incoming signals on neighboring frequencies, passing one and excluding the other. It involves a progressively increasing attenuation of the radio frequency (or intermediate frequency), tuning system toward frequencies increasingly removed from the desired signal frequency.

It should be noted in this connection that the sensitivity of a receiver will apparently influence its working selectivity. Highly sensitive receivers, which give extremely powerful sounds from the loud speaker when actuated by feeble incoming waves, will correspondingly give an audible response from an interfering signal under circumstances in which a less sensitive receiver, while giving a weaker loud speaker sound, will not seem to produce any interfering signal because the interfering signal has been dropped below the audibility limit. The obvious remedy for interference which accompanies excessively loud signals from weak stations, produced by an ultra-sensitive receiver, is to reduce the receiver sensitivity by volume control manipulation (assuming that the selectivity of the receiver is independent of its sensitivity, which is sometimes not the case).

Of analogous nature is the interference resulting from the use of an antenna or pick-up system of excessive dimensions whereby an inappropriately large signal voltage is impressed upon the receiver, perhaps overloading one or more stages of amplifier tubes. Under such circumstances, even feeble interfering signal voltages will cause an audible response in the loud speaker, and normal signal voltages will cause undesirably loud or distorted signals. In this case the indicated remedy is a reduction in the size of the wave pick-up system.

It is clear that the practical usefulness of feebly selective receivers is limited to locations where there are only weak signals, on considerably separated frequencies. Such signals from distant or low-power stations are generally found exclusively in rural districts under present broadcasting conditions.

By contrast, highly selective receivers have a wider (and in fact, practically universal) sphere of usefulness. They are capable of receiving weak signals from comparatively distant low-power stations without interference even though there are nearby powerful stations in operation.

(c) *Psychological Influences.* Interference is astonishingly odious to the average broadcast listener despite the absence of direct financial participation by him in the expense activities of the broadcasting stations which attempt to serve him. A listener may receive eleven stations perfectly, but fail to receive the twelfth because of interference from a thirteenth station. Under these circumstances, the listener-reaction in the extreme case is somewhat as follows: The eleven stations which he can receive become uninteresting to him, and are neglected. The twelfth station which he cannot receive, regardless of its intrinsic merits, becomes the grimly desired goal of his radio ambitions. The thirteenth, or interfering station, also regardless of its program merits and tone quality, appears to him as the serpent in what would otherwise be a radio paradise and, unless restrained, he will bruise the head of serpent beneath his heel.

It is also found that the designation given to a broadcasting station makes a great difference to many listeners. The following, for example, is fairly typical: A listener will be located a mile from a one-half kilowatt station, or perhaps three miles from a 5-kilowatt station. He will experience a certain amount of interference due to the high field strength of the incoming waves, but, since the stations in question seem to be sanctioned by time-honored custom, it will never occur to him to complain of their existence. Other listeners, located say ten miles from a 50-kilowatt station, and experiencing no greater field strengths than the uncomplaining listener just mentioned, will learn to their astonishment that they are only ten miles from a "super-power station." They may then experience psychological as well as physical interference, and some will protest. Unfortunately field strength is not the sole determinant of public satisfaction.

One may also briefly touch on the possible misinterpretation of the purpose of a newly established broadcasting station of considerable power. Radio is a new and complicated art, imperfectly understood by the public; and it is a simple matter for the good people of the locality in which an efficient broadcasting station has been established somehow to get the opinion that there is some objectionable motive responsible for the establishment of the station in question. In common with other important elements in broadcasting (censorship, copyright privileges, wave length allocations, operating time, and the like), the location and power of broadcasting stations have controversial aspects.

2. Analysis of Receiver Selectivity

(*a*) *Basis of Selectivity.* Essentially all present-day receivers depend for their selectivity on a well-known characteristic of a circuit (or circuits) containing inductance and capacity. Such a circuit shows a minimum reactance (or impedance) at a certain specified frequency, to which frequency it is said to be "tuned." Maxima of voltage or current may be produced in this circuit at this frequency. The reactance of the tuned circuit is greater at frequencies above or below the frequency to which it is tuned, and the increased impedance of the circuit results in a larger attenuation of currents at off-tune, or undesired frequencies. This simple circuit still forms the basis of modern receiver selectivity.

(*b*) *Improved Selectivity.* In general, the selectivity of a single tuned circuit is insufficient to meet existing broadcast interference problems. While the current response, produced by a given voltage, at an undesired frequency is less than that at a nearby desired frequency, yet the ratio of the undesired current to the desired current is often not so small as is necessary to reduce interference to inaudibility. Among the methods which may be employed in practice to increase the selectivity of the receiver are the following:

(*b*-1) A succession of tuned circuits may be coupled to each other, and the desired signal energy, as well as the undesired signal energy may be caused to traverse the successive circuits.

The attenuation toward off-tune currents may be considerably increased in this fashion, and the selectivity improved.

(*b*-2) The incoming signals, both desired and undesired, may be caused to pass through a sequence of tuned circuits each of which is more or less independent of the preceding. Generally such circuits are electrically separated by one-way repeaters of the triode type. It is attempted to reduce the back coupling between successive circuits to a negligible quantity, and this requires in general the neutralization of the effects of inter-electrode capacity in the triode, as well as the choice of suitable geometrical configuration for the tuning elements in the successive circuits, and also the adoption of certain other expedients. As an ideal, the attenuation toward off-tune currents in a succession of such independent circuits is a summation of the attenuations due to each one of the circuits, so that the over-all selectivity of such systems may reach high values.

(*b*-3) An intermediate frequency selectivity may be utilized, generally in addition to radio frequency selectivity secured according to the preceding methods. This is accomplished in the super-heterodyne receivers. The incoming desired wave is converted to a fixed intermediate frequency by heterodyning with a tunable local oscillator. In the reception of speech or music, a super-audible intermediate frequency is employed. The converted or intermediate frequency is then generally passed through correspondingly tuned amplifiers. Undesired waves are converted to frequencies which are highly attenuated by the intermediate frequency circuits. In view of the considerable ratio of the incoming radio frequency to the intermediate frequency (about 25-to-1 in ordinary broadcast receivers), an unusually sharp cut-off of currents at undesired frequencies close to the desired signal is obtainable.

(*c*) *Necessary Limitation of Selectivity.* Although the opposite is well known to radio engineers, there has been a widespread public impression that the selectivity of receivers may be indefinitely increased, and that interference can therefore be eliminated by the use of sufficiently selective receivers.

Considering first the ideal case, it may be assumed that the transmission from a radio telephone station of high quality will include the carrier frequency and two side bands extending to frequencies 10 kilocycles above and below the carrier frequency. Such a transmission therefore occupies 20 kilocycles, which is the proper width for a radio channel. Adjacent carrier frequencies should, therefore, be separated by 20 kilocycles. Unfortunately, the urgent pressure applied by prospective broadcasters has necessitated the assignment of broadcasting frequencies only 10 kilocycles apart. At best such a system is a compromise. Under such a regime, however, a receiver should admit, without attenuation, a band of frequencies 10 kilocycles wide. For example, when tuned to 660 kilocycles, all frequencies from 655 to 665 kilocycles should be equally passed through the receiver, whereas all frequencies outside of this band should be weakened to inaudibility even if the external field strength corresponding to them is considerable. The transmission band of such a receiver, being flat-topped, and having sharp cut-offs, will permit reception without quality distortion at audio frequencies (assuming a suitable audio frequency detector, amplifying system, and loud speaker).

Actual receivers do not behave in this fashion. Their admittance curve is sharply peaked in many cases, and their cut-off gradual. As a result, tone quality is injured by selective attenuation within the side bands, and interference from stations on neighboring frequencies is admitted. Without going into further details, it may be stated that the further a receiver deviates from the flat-top and abrupt cut-off admission band, the less desirable it is from the standpoint of selectivity and tone quality. As an obvious secondary consequence, the useable selectivity of receivers is definitely limited.

3. Performance of Present Day Transmitters and Receivers

It has not yet proved feasible to employ, for broadcasting purposes, transmitters emitting a single side band, the other side band and the carrier being eliminated. Nor has multiple transmission (of the same program) on an identical frequency at each of a number of interconnected stations become a part of standardized broadcasting practice. Both of these systems have been experimentally tried, and their practical capabilities will no doubt be determined by further trial. For the present, however, they need not be considered.

(*a*) *Transmitter Power.* The power of transmitting sets for broadcasting purposes varies over the wide range of 10,000-to-1. A number of midget transmitters of 5 watts are employed for purely local transmission, and a number of 50-watt sets are also in use to cover certain limited areas. The reliable service range of such transmitters, is, however, too limited for serious consideration in dealing with broadcasting problems of national scope.

It has long been the contention of far-sighted radio engineers that the only range of transmitters deserving real weight is the true "service range." Quantitatively, we cannot exactly define the service range of transmitters because of the somewhat irregular nature of radio transmission. However, a rough idea of what is meant can be gained from the tentative definition that "the service range of a transmitting station is that distance, over which it will produce, by day or night and at all seasons of the year (except during unusually severe atmospheric disturbances), a signal having at least as great a ratio to all disturbing sounds as the music from a high quality phonograph on a well-cut new record bears to the incidental needle scratch."

The basis of this definition is the acceptance by the public of high-quality phonographic reproduction as a service of human value. It is to be noted that this type of reproduction is taken as marking a minimum or lower limit of acceptability for radio signals received within the service range. A radio signal which is not so "clean" as the output of a good phonograph is received at a point outside of the service range of the corresponding transmitting station for critical listeners.

To persons accustomed to the ranges secured by professional radio operators and amateurs, with telegraph signals, and under favorable conditions, the limited service ranges secured by broadcasting stations of a given power will come as a shock. It must be remembered that broadcasting stations communicate *telephonically*. An artistic effect is to be produced, and interference which can be overlooked in telegraphic reception of commercial material would be fatal to the enjoyment of the broadcast listener. Then too, the manipulation of receivers by the public is less skilled than that of the professional radio telegraph operators. Loud speaker operation is demanded in broadcasting in many instances, and extraneous sounds and disturbances in the same room require the loud speaker to deliver an unusually clear and loud signal for satisfactory results.

For these reasons the service range of stations of various powers in the eastern portion of the United States may be estimated as follows:

TABLE 1

Antenna Power	Service Range
5 watts	1 mile
50 watts	3 miles
500 watts	10 miles
5,000 watts (5 kilowatts)	30 miles
50,000 watts (50 kilowatts)	100 miles

These figures are primarily based on analysis of reception data by the Bureau of Standards of the Department of Commerce, and published statements of Secretary of Commerce, Herbert Hoover.

Of course these service ranges will be considerably exceeded many times under favorable conditions. On the other hand, at some points within the service range area where local conditions happen to be unusually unfavorable, good service will not be secured. A typical cause for poor reception in a limited zone, within the general service area, is the radio shadow cast by great masses of steel buildings.

(*b*) *Field Strengths*. The field strengths required for satisfactory broadcasting reception, within the service range, are far beyond those which have been regarded as commercially necessary in marine and transoceanic radio telegraphy, and for the reasons given in the previous discussion. The following table gives a general idea of the type of service, in its relation to disturbing sounds, which is yielded by various field strengths of waves within the broadcasting band:

TABLE 2

Signal Field Strength	Nature of Service
0.1 millivolt per meter	Poor Service
1. millivolts per meter	Fair Service
10. millivolts per meter	Very Good Service
100. millivolts per meter	Excellent Service
1,000. millivolts per meter	Extremely Strong

The field strength corresponding to the outer boundary of the "service range" lies between 1. and 10. millivolts per meter and, in general, is nearer the latter value than the former.

The clear and outstanding conclusion from an analysis of these figures is that it is necessary, in a large country like the United States with its great rural areas, to have stations which can lay down field strengths in excess of 1. millivolt per meter over great areas. Every device of human utility has passed from the play-toy stage into the stage of reliable service. In terms of broadcasting, this means that field strengths of the order of tenths of a millivolt per meter, despite their sporting fascination to some people, will play little part in the future development of broadcasting. Conversely, it means that field strengths of the order of tens of millivolts per meter represent the goal of service for broadcasting of the future.

(*c*) *Receiver Classification and Performance.* The great majority of receivers now used for broadcast reception fall into the following classes, which are arranged in order of increasing selectivity:

Receivers employing a single radio-frequency tuning stage, generally with adjustable regeneration.

Receivers employing three radio-frequency tuning stages, each stage being fairly heavily damped and without effective neutralization of coupling between stages of radio-frequency amplification.

Receivers utilizing three radio-frequency tuning stages, generally of low damping, and with more or less complete neutralization of interstage couplings.

Receivers utilizing one or more intermediate-frequency tuning stages, and one or more radio-frequency tuning stages.

The typical performance of some of the above receivers is given, approximately, in the following table. It is assumed that the receiver is tuned to 660 kilocycles (455 meters) and that the voltage reaching the final detector grid from a given signal, corresponding to satisfactory volume in a loud speaker attached at the end of the audio frequency amplifier, is measured. An equal signal voltage is then applied to the receiving set, but at a frequency of 670 kilocycles, or 10 kilocycles off the desired signal frequency. The ratio of the voltage produced by the desired signal to that produced by the undesired signal, at the detector grid in this case, is given in the second column of the table. If the undesired signal is 710 kilocycles, or 50 kilocycles removed from the desired signal frequency, the corresponding voltage ratios of desired to undesired signal at the detector grid, are given in the third column of the table. It must be remembered that individual receivers vary in this regard, and that the following values represent order of magnitude only in each case:

TABLE 3

VOLTAGE RATIOS AT DETECTOR GRID

Type of Receiver	10 kilocycles off carrier	50 kilocycles off carrier
One Radio-frequency Stage	1.5	5.5
Same, but with Regeneration	18.	60.
Three Neutralized Radio-frequency Stages	15.	8000.
One Radio-frequency and two Intermediate-frequency Stages (Superheterodyne)	800.	over 10000.

It is obvious that suitable tuned circuits have the same functional importance in receivers as red corpuscles have in the blood. On this basis it is found that some of the simpler receivers are suffering severely from pernicious electrical anemia. Their present debilitated condition results from their failure to meet the stringent broadcasting conditions of today, however placid and useful may have been their existence in the pioneer period of broadcasting.

It is clear that there are possibilities of trouble from interference in a district where owners of receivers using a single radio-frequency tuning stage have become accustomed to receive distant signals from weak stations fairly well, but where receiving conditions are altered by the establishment in that district of a powerful transmitting station. Receiving sets which have been getting signals of the order of 0.5 millivolt per meter, will then have impressed upon them signals of the order of 100 millivolts per meter. The unsuitability of such receivers for modern broadcasting conditions will be glaringly displayed, and listener dissatisfaction results. Yet radio progress, as pointed out in the previous discussion, depends upon the production of higher field strengths from broadcasting stations of increased power, whereby real service can be given to large areas.

In the case of the establishment of the Bound Brook station, it was found that the great majority of complaints came from owners of home-made sets. Few complaints were received from owners of factory-made sets, except those of the single radio-frequency tuning stage variety, and of the three highly damped radio-frequency tuning stage type. The detailed data on this point will be analyzed in another portion of this paper.

4. The Bound Brook, New Jersey, Experimental Broadcasting Station

When it became evident to the executives and engineers involved that the next major forward step in broadcasting involved the establishment of a high power broadcasting station, careful preliminary studies were made of the anticipated performance of a 50-kilowatt transmitter located in the neighborhood of New York City. Numerous apparently suitable sites were selected, and the field strength distribution around a station located at each of these sites and at various distances from the station was calculated and plotted in map form. It was found that many important conditions had to be met by any location to be finally selected as suitable. These conditions will not be given in this paper since they will appear in a forthcoming Institute paper.*

Ostensibly cooperative persons kindly suggested that the station be located at the tip of Montauk Point, Long Island, on a remote lightship, on the highest and most inaccessible peak of the Alleghany Mountains, or even on an anchored balloon high in the air. Suffice it to say that unsympathetic engineers did not regard these proposals as feasible either technically or economically.

The most desirable location for the station having been predetermined to be near Bound Brook, the station was built and placed in experimental operation for a week early in November, 1925. After certain modifications in the equipment had been completed it was again placed in experimental operation early in December, 1925, and has been transmitting since that time under the call letters 2XAR or WJZ.

As soon as the station had been in operation for a few days it was found that some interference was being created in a region which we may term the "interference area"—a roughly circular region centering on Bound Brook.

5. Establishment and Procedure of Interference Reduction Service

It was obvious to the engineers that the interference complained of could be reduced to negligible dimensions by suitable technical expedients. So far as is known, in every other case where a broadcasting station has been established, the listeners in that locality have in the main been permitted to discover for themselves how to eliminate the resulting interference. The managements of broadcasting stations have felt, perhaps properly, that their functions do not include educational campaigns on receiver construction and performance. However, it was believed that a demonstration of the usefulness of high power broadcasting was of such fundamental importance to the radio art that the management of the Bound Brook station was justified in going to unusual lengths in assisting the listeners who experienced difficulty in eliminating interference from that station, in order that practically the entire listener-community might be satisfied with the performance of the station. The causes of the interference, their correlation with receiver types, and the desirability of getting, at first hand, a cross-section of

*J. Weinberger, "The High Power Broadcasting Station of the Radio Corporation of America, at Bound Brook, New Jersey."

receiving conditions in 1925 and 1926 also were factors which led to the establishment of a special service for the benefit of the local listeners.

A qualified radio engineer, Mr. Bronson S. McCutchen, of Plainfield, New Jersey, was retained to direct the activities of sixteen skilled assistants who were suitably located in towns within the "interference area." These gentlemen were available to call on each complainant and, through actual demonstration, to prove to him that the interference could be reduced or eliminated by a suitable and simple addition of equipment to the existing receivers. No charge was made for this service to the listeners, nor was any equipment sold by the Radio Corporation of America or its representatives. The entire costs of the interference reduction service were borne by the Radio Corporation. In Appendix A, the geographical organization of the staff is given. At this point, I wish to express my appreciation of the intelligent way in which the gentlemen involved carried out their duties.

Copies of all complaints received by the Department of Commerce were forwarded to the representatives of station WJZ, and this cooperation by the Department was extremely helpful. These complaints, together with those received by the station directly, were then handled in accordance with the following routine:

(*a*) A pamphlet entitled, "Reducing Interference from a Near-by Broadcasting Station of High Power" was at once mailed to the complainant. Pertinent excerpts of this pamphlet, showing the recommended methods, are given in Appendix B. While elementary, this material is included because it may be of help to other station executives facing similar problems. The simplicity and inexpensiveness of the recommended methods are obvious. The methods described in the pamphlet, as well as similar methods, also received wide publicity through the cooperation of the radio editors of local newspapers.

(*b*) The interference reduction service telephoned the complainant shortly thereafter to determine whether the trouble still existed or whether it had been cleared by the complainant himself using the methods recommended in the pamphlet or by other methods. This avoided unnecessary visits to persons no longer experiencing interference. It was also necessary to telephone in advance because of the difficulty in making night appointments with the listeners.

(*c*) If the interference still existed, a call was made by a member of the interference reduction service who determined the best method of eliminating the interference. After demonstration of this method to the listener, he was invited voluntarily to fill out and sign a blank stating his opinion of the results obtained. It was hoped to gather valuable statistical data from these blanks, a typical one of which is reproduced in Appendix C.

The results of these activities were extremely gratifying. Although an unusually severe winter rendered the New Jersey roads almost impassable for considerable periods during December, 1925, and January and February, 1926, thus rendering visits to complainants very arduous, the number of complaints on hand never became so great as to be unmanageable. In Figure 1

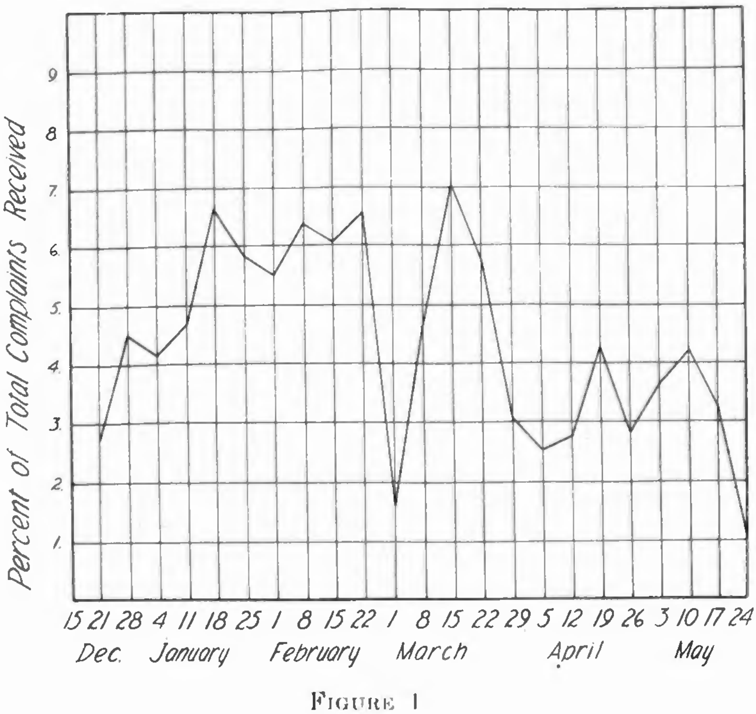

FIGURE 1

are given the percentages of the total complaints received each week for a total of 23 weeks from December 15, 1925, to May 24, 1926. The complaints built up rapidly after the first week of December, 1925, when the station began program transmission. About 6 per cent of the total complaints were then received per week during January, February, and March, 1926. During April and early May, 1926, about 3.5 per cent were received per week, constituting an appreciable reduction. Thereafter the complaints practically disappeared. During June and July, 1926, complaints were received at the low rate of one every week or two. A classification of the relative proportions of the various methods whereby the complaints were cleared will be given at the end of this paper.

It is interesting to note that this work constitutes in all likelihood the most extended systematic interference study so far carried out in the homes of the listeners.

6. Statistical Data on Broadcast Station Interference

As pointed out in Section 1 of this paper, the primary factors in interference with broadcast reception are field strength, receiver selectivity, and certain psychological influences. The results of the interference reduction service activities have been systematically tabulated in such a way as to enable an analysis of the effect of these different factors.*

(*a*) *Dependence of Complaints on Field Strength.* The complaints received were first classified, using percentage of total complaints against field strength at the corresponding receiving stations. The results are given graphically in Figure 2. The

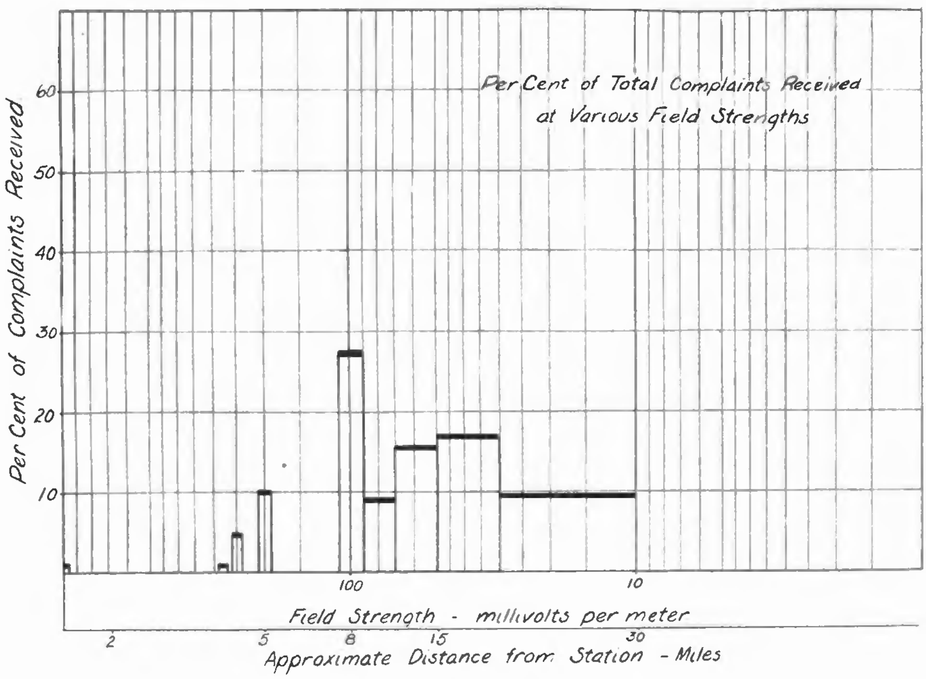

Figure 2

approximate distances from the station are also plotted along the ordinate axis as well as the field strengths.

The average density of population within 6 or 8 miles of the

*For which I desire to express my thanks to Messrs. T. A. Smith and G. Rodwin who carried out this work under my direction, and with numerous helpful suggestions from Mr. J. Weinberger.

station is small (which was one reason for the choice of the station location). In consequence the percentage of complaints within 6 miles of the station is also small, a condition which would presumably exist for any station judiciously located. In order to avoid excessive numbers of complaints, it is important in the present stage of the receiver art, to avoid locating new 50-kilowatt stations within 5 or 10 miles of moderately populous communities, accustomed to powerful signals, and to keep correspondingly further away from large cities.

The highest percentage of the total complaints (28 per cent) occurs about 8 miles from the station in the zone corresponding to the 90 to 110-millivolt-per-meter field strengths. The percentage of total complaints drops to less than 10 per cent for the zone having field strengths from 10 to 30 millivolts-per-meter (about 20 to 30 miles from the station).

Beyond this zone there are practically no complaints.

The same data are presented in another form in Figure 3. Percentages *of total population* residing in localities experiencing

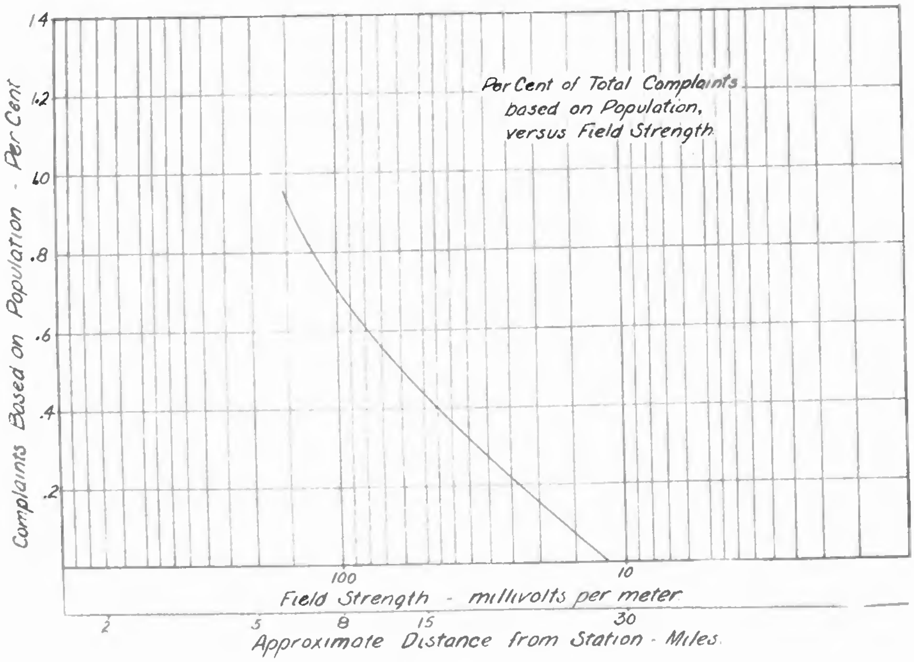

FIGURE 3

a certain field strength and complaining thereof are plotted against field strength (and corresponding distance from the Bound Brook station). The curve has necessarily been smoothed judiciously by the draftsman but is closely correct. It will be seen that for a field strength of about 170 millivolts-per-meter (at a distance of approximately 6 miles from the station), only 1 per cent of the total population protested. At a field strength of 10 millivolts-per-meter (or a distance of 30 miles), complaints (except of the most unusual sort) disappear. These data are roughly applicable to similarly located 5-kilowatt stations by dividing distances by 3, and to 0.5-kilowatt stations by dividing distances by 10.

These figures are no doubt astonishing to those who have heard lurid reports of the overwhelming percentages of complainants, supposedly numbering hundreds of thousands of individuals. They could have been anticipated, however, by considering that the population density in the area around Bound Brook (where field strengths in excess of 60 millivolts-per-meter are produced) is about 700 persons per square mile, whereas the population density in New York City, in the neighborhood of numerous 0.5- to 5-kilowatt broadcasting stations is roughly 400 times greater or 280,000 persons per square mile. Yet there are few interference complaints from New York City listeners. Similarly there were few complaints from the important city of Newark, although its population is large (415,000 persons), because of the long experience of the Newark listeners in handling the powerful signals of a 0.5-kilowatt station in that city.

An interesting comparison can be made between Figures 4 and 5. The former gives calculated lines of equal field strength in millivolts-per-meter in the region around Bound Brook. The latter gives lines of equal percentage of complainants (referred to total population). These have been termed "isoplaint lines." The isofield and isoplaint lines are seen to be generally similar, as was to be expected. Field strengths of 20 millivolts-per-meter lead to total complaints from about 0.1 per cent or 1/1000th of total population, and may be considered to be innocuous even in the present youthful state of the art and for the relatively non-selective receivers frequently used in districts unaccustomed to strong signals. Of course highly selective receivers can do much better, and are a definite necessity as broadcast service evolves and becomes more reliable through the furnishing of adequate signals to substantially the entire listening public.

Figure 5 also shows the interesting fact that only a small portion of the area of the state of New Jersey experienced interference from the Bound Brook station. This was confirmed by the fact that 70 per cent of the New Jersey mail, even in December, 1925, and January, 1926 (at the height of the psychological (crisis, was favorable. The New Jersey listener response at present is, as previously stated, substantially free from complaints and, in fact, highly appreciative of the excellent service rendered through summer atmospheric disturbances.

(*b*) *Dependence of Complaints on Receiver Selectivity.* In each case where demonstrations of interference reduction were given to the listener, the type of receiver experiencing the interference

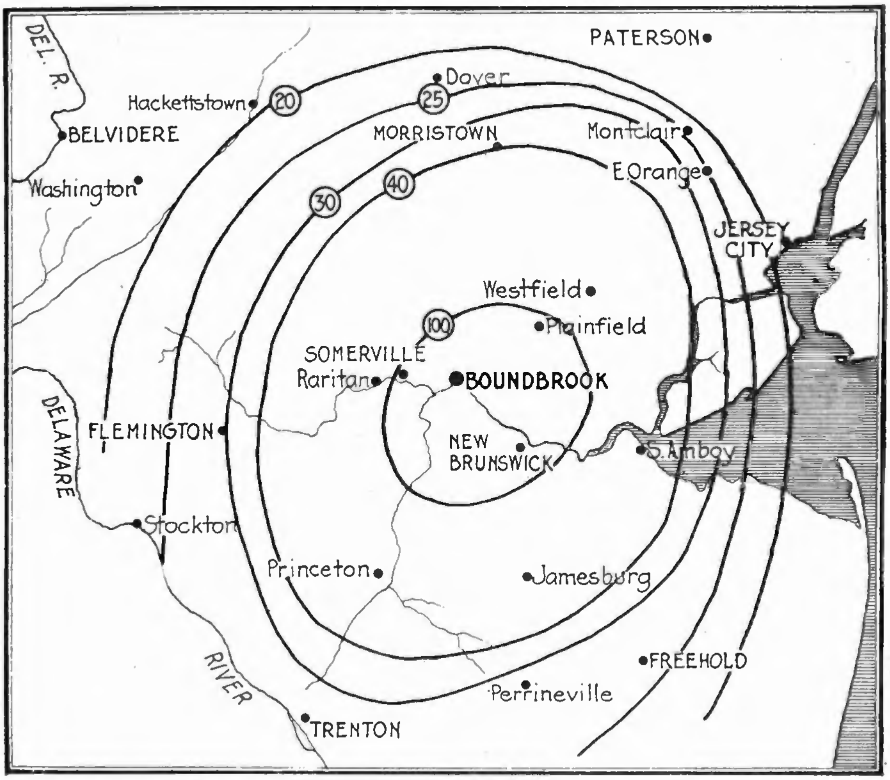

FIGURE 4—Lines of Equal Field Strength

was noted on the report blank. The percentages of each type of set found are given in Table 4.

TABLE 4

PERCENTAGES OF SETS VISITED, EXPERIENCING INTERFERENCE FROM NEARBY HIGH-POWER STATION

Single-circuit	59.0 per cent
Two-circuit	12.1 per cent
Three-circuit	27.3 per cent
Four-circuit	0.4 per cent
Super-heterodynes (including home-made)	1.2 per cent

It is seen that single-circuit receivers were most open to interference, and actually nearly 60 per cent of the instances of interference from Bound Brook were found in receivers of this type. The primary usefulness of such receivers is found in large territories where radio interference is lighter and will probably remain so.

Next came the two-circuit and three-circuit receivers. Here it was found that more than twice as many three-circuit receivers experienced interference as two-circuit receivers. However, the explanations are simple. In the first place, very few two-circuit receivers are used nowadays. In the second place, the two-circuit receivers in general utilized tuning circuits of average quality and damping. In the third place, the three-circuit re-

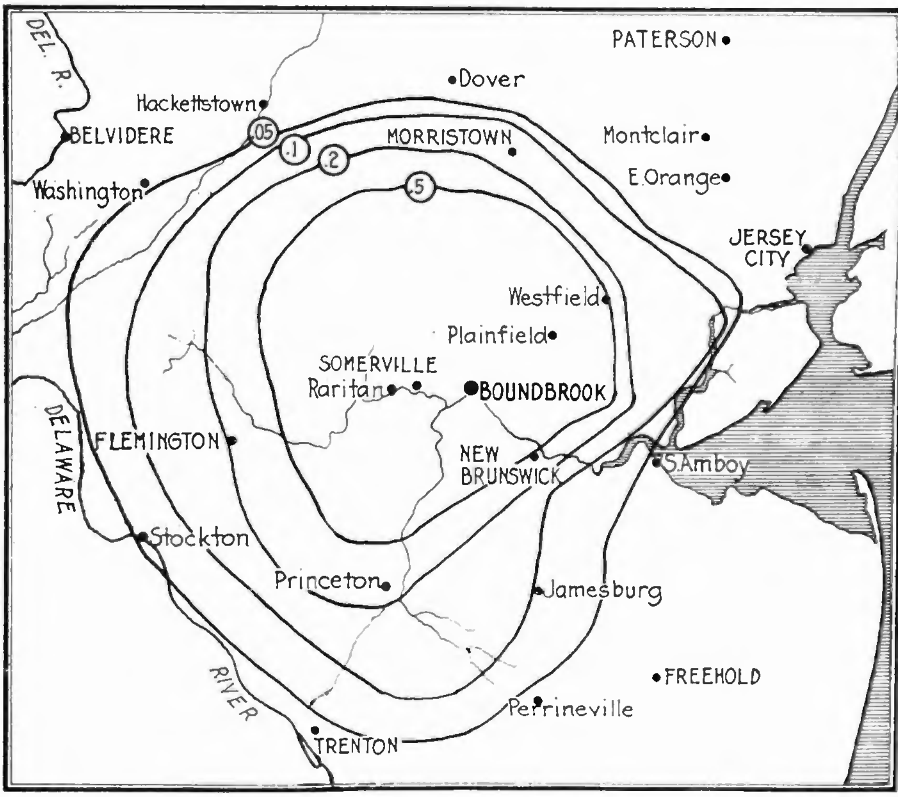

Figure 5—Lines of Equal Percentage of Complaints

ceivers (which were largely of the unneutralized factory-built "tuned radio-frequency" types), utilized alleged tuning circuits which were artificially damped to prevent self-oscillation. As a result, the high losses of the various circuits broadened the tuning and lowered the selectivity to the point of making such so-called three-circuit receivers quite open to interference. This is a point to be borne in mind by radio engineers interested in the progress of broadcasting.

As was to be expected, only negligible percentages of super-heterodyne receivers (including home-made super-heterodynes), and four-circuit receivers experienced interference. There was an early impression among some of the prematurely disconsolate listeners that the interference problem presented was insuperable, and some wrote in lugubrious fashion assuring the station officials that the interference could not be eliminated by any conceivable remedy. Quite a volume of propaganda to this effect was also circulated at one time.

To study in greater detail the performance of the various types of receivers, Figures 6, 7, and 8 were prepared. These show the complaining percentages *of the total population* for various field strengths when using single-circuit, two-circuit, and

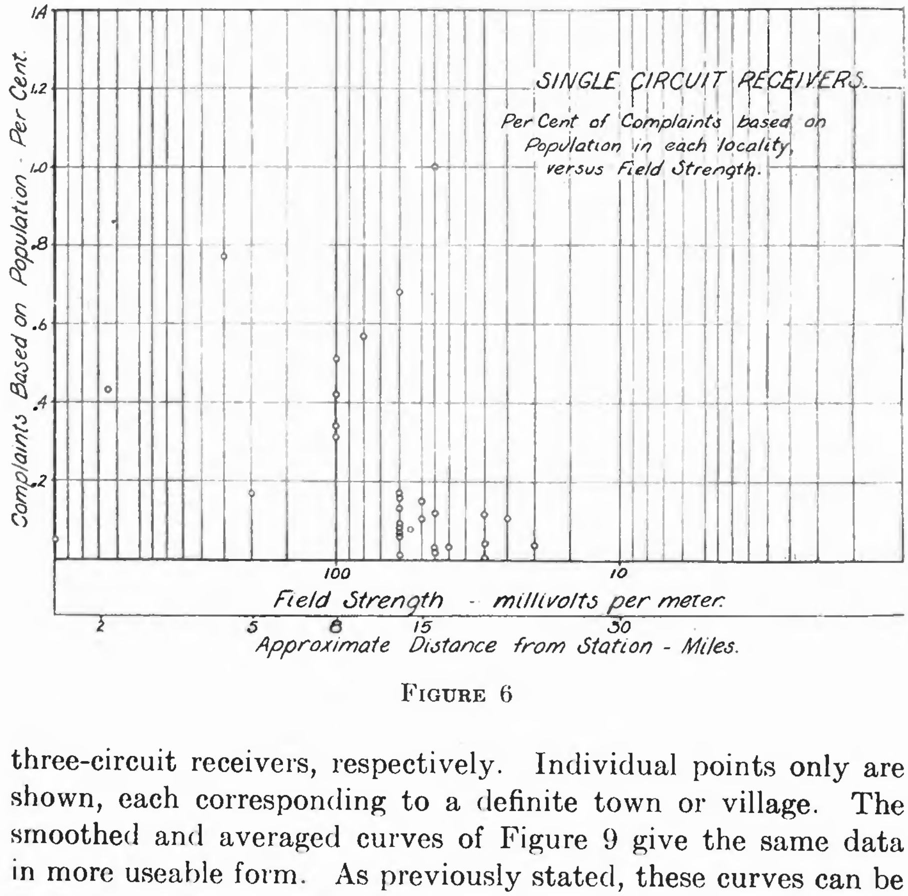

FIGURE 6

three-circuit receivers, respectively. Individual points only are shown, each corresponding to a definite town or village. The smoothed and averaged curves of Figure 9 give the same data in more useable form. As previously stated, these curves can be used with approximate correctness for similarly located 5-kilowatt stations by dividing distances by 3, and for 0.5-kilowatt stations by dividing by 10.

Again it must be remembered that what are here termed "three-circuit receivers" are widely current, but poorly selective devices. They do not include neutralized three-circuit receivers having high-quality tuning circuits, from the users of which practically no complaints were received. Clearly only superheterodyne receivers and high-grade three-circuit receivers fully meet modern selectivity requirements in the vicinity of average modern broadcasting stations.

(c) *Dependence of Complaints on Psychological Factors.* A rather astonishing number of listeners will sign a vigorously protesting petition more or less as a favor to a friend, or for some other inherently inappropriate reason. Excessive caution leads some persons having no radio sets to protest vehemently. For example, the following were among the letters of this sort received:

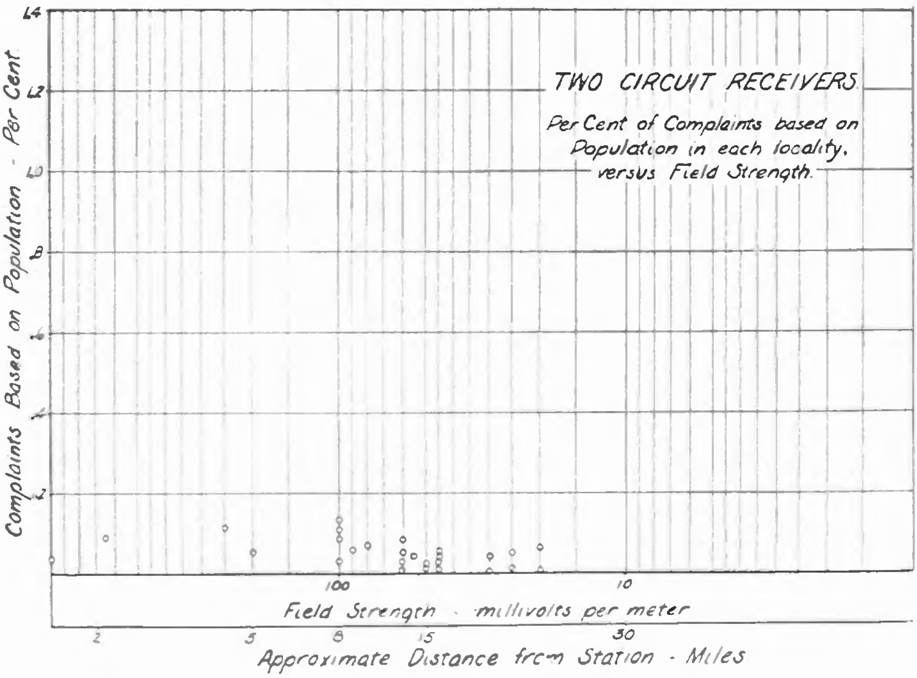

FIGURE 7

"Have no radio, but if any trouble ensues from WJZ, will come back at you for improvement."

"——— petition was signed by Mr. ———. He has no radio but he thinks perhaps some day he will have one and he wouldn't like any interference."

To our regret, we are bound to confess that we were unable to eliminate potential interference perhaps to be experienced in the distant future by prospective radio listeners using poorly selective receivers. However, there was a redeeming and bright side to the situation in the form of splendid letters of enthusiastic commendation which were received from great groups of listeners.*

*Some typical and interesting examples of these are given in my statement before the Committee on the Merchant Marine and Fisheries, House of Representatives, 69th Congress, First Session, on H. R. 5589 (Government Printing Office, Washington).

7. Clearing of Interference Complaints

A compilation of the disposition of complaints during each week has been made, covering the twenty-three weeks from December 15, 1925 to May 24, 1926. It is presented in graphical form in Figure 10. All the space shown in clear white above the shaded portions represents the percentage of listeners who were entirely satisfied after the demonstration visit. "Partly satisfied" listeners were those who agreed the interference could be eliminated, but had some adverse comment or expressed reserva-

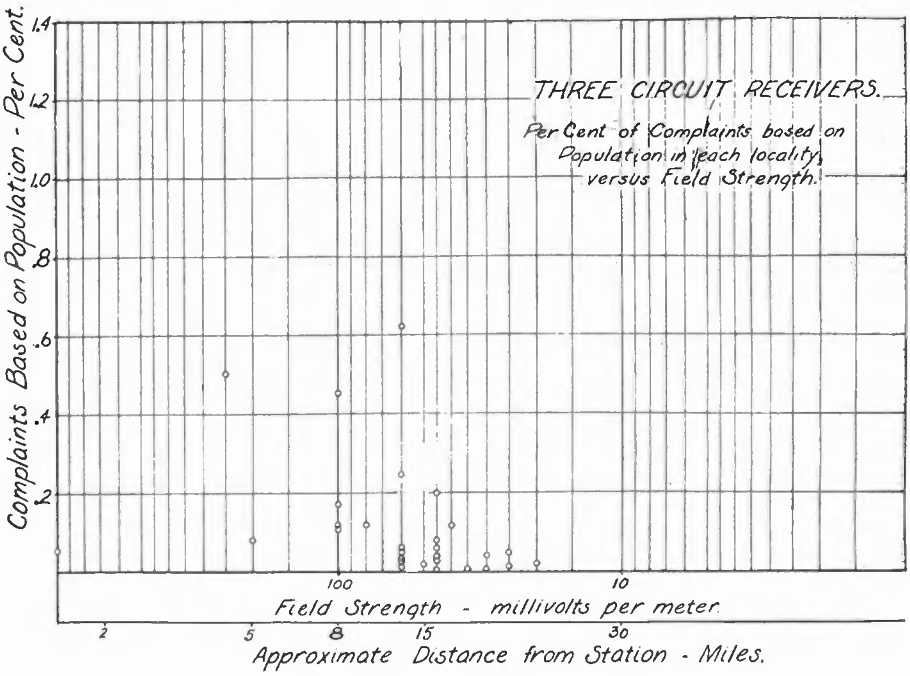

Figure 8

tion as to the necessity for eliminating it. Broadly speaking, such listeners felt that the responsibility for eliminable interference rested entirely or largely on the transmitting station and not at all on the receiving station. In view of the wide range of selectivity of receivers, this is an untenable and inequitable conclusion. The responsibility for the interference experienced by the user of a poorly selective receiver cannot properly rest on the transmitting station. A considerable number of listeners, increasing as time went on, cleared up their own trouble. Others, becoming convinced by their friends or local dealers that their sets were at fault, purchased new and better sets of adequate selectivity. This group grew rapidly during the Spring of 1926, and represents a hastened radio evolutionary process.

The "irrelevant" class of complainants included some anomalous cases. For instance, there were found persons who never had owned a receiver, others who had receivers in such lamentable condition that interference made the normal signals sound no worse, and still others who, though protesting, were unwilling to accept proffered assistance. There were also a number of people who had originally complained, but who had since decided

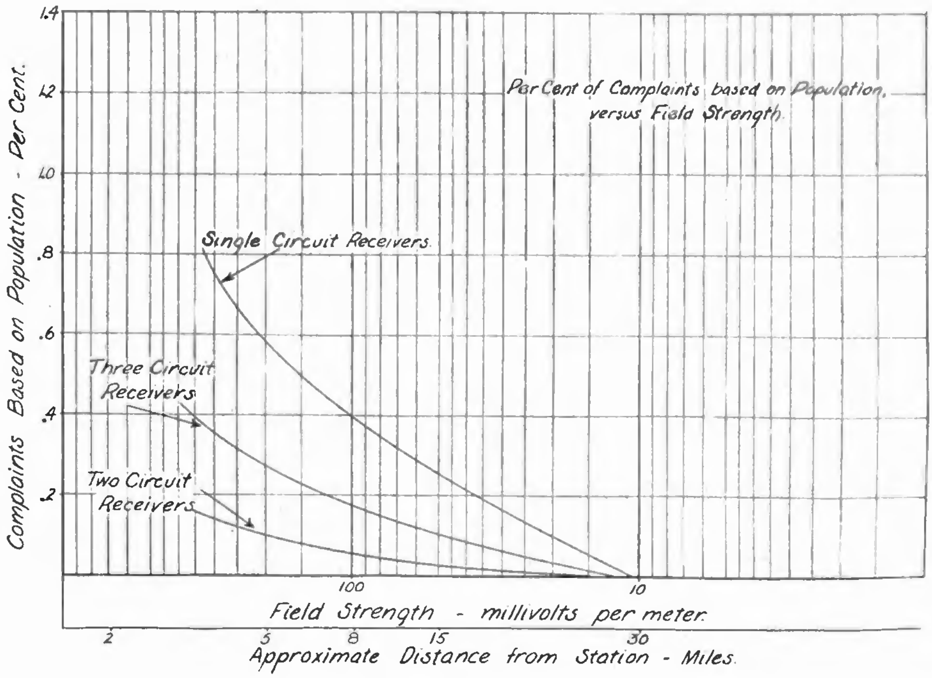

FIGURE 9

that they had no real cause for complaint. Altogether a very human situation was disclosed.

The outstanding features were the increasingly rapid elimination of the interference by the listeners themselves as time went on, and the reduction in the proportion of partly satisfied and dissatisfied complainants.

As will be seen from Table 5, the total number of complaints was less than 1,500. Only a little over 2 per cent of these remained dissatisfied, which is a most satisfactory result. It may safely be stated that these figures are far below the impressions which might have been gained from the press at the height of the initial dissatisfaction when interference from the Bound Brook station was first experienced. Sensational reports under such conditions obviously require liberal discounts before acceptance.

The summarized disposition of the complaints is given

TABLE 5

Disposition of Complaints	Number		Percentages
Total Complaints	1473		100%
Cleared Own Trouble	97		6.6
Bought New Set	109		7.4
Partly Satisfied	83		5.6
Dissatisfied	34		2.3
Satisfied by Visit—Series Trap	706	936	63.6
Shunt Trap	100		
Both	22		
Learning to Tune	32		
Other Method	76		
Irrevelant—Have no Set	15	214	14.5
No Demonstration Desired	41		
Have no Complaint Now	86		
Out of Order or Have Sold Set	72		

graphically in Figure 11. It should be added that, during the total period covered by the preceding study, there were received

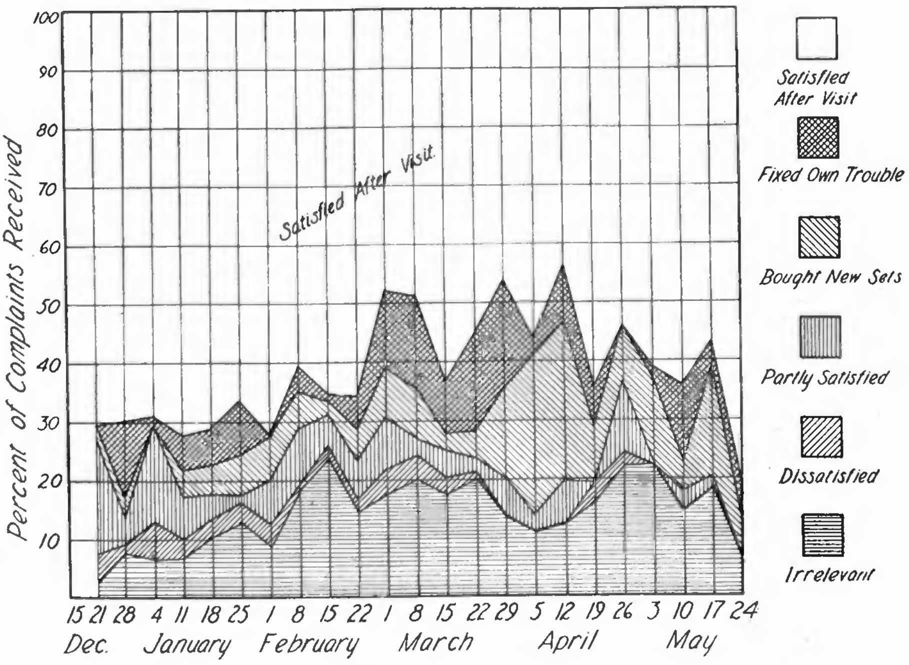

FIGURE 10

by the station approximately one hundred times as many favorable letters (from the entire United States) as complaints from the "interference area."

In other words, only a few *hundredths of one per cent* of the total listeners to the station remained dissatisfied because of interference. Certainly the proportion of dissatisfied listeners in the radio audience of a high-power broadcasting station is less than one out of every thousand, which state of affairs represents an overwhelming verdict in favor of such broadcasting and a degree

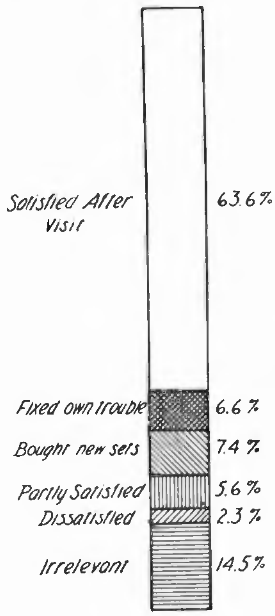

FIGURE 11

of public favor probably unattained by any other entertainment or educational enterprise.

It is not appropriate in this paper to present a study of the general comments of the listeners relative to the station nor their reactions toward the reliability of service given even at considerable distances. In summary, the listener response is exactly what would be expected from the technical considerations presented above and justifies the further development of high-power broadcasting, which, as is now clear, can safely proceed free from the imaginary bugbear of supposedly serious and unavoidable interference.

SUMMARY: The factors in station interference with broadcast reception, namely, signal field strength, receiver selectivity, and psychological reactions of the listeners, are analyzed.

Statistical data correlating these factors with interference complaints from listeners in the vicinity of the 50-kilowatt broadcasting transmitter at Bound Brook, New Jersey (WJZ), are then presented, these data being the results of a survey by a special interference reduction service.

The clearing-up of the complaints by this service, using simple methods which are described, indicates the feasibility of high-power broadcasting stations, as well as the necessity for them because of the requirement of reliable broadcasting service over large areas.

APPENDIX A

The Special Interference Reduction Service was under the general direction of Mr. Bronson S. McCutchen, assisted by Mr. C. V. Sandell, both of Plainfield, New Jersey.

The following gentlemen handled the localities mentioned:

Mr. W. J. Freuler	Bound Brook and Somerville
Messrs. W. L. Shepard and Walter G. Wright	New Brunswick
Mr. C. Brokaw	Dunellen, New Market, and vicinity
Mr. J. C. McNiece	Trenton, Princeton, Hopewell, Lambertville, Hightstown, and vicinity
Messrs. E. S. Cooke, T. L. Worth, L. Bullman, G. A. Ewald, and D. D. Porter	Plainfield and vicinity
Messrs. T. C. Rogers and R. U. S. Hillier	Westfield, Cranford, Garwood, and vicinity
Mr. R. W. Muller	Perth Amboy, South Amboy, Rahway, Metuchen, and vicinity
Messrs. Lloyd Snell and J. P. McClary	On general detail, covering remote points, outlying farms, and the like.

The above indicates the general type of geographical distribution of staff desirable in such surveys.

APPENDIX B

"People living very near to a powerful broadcasting station may find that this station comes in loudly enough to interfere with reception of other stations even when the receiving set is most carefully tuned to the station that they want to hear. Particularly is this the case in large cities like New York (which city has no less than twenty-two broadcasting stations, operating on powers up to 5,000 watts and in general with many hundreds of thousands of people living within a few miles of each of these stations). With a receiver having poor selectivity, it may be that the nearest or most powerful station will be heard no matter how the set is tuned, but with a receiver of very great selectivity, only perhaps two or three stations of very nearly the same wave-length as the local station will be interfered with. Thus the seriousness of the interference depends upon the selectivity of the receiver, the distance from the interfering station, and the power of the latter. In the following, the methods of eliminating or greatly reducing such interference at minimum expense and trouble are given.

"Fortunately, in most cases the interference may be reduced to a point where it is unobjectionable by the use of one or more wave traps. These are simple devices that can be bought fairly cheaply, and can be made at home very easily for almost no cost beyond that of a variable condenser.

"In the great majority of cases the interference can be eliminated by the use of what is called a *series wave trap.*

"The series wave trap has two binding posts, one of which is connected to the antenna post of the receiver, and the other is connected to the antenna. (The antenna is thus disconnected from the set, and the signals have to go through the trap to reach the set. This is why it is called a series trap.) See Figure 1, which shows how to connect a series trap. In addi-

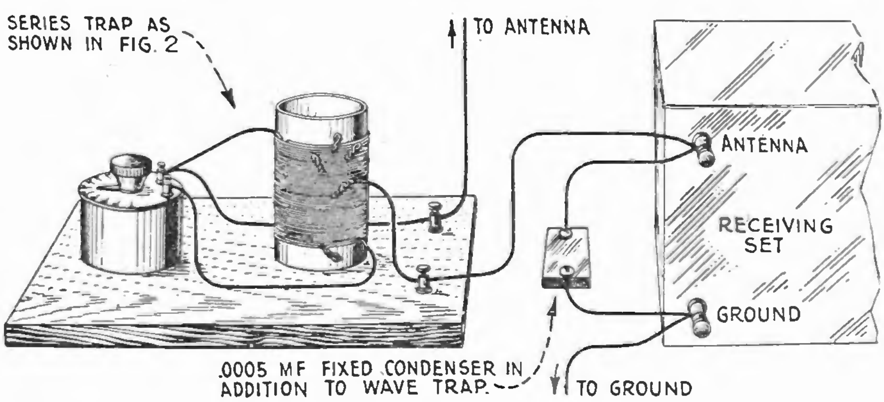

FIGURE 1

tion to the wave trap a .0005 microfarad fixed condenser should be connected across the antenna and ground binding posts of the receiving set.

"The series trap offers a very great obstruction to the interfering signal and thus reduces the amount that gets through the set, but offers comparatively little obstruction to the desired signals.

CONSTRUCTION OF A SERIES WAVE TRAP

"A satisfactory series trap can be made of the following parts: one .0005 microfarad variable condenser, one cylindrical cardboard cover off an old dry cell (about 2½ inches in diameter), a spool of Number 24 double-cotton covered wire, a small board to mount the parts on, two binding posts or Fahnestock clips for connecting to antenna and to receiving set. (See Figure 2.) Wind a coil with the wire on the cardboard tube, with the turns close together, about 60 turns. Twist a few loops in the wire for connections at several points, say turns number 5, 10, 18, and 30, and also at the last turn.

"Remove the cotton covering from the wire on the coil at these points, so that connection can be made to any one of them by means of the flexible piece of wire marked 'A.' Such places, where connection may be made to certain turns on the coil, are called 'taps.'

"Mount the variable condenser and coil on a wooden board, provided with two binding posts as shown in Figure 2. Connect

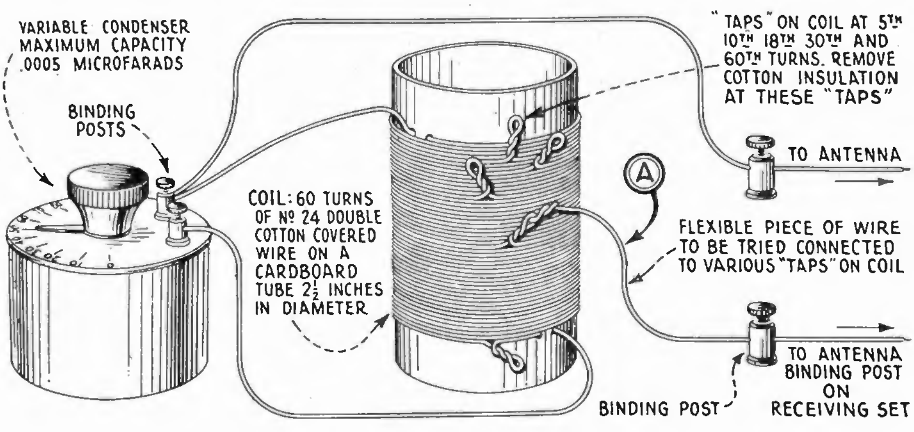

FIGURE 2

the first and last turns of the coil to the variable condenser, as shown in the figure. Then connect one of the binding posts on the board to one of the binding posts on the variable condenser, as shown in the figure. To the other binding post connect a piece of flexible wire (the No. 24 cotton covered wire can be used, but a piece of stranded flexible, insulated wire would be better) and remove the insulation from the free end so that it may be connected to one of the 'taps' which were made on the coil, as will be described in the second paragraph below.

Operation

"Remove the antenna wire from the 'antenna' binding post on your receiving set and connect it to the right-hand binding post on the wave trap, and connect the left-hand binding post on the wave trap to the binding post on your receiver to which the antenna wire previously went (see the figure). Next, connect the .0005 microfarad fixed condenser between the antenna and ground binding posts of the receiving set.

"Now twist the 'flexible' wire connection on the wave trap, around the 'tap' at the 30th turn, being sure to make a good connection. Then start up the receiving set, set the wave trap condenser pointer at zero, and tune for some desired station. This may come in at a different place on the receiver dials from those found previously. If the interfering station is now heard along with the desired one, turn the knob of the wave trap condenser very slowly until the interference disappears.

"If the desired station goes out along with the interfering one, change the flexible connection on the wave trap to the 18th turn, and repeat the operation. If the same thing still occurs, try 10 turns and 5 turns in succession. In each case, before changing the tap connection, try re-tuning or re-adjusting your receiver, to see whether or not the desired station can be brought in, and also re-adjusting the wave trap slightly to keep out the interfering signal. A certain amount of back and forth adjustment between the receiver and wave trap may be necessary.

"If with the tap connection on the 30th turn the interfering signal can still be heard under the desired one, when the wave trap is tuned, to give its maximum reduction of interference, change the tap connection to the 60th turn and repeat the operation described above.

"A certain amount of experimenting will be necessary, in order to learn the effect of the wave trap on the receiver adjustments, and in order to learn how to adjust the wave trap as well as what tap on the coil is best for your particular receiving set and antenna.

"If the trap does not work when first made and connected, inspect it carefully to see that it was made in accordance with the foregoing instructions. Traps such as the one described have actually been made, and have been used successfully with many hundreds of receivers, of the widest variety of manufacture.

Loop Sets

"Less interference will be found usually when using loop sets because the loop is more selective than an antenna. Also the loop can be turned into a position where the interference is very much reduced. And finally, a wave trap can easily be made that will cause a great decrease in interference, as follows:

"Wind about 20 turns of double-cotton-covered Number 24 wire in a bunch around a regular size 45-volt 'B' battery (which is about 7 inches by 8 inches). Slip the coil off and tie or tape it together to keep from falling apart. Connect it to a variable condenser. Then hold the coil near the loop and adjust condenser to make the interference as little as possible."

APPENDIX C

Radio Corporation of America

Special Interference Reduction Service

(The following to be filled in by the Radio Corporation of America Representatives)

A receiving set located at New Brunswick ....
(Town) (County) (State)

and belonging to Mr L P Janeway 192 Livingston Ave
(Name of owner or listener)

has experienced interference from W.J.Z. .... at Bound Brook N. J.
(Station call letters) (Town, State)

The type of Receiver is ...., 5 Tube neutrodyne ....
(Name of maker) (Model or Type Number)

Successful Method of Eliminating Interference Series trap ....
(Series trap, shunt trap, series and shunt

....
traps, link circuit, shorter antenna, rotating set, or other methods to be mentioned)

Date of call of RCA representative April ....., 8 ....
(Month) (Day)

Name of RCA representative Walter L. Shepard ....

....

In order to get the opinion of a large number of set owners as to the success of the interference elimination methods demonstrated to them under field conditions, it will be greatly appreciated if the following report will be filled in.

An attempt was made to eliminate interference at my home from the above station, and the results of the demonstration were successful in eliminating the trouble. Thanking you for the assistance

....

....

....

....

(Signed) L P Janeway ....

COMBINED ELECTROMAGNETIC AND ELECTROSTATIC COUPLING AND SOME USES OF THE COMBINATION

By

Edward H. Loftin and S. Young White

The energy transfer characteristic of the normal forms of coupling employed in radio receivers is well known to all of us and in the usual forms transfers energy more readily at higher frequency than lower. This characteristic makes for higher efficiency and consequently greater tendency towards instability of commercial vacuum tube receivers on the high-frequency portion of the broadcast band.

Our investigations of the combination of electromagnetic and electrostatic couplings were for the purpose of removing this objectionable characteristic, and we undertake in this paper to outline some of the more salient of our observations during these investigations, as well as some uses made of the combination. One of these features is the use of a coupling means which has its frequency characteristic reversed in that its most efficient energy transfer takes place at the lowest frequency. By suitably combining this coupling means with a coupling having the usual characteristic, we are enabled to so design the combined coupling that the total energy transfer will vary in any desired manner with frequency.

Starting in an elementary way, let us consider the various voltages existing in the oscillatory circuit shown in Figure 1. With an impressed voltage E_I across both the inductive leg and the capacitive leg, any desired fraction of this voltage may be obtained by tapping the inductive leg, resulting in a voltage E_L, which increases in value with the number of turns in the tapped portion of the inductance. Similarly the capacity leg may be tapped by dividing its capacity into two series portions, as is shown by condensers C_1 and C_2. Assuming a resonant condition, the voltage developed across C_2 will be inversely proportional to its ratio with C_1. For example, if C_1 and C_2 are equal, then the voltage E_{C2} will be just half the impressed voltage E_I.

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If C_2 is larger than C_1 it will have proportionally less voltage across it, and vice versa.

Keeping these voltage relations in mind, let us examine Figure 2. In this circuit C_1 has been made variable, while C_2 remains fixed. It is evident that C_1 has now become the variable tuning condenser for the system. However, in varying C_1 we find that we continuously vary its ratio with C_2. The larger C_1 becomes in its relation to C_2, the higher will be the voltage E_{C2}. However, when C_1 is maximum, the frequency to which the system is resonant is minimum, and we have the condition that

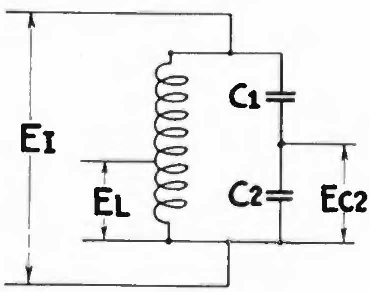

FIGURE 1

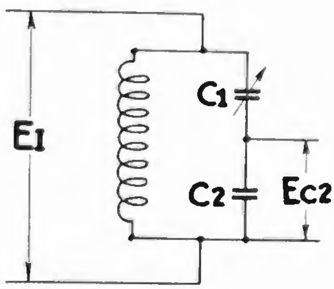

FIGURE 2

the voltage E_{C2} is maximum when the frequency is minimum, and this voltage can be made any desired portion of E_1 by adjusting the capacity ratio of C_2 and C_1.

This point might be brought out a little more clearly by a specific example. Assuming the condenser C_1 is a variable with a minimum capacity of 50 $\mu.\mu.$f., and a maximum of 500 $\mu.\mu.$f., and that C_2 is a fixed value of 5,000 $\mu.\mu.$f., let us examine the voltage developed across C_2. At the maximum frequency C_1 will be at its minimum value—50 $\mu.\mu.$f. C_2 is now 100 times as large and will have roughly 1 percent of the voltage E_1 across it. At the lowest frequency C_1 will be 500 $\mu.\mu.$f., and the value of C_2, remaining at 5,000 $\mu.\mu.$f., will now be ten times as large as C_1, and voltage E_{C2} will be roughly 10 percent of E_I.

One practical application of this effect is shown in Figure 3, where the arrangement of Figure 2 is used as a portion of an interstage coupling for a three-electrode vacuum tube amplifier system of the so-called tuned radio frequency type. The principal addition lies in the use of a coil $L1$, through which the output of the tube passes before reaching the branch point of the two condensers $C1$-$C2$. The energy transfer due to $L1$ has the normal characteristic of increasing with an increase of frequency, while the coupling due to the varying reactance of $C2$ with variations of tuning condenser $C1$ has the reverse characteristic.

It is obvious that the electromagnetic coupling, due to $L1$ may be combined with the electrostatic coupling due to $C2$ in either an opposing or an aiding phase. If they are combined in an opposing phase and are of approximately equal coupling effects, it is found that at the minimum frequency, the electrostatic coupling will predominate, while at maximum frequency the electromagnetic coupling will predominate. Thus there will be some point in the frequency band where they will be equal, and since they oppose, a balance will obtain at this point and no energy transfer will take place. It is, therefore, obvious that

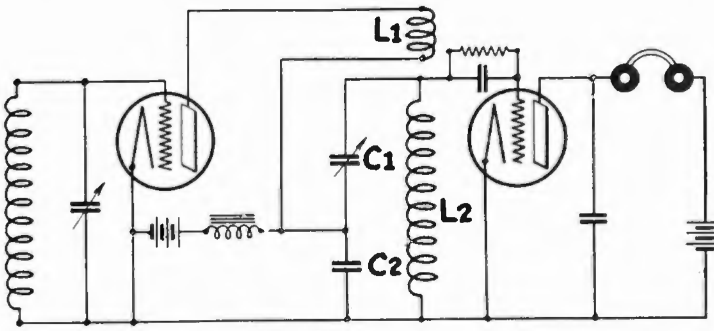

FIGURE 3

an adjustment of this kind would be of no value in receivers which must operate equally well throughout a wide range of frequencies.

To satisfy the requirements of receivers that must cover wide ranges of frequencies, such as broadcast receivers covering the broadcast band, we have found that by combining electromagnetic and electrostatic couplings to transfer energy in phase, and using at the same time the reverse characteristics of these two couplings properly adjusted, most satisfactory results are obtained in the production of a total energy transfer, which will, if desired and by proper adjustment, increase with frequency increase, decrease with frequency increase, or remain substantially constant throughout the frequency band. Figure 4 is illustrative of the manner in which the variable characteristic of electromagnetic coupling is combined with the reverse frequency characteristic of the variable electrostatic coupling, the figure showing how we obtain an overall energy transfer which can be made substantially constant throughout a wide range of frequencies (f). In Figure 4, the curve $L1$ represents the variation of energy (w) transfer with the electromagnetic coupling and the curve $C2$ a predetermined variation of energy transfer with the electrostatic coupling, and the dotted line represents the in-phase combination of the two. The portion below *f* represents a reverse phase effect of *C*2.

Again considering Figure 3, we find that by judicious proportioning of constants we can so adjust the coupling that at any point throughout the frequency range there is the correct amount of inductive reactance in the plate circuit to maintain the tube in a condition of critical regeneration. The tube can also be made to oscillate or to regenerate slightly throughout the band, as desired. It will be noted that the plate circuit is energized through a radio frequency choke. Any actual design

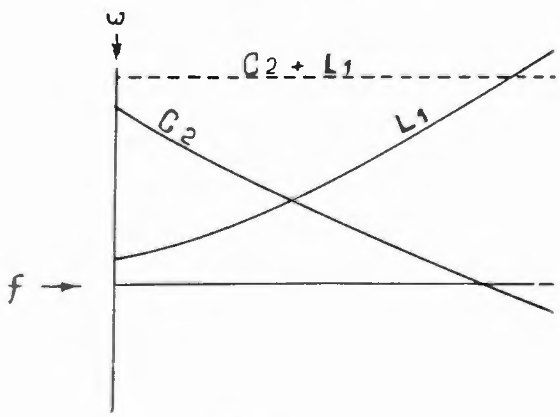

FIGURE 4

of this type of receiver must take into consideration the amount and phasing of stray feedbacks, if operation with extreme regeneration is required. The frequency band covered by this combination is quite large, larger than usual, due to extreme loose coupling at the highest frequencies.

A commercial application of the coupling is shown in Figure 5, and it will be noted that the system is similar to that described in Figure 3, with the exception of condenser *C*3.

The principal cause of oscillation in a radio frequency amplifier system is feedback through the capacity between electrodes of the tube. It is necessary that this feedback energy be in phase with the impressed grid voltage in order to produce regeneration and oscillation. It has been found that this positive feedback occurs only when the plate circuit is predominantly inductively reactive. If the plate circuit reactance is predominantly capacitive, energy will also be fed back through the tube capacity, but in a negative phase. However, if the inductive and capacitive reactances of the plate circuit are equal, they create a non-reactive condition leaving only a resistive plate circuit, which will not feed back through the tube capacity in either sense.

When this non-reactive condition exists, the plate circuit becomes quite independent of the tube characteristics, since no feedback can occur through the tube capacity. In actual practice, commercial models are designed for this condition so that tubes of any type or make can be used with no tendency toward regeneration or oscillation.

In Figure 5 the condenser $C3$ is in series with the plate to provide the required capacity reactance to balance the inductive reactance due to the coupling means. Since the capacity of $C3$ is fixed, its reactance varies inversely with the frequency, so it

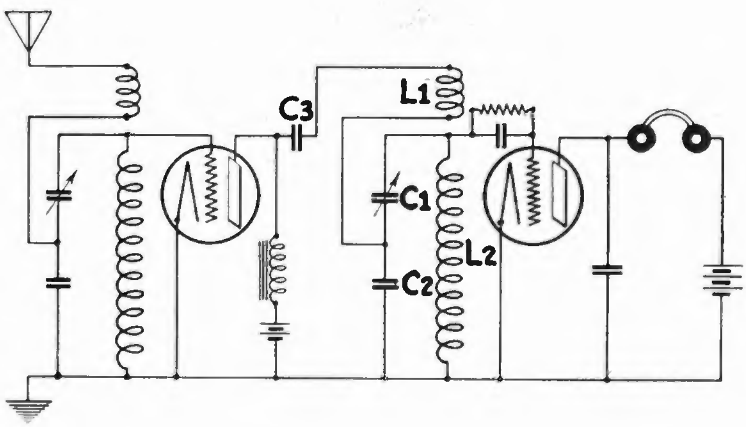

FIGURE 5

is necessary to design the coupling to provide an inductive reaction which also varies inversely as the frequency, and to the same degree. This is accomplished by properly proportioning the couplings and values of C_1, C_2, C_3, L_1, and L_2. In actual practice, it is occasionally found desirable to leave the plate circuit with slight predominance of capacitive reactance, since under these conditions a slight negative feedback will exist in the tube, which will oppose any stray positive interstage feedbacks. In other words, the relative values of C_1, C_2, C_3, L_1 and L_2, vary in different styles of assemblies.

In Figure 5 the automatic variation of the antenna coupling is also employed. This allows the coupling at the highest frequency to be quite loose, which is found to widen the frequency band covered by the tuned circuit associated with the antenna. The so-called absorption hump, which occurs when the antenna tune falls in the reception band, is also much reduced in effect.

A variation of the circuit is shown in Figure 6, where it is used to couple the plate circuit of a regenerative detector directly to the grid circuit, to produce either regeneration or oscillation throughout the band. If a coupling similar to that previously discussed is used, it is found that the instantaneous polarity of the fed-back energy is in a negative sense, which necessitates the re-arrangement shown, which allows direct capacitative feed-back in a positive phase. The variable resistance R controls the amount of feedback. This form of coupling is also used between stages of a radio-frequency amplifier, where it is necessary to ground the condenser $C1$, for single control receivers and the like.

The phenomena so far discussed allow designing circuits which will permit a vacuum tube amplifier or detector type of

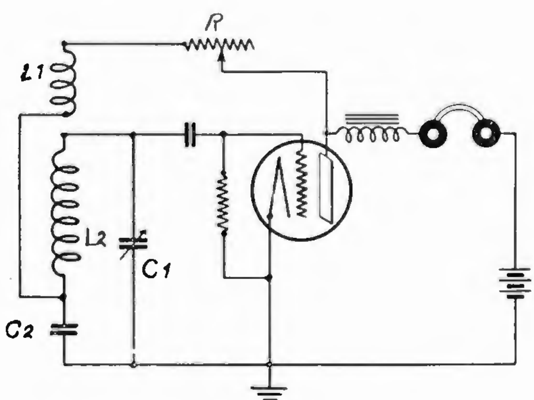

FIGURE 6

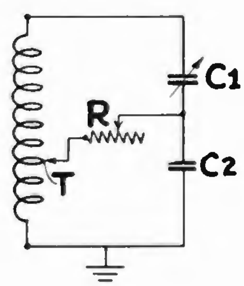

FIGURE 7

receiving set to oscillate at the upper or lower or at all dial settings. Figure 7 shows an arrangement which allows oscillation at any one intermediate dial setting.

As we have observed before, the point between the two capacities $C1$, $C2$ is at a potential difference to the grounded side of the system, which is determined by the ratio of $C1$ to $C2$. Whatever value this voltage has we can also always find a point T on the inductance of exactly the same potential to ground. If we join these points with a resistance R of any value, no current will flow through R, since both points are at equal potential to ground. If we now vary $C1$ as in tuning, we find that a potential difference develops across R, since point T remains at substantially the same voltage, while the potential across $C2$ varies. This potential difference becomes greater as we vary $C1$ either up or down from the value at which we balanced the system. If we balance midway of the dial reading of $C1$, we find that to be the only spot where the absorbing action of R has no effect, and if this Figure 7 arrangement is placed across the input of a vacuum tube whose plate circuit is sufficiently reactive to allow of oscillation throughout the frequency band, R can be so adjusted as to stop oscillation at all points except the balance point. If we balance at the lowest frequency, the damping action of R will increase with the frequency, and can be adjusted to prevent oscillation throughout the band. Precaution should be taken that R does not reach a sufficiently low value to allow the portion of the inductance below T to form a resonant circuit with C_2.

While we have investigated and used numerous other applications of the above, those we have outlined are considered sufficient to illustrate the principles involved.

SOME MEASUREMENTS OF SHORT WAVE TRANSMISSION*

By

R. A. Heising† and J. C. Schelleng† and G. C. Southworth‡

Introduction

The advent of short waves in the communication field has brought to light certain peculiarities of radio transmission previously unknown. The distances over which short-wave communication has been possible, together with the vagaries reported from time to time, raised the question, at one time, as to whether the phenomena involved were in any wise orderly or entirely chaotic. Much progress has since been made in the process of systematization until now it appears that there is really more order to the behavior of short waves than was previously suspected. One of the outstanding pieces of work in this direction is that of Dr. A. H. Taylor[1], who has correlated the work of amateurs, much of which has been reported in Q S T, with the short wave experience of the Navy. This has shown that in general short waves tend to skip the surface of the earth for a portion of their journey and be received at a distance with considerable intensity. The magnitude of this skip distance seems to vary with the time of day and the frequency (wavelength) used. Theories and calculations have been offered which for the present, at least, satisfactorily explain many of the short wave abnormalities.[2] It is the purpose of this paper to present transmission data on field strength, fading and telephonic intelligibility, together with some of their variations with time and distance. The studies of which these data form a part are still incomplete, and do not include a sufficient range of conditions

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†Bell Telephone Laboratories, Incorporated.

‡American Telephone and Telegraph Company.

[1]A. H. Taylor, Proc. I. R. E. Dec., 1925, p. 677.

[2]Larmor, Phil. Mag., 1924.

Nichols and Schelleng, Bell System Tech. Jl., Vol. IV, 1925, p. 215; Popular Radio, Oct., 1925.

Taylor and Hulburt, Phys. Rev., Feb., 1926, p. 189.

Rice and Baker, Paper presented at midwinter convention A. I. E. E., N. Y. C., February, 1926.

to be altogether conclusive. Therefore, many deductions possible at this time have been deferred to a later date when the attending facts have been more definitely established.

Scope

In the study of transmission the plan generally pursued was to send observers with the necessary measuring apparatus to points of vantage. Test signals were sent out hourly on each of several frequencies in accordance with a prearranged schedule. In most cases the schedule extended over several consecutive days. The tests were arranged to provide specific information on the diurnal variation of electric field strength, intelligibility and noise for each frequency, and for each distance where observations were made. The observing points were in some cases so selected as to bring out any marked differences that might exist between over-water and over-land wave propagation, and in others were arranged in a straight line to reduce the number of possible variables. Simultaneous measurements were made at as many as six locations. The observations totaled over 6,000 where each observation consisted of an average field strength measurement, a maximum field strength measurement, noise measurement, intelligibility measurement and fading observation.

The frequency range covered was from 2.7 to 18 megacycles, roughly 111 to 16½ meters. This was covered in seven convenient steps with occasional tests on other frequencies. The greater part of the observations were made on 2.7, 4.5, 6.8, and 9.7 megacycles. Most of the tests were made between September and December, 1925. They include observations in several directions up to over 1,000 miles, and a few in England.

Experimental Apparatus

The transmissions were made largely from the short wave laboratory at Deal, N. J. The transmitter is of the oscillator-amplifier type, in which the frequency is set by an oscillator, and harmonics are generated and amplified. The oscillator was stabilized against frequency variations. The carrier was modulated at a level of about 200 watts after which it was amplified by water-cooled tubes and delivered to the antenna. The radiated power varied with frequency, being about 1 kw. on 9.7 megacycles (31 m.), and 4 kw. on 2.7 megacycles (111 m.). In addition to the regular Deal transmitter, a similar low-power transmitter was operated at the building at 24 Walker Street, New York City, during two regular tests. This extended the range to 18 megacycles (16½ m.). The radiated power did not exceed 200 watts.

Various types of antennas were used at Deal. The one usually employed on the lower frequencies consisted of a vertical conductor functioning approximately as a quarter-wave radiator. For the higher frequencies a vertical copper rod was used, which operated substantially as a half-wave radiator. Figure 1 is an

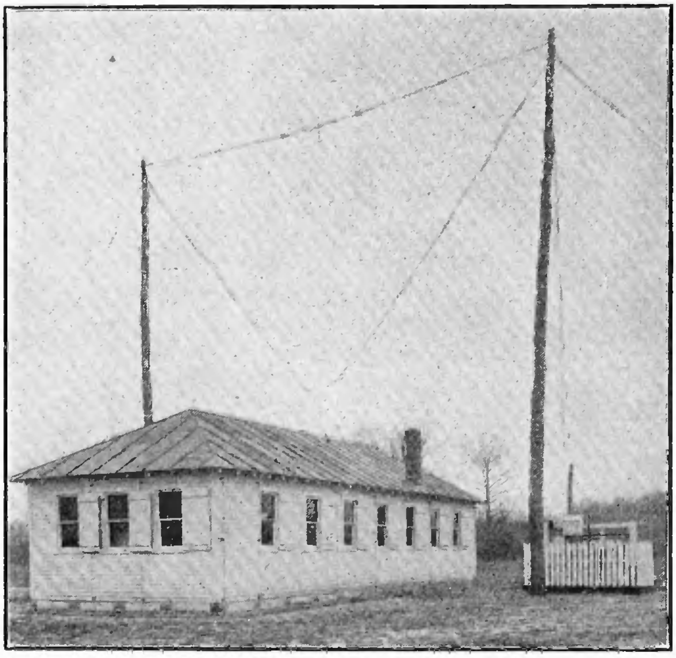

FIGURE 1—Short Wave Transmitting Laboratory and 66-meter Antenna at Deal, N. J.

illustration of the building and one of the antennas used at Deal. At the Walker Street transmitter half-wave radiators were used in all cases.

The observations were taken with field strength measuring sets and automatic field strength recorders of types which will be described in another paper. Illustrations are given in Figures 2 and 3. Loops were used when possible on all measuring and recording sets, but vertical antennas were resorted to whenever the signal became too weak for the loop.

DIURNAL TRANSMISSION CURVES

Sample field-strength curves are given in Figures 4 to 7, inclusive, for 24-hour periods for Nantucket, Detroit, Mich., Columbus, Ga., and a complete trip on board a ship enroute from New York to Bermuda. The diurnal curves vary from day to day, but in the main have certain characteristics which repeat. Where our tests ran several days, we averaged the readings for each hour of the several days to secure an average diurnal curve for each observing point. Such curves are shown in Figures

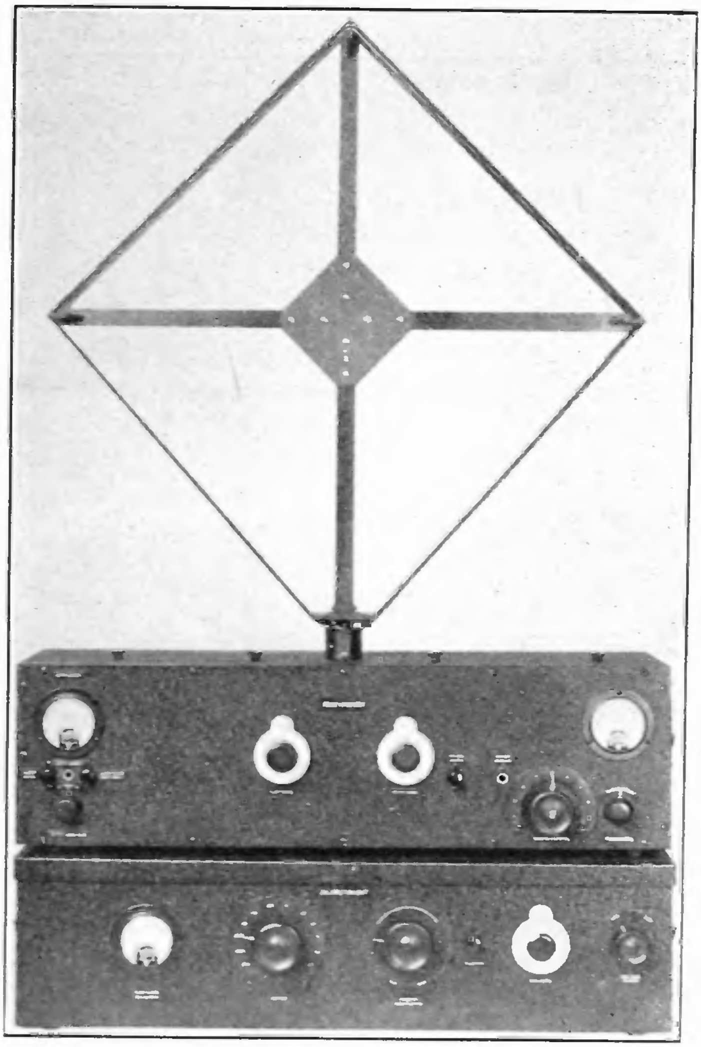

FIGURE 2—Portable Short Wave Field Strength Measuring Set

8, 9, and 10 for England, September 10-13, Columbus, Georgia, and Fairfax, Virginia, December 11-14, inclusive. As a rule, on the lower frequencies, a minimum field strength occurs during the day. On 6.8 megacycles (44 m), at about 200 miles, the minimum usually occurs at night. On still higher frequencies at 700 miles there appears to be a minimum both during the day and during the night.

The curves for 4.5 megacycles taken in England, Figure 8, show an absence of signal during the day, but a fairly strong signal at night. This curve should not, however, be taken as an example of what can be expected at that distance every time, as other experiments showed that at the time of these particular

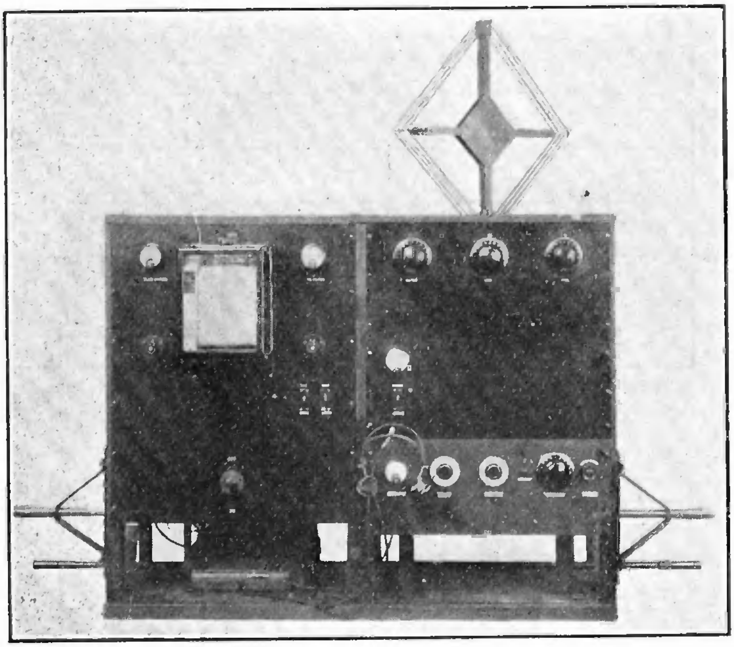

FIGURE 3—Automatic Recording Set. This Apparatus Makes Continuous Records of Either Signal or Noise Field Strength

tests the transmission to England at this frequency was exceptionally good.

VARIATION OF FIELD WITH DISTANCE

Until short waves attracted attention about three years ago, it was thought that their attenuation as a function of distance was always very much greater than for the longer waves. For distances up to 100 miles this is found to be true. However, the phenomenal distances reached by short waves with small power have shown that our theory of transmission was incomplete. In order to explain how such distances are covered it has been assumed that at least a portion of the wave travels in an indirect overhead path, being deflected back to earth by some upper ionized layer and suffering little attenuation over this longer path.

Our observations bear this out. Up to a distance of about 100 miles the attenuation was of the order of magnitude expected, after which the signal, instead of decreasing with distance, actually increased. Figure 11 shows curves taken at two wave-lengths over water up to a distance of 30 miles, where both transmitter and receiver were located at the water's edge with no intervening land. The distance was too small to secure any

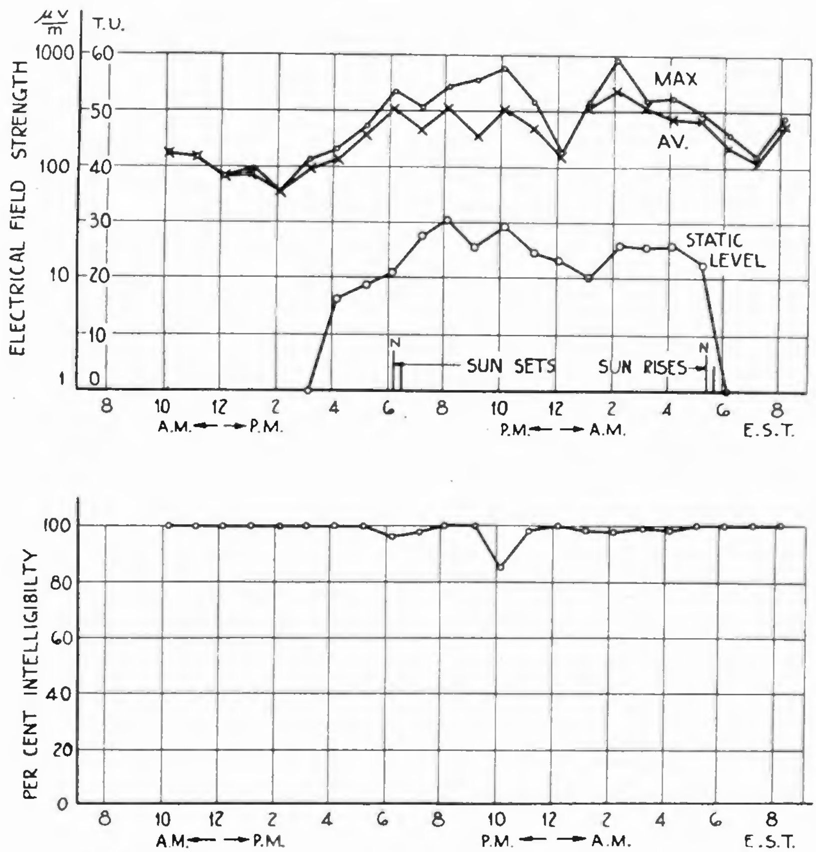

FIGURE 4—Typical Curves of Field Strength, Noise and Intelligibility Taken at Nantucket, Mass., Sept. 11-12, 1925, 2.7 mc.

exact measurements of attenuation, though the results indicate that excessive attenuation does not occur. Incidentally, there was not the slightest indication of fading or bad quality in these tests. With over-land transmission made at the same time, the attenuation was observed to be enormous, due evidently to obstructions on the surface of the ground and to the ground itself. The observations plotted in Figure 11 were not made simultaneously at the various locations, but were made in succession. Some were checked at other times, indicating that at such small distances the time of day had little or no effect.

Figures 12 and 13 show measurements made over distances up to 1,050 miles on 6.8 megacycles (44 m.). The curves give average field strength as measured simultaneously at three stations in a straight line, one group of readings being 7:00 p. m., and the other at midnight on four successive nights. These figures show that the transmission curve, as a function of distance

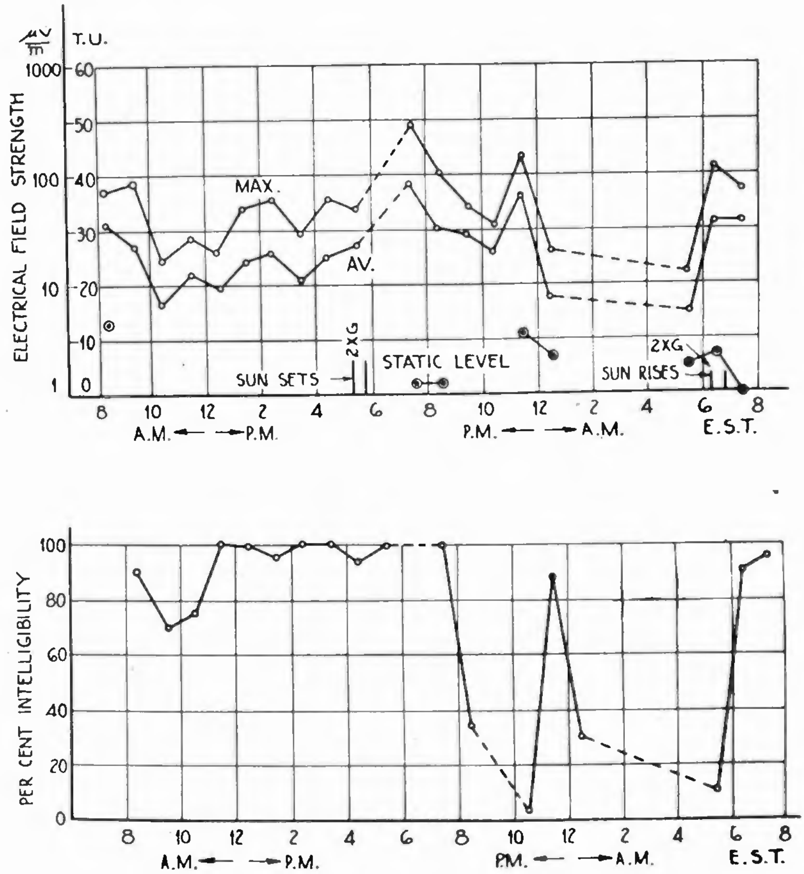

FIGURE 5—Typical Curves of Field Strength, Noise and Intelligibility Taken at Detroit, Mich., Oct. 21-22, 1925, 6.7 mc.

varies from time to time and in some cases varies over a wide range.

To secure a curve as a function of distance which could be called an average curve, the measurements taken at each observation point were averaged. That is, a mean daylight value was obtained for each location by averaging all the readings taken when the path of the wave lay entirely in a daylight region. A night average was obtained in a similar way. Several days' data at each location were made use of. Figures 14, 15, and 16 represent average curves as a function of distance on 6.8, 4.5 and

2.7 megacycles (44, 66 and 111 m.). Figure 14 indicates that the overhead wave on 6.8 megacycles (44 m.) comes back to earth, giving a maximum signal about 600 miles away at night or 350 miles in the day. At these points the signal strengths are of the order of magnitude that are normally received over 50

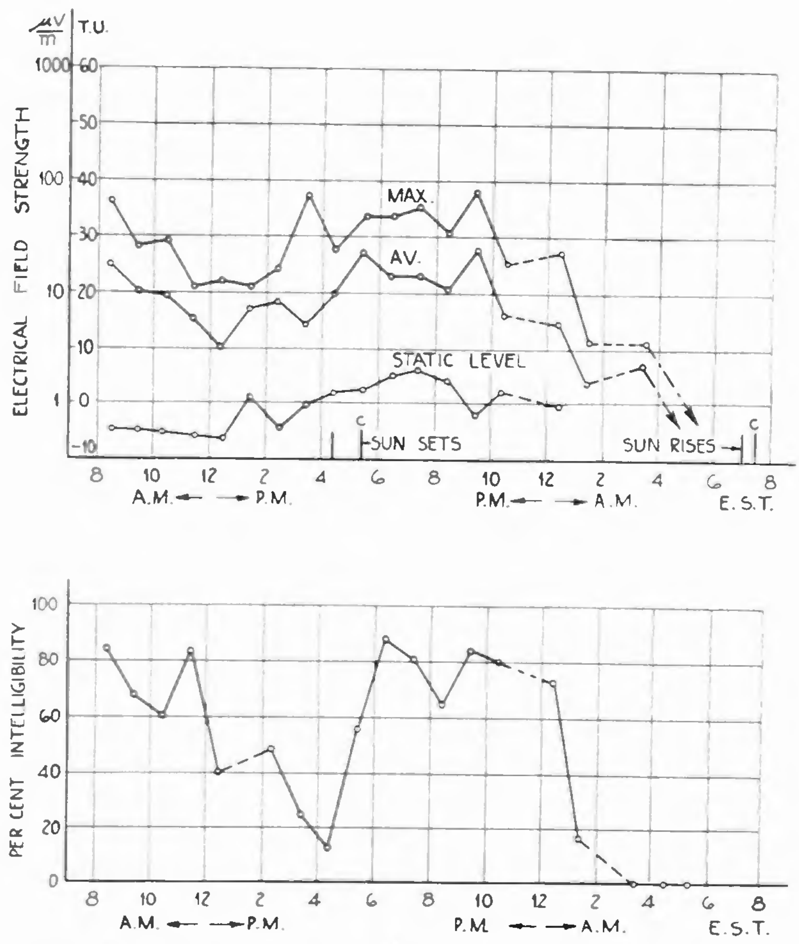

FIGURE 6—Typical Curves of Field Strength. Noise and Intelligibility Taken at Columbus, Ga., Dec. 14-15, 1925, 9.7 mc.

miles of water. Even at a thousand miles the signal is as strong as it is over 75 miles of water. There is a region of low field strength a short distance from the transmitter which is at present interpreted as a region which is too close to the transmitter to receive much by the indirect wave and a little too far to receive much of the direct wave. This appears as a decided depression in the curve. This region of weak signals becomes much more pronounced at shorter waves and gives rise to what is called the skip distance. This skip distance hollow increases in width as well as depth as the frequency is raised. Figure 15 shows the

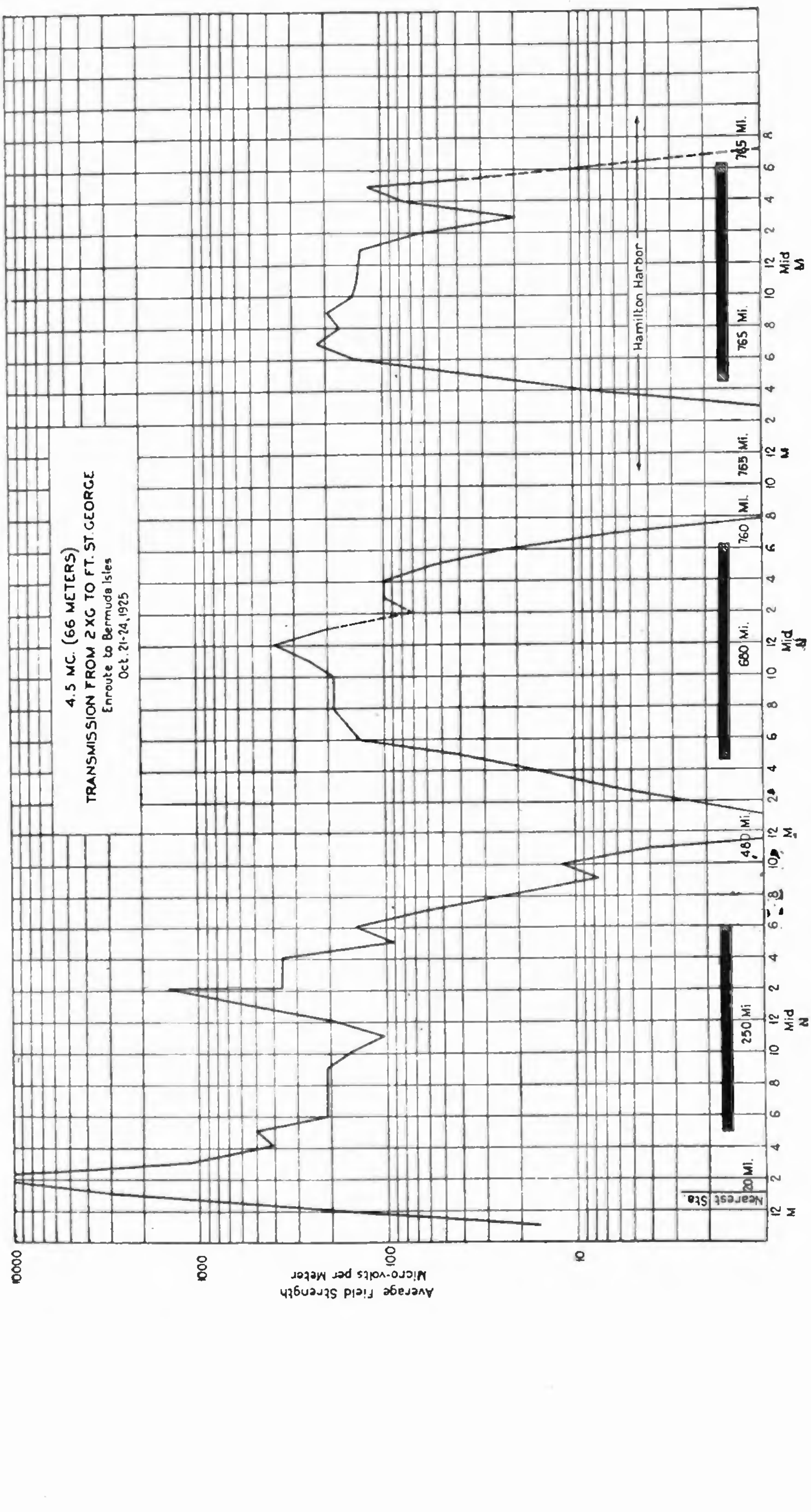

FIGURE 7—Field Strength Received From Deal, N. J., Aboard a Boat Enroute New York to Bermuda, Oct. 21-24, 1925, 4.5 mc.

curves of field strength and intelligibility as a function of distance on 4.5 megacycles (66 m.). The skip distance effect is also quite noticeable here. The distance at which the maximum signal occurs is reduced to around 300 miles at night and 250 in the daytime. The skip distance depression is sharper and narrower than for 6.8 megacycles (44 m.), though it must be stated that the shape of this is partly guess-work, being based upon measurements taken at 30, 90 and 240 miles. Figure 16 gives

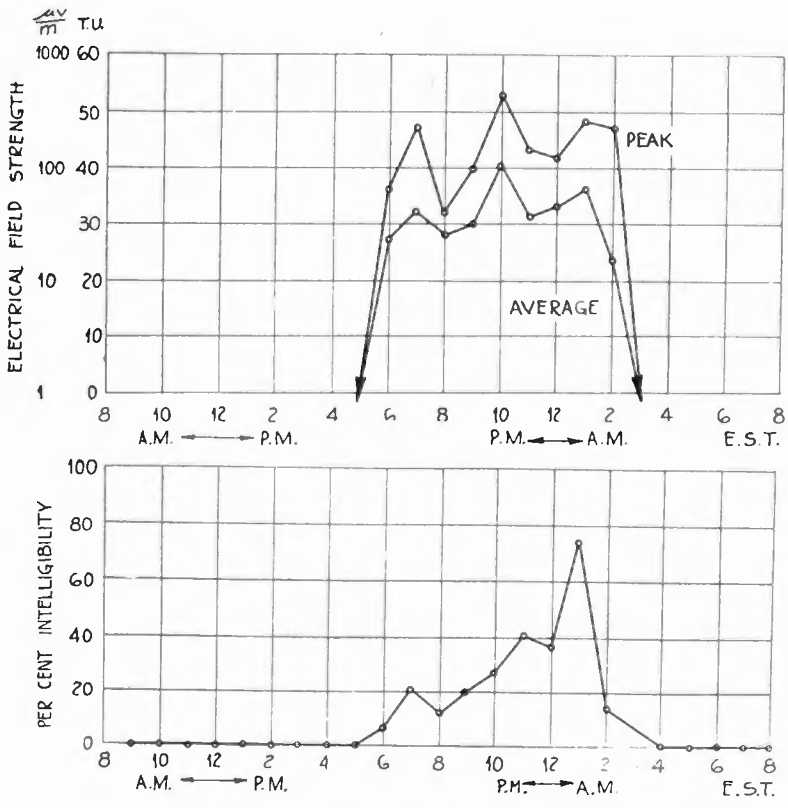

Figure 8—Curves of Average Field Strength and Intelligibility Received at Chedzoy, Somerset, England, from Deal, N. J., Sept. 10-13, 1925, 4.5 mc.

corresponding curves for 2.7 megacycles (111 m.). At this wavelength there is just an inkling of the skip effect. The magnitude of the signal at distances above 200 miles is, however, considerably greater than what would have been secured if there were actually no overhead wave. In the region where the signal is secured from the ground wave only, the strength is very much less at all of these three wavelengths than that given by the Austin-Cohen empirical formula. Beyond the skip distance the signal is usually actually greater.

Figure 8, for transatlantic transmission at 4.5 megacycles, is of interest, because of the fact that the field strength at times reaches values as great as ten times that calculated by assuming the inverse distance law. It is well to remember, however, that since the wave is presumably diverging in two dimensions rather

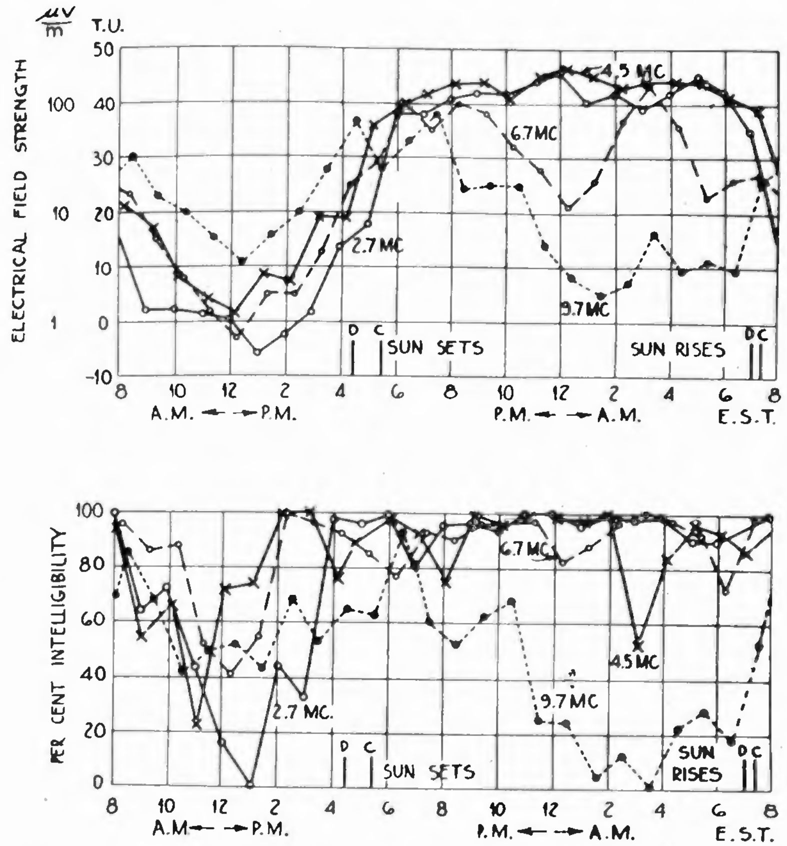

FIGURE 9—Diurnal Curves of Average Field Strength and Intelligibility Secured at Columbus, Ga., Dec. 11-16, 1925, on 2.7, 4.5, 6.7 and 9.7 mc. Times of Sunset and Sunrise are Indicated by D=Deal, C=Columbus

than three, we should not expect the inverse distance law to apply.

IDEALIZED TRANSMISSION SURFACES

As indicated above, field strength is a function of both distance from the transmitter and the hour of the day. Therefore, a complete graphical representation for one frequency requires a three-dimensional figure such as shown in Figure 17. A figure of this kind may be considered as a surface made up from an infinite number of diurnal variation curves, each taken at a different distance from the transmitter. Since measurements taken at a given point are subject to wide variations, it has been necessary to idealize the data to a considerable extent, taking into consideration only those characteristics which are known in general to repeat day after day. A plane passed through each figure at the 1 microvolt-per-meter level has been taken arbitrarily as the limit or noise level below which a signal is no longer useful. If a higher level had been chosen, it would not have

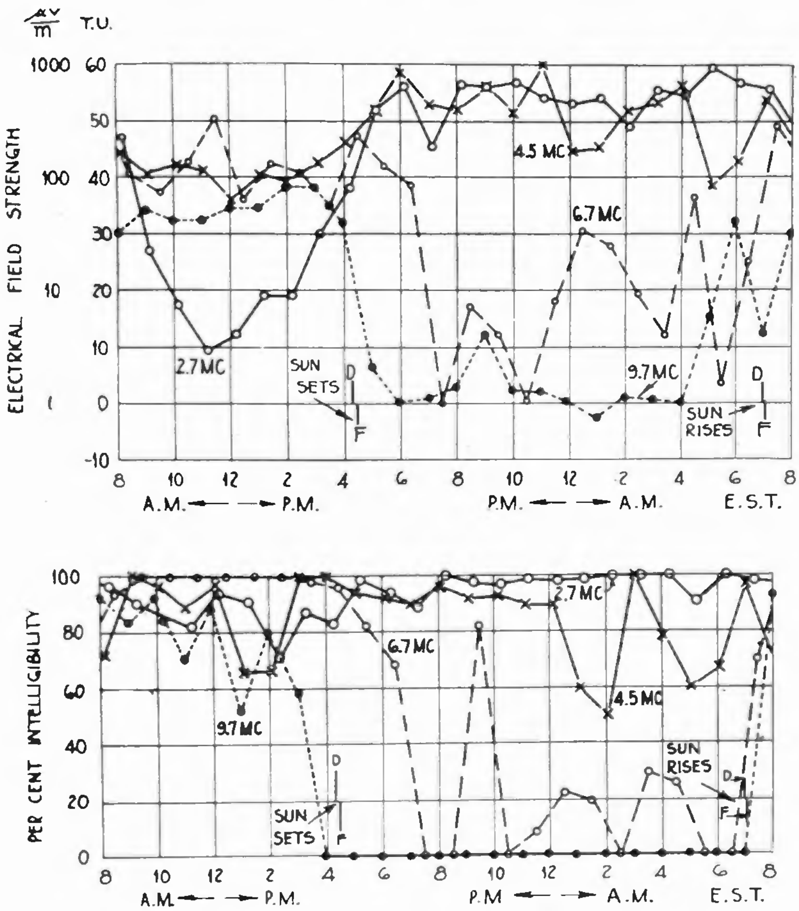

FIGURE 10—Diurnal Curves of Average Field Strength and Intelligibility Secured at Fairfax, Va., Dec. 11-16, 1925 on 2.7, 4.5, 6.7 and 9.7 mc. Times of Sunset and Sunrise are Indicated by D=Deal, F=Fairfax

seriously altered the shape of the figures. Actually the datum level adopted was approximately the lower limit of the measuring methods used. In constructing these surfaces the general procedure was to smooth out each data curve and correct it to approximately 1 kw. of radiated power and piece the whole into a general mean which seemed to be most representative of average conditions.

It should be borne in mind that data taken at a given place vary considerably from day to day. On this account, the surfaces as well as the average curves shown represent only the outstanding characteristics to be expected, and this picture of trans-

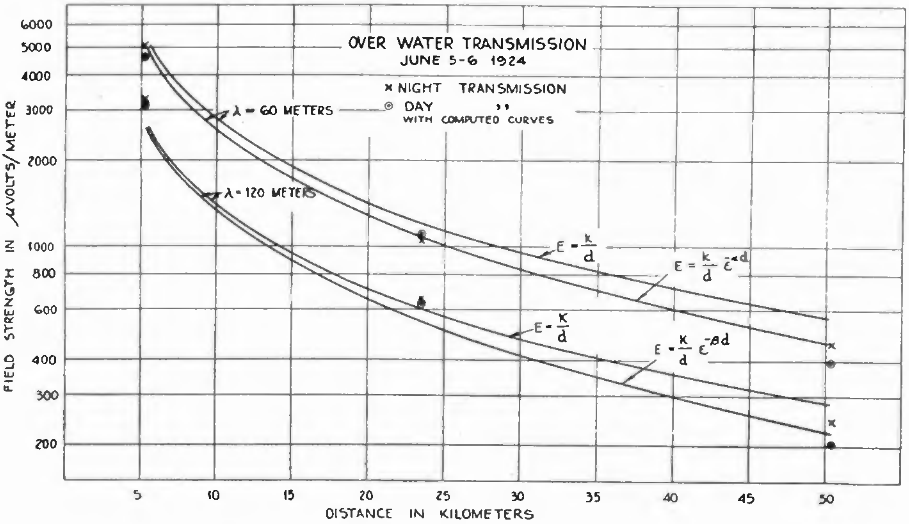

FIGURE 11—Field Strength Measurements for Transmission Entirely Over Sea Water at Frequencies of 2.5 and 5 mc., Distances up to 50 km. Within the Range of these Curves the Austin-Cohen Values Agree with Those Calculated According to the Method of Sommerfeld

mitting conditions for any given frequency holds only in a general way for that region of the radio-frequency spectrum speci-

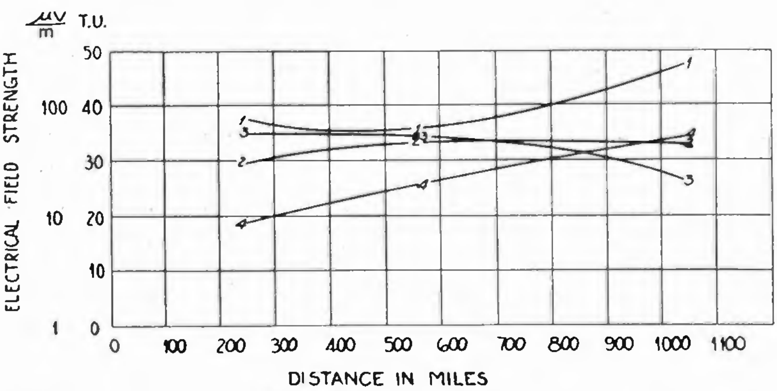

FIGURE 12—Average Field Strength as a Function of Distance on Four Successive Days at 7 p. m. for 6.7 mc.

fied. It does not distinguish between east and west and north and south transmission. On some days 6.7 megacycles (45 m.) data resemble closely those depicted for 4.5 megacycles (66 m.), while on the other days they may be more like the 9.1 megacycles (33 m.) surfaces shown. Consequently, it is rather difficult to specify at just what wavelength and at what distance discontinuities, such as the night minimum shown in the third surface begin. Cosmic phenomena, such as observed about April 15 of this year, seem to alter materially the whole aspect of short wave transmission as it also does transmission at 5,000 meters. It is convenient to regard these surfaces as means of widely varying instantaneous states, which are changing even while observations are being taken. From this point of view fading is the direct result of the rapid transition from one state to another.

Discussion of Transmission Surfaces

As indicated above, a typical diurnal variation curve for 2.7 megacycles (111 m.), is in general a periodic curve having a

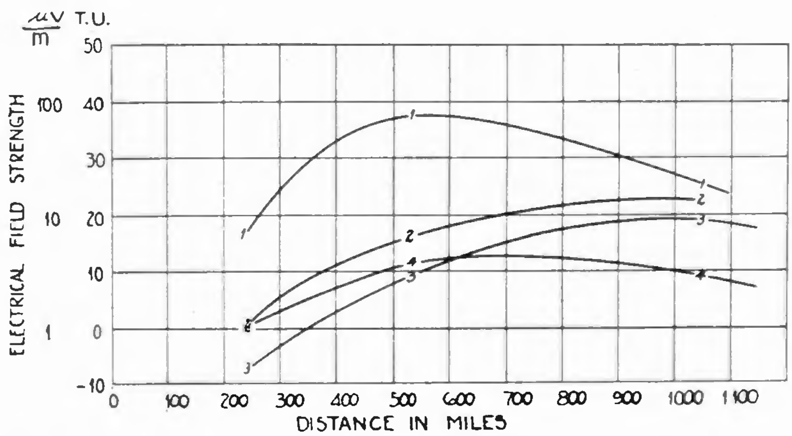

Figure 13—Average Field Strength as a Function of Distance on Four Successive Days at Midnight for 6.7 mc.

maximum at night and a minimum in daylight. For points near the transmitter, the difference between day and night signals is less than at a distance and at no time does the signal sink below the arbitrary datum level of 1 microvolt per meter. At more remote points, say 500 miles, the signal is heard only during the night. The number of hours for good signals becomes less and less the greater the distance. Observations made in England indicate that the 2.7 megacycles (111 m.) signals are rarely heard when moderate amounts of power are used. This means that the top of the surface seldom appears above the assumed noise level. However, when the signal does appear, it usually takes place about midnight. The distance of 300 miles is of particular interest in that beyond this point signals would not ordinarily be heard throughout all the 24 hours. This distance probably varies considerably from day to day, depending on influences not yet known.

The transmission surface for 4.5 megacycles (66 m.) resemble closely that for 2.7 megacycles (111 m.). However, on closer

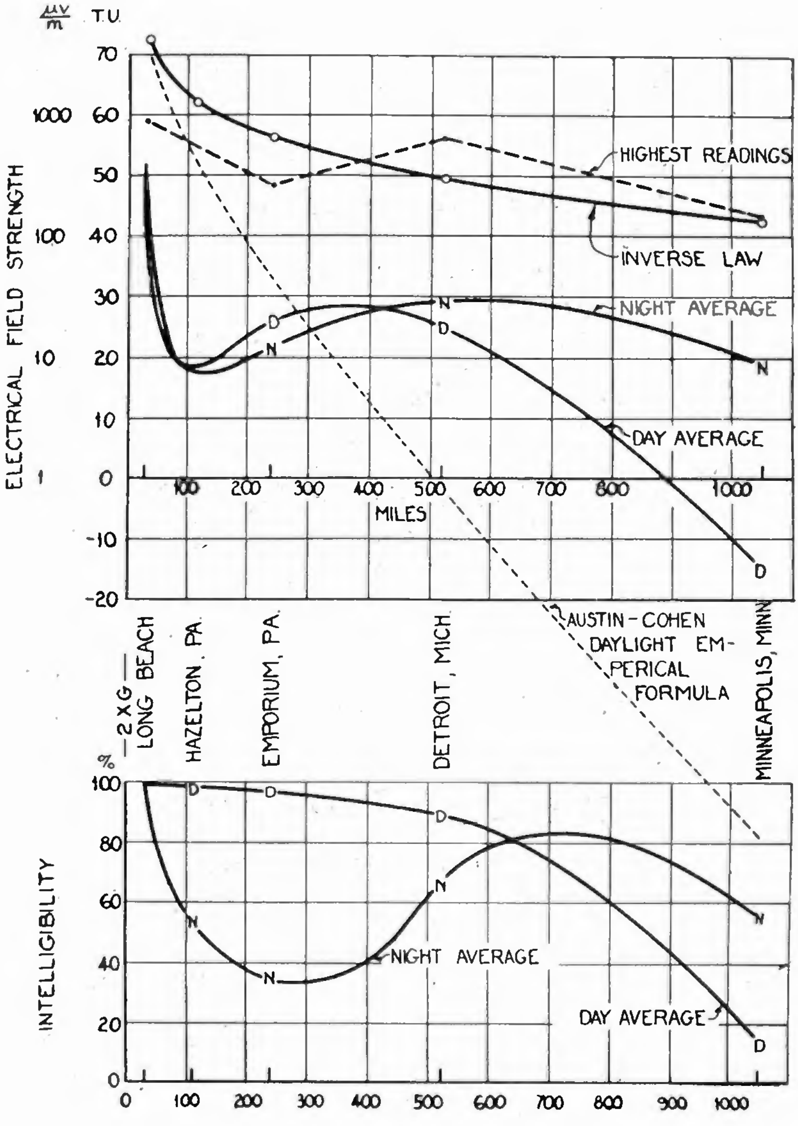

FIGURE 14—Field Strength and Intelligibility as a Function of Distance for 6.7 mc. Curves Represent the Average of Data for Several Days

examination it will be observed that the maximum night signals are somewhat stronger, and that, in general, these signals may be heard during more hours of each day. The night depression observed for this surface is much more pronounced than in the preceding surface. In some instances depressions have been observed in the diurnal variation curve around midnight even at distances of several hundred miles. In a few cases this has been observed in the 2.7 megacycles (111 m.) surface.

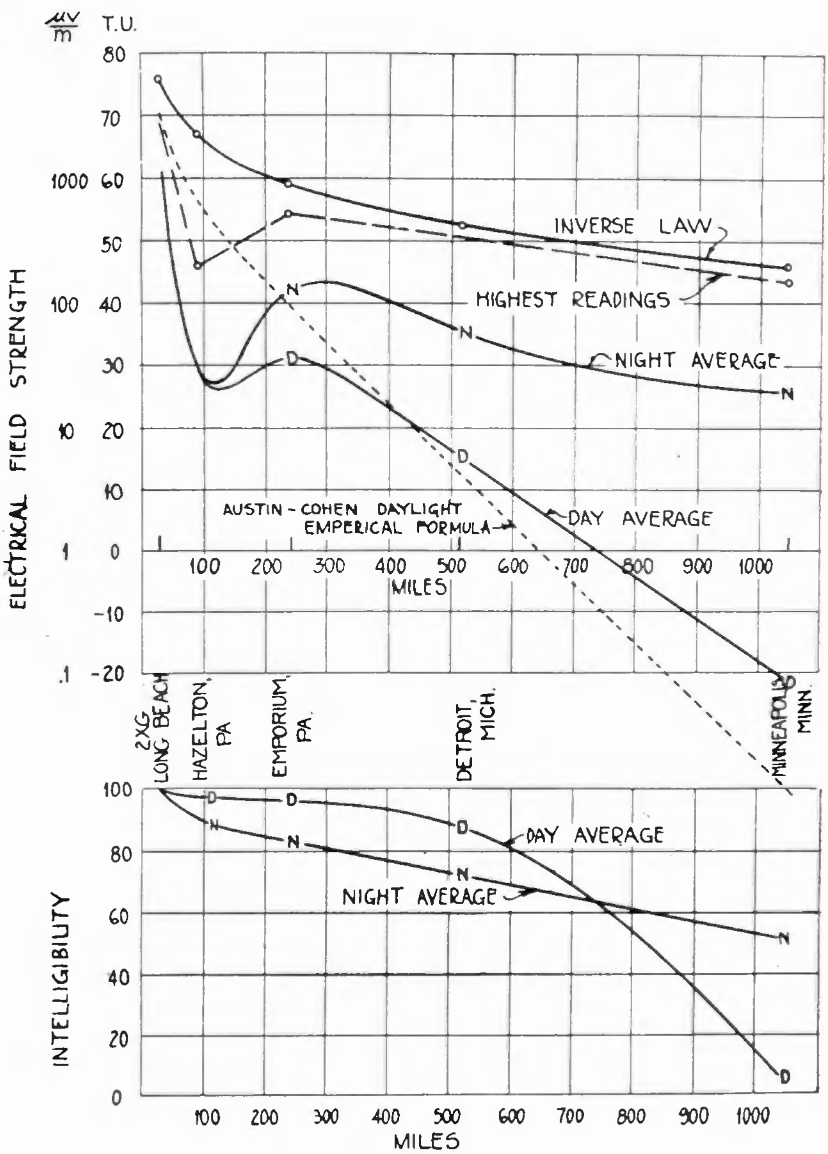

FIGURE 15—Average Field Strength and Intelligibility as a Function of Distance for 4.5 mc. Average for Several Days

The distance at which noon signals can just be heard becomes considerably greater as the wavelength is reduced. One would infer from this that for a given amount of radiated power the shorter wavelengths would in all cases be more efficient. This is not true as we have already shown.

The 6.7 megacycles (45 m.) surface differs markedly from that for the longer waves. The slight depression observed in the 4.5 megacycles (66 m.) surface at 200 miles and after midnight has now developed into a pronounced bifurcation extending beyond the limits of the figure. The lowest point is probably

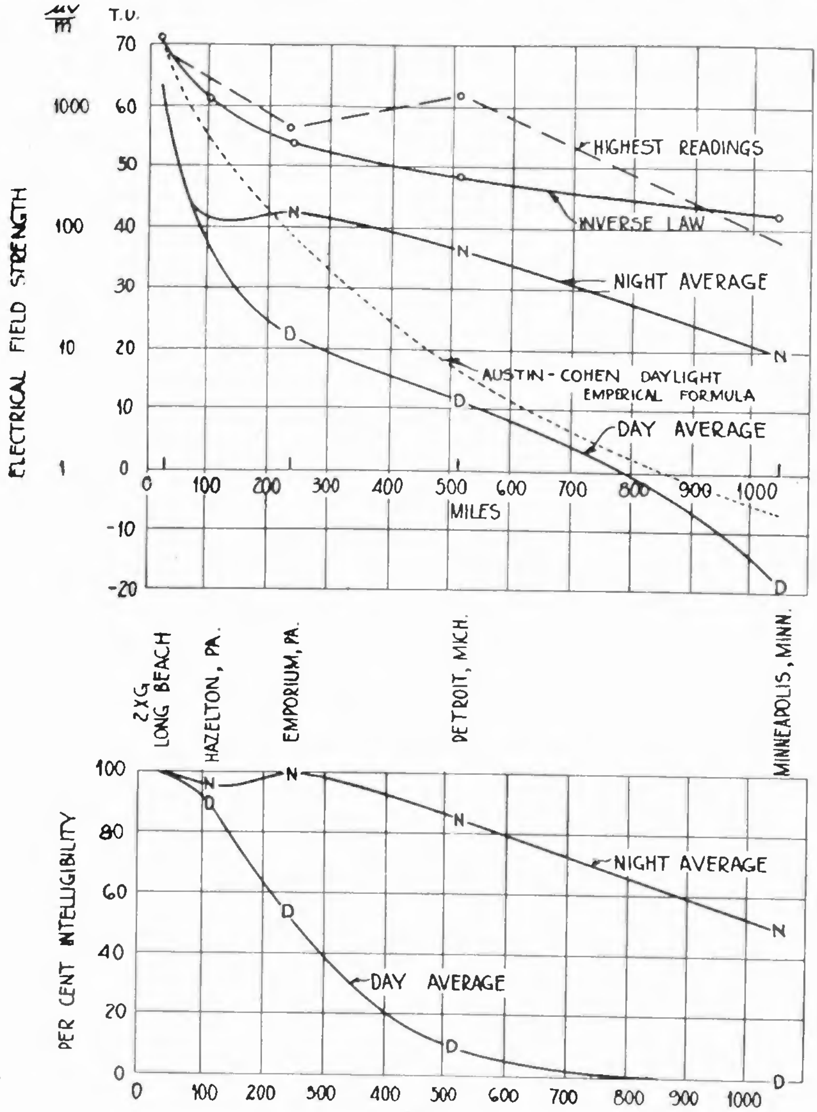

FIGURE 16—Average Field Strength and Intelligibility as a Function of Distance for 2.7 mc. Average for Several Days

about 300 miles from the transmitter and, of course, is below the zero level. The maximum distance for noon signals has been pushed out to perhaps about 700 miles. The width of this weak signal period appears to vary somewhat from night to night. At one time tests were made on 5.7 megacycles (52 m.) to find out whether the transmission on this frequency resembled the 4.5 megacycles (66 m.) transmission more than that for 6.7 megacycles (45 m.). On this particular day the night opening in the

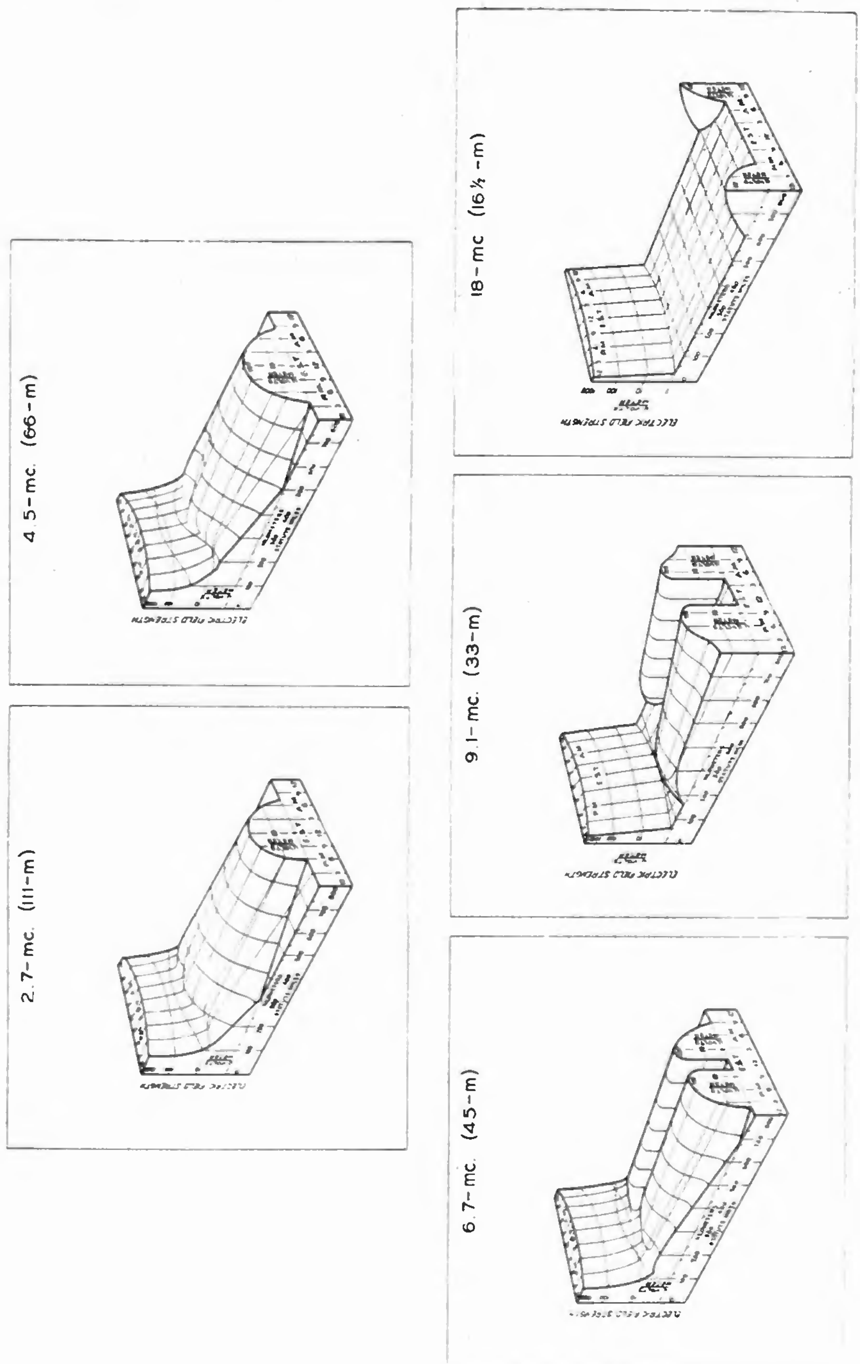

Figure 17—Idealized Transmission Surfaces, Variation of Field Strength with Time and Distance

6.7 megacycles surface was unusually wide. A very definite but narrower one was observed at 5.7 megacycles, and the night signals at 4.5 megacycles were found to be very unstable.

In passing from the 6.7 megacycles surface to that for 9.1 megacycles (33 m.), one observes that the depressions mentioned above have become so pronounced that a short skip distance results where no signal is heard at any hour of the day, and the night opening is considerably widened. It is well to bear in mind that while, for practical purposes this skip distance is very real, it is only the result of the surface intersection evident at the longer wavelengths, taking place below the arbitrary zero level chosen. With improved receiving methods, this distance may be reduced somewhat. It will be observed that the maximum distance for noon signals has increased until it has passed on out beyond the 800-mile point. However, there are signs of the noon diminution of signals remaining. As indicated by the surface, signals are heard at all hours of the day at points near the transmitting station.

The last surface in the figure shows what may be expected on the very high frequency of 18 megacycles (16 m.). It will be noted that the skip distance has been increased considerably and the time when signals may be heard has been reduced to a very few daylight hours. The time limits when signals were heard are known more definitely than the distance which the surface extends along the distance axis.

Considering the several surfaces consecutively in the order of increasing wavelength or decreasing frequency, we observe a general continuity from one type to another. As we pass from 18 megacycles (16½ m.) to 9.1 megacycles (33 m.), the daylight signal, evident only at distances of approximately 750 miles, increases in magnitude and covers a greater portion of the time and space domain. At 9.1 megacycles (33 m.) the signal becomes somewhat weaker about noon, but the surface continues to cover more and more of space and time. After the frequency has been decreased to 6.7 megacycles (45 m.), this area has extended back to the transmitter and covers practically all but a few of the night hours. During this time a noon signal depression has developed, so that at 800 miles there are two times each day when the signal is weak. Upon further decrease of frequency the night signal depression closes up and the maximum distance for noon signal reception recedes toward the transmitter as the whole surface sinks downward toward the arbitrary noise level of 1 microvolt per meter.

Intelligibility

In determining the usefulness of short waves it was felt that signal strength was by no means the only observation necessary. Rapid fading, though not interfering with field strength measurement or telegraphic reception, was known to play havoc with speech quality at times. It was, therefore, decided to make tests on the intelligibility of received speech in addition to the field strength measurements.

In these tests a series of disconnected words was transmitted and the percentage of words clearly understood at the receiving station was taken as a measure of the intelligibility. It is realized that such an intelligibility test is by no means exact; in fact, different observers listening under the same conditions get material differences. On the other hand, considering the large number of observations required and the widely varying conditions under which they must be made, it is necessary to use as simple an intelligibility test as can be devised. These percentages, although not an exact measure of intelligibility, undoubtedly give us an idea of telephonic limitations.

In order to insure that the intelligibility measurements were really observations of the effect of the transmitting medium on the radiated wave, all known precautions were taken to eliminate distorting effects dependent upon the apparatus. The frequency of the master oscillator was stabilized. High quality microphones, amplifiers and modulating coils were used. Monitoring observations were made to insure good quality in the amplifying and modulating processes. Receiving apparatus was located, whenever possible, away from all wires, lines, or other obstructions that would distort the field or introduce noise. The observations were usually made at the same audio level.

The intelligibilities thus measured were plotted along with other data. Sample daily curves are included in Figures 4, 5, and 6, and average daily curves in Figures 8, 9, and 10.

At each location all of the daylight and night values were separately averaged. Curves of average intelligibility have been plotted along with the curves for field strength in Figures 14, 15, and 16. To a certain extent the intelligibility is dependent upon the signal strength. This is especially the case with the apparatus used when the signal strength falls below 10 microvolts per meter, due to the fact that at these low intensities the necessary amplification brings in sufficient noise to impair the intelligibility. On the other hand, as is readily seen from the curves for 6.7 megacycles (45 m.), poor intelligibility is often observed at field strengths which, under other circumstances, are accompanied by high intelligibility. Under the conditions of these tests rapid fading has been found to be the greatest element in reducing the intelligibility on short waves.

On 6.7 megacycles, in the region of the skip distance depression, the day average stays up, while at night it drops, due to the greater fading, although the signal strengths are closely the same in the two cases. The fading on 4.5 megacycles is less than on 6.7 megacycles, and the night intelligibilities (Figure 15) are correspondingly higher. At both these frequencies the weakness of signal began to affect the intelligibility at 1,000 miles. On 2.7 megacycles at 500 miles and over, the low day intelligibility is due to the total absence of signal during a large part of the day.

Over-land vs. Over-water Transmission

On several occasions strong signals of the order of 1,000 microvolts per meter have been observed at Long Beach, Long Island, which showed an extremely rapid falling off in intensity as the receiving station was moved inland in a direction away from the transmitter. The distance from Deal to Long Beach is about 31 miles, of which about 3 miles is over land. At a point 12 miles inland from Long Beach the signal strength had decreased from 1,000 down to around 100. As indicated in Figure 11, entirely over-water transmission should not produce such a rapid falling off. This is corroborated by the observations shown in Figures 14, 15, and 16, for the 90-mile point where the path was mainly over water. It was suspected that, although signals received nearby were attenuated rapidly over land, there would be very little difference between over-water and over-land transmission to great distances if the signals travelled by an overhead path.

Last December, therefore, tests were made for the purpose of comparing over-land vs. over-water transmission. Some of the data are plotted in Figures 18 and 19. The curves in Figure 18 are for over-water and over-land stations, which are a little over 200 miles from Deal. The average field strength curves by day and by night, for these places are similar both in shape and in value. They are closer than would be expected from any previous experimental results. In Figure 19 similar curves are given for distances slightly over 700 miles. They show even less dissimilarity in magnitude than the ones taken around 200 miles. The signals received at Bermuda and Columbus, Georgia, were most likely entirely of the overhead type, while the 2.7 megacycles (111 m.) wave at Nantucket probably contained some ground wave.

The intelligibility curves for the 200-mile distances are similar, as are those for the 700-mile distances, though there is a little more difference in the latter. It is evident from these, as well as from previous experiments, that for distances greater than a few hundred miles and less than a thousand miles, there

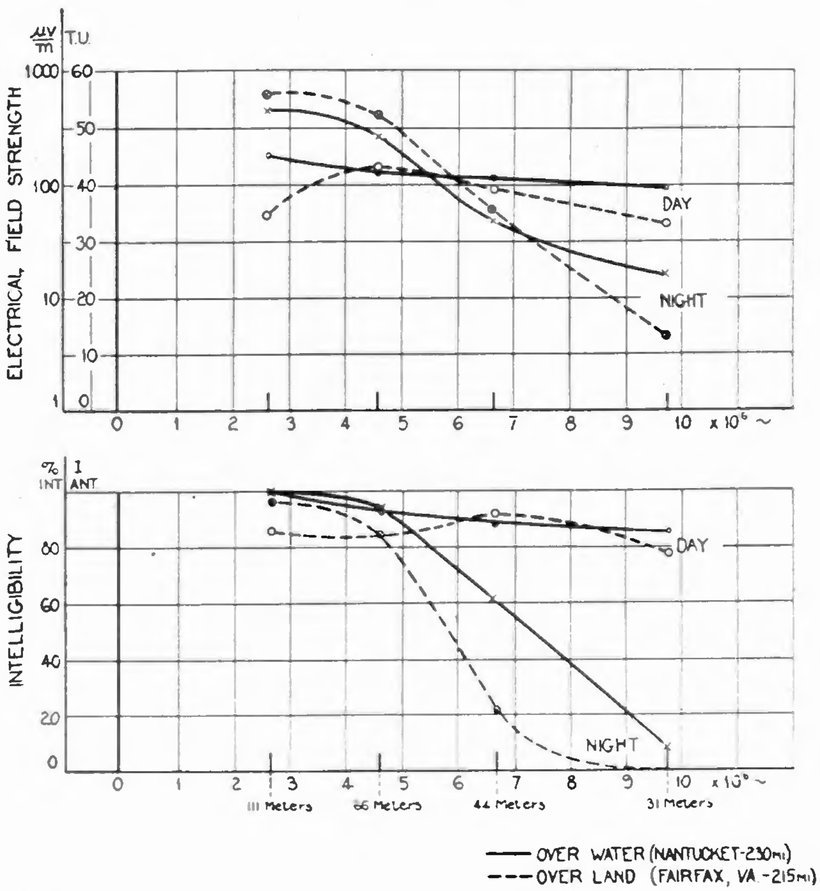

FIGURE 18—Comparison of Over-land and Over-water Transmission. Field Strength and Intelligibility Are Shown as Functions of Frequency for Distances of Approximately 200 miles

is very little difference between over-water and over-land transmission.

TRANSMISSION AS A FUNCTION OF FREQUENCY

Figures 20 and 21 give the average strength of the signals received at Quogue, 90 miles, and Detroit, 500 miles, as a function of frequency. The difference between day and night signals at Quogue is very small. The signal strength decreases as the frequency is raised. There are many reasons for believing that the Quogue signals were largely of the ground wave type. The curves in Figures 18 and 19, referred to in connection with over-land vs. over-water transmission, are plotted also as a function of frequency. At distances of 200 miles there is no great variation in value of the day signal with frequency. The night signals appear to show a falling-off at the higher frequencies, the signals being actually weaker during the night than during the day. At the greater distances, such as at Bermuda and Columbus, the day signal increases with frequency. In this particular case,

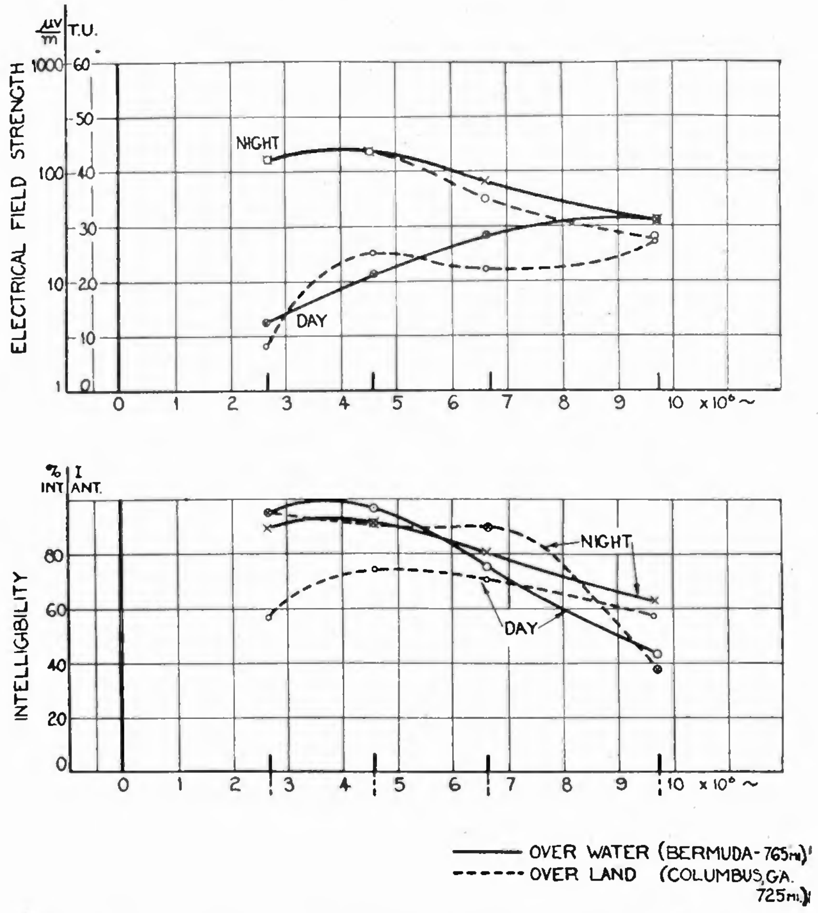

FIGURE 19—Comparison of Over-land and Over-water Transmission. Field Strength and Intelligibility are Shown of Frequency for Distances of Approximately 700 miles

the day signals reach the same value as the night signals at about 10 megacycles (30 m.). At Detroit, slightly over 500 miles, Figure 21, the same characteristics appear as at Bermuda and Columbus, but the day and night signals in this case would be of equal value at a point just above 7.5 megacycles (40 m.).

Night and Day Effects

Inspection of Figures 18, 19 and 21, shows that at some frequency the curves for signal strength at night will cross those for the daytime and that the value at which they cross is connected with the distance. Inspection of the diurnal curves shows that in some locations on some frequencies the day signal is stronger than the night signal. This is contrary to experience at lower frequencies, where better transmission is obtained at

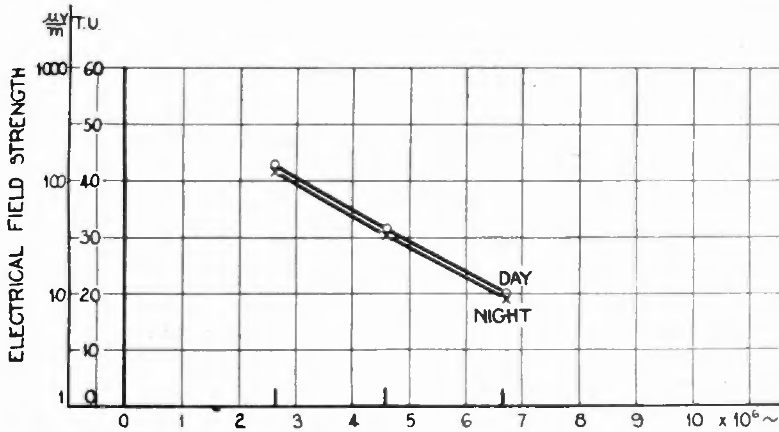

Figure 20—Signal Strength as a Function of Frequency at a Point Where the Ground Wave Dominates. Signals Received at Quogue at a Distance of 90 Miles All Over Sea Water Except for About Two Miles Near Deal

night than during the day. The relation between average night and day signals is shown in Figure 22, where the difference between day and night transmission in transmission units is plotted as a function of frequency. The curves are labelled according

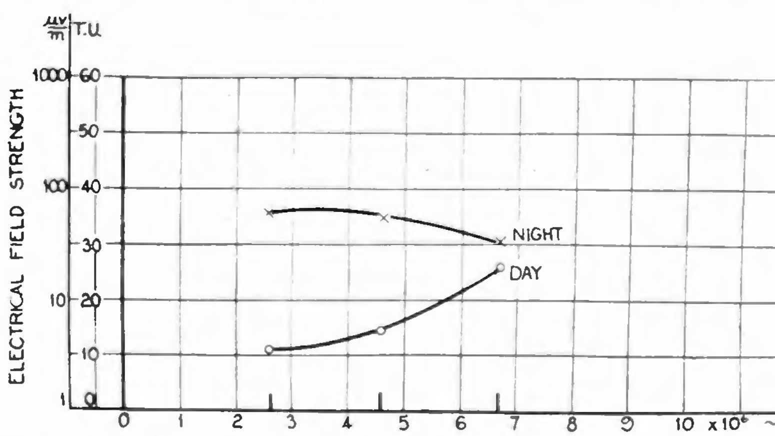

Figure 21—Signal Strength as a Function of Frequency at a Point Where the Ground Wave Does Not Dominate. Signals Received at Detroit, 520 Miles Over Land

to the locations at which the data were secured. They show that around 2.7 megacycles (111 m.), the night transmission is universally better, but as we go to the higher frequencies it becomes less and less so, until finally, in the case of Nantucket, Emporium, Pennsylvania, and Fairfax, Virginia, all located approximately 220 miles from the transmitting station, a change occurs, and from 6.7 megacycles (45 m.) to the higher frequencies the day transmission is better. At other locations still further away, there are indications that for each distance a frequency will also be found which will give better signals by day than by night. This checks with the present theory of short wave trans-

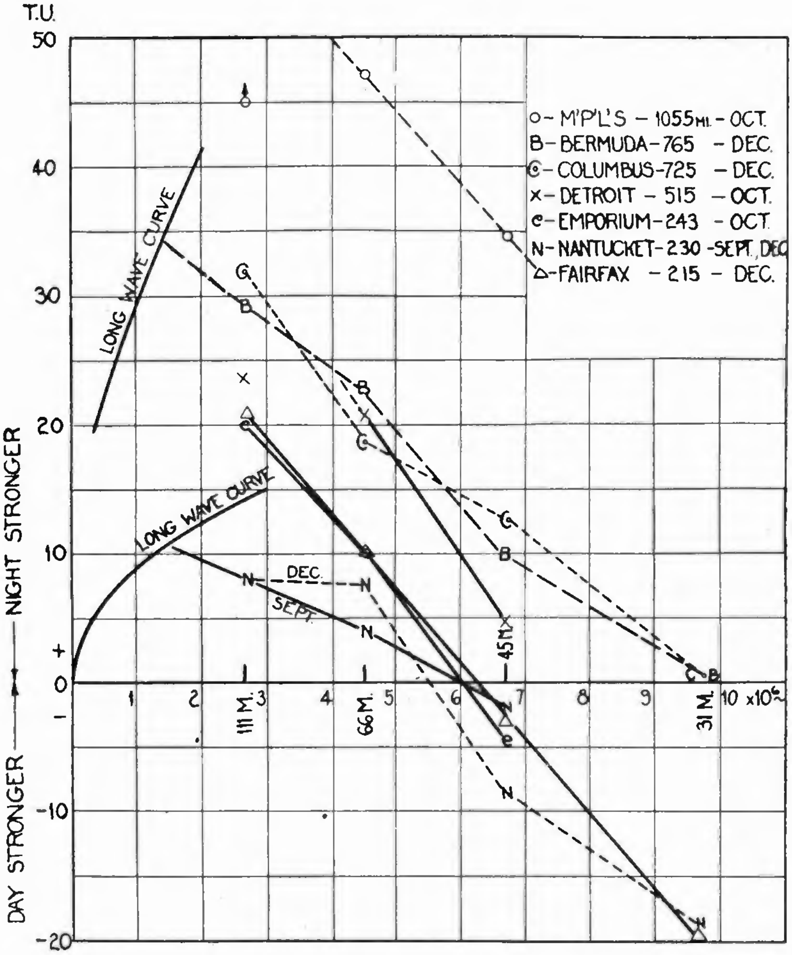

FIGURE 22—Ratio of Average Night to Average Day Signals as a Function of Frequency

mission in that the overhead wave returns to earth at greater and greater distances as the frequency is increased.

On this same sheet are plotted two semi-empirical long wave curves for distances corresponding to Nantucket and Bermuda. The values for day transmission were assumed as those given by the Austin-Cohen formula. The values for night transmission were assumed as being inverse law values without any absorption. This second assumption makes the ordinates of the curve larger than their actual values should be. The two over-water curves, which were secured at Bermuda and Nantucket, when extrapolated backwards, intersect these curves in the neighborhood of 1.5 megacycles (200 m.). The maximum advantage of night over day transmission should occur around this value and the change in sign of the slope in passing the intersecting point would indicate that some unusual phenomena occur there. It may be more than a coincidence that this point is near the critical frequency, which Nichols and Schelleng pointed out as due to the motion of free electrons in the earth's magnetic field.

Fading and Quality

All rates of fading have been observed from zero to probably 100 per second. Records were taken, both with an oscillograph and with signal strength recorders. Most fading is relatively slow; also, it is more prevalent at night. At any given location frequencies very close together do not fade simultaneously. The types of fading may be the same, but there is no connection between their maximum or minimum values. Figures 23 and 24 are copies of our fading records, made with the recorder at Columbus, Georgia, and Hamilton, Bermuda, between 4:05 p. m. and 8:45 p. m., December 15, 1925. Comparison of these records shows that at times the types of fading at the two locations are the same and at other times they are different. A survey of all our records at locations for which we have simultaneous observations, shows that there is a slight tendency towards similar types of fading occurring at two locations. As a rule the fading on the longer waves is less than on the shorter, although there are cases where the fading on the shorter waves is small.

The observed fading might be classed as first, uniform or synchronous (where carrier and side band fade together), and second, asynchronous (where the frequencies do not fade together). The former is easily compensated for by a gain control adjustment while the latter is not. Asynchronous* fading is most troublesome at the moment the carrier is reduced to the magnitude of the side bands or lower. When the carrier drops to such a value, the distortion of the signal becomes so great that a word may be lost. When in addition, fading is rapid, that is,

*This type of fading is discussed by Bown, Martin and Potter in the I. R. E. Proceedings for February, 1926.

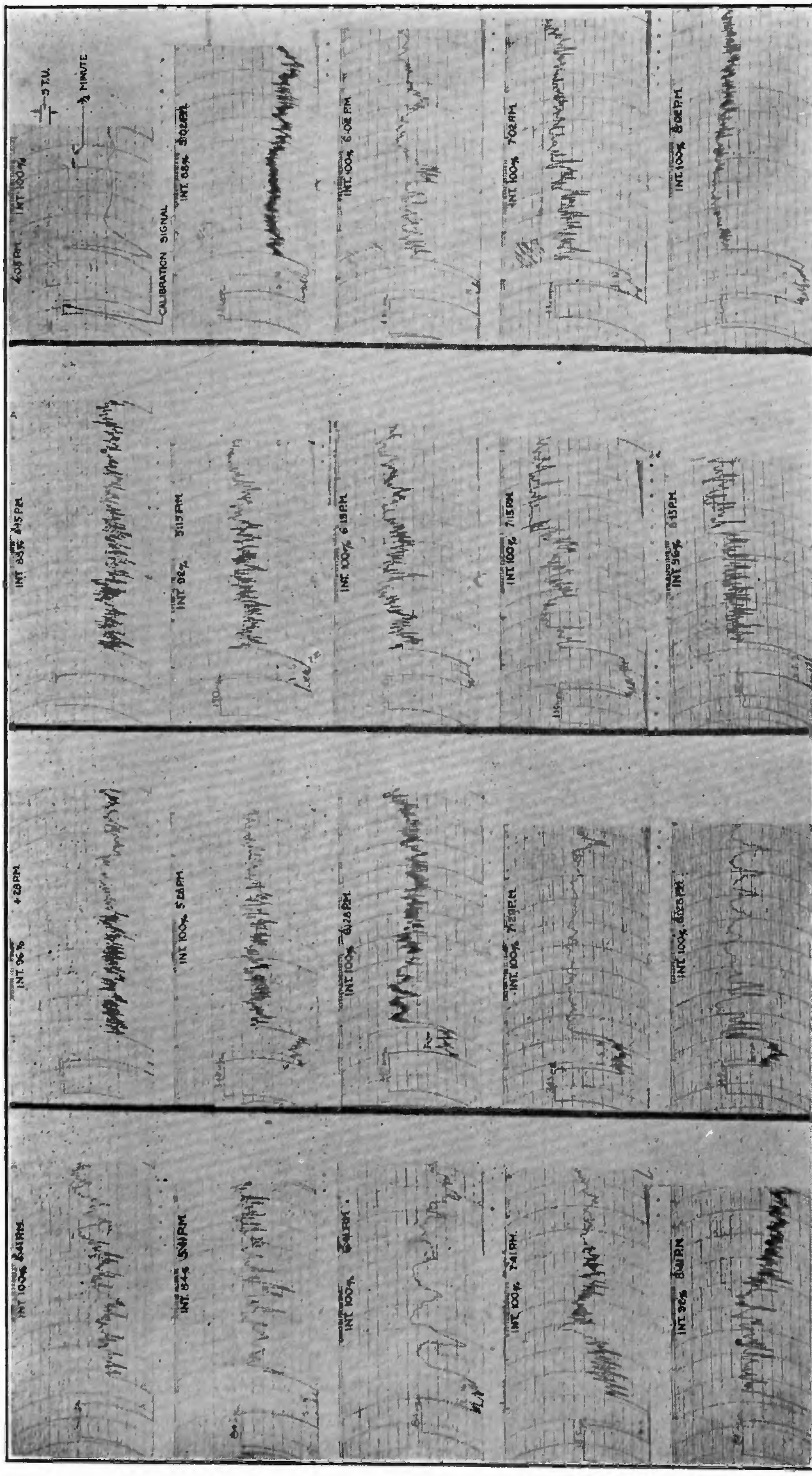

FIGURE 23—Records Showing Signal Strength and Fading Taken with Recorder at Columbus, Ga., Between 4:00 and 8:45 p. m., Dec. 15, 1925

several times a second, speech may be practically unintelligible.

When the fading is asynchronous, the quality may vary over a wide range. Some preliminary experiments indicate that single side band reception gives noticeably higher intelligibility and quality than ordinary double side band carrier reception under asynchronous fading conditions.

Noise

There was very little trouble due to strays, although the measuring equipment had been made more sensitive than it was expected such strays would allow. Actual limit for the reception of signals was fixed by set noise.

Transmission From Horizontal Antennas

In the tests which have been described vertical antennas were employed at the transmitting station. In addition to these, however, tests in which a horizontal radiating conductor was used have been made at certain wavelengths. This form of radiator was originally provided for use in special experiments in which the usual "ground wave" is eliminated. A horizontal current above a plane perfectly conducting earth radiates scarcely anything in a horizontal direction, due to the fact that the effect of the image is equal and opposite to that of the antenna itself. Imperfect conductivity in the earth will, of course, increase the amount radiated horizontally, but there are good reasons for expecting that this will be quickly absorbed. The second reason for the use of a horizontal radiator lay in the possibility of its affording a more efficient antenna than the vertical type under certain conditions. It is the purpose of the present paper to discuss only the transmission features of this type of antenna and not its design.

It was soon found that there are times when the signal from the horizontal antenna is actually greater than that from the vertical antenna, the currents in both being equal. The fact that any signal is received at all at a point on the earth's surface at right angles to the antenna seems to be direct proof that there is, somewhere above the surface of the earth, a deflecting layer which is able to bend a wave, originally proceeding upward, so that it will return to the earth.

In Figure 25 are shown three pairs of records taken at Albertson and Quogue, Long Island, on a vertical loop or antenna at a frequency of 4.5 megacycles (66 m.). These are typical of

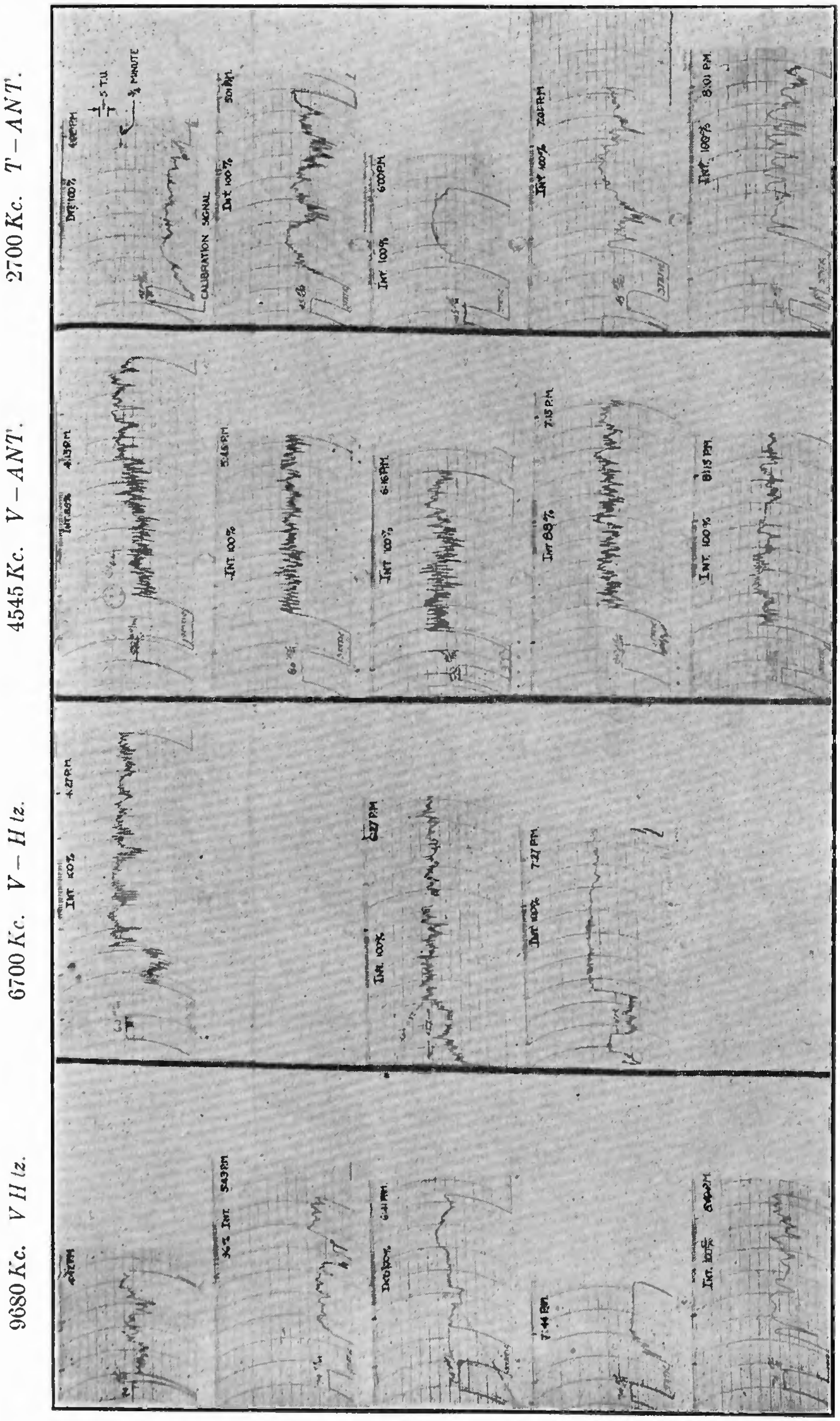

FIGURE 24—Records Showing Signal Strength and Fading Taken with Recorder at Bermuda at the Same Time as Records of Figure 23

what is observed at receivers which lie within the range of the ground wave. Records of both horizontal and vertical transmission are given so that a comparison may be made of the manner in which the signals fade in the two cases. The pair for 9:00 a. m., September 11 (Albertson), show that it is possible for the signal received from the vertical antenna to be constant at the same time that violent fading is obtained in that from the horizontal antenna. In this case the signal from the horizontal type changes from a value which is greater than that from the vertical to one which is less within three minutes. In the pair for 5:00 p. m., September 12 (Albertson), the maximum amplitude from the horizontal exceeds the maximum from the vertical by 19 T. U., or nearly ten times. Fading is also observed from the vertical antenna. At 1:00 p. m. on September 11 (Quogue), the signal from the vertical antenna was considerably lower in intensity than that from the vertical, and faded rapidly.

This difference in the character of signals from two types of antennas clearly shows that the signal is made up of components which are traveling along different paths. This evidence is obtained only when the receiver is not so distant that the ground wave is eliminated. For distant points, as will be shown later, these differences are not found and evidence for more than one path must be sought by other methods. Records have been taken at distant points but are not shown.

It is of interest to notice the differences which are found between these two types of radiators with respect to the shape of the curves which show diurnal variation. Such a comparison is made in Figure 26, which shows curves taken at various distances. At Long Beach, Albertson and Quogue, all less than 100 miles (161 km.) from the transmitter, the signal received from the vertical antenna is nearly constant throughout the whole 24 hours, indicating that the ground wave predominates. However, there are variations in average signal of approximately 20 T. U. (10:1), when the horizontal antenna is used. This is further evidence that the wave travels along two or more different paths. At Nantucket, a distance of 230 miles (380 km.), the signal from the vertical antenna varies considerably throughout the day. The shape of the curve from the vertical antenna resembles that from the horizontal antenna, although the variations in the latter are the greater. In each of these curves there is a minimum occurring a few hours before dawn, and also one shortly after noon.

The same shape of curve is thus characteristic of the signal

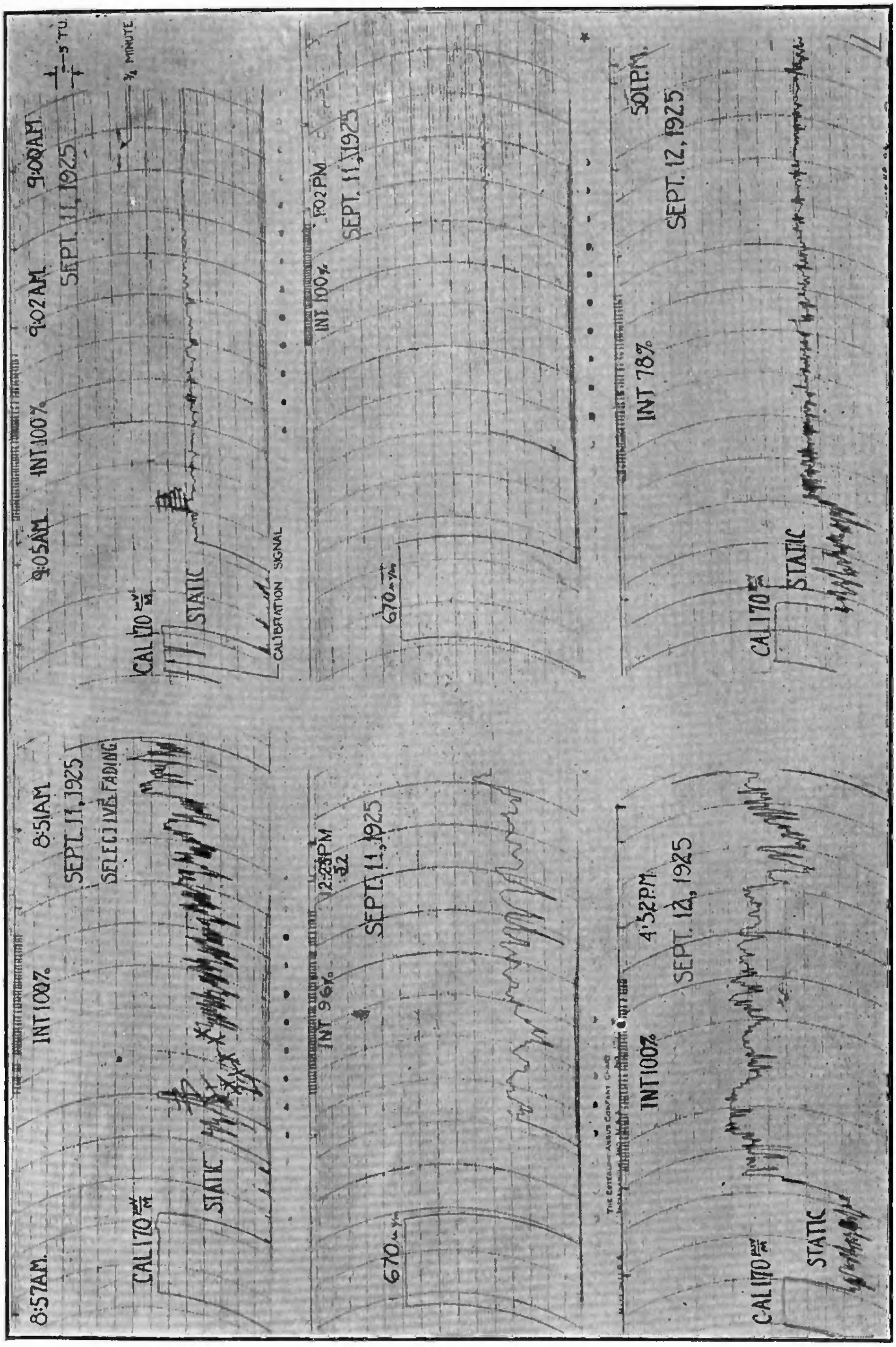

FIGURE 25—Comparison of Signals Received From Horizontal (left) and Vertical (right) Transmitting Antennas. First and Third Pairs of Records Were Taken at Albertson, 47 Miles, Second Pair Taken at Quogue, 90 Miles ← Time

received from the vertical antenna at moderate distances and that from the horizontal antenna at a nearby point. It is of interest to notice that at the more distant locations, Detroit and Minneapolis, the differences between signals from the two antennas disappear. This is evidence that the wave follows the same path to distant points regardless of the form of the transmitting antenna, and hence of its initial state of polarization. Since the radiation from the horizontal antenna must be primarily at an elevated angle, this indicates that the only signal from the vertical antenna that ultimately arrives at a distant point is that which is emitted at an angle above the horizontal.

One characteristic of these curves is that under the conditions of this experiment, the horizontal antenna is superior to the vertical at distances up to 100 or 200 miles in the early evening. On the other hand, the vertical antenna is more effective at noon and a few hours before sunrise.

Discussion of Results

It is not our purpose in the present paper to discuss in great detail the theoretical aspects of the short wave problem. It will be well, however, to note some of the more important points of contact between the quantitative results presented and certain theoretical ideas. Broadly speaking, most of the typical short wave characteristics may be interpreted in terms of the Eccles-Larmor theory of ionic refraction. The magneto-ionic theory is also of use in explaining phenomena at the upper boundary of the short wave region, and the work of Sommerfeld can be applied at distances for which the ground wave is of importance.

In considering transmission of the overhead wave, two somewhat related phenomena must be taken into account. One of these is absorption; the other is refraction. With respect to the former we may in most cases neglect that which is due to the ground. It is true, however, that the nature of the earth is of importance, both in transmission to nearby points and in cases of multiple "reflection." In other cases, when the signal fails it is interpreted as due either to absorption in the upper atmosphere, or to the absence of the proper ionization to produce the necessary bending of the wave.

Absorption is probably the cause of the daylight minimum, commonly found at frequencies below 7.5 megacycles (40 m.), and at such distances from the transmitter that the overhead wave dominates. It is possible that such absorption may play a part in producing the skip depression of the surfaces at nearby

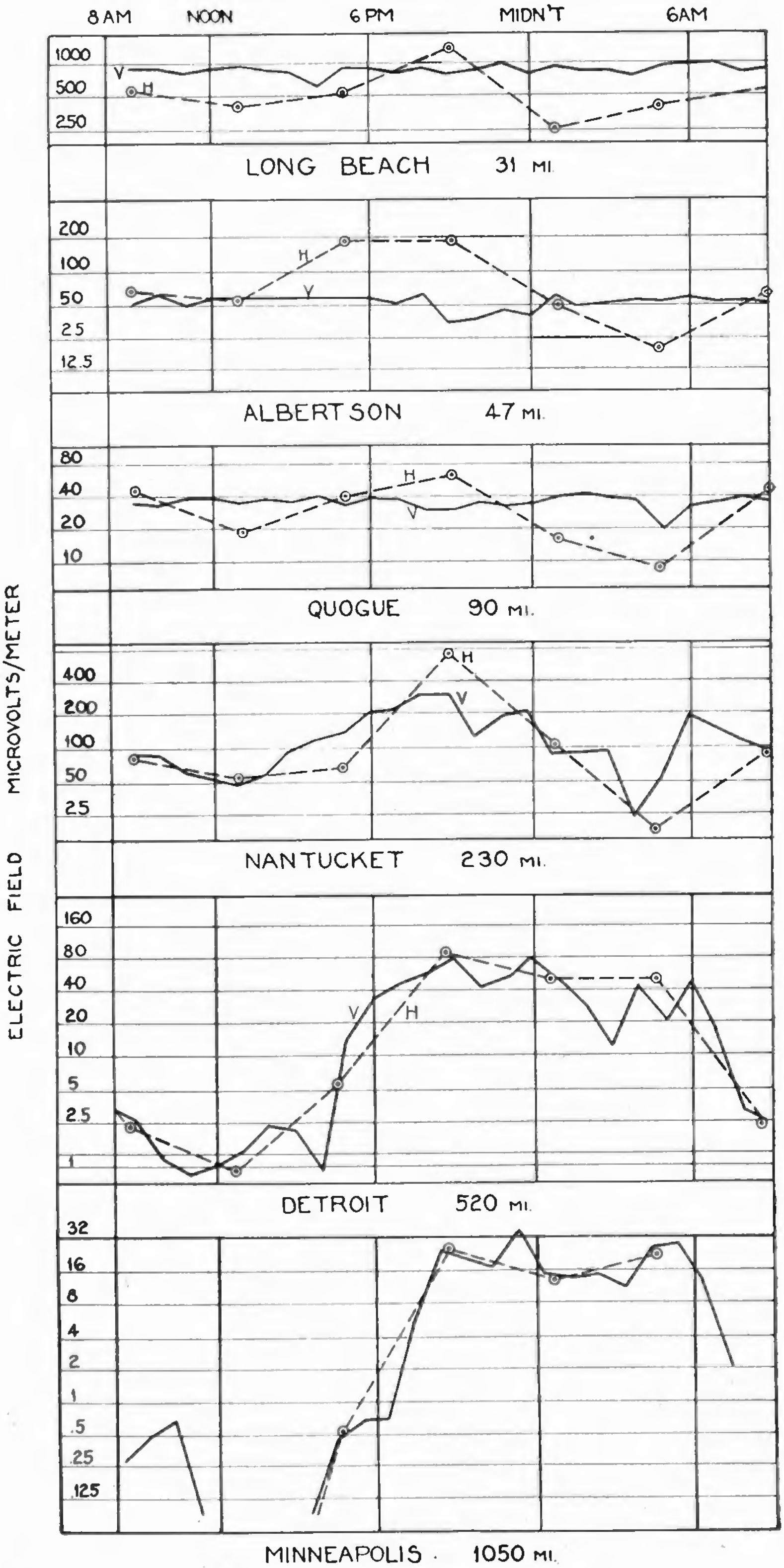

FIGURE 26—Diurnal Curves for Horizontal and Vertical Transmitting Antennas Compared

points, as suggested by E. V. Appleton, but we do not believe that it is the most important reason. The other explanation of the skip phenomenon assumes with Eccles (Electrician, vol. 71, 1913, pp. 969-970), that with increasing height the ionization increases, approaching a maximum value. Eccles showed that, under certain conditions, the index of refraction becomes zero and that this results in very abrupt bending, almost equivalent to reflection even with nearly normal incidence. (Elect. vol. 69, 1015.) He calculated trajectories for several assumed distributions of ionization and indicated that, with certain assumptions regarding the variations of refractive index, caustics and foci are found. The recent work of Hulburt has led to much more definite agreement between the theory and experimental results.

Reference has been made to the mass of qualitative evidence which has accumulated, indicating the existence of a skip effect. The quantitative data of the present paper confirms this position. As the frequency is increased the skip distance increases, appearing at first during the early hours of morning when recombination has reduced ionization below the value required for transmission. As the frequency increases the time during which the skip effect occurs increases, as should be expected from theory. In addition, the high degree of ionization which obtains during the day, becomes less harmful to the signal, a result predicted by the theory, which indicates that under similar conditions the absorption constant should be inversely proportional to the square of the frequency. Thus the signal is weakened during the night, but encounters better conditions during the day, a reversal of the trend at long wavelengths. At a distance of 800 miles, the frequency of 18 megacycles is so high that the noon-time ionization is just barely sufficient to produce the necessary bending. A small increase of frequency will probably cause the signal not to be heard at all during the 24 hours. This agrees roughly with the data of Taylor and Hulburt.

It is of interest to observe that the data checks the experiments of Taylor in the neighborhood of 4.5 megacycles, where the pronounced skip effect begins to take place, but there are some traces of the effect at even lower frequencies. It may be added that to a certain extent the skip depression is the result of the fact that the wave reaching the observing point is weak, regardless of which path it follows. If it travels over the ground path it will be greatly attenuated by absorption. If it follows the overhead path, the inefficiency of radiation of the vertical antenna at the high angle at which it must leave will make it weak at the start. This effect, however, does not affect the results materially except perhaps at nearby points.

The frequency which can best be used for a particular service is a function of distance and time of day. The results of the present study indicate that for telephonic communication to distances of 200 miles, frequencies of 3 megacycles or less are the most useful of the short wavelength range, while distances of 500 miles call for about 6 megacycles. These frequencies will in general provide 24-hour service on a single wavelength. Continuous contact with stations at much greater distances in general requires a shifting of frequencies. Thus, for distances of 1,000 miles, frequencies of the order of 10 megacycles are of use during the day, while lower frequencies become preferable during the night and in fact are necessary at times.

For transatlantic communications the 3 megacycles wave is not of much use for telephony even at night when the radiated power is a few kilowatts. The reservation should be made, however, that this statement may not be correct when the single sideband transmission or directive radiation or reception is employed. It may be added that on those occasions when the signal has been strong at this frequency, the quality has usually been superior to that on the higher frequencies. During the day, frequencies of the order of 15 megacycles appear to be useful, although the indications are that 24-hour service will require a frequent shift of wavelength.

Credit for many valuable suggestions must be given the late Dr. H. W. Nichols, under whose direction this work was begun and largely carried out, and to Mr. J. F. Farrington, who made our early experiments and developed most of the present measuring equipment. It is evident from the scope of this work that the writers are acting as spokesmen for the group of engineers whose able and untiring participation in these experiments have made them possible.

SUMMARY: Quantitative data on field strength and telephonic intelligibility are given for transmission at frequencies between 2.7 megacycles (111 m.) and 18 megacycles (16 m.), and for distances up to 1,000 miles with some data at 3,400 miles. The data are presented in the form of curves and surfaces, the variables being time of day, frequency and distance. Comparisons are made between transmission over land and over water, between night effects and day effects, and between transmission from horizontal and from vertical antennas. Fading, speech quality and noise are discussed. The results are briefly interpreted in terms of current short wave theories.

THEORY OF DETECTION IN A HIGH VACUUM THERMIONIC TUBE*

By

Lloyd P. Smith

Some phases of the subject of detector action have been more or less vaguely understood in the past, due in part to the fact that the detector, as such, worked fairly well and all attention was turned to the amplification of the detected signal and to reproduction by means of the loud speaker. Amplifiers and loud speakers have been developed which reproduce the detected signal very accurately and so attention has been again centered around the detector. One common method of detection is by use of the high vacuum triode with the so-called grid leak and condenser, commonly called grid rectification. It is the mechanics of this method that will be discussed in this paper.

Effect Produced by Alternating E.M.F. on the Grid

In grid rectification the grid current-grid voltage characteristic of the tube is used. Three of these characteristic curves are shown in Figure 1, taken at plate voltages of 45, 90 and 135 volts. The reason that the grid current decreases when the plate potential is increased, with a constant grid potential, is that the electrons are given a higher velocity toward the plate and are not deflected from their path so easily with given grid potential and therefore fewer electrons strike the grid, and the grid current is consequently smaller.

Now let us investigate what takes place when the potential of the grid is varied. Suppose, for analysis, that we take a static characteristic as shown in Figure 2 and fix the grid potential at a value corresponding to the point a. If we impress an alternating *e.m.f.* on the grid of instantaneous magnitude e, and a maximum E, the grid potential will oscillate about the point a, an equal amount on either side, parallel to the voltage axis. Because of the shape of the characteristic the grid current will not oscillate symmetrically about the steady or continuous current I_c but will be distorted somewhat and displaced above the steady current

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line I_c. It is evident then that the average grid current will be increased by an amount ΔI_c. Since the potential a, impressed on the grid remains constant and the average grid current in-

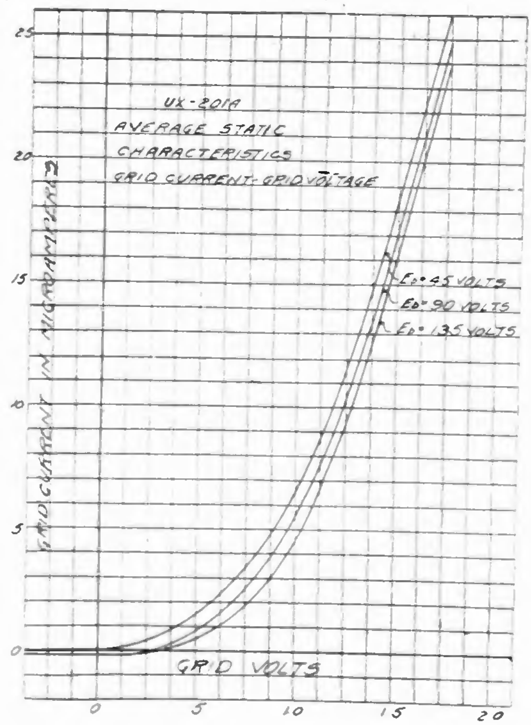

FIGURE 1

creases, a point b will be determined on a new or dynamic curve shown by the dotted curve. From this reasoning it would appear

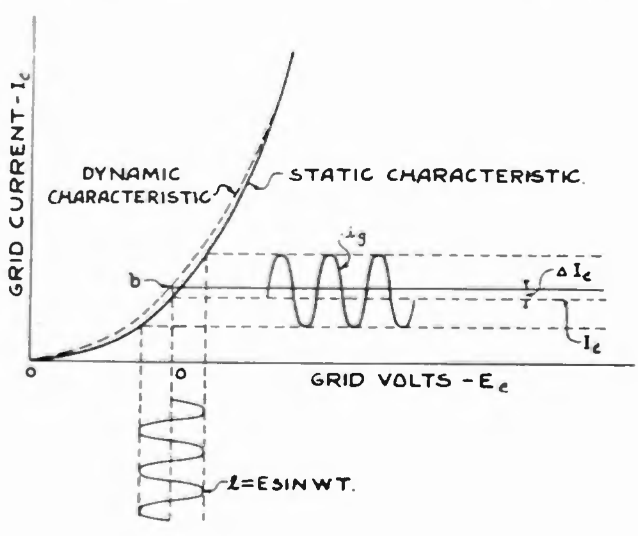

FIGURE 2

that such a dynamic curve would deviate from the static curve in the part where it had curvature—*i.e.*, where rectification took place—and approach the static characteristic where the curvature became inappreciable.

To verify this theory a static characteristic was taken on a UX 201-A tube with a constant plate potential of 45 volts and a filament potential of 5 volts. The range of grid potential covered was from 0 to +1.75 volts. Then with the same conditions two dynamic curves were taken, one with 100 millivolts and the other with 200 millivolts of approximately one million cycles radio frequency impressed on the grid. The results of these experiments are shown by the curves of Figure 3, together with additional dynamic curves corresponding to greater signal amplitude. As can readily be seen, the dynamic characteristics do depart from the static characteristic throughout the curved portion, and verify the preceding theory. From the spacing of these curves it is at once evident that the increase in current does not vary directly with the magnitude of the impressed radio frequency voltage.

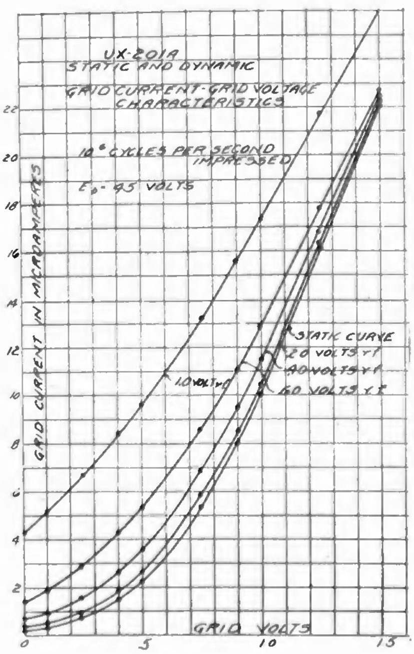

FIGURE 3

It will be interesting at this time to investigate the relation existing between the increase in grid current and the magnitude of the radio frequency *e.m.f.*, since for the static case the grid current Ic is a function of the grid potential Ec, which will not be specified but will be represented as follows:

$$^{*}I_c = f(E_c) \tag{1}$$

The instantaneous increase in grid current due to an instantaneous potential e on the grid is denoted by i_g, and the total grid current at any instant is

$$I_c + i_g = f(E_c + e) \tag{2}$$

Expanding this by Taylor's theorem gives

$$I_c + i_g = f(E_c) + f'(E_c)e + f''(E_c)\frac{e^2}{2!} + f'''(E_c)\frac{e^3}{3!} + f''''(E_c)\frac{e^4}{4!} + \ldots. \tag{3}$$

Differentiating expression (1)

$$f'(E_c) = \frac{dI_c}{dE_c}$$

$$f''(E_c) = \frac{d^2I_c}{dE_c^2} etc.$$

and substituting these relations in (3) gives

$$I_c + i_g = f(E_c) + \frac{dI_c}{dE_c}e + \frac{dI_c}{dE_c^2}\frac{e^2}{2!} + \frac{d^3I_c}{dE_c^3}\frac{e^3}{3!} + \frac{d^4I_c}{dE_c^4}\frac{e^4}{4!} + \ldots. \tag{4}$$

But from equation 1, $I_c = f(E_c)$. Therefore the increase in grid current i_g is approximately as follows, using only the first four terms of the series

$$i_g = e\frac{dI_c}{dE_c} + \frac{e^2}{2!}\frac{d^2I_c}{dE_c^2} + \frac{e^3}{3!}\frac{d^3I_c}{dE_c^3} + \frac{e^4}{4!}\frac{d^4I_c}{dE_c^4} + \ldots \tag{5}$$

Since e is a function of time and in this case assumed to be a simple sine function

$$e = E \sin wt$$

The average change, ΔIc, of grid current will be $1/2\pi$ times the integral of the right hand member of equation (5) from 0 to 2π. Substituting the value of e in (5) and integrating, expression 5 becomes

$$\frac{dI_c}{dE_c}\frac{1}{2\pi}\int_o^{2\pi} E \sin wt\, dt = o \tag{6}$$

Integrating the second term gives

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*J. C. Carson and J. H. Morecroft have given somewhat similar mathematical treatments, but without any relation to dynamic characteristics, and it therefore was thought necessary to carry out a mathematical development with this purpose in view.

$$\frac{d^2I_c}{dE_c^2}\frac{1}{2\pi}\int_o^{2\pi}\frac{E^2}{2!}sin^2 wt\, dt = \frac{E^2}{4}\frac{d^2I_c}{dE_c^2} \tag{7}$$

Integration of the third term gives

$$\frac{d^3I_c}{dE_c^3}\frac{1}{2\pi}\int_o^{2\pi}\frac{E^3}{3!}sin^3 wt\, dt = o \tag{8}$$

Integration of the fourth term gives

$$\frac{d^4I_c}{dE_c^4}\frac{1}{2\pi}\int_o^{2\pi}\frac{E^4}{4!}sin^4 wt\, dt = \frac{E^4}{64}\frac{d^4I_c}{dE_c^4} \tag{9}$$

Adding (7) and (9) we obtain a very close approximation for the average increase in grid current, thus

$$\Delta I_c = E^2\frac{dE_c^2}{d^2I_c} + \frac{E^4}{64}\frac{d^4I_c}{dE_c^2} \tag{10}$$

From (10) it is seen that the average rectified current varies as the square and fourth power of the maximum input voltage. This is a fault inherent in rectification by curved characteristics and leads to distortion. Since the value of E in equation (10) is always small—usually very much smaller than 1—it is evident that the second term of equation (10) will be very small compared to the first and can be disregarded in all practical considerations. Therefore

$$\Delta I_c = \frac{E^2}{4}\frac{d^2I_c}{dE_c^2} \tag{11}$$

where the impressed voltage is a sine wave.

Effect of a Modulated E.M.F. on the Grid

Now let us extend this discussion to the case where a modulated wave is impressed on the grid. The instantaneous voltage of the ordinary modulated wave can be expressed mathematically as follows:

$$e = E\, cos\, pt\, (1 + K\, cos\, qt) \tag{12}$$

where $E\, cos\, pt$ represents a wave of radio or carrier wave frequency and $EK cos qt$ is a wave of audio frequency. K is the ratio of the amplitude of audio frequency to that of the radio frequency and is a measure of the per cent modulation. When $K = 1$, the amplitudes of the audio and radio frequency are equal and the resulting wave is said to be 100 per cent or completely modulated.

It is interesting to note what the instantaneous value of the increase in grid current, i_g, is, with a modulated wave of the form shown in equation (12). Substituting the value of e from equation (12) in equation (5), we have

$$i_g = \frac{d\,I_o}{d\,E_c}\left\{E\cos p\,t(1+K\cos q\,t)\right\} + \frac{d^2\,I_c}{d\,E_c^2}\left\{\frac{E^2}{2\,!}\cos^2 p\,t(1+K\cos q\,t)^2\right\} + \qquad (13)$$

The remaining terms in equation (5) will be omitted, since they are very small and can be disregarded.

The first term in (13) does not contain a pure audio frequency term and will not be considered, as we are interested in the rectified audio component only. It will not give an increase in the average grid current.

The second term of (13) contains a direct current component as well as audio frequency components, which will be seen by expanding the second term as follows:

$$\frac{d^2\,I_c}{d\,E_c^2}\left\{\frac{E^2}{2\,!}\cos^2 p\,t(1+K\cos pt)^2\right\} = \frac{d^2\,I_c}{d\,E_c^2}\,\frac{E^2}{2\,!}\left[\begin{array}{l}\cos^2 p\,t+2\,K\cos^2 p\,t\cos q\,t\\ +K^2\cos^2 p\,t\cos^2 q\,t\end{array}\right] \qquad (14)$$

Expanding further we have

$$d\,g = \frac{E^2}{2\,!}\left[\begin{array}{l}\frac{1}{2}+\frac{1}{2}\cos 2\,p\,t+K\cos q\,t+K\cos 2\,p\,t\cos q\,t+\\ \frac{K^2}{4}+\frac{K^2}{4}\cos 2\,q\,t+\frac{K^2}{4}\cos 2\,p\,t+\frac{K^2}{4}\cos 2\,p\,t\cos 2\,q\,t\end{array}\right] \qquad (15)$$

In this expression we are interested only in the direct current components and the audio frequency components, so we will disregard the radio frequency terms and those which represent the side band frequencies. The resulting expression for the direct current and audio components of grid current is

$$i_g = \frac{E^2}{2}\left[\left(\frac{1}{2}+\frac{K^2}{4}\right)+K\cos q\,t+\frac{K^2}{4}\cos 2\,q\,t+\ldots\ldots\right]\frac{d^2\,I_c}{d\,E_c^2} \qquad (16)$$

This equation gives a close approximation to the instantaneous increase in grid current. An analysis of this expression shows several interesting points—for instance, the first group of terms represents the direct current component of the increase in grid current; the second term, $K\cos qt$, is the most important term for this is the change of grid current corresponding to the audio frequency impressed on the grid in the modulated wave. This term will be discussed in detail later. The third term, $\frac{K^2}{4}\cos 2\,q\,t$, represents the second harmonic of the audio frequency. This term is worthy of note, since if 100 per cent modulation is used

$K=1$ and the detected audio note will contain 25 per cent second harmonic.

Let us now consider what the relation is between the results derived above and the change in the dynamic characteristic of the tube. The average increase in grid current for the pure sine wave is given by equation (11). By inspection of the expression it is at once evident that the increase in average grid current varies as the square of the impressed voltage, and this accounts for the increase in spacing between the dynamic characteristics shown in Figure 3. The effect of a modulated wave, of the form expressed in equation (12), on the tube characteristic is somewhat more complex. The average increase in the grid current will be given by integrating the right hand member of equation 15 over a long period of time. If this is done all of the cosine terms become zero and the average increase in grid current ΔI_c (modulated) becomes that corresponding to the first terms of equation (16), *e.g.*

$$\underset{(mod)}{\Delta I_c} = \left[\frac{E^2}{4} + \frac{E^2 K^2}{8}\right] \frac{d^2 I_c}{d E_c^2} \tag{17}$$

Now for the moment let us forget the cosine terms in equation 16, since they do not affect the average value of the grid current, and draw a characteristic of the tube in which the total grid current will be $I_c + \Delta I_c$. This is shown in Figure 4. It is clear

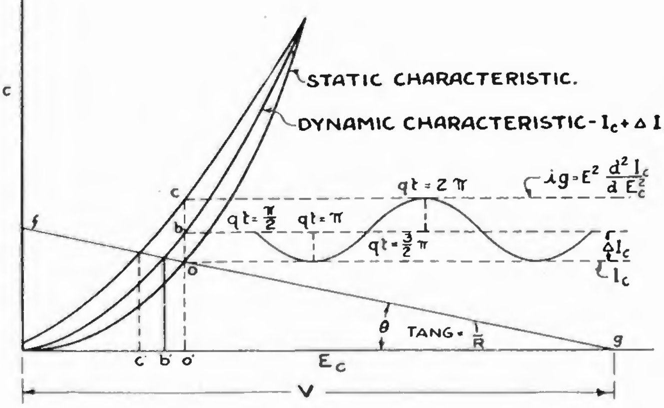

FIGURE 4

that the instantaneous value of the change in grid current, i_g, will oscillate about the average value of grid current, $I_c + \Delta I_c$. Suppose we impress a modulated wave on the grid with a definite grid potential a. The grid current will be increased by ΔI_c, and therefore will increase from the point a to be when $qt = \frac{\pi}{2}$ in equation (16). When qt increases to π equation (16) becomes

$$i_g = \left[\frac{E^2}{4} + \frac{K^2 E^2}{8} - \frac{K E^2}{2} + \frac{K^2 E^2}{8}\right] \frac{d^2 I_c}{d E_c^2} \qquad (18)$$

Now when the wave is 100 per cent modulated $K=1$, the right hand member of 18 reduces to zero and the grid current corresponds to the static value of I_c. Therefore between the values of qt equals $\frac{\pi}{2}$ and π the grid current decreases from b to a (Figure 4). Likewise when $qt = 2\pi$ the right hand member of (18) becomes $E^2 \frac{d^2 I_c}{d E_c^2}$, when $K=1$ and the grid current is increased from a *to* c. From this it is seen that the current varies periodically about the point b, between the static and dynamic characteristic through the point c. This is the phenomenon which takes place in the tube when a modulated wave is impressed on the grid without grid leak and condenser. There is obviously no change in the grid potential at an audio frequency, only an audio frequency change in grid current, *so there could be no change in plate current and therefore no detection.*

Function of Grid Leak and Condenser

In the case of detection with a grid leak and condenser the plate current decreases when the signal is impressed on the grid, and this occurs by a decrease in the grid potential. Referring to Figure 5, which is the ordinary grid lead and condenser circuit

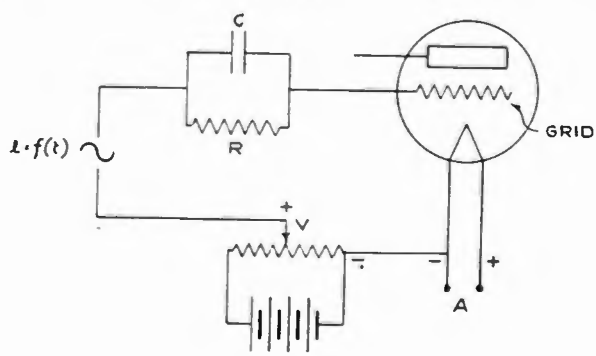

Figure 5

used with a high vacuum tube, it is evident that any increase in the direct current flowing to the grid must pass through the grid leak, R, which is a high resistance of about 1 to 10 megohms. In this circuit is an arrangement for varying the potential of the grid which makes it possible to operate the tube on any part of its characteristic—in other words, to vary the position of the point a (Figure 4). The current passing through the grid leak R for any voltage V can be represented by the straight line fg (Figure 4) so that the intercept on the voltage axis corresponds to the value V and the slope $1/R$. This assumes, of course, that the resistance of the leak remains constant. Now suppose V is adjusted so that the line fg intersects the static characteristic at the point a. The intersection of the grid leak line and the static characteristic determines the initial value of the grid potential.

Then if a sine wave of radio frequency is impressed on the grid, such that it will produce an increase in grid current from a to b, this increase in average grid current must flow through the grid leak, causing an increased voltage drop across the leak, and therefore must follow along the grid leak line. The point of equilibrium will be at the point where the grid leak line fg and the dynamic characteristic through the point b intersect. This will decrease the grid potential from a' to b' and thus cause a drop in plate current. It is assumed that all of the radio frequency passes through the condenser as its reactance to high frequency is small compared to the large value of R. This explains why grid leak and condenser detection takes place with a decrease in plate current.

If a modulated wave be impressed on the circuit of Figure 5, such that the increase in average grid current is ΔI_c and the value of qt in equation (16) is equal to $\pi/2$, the grid current will come to the equilibrium point as before where the line fg intersects the dynamic characteristic through b. It was shown before that the grid current varied at an audio frequency made up of the fundamental and second harmonic, as shown in equation (16). Now since the capacity of the grid condenser C is very small—about .00025 microfarads—it offers a relatively high reactance to the audio frequency and it will be assumed for the present that all of the audio frequency passes through the grid leak. This varying current therefore must follow along the grid leak line fg at audio frequency. If the wave is 100 per cent modulated, $K = 1$ and the limiting movement for one complete cycle of audio frequency is the intersection of the grid leak line fg with the static characteristic on one hand and its intersection with the dynamic characteristic through c. It is then clear that the potential of the grid must vary harmonically at audio frequency between the points a' and c'. It is this variation in grid potential that produces a corresponding change in plate current.

By inspection of Figure 4 it is evident that the greatest change in grid potential will take place when the grid leak line approaches a horizontal position—*i.e.*, the value of R is increased and at the same time it must pass through the tube characteristics where they are the greatest distance apart. Thus a high value of grid leak can be used provided V is increased to a value such that the line will pass through the characteristics at the point where they are spaced farthest apart. Likewise for smaller values of R the slope of the line fg will be increased and V will have to be adjusted as before. A grid leak line corresponding to 1.5 megohms is fairly flat and very little is gained by increasing the grid leak resistance above this value excepting that it brings the line through the correct part of the characteristics when the value of V is fixed—*e.g.*, when the grid is returned to the positive side of the filament.

Experiments were made in which a radio frequency of approximately one million cycles per second was modulated 100 per cent by an audio frequency of 500 cycles per second. The circuit used was so arranged that the grid bias could be adjusted and the output of a tube could be measured for definite values of input voltage impressed on the grid. With this arrangement various values of grid leak were tried—from ¼ megohm to 10 megohms—and the potential of the grid was readjusted to give maximum output. In every case this was found to agree with a value determined by the slope of the grid leak line and the portion of the characteristics where the spacing was greatest—all of which shows that the grid potential should be adjusted to the point where the rate of change of slope of the grid characteristic is a maximum; *e.g.*, $\frac{d^2 I_c}{d E_c^2} = \text{maximum}$.

It is now necessary to make a modification of the change in grid potential due to the movement along the grid leak line to take into account the effect of the grid condenser. At very low frequencies the above explanation holds, but for high audio frequencies and their harmonics a considerable part of the audio frequency current passes through the condenser. In order to see the combined effect of the capacitance and resistance it will be best to investigate what happens in the case of a pure reactance alone. If we have a circuit with a pure reactance the combined effect of the current and voltage will be an ellipse as shown in Figure 6. If the capacity is reduced the effect is to make the ellipse more slender and vice versa. If a resistance is put in parallel with the condenser, the result will be to shift the ellipse with reference to the current and voltage axes. Figure 7 shows an ellipse due to capacity and a straight line due to a pure resistance. To find the resultant path when a resistance and capacity are in parallel it is only necessary to add the currents, the voltage across them remaining constant. The resultant figure is shown in Figure 7. It should be pointed out that the resistance line does not coincide with the major axis of the resultant ellipse.

The case shown in Figure 7 is analagous to what happens in the grid leak and condenser. To determine the part played by

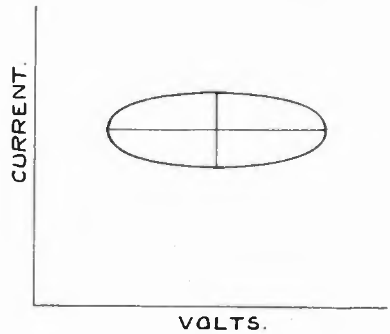

FIGURE 6

the condenser in conjunction with the tube characteristics we will refer to Figure 8, in which a section of the dynamic characteristic is shown on a large scale. In this case the ellipse due to the grid leak and condenser must remain tangent to the dynamic

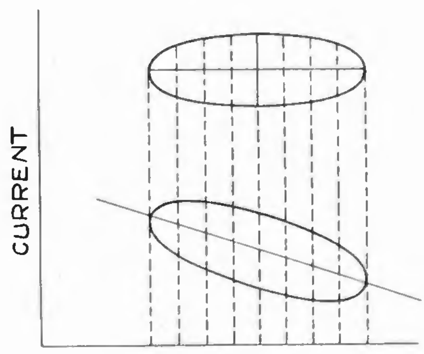

FIGURE 7

characteristic. Furthermore this ellipse is determined by the audio frequency change in the grid current, and it should be noted that it can not be a true ellipse because of the harmonics in the grid current. In this case the maximum change in grid potential is given by drawing lines $a\ a'$ and $b\ b'$ perpendicular to the voltage axis and tangent to the ellipse. This change is then $a'b'$.

It is evident that the ideal case would be to decrease the capacity and therefore make the ellipse approach the straight resistance line. In the practical case this is impossible because if the capacity is reduced the reactance to radio frequency is increased and the actual radio frequency voltage on the grid is very much reduced. If the capacity is increased or the audio frequency increased the effect is the same; the ellipse becomes broader or elongated in the vertical direction as shown in Figure 8 by the dotted ellipse, and the change in potential of the grid through one cycle of audio frequency is smaller than for a low capacity or low audio frequencies. This was verified by putting a variable condenser in parallel with the grid leak and the capacity

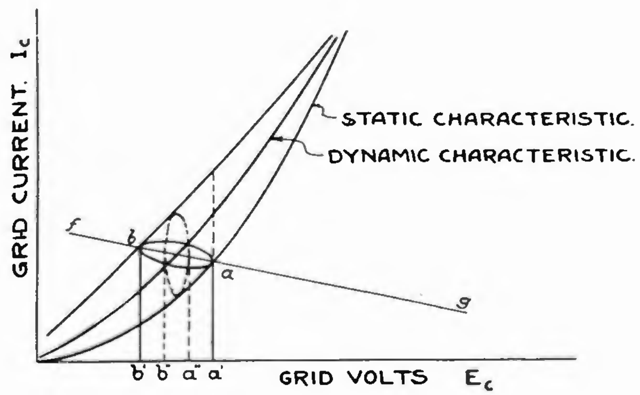

FIGURE 8

was varied from 50 to 500 micromicrofarads. It was found that the detector output increased rapidly until a capacity of 250 micromicrofarads was reached, then decreased less rapidly for large capacities. The reason for the small output at low capacities is the fact that the reactance to radio frequency causes a large drop in voltage across the condenser and the amplitude actually impressed on the grid is very small. After the 250 micromicrofarad capacity is reached the drop in output is due to the shifting of the ellipse as shown in Figure 8. There is also another capacity effect which causes a decrease in radio frequency voltage on the grid, and that is the interelectrode capacity of the tube. This produces somewhat the same effect as the grid condenser, but is much smaller. Thus it is seen that the grid leak and condenser method of detection produces frequency distortion.

From the preceding discussion it is evident that if the grid could be held at the correct initial potential good detector action could take place due to the capacity alone, since the capacity alone gives an ellipse whose axes are parallel to the coordinate axes. In order to verify this a high inductance was placed in the circuit in place of the grid leak. The inductance was such as to offer a reactance of about 6 or 7 megohms to an audio frequency of 500 cycles, and at the same time the resistance to direct current was relatively very small. If plotted this would give a grid leak line very close to perpendicular to the voltage axis, so the effect of resistance could be neglected. The potential of the grid was adjusted by varying the grid bias so that the tube was operating on the correct part of the characteristic. This condition approached that of a pure reactance circuit and it was found that the output of the tube was slightly greater than for the case of a grid leak, with the proper bias.

From the foregoing it is quite evident that the amplitude of the detected signal will vary as a function of the frequency of modulation. Thus for high frequencies the effect is the same as increasing the capacity and thereby decreasing the amplitude of the audio change in grid potential—in other words, the output will be decreased.

To determine whether a change in plate potential produced an appreciable effect on the dynamic and static characteristics of the tube three grid current-grid voltage curves were taken at values of plate voltage of 50, 45 and 40 volts. These curves are shown in Figure 9. They are quite close together with a 5-volt

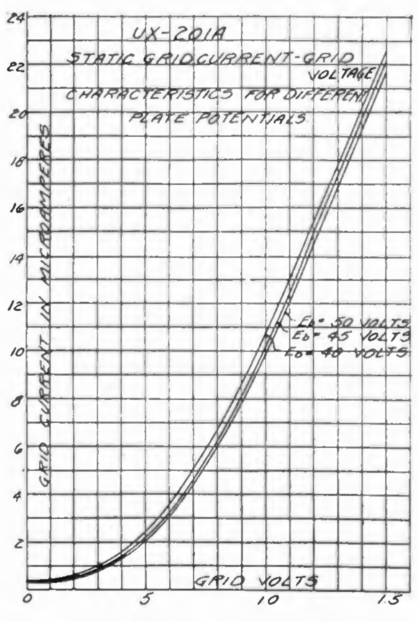

FIGURE 9

difference in plate potential and since the variation in plate potential is always very much smaller than this the effect can be disregarded as far as the preceding analysis is concerned.

The actual plate current produced by the variation in grid potential can be calculated but will be omitted here since it is not the purpose of this paper to enter into calculations of the plate circuit.

In conclusion the writer wishes to thank Mr. J. C. Warner and Mr. A. V. Loughren for their helpful suggestions in the preparation of this paper.

SUMMARY: In this paper some new ideas have been presented regarding tion by means of the high vacuum tube in connection with a grid leak and condenser with a grid leak and condenser, which show the function of the grid leak and condenser as well as their proper values for best detection. It has been shown that three main sources of distortion exist with this method of detection. They may be briefly stated as follows: Two sources from the curvature of the grid characteristic—one of which is frequently distortion due to the harmonics produced, and the other an amplitude distortion arising from the fact that the rectified grid current does not vary linearly with the input voltage. The remaining distortion is produced by the grid leak and condenser.

LONG DISTANCE RADIO RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE BUREAU OF STANDARDS IN 1925*

By

L. W. Austin

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The following is a resume of the measurements made by the Bureau of Standards on long wave, long distance signal intensities and atmospheric disturbances during 1925, with the addition of some comparisons of the field intensities and disturbances from 1922 to the present time.

The method of measurement is the same as has been used in former years, except in the case of reception through disturbances considerably stronger than the signals which, as is well known, tend to reduce the apparent signal strength. The necessary correction under these circumstances is now determined for each individual case by observing an artificial signal of the same apparent strength as the signal being measured both with and without the disturbances. In this determination the artificial signal is introduced directly into the secondary of the receiver (not through the antenna) from a loosely coupled radio frequency generator.

In the first case, the antenna is coupled normally so that the disturbances are received with the artificial signal, then the antenna is replaced by an artificial antenna with exactly the same constants and coupling to the secondary so that the beat note remains unchanged in shifting from one to the other. A simpler method of correction described in the report for 1924 did not prove entirely satisfactory under all circumstances on account of variations in the character of the disturbances.

In April 1925, Dr. Dellinger, Chairman of the Committee on Measurements and Standards of the American Section of the U. R. S. I., requested the Radio Corporation of America and the Bell Laboratories to bring long-wave field intensity measur-

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ing apparatus to Washington for comparison with the apparatus used at the Bureau of Standards. The methods used by the two companies were alike in employing a radio-frequency comparison in which the signal being measured is matched by an artificial signal of adjustable intensity, produced by a local radio-frequency generator.

In the Bell Laboratories system[1] the current for the local signal is first measured and then attenuated in a resistance network and introduced into the coil antenna at its middle point across a 1-ohm resistance; while the Radio Corporation[2] regulates the intensity of the local signal and introduces it by means of a calibrated mutual inductance. The Radio Corporation method is of especial interest since it is identical in principle with the methods commonly used for radio field intensity measurement in England, France and Germany. At the Bureau of Standards, long-wave field intensities are measured with the telephone comparator[3] in which a known audio-frequency signal is matched against the signal as heard in the telephones of the receiving set. Special calibrations of the apparatus are made from time to time either by means of a local generator or from signals of known intensity. The agreement between the three systems of measurement was very satisfactory, when the disturbances were not too heavy; the differences being generally less than 20 per cent on distant signals, with still better agreement on the nearer stations.

The tables and curves[4] giving the results of the year's work at the Bureau of Standards are self explanatory. In addition to the data for 1925, the curves show also some comparisons of the field intensities of various stations and the strength of the atmospheric disturbances in former years.

The seasonal variations of the continental European stations as observed in Washington now seem to be fairly clear. The 10 A.M. observations give all daylight path conditions, though during the shortest days of winter the Nauen observations, with

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[1] Proceedings of the Institute of Radio Engineers, vol. 11, p. 115; 1923.

[2] Proceedings of Radio Engineers, vol. 11, p. 661; 1923.

[3] Proceedings of The Institute of Radio Engineers, vol. 12, p. 521; 1924.

[4] The measurements are taken when possible on moderate speed transmission, as speeds above fifty words per minute are found to reduce the measured field intensity in a marked degree.

It is also to be noted that the two Ste. Assise stations formerly UFT and UFU are now FT and FU, while the old Nauen POZ is now AGS.

[5] Proceedings of The Institute of Radio Engineers, vol. 14, p. 7; 1926.

6 hours difference of time, have to be taken somewhat before 10 A. M. The winter A. M. signals of the northern European stations are weak in America, owing either to the approach of sunset in Europe, or to the proximity of the arctic darkness along the signal path as suggested by Espenschied, Anderson and Bailey[5] or possibly to a combination of these causes. The 10 A. M. signals become in general stronger through the spring and summer and reach a distinct maximum about September, after which they fall to their low winter values. The course of the 3 P. M. signals which are transmitted at about 8 P. M.

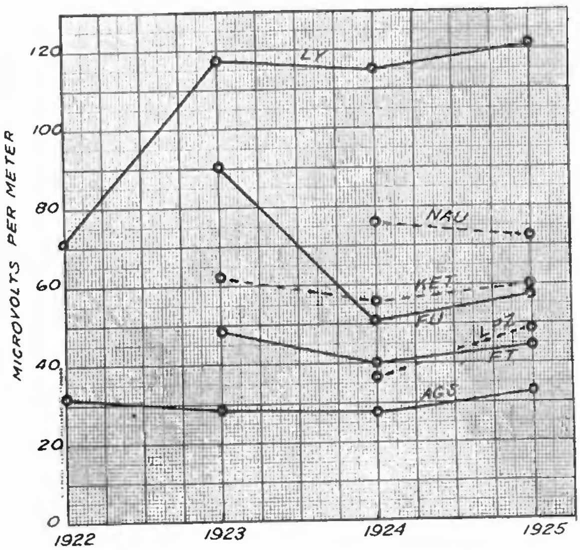

FIGURE 1—Annual Average Signal—10 A. M.—
for 1922, '23, '24, '25

in western Europe or 9 P. M. in central Europe and hence have a path of partial darkness during most of the year is the reverse of that of the 10 A. M. all daylight signals. The maximum occurs in mid-winter with a minimum in summer. The 10 A. M. and 3 P. M. curves cross each other as a rule in March and October. The 3 P. M. winter maxima are particularly strong in the case of the longer wave stations, Bordeaux LY, Ste.Assise FU, and Nauen AGW.

This strengthening of the 3 P. M. European signals in winter, with darkness extending over part of the signal path, does not seem to agree with the observations of Espenschied, Anderson and Bailey on signals between England and America, who found low intensities for partly dark signal path. We have, however, no observations on European stations of a wave length below

12,000 m., while the most pronounced drop in intensity as noted by the Bell observers was at much shorter wave lengths.

The west-east transcontinental signals from KET, Bolinas, California (three hours time difference), which have an all-daylight path during both observation periods show practical equality of the 10 A. M. and 3 P. M. signals in winter, while in summer the afternoon signals fall well below those of the morning. The same can also be said in regard to the signals of NAU,

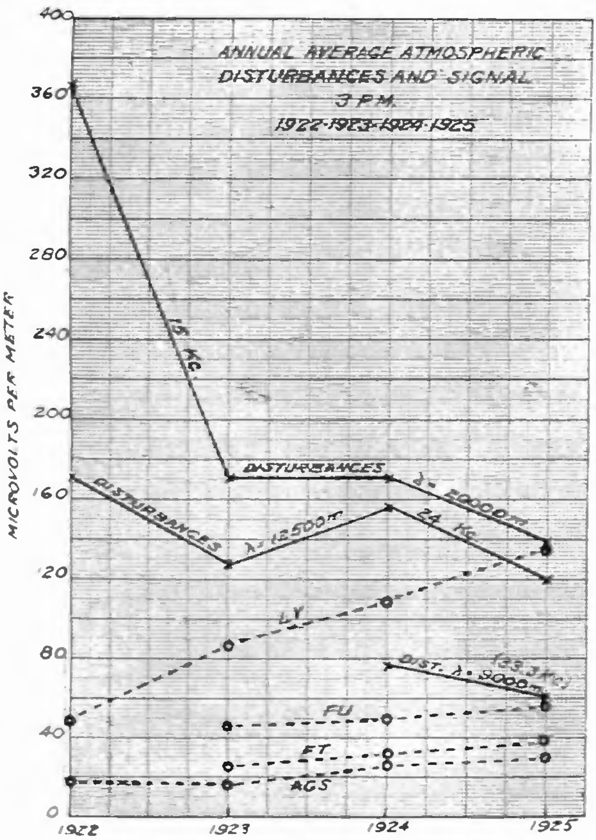

FIGURE 2

Cayey, Porto Rico (approximately south-north transmission) at a distance of 2,500 km. In the case of Monte Grande, Argentina, LPZ (south-north transmission) at a distance of 8,300 km. and with a little more than an hour's difference in time, there has been until recently no regular afternoon transmission. The morning signals from this station have shown no great seasonal variations, which was to be expected since the signal path is divided nearly equally between the northern and southern hemispheres. From the data available it seems that the afternoon signals are much weaker than those of the morning in winter and spring, and it is probable that this difference persists throughout the year. The cause of this weakening of signals in the afternoon, which is observed on practically all stations in summer, even when there is comparatively little difference of time and no question of sunset or darkness effect, is not clear. It may be connected with absorption due to ionization in the lower atmosphere along the signal path, produced by the same

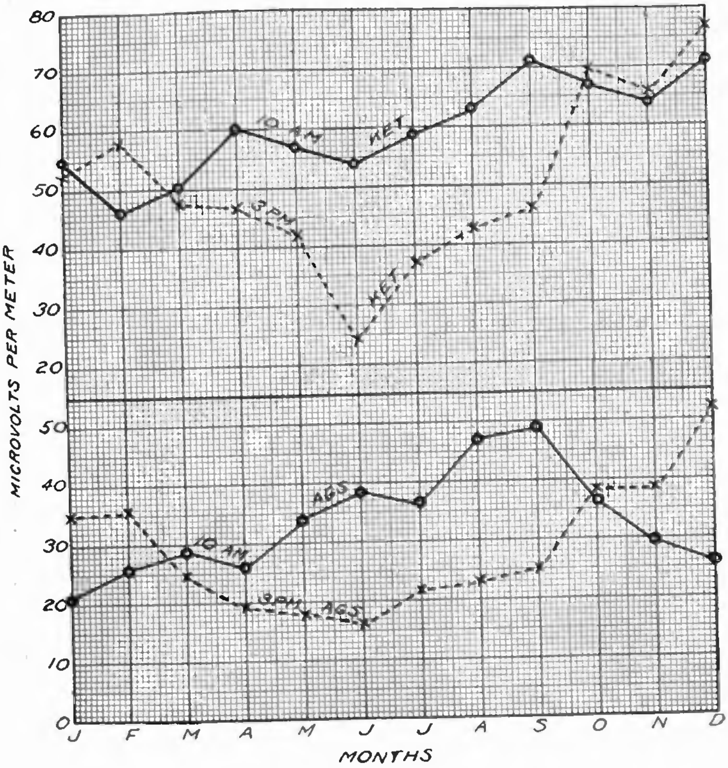

FIGURE 3—Nauen (A G S) and Bolinas (K E T)—Average Signal 10 A. M. and 3 P. M.. 1925

conditions which produce atmospheric disturbances in the afternoon along the same path[6].

In Figure 5, the monthly averages of the 3 P.M. signals from Bordeaux (LY) received in Washington and those of the corresponding signals taken at Meudon near Paris ($d=510$ *km.*) are shown. The remarkable agreement in seasonal variation at these two receiving stations, which has not been observed in other signals taken at moderate and long distances, and which did not occur before LY's change of wave length from 23,400 m.

[6] Several years ago Navy operators in Panama reported weak signals from Washington whenever bad disturbance days occured in the eastern United States.

to 18,900 m., indicates that the variations observed in Bordeaux signals are due to causes in the neighborhood of the transmitting station and not in the general transmission paths. In addition to the agreement in seasonal variations at Washington and Meudon, it is to be noticed that there has been a gradual increase in Bordeaux's intensity at both receiving stations which is out of proportion to the average increase in antenna current.

During the year a slight modification has been made in the constants of the exponential term e^{-u} of the Austin-Cohen trans-

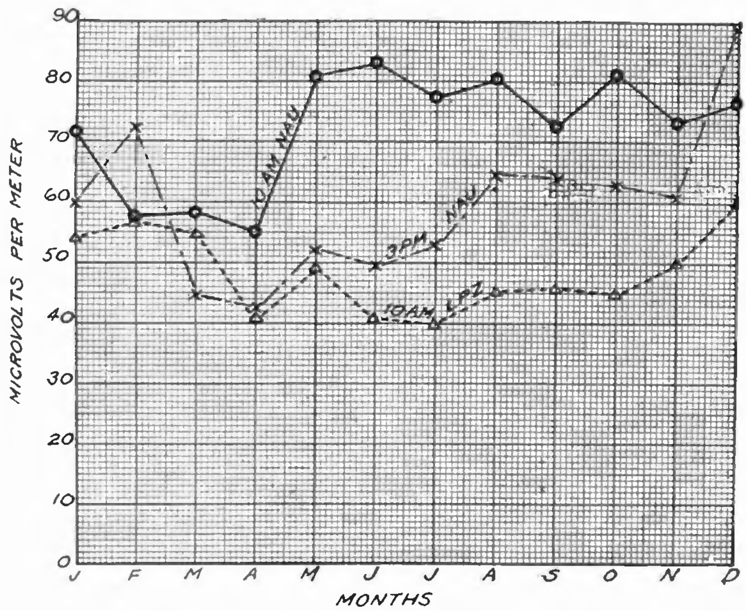

FIGURE 4—El Cayey (N A U) and Monte Grande (L P Z)—
Average Signal 10 A. M. and 3 P. M., 1925

mission formula, which has resulted in a great improvement in the agreement between the observed and calculated values at the greater distances without impairing the accuracy of the formula at moderate distances. The value of the exponent, u, expressed in km. and wave lengths, is now $\frac{1.4.10^{-3}d}{\lambda^{0.6}}$ instead of $\frac{1.5.10^{3}d}{\lambda^{0.5}}$, where d is the distance and λ the wave length, or expressed in km. and kc., $u=4.57.10^{-5}d.f^{0.6}$. This change approximately doubles the calculated values at 6,000 km. and increases them about four times at 12,000 km.

An examination is now being made of the transmission data already collected for the purpose of finding possible connections with other natural phenomena. Special study has been given to possible meteorological relations. It appears that for long-distance long-wave transmission, for example between Europe and America, the connection between signal strength and American weather is not close. This is not remarkable since the meteorological data in America can apply to only a small portion of the signal path. A much more distinct relationship exists in transmission over a few hundred km. because in these cases the

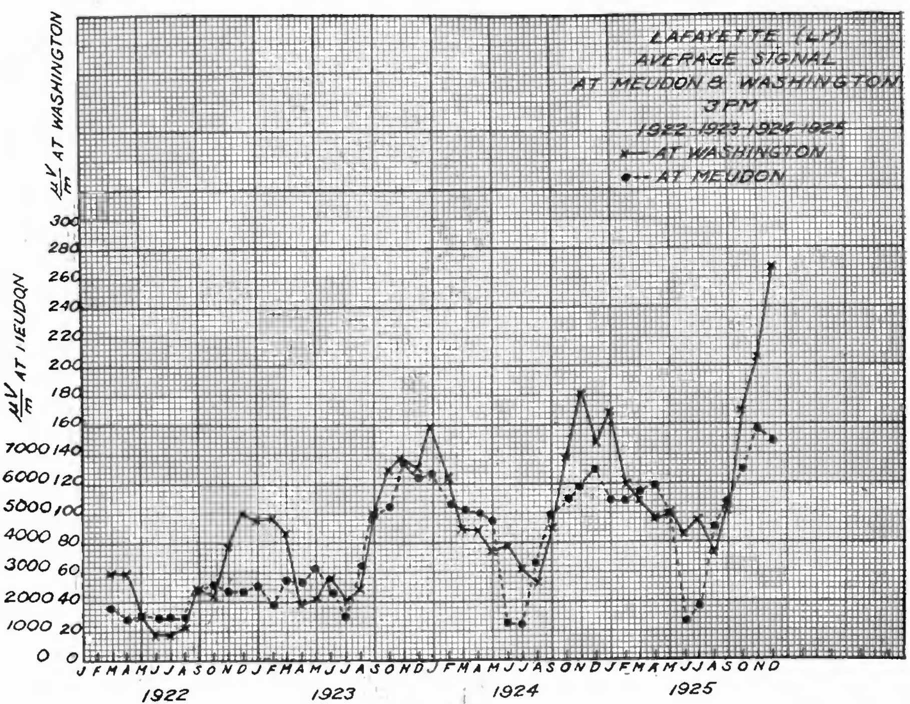

FIGURE 5

weather is comparatively uniform over the whole path. This will be discussed in a later report.

Comparisons have also been made between European signal intensity in Washington and the occurrence of sun spots[7] and magnetic storms. Thus far no certain relationship has been observed between sun spots and abnormal signals, but there appears to be in many cases an undoubted effect of the more severe magnetic storms upon transmission[8].

During the year directional measurements on the atmospheric disturbances were made at frequencies of 21.4 and 15 kc. (14,000

[7] For a complete study of the possible relationship between radio phenomena and solar activity observations covering at least one complete sun spot cycle will be necessary.

[8] Espenschied, Anderson and Bailey, loc. cit., have noticed in their measurements of signals between England and America that magnetic storms produce a marked decrease in night signals and a slight increase in day signals.

and 20,000 m.) at the U. S. Naval radio receiving stations at Colon and Balboa at the two ends of the Panama Canal.

The data obtained seem to warrant the following conclusions:

1. During the dry season, probably from January 15 to April 1, the atmospheric disturbances both at Balboa and Colon come almost entirely from the South American continent, *i.e.*, from the southeast.

2. When the dry season comes to an end and local storms begin to appear, the local disturbances from the low mountains

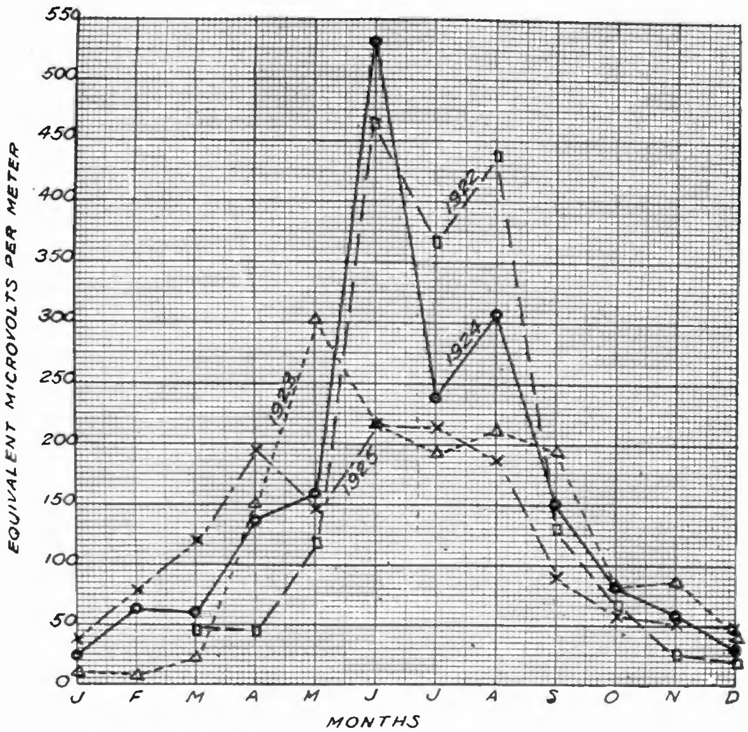

FIGURE 6—Average Atmospheric Disturbances, 3 P. M., 1922, '23, '24, '25—24 kc. (12,500 m.)

of the Isthmus begin to be prominent. This shifts the prevailing direction at Balboa at times from the southeast to the north, but has little effect on the direction at Colon since the mountains containing the local centers of disturbance here lie to the south and east, or roughly in the direction of the disturbance sources in Colombia.

3. In midsummer, while there is probably much disturbance from Central America and Mexico, the local disturbances from the Isthmus mask this to such an extent that the prevailing direction at Colon continues roughly southeast, while at Balboa the distant and local disturbances unite to give a northerly or northwesterly direction.

4. The observations further indicate that from northern sending stations, Balboa and Colon should give nearly equally good unidirectional reception in the dry season, but during the rest of the year, where the disturbance conditions are more troublesome, Colon should have considerable advantage over Balboa.

Observations in Washington show that in winter the prevailing afternoon disturbances come roughly from the southeast,

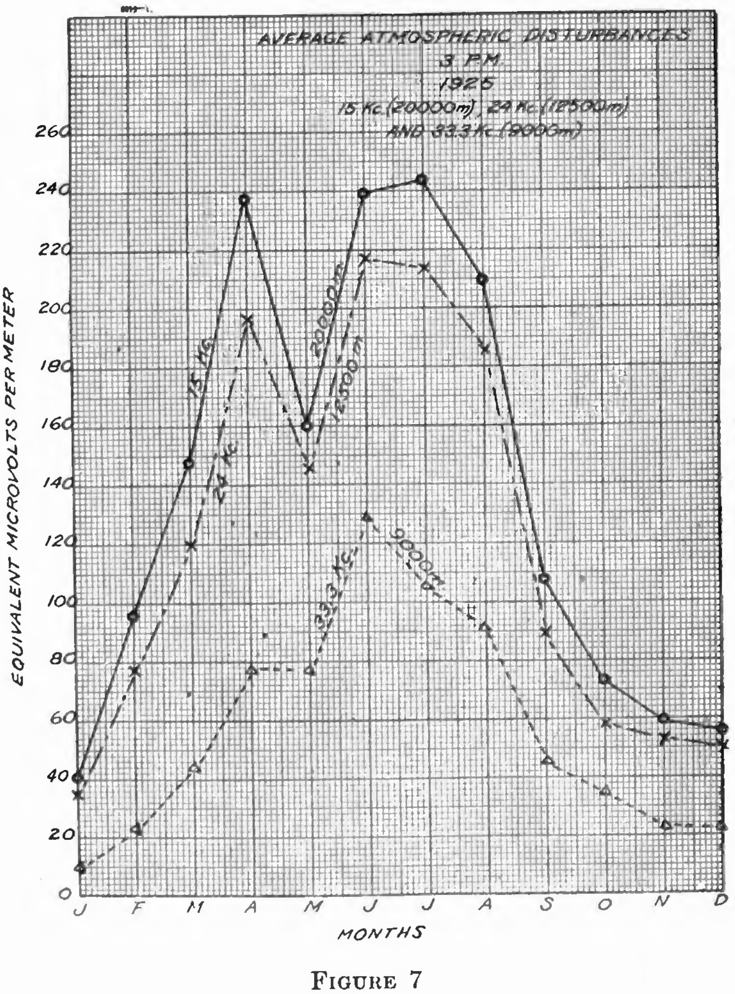

FIGURE 7

that is from the direction of eastern South America or perhaps in part from Africa. In summer the direction is southwesterly apparently from Mexico or the southwestern United States. This is in accord with the idea that disturbances generally originate over land and are most intense in the afternoon and evening in the regions where the sun passes very nearly overhead.

TABLE 1

Approximate Transmission Data

		Frequency f	Wave Length λ	Antenna Current I	Effective Height h	Distance d
LY*	Bordeaux	15.9	18900	540	180	6160
FU	Ste. Assise, Paris	15.0	20000	475	180	6200
FT	Ste. Assise, Paris	20.8	14400	380	180	6200
AGW*	Nauen, Berlin	16.5	18100	460	170	6650
AGS*	Nauen, Berlin	23.4	12800	400	130	6650
IDG	Pisa	14.2	21000	—	—	7300
KET*	Bolinas, San Francisco	22.9	13100	670	51	3920
LPZ	Monte Grande, Buenos Aires	23.6	12700	600	150	8300
GBL	Leafield, Oxford	24.4	12300	260	75	5900
NAU	Cayey, Porto Rico	33.8	8870	150	120	2490

* Daily antenna current reported.
Other antenna currents more or less uncertain.

TABLE 2

Average Signal Intensity and Atmospheric Disturbances for Lafayette (LY), Ste. Assise (FU) Nauen (AGW) and Pisa (IDG) in microvolts per meter.

1925	A. M.					P. M.				
	LY	FU	AGW	IDG	Dist.	LY	FU	AGW	IDG	Dist.
January	111.3	31.0	—	45.7	33.3	168.6	56.1	—	96.7	40.0
February	105.9	38.4	44.0	24.0	57.3	119.4	52.8	56.2	68.8	94.9
March	118.0	51.3	51.8	43.3	70.4	108.7	38.2	52.8	50.5	146.9
April	117.8	57.0	42.8	59.7	83.4	96.7	31.0	39.3	18.0	237.1
May	120.6	61.6	50.4	62.4	54.8	99.2	36.5	33.3	33.6	158.4
June	106.9	50.7	54.2	52.9	60.1	84.5	24.2	20.9	19.7	239.4
July	119.5	58.4	58.1	53.9	57.1	94.0	42.5	38.1	54.0	242.2
August	137.5	84.6	74.4	63.1	42.7	73.0	45.2	40.4	50.1	208.9
September	140.1	83.6	78.6	—	52.5	102.0	56.7	49.2	—	107.6
October	137.7	63.0	60.0	—	45.9	171.0	79.8	69.7	—	73.1
November	117.1	58.9	56.0	—	41.4	206.0	87.4	80.8	—	59.5
December	124.1	54.0	52.9	—	49.6	267.1	114.1	88.3	—	55.9
Average	121.2	57.4	56.6	50.6	54.0	132.5	55.3	51.7	48.9	138.6

TABLE 3

Average Signal Intensity and Atmospheric Disturbances for Ste. Assise (FT), Bolinas (KET) Nauen (AGS), Monte Grande (LPZ) and Leafield (GBL) in microvolts per meter

1925	A. M.						P. M.				
	UFT	KET	AGS	LPZ	GBL	Dist.	UFT	KET	AGS	PLZ	Dist.
January	31.9	54.2	20.0	54.2	—	26.0	44.8	52.4	34.7	—	35.6
February	35.6	45.4	24.6	57.1	—	44.5	35.8	56.7	35.1	—	76.2
March	36.9	49.4	27.1	55.7	—	56.8	29.4	48.0	24.4	26.8	119.1
April	44.8	59.2	24.7	41.8	—	67.3	28.0	45.9	18.8	19.7	194.2
May	46.1	56.4	32.9	49.0	15.5	46.2	27.5	41.9	17.4	23.5	145.0
June	46.8	53.7	37.5	40.2	17.9	51.3	18.5	23.4	16.0	—	217.4
July	45.4	58.0	35.8	39.9	19.6	42.5	28.6	36.6	21.4	—	213.0
August	53.1	62.1	46.5	45.6	23.2	32.7	28.0	43.0	22.9	—	185.5
September	50.6	70.6	48.6	45.9	21.7	38.7	33.3	46.5	24.7	—	88.2
October	47.5	66.7	35.8	44.9	21.5	38.7	46.2	69.5	38.5	—	58.5
November	41.6	63.0	28.1	50.7	17.1	34.0	56.7	65.0	38.5	—	52.2
December	48.5	70.4	24.1	60.3	23.6	41.6	71.3	78.0	49.2	—	48.5
Average	44.1	59.1	32.1	48.7	20.0	43.4	37.3	50.5	28.4	—	119.4

TABLE 4

Average Signal Intensity and Atmospheric Disturbances for El Cayey (NAU) in microvolts per meter

1925	A. M.		P. M.	
	NAU	Dist.	NAU	Dist.
January	71.1	9.5	59.3	8.5
February	57.2	15.3	72.2	22.6
March	58.2	22.0	44.2	44.0
April	55.1	25.6	42.4	77.9
May	80.3	28.6	52.4	77.4
June	83.3	25.7	49.1	129.1
July	77.6	28.1	52.1	104.5
August	80.2	15.0	65.0	91.8
September	72.2	22.1	63.9	46.1
October	81.5	26.1	62.6	35.0
November	73.0	16.5	60.7	23.0
December	77.0	21.2	89.7	22.5
Average	72.2	21.3	59.4	56.8

FIELD DISTRIBUTION AND RADIATION RESISTANCE OF A STRAIGHT VERTICAL UNLOADED ANTENNA RADIATING AT ONE OF ITS HARMONICS*

By

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I. Introduction

Current and voltage distribution, electromagnetic field and radiation resistance are some quantities, among many, of interest in the investigation of an antenna. Their more or less complete and accurate determination is possible, mainly due to the works of H. Hertz[1] and M. Abraham.[2] The principles, given in these and other works, have here been applied to the investigation of an unloaded antenna consisting of a straight vertical wire radiating at one of its harmonics. The term "unloaded" is important. An antenna consists of a system of conductors, representing distributed capacities and inductances, which conductors are connected to one or more circuits with usually concentrated capacities and inductances. This is the general form of the loaded antenna. If the latter circuits are of negligible influence, or if no such circuits exist at all, then the antenna is unloaded.

Previously, similar calculations have been made by M. Abraham,[2] G. W. Pierce,[3] S. Ballantine,[4] H. Chireix,[5] and M. A. Bontch-Broojevitch,[6] among others. Since the present article contains added information, its publication has been thought justified, particularly at a time when all data on short wave radio transmission are of interest.

The antenna may be grounded or not and, in the latter case, its lower end may be at any distance above ground. The in-

*Received by the Editor, January 13, 1926. Presented at the New York meeting of The Institute of Radio Engineers, September 1, 1926.

[1] H. Hertz, Ges. Werke, v. II.

[2] M. Abraham, Phys. Zeitschrift, v. 2, 1901, p. 329.

[3] G. W. Pierce, "Electric Oscillations and Electric Waves," New York, 1920, p. 435, particularly p. 481.

[4] S. Ballantine, Proceedings of The Institute of Radio Engineers, v. 12, 1924, p. 823.

[5] H. Chireix, "Radioelectricité," v. 5, 1924, p. 65 (Bulletin Technique).

[6] M. A. Bontch-Broojevitch, "Electritchestvo, April, 1925, p. 228.

fluence of this distance upon the radiation resistance and field distribution has here been investigated for the first time, as far as is known to the authors. In making this treatment the earth has been assumed to be a perfect conductor.

II. Current Distribution

The current distribution assumed is indicated by Figures

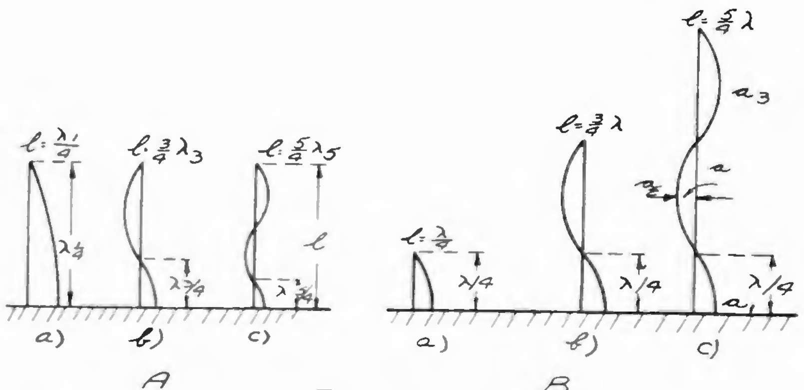

FIGURE 1

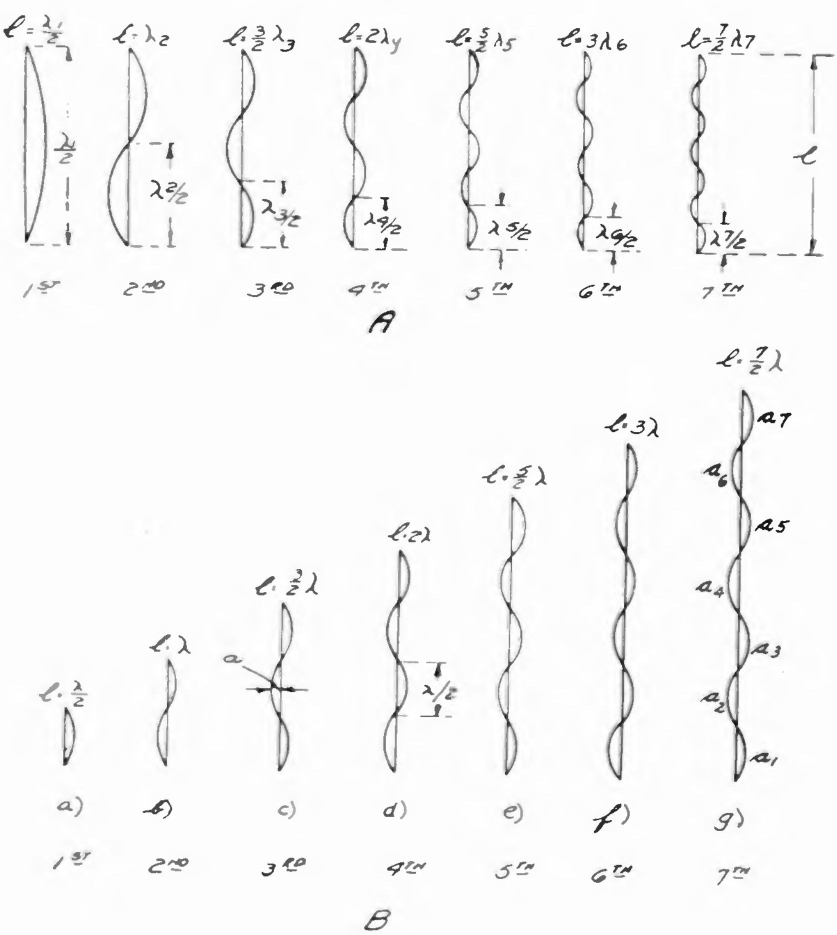

FIGURE 2

1 and 2, where all curves are of sine form. When the lower end is grounded—the grounded antenna—only odd harmonics are possible as shown in Figure 1, where the three first odd harmonics are indicated. At a constant operating wavelength λ, the height of the antenna depends upon the harmonic to be used (Figure 1, B). When the lower end is not grounded—the ungrounded antenna—it is possible to operate both at even and odd harmonics (Figure 2).

Analytically, the current distribution can be expressed in the following way, with reference to Figure 3. Let:

i = current value at the point x and the time t;
λ = operating wavelength;
I = length of the antenna wire;
$\lambda_o = 2\,I$ for the ungrounded antenna;
$\lambda_o = 4\,I$ for the grounded antenna;
c = the velocity of light.

Then:

$$\left.\begin{aligned} i &= -a \sin\frac{2\pi}{\lambda}\left(x-\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x>0 \\ i &= a \sin\frac{2\pi}{\lambda}\left(x+\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{4}t \qquad x<0 \end{aligned}\right\} \quad (1)^7$$

for the ungrounded antenna, when λ_o/λ equals an odd integer;

$$\left.\begin{aligned} i &= -a \sin\frac{2\pi}{\lambda}\left(x-\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x>0 \\ i &= -a \sin\frac{2\pi}{\lambda}\left(x+\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x<0 \end{aligned}\right\} \quad (2)^7$$

for the ungrounded antenna, when λ_o/λ equals an even integer; finally,

$$i = -a \sin\frac{2\pi}{\lambda}\left(x-\frac{\lambda_o}{4}\right)\sin\frac{2\pi c}{\lambda}t \qquad x>0 \qquad (3)$$

for the grounded antenna, where λ_c/λ is an odd integer.

There is some theoretical justification for the assumption regarding this current distribution.[8] If the antenna is considered as a line with inductance L and capacity C per unit length, uniformly distributed, then

$$\left.\begin{aligned} \frac{\partial i}{\partial x} &= -C\frac{\partial v}{\partial t} \\ \frac{\partial v}{\partial x} &= -L\frac{\partial i}{\partial t} \end{aligned}\right\} \qquad (4)$$

[7] At $x=0$ the two values are equal.

[8] A. Guyau, La Lumière Électrique, tome XV (2° Série), 1911, p. 13. Balth van der Pol, jun., Jahrbuch der drahtlosen Telegraphie, v. 13, 1919, 217. K. W. Wagner, Archiv. für Elektrotechnik, v. 8, 1920, p. 145. Also M. Abraham, l. c.

where v and i are the instantaneous values of voltage and current, respectively. The losses are assumed negligible. The boundary conditions are:

$$i \text{ always} = 0, \text{ for } x = \pm \frac{l}{2} \tag{5}$$

in the case of an ungrounded antenna, but

$$\left.\begin{array}{l} i \text{ always} = 0, \text{ for } x = l \\ v \text{ always} = 0, \text{ for } x = 0 \end{array}\right\} \tag{6}$$

in the case of a grounded antenna. If the current i is assumed as in equations (1)—(3), then the first equation in the system

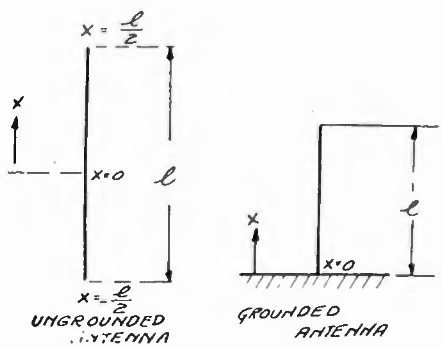

FIGURE 3

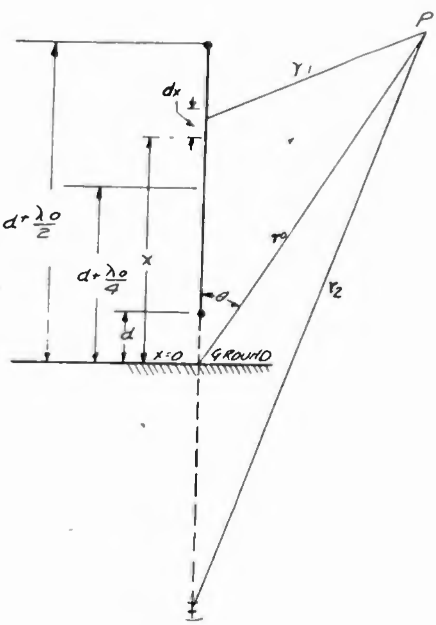

FIGURE 4

(4) is satisfied, if the voltage v is determined by integration of this equation. For instance, the voltage

$$v = -\frac{a}{C\,c} \cos \frac{2\pi}{\lambda}\left(x - \frac{\lambda_0}{4}\right) \cos \frac{2\pi c}{\lambda} t + C(x) \qquad x > 0$$

corresponds to the current i in equation (3). The constant of integration $C\ (x)$ is in general a function of x but here equals zero, since v must equal zero when the current a equals zero. These values of v and i will be found to satisfy the proper boundary conditions and also the second equation in the system (4) if $L\,C = 1/c^2$, which well-known relation can be supposed to be true in the cases under consideration. There are, of course, several ways of treating the equations (4) with boundary conditions (5) or (6).

Though it is usual to assume a current distribution according to a sine law,[9] this is not always done.[10]

It is possible for an antenna to vibrate at several frequencies simultaneously. As an illustration, consider the grounded antenna. The expression

$$i = \sum_{n=1}^{n} -a_n \sin\frac{2\pi}{\lambda_n}\left(x-\frac{\lambda_o}{4}\right)\sin\left(\frac{2\pi c}{\lambda_n}t+\varphi_n\right)$$

for odd, integral values of $n=\lambda_o/\lambda$ (equation (3)) and the corresponding value of v, determined by integration of the first equation in the system (4), satisfy the boundary conditions (6) and also the second equation in the system (4), provived that $LC=1/c^2$. Thus, the expression represents a possible current distribution. Usually one component is pronounced while all the others are very weak.

III. Electric Field

A. *Hertz Formula*—Consider an element of the antenna at a distance x above ground (Figure 4) and represent the current in it by

$$i=i_x \sin\frac{2\pi c}{\lambda}t \tag{7}$$

where i_x is a function of x. The electric field at a distant point P is

$$d\,e_1=\frac{\sin\theta}{c^2 r_o}\ddot{f}\left(t-\frac{r_1}{c}\right),$$

where

$$\ddot{f}(t)=\frac{\partial i}{\partial t}d\,x.$$

Thus

$$d\,e_1=\frac{\sin\theta}{c^2 r_o}i_x\,d\,x\frac{2\pi c}{\lambda}\cos\frac{2\pi c}{\lambda}\left(t-\frac{r_1}{c}\right)$$
$$=\frac{2\pi}{c\,r_o\,\lambda}i_x\,d\,x\sin\theta\cos\frac{2\pi}{\lambda}(c\,t-r_1).$$

Assuming a perfect conducting earth,[12] the field due to the image is

$$d\,e_2=\frac{2\pi}{c\,r_o\,\lambda}i_x\,d\,x\sin\theta\cos\frac{2\pi}{\lambda}(c\,t-r_2).$$

[9] M. Abraham, l. c.; G. W. Pierce, l. c.; S. Ballantine, l. c.; among others.
[10] M. Abraham, Annalen d. Phys., v. 66, 1898, p. 435.—A. Press, Proceedings of The Institute of Radio Engineers, v. 8, 1920, p. 441.—See also Encyklopädie der Math. Wissenchaften, v. V, 2, p. 483.
[11] See for instance, G. W. Pierce, l. c.
[12] M. Abraham, l. c., or G. W. Pierce, l. c.

The total field is

$$d\,e = d\,e_1 + d\,e_2,$$

which gives[13]

$$d\,e = \frac{4\,\pi}{c\,r_o\,\lambda} i_x\,d\,x \sin\theta \cos\frac{2\,\pi}{\lambda}(c\,t - r_o)\cos\left(2\,\pi\frac{x}{\lambda}\cos\theta\right) \tag{8}$$

because

$$r_o = \frac{r_1 + r_2}{2}, \quad r_2 - r_1 = 2\,x\cos\theta.$$

B. *Ungrounded Antenna Operating at Odd Harmonics*—The lower end of the antenna may be at a distance $x = d$ above the ground as in Figure 4. The upper ene is then at a distance $x = d + \frac{\lambda_o}{2}$ above ground. From equation (1) is obtained, by a simple transformation of coordinates,

$$i_x = -a \sin\frac{2\,\pi}{\lambda}\left(x - d - \frac{\lambda_o}{2}\right) \tag{9}$$

for all points between $x = d + \frac{\lambda_o}{4}$ and $x = d + \frac{\lambda_o}{2}$;

and

$$i_x = a \sin\frac{2\,\pi}{\lambda}(x - d) \tag{10}$$

from $x = d$ to $x = d + \frac{\lambda_o}{4}$. a is equal to the current amplitude. The electric field at a distant point is by equation (8),

$$e = \frac{4\,\pi}{c\,r_o\,\lambda}\cos\frac{2\,\pi}{\lambda}(c\,t - r_o)\sin\theta \int_d^{d+\lambda_o/2} i_x \cos\left(2\,\pi\frac{x}{\lambda}\cos\theta\right) d\,x,$$

which with reference to equations (9) and (10), after elementary, but somewhat extensive calculations, gives for odd integral values of $\frac{\lambda_o}{\lambda} = n$.

$$e = \frac{4\,a}{c\,r_o}\cos\frac{2\,\pi}{\lambda}(c\,t - r_o)\cos\frac{2\,\pi}{\lambda}\frac{(\lambda_o + 4\,d)\cos\theta}{4}\sin\theta \times \\ \times \frac{\cos\left(\frac{\pi}{2} n \cos\theta\right)}{\sin^2\theta} \tag{11}$$

For convenience let

$$\left.\begin{aligned} a &= \frac{2\,\pi}{\lambda}\frac{\lambda_o + 4\,d}{4} = \frac{\pi}{2} n\left(1 + \frac{4\,d}{\lambda_o}\right) \\ \beta &= \frac{\pi}{2} n \\ \gamma &= 1 + \frac{4\,d}{\lambda_o} \\ a &= \beta\,\gamma, \end{aligned}\right\} \tag{12}$$

[13] See also Balth van der Pol, jun., l. c.

where n may be odd or even.
Then

$$e=\frac{4a}{c r_o}\cos\frac{2\pi}{\lambda}(ct-r_o)\cos(\beta\gamma\cos\theta)\sin\theta\frac{\cos(\beta\cos\theta)}{\sin^2\theta}. \quad (13)$$

C. *Ungrounded Antenna Operating at Even Harmonics*—Similarly, when n is an even integer

$$e=-\frac{4a}{c r_o}\cos\frac{2\pi}{\lambda}(ct-r_o)\sin(\beta\gamma\cos\theta)\sin\theta\frac{\sin(\beta\cos\theta)}{\sin^2\theta} \quad (14)$$

D. *Grounded Antenna*

$$e=-\frac{2a}{c r_o}\cos\frac{2\pi}{\lambda}(ct-r_o)\frac{\cos(\beta\cos\theta)}{\sin\theta}, \quad (15)$$

where n is an odd integer, and the limits of integration are now zero and $\frac{\lambda_o}{4}=i$.

E. *Power Distribution Curves*—The numerical value of the Poynting vector[14] is $\frac{c}{4\pi}e^2$, where e can be obtained from the equations (13)(15). Since only relative values of this vector are of interest here, the factor $\cos\frac{2\pi}{\lambda}(ct-r_o)$ may be omitted in the evaluation of e^2, as at a given moment it has the same value at all points. If in a polar diagram the length of the radius vector, corresponding to the angle θ, is made proportional to e^2, then

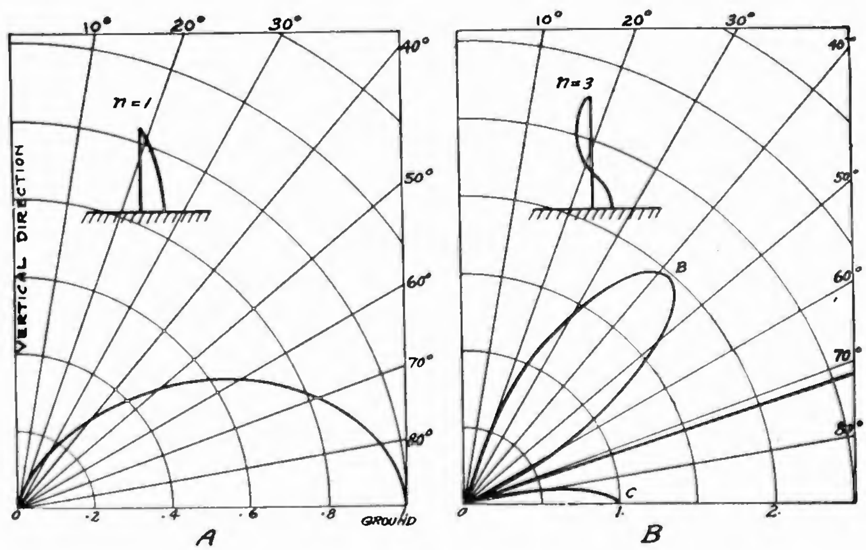

FIGURE 5

[14] See for instance, Pierce, l. c.

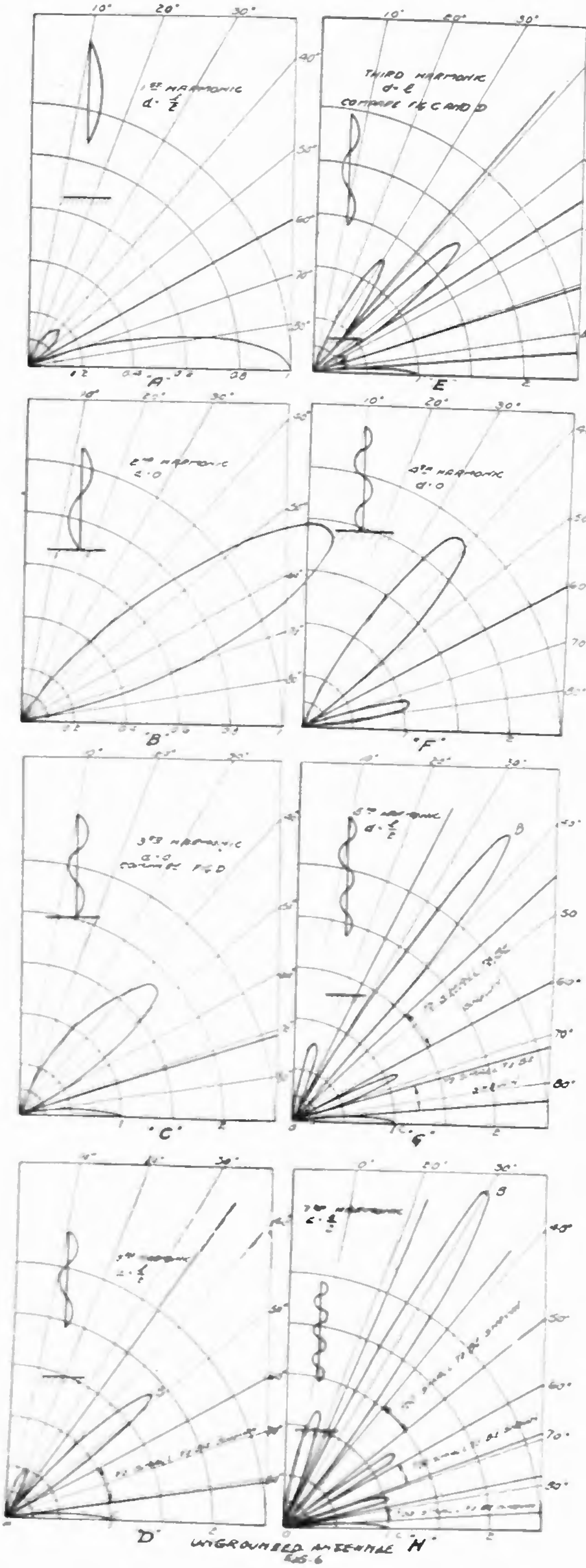

FIGURE 6

the locus of its end point is a curve, which may be called the power distribution curve. See Figures 5-6, which are self-explanatory.

IV. Radiation Resistance

A. *Power Radiated by the Ungrounded Antenna at Odd Harmonics*—In order to obtain the radiated power p,[12] multiply $\frac{e}{4\pi}e^2$ by the surface element $d\,s = 2\pi\, r_o^2 \sin\theta\, d\,\theta$ and integrate from $\theta = 0$ to $\theta = \frac{\pi}{2}$. This gives

$$P = \frac{8a^2}{c} S_1 \cos^2 \frac{2\pi}{\lambda}(ct - r_o), \tag{16}$$

where

$$S_1 = \int_0^{\pi/2} \cos^2(\beta\chi\cos\theta)\frac{\cos^2(\beta\cos\theta)}{\sin\theta}\,d\,\theta \tag{17}$$

or

$$S_1 = \frac{1}{2}\int_0^2 \frac{\cos^2[\alpha(z-1)]\sin^2\beta Z}{Z}\,dZ, \tag{18}$$

as will be shown briefly. Note that $\alpha = Bz$ and put $U = \cos\theta$

Then
$$S_1 = \frac{1}{2}(S_{11} + S_{12})$$

where

$$\left.\begin{aligned} S_{11} &= \int_0^1 \frac{\cos^2(\alpha U)\cos^2(\beta U)}{1+U}\,dU \\ S_{12} &= \int_0^1 \frac{\cos^2(\alpha U)\cos^2(\beta U)}{1-U}\,dU \end{aligned}\right\}$$

Consider first S_{11}. Since

$$\left.\begin{aligned} \alpha U &= \alpha(1+U) - \alpha \\ \beta U &= \beta(1+U) - \beta \end{aligned}\right\},$$

the transmission $1 + U = Z$ gives

$$S_{11} = \int_1^2 \frac{\cos^2[\alpha(\alpha-1)]\cos^2[\beta(Z-1)]}{Z}\,dZ.$$

But $\beta = \frac{\pi}{2}n$, where n is an odd integer. Thus

$$\cos[\beta(Z-1)] = \pm\sin\beta Z.$$

$$S_{11} = \int_1^2 \frac{\cos^2[\alpha(Z-1)]\sin^2\beta Z}{Z}\,dZ.$$

Finally, the substitution $U = -V$ gives

$$S_{12} = \int_{-1}^0 \frac{\cos^2(\alpha V)\cos^2(\beta V)}{1+V}\,dV.$$

which is of the same form as S_{11} and is found equal to

$$S_{12}=\int_0^1 \frac{\cos^2 [\alpha(Z-1)] \sin^2 \beta Z}{Z} dZ.$$

B. *Power Radiated by Ungrounded Antenna at Even Harmonics.*

$$P=\frac{8 a^2}{c} S_2 \cos^2 \frac{2\pi}{\lambda}(c t-r_o), \tag{19}$$

where

$$S_2=\int_0^{\pi/2} \sin^2 (\beta \gamma \cos \theta) \frac{\sin^2(\beta \cos \theta)}{\sin \theta} d\theta, \tag{20}$$

or

$$S_2=\frac{1}{2}\int_0^2 \frac{\sin^2[\alpha (Z-1)] \sin^2 \beta Z}{Z} dZ. \tag{21}$$

C. *Power Radiated by Grounded Antenna*

$$P=\frac{2 a^2}{c} S_3 \cos^2 \frac{2\pi}{\lambda}(c t-r_o), \tag{22}$$

where

$$S_3=\int_0^{\pi/2} \frac{\cos^2 \left(\frac{\pi}{2} n \cos \theta\right)}{\sin \theta} d\theta, \tag{23}$$

or

$$S_3=\frac{1}{2}\int_0^2 \frac{\cos^2 \frac{\pi}{2} n (Z-1)}{Z} dZ. \tag{24}$$

D. *Radiation Resistance*—The time average of

$$\cos^2 \frac{2\pi}{\lambda}(c t-r_o)$$

in the equations (16), (19) and (22) is equal to ½. The time average of the current square is equal to ½ a^2. The radiation resistance[12] R may be defined as the time average of the power divided by ½ a^2. Thus:

$$R=\frac{\frac{8 a^2}{c}\frac{1}{2} S_1}{\frac{1}{2} a^2}=\frac{8 S_1}{c}$$

or

$$R=240\, S_1 \text{ ohms} \tag{25}$$

for an ungrounded antenna operating at odd harmonics. At even harmonics

$$R=240\, S_2 \text{ ohms} \tag{26}$$

For the grounded antenna

$$R=60\, S_3 \text{ ohms} \tag{27}$$

The definite integrals S_1 and S_2 have been computed and are plotted in Figure 7, which allows the calculations of the radia-

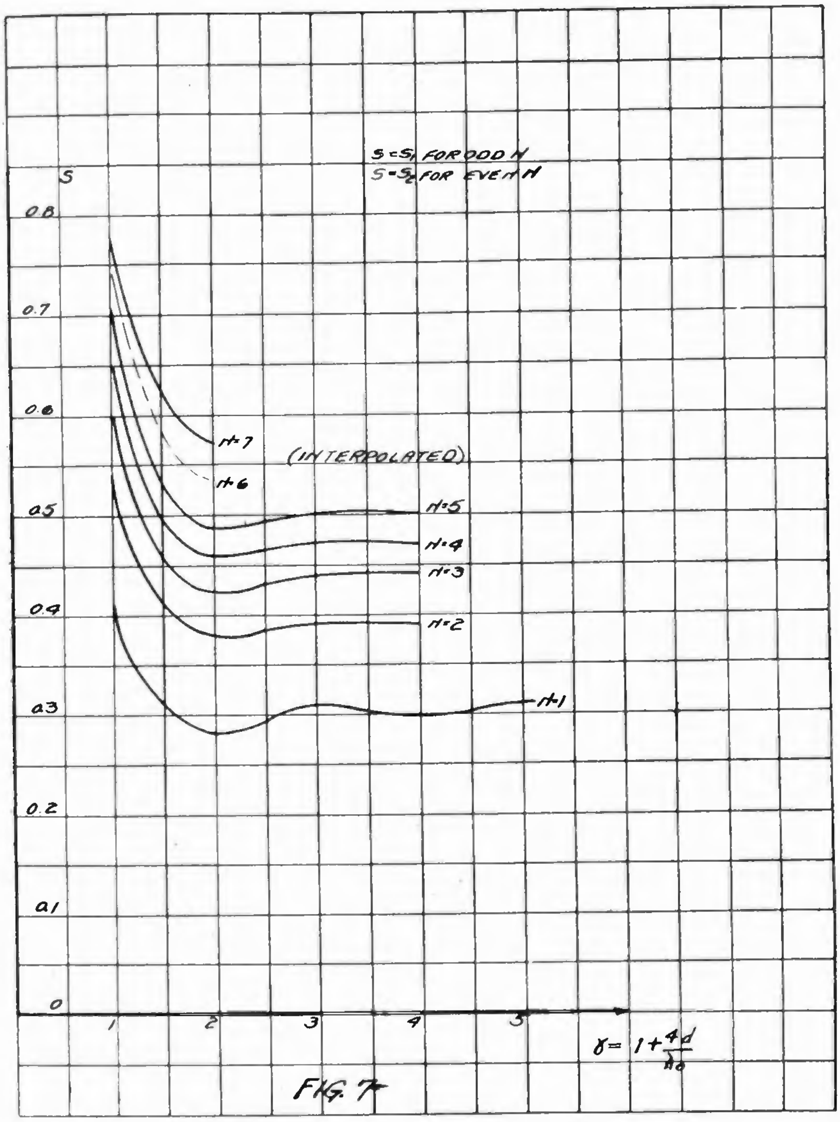

FIGURE 7

tion resistance for an ungrounded antenna up to the 7th harmonic and for various distances above ground.

Examples:

(1) $n=1$ and $d=0$;

$\therefore$ $\gamma=1$ and $S_1=0.41$;

$\therefore$ $R=240\times0.41=98.4$ ohms.

(2) The same as above but $d = i$;

$$\therefore \quad \gamma = 1 + \frac{4\,d}{\lambda} = 1 + \frac{4\,i}{2\,i} = 3 \text{ and } S_1 = 0.31;$$

$$\therefore \quad R = 74.4 \text{ ohms}.$$

The integral S_3 has also been evaluated for odd values of n. The value of $R = 60\,S_3$ is shown in the following table.

TABLE 1

Harmonic (n)	Rad. Res. (ohms)
1	37
3	52
5	60
7	65
9	68
11	71
13	73 [15]
15	75 [15]
17	77 [15]
19	79 [15]
21	81

The solution of the problem rests on the evaluation of the integrals (18), (21) and (24 and it seems worth while to give briefly the method used in calculating them.

$$S_1 = \frac{1}{2}\int_0^2 cos^2\left[\frac{\pi}{2} n\,\gamma\,(Z-1)\right] \frac{sin^2 \frac{\pi}{2} n\,Z}{Z}\,dZ,$$

n being here an odd integer and γ greater than or equal to unity. For a given n, S_1 has to be found for $\gamma = 1, 2, 3$, etc. The process has to be repeated for different values of n. Then the curves of Figure 7, corresponding to n odd, are obtained. For a given n and γ, the value of S_1 can be determined thus. Calculate the values of Z, between and including zero and two, at which

$$sin^2 \frac{\pi}{2} n\,Z = 0 \text{ and } cos^2\left[\frac{\pi}{2} n\,\gamma\,(Z-1)\right] = 0.$$

The function under the sign of integration is equal to zero for all these Z-values. Example: $n = 3$, $\gamma = 3$. The zero points are $Z = 0, \frac{2}{7}, \frac{4}{9}, \frac{6}{9}, \ldots\ldots \frac{18}{9} = 2$. Take, for instance, $\frac{1}{6} \times \frac{1}{9} = \frac{1}{54}$ as interval, that is, calculate for $n = 3$, $\gamma = 3$,

$$cos^2\left[\frac{\pi}{2} n\,\gamma\,(Z-1)\right] \frac{sin^2 \frac{\pi}{2} n\,Z}{Z}$$

[15] These values are interpolated.

at
$$Z=0, \frac{1}{54}, \frac{2}{54}, \ldots\ldots \frac{108}{54}=2.$$

Add all these calculated values. In this example, the sum equals 49.587. Then is

$$S_1=\frac{1}{2}\left(\frac{2}{108}49.587\right)=0.46.$$

Since
$$sin^2[a(Z-1)]=1-cos^2[a(Z-1)],$$

$$S_2=\frac{1}{2}\int^{2}\frac{sin^2\beta Z}{Z}dZ-\frac{1}{2}\int_o^{2}\frac{cos^2[a(Z-1)]sin^2\beta Z}{Z}dZ.$$

The last integral is calculated for n even exactly as the integral S_1 for n odd. The first integral is independent of γ. Its value for $n=2$ or other even n-values is obtained as above, if the points at which $\frac{sin^2\beta Z}{Z}=0$ are determined.

Finally, S_3 is found after determination of the points at which

$$\frac{cos^2\frac{\pi}{2}n(Z-1)}{Z}=0.$$

The values

$$\frac{sin^2\frac{\pi}{2}nZ}{Z}, \quad \frac{sin^2\beta Z}{Z} \text{ and } \frac{cos^2\frac{\pi}{2}n(Z-1)}{Z} \quad (n \text{ odd}),$$

considered above, have at $Z=0$ the form $\frac{0}{0}$, but a definite limit exists and is equal to zero. It is easy to see that the functions to be integrated, see equations (18), (21) and (24), are continuous at all points, including zero and are thus integrable.

V. Voltage

Since the maximum antenna voltage is of interest in the determination of corona, insulation, etc., its estimation will be illsutrated briefly for the case of an ungrounded antenna operating at odd harmonics. The first equation in (4), symbolically written, gives

$$\frac{\partial i}{\partial x}=-j\omega C V=-j\frac{2\pi c}{\lambda}C V,$$

where i and V may be the maximum values at the point x. From equation (1) is obtained

$$i=\mp a\, sin\frac{2\pi}{\lambda}\left(x\mp\frac{\lambda_0}{4}\right),$$

thus

$$\frac{\partial i}{\partial x} = \mp a \frac{2\pi}{\lambda} \cos \frac{2\pi}{\lambda}\left(x \mp \frac{\lambda_o}{4}\right) = -j \frac{2\pi c}{\gamma} C V.$$

Numerically,

$$V = \frac{a}{cC} \cos \frac{2\pi}{\lambda}\left(x \mp \frac{\lambda_o}{4}\right).$$

The greatest value of V is equal to

$$(V)_{max} = \frac{a}{cC} \text{ volts.}$$

a is the maximum antenna current in amperes at a current loop and equals

$$\sqrt{2}\sqrt{\frac{\textit{Antenna Power in Watts}}{\textit{Total Antenna Resistance in Ohms}}},$$

where the total antenna resistance is referred to a current loop. The value of C is to be expressed in farad per cm. and c equals the velocity of light, that is, 3×10^{10}.

SUMMARY: The operation at the harmonics of the grounded antenna and of an ungrounded antenna at any distance above ground has been considered as far as current, voltage and power distribution, electromagnetic field and radiation resistance are concerned. The antenna is always assumed to be a straight vertical wire and unloaded. The ground is supposed to be a perfect conductor.

A METHOD FOR MAXIMIZATION IN CIRCUIT CALCULATION*

By

Walter van B. Roberts

(Radio Corporation of America, New York)

As an example of a problem involving a maximization, consider the circuit of Figure 1, where it is desired to determine what value of coupling makes the secondary current greatest. From the circuit equations the secondary current is readily found to be:

$$i_2 = -\mu\, e\, Z_c \frac{Z_m}{[Z_o Z_1 (R+Z_c) + Z_o Z_c R] - (R+Z_c) Z_m^2}. \qquad (1)$$

Now the straightforward method for finding the value of Z_m that makes i_2 a maximum is to reduce this expression for i_2 to its absolute value (by replacing Z_1 by $r_1 + j\,x_1$, Z_o by $r_2 + j\,x_2$, Z_c by

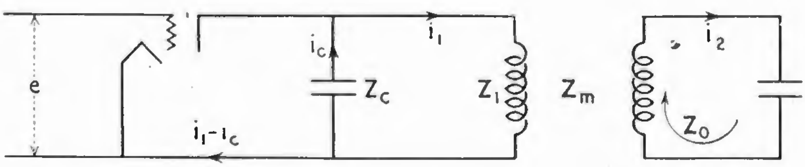

Figure 1—Internal Plate-Filament Resistance of Tube = R. Amplification Constant of Tube = μ. Z_o is Total Impedance Measured Around Secondary Circuit

$-j\,x_c$, and Z_m by $j\,x_m$), differentiate the absolute value with respect to X_m, set the derivative equal to zero, and solve for X_m. This is an extremely tedious process and leads to the result:

$$x_m^4 = (r_2^2 + x_2^2)\left[(r_1^2 + x_1^2) + \frac{R^2 x_c^2}{R^2 + x_c^2}\left(1 - 2\frac{x_1}{x_c} + 2\frac{r_1}{R}\right)\right], \qquad (2)$$

which result conveys little physical significance.

A much easier and more useful solution of the problem is, however, possible, based upon the following considerations: Let $f\,(Z)$ be any analytic function (and no other kind of function will be encountered in ordinary circuit theory) of the complex

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quantity Z. If the value of Z is varied in some definite manner, the locus of $f(Z)$ in the complex plane will be some sort of curve. Figure 2 shows a portion of such a curve, including a maximum of absolute value. At this maximum point it is obvious thata-very small change in the value of Z will move the point repree senting $f(Z)$ in a direction perpendicular to the vector from the origin to the point of maximum absolute value. Now the change

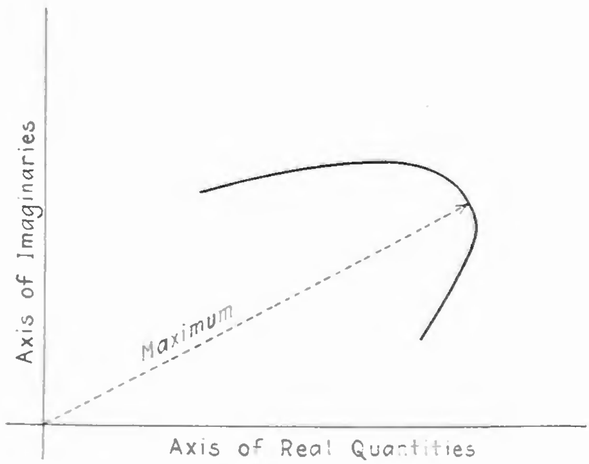

FIGURE 2

in $f(Z)$, due to a small change dZ in Z is $f^1(Z)\,dZ$, where $f^1(Z)$ is the function of Z obtained by differentiating $f(Z)$ with respect to the letter Z according to the ordinary rules of differential calculus. Hence, considering all these complex quantities and functions as vectors, the condition for maximum or minimum absolute value of $f(Z)$ is simply that the vector $f^1(Z)\,dZ$ must be perpendicular to the vector $f(Z)$.

Two special cases of this general condition are all that are usually required, for in circuit problems dZ is usually either a pure real quantity (such as a change in resistance of a circuit element) or a pure imaginary (such as a change in reactance of an element). In these cases we have the special conditions:

$f^1(Z)$ must be perpendicular to $f(Z)$ if dZ is real, (3)

$f^1(Z)$ must be parallel to $f(Z)$ if dZ if imaginary. (4)

which may be expressed in the more useful form:

The real part of $\dfrac{f(Z)}{f^1(Z)}$ must be zero if dZ is real. (5)

The imaginary part of $\dfrac{f(Z)}{f^1(Z)}$ must be zero if dZ is imaginary. (6)

Now going back to the problem of Figure 1, i_2 is seen to be of the form

$$i_2 = \frac{Z_m}{A - B Z_m^2}, \tag{7}$$

where A and B are complex constants. In Figure 1, Z_m is a pure reactance, so $d Z_m$ is imaginary, and condition (6) is applicable.

That is, the imaginary part of $\dfrac{i_2}{\dfrac{d i_2}{d Z_m}}$ must be zero, or, imaginary

part of $\dfrac{\dfrac{Z_m}{A - B Z_m^2}}{\dfrac{A + B Z_m^2}{(A - B Z_m^2)^2}}$ must be zero.

Simplifying, we have: Imaginary part of $\dfrac{A - B Z_m^2}{A + B Z_m^2} Z_m$ must be zero. To find out what value of Z_m satisfies this condition, replace A by $a + j\alpha$ and B by $b + j\beta$ and Z_m by $j x_m$. Then equate the imaginary part of the resulting expression to zero and it is readily found that $x_m^4 = \dfrac{|A|^2}{|B|^2}$.

Replacing $\dfrac{|A|}{|B|}$ by the proper quantities for this particular problem as given by equation 1, the solution becomes:

$$|Z_m^2| = |Z_o| \times \left|Z_1 + \frac{R Z_c}{R + Z_c}\right| \tag{8}$$

This solution is exactly the same as given by equation (2), as can be proved by reducing the indicated absolute values to an expression in terms of the quantities used in equation (2). This solution, however, gives a much simpler physical picture of conditions than equation (2). The last term is obviously the impedance of a circuit consisting of Z_1, connected in series with the combination of R and Z_c in parallel. (Let this be called for the moment the generator circuit.) And $\dfrac{|Z_m^2|}{|Z_o|}$ is immediately recognized as the impedance introduced into the "generator circuit" by the presence of the secondary. (Call this the load impedance.) Then the equation simply states that for maximum power in the load, the load impedance should be equal to the impedance of the "generator circuit" in absolute value. This is a very familiar type of statement.

Another Example of the Use of the Method

Figure 3 shows a common method for coupling an antenna to a tuned circuit. If a signal voltage e acts in the antenna

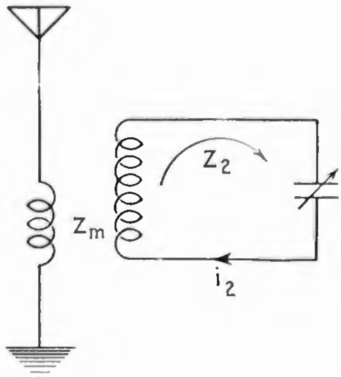

Figure 3—Impedance of Antenna Circuit = Z. Total Impedance Measured Around Secondary Circuit Above = Z_2. Mutual Impedance Between Circuits = Z_m

circuit, the secondary current is easily calculated:

$$i_2 = -e \frac{Z_m}{Z_1 Z_2 - Z_m^2}. \tag{9}$$

Suppose it is required to calculate what adjustment of the tuning condenser must be made to give maximum secondary current. Z_2 is the element that is to be varied, and although Z_2 is not pure imaginary, $d\,Z_2$ is pure imaginary because it is merely the reactance change due to varying the capacity. Therefore, to find what value of Z_2 makes i_2 maximum, apply condition (6). $\frac{d\,i_2}{d\,Z_2} = \frac{e\,Z_m\,Z_1}{(Z_1 Z_2 - Z_m^2)^2}$, so the condition is: Imaginary

part of $\dfrac{\dfrac{-e\,Z_m}{Z_1 Z_2 - Z_m^2}}{\dfrac{e\,Z_m\,Z_1}{(Z_1 Z_2 - Z_m^2)^2}}$ must be zero.

Simplifying, this becomes, imaginary part of $\left(Z_2 - \frac{Z_m^2}{Z_1}\right) = 0$ (10)

The nature of this result is evident, for the imaginary part of Z_2 is the reactance of the secondary circuit, while the imaginary part of $-\frac{Z_m^2}{Z_1}$ is the reactance introduced into the secondary by the primary. Thus the secondary condenser must be adjusted just enough "off tune" to offset the reactance introduced by the primary. It is easy to see that the larger Z_1 or the smaller Z_m, the less the condenser will be thrown "off tune." Also, if the primary coil is too small to resonate with the antenna capacity, Z_1 has a condenser or negative reactance component, and the reactance introduced into the secondary will be positive, so that the tuning condenser will have to be reduced in capacity from its normal value to compensate. On the other hand if the antenna inductance is larger than the value required for resonance with the antenna capacity, all the statements just made are reversed. Intermediate between the two conditions a large resistance is introduced into the secondary and no distinct maximum is obtained by varying the condenser. To minimize these peculiar effects upon the secondary tuning, the antenna circuit reactance is usually kept at a large negative value by means of a series condenser, or using few enough turns for each wavelength being received to assure that the antenna circuit reactance remains negative and of large value. As far as the equations go, it should also be possible to minimize the effect upon the secondary tuning by using a primary of inductance so large as to assure a large positive reactance in the antenna circuit.

It should be noted that (10) is an equation in the imaginary parts of the expression, so that the expression cannot be arranged to read $Z_1 - \frac{Z_m^2}{Z_2} = 0$, or even the imaginary part of it equal zero. Thus while the secondary circuit is tuned in the sense that the total effective reactance is made zero for maximum current, it is not true that the effective reactance of the antenna circuit is zero at the same time. This fact gives a certain amount of justification for calling this type of antenna circuit "untuned," though not for calling it "aperiodic."

SUMMARY: Having found the expression for a current (or voltage or power, etc.) in terms of complex quantities representing the constants of a circuit, it is often desired to determine what value of some one of these complexes makes the absolute magnitude of the current (or voltage, etc.) a maximum or a minimum. Rather than reduce the expression to its absolute value first, and then maximize in the usual way, it is often much less tedious to differentiate the expression while in the complex form. The condition that the absolute value is an extremum is then not that the derivative is equal to zero, but that the derivative multiplied by a small increment of the independent variable gives to the dependent variable an increment which is at right angles to the vector representing the dependent variable itself The condition of maximum obtained by this method is often in a form that is more compact and that has obvious physical significance. Two examples of the use of the method are given.

ON THE ORIGIN OF THE SUPER-HETERODYNE METHOD*

By

Walter Schottky

Mr. E. H. Armstrong recently explained in this Journal[1] that the idea of the receiving method named by him "Super-Heterodyne Reception" first occurred to him as a solution of the requirements of a war problem, and that in the course of further investigations, and due to various suggestions for improvements, this idea resulted in the excellent broadcasting receiving set that we admire so much to-day. As interchange of views and, consequently, uniformity of scientific and technical development have now apparently been re-established to a large extent between the enemy countries, you will no doubt allow me to give a short outline of how and when the corresponding idea took shape in Germany.

It was a special and relatively unimportant war problem, namely wireless remote control, which claimed the collaboration of the Siemens Laboratory—whose experiments were in part managed by me—in the course of 1917[2].

As in the case of the problem mentioned by Mr. Armstrong, discrimination against waves of other frequencies and atmospheric disturbances was the dominant aim, and thus led to theoretical investigations relating to the selectivity problem of radio reception in general. The most obvious suggestion of improvement consisted in modulating the transmitted high frequency by means of a lower one, and in providing a correspondingly double-tuned receiving set,—a suggestion which, as we now know, was the chief claim of Lucien Lévy's patent application, filed in the summer of 1917[3]. An exhaustive investigation which I made in December 1917, of the advantages that

*Received by the Editor, April 20, 1926.

[1] The Super-Heterodyne, Its Origin, Development and Some Recent Improvements, October, 1924.

[2] The Zentrallaboratorium of the Wernerwerk, known at that time as "Schwachstromkabel (K—) Laboratorium."

[3] English Pat. 143583 dated August 4, 1917. See also B. F. Meissner, Radio Dynamics 145-149, New York, 1916.

might be gained by this method as applied to transmitting and receiving sets showed, however, that these would not altogether fulfil our immediate expectations. Under the most varying conditions possible, I compared the effects which an impulse (*i.e.* a sudden alteration of the electric field intensity) or a non-modulated radio frequency signal would produce in the terminal set, with the effect of the signal to which the receiving set was intended to respond; and I established the fact that insensibility to impulse disturbances is, to a large extent, *only dependent on the ratio of the period*[4] *required for the terminal signal, to the period inherent to the (most rapid) radio frequency cycle employed.* Only in the case of interference due to non-modulated radio frequency signals lasting longer than about one-third of the mean frequency cycle, did a correspondingly reduced sensitivity result, compared with a simple receiving *circuit* tuned to this interfering frequency. Furthermore, the ratio of interference sensitivity to signal sensitivity was chosen to be dependent on whether the rectification of the mean frequency followed a linear law or, (as in the case of weak signals in ordinary detectors and rectifiers) a square law; it was shown that the square law rectifying action prejudicially affected the ratio of interference sensitivity to signal sensitivity. For this reason, and on account of the well-known loss in amplification which cannot be avoided with weak signals under square-law rectification, I considered the possibility of amplifying, by means of a non-selective radio frequency amplifier, the two adjacent frequencies γ_1 and γ_2 contained in the modulated carrier wave, to such an extent before their passage through the first rectifier, that the rectifying action would become approximately linear. But here I encountered a problem, the general importance and difficulties of which were already familiar to me, and which I had at first hoped to solve by the construction of special amplifying valves having large electronic currents and small internal resistance[5]. My acquaintance with the idea of inaudibly-modulated carrier frequency presented me (at the end of February and beginning of March) with a new solution, viz: that the incoming high frequency (at frequencies γ_1 and γ_2 or, in case of non-modulated high frequency transmission, at frequency γ) could be converted linearly like ordinary heterodyne reception—into a lower fre-

[4] Where mechanical relays are operated, the period of the terminal signal may be the natural oscillation of the armature; in the case of telephonic signals —the cycle of the highest frequency that can be transmitted.

[5] D. R. P. 366829, filed November 11, 1917.

quency wave which could be easily amplified, by causing the first receiver valve to oscillate at a frequency which would give inaudible beats when receiving the incoming high frequency. In order to obtain the linear conversion of the wave, the amplitude of this auxiliary oscillation should be dimensioned in such a manner that it entirely *controlled the super-heterodyne valve over about one-half its characteristic.*

It was by no means difficult to recognise the importance of this method, which actually represents the super-heterodyne principle, for all purposes of radio reception. In fact, the following entry was made by me in the journal of the K = Laboratorium for the period February 25 to March 16, 1918:

> "*A Frequency Transformation for Radio Reception*
>
> "As the amplification of very short waves in many "cases involves a large consumption of energy in the "amplifier valves employed, it is of advantage to be able "to convert short waves at their reception, without any "loss of energy, into longer, similarly inaudible waves and "then to amplify these only. This is accomplished by "heterodyning another frequency differing by about "10 % so that the beat-wave again becomes high frequen- "cy, but longer. Of special importance for radio telephony "in which ordinary heterodyning is not possible."

The German patent for this method was filed on the 18th June, 1918[6]; since I could not myself draw it up nor pursue the matter further, it did not, unfortunately, assume the form I should have wished. Nevertheless, it emphasizes the essential features of the super-heterodyne method and, thanks to the Nolan Act, patents have been granted in America and England, so that according to the present state of patent law in these countries as well as in Germany, the manufacture of at least such heterodyne sets as permit the *amplification* of the transformed (inaudible) high frequency, is involved in the possession or right of utilization of this patent.

I should like to conclude this little historical note by referring to some still earlier publications and patent applications in our field[7], which are of historical importance in relation to the super-heterodyne idea, but were, probably, as unknown to Mr. Armstrong as to me. The idea of employing the advantages of heterodyne reception for radio telephony also, by selecting an

[6] D. R. P. 368937; English Pat. 135177, appl. 1502063. The first patent E. H. Armstrong is dated 30th December, 1918.

[7] See also the report of J. H. More, Electrician, 1925, p. 121.

inaudibly high beat frequency, was probably published originally in 1913 by Mr. Hogan in the course of a discussion[8]. The idea of producing a beat frequency by means of a local source of oscillation, which was not intended to make the signals audible, but expressly to provide for another tuning and thereby increased selectivity, has been patented by Graf Arco and A. Meissner[9], and by H. J. Round[10]; Round's application also lays stress on providing inaudible beat frequencies, but actually offers no good selectivity against interference owing to the inherent necessary detuning of the aerial. Finally, the aforementioned patent of Lucien Lévy[11] is of fundamental importance to the whole field; he must be considered, at least from the point of view of patent law, as the true originator of the super-heterodyne method, since the super-imposition of an adjacent frequency, an intermediate circuit tuned to inaudible frequencies, and a further rectification in order to convert into the desired signal, are described explicitly in his application (as one of several constructions). In regard to earlier existent publication, there may be a doubt as to whether the information would have brought about the desired technical progress we owe to the super-heterodyne method, as conceived by Mr. Armstrong and also described in the German application. After all, the actual aim of the high-frequency transformation or super-heterodyning principle consists in providing a suitable and relatively convenient radio frequency amplifier for short waves, whereas the selectivity effects that Lévy solely had in view are less important, according to the above considerations, and might be obtained as well by the use of a slightly attenuated or reaction-coupled radio frequency syntonizing circuit. The drawings of this application also leave it doubtful whether the elimination of the square-law rectifying action, which is so essential for the commercial use of the apparatus, would have been obtained by means of experimental sets constructed on the principle indicated in the application.

The "word" seems, at any rate, to have been far less important in this field than the "deed," and there appears to be no doubt that it is Mr. Armstrong and his collaborators to whom we owe the deed, which has made the super-heterodyne method such as invaluable instrumentality in radio engineering.

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[8] Hogan, PROCEEDINGS OF THE INSITUTE OF RADIO ENGINEERS, 1,97 (1913).

[9] English Pat. 252, 1914, filed January 5, 1914 and D. R. P. 300896, January, 15, 1917.

[10] English Pat. 27480, 1913, filed November 11, 1913.

[11] English Pat. 143583, date of appl. April 8, 1917.

DISCUSSION ON PORTABLE RECEIVING SETS FOR MEASURING FIELD STRENGTHS AT BROADCASTING FREQUENCIES, BY AXEL G. JENSEN*

By
G. D. Gillett
(Department of Development and Research, American Telephone and Telegraph Co.)

Mr. Jensen has so fully covered the technical features of these new measuring sets that I think it would be impossible for me to add anything of importance to that phase of the subject except to emphasize, as Mr. Jensen failed to do through modesty, just how great an advancement the replacing of the method of balancing voltages impressed on the grid of the first detector with one involving the balancing of the voltages induced in the loop represents in the art of measuring field strengths at broadcast frequencies. Advancement both in the sustained accuracies obtainable in field work and even more in their ruggedness and convenience in the field. We have found that on the average we can accomplish nearly twice as much work with these new sets as we could with the old type which they replace. Also, it may be of interest to you to see how these sets are being used in the field in actual field strength measuring work, and to review both the uses to which they have been put as well as the ones to which they may be put and for which they are peculiarly well adapted.

Originally our field work was done with sets which we carried on the back seat of an ordinary touring car, relying on the cushion effect of the seats themselves to protect them from severe road shock. This involved lifting them up on a small platform every time a measurement was to be made, and attempts were made to develop a spring mounting which would satisfactorily protect them from road shock and at the same time carry them in position ready for instant use. Figure 1 will show our solution of this problem with the sets closed and the loop mounted on the running board of the car ready to go.

*Received by the Editor, May 19, 1926.

The mounting for the sets consists of a heavy wooden box supported on an equally heavy angle iron frame, this box being lined on the bottom, sides, and back with heavy automobile type cushions, and the sets are carried in a felt lined light wooden frame upon these cushions. Since it is necessary to reach the front and top of the sets during operation, it was impossible to surround them entirely by cushions, and instead the sets were clamped into the light frame, and this box frame is held against

FIGURE 1

the cushions by four heavy steel coil springs located at the bottom and top rear corners of the mounting. This cushion mounting has been very successful in protecting the sets from injury by road shock as well as convenient in operation. We also thought it looked quite handsome until the proprietor of an electrical shop where we stopped to get some batteries asked us, "What kind of a washing machine is that?"

Figure 2 shows the sets with the loop inserted in its socket and the set in operation. When a measurement is to be made, all that is necessary is for the driver to remove the loop from the spring clips in which it is held, insert it in the socket on the top of the set, and plug in his receivers. The batteries are turned on by the insertion of the receiver plug. The condenser dials are fitted with clamps so that the set remains in tune. This makes it a very convenient arrangement and we have found it possible to make as many as nine separate measurements in an hour at points spaced one mile apart.

FIGURE 2

Examples of the first work done in the field with measuring sets involved a small survey around New York City and another around Washington, D. C. The results of these surveys are shown in Figures 3 and 4. The form of the contour lines show clearly for the first time the very wide departure of field strength distribution from the ideal, especially in congested areas filled with absorbing metallic structures. In the case of New York City, the shadow cast by the 42nd Street district north over the Central Park area, and another cast by the downtown sky-scrapers over Governors Island and lower Brooklyn are clearly shown by the marked dents in the contour lines. These data were included in a paper by Mr. Bown and myself presented before this Institute in 1924.

Shortly after these surveys were made, field strength measuring sets of the early type were used to make a quantitative comparison of the transmission from a transmitting station located at 24 Walker Street and a transmitting station located only one mile away at 463 West Street, both in New York City. The results of these comparative measurements rather surprised us by showing a difference, at certain points in the lower tip of Connecticut, of over 100 to 1 in power efficiency of transmission between these two stations, only a mile apart.

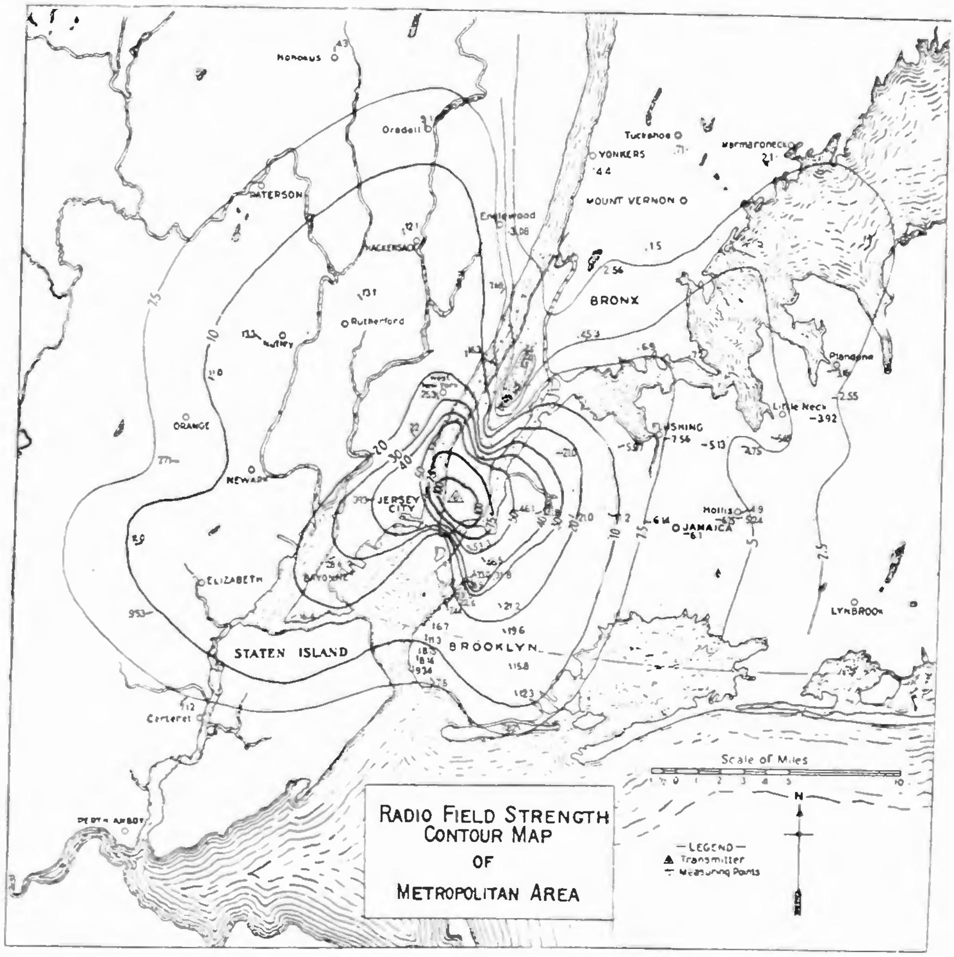

FIGURE 3—Radio Field Strength Contour Map of Metropolitan Area (Field Strenghts in Millivolts per Meter)

In an attempt to get some explanation of the possible causes of such a condition, a complete detailed survey was made of Westchester County and the lower tip of Connecticut, which resulted in the field strength contour map shown in Figure 5. The contours on this map show that there is a series of long nearly parallel hills and valleys of field strength. There has occurred to us, as an explanation, that this hitherto uncharted form of field strength distribution is a gigantic wave interference pattern. This interference pattern probably results from the extremely heavy absorption of the high building area around the 42nd Street district with its resulting shadow and the feeding in from each side of this shadow as the waves progress out over Westchester.

This same shadow effect has been definitely located by means of these measuring sets in connection with the use of a portable transmitter, shooting at this 42nd Street district from different directions. In Figure 6 is shown the location of the portable transmitter at these different points with a large enough fragment of the resulting contour map to show the shadowing effect. The intersections of the lines drawn from the shadows to the transmitter fall at approximately 38th Street in the vicinity of

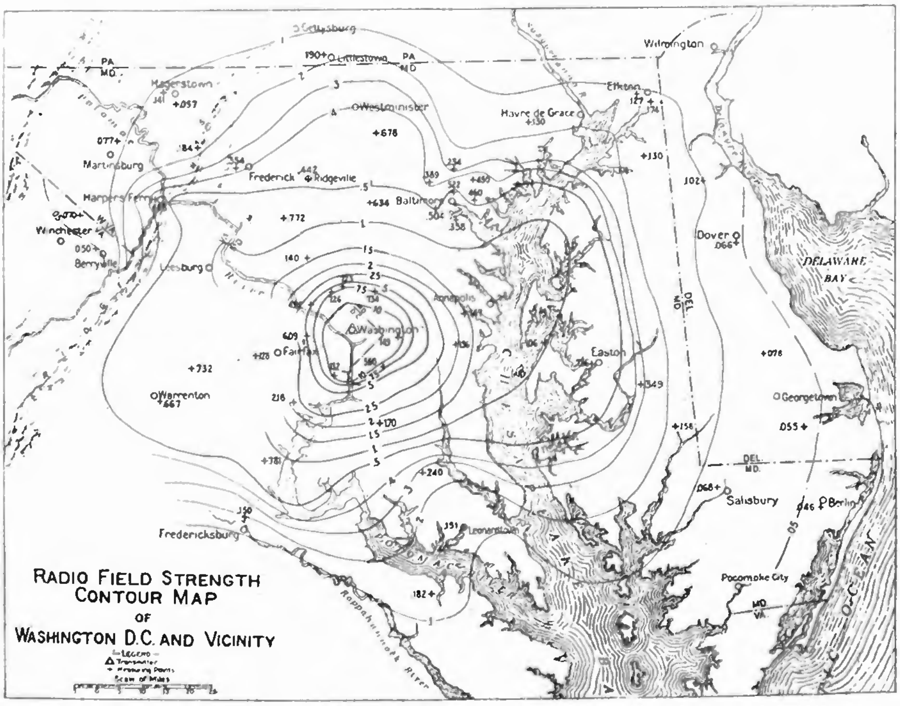

FIGURE 4—Radio Field Strength Contour Map of Washington, District of Columbia and vicinity

Sixth Avenue, definitely locating the center of gravity at least of the area of abnormally heavy absorption. The interference pattern given above and our conclusions as to the nature of the effect of the building area on the interference pattern were first described in a paper presented before this Institute last fall, "Some Studies in Radio Broadcast Transmission," by Messrs. Bown, Martin and Potter.

Finally, I should like to point out that such sets as these are the only means available at the present time for making accurate and complete field strength surveys of a broadcasting station. By the use of a portable transmitter, in connection with surveys made in this way, it is possible to evaluate accurately in advance of any costly construction, the relative merits of different sites for the location of a new broadcasting station, and thus avoid the chance of unsatisfactory performance which has been experienced by so many stations located in dense metropolitan areas.

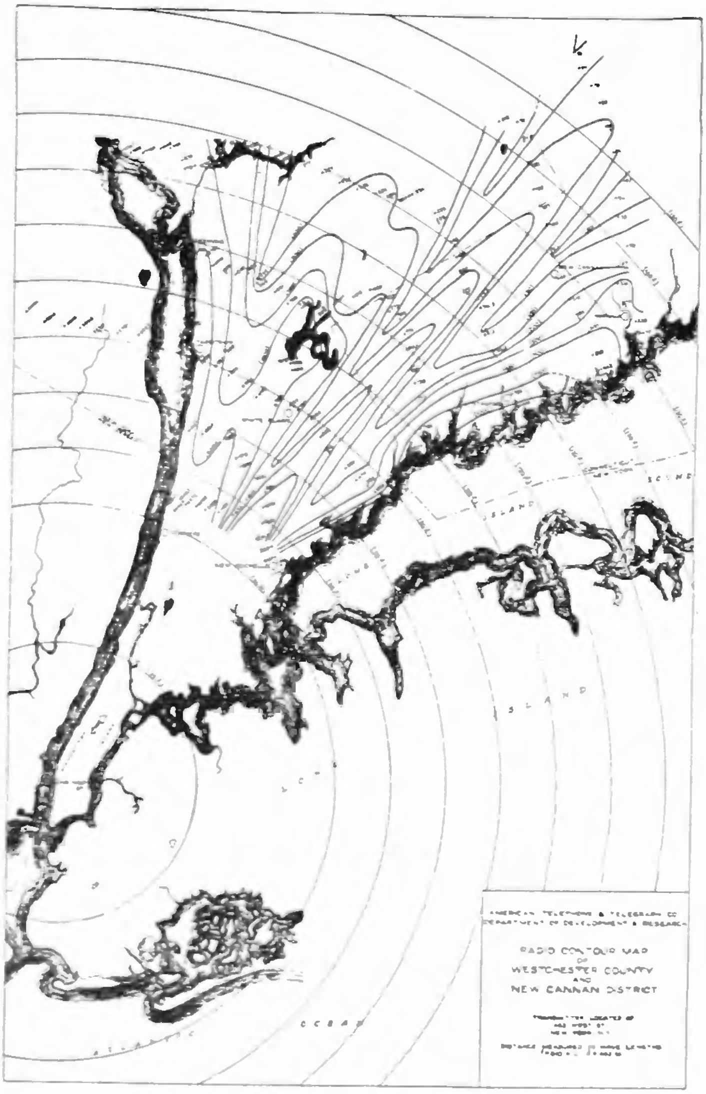

FIGURE 5—Radio Contour Map Showing Wave Interference Pattern

These sets also are peculiarly well adapted for the location of noise or interference of any sort. Heretofore, it was necessary to have a carrier from some transmitting station in order to bring the noise or interference in as sideband and thus raise it to an audible level in the receiver comparable to ordinary receiving conditions. But due to the directional characteristic of the carrier it was impossible to use a directional receiver to determine the bearing of the source of the noise. With these sets it is possible, from the local signal input oscillator, to supply a carrier of any known or desired value and frequency without a directional characteristic, and to use this carrier to sensitize the receiver so that the loop's directional characteristic may be used to locate the bearing of the incoming noise and thus to trace down the source of noise.

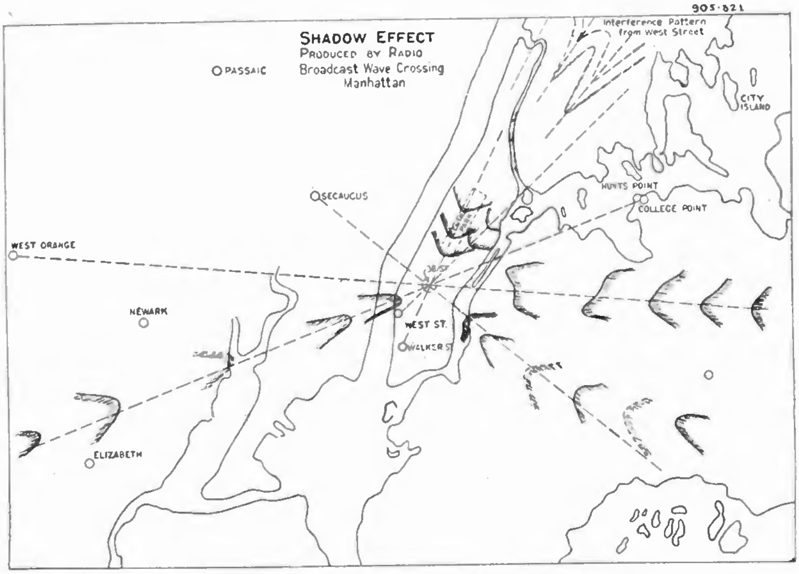

FIGURE 6—Map Showing Location of Radio Obstruction on Manhattan Island as Determined by the Intersection of Lines Between Various Transmitting Points and Their Corresponding Shadows

In conclusion, perhaps the best indication of the value of these sets in research work is given by the fact that we have thought it worth while to carry sets of these types over 15,000 miles in the last three years in the making of field measurements and have made a total of about three thousand separate measurements.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY

Issued May 11, 1926—June 30, 1926

By

JOHN B. BRADY

(Patent Lawyer, Ouray Building, Washington, D. C.)

1,584,015—G. S. CORNISH, of Madisonville, Ohio. Filed November 22, 1924, issued May 11, 1926. Assigned to the Cincinnati, Patent Engineering Company.

CONDENSER AND LEAD FOR RADIO CIRCUITS, where a pair of condenser plates are disposed at right angles to each other on an insulated base and their terminals shunted through a high resistance coating.

1,548,220—H. FARKOUGH, of Brooklyn, N. Y. Filed May 21, 1923, issued May 11, 1926.

PORTABLE RADIO RECEIVING SET, in the form of a suit case having extensible feet thereon by which the suit case may be set up at an angle for convenience in operation.

1,584,490—A. H. TAYLOR, of Washington, D. C. Filed November 30, 1925, issued May 11, 1926. Assigned to Wired Radio, Incorporated, of New York City.

THREE-PHASE OSCILLATOR, where three single phase oscillation generator circuits are connected in Y and the oscillation circuits controlled by a piego-electric crystal for maintaining the several currents in proper phase displacement.

1,584,551—E. W. KELLOGG, of Schenectady, N. Y. Filed October 29, 1924, issued May 11, 1926. Assigned to General Electric Company.

RADIO RECEIVING SYSTEM, in which a pair of directionally extending horizontal conductors are provided with means for producing reflection of different phases in the two conductors for the selective reception of signals.

1,584,893—F. A. RAFFERTY, of Villanova, Pennsylvania. Filed June 21, 1923, issued May 18, 1926.

CONSTANT INDICATOR FOR VIBRATORY CIRCUITS, consisting of a meter in which the frequency of the electromagnetic wave may be read directly in kilocycles and cycles or in meters and the product of inductance and capacities in micro-henries and micro-farads may be read directly.

1,585,244—W. H. HOFFMAN, of Madison, Wisconsin. Filed February 17, 1925, issued May 18, 1926. Assigned to C. P. Burgess Laboratories.

SHORT WAVE LENGTH TRANSMITTER, in which an electron tube circuit is stabilized for operation by means of a bridge circuit which maintains the system in a condition of oscillation at constant frequency.

1,585,431—W. O. SNELLING, Allentown, Pennsylvania. Filed September 24, 1923, issued May 18, 1926.

CURRENT-RECTIFYING DEVICE, consisting of a metallic sulphide prepared in the presence of a reagent comprising sulphide dioxide and carbon bisulphide.

1,585,445—J. C. WARNER, Schenectady, N. Y. Filed February 29, 1924, issued May 18, 1926. Assigned to General Electric Company.

ELECTRON DISCHARGE APPARATUS AND METHOD OF OPERATING THE SAME, in which a pair of grid electrodes are provided, interposed between the cathode and anode and the flow of current between the cathode and anode controlled by the conjoint action of two grids.

1,584,923—O. GRUENBERGER, Wauwatosa, Wisconsin. Filed December 29, 1922, issued May 18, 1926.

ELECTRICAL CONDENSER, in which a pair of plate members is provided and the mutual exposure controlled by flexing or rolling of one plate upon another.

1,586,060—R. BAINTON, Greeley, Colorado. Filed July 18, 1922, issued May 25, 1926.

MEANS FOR GUARDING AGAINST THE UNAUTHORIZED RECEIVING OF RADIO COMMUNICATIONS, employing a cam operated mechanism at both the transmitting and receiving stations for varying the operating wave length in accordance with a definite law for the purpose of secrecy.

1,586,144—H. J. J. M. de R. de Bellescize, Toulon, France. Filed August 18, 1919, issued May 25, 1926.

STATION FOR DUPLEX RADIO TELEGRAPHY, employing a loop antenna perpendicular to the direction of the transmitter with a directional collector coupled to the loop for compensating for any unsymmetrical relations between the loop and the conductors of the transmitter having oscillations induced therein.

1,586,162—J. C. R. PALMER, New Rochelle, N. Y. Filed March 29, 1923, issued May 25, 1926. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE, where the control electrode consists of a wire helix surrounding the cathode with the control circuit connected across the wire helix.

1,585,650—G. H. CLARK, Brooklyn, N. Y. Filed June 27, 1922, issued May 25, 1926. Assigned to Radio Corporation of America.

ARC GENERATOR, wherein oscillations are maintained at constant frequency by a plurality of windings around the arc field.

1,585,766—L. W. CHUBB, Edgewood Park, Pennsylvania. Filed May 15, 1917, issued May 25, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

THERMIONIC CONVERTER, embodying two electrodes having different electron emissivity when equally heated and arranged for the passage of uni-directional current between the electrodes.

1,585,878—H. O. RUGH, Chicago, Illinois. Filed November 16, 1922, issued May 25, 1926.

THERMIONIC VALVE for connection in an incandescent lamp socket, serving as a complete radio receiving set for the external connection of a headset and tuning circuit therewith. The valve functions as a rectifier of incoming signaling energy.

1,586,199—G. HOLST, E. OOSTERHUIS and J. BRUIJNES, of Eindhoven, Netherlands. Assigned to Naamlooze Vennootschap Philips' Gloeilampen-Fabrieken.

ELECTRICAL DISCHARGE DEVICE for the purpose of rectification where two electrodes are provided with a shield of insulating material interposed between the electrodes.

1,586,419—W. S. FREESLAND, of Norfolk, Virginia. Filed October 2, 1922, issued May 25, 1926.

MULTICONTACT CRYSTAL DETECTOR, where a switching arrangement is provided for selecting a plurality of sensitive points of a crystal and effectively including such points in a circuit.

1,586,498—S. K. WILSON, of Philadelphia, Pennsylvania. Filed January 26, 1925, issued May 25, 1926.

CONDENSER for variable adjustment in which a pair of cylinders are provided axially movable one within the other.

1,586,524—R. A. HEISING, Millburn, N. J. Original filed December 29, 1916; renewed April 28, 1924, issued June 1, 1926. Assigned to Western Electric Company.

CONSTANT FREQUENCY SYSTEM, where an arc excited oscillating circuit is controlled in stable condition independent of variations which occur in the resistance of the load circuit.

1,586,558—J. E. HARRIS, Newark, N. J. Filed November 20, 1922, issued June 1, 1926. Assigned to Western Electric Company.

MANUFACTURE OF ELECTRON DISCHARGE DEVICES, where the electron tubes are evacuated while establishing a space discharge between the electrodes in an atmosphere of carbon monoxide.

1,586,580—J. C. SCHELLENG, Millburn, N. J. Filed August 20, 1925, issued June 1, 1926. Assigned to Western Electric Company.

OSCILLATING SYSTEM, where the frequency of the system may be changed by varying the inductance and capacity circuits simultaneously by means of a mechanical switching system.

1,586,653—F. CONRAD, Pittsburgh, Pennsylvania. Filed March 10, 1922, issued June 1, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

RADIO TRANSMISSION SYSTEM, where a plurality of non-parallel antennae are provided tuned to the same frequency and a connection between a source of oscillations with one of the antenna circuits, the other antenna circuits being connected between points of like potential and the oscillation circuit for oscillating in unison.

1,586,657—S. DAVIDSE, Wheeling, West Virginia. Filed May 17, 1923, issued June 1, 1926.

INDUCTIVE LOOP ANTENNA, where a plurality of separate loop frames are variably positioned upon a support for mutual adjustment thereon.

1,586,672—E. L. HACKETT, Wyoming, N. J. Filed September 5, 1922, issued June 1, 1926. Assigned to M. H. Avram & Company, Incorporated.

CRYSTAL DETECTOR, having a micrometer adjustment for the cat whisker with respect to the crystal.

1,586,755—J. F. LINDBERG, Chicago, Illinois. Filed September 25, 1922, issued June 1, 1926. Assigned to Reliance Die & Stamping Company.

INDUCTANCE APPARATUS, comprising an inductance coil concentrically mounted around a condenser with a mechanical device for changing the angular position of the inductance coil with respect to the condenser.

1,586,828—A. H. MILLER, Detroit, Michigan. Filed November 26, 1923, issued June 1, 1926.

RADIO DETECTOR, where a crystal is embedded in a low fusing alloy and mounted within a tubular container with a contact device permanently secured upon a sensitive point of the detector.

1,586,895—J. J. GILBERT, Port Washington, N. Y. Filed May 15, 1922, issued June 1, 1926. Assigned to Western Electric Company.

SUBMARINE CABLE SIGNALING for two-way signaling between two stations where a mechanical arrangement is provided for permitting simultaneous transmission from both stations and reception at both stations over equal periods of time.

1,587,095—B. R. WEBSTER, Chicago, Ill. Filed April 28, 1924, issued June 1925. Assigned to Reliance Die & Stamping Company.

ELECTRICAL CONDENSER, having rotor and stator plates with the movable shaft reduced in the form of a quill and journal in the condenser frame for accurate adjustment therein.

1,587,096—A. E. WHEELER, Logansport, Indiana. Filed June 30, 1925, issued June 1, 1926.

COMBINED RADIO LOUD SPEAKER AND LAMP, wherein an acoustic horn is combined with a support for a lamp.

1,587,156—W. G. HOUSKEEPER, New York City. Filed November 26, 1920, issued June 1, 1926. Assigned to Western Electric Company.

VACUUM INSULATOR for the lead in of conductors into a high power vacuum tube where inner and outer axial cylinders of insulating material form a passage for the lead in through the wall of the vacuum tube.

1,587,168—M. MATHIESEN, of Chicago, Illinois. Filed April 13, 1925, issued June 1, 1926. Assigned to Mathiesen-Sandberg Company.

LOOP AERIAL, designed for portable erection where the frame members are hinged together.

1,587,389—O. G. LISSEN, Jersey City, N. J. Filed March 13, 1924, issued June 1, 1926.

CONDENSER of multiple construction with a single shaft for controlling the condenser simultaneously and a friction device for independently controlling the movement of the condensers.

1,587,210—R. V. L. HARTLEY, East Orange, N. J. Filed February 3, 1919, issued June 8, 1926. Assigned to Western Electric Company.

NONRESONANT SYSTEM, including a plurality of electron tube repeaters with circuits for driving current through each repeater and an electromagnetic control operated by the flow of current through each repeater tending to reduce the simultaneously existing current through the other repeater.

1,587,696—A. J. CARTER, Chicago, Illinois. Filed March 14, 1924, issued June 8, 1926. Assigned to Carter Radio Company.

ELECTROSTATIC CONDENSER of the stack type where U-shaped terminals are provided for subjecting the stack to pressure and establishing connection with opposite sides of the condenser.

1,587,786—J. MASSOLLE, HANS VOGT and DR. JOSEF ENGL, of Grunewald, Berlin and Grunewald, Germany, respectively. Filed April 4, 1921, issued June 8, 1926. Assigned to Tri-Ergon Limited of Zurich, Switzerland.

ELECTRON TUBE having anode screening means with a connection between the source and the anode screening means.

1,587,880—R. A. WEAGANT, New York, N. Y. Filed February 7, 1919, issued June 8, 1926. Assigned to Radio Corporation of America.

METHOD AND APPARATUS FOR RADIO SIGNALING, wherein a pair or horizontally extending antennas are arranged to be moved in a vertical or horizontal plane for securing the maximum response to signaling energy free of static disturbances.

1,587,595—F. LOWENSTEIN. Filed November 5, 1920, issued June 8, 1926. Assigned to Radio Patents Corporation.

TELEPHONY, wherein the efficiency of transmission and reception is considerably increased by suppressing at the transmitter the lower frequency notes which normally require considerably more power for transmission than the higher frequency notes and restoring the lower frequency notes at the receiver. The patent covers both the method of transmission and apparatus for effecting such transmission.

1,587,657—F. A. KOLSTER, of Burlingame, California. Filed December 5, 1921, issued June 8, 1926. Assigned to Federal Telegraph Company.

RADIO SIGNALING SYSTEM for signaling between one station and either of two others which are substantially in the same line and in the same direction with respect to the first station. Circuits are provided for the selective transmission and reception of the signaling energy in a definite prescribed path.

1,587,662—F. LOWENSTEIN. Filed November 29, 1918, issued June 8, 1926. Assigned to Radio Patents Corporation.

APPARATUS FOR GENERATING ALTERNATING CURRENT for radio transmission where a pair of parallel branch circuits each including an electron tube system are so connected with an antenna system as to conjointly deliver energy to the antenna system with a circuit for modulating the effects of transmitted energy.

1,587,924—H. J. ROUND and A. McLELLAN, of London and Swansea, England, respectively. Filed March 30, 1921, issued June 8, 1926. Assigned to Radio Corporation of America.

RADIO SIGNALING SYSTEM, where a circuit arrangement is provided for maintaining the tuning of an antenna constant under conditions of change in load.

1,587,932—G. D. BAGLEY, Flushing, N. Y. Filed December 4, 1922, issued June 8, 1926. Assigned to Electro Metallurgical Company.

SPARK GAP APPARATUS, comprising separate intercommunicating electrode chambers containing hydrogen. Electrodes are arranged in the chamber and adjustable mercury pools provided for the other electrodes whereby discharge takes place in hydrogen.

1,587,942—W. DUBILIER, of New York, N. Y. Filed March 7, 1919, issued June 8, 1926. Assigned to Dubilier Condenser & Radio Corporation.

CONDENSER STRUCTURE, wherein a stack is secured under pressure and a casing engaged over the stack and secured to an insulating block arranged adjacent one end of the stack.

1,588,047—M. Osnos, of Berlin, Germany. Filed February 12, 1923, issued June 8, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

CIRCUIT ARRANGEMENT FOR RADIO SIGNALING, including a source of high frequency energy with an oscillatory circuit connected therewith, the oscillatory circuit comprising inductance and capacity so adjusted as to resonate the transmitting frequency while bi-passing all the undesirable higher frequencies.

1,588,248—D. G. McCAA, Lancaster, Pennsylvania. Filed March 23, 1923, issued June 8, 1926. Assigned to The Electric Apparatus Company.

ANTISTATIC SYSTEM for radio receiving systems where a vibratory contact member is actuated at the receiver in step with received telegraphic signals for the reception of the signals independent of interference.

1,587,512—W. DORNIG, of Berlin-Steglitz, Germany. Filed February 2, 1921, issued June 8, 1926.

HIGH-FREQUENCY TRANSFORMER for radio transmission where the transformer circuit is coupled to an antenna system through an intermediate tuning circuit for controlling the effect of the high frequency energy thus developed upon the antenna.

1,588,074—C. D. WHITE, HARRY STEVENSON and DAVID H. MOSS. of New Jersey. Filed November 4, 1925, issued June 8, 1926. Assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.

AUDIO-FREQUENCY TRANSFORMER, where the windings are magnetically shielded by a pair of closure members which embrace opposite sides of a channel-shaped frame.

1,587,764—ROBERT D. DUNCAN, JR., of East Orange, New Jersey. Filed December 23, 1925, issued June 8, 1926. Assigned to Wired Radio Incorporated, of New York City.

WIRED RADIO TRANSMITTING SYSTEM, in which a plurality of transmitters may be arranged for impressing high-frequency oscillations on line wire circuits without interference between the several transmitting frequencies for the transmission of a plurality of programs over a line wire network to a multiplicity of subscribers.

1,588,545—W. H. Gerns, of East Orange, New Jersey. Filed November 28, 1925, issued June 15, 1926. Assigned to Brandes Laboratories, Incorporated, of Newark, New Jersey.

ELECTROMAGNETIC DRIVER, particularly adapted for a conical diaphragm sound reproducer, wherein an armature member is driven by a pair of electromagnetic systems positioned on opposite sides of the armature. The armature is constructed for the efficient reproduction of notes over the entire musical scale.

1,588,438—H. N. BLISS, Ithaca, New York. Filed November 4, 1924, issued June 15, 1926.

METHOD AND APPARATUS FOR SELECTIVE ELECTRICAL TUNING, in which a set of rotor plates may be variably interleaved with a set of stator plates and independent movement imparted to the stator plates for compensating for variations in the differences in the plurality of stages of amplification.

1,588,474—A. A. KENT, Ardmore, Pennsylvania. Filed June 6, 1925, issued June 15, 1926.

CONDENSER for panel mounting within a receiver where the stator elements are supported from a bracket engaging the panel and the rotor elements are journaled in a single bearing carried by the panel.

1,588,519—Q. A. BRACKETT, Springfield, Massachusetts. Filed September 29, 1921, issued June 15, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

GRID LEAK formed within an electron tube by means of an auxiliary cathode device which is arranged parallel to the normal cathode and maintained at electron emitting temperature for providing a leak path with respect to the grid electrode.

1,588,671—C. S. GERBER, Pittsburgh, Pennsylvania. Filed April 1, 1925, issued June 15, 1926.

ELECTRIC CONDENSER, in which a rotatable member carries a pair of shaped plates on opposite sides of a stationary plate for variation in capacity in accordance with a definite law.

1,588,813—W. SCHEPPMAN, Berlin, Germany. Filed August 31, 1921, issued June 15, 1926. Assigned to Lorenz Aktiengesellschaft.

OSCILLATION CIRCUIT for the production of sustained oscillations where an electron tube system has the constants proportioned for the generation of oscillations with a condenser in shunt with the grid and plate circuits for the sustaining of oscillations.

1,589,008—J. B. KIRBY, West Richfield, Ohio and H. S. SCOTT, Cleveland, Ohio. Filed August 5, 1925, issued June 15, 1926. Said Scott assignor to said Kirby.

RADIO CONDENSER, having an attachment consisting of a plate of insulating material adapted to be inserted to a variable extent between certain of the plates of the condenser for fixing the capacity of the condenser.

1,589,204—L. H. MILLER, Lakewood, Ohio, and M. W. SEVERANCE, Cleveland, Ohio. Filed December 14, 1922, issued June 15, 1926. Assigned one-third to Arthur H. Voigt.

VARIABLE CONDENSER for accurate adjustment of the capacity of an electrical circuit wherein a tubular member is rotated within a screw threaded cylinder and the gap therebetween filled with dielectric.

1,589,308—J. A. VICTOREEN, Cleveland, Ohio. Filed April 30, 1926, issued June 15, 1926.

RADIO-FREQUENCY APPARATUS, consisting of a combined transformer and variable condenser unit forming a coupling device for electron tube circuits.

1,589,344—M. K. AKERS, Troy, Ohio. Filed December 2, 1920, issued June 22, 1926. Assigned to Western Electric Company, Incorporated.

RADIO-SIGNALING SYSTEM, arranged for duplex operation where locally transmitted energy is prevented from interfering with reception by means of a balanced transformer associating the transmitting and receiving apparatus in conjugate relation with respect to a closed loop and open antenna.

1,589,483—G. H. PERRYMAN, New York City. Filed November 3, 1925, issued June 22, 1926. Assigned to Perryman Electric Company, Incorporated.

VACUUM TUBE having a brace member for the electrodes within the tube for strengthening the electrode support and preventing injury to the electrodes as a result of rough handling.

1,589,925—R. R. BATCHER, Jamaica, New York. Filed December 19, 1924, issued June 22, 1926. Assigned to A. H. Grebe & Company, Incorporated.

RADIO-RECEIVING APPARATUS of the superheterodyne type in which a single control is provided for securing straight line frequency variation in the receiving system.

1,589,927—A. E. BEATTIE, Manzanillo, Cuba. Filed April 7, 1925, issued June 22, 1926.

THERMIONIC VALVE having stout annular glass envelope with electrodes arranged therein for high power operation.

1,589,946—E. G. DANIELSON, San Francisco, California. Filed May 19, 1925, issued June 22, 1926. Assigned to E. T. Cunningham.

RADIO-TUNING DEVICE, where a plurality of condensers are geared together for simultaneous control.

1,589,979—D. G. McCAA, Lancaster, Pennsylvania. Filed June 25, 1924, issued June 22, 1926. Assigned to The Electric Apparatus Company.

RADIO SYSTEM, having a plurality of electron tube circuits arranged for reduction of static disturbances where signaling energy is received in a path having a natural period longer than the period of the received oscillations, the natural period of the path being changed by the effect upon the reactance thereof by regularly produced oscillations.

1,590,198—D. G. McCAA, of Lancaster, Pennsylvania. Filed January 19, 1925, issued June 29, 1926. Assigned to The Electric Apparatus Company.

RADIO SYSTEM for the separation of undesired signals from desired signals, where a receiving circuit is provided with a path having inductances in parallel with a circuit for selectively amplifying the energy traversing one of the inductances to vary its reactance to the said signaling energy.

1,590,224—L. C. BLUME, Chicago, Illinois. Filed June 28, 1923, issued June 29, 1926.

RADIO DETECTOR, in which a readily adjustable mounting is provided for the cat whisker on a U-shaped supporting member for establishing contact with a crystal.

1,590,236—H. GERNSBACK, New York City. Filed September 18, 1924, issued June 29, 1926.

CRYSTAL DETECTOR, where a contact device in the form of a flat spring is provided with a point which engages a crystal where the crystal is secured in a cup readily movable under the contact.

1,590,346—L. M. CLEMENT, East Orange, New Jersey. Filed September 25, 1920, issued June 29, 1926. Assigned to Western Electric Company.

RADIO DIRECTION FINDING, including a system of undamped wave transmission where a continuous wave is modulated in accordance with a wave having a cyclically and continuously varying frequency for insuring rectilinear propagation in all directions for selective reception on a directional receiver.

1,590,352—J. M. EGLIN, East Orange, New Jersey. Filed June 20, 1924, issued June 29, 1926. Assigned to Western Electric Company.

ELECTRON-DISCHARGE DEVICE, in which a getter is supported within the tube by a refractory metal ring extending from one of the electrodes for insuring a high degree of vacuum throughout the life of the tube.

1,590,374—L. C. F. Horle, Newark, New Jersey. Filed January 16, 1926, issued June 29, 1926. Assigned to Federal Telephone Manufacturing Corporation.

RADIO TRANSMISSION SYSTEM, which comprises generating at a control station a carrier wave of frequency above audibility but of comparatively low order of frequency for line wire transmission, which carrier wave is conveyed to the transmitting station and changed in frequency to produce a carrier wave of high frequency which is modulated for the transmission of signals.

1,590,678—W. FUHRMANN, Westfield, New Jersey. Filed April 7, 1925, issued June 29, 1926. Assigned to Furnell Manufacturing Corporation.

CONDENSER FOR ELECTRIC CIRCUITS, wherein a pair of evolute coil strips are arranged to be shifted one within the other for varying the exposure therebetween and correspondingly the electrical capacity between the strips.

D-70,407—ROBERT D. DUNCAN, JR., East Orange, New Jersey. Filed March 29, 1926, issued June 22, 1926. Assigned to Wired Radio, Incorporated, of New York City.

WIRED RADIO RECEIVING APPARATUS for the reception of programs broadcasted over line wire circuits.

1,589,692—E. E. HILER, of Bloomfield, New Jersey. Filed August 27, 1925, issued June 22, 1926. Assigned to Irvington Varnish & Insulator Company, of Irvington, New Jersey.

CHOKE COIL AMPLIFICATION UNIT, where a pair of choke coils are mounted upon a laminated iron core structure and housed within a casing.

1,590,428—ROBERT D. DUNCAN, JR., of East Orange, New Jersey. Filed August 25, 1925, issued June 30, 1926. Assigned to Wired Radio, Incorporated, of New York City.

WIRED RADIO BROADCASTING SYSTEM, in which high-frequency currents are super-imposed of line wire circuits and transmitted to a multiplicity of subscriber stations.

1,590,413—C. BOL and B. VAN DER POL, Eindhoven, Netherlands. Filed June 27, 1924, issued June 29, 1926. Assigned to N. V. Philips' Gloeilamphenfabrieken.

ELECTRIC DISCHARGE TUBE of high power construction arranged for cooling the electrodes during operation.

1,590,467—F. S. McCULLOUGH, Wilkinsburg, Pennsylvania. Filed December 11, 1922, issued June 29, 1926.

SPACE DISCHARGE DEVICE, including an evacuated vessel with elements therein and a circuit for producing extremely high potential from alternating current which is impressed upon the elements which are arranged for the rectification of the potential thus produced.

1,590,635—D. G. McCAA, Lancaster, Pennsylvania. Filed May 5, 1925 issued June 29, 1926. Assigned to The Electric Apparatus Company.

RADIO SYSTEM for the reception of signaling energy substantially free of of static disturbances. A balanced circuit is provided the adjustment of which is disturbed by incoming oscillations to effect operation of a responsive device to the exclusion of static disturbances.

ISSUED JUNE 22, 1926—AUGUST 31, 1926

1,507,120—C. H. TEEGARDEN, Buffalo, N. Y. Filed July 10, 1924, issued August 24, 1926.

INDICATOR MECHANISM for radio receiving apparatus, whereby the frequency setting for any particular station may be readily determined and logged for immediate adjustment of the receiver for the particular transmitting station.

1,597,247—E. C. RANDLE, Cincinnati, Ohio. Filed October 19, 1923, issued August 24, 1926.

RADIO INSIDE AERIAL, in which a strip is wound upon a rectangular frame in spiral formation and the turns are spaced from the frame for eliminating dielectric losses.

1,597,291—J. A. ROSEMOND, Charleston, South Carolina. Filed February 24, 1925, issued August 24, 1926.

CAPACITY UNIT, in which a plurality of condenser plates are mounted in compact relationship with plates of opposite potential, alternately positioned and secured upon bars which are substantially insulated from the plates.

1,591,177—E. MINGE, Chicago, Illinois. Filed May 22, 1922, issued July 6, 1927.

RADIO CONDENSER formed in a plug which may be screwed into an electric light socket. The condenser is formed by a plurality of separate insulated disposed in the plug.

1,592,834—G. W. LILIENTHAL, New York City. Filed April 21, 1925, issued July 20, 1926. Assigned to Wireless Radio Corporation.

CONDENSER, in which the rotor and stator plates are mounted upon the same end plate and insulated with respect to each other.

1,592,901—R. S. OHL, New York City. Filed May 23, 1924, issued July 29, 1926. Assigned to American Telephone and Telegraph Company.

OSCILLATOR for generating high frequency currents, in which a harmonic producing transformer having primary and secondary windings is arranged with its primary connected to a generator of low frequency oscillations and its secondary connected with a circuit tuned to a frequency which is a multiple of the frequency of said generator with a circuit for producing a sharp cut-off characteristic in the wave form produced in the secondary for securing shock excitation in the tuned circuit.

1,591,601—A. S. ALBRO, Washington, D. C. Filed September 12, 1922, issued July 6, 1926.

STATIC ELIMINATING SYSTEM, in which a Faraday cage is employed as part of the radio frequency energy collecting system and the receiving apparatus connected thereto, the cage acting as an unloaded vertical antenna.

1,591,717—J. W. MARDEN, East Orange, New Jersey. Filed September 28, 1922, issued July 6, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

ELECTRON EMISSION MATERIAL AND METHOD OF MANUFACTURE, wherein tantalum wire is provided with a uniform mixture of metallic tantalum and alkaline earth material.

1,592,075—B. BRUSKIN, Brooklyn, New York. Filed May 9, 1924, issued July 13, 1926.

ELECTRON TUBE, which includes a plurality of sets of electron tube elements within the same vessel. The patent relates to a particular construction of tube by which the elements are maintained in compact relationship.

1,592,234—J. SCOTT-TAGGART, Bolton, England. Filed October 26, 1920, issued July 13, 1926.

VACUUM TUBE FOR RADIO APPARATUS, in which the cathode is supported by means of a device fastened to a portion of the glass envelope.

1,592,272—M. J. KELLY, New York City. Filed April 13, 1923, issued July 13, 1926. Assigned to Western Electric Company.

ELECTRON DISCHARGE DEVICE for high power operation, wherein the electrodes are supported from a central tubular member within the tube by means of a collar which surrounds and grips the central tubular member.

1,592,364—W. G. HOUSKEEPER, New York City. Filed April 26, 1921, issued July 13, 1926. Assigned to Western Electric Company.

IONIZATION MANOMETER for measuring exceedingly minute pressures such as are present in vacuum tubes. Alternative positive and negative potentials are impressed upon the grid and plate electrodes, while maintaining one of the electrodes at a predetermined potential and measuring the resultant current in the circuits of the tube.

1,593,387—G. SEIBT, Berlin Schoneberg, Germany. Filed August 26, 1925, issued July 13, 1926.

ELECTRIC DISCHARGE TUBE, having a heated cathode and a plurality of grid like electrodes arranged in spaced and substantially parallel planes.

1,592,546—L. B. VICTOR, New York City. Filed May 14, 1924, issued July 13, 1926.

VERNIER PLATE CONDENSER, having rotor and stator elements arranged to be interleaved with respect to each other with an independent vernier plate arranged to be shifted with respect to the sets of plates for actively adjusting the capacity of the condenser.

1,592,554—A. A. BURNS, Elizabeth, New Jersey. Filed October 4, 1924, issued July 13, 1926. Assigned to Garod Corporation.

NEUTRALIZING CONDENSER for securing exceedingly fine degrees of capacity adjustment in amplifier circuits where the condenser consists of an interiorly threaded tubular member of insulating material with metallic bushings in opposite ends of the screw threaded tubular member adjustable with respect to each other for fixing the capacity of the condenser.

1,592,612—F. W. MEYER, Brunswick, Germany. Filed December 8, 1924, issued July 13, 1926. Assigned to General Electric Company.

RELAY SYSTEM, including an electron tube arranged to have the potential of its grid changed from a non-operative to an operative value in response to an operation which may be performed either manually or automatically for effecting the closing or opening of a circuit. The tube has a cathode and anode with an insulated grid there between with an ionizable medium having its pressure regulated to cause a relay to be operated at a predetermined time after the supply of energy to the tube circuits.

1,592,628—W. F. EINTHOVEN, Delft, Netherlands. Filed October 21, 1922, issued July 13, 1926. Assigned to Nederlansch-Indie.

RECEIVING OF RADIO SIGNALS, where an electrical circuit is provided for taking up the oscillations of a string galvanometer individually tuned mechanically to the radio frequency of the incoming signals. The vibrations of this string are observed for determining the signals.

1,592,710—J. SCOTT-TAGGART, Bolton, England. Filed July 5, 1921, issued July 13, 1926.

MODULATION SYSTEM, comprising a circuit in which the conductivity of a two-electrode rectifier to radio frequency currents is controlled by impressing low frequency modulating currents on the anode voltage and applying a steady negative potential thereto of a value which will substantially prevent the flow of radio frequency currents while no modulating currents are impressed upon the anode voltages.

1,592,738—N. LEA, Strand, London, England. Filed March 3, 1926, issued July 13, 1926.

ELECTRIC COUPLING DEVICE FOR THERMIONIC VALVES. which consists of a mounting which includes a condenser, a resistance winding wound on a bobbin and a removable resistance unit centrally positioned within the bobbin.

1,592,775—O. G. LISSEN, Jersey City, New Jersey. Filed January 12, 1924, issued July 13, 1926.

VARIABLE CONDENSER, comprising a plurality of stator plates and a plurality of sets of movable plates co-acting therewith where one set of movable plates has a greater capacity than the other. The movable plates may be either independently or simultaneously rotated.

1,592,925—F. CARBENAY, Paris, France. Filed April 4, 1924, issued July 20, 1926.

SYSTEM OF RADIO SIGNALING, in which a receiver is provided with a tapped inductance coil with socket members for the insertion of a plug by which desired portions of the inductance may be conveniently included in the circuit.

1,592,934—R. V. L. HARTLEY, East Orange, New Jersey. Filed May 29, 1918, issued July 20, 1926. Assigned to Western Electric Company.

MEANS FOR MODULATING HIGH FREQUENCY OSCILLATIONS, where the high-frequency oscillations are generated by an electron discharge device and a potential varying in audio frequencies is supplied to the plate circuit for controlling the operation of the transmitter.

1,593,033—G. M. PROUDFOOT, Chicago, Illinois. Filed Aug 1, 1924, issued July 20, 1926. Assigned to Cruver Manufacturing Company.

CASING FOR MECHANISM, in which a pair of end plates are provided with annular grooves into which a cylindrical side strip is disposed and engaged therein for enclosing the apparatus.

1,593,269—H. J. ROUND, London, England. Filed March 30, 1922, issued July 20, 1926. Assigned to Radio Corporation of America.

RADIO TELEGRAPHY, in which a number of short wave transmitting stations are arranged in such relation to each other that short gaps may be bridged by successive reception and re-radiation of the waves for establishing the long-distance communication channel.

1,593,276—J. McW. STONE, Chicago, Illinois. Filed December 1, 1924, issued July 20, 1926. Assigned to Operadio Corporation.

RADIO DIRECTION FINDER, which is combined with a magnetic compass by which the position of the loop may be determined at all times.

1,593,361—R. A. RIDENOUR, College Corner, Ohio. Filed June 28, 1924, issued July 20, 1926.

RADIO RECEIVING APPARATUS, including a plurality of electron tubes connected in selective circuits, in which the signal energy is initially partially detected and the undetected portion amplified, followed by the steps of redetecting the same wave and amplifying the ensuing audio frequencies.

1,593,483—M. YAMAMOTO, Glen Head, New York. Filed March 7, 1924, issued July 20, 1926.

ELECTRON DISCHARGE DEVICE, in which a plurality of sets of cylindrical electrodes are mounted within an electron tube by means of an insulated spacing member.

1,593,538—M. MATHIESEN, Chicago, Illinois. Filed May 29, 1925, issued July 20, 1926. Assigned to Mathiesen-Sandberg Company.

COLLAPSIBLE LOOP AERIAL, in which a series of turns are spaced upon a frame and the frame arranged to be folded for securing desired portability.

1,593,662—A. MEISSNER, Berlin, Germany. Filed September 3, 1921' issued July 27, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

SENDING ARRANGEMENT, in which undesired oscillations in the transmitting antenna are absorbed by a trap circuit while permitting the radiation of desired frequencies.

1,593,837—G. A. MATHIEU, London, England. Filed March 10, 1922, issued July 27, 1926. Assigned to Radio Corporation of America.

RADIO SIGNALING SYSTEM for the operation of a relay at a receiving station where a plurality of electron tubes are arranged in a stabilized circuit for the control of the relay without interference from undesired oscillations.

Re-16,385—Ralph Bown and Edward L. Nelson, East Orange, New Jersey. Original filed April 26, 1921; reissue filed June 4, 1926, issued July 20, 1926. Assigned to American Telephone and Telegraph Company.

RADIO WIRE CONNECTING CIRCUITS for establishing a link between wire lines and radio systems for permitting use of the telephone network as the connecting medium between a subscriber and the radio station by which both the line wire and space gap may be bridged in a communication channel.

1,594,060—J. HUFF, New York City. Filed June 21, 1918, issued July 27, 1926. Assigned to General Electric Company.

HOT FILAMENT MAGNETIC RECTIFIER, comprising an evacuated container with two electrodes capable of emitting electrons of an elevated temperature, and a cooperating electrode. An alternating current supply is connected across the two electrodes. A magnetic field is produced to direct the flow of electrons from each of the two electrodes to the cooperating electrode.

1,594,124—J. E. SHRADER, Edgewood Park, Pennsylvania. Filed December 13, 1920, issued July 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

CONDENSER, formed by a stack of alternate unimpregnated solid dielectric and conducting material which are secured under pressure and then subjected to a combined heat and vacuum treatment after which the condenser is impregnated with insulating compound.

1,594,179—S. LOEWE, of Berlin, Germany. Filed August 26, 1921, issued July 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

VACUUM TUBE, in which a plurality of paths of thermionic current are provided, one of the paths being arranged to control the operation of the other path for the production of oscillations.

1,594,846—E. F. NORTHRUP, Princeton, New Jersey. Filed June 18, 1917, issued August 3, 1926. Assigned to Ajax Electrothermic Corporation. DISCHARGE GAP, in which there is arranged a solid electrode and mercury in the presence of air at approximately atmospheric pressure with a non-carbonizable vapor mingled with the air.

1,594,699—W. K. THOMAS, Crafton, Pennsylvania. Filed September 12, 1922, issued August 3, 1926.

RADIO RECEIVING SET, including a cabinet containing a detecting unit with guides formed within the cabinet, and a plurality of terminals in line with the guides so that terminals on the panel will cooperate with terminals on the cabinet for completing the electrical circuits.

1,594,700—A. G. TRIGG, London, England. Filed June 15, 1926, issued August 3, 1926.

VARIABLE CONDENSER FOR RADIO TELEPHONY, where rotatable plates are arranged for independent movement in the manner of a fan for varying the electrical capacity with respect to a set of stationary plates.

1,595,166—O. CHELLER, Berlin, Germany. Filed February 3, 1925, issued August 10, 1926. Assigned to C. Lorenz, Aktiengesellschaft.

MULTIPLE ANTENNA, in which a plurality of conductors are radially positioned and extend from a relatively high central point to lower elevations. Down leads are provided at points along the conductors in which inductances are interposed, the points of connection of the down leads decreasing in spaced relationship in proportion to the height of the conductor.

1,595,184—W. FUHRMANN, Westfield, New Jersey. Filed December 30, 1924, issued August 10, 1926. Assigned to The Furnell Manufacturing Corporation.

CONDENSER FOR ELECTRIC CIRCUITS, in which the movable and stationary plates comprise single flat strips of material curbed in the general form of an evolute arranged on frame structures for reciprocal motion of one coil with respect to the other.

1,595,729—A. PRESS, Wilkinsburg, Pennsylvania. Filed June 17, 1920, issued August 10, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

RECEIVING SYSTEM, in which an electron tube is provided having a grid plate circuit and a grid cathode circuit, the grid being rendered positive with respect to both the plate and cathode. The signal impulses in the grid cathode circuit affect the grid plate circuit to increase the amplitude of current therein, while during non-signaling periods the current in the grid plate circuit is reduced to a negligibly small value by the proper arrangement of the potentials on the tube electrodes.

1,595,730—A. PRESS, Wilkinsburg, Pennsylvania. Filed June 17, 1920, issued August 10, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

BALANCED REGENERATIVE DETECTOR, where an electron tube has two of its electrodes maintained at a common potential, while the third electrode is charged positively with respect to the common potential of the two electrodes, the electrodes being regeneratively coupled to improve sensitivity.

1,595,777—J. H. HAMMOND, JR., Gloucester, Massachusetts. Filed May 6, 1918 (original), issued August 10, 1926.

MEANS FOR CHANGING THE INTENSITY OF SIGNALS IN RADIODYNAMIC RECEIVING SYSTEMS, in which a leak path across the grid condenser is provided which consists of a thermionic valve in shunt with the grid condenser, whereby the functioning voltage of the shunt may be varied.

1,595,794—D. G. LITTLE, Edgewood Park, Pennsylvania. Filed June 30, 1921, issued August 10, 1926. Assigned to Westinghouse Electric and Manufacturing Company.

RADIO TELEPHONE SYSTEM, in which an electron tube oscillator circuit has bridged across the grid and plate elements thereof a circuit including a condenser and microphone, the microphone operating to vary the effective capacity of the condenser for modulating the oscillator.

1,595,810—C. T. ALLCUTT, Pittsburgh, Pennsylvania. Filed December 13, 1919, issued August 10, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

PLATE CONDENSER ELEMENT AND METHOD OF MANUFACTURE THEREFOR, in which the condenser plates are spaced by soft metallic members which may be pressed into such thickness that the plates are uniformly spaced apart and secured in position.

1,595,870—E. Y. ROBINSON, Manchester, England. Filed March 29, 1924, issued August 10, 1926. Assigned to Metropolitan-Vickers Electrical Company, Limited.

ELECTRIC VACUUM TUBE AND THE LIKE for high power operation where the failure of the supply of cooling waters to the anodes of the high power tubes is avoided by the provision of an auxiliary supply of cooling fluid. In the event that the main water supply becomes inoperative the auxiliary water supply is automatically placed in operation for saving the tube from destruction.

1,596,093—R. C. GALLETTI, Murs, France. Filed August 23, 1921, issued August 17, 1926.

SYNTONIZATION OF CIRCUITS USED IN RADIO SIGNALING, in which the characteristics of frequency and wave shape of the current in several circuits is completely in accord by the specific relation of the inductance capacity and resistance elements of the circuits.

1,596,198—S. LOEWE, Berlin, Germany. Filed March 19, 1921, issued August 17, 1926. Assigned to Western Electric.

SYSTEM FOR GENERATING OSCILLATIONS, in which an electron tube functioning both as an amplifier and an oscillator, is arranged in circuit with an antenna system for transmitting oscillations to the output circuit of the electron tube system at a frequency substantially independent of variations in the load.

1,596,374—W. H. PREISS, Belmont, Massachusetts. Filed June 6, 1921, issued August 17, 1926. Assigned to Wireless Specialty Apparatus Company.

ELECTRICAL CONDENSER AND METHOD OF MAKING THE SAME, in which a stack of condenser sections are secured under pressure within a casing with a heat radiating member extending from the upper pressure plate for preventing undue rise in temperature in the condenser.

1,596,636—A. H. TAYLOR, Washington, D. C. Filed July 2, 1920, issued August 17, 1926. Assigned to Wired Radio, Incorporated.

RADIO RECEIVING CIRCUIT, in which antennae of differing characteristics are extended in opposite directions and connected adjacent their inner ends with receiving apparatus with a circuit at the receiver for rendering the reception highly directional and receptive in one direction while non-receptive in the opposite direction.

1,596,692—A. LUCKASH, Morann, Pennsylvania. Filed February 5, 1924, issued August 17, 1926.

AUDION TUBE, in which the electrodes are supported on annular frame structures concentrically arranged within the electron tube.

1,596,875—L. A. HAMMARLUND, New York, N. Y. Filed Fenruary 14, 1924, issued August 24, 1926. Assigned to Hammarlund Manufacturing Company.

VARIABLE CONDENSER, in which the rotor shaft may be moved through small increments by means of a rock shaft independent of the rotation of the rotor shaft.

1,596,984—A H. MARKS, New York, N. Y. Filed March 26, 1923, issued August 24, 1926.

METHOD AND APPARATUS FOR BROADCASTING, in which the performer is enabled to listen to the results of actual reception at a broadcast receiver for thereby securing the proper expression of the composition being transmitted.

1,597,379—F. A. KOLSTER, Washington, D. C. Filed May 29, 1919, issued August 24, 1926. Assigned to Federal Telegraph Company.

RADIO METHOD AND APPARATUS for transmission and reception systems, in which a closed circuit including capacity and a divided inductance coil for absorbing energy directly from the media is provided. A coupling coil is connected between the parts of the inductance coil and in series with the closed circuit. Receiving apparatus is connected to the coupling coil and an antenna is connected to a point intermediate the terminals of the coupling coil. The circuit permits selective reception of signals in a particular direction.

1,597,398—L. T. WILSON, West Somerville, Massachusetts. Filed May 1, 1920, issued August 24, 1926. Assigned to Powel Crosley, Jr.

OSCILLATION CIRCUIT, including a plate circuit having two plates, a cathode circuit and a grid circuit with a transformer arranged to have its primary connected to the alternating current source and having the ends of its secondary connected with the plates. The grid circuit is tapped into the secondary of the transformer in such manner that the voltage in the grid circuit is opposite to the voltage applied to the plate circuit.

1,597,416—C. B. MIRICK, Washington, D. C. Filed September 1, 1923, issued August 24, 1926.

ELECTRICAL DISTANT CONTROL SYSTEM for effecting the operation of any desired circuits of a plurality of circuits at a distant receiver from a transmission station. The transmitter is modulated at different frequencies for effecting transmission of different control signals and at the receiver these signals actuate particular relays to the exclusion of other relays for controlling a particular circuit.

1,597,431—W. B. BURGESS, Washington, D. C. Filed May 14, 1923, issued August 24, 1926.

RADIO RECEPTION SYSTEM, wherein the capacity effect of the leads from the electron tube amplifier circuits of the receiver to the batteries is substantially eliminated by interposing radio frequency choke coils in the battery leads so that radio frequency is eliminated from the battery supply system.

1,597,591—F. G. FREESE, Aldan, Pennsylvania. Filed February 6, 1925, issued August 24, 1926.

RADIOCONDENSER, in which the plates of a variable condenser may be apertured for decreasing the metallic area of the plate exposed to each other for fixing the capacity of the condenser.

1,597,643—C. P. WIEGNER, Donnellson, Iowa. Filed January 19, 1925, issued August 24, 1926.

RADIOTUBE, including a base from which a U-shaped member projects for supporting the electrodes within the tube structure.

1,597,764—G. H. CLARK, Brooklyn, New York. Filed July 1, 1922, issued August 31, 1926. Assigned to Radio Corporation of America.

ARC GENERATOR, where the arc discharge takes place within an enclosed chamber to which volatile liquid is supplied, and liquid is fed to the arc by a drip gravity feed system from a vessel where the pressure is equalized with respect to the pressure in the arc chamber.

1,597,825—V. D. Renwick, Camden, New Jersey. Filed October 16, 1924, issued August 31, 1926.

DETECTOR of the crystal type for mounting upon the rear of a panel to which a plurality of conductors establish contact with the rectifying element within a hermetically closed casing.

1,597,829—H. J. ROUND, London, England. Filed June 12, 1922, issued August 31, 1926. Assigned to Radio Corporation of America.

OSCILLATION GENERATOR, in which a rotary commutator having a plurality of segments and brushes are connected in separate circuits for building up increments of current into oscillations.

1,597,835—J. E. SHRADER, Pittsburgh, Pennsylvania. Filed May 24, 1921, issued August 31, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

LEAKY CONDENSER, in which a coil is wound upon an electrode, but insulated therefrom, the electrode serving as one terminal and the coil serving as the opposite terminal.

1,597,848—R. A. WEAGANT, New York, N. Y. Filed October 6, 1920, issued August 31, 1926. Assigned to Radio Corporation of America.

METHOD AND APPARATUS FOR RADIO SIGNALING, in which two antennæ of different types are employed and the signal and static currents geometrically combined for eliminating the effects of the static currents.

1,597,893—H. K. HUPPERT, San Francisco, California. Filed June 11, 1924, issued August 31, 1926.

RADIO TUBE, including a pair of sets of independent electrodes supported by means of Y members within the tube.

1,597,910—M. LOCK, Berlin, Germany. Filed December 5, 1922, issued August 31, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

CONTROLLING ARRANGEMENT FOR TUBE SENDERS SUPPLIED WITH ALTERNATING CURRENT, in which an inductive resistance is connected in the plate circuit and a direct current circuit coupled to the inductive resistance for magnetizing it and varying the value of the resistance for the production of signals.

1,598,000—J. NILSON and J. F. PRINCE, Chicago, Illinois. Filed October 1, 1924, issued August 31, 1926.

RADIO CONDENSER ADJUSTMENT, wherein a number of variable condensers are operated simultaneously through a system of gears.

1,598,226—P. WARE, New York, N. Y. Filed February 8, 1918 (original), issued August 31, 1926. Assigned to Ware Radio, Incorporated.

DUPLEX CUT-IN SYSTEM OF RADIO TELEGRAPHY, where the two inter-communicating stations are arranged for continuous wave operation and signals are transmitted on different frequencies and the receiver is provided with an oscillator for producing oscillations for combining with the incoming oscillations. The sending key controls both the outgoing oscillations and the detecting means to enable simultaneous radiation of oscillations and reception of incoming signals with the key in determined position, said key controlling the transmission of signals.

1,598,227—P. WARE, New York, N. Y. Filed February 8, 1918 (original), issued August 31, 1926. Assigned to Ware Radio, Incorporated.

CUT-IN SYSTEM OF RADIO TELEGRAPHY, whereby simultaneous transmission and reception may be effected from the same antenna-ground circuit. The transmitting key controls the receiver in such manner that incoming signals can only be normally detected when the key is in normal position for sending signals.

1,598,144—A. LEIB, Berlin, Germany. Filed May 3, 1922, issued August 31, 1926. Assigned to Gesellschaft fur Drahtlose Telegraphie.

RADIO RECEIVING APPARATUS, for determining direction of incoming signals in which a circuit which includes a balancing antenna and a loop circuit which are employed for securing accuracy in the location of the transmitter.

1,598,526—L. A. JENNY, Dumont, New Jersey. Filed May 17, 1924, issued August 31, 1926.

RADIO TUNING DEVICE, in which the inductance coils of a tuning circuit are disposed about an electron tube for the purpose of reducing the length of the connectors to a minimum.

1,591,019—R. C. DA COSTA, Philadelphia, Pennsylvania. Filed April 2, 1920, issued July 6, 1926. Assigned to Atwater Kent Manufacturing Company.

CONDENSER AND HOLDER THEREFOR for automobile ignition systems, in which a rolled condenser is secured within a holder by means of a resilient bearing member.

1,591,025—R. D. DUNCAN, JR., East Orange, New Jersey. Filed July 24, 1925, issued July 6, 1926. Assigned to Wired Radio, Incorporated.

DUPLEX RADIO TELEPHONE SYSTEM, by which signals may be transmitted and received on closely adjacent antennæ systems without interference from side tones. A three-phase high frequency source is provided at the transmitter and one of the phases is impressed upon the receiving system for neutralizing the effects of the components of the other phases of the source upon the receiving apparatus.

1,591,131—J. J. JAKOWSKY, Pittsburgh, Pennsylvania. Filed April 30, 1924, issued July 6, 1926. Assigned one-fourth to A. B. McCall.

DIELECTRIC SUPPORTING PLATE FOR VARIABLE AIR CONDENSERS, wherein a strip of skeleton formation is secured to the stator plate supports for providing bearings for the rotor plates with minimum dielectric losses.

D-70,750—WILLIAM H. GERNS, East Orange, New Jersey. Filed May 25, 1926, issued August 3, 1926. Assigned to Brandes Laboratories, Incorporated.

DESIGN FOR POWER SPEAKER CABINET, in which the complete power equipment and cone speaker is housed as a portable unit for connection to the output circuit of a radio receiving apparatus.

1,597,711—WALLACE A. BARTLETT, London, England. Filed September 19, 1925. Issued August 31, 1926. Assigned to Brandes Laboratories, Incorporated.

ADJUSTABLE ELECTROMAGNETIC SOUND REPRODUCERS, where the electromagnetic driving force is adjustable with respect to the sound reproducing diaphragm. The structure of this patent is the feature of the adjustable table talker developed by the Brandes organizations.