M. G. Sateren

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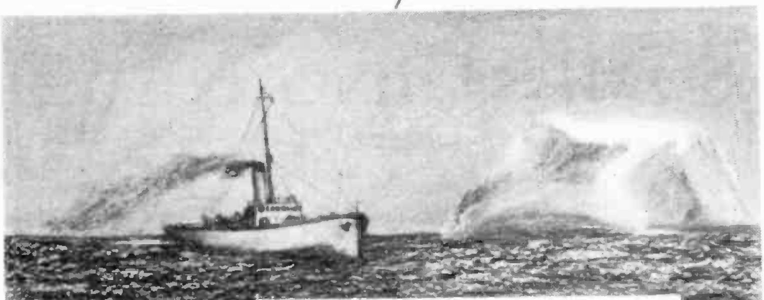

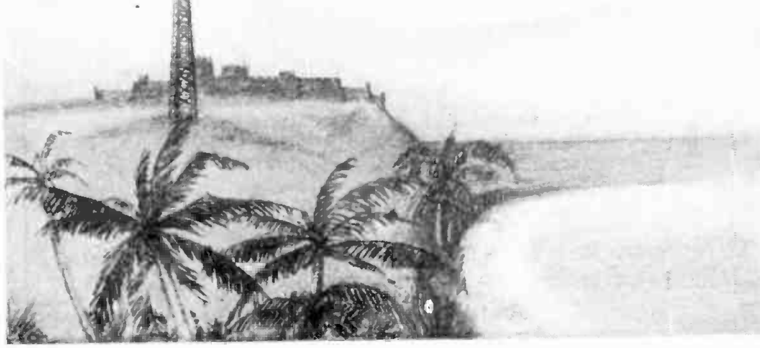

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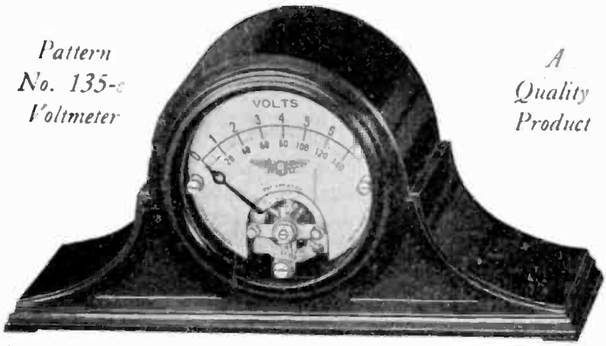

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PROCEEDINGS OF
The Institute of Radio Engineers

Volume 15 MAY, 1927 Number 5

CONTENTS

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INSTITUTE ACTIVITIES

April Meeting of the Board of Direction

At the meeting of the Board of Direction of the Institute held at 4:00 p. m., on April 6, 1927, in the Institute Offices, the following were present: Dr. Ralph Bown, President; Frank Conrad, Vice-President; W. F. Hubley, Treasurer; Melville Eastham, J. V. L. Hogan, R. A. Heising, R. H. Manson, R. H. Marriott, L. E. Whittemore and J. M. Clayton, Assistant Secretary.

Upon recommendation of the Committee on Admissions the following admissions and transfers were approved: Transfer to the grade of Member: Pierson A. Anderson and R. S. Van Cleve. Election to the grade of Member: Stewart Aikenhead, Theodore C. Brown, Harold Buttner, Lieut. W. B. Goggins, W. H. Griffiths, Kenneth Harkness, O. T. McIlvaine, O. W. A. Oetting, Miles Pennybacker, L. E. Wells and Dr. Lewis M. Hull.

One hundred and forty-nine Associates and three Juniors were elected.

The Board voted that the Institute Medal of Honor for this year be awarded to Dr. L. W. Austin for his pioneer work in the quantitative measurement. The medal is to be presented at the June meeting of the Institute.

A petition from members residing within the vicinity of Cleveland, Ohio, for the formation of a Cleveland Section of the Institute was approved and the Section recognized.

New Institute Badge

To meet an insistent demand, the Institute badge is now available in the form of a watch charm emblem. It is of 14 karat gold, provided with a swivel ring for attaching to a watch chain or fob, and is finished on both sides. These watch charm emblems can be obtained from the office of the Secretary for Five Dollars each.

NEW YORK MEETING

At the meeting of the Institute held on April 6, 1927, in the Engineering Societies Building, 37 West 39th St., a paper entitled, "Short Wave Commercial Long Distance Communication," by H. E. Hallborg, L. A. Briggs and C. W. Hansell, was presented by C. W. Hansell. In the discussion which followed Mr. Hallorg presented a portion of his paper, "Some Practical Aspects of Short Wave Operation at High Power." Both of these papers will appear in the June issue of the PROCEEDINGS. The discussion was participated in by many of those present.

The attendance at this meeting was over two hundred and fifty.

News of the Sections

ROCHESTER SECTION

On March 4, 1927, a meeting of the Rochester Section was held in the Sangamo Hotel. Virgil M. Graham presided. The meeting was addressed by Dr. A. Hund, of the Bureau of Standards, on the subject of Piezo Electric Crystals.

This meeting was jointly held with the Rochester Section of the Optical Society. There were one hundred and twenty-five persons present.

The next meeting of the Rochester Section will be held on April 15, 1927, at which time a paper by Charles Bartlett, of the Weston Electrical Instrument Corp. will be read.

CANADIAN SECTION

The Canadian Section held its March meeting on the 2nd of the month in the Electrical Building of the University of Toronto. D. Hepburn presided. A paper by J. M. Thomson on "Audio Frequency Amplification with Transformer Coupling," was presented. A general discussion folowed.

The attendance was forty-six.

The April meeting of the Canadian Section was held in the Electrical Building, University of Toronto, on April 6th. D. Hepburn was the presiding officer.

J. P. Henderson, of the Dominion Observatory, Ottawa, read a paper, "Radio in Surveying and Wireless in Time Signals." C. L. Richardson, A. M. Patience, V. G. Smith, F. K. Dalton and others discussed the paper.

There were eighteen members and fifteen visitors at the meeting.

Seattle Section

A meeting of the Seattle Section was held in the Telephone Building, Seattle, Washington, on March 5, 1927. John Greig delivered a paper on "Filtering Rectified A. C." The paper was discussed by Tyng Libby and others.

In the election of officers of the Seattle Section, which followed the presentation of the paper, the results were as follows: Chairman, Tyng Libby; Secretary-Treasurer, W. A. Kleist.

There were twenty-five members present.

The next meeting of the Seattle Section will be held in the Club Room of the Telephone Building, Seattle, on April 2, 1927. J. J. Ritter, of the Electro-Chemical Converter Company, will deliver an address on "Battery Eliminators for Radio Receivers."

Detroit Section

The Detroit Section held a meeting on March 18, 1927, in the Conference Room of the Detroit News Building. Thomas E. Clark presided. Three moving picture films, "The Audion," "The Electrical Transmission of Speech," and "The Story of a Broadcasting Station," were shown. A discussion participated in by Messrs. Hoffman, Buchanan, Glatzel and others followed.

In the election of officers which followed, Thomas E. Clark was elected Chairman, and W. R. Hoffman, Secretary-Treasurer. The regular meeting date of the Detroit Section was set for the third Friday of each month, except during July and August.

The next meeting of the Detroit Section will be held on April 15, 1927, in the Conference Room of the Detroit News. James McNary will deliver a paper entitled, "Measuring the Intensity of the Field Surrounding a Broadcasting Station."

Los Angeles Section

On March 21, 1927, a meeting of the Los Angeles Section was held in the Los Angeles Commercial Club. L. Taufenbach presided. The address was by A. P. Hill, Supervising Radio Engineer of the Southern California Telephone Company, on "Recent Developments in Broadcast Transmission." The discussion which followed was general.

Cleveland Section

As previously announced, the formation of Cleveland Section has been approved. The officers of this Section are as follows: Chairman, John R. Martin; Vice-Chairman, R. E. Farnham; Secretary-Treasurer, L. L. Dodds.

Proposed Sections

Correspondence looking to the formation of Sections of the Institute is being held with interested Institute members in the following territories: Milwaukee, Wisc.; Schenectady, N. Y.; Pittsburgh, Penna.; New Orleans, La., and Minneapolis, Minn.

Committee Work

Committee on Admissions

At the meeting of the Committee on Admissions twenty-five applications for admission or transfer to various grades of membership in the Institute were considered. Twelve of these applications were approved, three were not acted upon for lack of sufficient information and ten were not approved.

Committee on Sections

The Committee on Sections, David H. Gage, Chairman, has been very active this year, having held four meetings since the first of January.

At present the Committee is working on the following matters: Preparation of a booklet of instructions to be used in the formation and management of Sections; Partitioning Sections into geographical districts by the Counties they include; A model form of Constitution and By-Laws for use in governing Sections; and establishment of new Sections in localities where there are a sufficient number of Institute members to maintain an active Section.

Committee on Membership

The Comittee on Membership, H. F. Dart, Chairman, has just completed a booklet describing the aims and activities of the Institute. This booklet will be useful in bringing the Institute before prospective members. It will be circulated to all Sections and other interested Institute members.

Committee on Publicity

The Committee on Publicity, W. G. H. Finch, Chairman, has regularly secured space in a number of newspapers announcing meetings of the Institute and reporting thereon. Much credit for the excellent attendance at the New York meetings of the Institute can be attributed to this Committee's work.

Papers in Pamphlet Form

The following papers are available in pamphlet form. Copies may be obtained free of charge by members by applying to the office of the Institute. The price to non-members is 50 cents per copy:

"Simultaneous Production of a Fundamental and a Harmonic in a Tube Generator," by Hoy J. Walls.

"Some Measurements of Short Wave Transmission," by R. A. Heising, J. C. Schelleng and G. C. Southworth.

"Reduction of Interference in Broadcast Reception," by Alfred N. Goldsmith.

"Dry Cell Batteries," by W. B. Schulte.

"A Theoretical and Experimental Investigation of Detection for Small Signals," by E. L. Chaffee and G. H. Browning.

"Vacuum Tube Nomenclature," by E. Leon Chaffee.

"Quantitative Measurements on Reception in Radio Telegraphy," by G. Anders.

"Piezo-Electric Crystal-Controlled Transmitters," by A. Crossley.

"Piezo-Electric Crystals at Radio Frequencies," by A. Meissner.

SECTIONAL COMMITTEE ON RADIO, A. E. S. C.

The activities of the Sectional Committee on Radio of the American Engineering Standards Committee for the past month have been as follows:

Component Parts and Wiring

A meeting of this technical committee was held at 29 West 39th Street, New York City, on March 2nd. The Chairman reported having received a list of N. E. M. A. standards for consideration by this Committee. This list of standards as well as vacuum tube standardization in general, was considered. It was agreed to defer standardization of vacuum tube bases until a report of the activities of the Vacuum Tube Committee has been received.

The standard A. E. S. C. vacuum tube socket markings were proposed and received unanimous approval of the committee members present. The Secretary has submitted this standard to the balance of the membership for vote.

The proposed date of the next meeting of this Comittee is April 6, 1927.

Vacuum Tubes

During the month drawings giving the exact dimensions and tolerances of the two forms of the "UX" base were received by the Chairman of the Committee, and were distributed to the membership for consideration for later standardization.

Electro-Acoustic Devices

No meetings of this Committee were held during February. A meeting is planned for the latter part of March.

Power Supply and Outside Plant and Transmitting and Receiving Sets and Installations

There were no activities of these Committees during the past month.

Radio Manufacturers' Association Representatives

On vote of the Executive Committee of the Sectional Committee on Radio, an invitation to the Radio Manufacturers' Association to appoint a representative on all five of the Technical Committees of the Sectional Committee on Radio has been extended by the Secretary.

MEETING OF THE ELECTRO-ACOUSTIC DEVICES SUB-COMMITTEE

The Electro-Acoustic Devices Committee of the Institute's Standardization Committee held a meeting on April 5, 1927, in the offices of the Institute.

The following members of this sub-committee were present: R. H. Manson (Chairman), H. A. Frederick, F. C. Barton, C. R. Hanna, Irving Wolff, C. E. Brigham, Melville Eastham, A. Hund, B. E. Brown, Paul Andres and L. E. Whittemore. As guests the following attended: Messrs. Bostwick, McKown, Olney and Graham.

At this meeting forty terms and definitions were adopted.

These definitions include broad terms for the types of devices that are actuated by power from one system and supply power to another system, regardless of whether the systems are electrical, mechanical or acoustical. The word "transducer" has been taken as a fundamental term to designate a device of this type. By following this plan it was possible to build up a system of definitions that appear to cover the subject in a most complete form. For example, an electro-acoustic transducer is defined as a "transducer which is actuated by power from an electrical system and supplies power to an accoustical system, or vice versa."

The definition of a specific device such as a telephone receiver was built up in the following manner:

"A telephone receiver is an electro-acoustic transducer actuated by power from an electrical system and supplying power to an acoustic system, the wave form in the acoustic system corresponding to the wave form in the electrical system."

It was found necessary to refer to "wave form" in this definition in order that the scope would not be too broad and include such devices as an electric automobile horn.

In order to differentiate between the various types of telephone receivers, reference is made to the acoustic load into which these devices operate. For example, a head receiver is defined as, "a telephone receiver designed to be fastened on the head of the user, and to operate into the ear as an acoustic load." On the other hand a loud speaker is, "a telephone receiver designed to radiate acoustic power into a room or open air."

In selecting terms to designate some of the particular elements of the electro-acoustic devices, it was found advisable to give serious consideration to present usage. Thus, the mechanical element that operates a telephone receiver or loud speaker is designated as a "driver element" and is defined as follows:

"The driver element of a telephone receiver is that portion of the receiver which receives power from the electrical system and converts it into mechanical power."

By using the former as a broad term, several terms to designate specific types were adopted, such as electromagnetic driver element, electrodynamic driver element and electrostatic driver element, etc.

It was considered that the scope of the Committees work included all electro-acoustic devices, therefore, definitions were adopted covering electro-mechanical devices, such as are now commonly employed in connection with electrical reproduction from phonograph records. After considerable discussion it was decided to use the term "phonograph pick-up" to designate the device that is actuated by a phonograph record and delivers power to an electrical system, the wave form in the electrical system corresponding to the wave form in the phonograph record. Thus, a "magnetic pick-up" is a phonograph pick-up whose electrical output is generated in a coil or conductor in a magnetic circuit or field.

One of the subjects that created considerable discussion in the committee is the proposed use of the "transmission unit" (abbreviated TU) in expressing the performance of electro-acoustic devices. This unit has been adopted as a telephone standard in practically all of the countries of the world and has already been used extensively in the radio industry. It was thought, however, by some members of the Committee, that the measurement of the output of a loud speaker was best expressed in dynes per square centimeter. For this reason further consideration is being given to the subject of Performance Indices.

NEMA HANDBOOK OF RADIO STANDARDS

The Second Edition of the Radio Division of the National Electrical Manufacturers' Association Handbook of Radio Standards is now available. This Handbook contains fifty pages of standards for many radio devices as adopted by the National Electrical Manufacturers' Association. Copies may be obtained at a dollar each from the Association at 420 Lexington Avenue, New York City.

Measurements at Radio Frequencies at A. I. E. E. Meeting

Information of very great interest to radio engineers will be presented in a symposium on measurements at high frequencies at the Regional Meeting of the American Institute of Electrical Engineers to be held at the Maplewood Hotel in Pittsfield, Mass., May 25-28. Members of the I. R. E. are invited to attend this symposium which will start at 10:30 A. M., Wednesday, May 25.

Fifteen papers are included in the symposium and they cover such subjects as radio-frequency voltmeters and current transformers; quantitative determination of radio-receiver performance; measurement of large high-frequency currents, radio field strengths, communication lines and apparatus, etc.

A complete program is published in the May issue of the *Journal* of the American Institute of Electrical Engineers.

LOUD SPEAKER TESTING METHODS*

By
I. Wolff and A. Ringel

(Radio Corporation of America, Technical and Test Department)

A perfect loud speaker is one which when receiving perfect broadcasting through a flawless set will create the illusion of reality. Physically this means that the whole reproducing system should be able to transfer bodily a series of wavefronts without change from a certain region of the broadcast studio or concert hall to the listeners' room. The final test for the quality of a loud speaker is then the direct one of putting it on a receiving set, listening to it, and noting how nearly it fulfills this ideal.

For the person who wishes to develop and improve loud speakers this test is not sufficient. Neither broadcasting stations nor sets available are in the perfect class, and what sounds excellent on one combination may be very poor on another. The conditions given above can be more nearly satisfied by building a high quality speech amplifier for laboratory use. This is easily done with the aid of a condenser transmitter, resistance coupled amplifier, and a little equalization, the combination giving very nearly uniform response over the audible range. Precautions should also be taken to have the output tube of the amplifier capable of delivering the required voltage output without distortion. If someone talks into the transmitter in one room and a loud speaker is placed in an adjacent one, the listener in the second room can judge the quality of the reproduction. The weakest link in this chain of calibration lies in the sound pick-up. This problem is still far from solved in its acoustic aspects and of course until this is done the illusion of reality cannot be obtained. The value of this interesting test in the search for the perfect loud speaker, lies mainly in giving some uniform basis on which to compare models. For many purposes the best loud speaker is not the perfect one, but

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the one which sounds best on the sets and broadcasting stations as they are.

In lieu of better apparatus, the speech amplifier may be used to determine what is wrong with a loud speaker which does not sound right. Resonance peaks stand out quite plainly and a person with a little experience can learn to detect and place them. Depressions in the response curve are not so apparent. It soon becomes obvious that some more quantitative method of making these tests is necessary

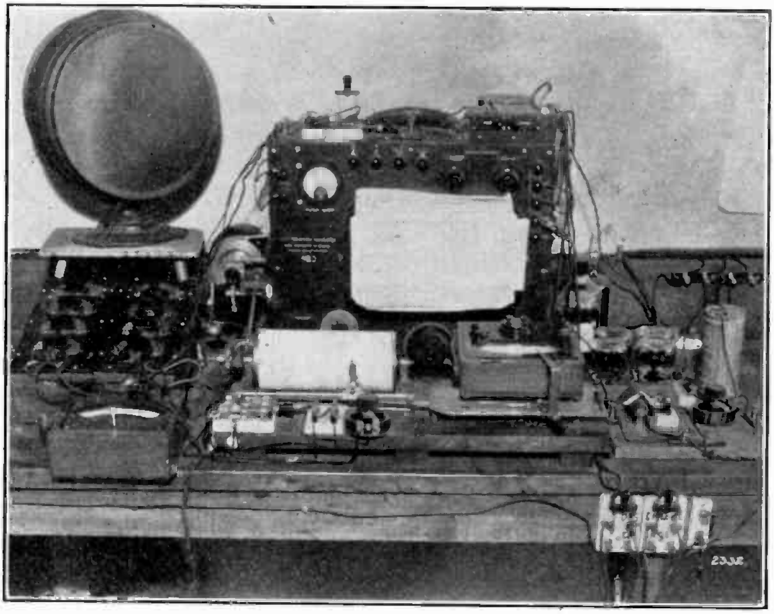


Figure 1—Oscillator and Recording Apparatus

if a real study and improvement of loud speakers is to be made. In order to find out the causes of certain defects in the response curve it is often necessary to know quite accurately the position and magnitude of the peaks and depressions.

The next obvious step is to use an electric oscillator of some kind giving as pure a wave as possible and impress its output on the loud speaker. The observer can get a pretty good idea, by listening, of the way the speaker responds to different tones in the audible frequency spectrum. It is however quite difficult to compare the intensities of tones of different frequency and the memory of the ear for tonal intensities which do not differ from each other greatly is poor. After an interval of a day or even an hour it is not possible to say whether a certain tone is more intense than the one heard previously. A test is required which will record absolutely the intensity of the tone.

We have found most satisfactory a system which makes a written record in two or three minutes of the loud speaker output measured in pressure of the sound wave. The apparatus used and the procedure followed will be described below under the headings—Oscillator, Sound Pickup and Recording Apparatus, and Position of the Pickup. A picture showing the oscillator and attached recording apparatus is shown in Figure 1.

Oscillator

For making loud speaker measurements the most convenient electrical source will give a pure, simple harmonic output of constant voltage over the whole range to be

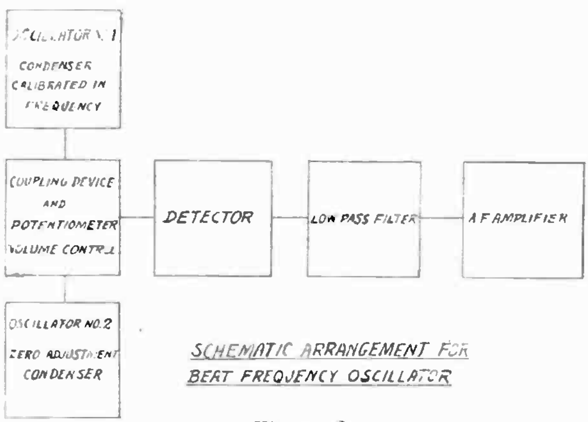


Figure 2

studied. It is also advantageous to have the frequency continuously variable rather than changed in jumps.

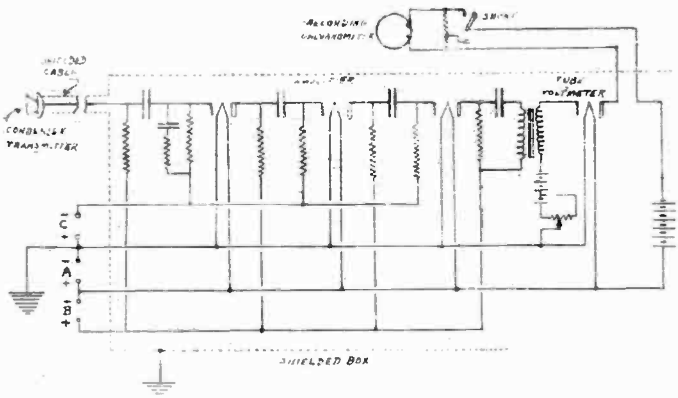
The above requirements are all reasonably well attained in an oscillator where the audible tone is the result of the beating of two tones above the audible range which differ somewhat in frequency. In the oscillator used in this laboratory one of the circuits is kept fixed at about 135,000 cycles while the other is varied by means of change in capacity to give the audible frequency wanted. One of these oscillating circuits has a fine adjustment for zero setting as will be described below. These two circuits are loosely coupled through a potentiometer volume control to a detector, which feeds through a low-pass filter with cut-off at 75,000 cycles to a two step resistance coupled amplifier. A low impedance tube is used in the last stage to give high power output. The oscillator is shown schematically in Figure 2.

A voltmeter placed in the output of the oscillator indicates that the output does not vary more than 5% from 30 to 10,000 cycles per second. A difficulty always encountered in instruments of this kind is the drift in frequency caused by changing filament current. This is reduced somewhat by having the two oscillating circuits as similar as possible. It is always necessary however to have some means for adjusting the zero point. If the frequency of both circuits remained constant for any particular condenser setting one of the circuits could be kept fixed and the other could have its condenser calibrated directly in frequency. Now suppose that the frequency of the calibrated circuit should change somewhat, due to a change in tube characteristics. The whole calibration would be thrown off by an amount almost constant over the whole range, and therefore if the other circuit had its frequency readjusted so as to make the calibration correct again at one point the whole scale would be correct. We therefore have the dial on the condenser in one of the oscillating circuits calibrated in frequency, while the other is used for zero adjustment. This adjustment can always be easily made by means of a tuning fork or by comparison with the 60 cycle power line. It should be made at some fairly low frequency so that if there is a non-constant shift in the calibration due to change in base frequency the per cent change in the audible frequency will be small.

The current to the loud speaker should be fed to it in such a way as to represent the output of a perfect set. Now in the perfect set the potential impressed on the grid of the last tube will be the same at all frequencies. Due to the fact that the ratio of the plate impedance of this tube to the loud speaker impedance is not always small or constant, the output potential applied to the loud speaker will not be constant. In order to represent the conditions of a perfect set as nearly as possible the constant potential should be applied to the loud speaker through a resistance equal to the plate impedance of the tube with which it is to be used. This potential can then me measured with an a-c. voltmeter.

Sound Pickup and Recording Apparatus

The condenser transmitter developed by E. C. Wente[1] has been found most practical as sound pickup. One of these transmitters, calibrated by The Bell Telephone Laboratories, is used to feed into an amplifier made up of two resistance coupled stages and a third tube feeding through a transformer to a vacuum tube detector. The output of the detector is measured by means of a d-c. galvanometer. The condenser transmitter is ordinarily more sensitive at low and high frequencies[2] than in the middle range. The overall characteristic of transmitter plus amplifier and detector can thus be very closely equalized by choosing the proper trans-



WIRING OF AMPLIFIER AND DETECTOR

Figure 3

former to feed the detector, and correct grid impedances for the first tube. A diagram showing amplifier, detector, and equalization is given in Figure 3. The electrical part of the combination can be calibrated experimentally by introducing a small e.m.f. in series with the transmitter and determining the value of this e.m.f. required to give a constant output deflection of the galvanometer. The combination of this characteristic with the sound pressure e.m.f. calibration of the condenser transmitter gives the relation between gal-

[1]Phys. Rev. 10, 39, 1917. 19, 499, 1922.
[2]I. B. Crandall Phys. Rev. 11, 449, 1918.

vanometer deflection and sound pressure at different frequencies. With proper equalization the maximum deviation from mean in this curve does not amount to more than 5 per cent.

The relation between galvanometer deflection and magnitude of the input potential can be determined in a similar manner. The curve will not in general be a straight line over the whole range so that it is not possible to plot galvanometer deflections as proportional to sound input.

The combination of apparatus described above gives a means for applying a constant potential to a loud speaker at all frequencies, the change in frequency being obtained by turning a single condenser dial. It also includes a sound pickup, amplifier and indicator which will indicate sound pressures at all audible frequencies, correction only being necessary for the non-linearity of the amplitude characteristics. This correction is made by means of the recording apparatus to be described below.

The recording apparatus and oscillator have been designed so as to plot the loud speaker output on paper with a logarithmic frequency scale and linear output scale. The broadness of loud speaker response peaks is in general rather proportional to the frequency. For this reason and also because a more equitable amount of space is accorded to the various regions of the frequency spectrum, logarithmic frequency paper is preferable to linear. It is somewhat more difficult to determine the proper scale to use for intensities. The relation between sound intensity as recorded by the ear and that as given by pressure is a rather complicated function of intensity and frequency. It therefore seems best not to try to represent the ear response but to record sound pressure on a linear scale.

The recording system used is manually operated. That is, a hand operated pointer is made to follow the galvanometer needle and move a pen back and forth on a slowly rotating drum to which the paper is attached. The connection between the pointer and pen (shown in Fig. 4) is built so as to take care of the non-linearity of the detector characteristic, and the motion of the pen is proportional to sound input. The recording drum is geared to the shaft of the condenser which is used to vary the frequency. This condenser has its plates so shaped that when its shaft is rotated with uniform velocity the frequency will change at a logarithmic rate. Logarithmic paper can be placed on the recording drum and the plotting will be on a correct scale. The operation of taking a loud speaker curve thus merely involves placing the loud speaker in the correct position before the

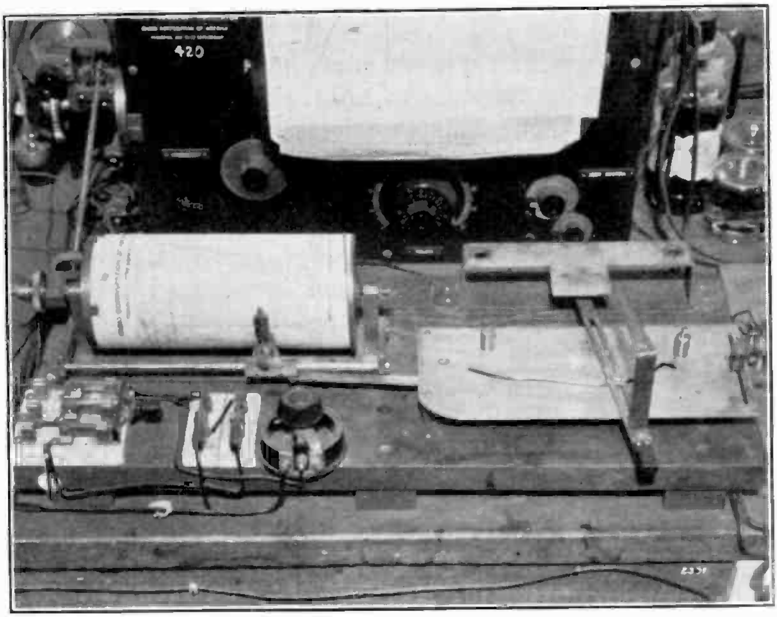


Figure 4—Recording System

microphone, adjusting the output of the oscillator at a predetermined value, and following the galvanometer needle with the pointer while the drum is rotated.

Position of Sound Pickup

The correct position of the microphone with respect to the loud speaker is an important and difficult problem. Offhand it would seem that the logical and simple thing to do would be to place the condenser transmitter about the same distance from the loud speaker as the ear of the listener would ordinarily be, and take a curve. Unfortunately this response is only an approximation to the free wave pressure which would be caused at this place by the loud speaker.

The room in which the loud speaker is placed will greatly affect the curve taken with the microphone placed as described. In the first place, a considerable proportion of the sound coming to the microphone gets there indirectly by reflection from the walls and objects in the room. The volume of this sound is naturally affected by the selective absorption and resonance characteristics of the room and our response curve therefore is affected by this room characteristic.

Whether the loud speaker curve should be taken so as to include the room response of an average room is a subject open for discussion. This question is inseparable from that of the microphone pickup and will have to be considered with it. The conclusion will be based on the following premises:

1. A person who has been in a room, which is not average, for a rather long time becomes accustomed to it, and is no longer struck by its acoustic peculiarities.

2. Reproduction to be most natural should in general include the acoustical background of the locale where the program would usually be placed as perceived by the listener in his accustomed position for listening to such a program.

The definition of the perfect reproducing system given at the beginning of the article should then be amplified to say that it should transfer an acoustic condition (pressure and velocity of the sound wave) from the studio to an average room. This will give natural reproduction, for if the room varies from average this will perhaps already have been discounted by the listener.

Our present microphones are essentially pressure measuring devices so that for the present we will have to be content with transferring this quality of the acoustic condition. A little thought will show that this cannot in general perfect reproduction. Assuming then that the microphone plus the amplifier make a perfect transfer of sound pressure to electrical potential, what must the loud speaker do? If the above reasoning is correct, it must in turn make a perfect transfer from electric potential to sound pressure in *an average* room at the *normal listener position.*

There is a point which should be noted regarding the correspondence between the conditions under which the microphone is calibrated and the conditions of its use. The microphones we have been using are calibrated by a method which applies a known pressure of required frequency directly to the diaphragm. (Calibration method described by Wente in article referred to above). The pressure at the microphone diaphragm caused by a moving wave is not that present in the wave when no object is in its path. Knowing the size of the microphone and its mechanical characteristics it is possible to get a relation between the true moving wave pressure and the pressure as recorded by the microphone.

At low frequencies the two calibrations will correspond but at the higher frequencies the reflection of the sound wave by the microphone surface will cause the pressure to be twice as great as it would be for the unhampered wave.

When a pure sound is released from some source in a room, a very distinct pattern of nodes and loops of intensity is apparent to a person moving in the room. The microphone having a relatively small surface will be at some point between maximum and minimum intensity. When the frequency is changed the node and loop pattern shifts and in a short range the position of the microphone may be moved from a region of maximum to minimum intensity without any real change in the output of the loud speaker. This gives the curve a series of peaks and depressions which of course obscure the real loud speaker characteristic. This second room effect should not cause an error when averaged over a sufficient frequency range, or region in the room, but may distort the curve very badly at some frequencies, when the microphone is kept in one position.

In order to eliminate this trouble some system of averaging must be developed. One way of doing this would be to rotate or oscillate the loud speaker or microphone or preferably both. At low frequencies the long wavelength and therefore large interference pattern would require a considerable amplitude of motion, comparable with the wavelength. The mechanical difficulties and unwieldiness of this method, in particular when loud speaker in large cabinets are to be tested, make some other way of avoiding this trouble preferable.

As the pickup is moved closer to the loud speaker, a continually smaller proportion of the sound comes by reflection from the walls and objects in the room and the microphone registers more exactly the sound that is coming directly from the loud speaker. Of course when the microphone is too close to the source it acts as a reflecting surface itself and causes an interference pattern to be set up between it and the speaker. The pickup also gets too large a proportion of its energy from a limited region of the radiating surface and does not give a true picture of the integrated output. We have found that a characteristic taken at a distance of about fifteen centimeters from the radiating surface gives a quite good indication of the response for loud speakers which radiate in one direction, and in which the radiating surface is not too big.

Loud speakers of the modern cone type however radiate from both sides. When the pickup is placed fifteen centimeters in front of the surface the cone itself will act as sufficient shield to reduce greatly the radiation from the rear which reaches the microphone. In particular when the loud speaker is placed in a cabinet the long path around will

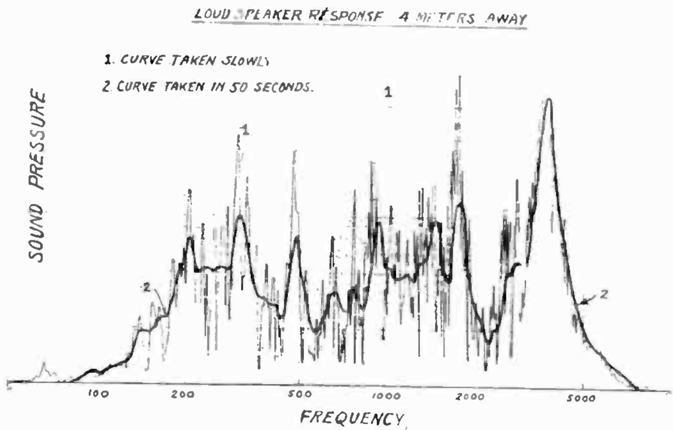


Figure 5

cause so much attenuation as to practically eliminate this part of the radiation. In loud speakers placed in cabinets the sound off the rear may be very important, as cabinet resonance will usually show up as radiation in this direction. Of course the obvious thing to do in a case like this is to take a second curve from the rear. The actual response will be some combination of the two curves, depending on the position of the listener.

There is still one serious error made in adding together the response of loud speakers taken at this small distance from front and rear. Sound is a wave disturbance and in any addition phase differences must be taken into account. This becomes particularly important at low frequencies. The radiation from the rear is naturally 180 deg. out of phase with that from the front, from single vibrating surfaces. If the path lengths to the listener differ by only a fraction of a wave, destructive interference will be set up. It then seems as if some kind of curve at a distance is still necessary. Since the characteristics taken at fifteen centimeters will show the fine structure of the loud speaker spectrum, such as sharp peaks and depressions, a rather rough curve at a distance will be sufficient.

If the galvanometer used to record the response does not have an extremely short period it is possible to change the frequency quickly enough so that the needle will not have time to respond to the room peaks and at the same time will be able to record the gross loud speaker characteristics.

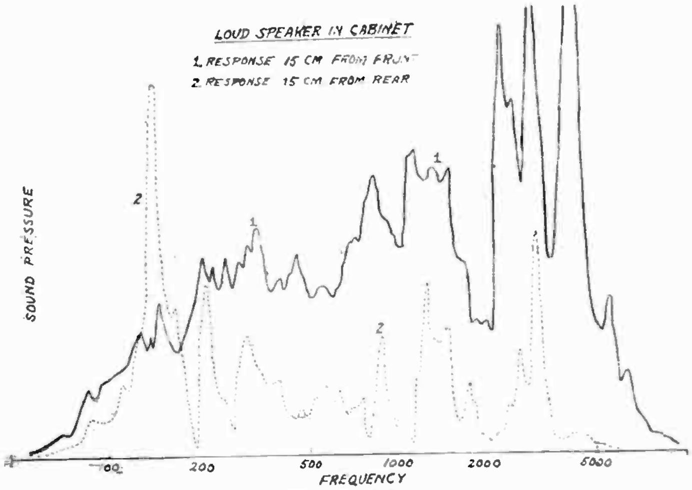


Figure 6-a

This curve we find gives a very good representation of the general response. Fig. 5 gives a comparison of a curve taken slowly at a distance with one taken as described.

Summary

The procedure of making a loud speaker test will be made a little clearer if we summarize here.

1. The output of an oscillator, continuously variable, and supplying constant potential, is fed to the loud speaker through a resistance equal to the plate impedance of the tube to be used with the loud speaker. Three curves showing sound output are taken as follows:

(a) Microphone fifteen centimeters in front of loud speaker, frequency varied slowly enough to show all peaks.

(b) Same with microphone fifteen centimeters to the rear.

(c) Microphone at normal listener's distance from loud speaker in an average room; oscillator condenser driven by motor quickly enough so that room peaks will not be recorded and slowly enough to show principal loud speaker characteristics.

Figure 6 shows three curves taken on the same loud speaker by methods (a), (b) and (c). The above test may

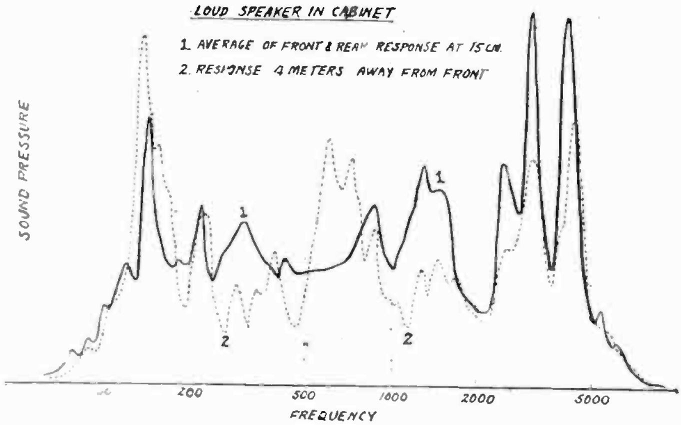


Figure 6-b

seem needlessly lengthy, but the time involved is really not great. The first two curves require about three to four minutes for recording and the last one takes rather less than a minute.

2. We have found that the loud speaker which has the best looking characteristic (most free from peaks) will in spite of the defects of existing broadcasting transmitters and receivers generally sound best when tried on radio.

We have never built a perfect loud speaker however, and the question always arises as to the relative undesirability of defects which can be substituted for each other. The only way to determine this is to try the loud speaker on a set receiving normal broadcasting.

When the loud speaker is to be used exclusively for phonograph reproduction, a phonograph test is of course substituted for the one with radio. When it is to be used in combination equipment both tests are required and a compromise must be reached, as the phonograph recording characteristic is, in spite of recent improvements, still different from the radio set response.

We have also at times gone somewhat farther in the test of the combination of set with loud speaker, using the oscillator to modulate a broadcast frequency wave which is impressed on the set. The mechanics of taking the curve is the same as that described when the oscillator is im-

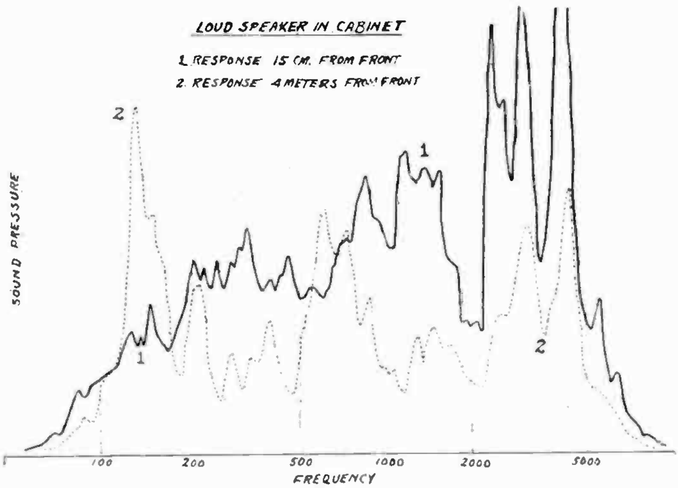


Figure 6-c

pressed directly on the loud speaker. The curve taken in this manner gives the response of the set plus loud speaker for uniform modulation of a constant amplitude broadcast frequency wave over the audible range.

The results of such tests are very interesting and show quite clearly why a poor quality loud speaker may at times sound better on a receiving set than a speaker which measures up well. It is very true however that the loud speaker which shows up best on the original tests described above seldom fails to sound best with a receiving set.

We are looking forward to the time when we may have the ideal condition when the oscillator can be impressed on the input end of the broadcast studio and a radio set tuned to this station will give an output through its loud speaker which draws a straight horizontal line across our curve sheet.

In concluding we would like to mention that Dr. John P. Minton was associated with us in a part of the work outlined above, and some of the ideas given are due in no small measure to this association.

HIGH ANGLE RADIATION OF SHORT ELECTRIC WAVES *

By

S. Uda

(Tohoku Imperial University, Sendai, Japan.)

(I) Introduction

As a means of producing high angle radiation of short radio waves, it is usual to make a straight vertical antenna operate at one of its harmonics. The field distribution of such an antenna has been theoretically calculated by B. van der Pol, S. Ballantine, S. A. Levin and C. J. Young, and others. No experimental work confirming these theoretical results seems to have ever been carried out.

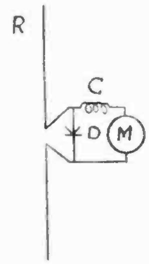


Figure 1

The present article contains some accounts of experimental work in connection with this, and also gives the test results on a new wave projector devised by the author with special reference to high angle radiation of short electric waves.

(II) Apparatus Used

The short wave generator used by the author is of a push-pull type which can produce stable continuous waves

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of few meters, in length. The receiving circuit is shown in Figure 1, where R is the receiving antenna forming a Hertz's resonator, and D and M are a crystal detector and a micro-ammeter respectively.

Now the receiving system is mounted in a wooden case and moved up and down along a vertical line by a pulley device as shown in Figure 2. A and B are two wooden poles erected 3.5 m. apart, the height of which being nearly equal to 10 meters.

The generator is placed at a certain distance from the

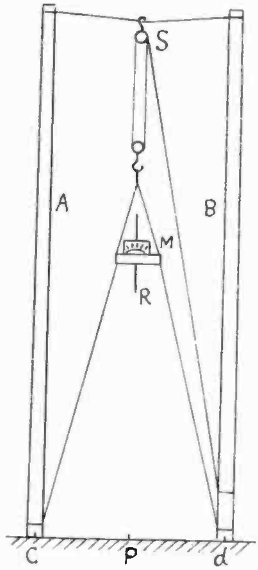

Figure 2

receiver and set close to the ground level. Field intensity due to the generator can thus be measured in various angular directions above the ground level by placing the receiver at various heights. The meter reading must be taken from a distant point through a telescope, for the observer's body causes a remarkable effect on the field distribution.

(III) Field Due to a Straight Vertical Antenna

In order to facilitate the change of antenna length, a straight telescopic brass tube was employed as the sending antenna. The antenna was unloaded and the operating wave length was kept constant at 2.66 meters throughout the experiments.

Since the wave length was kept constant, the total

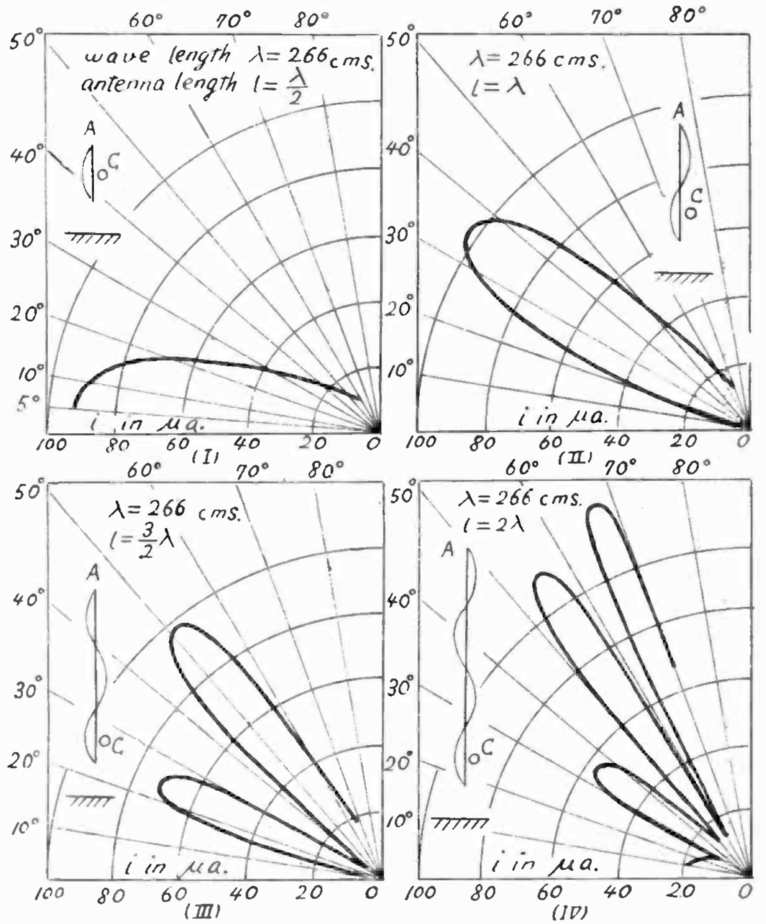

Figure 3

length of the sending antenna had to be altered according to the harmonic adopted. The grounded and the ungrounded antennae were used in the experiments.

(a) *Grounded Antenna.* When the lower end of the antenna is grounded, oscillation is possible at odd harmonics only, whereas the ungrounded antenna can operate either at an even or an odd harmonic.

Figure 3 shows the observed polar curves in the case of the grounded antenna, and the radius vector gives the measure of intensity in the receiving system placed in that direction. *A* is the sending antenna, and the current dis-

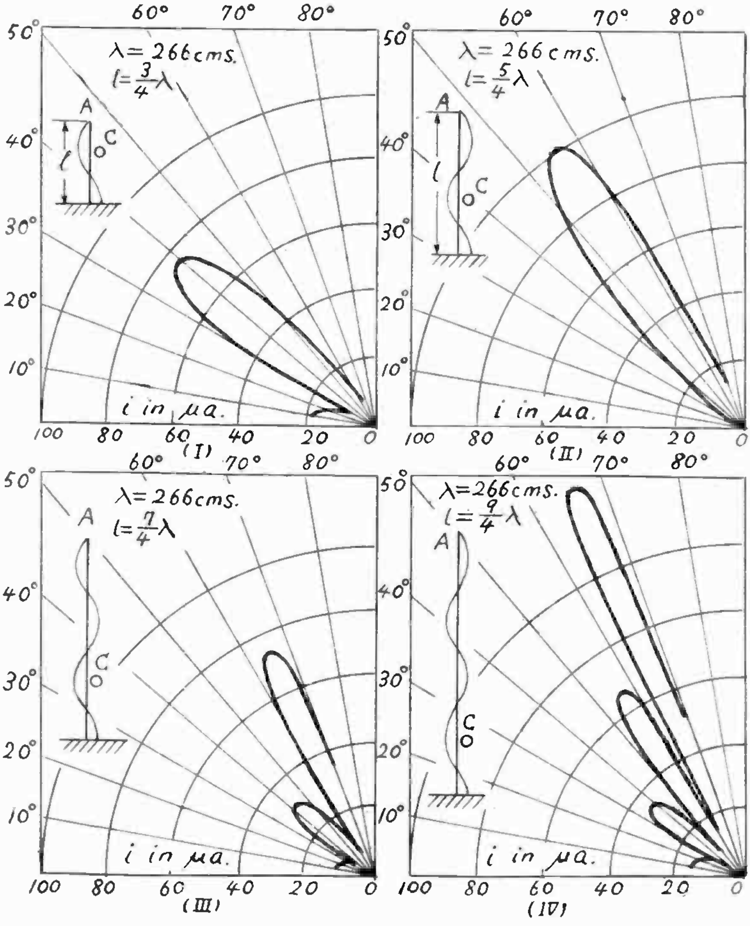

Figure 4

tribution in it is assumed to be a sine curve as indicated (Figure 3). *C* represents the oscillating coil of the short wave generator which is coupled with the antenna and placed near its current loop.

In all cases, it will be noticed that a considerable amount of energy is radiated in high angular directions, while the radiation along the earth surface is very small. If the length of the antenna is made equal to $\frac{7}{4}\lambda$ or $\frac{9}{4}\lambda$ corresponding to the 7th or the 9th harmonic, the wave projected upwards will be split up into several parts and there will then be several maxima of radiation. This is illustrated by (II) and (IV) in Figure 3.

It must be remembered that in our experiments only the vertical component of the field has been measured and

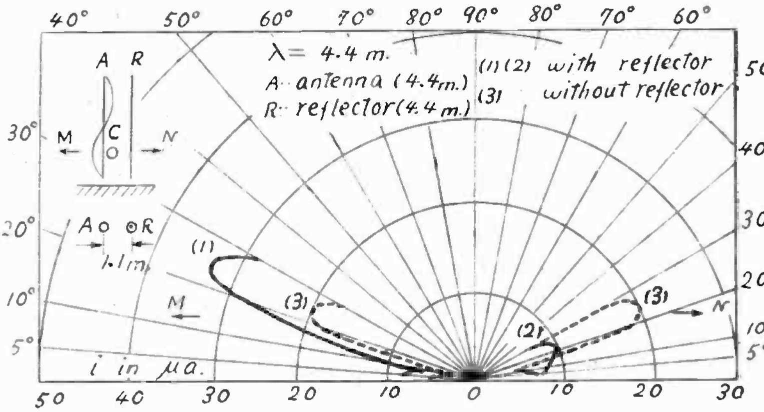

Figure 5

therefore the polar curves can not be strictly compared with the theoretically determined curves.

(b) *Ungrounded Antenna.* The same measurements were made with the ungrounded antenna. In this case, the lower end of the antenna was kept at a distance of about a quarter wave length above the ground. The observed polar diagrams are shown in Figure 4, where the horizontal base line is taken along the earth surface.

Here again is it noticeable that the radiation at higher angles is markedly predominant when the antenna oscillates at one of its harmonics.

(IV) High Angle Directional Beam

Suppose that a vertical antenna operating at the 2nd harmonic is sending out electromagnetic wave in all directions around it. If a single metallic rod of a full wave length is vertically erected at a distance of a quarter wave length behind the radiating antenna (Fig. 5), then this metallic rod, as is well known, will act as a wave reflector. Since this wave reflector will also act at the 2nd harmonic, it is obvious that the characteristic of the high angle radiation will become much augmented in a single direction due to the existence of the reflector. Thus we can easily obtain a high angle directional beam of short radio waves.

In Figure 5 is shown the directive effect of a single wave reflector. The curve (1) shows the radiating characteristic in the forward direction of the antenna, and (2) represents the same in the backward direction. The broken lines (3) represent the polar curves when there is

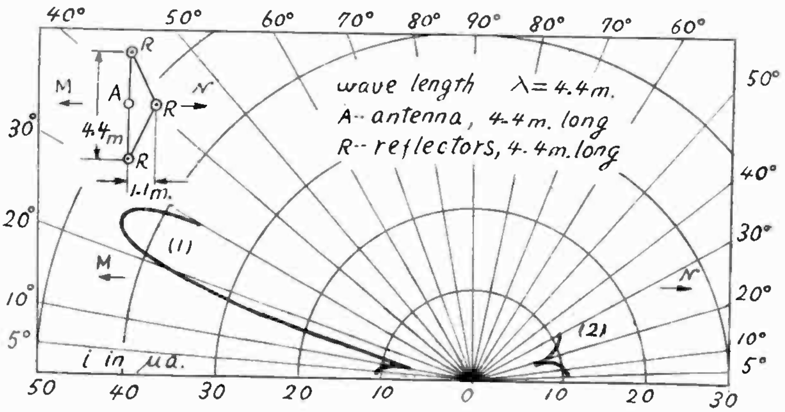

Figure 6

no reflector. The operating wave length is here equal to 4.40 meters, and both the antenna and the reflector are ungrounded, the lower ends of them being at a height of a few centimeters from the ground.

Again a reflecting rod is placed a quarter wave behind the antenna and two more reflectors, one being on the left and the other on the right side of it, are placed a half wave distant from the antenna (Fig. 6). These three rods form a triple-antenna reflecting system, which is comparatively simple in form yet fairly effective in action. For the future convenience, this reflecting system will hereafter be called a fundamental "trigonal reflector."

It is, of course, most efficient when these reflectors are all tuned to the 2nd harmonic, whereby they have nearly the same length as the main antenna. Figure 6 gives the observed diagrams in this case, where (1) and (2) represent the curves in front and in back of the antenna respectively.

In Figure 7 is shown the radiating characteristic in the side directions under the same operating conditions as in Figure 6.

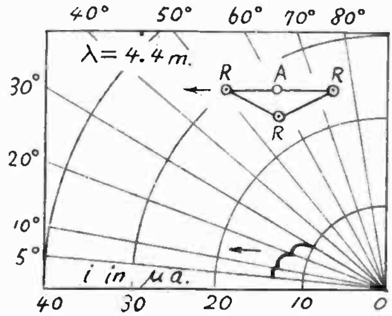

Figure 7

Now if several wave directors are arranged in front of the radiating antenna along the line of reflection, the directivity will be remarkably improved. This is evident from Fig. 8 and Fig. 9, for example, where six wave directors are employed.

The *D's* in the Figure are the directors which are hung along an inclined line lying nearly in the direction of maximum radiation (Fig. 8.) The length of each director is

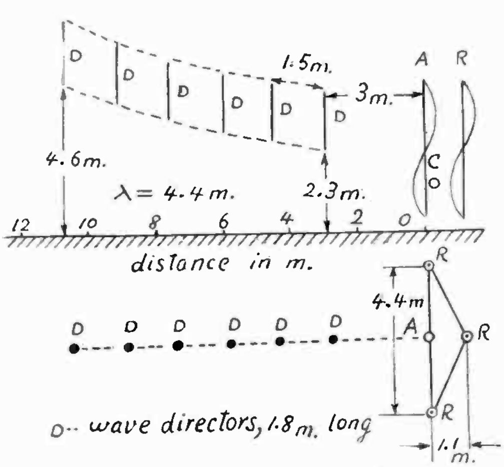

Figure 8

1.80 meters, and their separation 1.50 meters. Figure 9 shows the observed polar distribution in this case. For all the observations of Fig. 5 and Fig. 9, the field measurements were made under the same condition, and the short wave generator was also kept at exactly the same condition. The distance between the generator and the receiving apparatus was also made the same for all the above cases and was equal to 15 meters.

The series of wave directors acts as a means of converging the wave energy and transmitting it further along its direction, and may therefore, be called a "wave duct" or a "wave canal." The projection of the sharpest beam

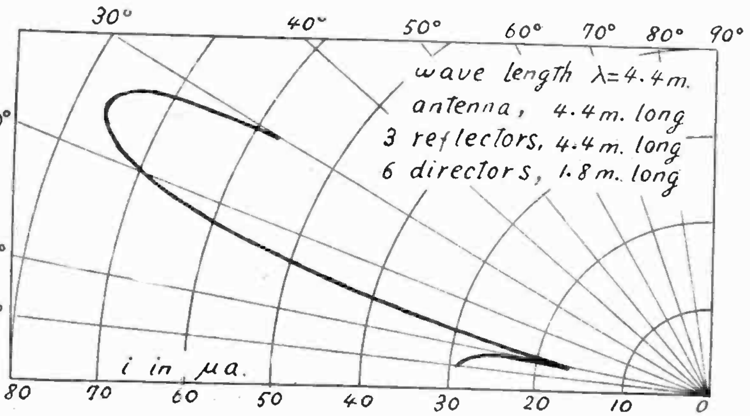

Figure 9

can be effected by combining a trigonal reflector with a wave canal. This combination is thus called a "wave projector." The sharpness of the beam can be improved by increasing the number of director rods contained in the wave canal.

Many observations have been made by the author on other types of wave projector, in which the antenna and reflectors operate resonantly at a half wave length. Polar curves thus obtained have proved that a beam with the sharpness never before attained could then be produced.

As regards the general study of this wave projecting system, a preliminary report was presented to the Imperial Academy of Japan. (YAGI and UDA, "Projector of the sharpest beam of electromagnetic waves," Proceedings Imp. Academy 2, 1926.) The full account of the study in detail has been published as a series of papers in the Journals of I. E. E., of Japan. (UDA. On the wireless beam of short elec. waves. I to VII written in Japanese). Two papers relating to the same subject were presented to the 3rd Pan-Pacific Science Congress held in Tokyo, November, 1926. (YAGI and UDA. A new electromagnetic wave projector and radio beacon. YAGI and UDA. On the feasibility of power transmission by electromagnetic waves).

In conclusion, the writer wishes to acknowledge his indebtedness to Saito Memorial Foundation for the grant which enabled him to undertake the work, and to Professor H. Yagi, of the Tohoku Imperial University, under whose direction the work was carried out.

SUMMARY

The paper describes some accounts of experimental work on the field distribution due to a straight vertical unloaded antenna operating at one of its harmonics. Short wave of 2.66 meters length were employed, and observations have been made with the grounded and the ungrounded antennas.

The paper also gives the test results on a new wave projector devised by the author with special reference to high angle radiation of short electric waves.

NOTES ON RADIO RECEIVER MEASUREMENTS*

By

THEODORE A. SMITH AND GEORGE RODWIN

(Technical and Test Department Radio Corporation of America)

It is very desirable to have a basis of comparison for radio receivers of different types. Methods of test for commercial electrical apparatus have been well established, and test codes for motors, boilers, engines and similar equipment have been adopted by engineering societies. At the present time, however, the specifications of the performance of a radio set are still in a more or less rudimentary stage. The purpose of this paper is to present some contributions to this subject.

Methods of test which enable diverse types of receivers to be compared and which would be of practical application were suggested some time ago by Mr. Julius Weinberger, of this department. Tests have been made on various receivers and the results obtained seem to warrant a description of the methods used.

In order to compare radio receivers electrically, it is necessary to select certain essential attributes which determine their performance. Different sets can then be compared with respect to these quantities. Three characteristics have been chosen as most important for measuring the performance of a receiver. They are Sensitivity, Selectivity and Fidelity. Two other factors of slightly lesser importance are the Accepted Frequency Range and the ability to control the volume of the output.

The essential characteristics mentioned above may best be shown by a series of curves. Sensitivity may be plotted as the receiver output at various radio frequencies. Selectivity may be indicated by a Resonance Curve. Fidelity can be shown in two ways. In the first, an overall curve may be plotted of the audio frequency output when constant amplitude modulation at progressive audio frequen-

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cies is received. While this curve represents the quality which may be expected, it is impossible to tell to what part of the set a deviation is due. A better method is to take a curve on the radio circuits, which shows the sideband transmission characteristics, and one of the audio amplifier characteristics. A combination curve may then be obtained, from all frequency selective circuits of the receiver, which will represent the quality to be expected from the set.

Method of Test

The attempt has been made, in testing receivers, to simulate actual conditions of normal use. The function of a radio set is to produce a definite loud speaker signal, and the set should be rated upon its ability to do this. A sensitive receiver is one which requires relatively little voltage from the antenna to actuate the loud speaker. A perfectly selective receiver requires an infinite field strength from an interfering station, to produce an audible loud speaker signal.

In order to determine the various factors mentioned previously, it is first necessary to define what is meant by a "loud speaker signal." The term "standard loud speaker signal" or simply "standard signal" has been taken to correspond as nearly as possible with the normal loud speaker output of a receiver as used in the home. This may be regarded as a highly indefinite term, but it is for this highly indefinite condition that receivers are being built, and as there is no ready-made term to define such a condition, it has been necessary to manufacture one. The "standard loud speaker signal" must be great enough to enable persons a distance away from a loud speaker, to hear a program distinctly and without effort. It must also be limited by the output capacity of the final amplifier tube. The standard loud speaker signal employed, has been arbitrarily defined as the signal corresponding to an average audio frequency (r. m. s.) voltage of 15 volts across a 5000 ohm resistance in the output circuit when 400 cycle modulation at 50% is furnished by the signal generator.

While such a "standard signal" may be useful to talk about and to form a basis of comparison, it is not easy to measure in practice. For this reason it becomes necessary to select an electrical analogue for measurement purposes. This is not difficult, as the detector of the radio set may be employed as an indicator by placing a milliammeter in its plate circuit. If a signal of constant degree modulation is being received, a certain change in detector plate current will correspond exactly to the above mentioned "standard signal." This value of plate current, or change in plate current from static value, will be used as a measure of the standard signal throughout. It is then unnecessary to use modulated signals for receiver measurements, although the amplification of the audio stages is taken into account.

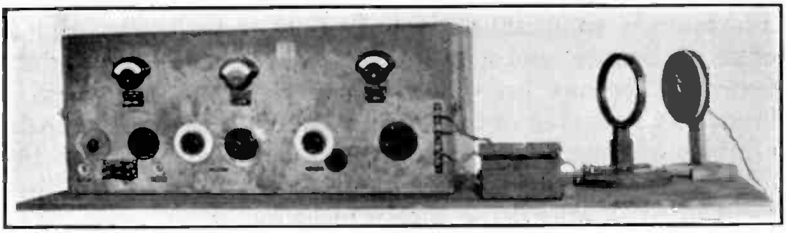


Figure 1—Test Oscillator used for taking all data. System comprises an audio frequency amplifier, modulators, oscillator, and power amplifiers with output metering device and modulation percentage indicator.

The manner in which the given loud speaker voltage is related to the detector plate current change, may be determined by experimental means or else by calculation. To compute it, the gain of the audio amplifier must be known. The loud speaker voltage, 15 volts, divided by this value will give the audio frequency voltage in the plate circuit of the detector. If an average degree of modulation of 50% is assumed, this audio frequency voltage will bear a definite relation to the voltage of the carrier frequency on the input side of the detector, and will be accompanied by a definite plate current change (dc) of the detector. This current value is a measure of the "standard signal."

All other factors are related to this value. Sensitivity curves may be taken as the field strength required to produce the "standard signal" or standard detector plate current change, at various radio frequencies, when the receiver is tuned to resonance at each frequency.

Resonance curves represent the field strength necessary to produce the standard signal at various radio frequencies when the receiver is left tuned to resonance at one particular frequency.

A volume control curve can be plotted of field strength required to produce standard signal when the receiver is tuned to resonance, versus settings of the volume control.

Method of Taking Curves

In all cases a radio frequency oscillator is necessary. For coupling to receivers requiring an antenna, a dummy antenna was provided consisting of a condenser of 0.0004 microfarads capacitance, a coil of 28 microhenrys and 2 ohms resistance, and a resistance of 23 ohms, connected in series. This has been found to simulate a fairly good broadcast receiving antenna. An effective height of 4 meters was assumed. The oscillator coil is coupled to the inductance coil of the dummy antenna, the general arrangement of apparatus being shown in Figure 1.

If the oscillator coil has a current I flowing in it at some radio frequency f and there is a mutual inductance M between it and the inductance in the dummy antenna, a radio frequency voltage $2\pi fMI$ will be induced in the dummy antenna circuit. This voltage could be induced by a field strength E in an equivalent actual antenna of effective height H, so that $E=\frac{2\pi fMI}{H}$ In using this expression E is in volts per meter, f in cycles per second, M in henrys, and I in effective amperes.

For loop receivers, the oscillator coil is used to produce known field intensities at the loop of the set. A coil of n turns with radius a and having a current I flowing in it will produce a flux density H at a distance x given by

$$H=\frac{2\pi a^2 In}{10(x^2+a^2)^{3/2}} \qquad (gausses)$$

Expressed as equivalent microvolts per meter this becomes

$$E=300H\times 10^{18}=18850\frac{na^2i}{(x^2+a)^{3/2}}\cos\alpha \,.\, 10^{6}$$

in which all distances are expressed in centimeters, i in amperes, α is the angle taking the planes of the two coils.

For taking sensitivity curves, the receiver under test is tuned to resonance, the oscillator output is adjusted so that the detector plate current change reaches the proper value for standard signal. Several points at different frequencies may be taken quickly in this manner and the sensitivity curve plotted as the field strength required to produce standard signal, versus frequency.

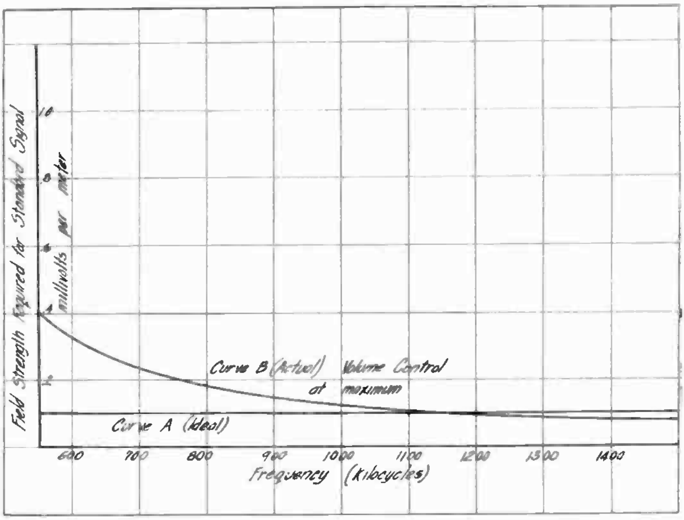


Figure 2—Sensitivity Curve—Field Strength Required to Produce Standard Signal vs. Frequency.

Resonance curves may be taken in two ways. By the first method, an oscillator is necessary in which the frequency can be varied in small steps and the output of which can be varied widely without change in frequency. A neutralized master oscillator-power amplifier system has been used. (See Fig. 1). The receiver is tuned to resonance and the oscillator adjusted to this frequency. The oscillator frequency is then varied and readings of field strength are taken at several frequency steps off tune, keeping the detector plate current change constant at the standard signal value.

In case such an oscillator is not available, an oscillator the output of which is constant over a small frequency range may be employed. In this method, a resonance curve is taken by keeping the oscillator output constant and reading the detector plate current changes for steps of frequency off resonance. By then plotting a curve of field strength versus plate current changes, this resonance curve may be translated to the previous form.

The volume control curve is self-explanatory.

From the resonance curve is shown the effect of the

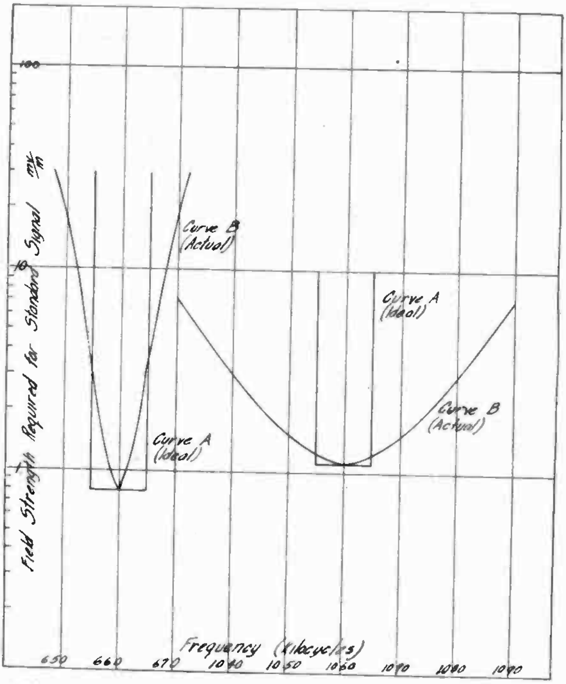


Figure 3—"Resonance" Curves—Curve at left taken with receiver tuned to 660 kc., curve at right with receiver tuned to 1060 kc.—Field Strength Required to Produce Standard Output vs. Frequency of Signal Generator.

receiver selectivity in cutting off the higher audio frequencies. However, it is more convenient to show this sharpness by replotting a portion of the resonance curve in different form. This new curve shows in effect the audio frequency voltage transmitted by the radio frequency circuits, plotted as a percentage of the transmission at the resonant frequency. As this quantity is proportional to the admittance of the circuits, the title of the ordinate, Percent. Resonant Admittance, seems a proper one. The data for this curve are obtainable by taking the average of the field strengths required to produce standard signal either side of resonance for frequencies in the audio

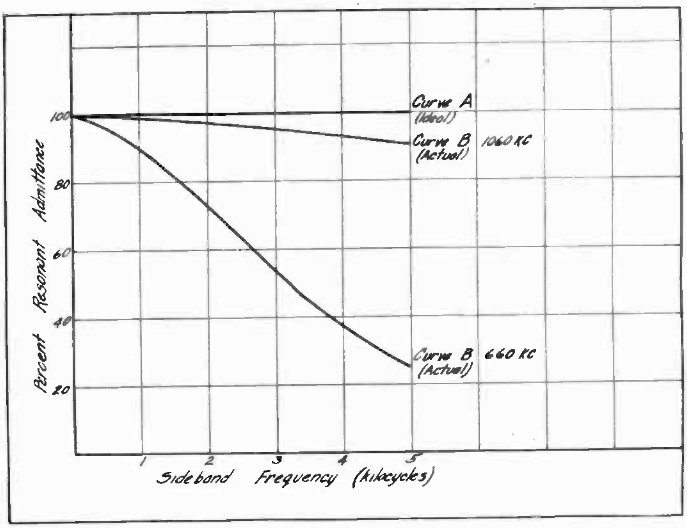


Figure 4—Sideband Transmission Characteristic Curves—Cutoff of high audio frequencies due to selectivity of radio frequency circuits.

range. This average field strength divided into the field strength required to produce standard signal at resonance, is the Resonant Admittance expressed as a percent.

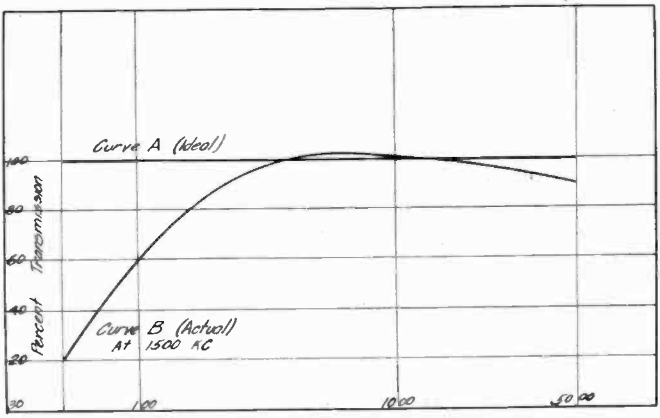


Figure 5—Audio Frequency Characteristics of Entire Receiver—Transmission of audio frequencies compared to transmission at 400 cycles.

By combining this curve with the curve of the audio amplifier, the frequency response curve of the receiver will be obtained, if there is no other frequency selective circuit, (such as the grid leak condenser combination). As the latter effect can be allowed for, the combined curve may be taken as truly representing the quality limitations of the receiver. As measurements are taken below the overload-

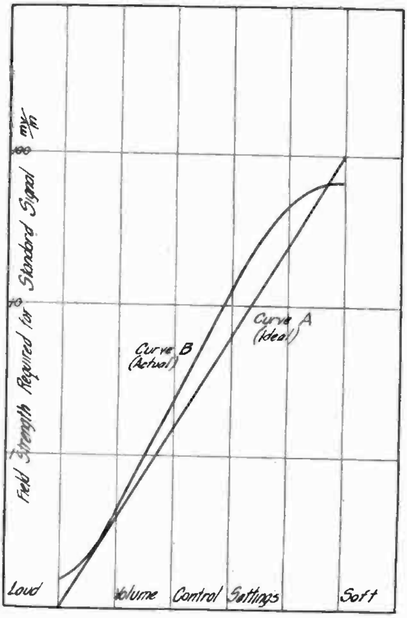


Figure 6—Volume Control Curve—Receiver and Signal generator in tune. Field strength to produce standard output at various volume control settings.

ing point of the amplifier tubes, no serious harmonic distortion is encountered.

The method of procedure for quickly taking audio frequency characteristic curves will be described in an accompanying paper by Mr. E. T. Dickey.

While the description of the method of test makes the process appear involved, the actual operation is relatively simple and curves may be taken with considerable speed.

Relation of Actual to Ideal Curves

When the curves of a receiver have been obtained, they may be compared with curves of other sets. Perhaps a good method of comparison is to note the deviation from a set of hypothetical, ideal curves which represent the ultimate aim of receiver design.

The shape of a series of ideal curves is shown in *A* of Figures 2, 3, 4, 5, and 6. Curves marked *B* in these figures represent actual curves of some receivers tested.

Conclusion

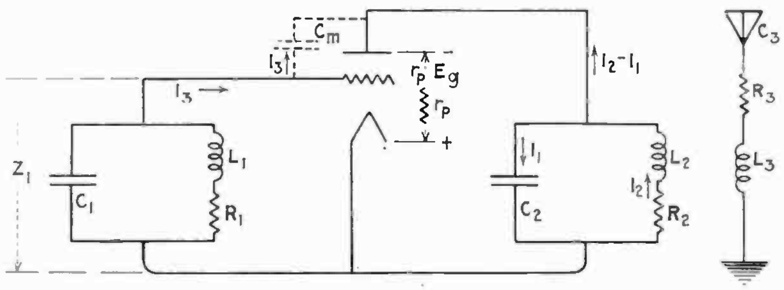
While it is not claimed that the methods employed herein are new, few attempts have been made previously to coordinate the testing of receivers, so that the results obtained may be correlated with broadcasting station performance. It is possible to predict how well a set in a given locality will receive signals from a broadcasting station, by inspection of the sensitivity curve of the set and a field strength map of the station. The quality which may be expected from a receiver is found from the frequency characteristic curves. The field strength which still overloads the set with the volume control device at its minimum position can be determined, and hence the area about a broadcasting station in which such a receiver cannot be used, is known. It is possible to tell from a resonance curve whether a broadcasting station will interfere with one being received if their respective field intensities are known. Thus it will be seen that the results obtained in this method of test are useful for practical as well as theoretical purposes.

It is to be hoped that some general method of test will be adopted, so that in the future receivers may be compared by means of definite engineering standards.

THE TUNED-GRID TUNED-PLATE CIRCUIT USING PLATE-GRID CAPACITY FOR FREED-BACK. A DERIVATION OF THE CONDITIONS FOR OSCILLATION.

By
J. B. Dow

Herewith is a circuit which has recently been popularized in short wave transmission. The necessary feedback for oscillation generation is obtained solely through the plate-grid capacity of the tube and not through external inductive or capacity coupling as in most other circuits.



The grid-filament and plate-filament capacities within the tube are considered to be lumped with the tuned circuit capacities C and C_2 respectively. R_1 is the equivalent resistance of the input resistance of the tube plus such resistance as is inherent in the tuned grid circuit. R_2 is the equivalent resistance of the load circuit L_3, R_3 C_3 plus the inherent resistance of the tuned plate circuit. L_2 and C_2 include the equivalent inductance and capacity of the load circuit L_3, R_3 C_3.

The problem is to develop equations showing the conditions required for oscillation.

It is assumed that the alternating current wave is sinusoidal when oscillation occurs. Owing to the presence of the tuned grid circuit, this assumption introduces no serious error in the results.

Kirchoffs Laws give

$$I_1 \frac{j}{C_2\omega} - I_2(R_2 + jL_2\omega) = 0 \tag{1}$$

$$(I_2 - I_1) r_p + I_1 \frac{j}{C_2\omega} = \mu E_g \tag{2}$$

Note: All I's, E's and z's are complex.

Digression on E_g:

$$\frac{1}{z_1} = \frac{1}{R_1 + jL_1\omega} - \frac{1}{\frac{j}{C_1\omega}}$$

$$z_1 = -\frac{(R_1 + jL_1\omega)\frac{j}{C_1\omega}}{j(L_1\omega - \frac{1}{C_1\omega}) + R_1}$$

$$I_3 = \frac{-I_1 \frac{j}{C_2\omega}}{z_1 - \frac{j}{C_m\omega}} = \frac{I_1 C_1\omega C_m\omega [R_1 + j(L_1\omega - \frac{1}{C_1\omega})]}{C_2\omega[[C_m\omega(R_1 + jL_1\omega) + C_1\omega[R_1 + j(L_1\omega - \frac{1}{C_1\omega})]]]}$$

$$E_g = I_3 z_1 = \frac{-jI_1 C_m\omega(R_1 + jL_1\omega)}{C_2\omega[[C_m\omega(R_1 + jL_1\omega) + C_1\omega[R_1 + j(L_1\omega - \frac{1}{C_1\omega})]]]} \tag{3}$$

Substituting (3) in (2), get

$$I_1 \left[\frac{j\mu C_m\omega(R_1 + jL_1\omega)}{C_2\omega[[C_m\omega(R_1 + jL_1\omega) + C_1\omega[R_1 + j(L_1\omega - \frac{1}{C_1\omega})]]]} + \frac{j}{C_2\omega} - r_p \right] + I_2 r_p = 0 \tag{4}$$

$$I_1 \frac{j}{C_2\omega} - I_2(R_2 + jL_2\omega) = 0 \tag{1}$$

Eliminating between (4) and (1) and multiplying both sides of the result by $C_2\omega$, get

$$jr_p + \left[\frac{j\mu C_m\omega(R_1 + jL_1\omega)}{[[C_m\omega(R_1 + jL_1\omega) + C_1\omega[R_1 + j(L_1\omega - \frac{1}{C_1\omega})]]]} + j - r_p C_2\omega \right] (R_2 + jL_2\omega) = 0 \tag{5}$$

Rationalizing the denominator of the fraction, then multiplying both sides of (5) by the new denominator, get

$$jr_p[R_1^2(C_m\omega+C_1\omega)^2+[[C_m\omega L_1\omega+C_1\omega(L_1\omega-\frac{1}{C_1\omega})]]^2]$$

$$+\Big\{j\mu C_m\omega(R_1+jL_1\omega)[[R_1(C_m\omega+C_1\omega)-j[C_m\omega L_1\omega$$

$$+C_1\omega(L_1\omega-\frac{1}{C_1\omega})]]]$$

$$+j[[R_1^2(C_m\omega+C_1\omega)^2+[C_m\omega L_1\omega+C_1\omega(L_1\omega-\frac{1}{C_1\omega}]^2]]$$

$$-r_pC_2\omega[[R_1^2(C_m\omega+C_1\omega)^2+[C_m\omega L_1\omega+C_1\omega(L_1\omega-\frac{1}{C_1\omega}]^2]]\Big\}$$

$$(R_2+jL_2\omega)=0 \tag{6}$$

Equation (6) expresses in complex form the conditions required for oscillation. The real part of (6) gives the first general condition of oscillation, viz:

$$\mu C_m\omega R_1(C_m\omega+C_1\omega)(R_2L_1\omega+R_1L_2\omega)+[C_m\omega L_1\omega+C_1\omega(L_1\omega-$$

$$\frac{1}{C_1\omega})](L_1\omega L_2\omega-R_1R_2)]$$

$$-[[R_1^2(C_m\omega+C_1\omega)^2+[C_m\omega L_1\omega+C_1\omega(L_1\omega-$$

$$\frac{1}{C_1\omega})]^2]](L_2\omega+R_2r_pC_2\omega)=0 \tag{7}$$

If the tuned grid circuit is adjusted to resonance, $L_1\omega=\frac{1}{C_1\omega}$, then the above equation reduces to the simpler form

$$\mu C_m\omega[R_1(C_m\omega+C_1\omega)(R_2L_1\omega+R_1L_2\omega)+C_m\omega L_1\omega(L_1\omega L_2\omega-R_1R_2)]$$

$$-[R_1^2(C_m\omega+C_1\omega)^2+(C_m\omega L_1\omega)^2](L_2\omega+R_2r_pC_2\omega)=0 \tag{8}$$

If $L_1\omega=\frac{1}{C_1\omega}$, and in addition, $R_1=0$, (7) reduces to the still simpler form

$$\frac{L_2}{C_2}=\frac{R_2r_p}{\mu-1} \tag{9}$$

The imaginary part of (6) gives another condition for oscillation from which the frequency can be determined. This second general condition is

$$\mu C_m\omega[[R_1(C_m\omega+C_1\omega)(R_1R_2-L_1\omega L_2\omega)+[C_m\omega L_1\omega+C_1\omega(L_1\omega-\frac{1}{C_1\omega})](R_2L_1\omega+R_1L_2\omega)]]$$

$$+[[R_1^2(C_m\omega+C_1\omega)^2+[C_m\omega L_1\omega+C_1\omega(L_1\omega-\frac{1}{C_1\omega}]^2]]\,[R_2+r_p(1-L_2\omega C_2\omega)]=0 \tag{10}$$

If as before, $L_1\omega=\frac{1}{C_1\omega}$, (10) reduces to

$$\mu C_m\omega[R_1(C_m\omega+C_1\omega)(R_1R_2-L_1\omega L_2\omega)+C_m\omega L_1\omega(R_2L_1\omega+R_1L_2\omega)]$$
$$+[R_1^2(C_m\omega+C_1\omega)^2+(C_m\omega L_1\omega)^2]\,[R_2+r_p(1-L_2\omega C_2\omega)]=0 \tag{11}$$

If $L_1\omega=\frac{1}{C_1\omega}$, and in addition, $R_1=0$, (10) reduces to

$$R_2(\mu-1)+r_p(1-L_2\omega C_2\omega)=0 \tag{12}$$

from which

$$\omega=\sqrt{1+\frac{R_2(\mu+1)}{r_p}}\,\frac{1}{\sqrt{L_2C_2}} \tag{13}$$

The last equation indicates that if $R_2\neq 0$, the frequency of oscillation is greater than the undamped frequency of the circuit $L_2C_2R_2$.

$\omega=2\Pi f$.

μ=plate amp. factor.

SELECTIVITY OF TUNED RADIO RECEIVING SETS*

KENNETH W. JARVIS

(Engineer, Crosley Radio Corporation)

In the design of modern broadcasting receivers, the radio engineer has three technical objectives. These three objects are the obtaining of selectivity, fidelity of reproduction and adequate sound volume. Selectivity means absolute choice of the wanted transmission, without interference of any kind. Adjacent stations, static and man-made interference should be entirely eliminated. Fidelity of reproduction defines itself. The final sound output should be exactly similar in amplitude, phase and tone as that before the transmitter microphone. Adequate sound volume implies sufficient amplification to increase any signal impulse, no matter how small, to any desired value.

An ideal radio receiver will have all of these factors incorporated in its design. The user may choose his program and control the output to suit his comfort. These should be independent problems, a more perfect solution of any of them contributing to the intrinsic value of the receiver. Unfortunately this situation is not even approached in present practice—a change in design which will affect any one of these factors will also affect the other two. It will therefore be appreciated that a paper on "Selectivity" would be meaningless if the entire combination of effects were not considered. The most that can be done is to show how the amplification and quality varies when the selectivity is the independent variable.

Before "selectivity" can be discussed, it is necessary to know what is to be "selected," and this involves an analysis of the method by which broadcasting is accomplished. The concept of side bands is well known. Broadcasting consists in the simultaneous radiation of two or more high frequency waves. Modulation is the operation of producing high fre-

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quency radiations at a frequency different from a carrier frequency by an amount equal to the audio frequency to be transmitted. The usual methods of modulation produce two such high frequencies, one on either side of the carrier. Thus if a million cycle carrier is modulated by an

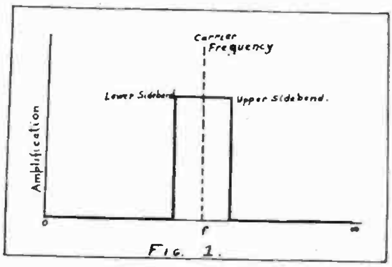

Figure 1

audio frequency of 1000 cycles, three frequencies are radiated, one million minus a thousand, one million, and one million plus a thousand cycles. The frequencies generated by modulation are termed side bands. It should be clearly realized that these side bands are *not* mathematical fictions, but are *physically existent* as a part of the broadcast transmission. It is the "beating" of the side bands on the

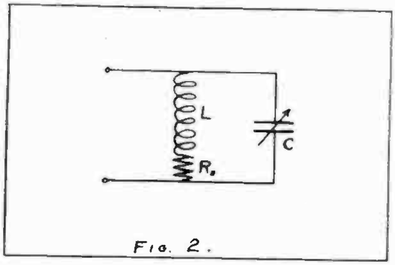

Figure 2

carrier which rectified produces the audio component of the detector output. The two side bands "beating" with the carrier wave add to give the original audio or modulating frequency.

It is obvious that the amplitudes and phases of the side bands must maintain their original relationship throughout any amplification or modifying stages to which the frequency band is subjected.

Considering the faithfulness of reproduction, or quality, a uniform response curve for all frequencies would be desired. Considering selectivity, this response band should cover only the frequencies included in the side bands of the desired station. Such a response curve is shown in

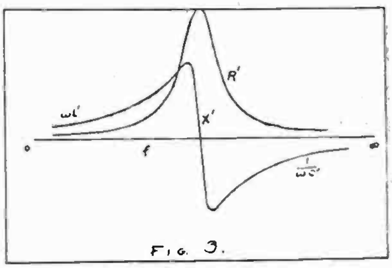

Figure 3

Fig. 1. Below the lower side band and above the upper side band no response is obtained while between these two limits the response is uniform. Such a response curve is obviously a discontinuous function of frequency, and as such requires an infinite series of terms to represent it accurately. This would probably mean an infinite series of selective circuits or circuit arrangements. More will be said later regarding the possibilities of such a system.

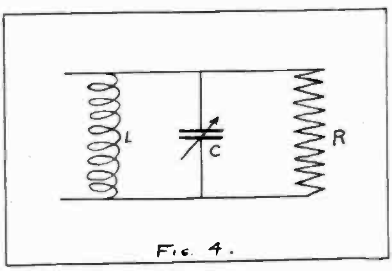

Figure 4

With this conception of the "ideal" response curve in mind, the response curves of the present type of selecting circuits will be more appreciated. The circuit is shown in Fig. 2. The fundamental operation of such a circuit depends upon its change of impedance with change in applied frequency. Below the resonant frequency the circuit is an inductive reactance, and above resonant frequency it is capacity reactance. As resonance is approached, the effective resistance increases, reaching a maximum close to the point of zero reactance. These facts are usually plotted in the form of the curves of Fig. 3.

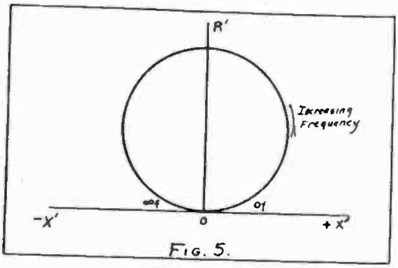

Figure 5

For the purposes of this paper, another viewpoint is preferable. It is a fundamental property of any circuit having a well defined resonant frequency that the curve between effective resistance and effective reactance should be approximately a circle. Thus take the simple circuit of Fig.

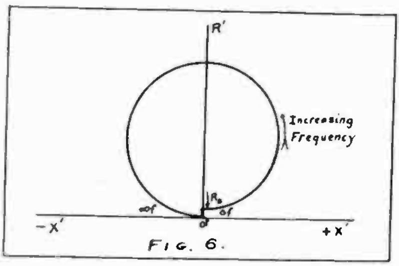

Figure 6

4. The curve between R' and X' is shown in Fig. 5. With zero frequency the inductance "shorts" the circuit. At resonance $\left[f = \frac{1}{2\Pi\sqrt{LC}}\right]$ the impedance of the L-C combination is infinite and the diameter of the circle is given by R. At infinite frequency the capacity "shorts" the circuit and thus completes a perfect circle. Changing L and C changes the resonant frequency; changing R changes the diameter of the circle.

In case there is no shunt resistance, but a series resistance in one, or both legs, the action is somewhat different. Fig. 6 shows the case with a resistance in the inductive leg only. The impedance "circle" begins with a small value R_s, equal to the coil resistance and ends with zero impedance as

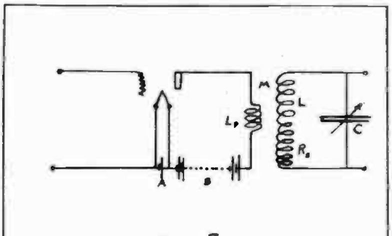

Figure 7

before. The "circle" is not a true circle, but if R_s is small compared with R' it may be treated as such without serious error. In all the cases discussed in this paper this has been done. The case where the error due to this assumption would be greatest has been checked and the error found to be considerably less than 1%, and is sufficiently accurate for all other cases of value to a radio engineer.

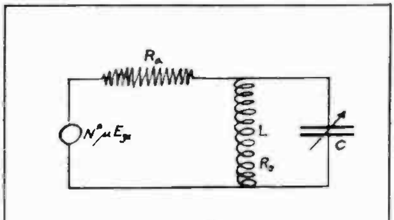

Figure 8

The next consideration is to determine the voltage across such a resonance circuit as the frequency is varied. The usual circuit connections for a vacuum tube amplifier are as shown in Fig. 7. It can be shown that a vacuum tube can be replaced by a generator of zero internal impedance having a voltage μE_{g1} in series with a resistance R_p equal to the plate-filament impedance of the tube. Also all of the circuit constants may be transferred to the secondary by multiplying by N^2. N is the effective transformer ratio, and with no leakage is $\frac{L_2}{M}$. If leakage is present, the transfer is still justified but N may be more difficult to determine numerically.

These changes have been made in Fig. 8, where $N^2\mu E_{g1}$ is the voltage of the transferred generator, and $R_a = N^2 R_p$. The vector diagram of the combination impedance is shown in Fig. 9. R_a adds in the direction of R'. The vector AC

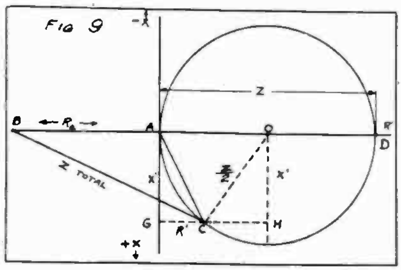

Figure 9

represents the impedance of the tuned circuit and the vector BC represents the impedance of the combination. As the applied voltage divides in direct ratio to the impedances, the response curve is given by the ratio AC/BC as the point C swings around the circle.

$$AC = \sqrt{R'^2 + X'^2} \tag{1}$$

$$BC = \sqrt{(R' + R_a)^2 + X'^2} \tag{2}$$

Let the response curve ratio $\frac{AC}{BC}$ be represented by B.

Then

$$B^2 = \frac{R'^2 + X'^2}{R'^2 + 2R'R_a + R_a^2 + X'^2} \tag{3}$$

From the geometry of the circle it can be shown that

$$X'^2 = ZR' - R'^2 \tag{4}$$

where Z is the maximum impedance of the tuned circuit, ie, the circle diameter, making the substitution of (3) in (4) gives

$$B^2 = \frac{ZR'}{R_a^2 + R'(2R_a + Z)} \tag{5}$$

The mathematical solution of the circuit constants (or variables) of a tuned circuit such as shown in Fig. 4 where $R=\frac{L}{R_s C}$ (resonance impedance) gives as the effective resistance a term so that

$$R'=\frac{\frac{L}{R_s C}\,\omega^2 L^2}{\frac{L^2}{R_s^2 C^2}(1-\omega^2 LC)^2+\omega^2 L^2} \tag{6}$$

where L, C and R_s are the inductance, capacity and the series resistance of the tuned circuit. At resonance $(1-\omega^2 LC)$ is zero and, as $R'=Z$ at this point,

$$R'_{max}=Z=\frac{L}{R_s C} \tag{7}$$

Substituting (6) and (7) in (5) gives

$$B=\sqrt{\frac{\omega^2 L^2}{(R_a R_s \omega C+\omega L)^2+R_a^2(1-\omega^2 LC)^2}} \tag{8}$$

At resonance $\frac{1}{\omega C}=\omega L$ and (8) simplifies into

$$B=\frac{1}{\frac{R_a}{Z}+1} \tag{9}$$

This means that if the transferred tube impedance is equal to that of the tuned circuit, ie $R_a=Z$, half of the tube generator voltage is effective across the tuned circuit.

This development can now be applied to the determination of selectivity. In this paper the term "selectivity" is used to represent the ratio between the wanted signal and an interfering signal. The usual method of measuring selectivity is based on the width of the resonance curve at half amplitude. While this is a convenient way of comparing two resonance curves, it is meaningless to an engineer who must interpret his solution to fit actual cases. We are interested in the comparative response of a desired station and one that is undesired. Such information is given only by the determination of the response ratios and not by any curve shape. Thus when a circuit is said to have a selectivity factor of five, it means that a wanted signal is five times the strength of an unwanted station, assuming equal inputs. This method has the disadvantage of having a different selectivity for every frequency off resonance. However, if all stations are working on a fixed frequency difference basis, such as the *10-kc.* separation of present broadcasting stations, and the selectivity factor is calculated using this difference, the result will be a positive answer to the question of selectivity and not a mere geometrical ratio.

Equation (9) gives the response at résonance, and equation (8) gives the response at any other frequency. $(\omega_2=2\Pi f_2)$. Dividing (9) by 8 will give the selectivity of the combination as defined above. Performing this operation and simplifying gives

$$S^2=1+\left(\frac{R_aZ}{R_a+Z}\right)^2\left(\frac{1}{\omega_2L}-\omega_2C\right)^2 \tag{10}$$

At resonance the product terms in (10) disappear and $S=1$. This is obvious from the definition of S. The last term is dependent on the frequency difference from resonance. For a given frequency difference, the only variable is that of $\frac{R_aZ}{R_a+Z}$

This term continuously increases as R_a increases. The value of R_a is the value of the tube impedance R_p transferred to the secondary. *Decreasing* the number of primary turns *increases* R_a and so increases the selectivity. It can be shown that when the primary turns are adjusted for maximum amplification $R_a=Z$. Under these conditions, the selectivity

$$S\propto\frac{Z}{2} \tag{11}$$

If the primary turns be decreased to zero, R_a approaches an infinite value. Substituting $R_a=\infty$ *in* (10) gives

$$S\propto\frac{\infty Z}{\infty+Z}=Z \tag{12}$$

It is thus apparent that decreasing the number of primary turns from the optimum amplification value to an infinitesimal value *cannot more than double the selectivity!*

The increase in selectivity by increasing Z is exactly the same as by increasing R_a. It must be noted however, that while $Z=\frac{L}{R_sC}$ it is not permissable to increase Z by changing the L-C ratio, as this also affects the second product term of (10). This effect will be discussed later. However decreasing R_s will increase the selectivity, and if the optimum transformer turn ratio be used, the selectivity will increase as the reciprocal of R_s. Notice that the only way to make the selectivity infinite is for R_s to be zero and the transformer turn ratio to be infinite.

In the above, notice that the square is dropped from S and the product terms. This can be done without error if the product terms are great with respect to 1. As the products terms approach zero, (due to $\frac{1}{\omega_2 L}-\omega_2 C$) the value of S does not differ greatly from 1.

The next problem is to determine how the selectivity changes with the L-C ratio. In order to do this, $\frac{L}{R_s C}$ must be substituted for Z in (10). Simplifying the resulting equation gives

$$S^2=1+\left[\frac{(\omega_r-\omega_2)^2}{\omega_2}\;\frac{R_a L}{R_a R_s+\omega_r{}^2 L^2}\right]^2 \tag{13}$$

In considering the action at any large frequency difference from resonance, the bracket term of (13) becomes large with respect to 1. Therefore

$$S=\frac{(\omega_r-\omega_2)^2}{\omega_2}\;\frac{R_a L}{R_a R_s+\omega_r{}^2 L^2} \tag{14}$$

The first of these product terms is dependent on frequency off resonance and is independent of circuit conditions. The second term is one which we can adjust. A simple differentiation shows that S is maximum when

$$\omega_r{}^2 L^2=R_a R_s \tag{15}$$

But R_a may also be determined by L, for $R_a=\left(\frac{L}{M}\right)^2 R_p$. Substituting this into (15) gives

$$M^2\omega^2=R_p R_s \tag{16}$$

This is the value to which M must be adjusted to give maximum amplification. This means that if the secondary inductance is adjusted for optimum amplification, the circuit is also adjusted for *optimum selectivity,* with respect to L-C ratio. This surprising statement indicates that if the circuit conditions are adjusted for maximum amplification, the selectivity is dependent on the L-R_s ratio only. It also means that if the circuit is adjusted for maximum amplification of a wanted signal, it will give the greatest ratio between the wanted signal and any interfering frequency.

While this gives optimum selectivity with respect to L-C, this is not the maximum possible selectivity. In general the problem is to obtain the greatest (or the least) selectivity for a given amplification. To this end the simplified equation for the amplification of a single tuned stage will be introduced.

$$A=\frac{M\omega\,.\,\mu\,.\,\omega L}{R_pR_s+M^2\omega^2} \tag{17}$$

Calling $\frac{(\omega_r-\omega_2)^2}{\omega_2}=K_1$, and substituting $R_a=\left(\frac{L}{M}\right)^2R_p$ in (13) gives

$$S^2=1+\left[K_1\frac{R_pL}{R_pR_s+M^2\omega^2}\right]^2 \tag{18}$$

Solving (17) for $M\omega$, and substituting $A=K_2\mu\omega$ in (18) and simplifying gives

$$S^2=1+\left[K_1K_2{}^2\frac{2R_p}{L\pm\sqrt{L^2-4K_2{}^2R_pR_s}}\right]^2 \tag{19}$$

For large frequency differences the 1 may be neglected and with a chosen amplification determining K_2,

$$S\propto\frac{R_p}{L\pm\sqrt{L^2-4K_2{}^2R_pR_s}} \tag{20}$$

The selectivity will be maximum when the denominator is minimum. If the second term under the radical be zero, the other denominator terms will cancel and the selectivity will be infinite. Notice that this means that R_s is zero, checking a previous conclusion.

The larger L becomes, the more nearly the radical term approaches the value of L, and the smaller the denominator. Maintaining the transformer turn ratio, etc., so as to give a constant chosen amplification, *increasing the secondary inductance will increase the selectivity.* This is a point not so well appreciated by the radio set manufacturer as it should be.

One other point is of interest. For any chosen amplification, i. e. K_2, there are two values of selectivity. One is where the amplification is below the optimum value due to too small a mutual inductance, and the other is with the mutual greater than the optimum value. If $L^2 = 4K_2^2 R_s R_p$, there is only one value for selectivity, that which occurs at the optimum amplification.

Before considering the quality factors of this discussion several curves illustrating the previously made points will

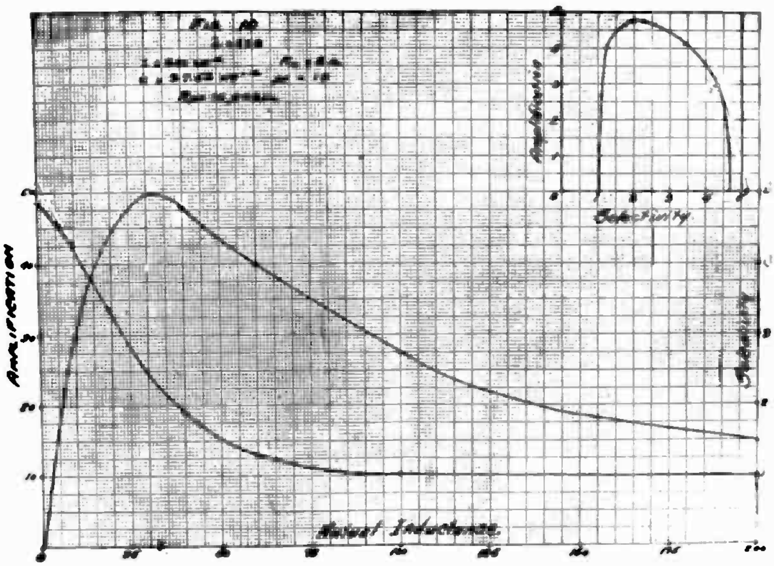

Figure 10

be given. The separate equations (17) and (18) were used in deriving the majority of these curves. In determining the selectivity, K_1 of (18) was calculated on the assumption that the interfering station was 10 kc. off resonance.

The first three curves, Figs. 10, 11 and 12, show the amplification and selectivity curves of a variable condenser tuned stage of radio frequency amplification. The inductance and resistance values chosen are typical of a very good transformer. The average receiver uses less inductance and often has several times 8 ohms in the circuit. These values were chosen to show how poor the selectivity factor is even with such an optimum practical case. Mutual inductance is used as the independent variable, it being customary to vary the primary turns to obtain a desired amplification or selectivity. In the corner of the curve sheets is an insert curve of amplification against selectivity. The important point to make here is that with the chosen coil and secondary resistance, every circuit condition *must lie on this curve!* No trick arrangement of capacity or inductance coupling or combination can serve to change the relationship between selectivity and amplification.

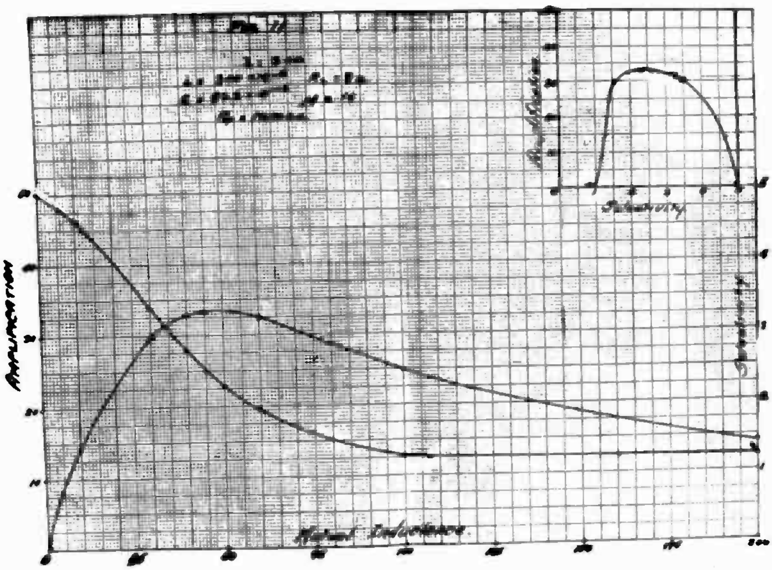

Figure 11

As selectivity is necessary in this type of receiver, a mutual below the optimum value is necessary. Thus in Fig. 10, a mutual of 10 microhenries might be chosen giving an amplification of 30 and selectivity of 4.2. With this fixed mutual the amplification and selectivity are as follows:

	Amplification	Selectivity
200 M	30.	4.2
300 M	14.5	4.6
600 M	4.0	4.8

Take another case. Assume that it is necessary to maintain a constant selectivity. Then we might have

	Amplification	Selectivity
200 M	42.0	3.5
300 M	29.0	3.5
600 M	15.5	3.5

Or again, assume that some coupling method is used whereby the amplification is constant. The maximum amplification of the 600-meter signal must be the limiting value. Taking approximately this as the constant amplification gives

	Amplification	Selectivity
200 M	16.0	4.6
300 M	16.0	4.5
600 M	16.0	3.1

The choice of the three methods depends on the class of the set and the difficulties involved in applying the method.

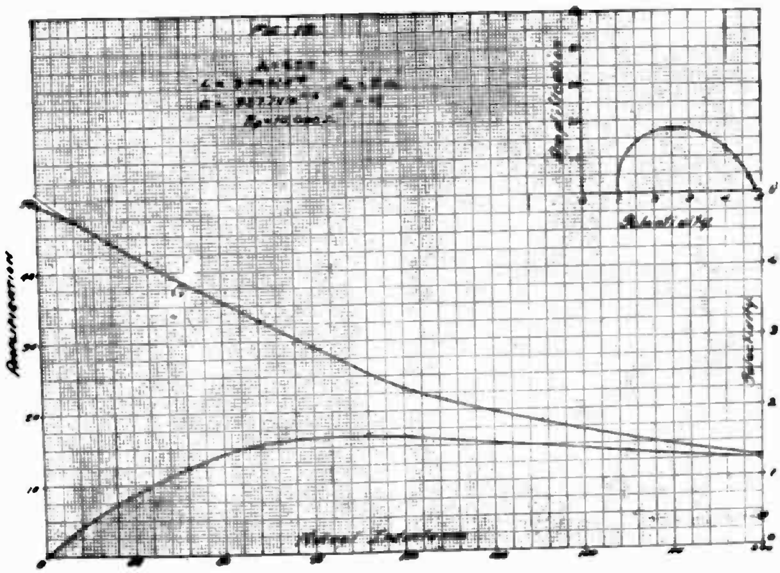

Figure 12

The first method, i. e., constant mutual, is the one which most set manufacturers have been using as it is the simplest. Recently several methods approaching the case of constant amplification have been placed on the market. A compromise between increased amplification and decreased selectivity seems to be the logical outcome of such developments.

Another interesting series of curves are given in Figs. 14, 15 and 16. Here the tuning capacity is left fixed and the secondary inductance varied to resonate the circuit. As it is harder to build a low resistance variometer than a single coil, the secondary resistance was chosen as 20 ohms. Primary inductance is chosen as the independent variable in this case, as the changing mutual with change in secondary inductance would not illustrate the usual case clearly.

With this method of tuning both the amplification and selectivity increases with increasing wavelength. A combination of inductance capacity tuning might prove ideal so

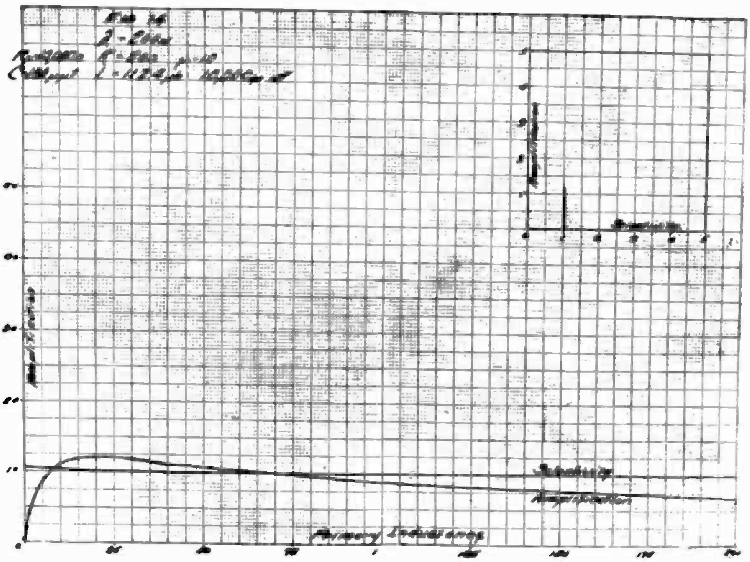

Figure 14

far as present tuning methods are concerned. No tables are offered from these curves as the curves themselves can be read with sufficient accuracy to give any desired information.

Data for amplification and selectivity have been obtained for many other cases and checked experimentally, but the essential facts are given above. Anyone interested in a specific case can substitute his values in Equations (17) and (18) and quickly determine the curves.

The discussion thus far has considered only the relation between selectivity and amplification. As was pointed out in the introduction, the quality of reproduction is affected by these other variables and must also be considered. There are several factors which affect the quality, each by a different amount. The major factor is that produced by the non-uniform amplification of the desired side bands.

In this discussion, percentage quality is defined as the area below the response curve and between the side band limits, divided by the area of the rectangle whose length is given by the maximum amplification and whose width is the side band separation. This meaning of quality assumes that all frequencies between the two side bands are present, and

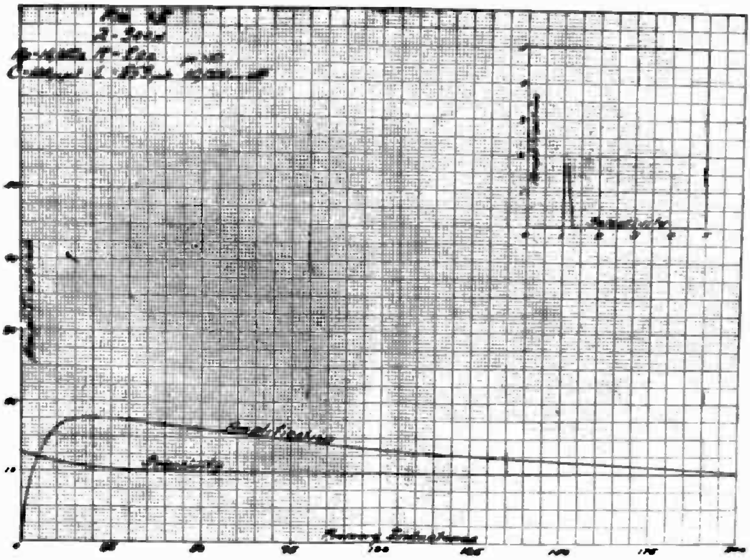

Figure 15

that the energy at each frequency is of equal importance. This may be too severe a restriction as undoubtedly some of the higher audio harmonics can be dropped without materially affecting the quality as perceived by ear. There seems to be no logical basis for making any other method of quality measurement involving a frequency spectrum, and it is to be hoped that some such method can be universally adopted. It might be preferable to plot both the amplitude and the side band frequencies (on both sides of resonance as a base line) in logarithmic units and measure the area in the customary square units. In any case, a fair definition of quality seems to be the area of the received frequency spectrum divided by the area of the ideal frequency spectrum having the same maximum amplification.

In a tuned radio frequency amplifier the grid to grid voltage amplification is increased in two places. First in the tube acting as an amplifier and second in the step up ratio of the transformer. The tube amplification will vary with frequency, depending on the impedance of the plate circuit. The transformer step up ratio is independent of frequency (assuming 100% inductive coupling only). Therefore in

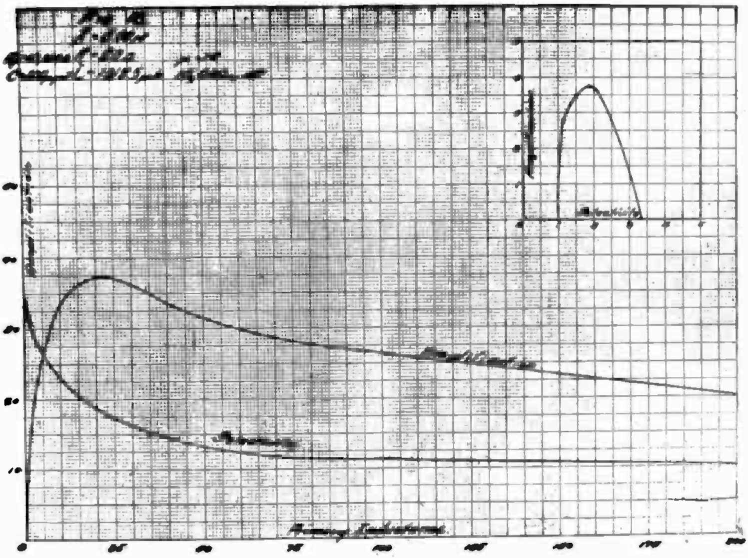

Figure 16

calculating selectivity the variable tube amplification only was used. The term B of Equation (8) (times μ) represents the tube amplification only. The complete amplification per A, is

$$A=\mu BN \tag{21}$$

all terms having been defined.

Substituting in (21) for B, and $N=\left[\frac{L}{M}\right]$ and in B substitute $R_a=N^2R_p$ which gives

$$A=\mu\sqrt{\frac{\left[\frac{M}{L}\right]^2}{\left[\frac{1}{\omega L}-\omega C\right]^2R_p^2+\left[\frac{M^2}{L}+\frac{R_p}{Z}\right]^2}} \tag{22}$$

Two series of curves are plotted using the values derived by equation (22). The first series, Fig. 17, is for the case of three variable resistance tuned circuits, of 5, 10 and 25 ohms respectively. The mutual inductance in each case has been adjusted to give the optimum amplification at the chosen resonant frequency of 1,000,000 cycles.

To determine the quality of a given circuit the area beneath the resonance curve might be found by integrating equation (22). This leads to an almost hopeless mathemati-

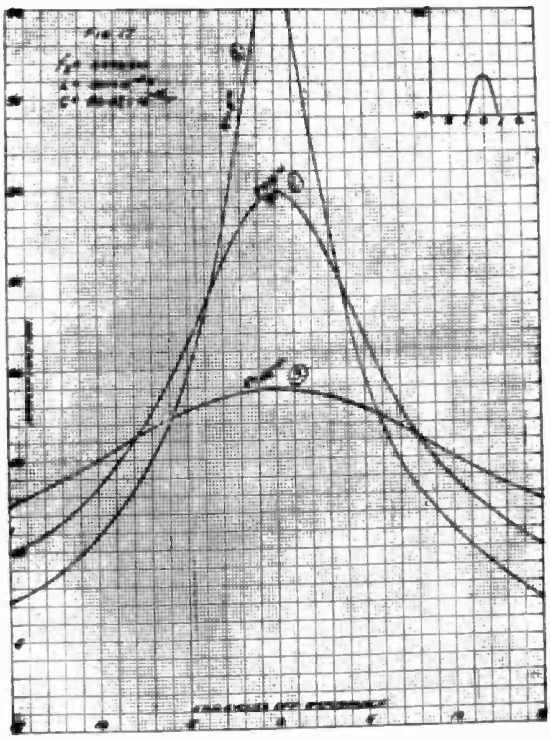

Figure 17

ca tangle, and an expression whose meaning cannot be clearly understood. Accordingly the areas involved in the measurement of quality were measured with a mechanical integrator, the plainimeteer, between the limits of 5000 cycles each side of resonance.

Other factors measured from the curves were selectivity and per cent. interference. The area between 5000 and 15000 cycles off resonance, corresponding to the chosen side band limits of the next broadcasting station, is a measure of that station's interference. The ratio of the area of the desired station's signal (actual case, not ideal) to that of the interfering station is a measure of the selectivity of the circuit. In the tables following this selectivity factor is called S_A, as it is based on the respective area. The selectivity factor as defined in the first part of this paper, i. e., the ratio of the resonant frequency signal to that 10,000 cycles off reso-

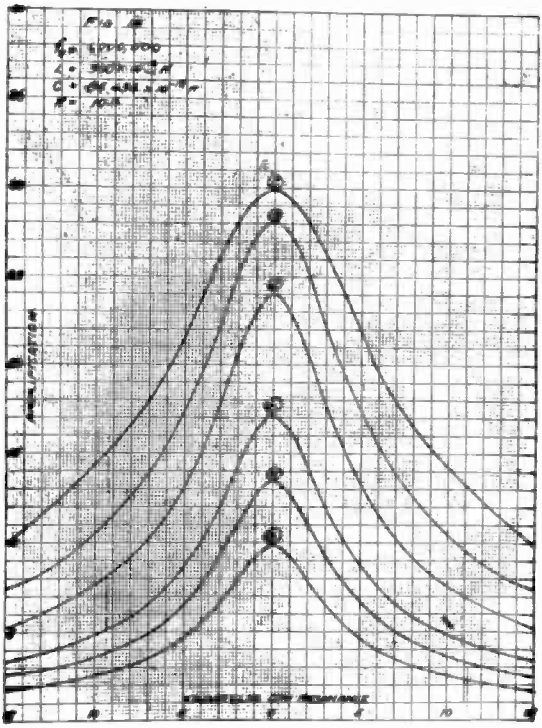

Figure 18

nance is called S_0 as it is based on respective ordinates. It is obvious that S_0 will be larger than S_A. S_A is approximately S_0Q where Q is the per cent. quality, or quality factor as previously defined.

As the circuit is made sharper, both the interference and the quality decrease. The ratio between quality and interference is also given in the tables. Notice that for a given resistance circuit the ratio does change much with M, although increasing both with decreasing R and increasing number of stages.

The second series of curves are those with a constant secondary resistance and varying mutual. Some of the values of mutual were chosen simply to make the amplification of the product stages equal.

Several curves were made of product stages and the data given were calculated from the shape and area of these curves. The curves themselves are not given as they would add nothing to the discussion.

TABLE 1. (Fig. 17)

Curve No.	Max. Amp.	M.	R_s	Q%	I%	Q/I	S_A	S_o
1	42.2	35.7	5	73.1	29.6	2.47	2.7	3.8
2	29.8	50.8	10	89.2	54.8	1.63	1.8	2.1
3	18.8	79.6	25	98.0	82.0	1.20	1.2	1.2

TABLE 2. (Fig. 18)

Curve No.	Max. Amp.	M.	R_s	Q%	I%	Q/I	S_A	S_o
2	29.8	50.8	10	89.2	54.8	1.63	1.8	2.1
4	28.1	35.8	10	84.0	46.9	1.83	2.1	2.7
5	23.8	25.4	10	79.4	42.9	1.85	2.3	3.1
6	17.1	16.1	10	75.9	40.6	1.87	2.5	3.5
7	13.5	12.1	10	75.0	39.5	1.90	2.5	3.6
8	9.8	8.6	10	74.8	38.5	1.94	2.6	3.9

TABLE 3

Curve No.	Obtained By	Max Amp.	Q%	I%	Q/I	S_A	S_o
9	6 x 6	293.	63.0	16.7	3.77	6.0	12.2
10	4 x 8	293.	67.0	21.9	3.09	4.6	7.8
11	5 x 5	567.	66.0	18.5	3.17	5.4	9.6
12	1 x 7	568.	58.8	14.8	3.97	6.7	13.5
13	5 x 5 x 5	13.144.	55.6	8.7	6.38	11.6	28.8
14	5 x 5 x 5 +2000 . 0 and −2000 . off resonance	10.000	64.0	10.6	6.04	9.4	22.0

The curve 14 of Table 3 is very interesting. This was made with the first stage tuned to 2000 cycles above the signal frequency of 1,000,000, the second stage was resonant and the third stage was tuned 2000 cycles below resonance. This corresponds to a capacity variation of approximately 4%, about that value to which most good variable condensers are held. The surprising thing is the fact that this curve is so little different from that of 13, where all stages are resonant. Apparently such a variation does not seriously affect the general characteristics.

It would be unwise to leave the subject of selectivity without some mention of regeneration, for regeneration has long been considered one of the most satisfactory means of increasing the selectivity of a tuned radio frequency amplifying circuit. If it is assumed that all of the vacuum tube parameters are constant or linear functions of the grid voltage, it may be shown that the power fed back by the tickler is equal to that which would be drawn from the amplifier tube ahead if the tuned circuit resistance were

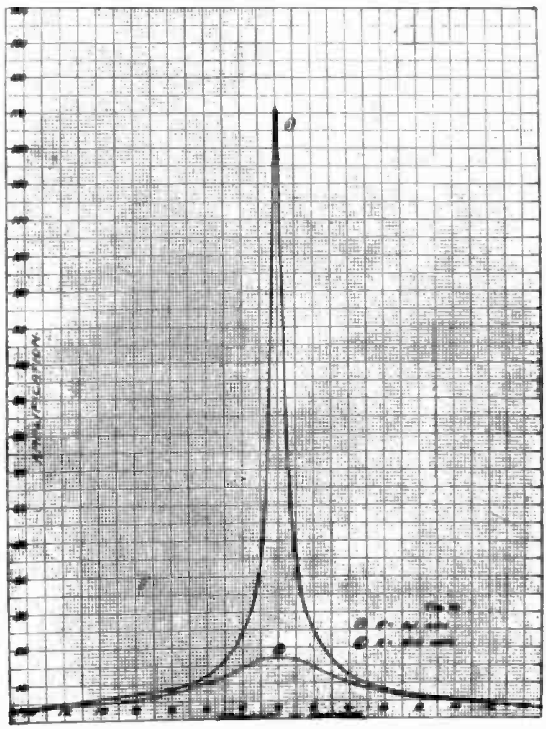

Figure 19

lowered. This fact has lead to the conception of regeneration as "negative resistance". It must be emphasized that the only basis for considering regeneration as the introduction of negative resistance into the tuned circuit, lies in the truth of the above assumption. This assumption is far from true when the "negative resistance" approaches the positive resistance in value. However, at values of "effective resistance" large with respect to infinitestimal values, certain calculations may be made without appreciable error.

A resonance curve for the case of Curve No. 6 where the effective resistance has been reduced to *0.1* of an ohm is plotted in Fig. 19. Notice that the low resistance of the secondary (constant mutual in both cases) does not produce *decreased* interference, but only an *increase* in signal amplitude, particularly in the range close to resonance. This of course increases the selectivity factor as previously defined, but also hurts the quality. These facts may or may not help the receiver, depending on other conditions.

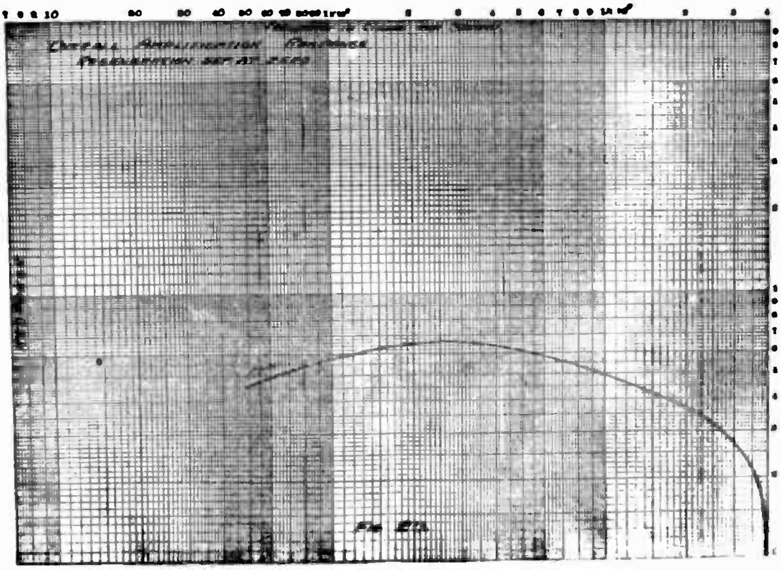

Figure 20

Two other points should be considered as affecting the quality. The first is the phase shift of the side bands as they pass through the amplifier. The peak of the "beat" between the lower side band and the carrier will not coincide with the "beat" between the upper side band and the carrier. If the receiver is tuned to resonance, these audio beats are symmetrical with the resonant period and add to give a single peak which is identical in phase but decreased slightly in amplitude from the original. If the receiver is not tuned to resonance the audio components will be shifted slightly with respect to each other, but as shown by Fletcher and others, a phase shift of as much as a cycle does not seem to affect the ear. The phase shift can therefore apparently be neglected as affecting quality.

The second factor is the transient response of the circuit. The previous equations dealt only with a constant amplitude, continuously applied frequency. In broadcasting, the amplitude variation of each single frequency must be followed. If the decrement of the receiver is too low, the grid voltage will not be able to follow the amplitude variations of the signal. This problem has been considered in detail elsewhere and will not be stressed here. A typical case where $L = 300 \times 10^{-6}$ *hy*, and $R_s = 10$ *r* was calculated and (neglecting additional damping of coupled plate resistance) it was found that only *0.00014* seconds were required to reduce the grid voltage to 1% of its original value. The additional damping of the coupled plate resistance brought this time down to about *0.00010* seconds, corresponding to a variation frequency of 10,000 cycles. As an alternating frequency current cannot well change in amplitude faster than its own frequency, and the lower limit shown above is approximately 10,000 cycles, the quality of present day receivers will not be much affected by this factor.

A consideration of the three factors of amplification, selectivity and quality leads directly to an old problem of design. Shall each step or unit in the instrument be as near perfect as possible to make it, or shall one unit attempt to compensate for the deficiency of another? Many arguments can be advanced both ways. Certainly the ideal way would be to have each unit perfect in itself. Is this possible commercially?

Fig. 20 shows the most interesting curve in this whole paper. The curve is the response curve for a well known 5-tube receiver, incorporating two stages of radio frequency amplification, a regenerative detector and two stages of audio frequency. The tuned circuits were designed, principally by adjusting the secondary resistance and transformer mutual inductance, to be quite selective and still maintain good amplification. The audio transformers were somewhat better than the average, although beginning to fall at 200 cycles and falling very rapidly below 90 cycles. Above 200 cycles, the audio transformer curves were practically flat to 6000 cycles and then rose slightly to 9000 cycles where they cut off sharp.

The regeneration was not critically adjusted, yet served to keep the amplification at low frequency (at least to 40 cycles) very good. Here was one case where peaked radio frequency amplification compensated for poor audio amplification. However, the sharpness of the radio frequency stages began hurting the audio response curve at about 500 cycles. At 2000 cycles the response falls very fast and at 4000 cycles no signal was obtained. The beautiful "flat" transformer characteristic above 500 cycles was absolutely useless. Considering 5000 cycles as the side band limit, the audio transformers should have had a peak at about 4000 cycles.

This discussion shows that even the audio transformers affect materially the selectivity of the receiver, and based on present ideas in set construction and present type selecting circuits, *should never have a flat top characteristic.* This point cannot be too strongly emphasized, for if we do not make *each* unit of our receiver almost perfect, there is no logic about only making one unit perfect. It is better to make one unit compensate for another, including everything from the antenna to the reproducing unit. This has always been the commercial way of getting results desired in the quickest time, and considering the engineering handicaps is often the best way.

However, in the long run, the ideal way will prove the best; that of making each unit perfect. How shall this be done? If the answer were known it would be done now. One statement is clearly true, however. In the ideal receiver, selectivity, amplification and quality will be absolutely independent. Selectivity may come through properly designed band pass filters. Amplification will be easily controlled by the operator and independent of frequency. With true aperiodic amplification, no phase distortion and high decrement pickup circuits, quality will be perfect. The road ahead of the radio engineer striving to build the ideal receiving set is long and hard.

RADIO PHENOMENA RECORDED BY THE UNIVERSITY OF MICHIGAN GREENLAND EXPEDITION—1926

By

P. C. Oscanyan, Jr.

(In Charge Expedition Radio)

Radio, and especially short wave radio, has found its place in the plans of almost every expedition which has left the United States within the past year, and because such radio equipment is being carried into the more or less inaccessible places of the world we are learning that the explored places are, in many cases, different from what we had expected.

The University of Michigan Greenland Expedition of 1926, directed and led by Prof. W. H. Hobbs, was the Expedition of which I was a member and in charge of radio. The Expedition went in search of meteorological data, to lay down a base station for work in 1927, and, in connection with the latter work, to determine a proper location for a short wave radio station to communicate with the Schooner Morrissey and the United States.

A base camp site was selected some 50 miles East of Holstensborg, on Maligiak Fiord, North of the Arctic Circle, Reference to the photograph will show that the camp was situated in the center of a natural bowl-like valley and it was close to the location of the tents that the radio station was first set up. Take careful note of the figures which are written in above the various high points which surround the camp.

At this point it is necessary that we digress for a moment. Last spring John L. Reinartz, in a speech before the A. R. R. L. Convention in New York City, brought to our attention, for the first time, the fact that when a radio receiving station which plans to work on wavelengths of 50 meters or below is placed at the foot of a hill or mountain which is of a height greater than 17 degrees from the horizontal of the station, then signals will be screened off from the receiver.

It was with a view to testing this that the station was first established at that point. The results were so prompt that they were thoroughly convincing. In order that we might be doubly sure of the height of these high points we

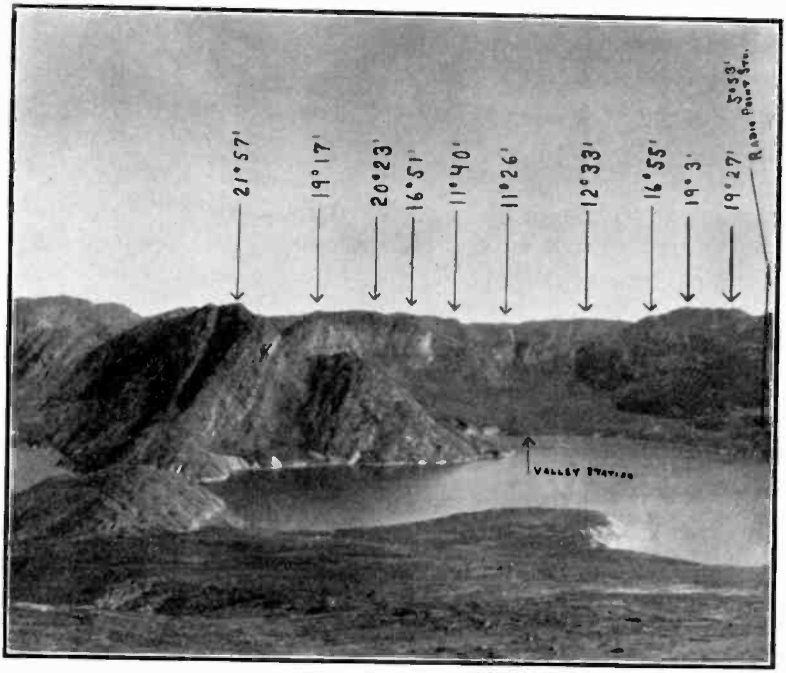

Photo by Prof. L. M. Gould

Figure 1. Figures and arrows indicate heights of hills surrounding the station in the valley.

(Mr. R. L. Belknap, Expedition Surveyor, and I) checked them with a theodolite which was placed midway between the mast and the receiving set, a matter of some 25 feet. The angles given in the illustration are the angles thus obtained.

Finding ourselves screened off from signals coming from the North, thus being cut off from the vessel which had taken us up and was to take us back after making arrangements by radio, and also being cut off from all but the most powerful short wave stations in Eastern and Central United States another location less sheltered was determined upon for the radio station. It is interesting to note here that in all probability due to the clearing effect of the screening, high points stations in the western U. S., in an unscreened direction from us, and stations in Europe and even New

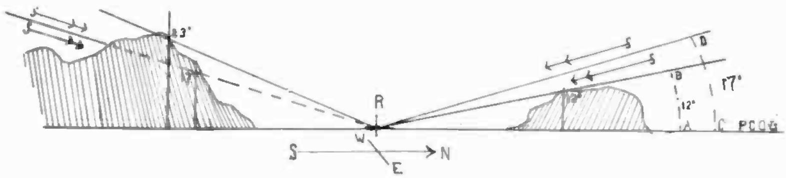

Figure 2. Outline illustration of method of obtaining angles and the blocking of signals by the surrounding territory.

Zealand, also in an unscreened direction, were logged having good strength whereas when our later location was reached these signals were, in all probability, drowned out by signals from stations closer by.

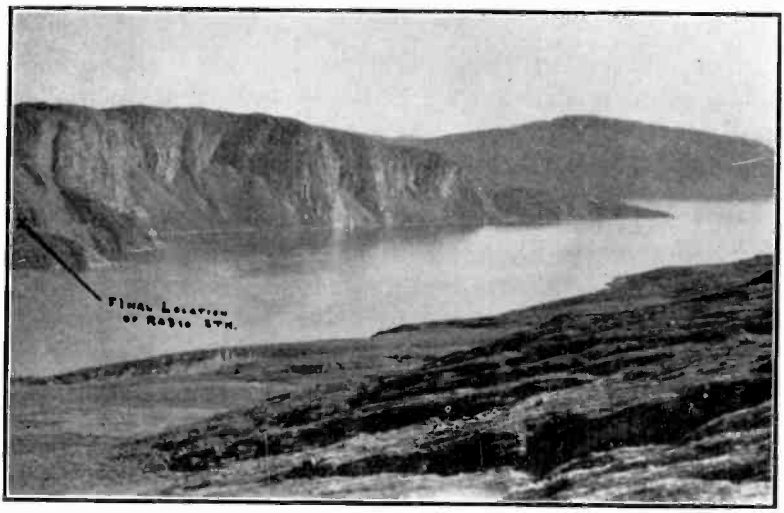

Photo by Prof. L. M. Gould

Figure 3. Cross at extreme left indicates location of Station on Point of land 400 ft. high and projecting out into fiord.

Relocating our station at point B, named Radio Point, gave a prompt and satisfying return to what would be the normal condition expected for that locality. It would also appear that static in that part of the world is the overflow from the more harassed lower latitudes, it not being present in sufficient quantity to cause notation in my log until after we had shifted our station to the higher point.

Another interesting point of note is that the distance within which "brute force" signals may be heard is greatly increased at sea. By brute force signals, I mean the signals which may be received from a short wave transmitter within a limited area surrounding the station. The radiated waves which follow the earth or sea surface die out within a comparatively short distance due to absorption.

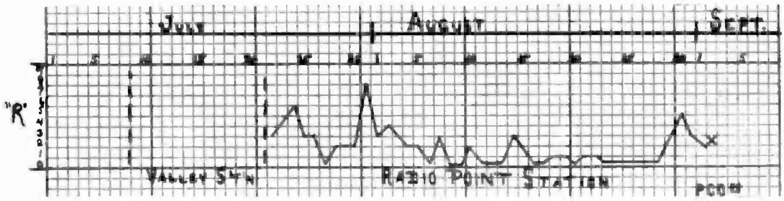

Figure 4

The thing which these experiments bring most forcibly to my mind is that such a critical angle of screening of short wave signals rather sets at odds the theory laid down by Dr. A. H. Taylor that there is a secondary, or even tertiary skip distance. The angle at which these short waves are screened out, points, as Mr. Reinartz has shown me, to the angle of refraction of light on pure water.

Now it is a known fact that dry air is heavier than moist and that as we ascend in the atmosphere there is more and more moisture present so that when the level of the cirrus cloud is reached we find that they are moisture frozen to minute ice particles, (such at least is the general condition). It is also true that this moist band of atmosphere experiences a diurnal change and is higher at the equator than at the poles, all of which would seem to point to the hypothesis that, if this 17 degree angle is at all significant it would warrant the assumption that high frequency radio signals are reflected by this moist and ionized upper atmosphere.

If the foregoing is true, then it would seem that unless the signal struck a reflecting surface of like character, when it reached the earth, it would never be sufficiently reflected so that it might rise again through the atmosphere to the Kennelly-Heaviside layer with sufficient strength to permit it to again appear at another point on the surface of this earth.

The popular idea that there is no static in the Arctic will receive a setback when the static audibility graph given herewith is consulted. I would greatly appreciate it if any

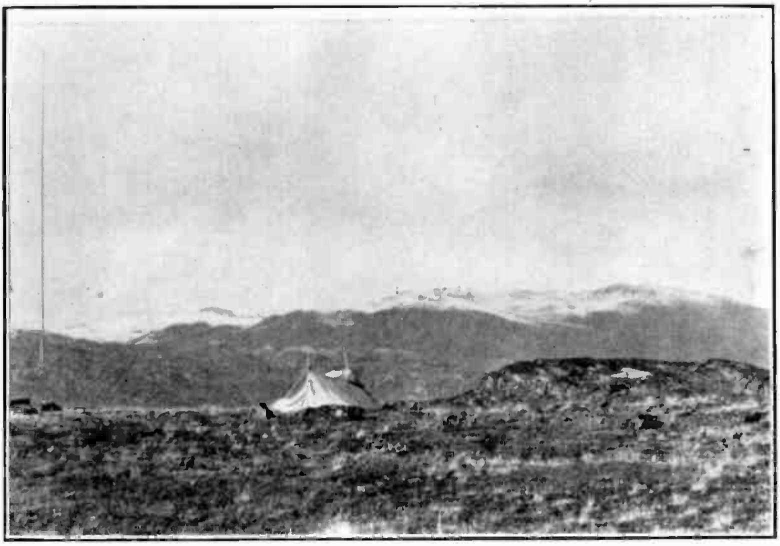

Photo by Prof. L. M. Gould

Figure 5. Radio station on the Point. Shelter tent housing apparatus and operator. Mast is sectional bamboo 35 ft. high. View N. W.

among those who read this article can give me any information as to whether the high audibility static on certain dates either precedes, accompanies, or follows, static of the same or greater intensity elsewhere in the world. A comparison of static recordings daily during the period shown would be of great interest to me.

As mentioned before, there is to be another expedition next year and it is planned to remain up there all during the winter of 1927-28. I appreciate that this will be an excellent opportunity for me to cooperate with anyone who wishes to collect comparative data or would like to suggest some particular field of radio for us to explore, since the radio station is to be a part of the expedition all during that time.

The antenna system consisted of a single wire 40 feet long suspended from a sectional bamboo mast 35 feet high. This mast was of 2 inch bamboo and in 5 foot sections, for strength and portability, guyed with stranded antenna wire, Pyrex insulators, and steel tent pegs. The counteerpoise consisted of 3 wires each 20 feet long, No. 14 rubber covered, laid out fanwise on the ground.

Photo by Prof. L. M. Gould

Figure 6. Looking North over the Station on the Point. Shelter tent rolled back to show method of housing and operation.

The receiver was especially made for the expedition by the Burgess Laboratories at Madison, Wis. The transmitter was a homemade one employing two Cunningham CX301A tubes. Using only 200 volts on the plates of these tubes we were able to communicate over distances greater than 1000 miles. The receiving circuit was a modified Reinartz, the transmitting circuit was a shunt feed Hartley. Detector and one step a. f. were sufficient for reception.

PUNCTURE DAMAGE THROUGH THE GLASS WALL OF A TRANSMITTING VACUUM TUBE*

By

Yujiro Kusunose

(Electrotechnical Laboratory, Hunisky of Communications, Tokyo, Japan)

Introduction

Puncture damage through the glass wall has rarely been met with radio transmitting vacuum tubes which are under operation at ordinary long wavelengths. However since short wave radio has recently come into use, frequent occurrence of this damage has been noted, which leads us to suspect the existence of some special causes other than those previously known (such as insulation breakdown of the glass wall or melting of the glass due to high ohmic losses at high temperature.) The causes have been investigated by the writer and are attributed to the dielectric loss in glass, as described below.

Type of Damage

The phenomenon was first encountered at the Hiraiso Branch Office of the Laboratory, when the Marconi valve MT-4 (anode 10 kv. 200 w.) was being used as a short-wave oscillator. That such a damage is due to dielectric loss may be seen from the conditions of its occurrence, viz., (1) the punctures always appear somewhere on the neck of the glass bulb on the side of grid stem, and marks of softening are observed on the glass wall around that part (Fig. 1), which may be considered to be region of most intense radio frequency electric field, and (2) the breakdown occurs at the instant when operating efficiency is high and anode loss rather low.

Theoretical Considerations

In the first place, the matter will be considered from the theoretical point of view and thus it will be found that the

*Received by the Editor, March 14, 1927.

softening of glass is due to dielectric loss. When a tube is oscillating, the anode and grid voltages are always opposite in sign, and therefore radio frequency alternating potential difference amounting to 10 kilovolts may exist between the two electrodes. Assuming the distribution of electric field built by the potential difference as depicted in Fig. 2 which

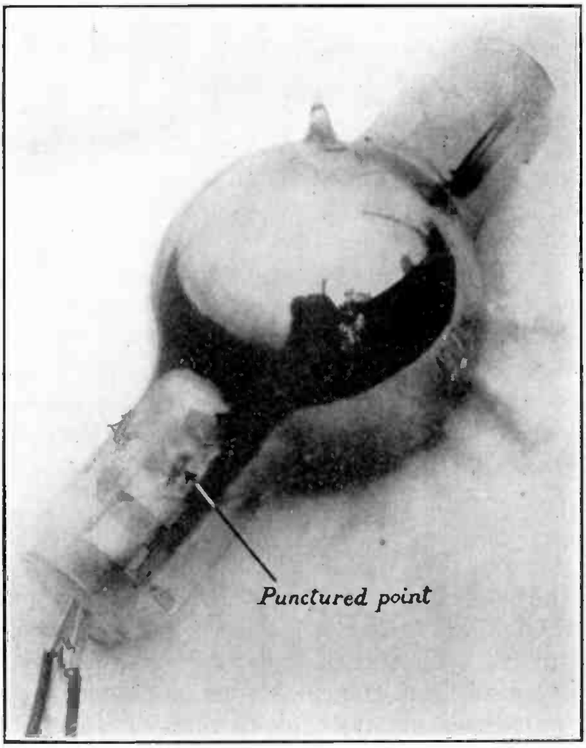

Figure 1

shows the construction of above mentioned valve MT-4, the most intense field may be supposed to exist around the neck of the bulb marked *b*, and is calculated to be of the order of 1 kv./cm.

The dielectric loss in glass as approximately

$$W = k\,F^2 f \qquad watts/cm^3$$

where F is the field strength in kv./cm. mentioned above, f the frequency in kilocycles, and k the factor depending on the material. The value of k for lead glass as used in the valve MT-4 has been found to be $k=19\times10^{-6}$, and assuming $f=15\times10^{3}$ *kc.* ($\lambda=20m.$) the loss at the above-mentioned part of the glass wall may be calculated from the formula to be 0.36 watt/cm³. The thickness of the glass being 0.17

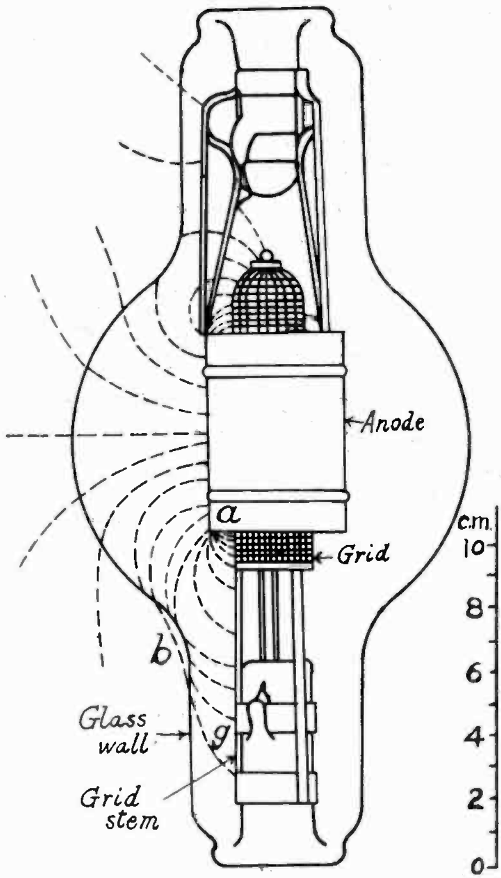

Figure 2

cm., the loss per unit of surface area becomes 0.061 watt/cm².

The temperature rise on this part of glass wall may be roughly estimated in the following manner. Under full load conditions, the valve MT-4 consumes 80 watts in the filament and dissipates 200 watts in the anode, and thus 280 watts in total are radiated as heat through the whole glass surface of 450 cm²; i. e. 0.62 watt/cm² is radiated in average. Assuming the fraction of the heat to be absorbed by the glass out of the radiation to be 20%, 0.12 watt/cm² will be lost in the glass. Actual observation under the same load condition has shown that the temperature of the glass wall reached 100 to 160°C.

Now that a dielectric loss of the order of 0.06 watt/cm² is added to the above under conditions of short wave opera-

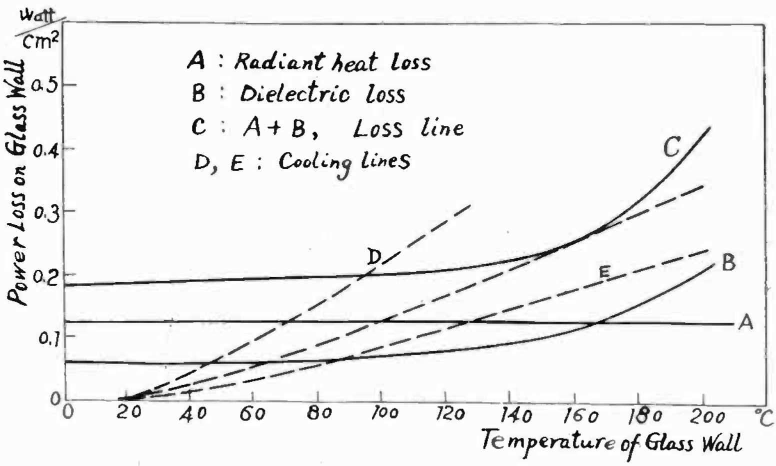

Figure 3

tion at full load, the final temperature may be estimated to reach 200°C or thereabout. This is, however, somewhat lower than the softening point of the glass (about 400°C) and cannot, therefore, explain the damage.

The above reasoning is based on the assumption that dielectric loss is independent of temperature. But this may not be the case; and therefore the variation of the factor k with temperature has been observed and the following results were obtained which show that the dielectric loss increases very rapidly with temperature at the higher temperatures.

Temp.	20	60	100	140	170	200	°C
k	19	20	24	31	43	69	$\times 10^{-6}$

From these measurements the softening of the glass may be explained in the following way. In Fig. 3 the abscissae represent the temperatures of the part of the glass wall under consideration, and the ordinates the amounts of power loss that take part in heating the glass. The heat radiated from the electrodes and absorbed in the glass is independent of temperature, and may be represented by a horizontal line A (0.12 watt/cm^2.)

The dielectric loss in the glass is 0.06 watt/cm^2 at room temperature, but increases with temperature in proportion

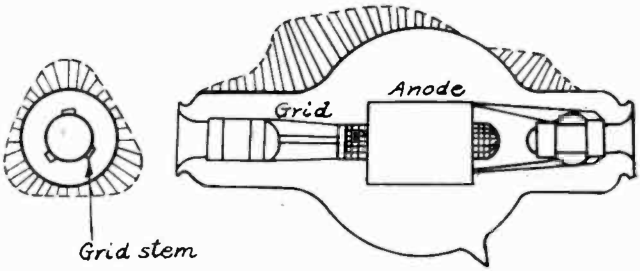

Figure 4

to the value of k in the above table. This may be represented by a curve B. Thus the total amount of power heating the portion of the glass is the sum of A and B which makes the "loss line" C.

On the other hand, the amount of heat which escapes from the glass wall increases with temperature. The dotted lines which are nearly straight represent these "cooling lines". The less effective the cooling, the less will be the inclination of the line.

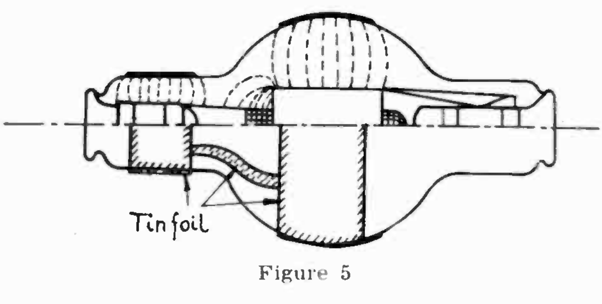

Figure 5

The final temperature reached by the glass is then indicated by an intersecting point of the "loss line" with the "cooling line", as shown D in Fig. 3; but if cooling is so poor that the "cooling line" does not at all meet the "loss line" such as E in the figure, the loss in the glass is by no means fully dissipated and the temperature rises indefinitely, and softening or melting of the glass eventually takes place. As a consequence of this cumulative effect and the lack of uniformity in heating and cooling of glass, some part of the glass begins to melt, which results in a puncture because of external air pressure.

EXPERIMENTS

1. The valve MT-4 was suspended horizontally and a radio-frequency voltage of 5,000 V. at 2,500 kilocycles was

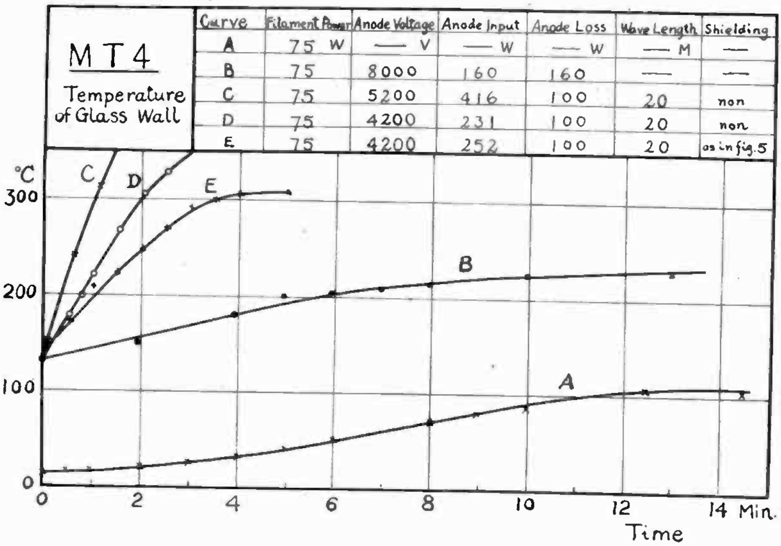

Figure 6

applied between the anode and grid, the filament not being lighted. The temperature of the glass bulb increased and finally attained the distribution illustrated in Fig. 4, the temperature around the neck of the bulb being the highest and reaching about 100°C. When the bulb was shielded by two sheets of tin foil connected electrically as shown in Fig. 5, no heating of this part could be perceived.

2. The same valve was put into operation as a short wave transmitter, and the temperature at a point on the neck of the bulb was measured. The data are plotted in Fig. 6. When the tube was oscillating at short wavelengths, the temperature rose quite high and sometimes had a tendency

to increase rapidly, even beyond 300° C, which would indicate the likelihood of damage resulting from continuation of operation.

Prevention of Damage

As the cause of the damage has been found to be the dielectric loss in glass, it is simply remedied; and a knowledge of the causes of puncture will also be helpful in securing high efficiency of operation.

The methods of prevention may be summarized as follows:

A. On operation of the tubes:

1. Thoroughly cool that portion of the glass wall which is likely to be exposed to intense radio-frequency electric fields.
2. Shield the glass wall electrostatically so as to prevent any portion of it from being exposed to an extremely intense electric field.
3. Carefully support the tube so that no part of supports may prevent meeting the above conditions.
4. Lower the anode voltage and output load from the rated values suitable for operation at long wavelengths to values which will keep the temperature of the portion within safe limits.

B. On designing of the tubes:

1. Use low-loss and heat-resisting material for the bulb.
2. Choose such shapes of the bulb and electrodes that strong stray electric field may not reach the walls.
3. Electrostatically shield the electrodes so as to avoid stray electric fields extending to the glass wall.

C. On manufacturing the tubes:

Continue evacuation of the tube after the usual bombardment, operating it meanwhile as a short wave oscillator.

DISCUSSION ON FIELD DISTRIBUTION AND RADIATION RESISTANCE OF A STRAIGHT VERTICAL UNLOADED ANTENNA RADIATING AT ONE OF ITS HARMONICS* (S. A. LEVIN AND C. J. YOUNG)

O. C. Roos: Two names stand out in the early work on antenna radiation at shorter than fundamental wavelengths: John Stone Stone of Boston, and F. Hack, a German. Since neither of these early investigators was mentioned in the paper of Messrs. Levin and Young in Vol. 14, No. 5, of the Proc. of the I. R. E., the present memorandum is undertaken as a contribution to the history of the early aspects of the subject.

Stone was the first investigator to study the radiations of a simple ungrounded antenna, taking into account the image of this antenna. In doing this he introduced the then comparatively new operational method of handling differential equations, discovered by Oliver Heaviside, from whom he received a grateful letter of thanks.

I had the privilege of reducing the latter part of this work to a form suitable for engineering use and in particular the differential equations for a receiving antenna, first given out at St. Louis in 1904. Their solution in 1907 by myself showed the possibility of the receiver vertical, vibrating at harmonics which were even multiples of 1, 3, 5, etc. As was shown in 1902 by Stone, a transmitter could not vibrate at any even multiple of its fundamental frequency.

The problem of radiation was considered by Stone to be that due to a double sheet of oscillating current elements of different length. One sheet was below the ground and was the image of the other. This was the first treatment of an oscillating Hertz "image" and was made public in the Electrical Review of October 15, 1904 and applied publicly on July 4, 1908 in a "Review" paper on "The Resistance Equivalent of Radiation."

*Received by the Editor November 2, 1926

In this paper the field at a distance of 200 or more wave-elngths, was obtained as is shown in Fig. 1.

In Fig. 1-A we have a Marconi wire a-t as a simple radiator driven at the base by a radio frequency alternator with one lead grounded. The frequency is 3/2 of the fundamental, hence a quarter wave is 2/3 the antenna height or c-t.

If the current at the base is called unity and is proportional to the horizontal a-b, then the maximum current at CD is proportional to cosecant 2/3 of 90 degrees or csc

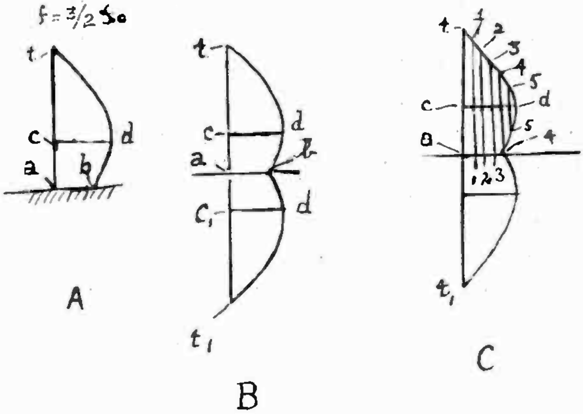

Figure 1

60 degrees. It is 1.16 approximately or 16% greater than the current at the base of the antenna.

In Fig. 1-B both the Marconi wire and its image a-ti are shown with their identical current distributions—both positive or adding their effects in producing radiation. However, at a great distance from "a" these effects are assumed quite practically, to be equal.

The field strength at a distant point is nearly doubled by the image and hence the mathematical determination of this field can be carried on by considering the current solely in the real Marconi wire and not in its image also.

By taking the energy flow at any point above ground, we quadruple it to get the total energy flow due to the Marconi wire and its image, since doubling the field quadruples the energy but the assumed perfectly reflecting and therefore isolating earth surface, halves this amount. This treatment of course, fails, close to the antenna, between say 1/4 wavelength and 10 wavelengths, but these distances are of no importance.

Stone and myself treated the Marconi wire as an unlimited number of Hertz "doublets" each carrying the same infinitesimal current element "*di*" but each one having a length proportional to the ordinate of the current curve 4-d-t at any point along a-4 in Fig. 1-C. This figure is shown for simplicity with 6 current elements, each having a value

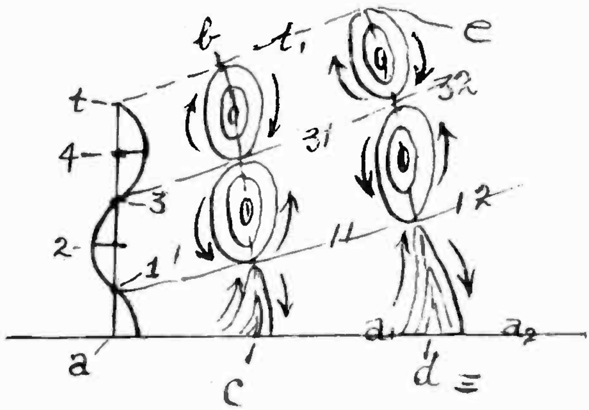

Figure 2

of 1/4 of the unit current a-4 at the base of the Marconi wire.

The "length" of these currents as compared to the Marconi wire length a-t is given by the average of a-t and 1-1, 11-22, 22-33, 33-44, 44-55, 55 and the average of 55 with zero. Integrating an infinite number of these "current doublets" we had an oscillating "current sheet", composed of an infinite of oscillating undamped current elements of length from 0 to the full height of the Marconi wire.

By dividing the field produced at a distant point as a result of the action of all these "elementary" oscillators by the unit current we got the average field strength produced by a single Hertz doublet with unity current and height equal to that of the Marconi wire. This is the concept known as the "effective height" of an antenna.

Where Stone differed from recent mathematicians in treating these higher frequencies, is in the fact that he did not contemplate current excitation at a loop of current or voltage excitation at a loop of potential by external means. All transmitter excitation was calculated on the basis of forced continuous wave voltage at the antenna base.

In embodying his work in 1905 and 1906 on practical receivers, I discovered that on the above basis of operation a transmitting antenna had infinite resistance as well as infinite reactance at even multiples of the fundamental frequency, since the current maximum was theoretically

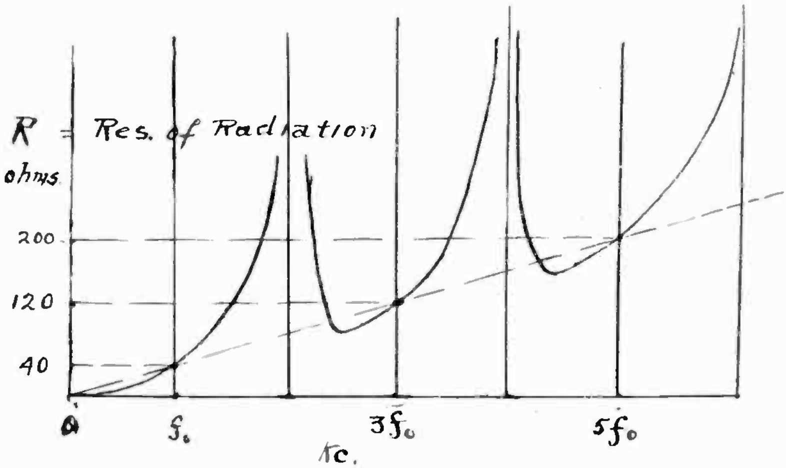

Figure 3

without limit relative to the antenna current at the base at such frequencies—if increased voltage was available to keep the base current constant. This made antenna resistance a periodic function, under the conditions above given.

When the frequency is an odd multiple of the fundamental value, the resistance equivalent of radiation becomes a simple odd multiple of that at the fundamental, e. g. 40-120-200 etc. ohms approximately, not allowing for azimuthal effects, as these were of no interest then. We had not then learned to "carom" on the electron cushion of the radio vault in order to play "celestial billiards"—in skipping oceans and lesser obstructions.

Hack's Work

Coming now to the upper multiple frequencies of the Marconi wire, such as the 5th etc. we find interesting factors bearing on Messrs. Levin and Young's paper. Reference may be had to *F. Hack, Am. Phys. Band 14, p. 539, 1904 and Band 18, p. 634, 1905*, for details of Hack's work.

What Hack showed was that in a Marconi antenna, as shown in Fig. 2—vibrating at its quintuple "free" or unloaded frequency—we have 2 complete sets of "free" waves from the segments t-3 and 3-1 respectively and a half of sliding wave from the segment a-1. From the properties of the electromagnetic field these "contacting" waves mutually repel each other and the top ones are forced further upwards on their way outward.

What is interesting to consider is this: Since these partial but self-sustaining harmonic radiations do not merge into each other, their energy equivalents should be expressed at the antenna base by a system of purely additive scalar resistances. In other words, if the resistance equivalent of the segment 1-a which is at its fundamental or "free" frequency—is about 40 ohms, then both segments 1-3 and 3-4 add 80 ohms respectively to the radiation resistance, making a total of about 200 ohms at a distant point near the equatorial or earth plane.

This seems to sustain my point of view in the July 4, 1908 Radio Review article that with constant current at the base the resistance equivalent of radiation varies with frequency approximately as the ordinates of Fig. 3.

It may be possible to bring to light these old records with Mr. Stone's permission. These results with Prof. Howes' recent work along the same general lines as Messrs. Levin and Young have so painstakingly worked out may well clear up any discrepancies which appear in tests of these theories.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELPHONY

Issued Jan. 4, 1927—Feb. 8, 1927

By

JOHN B. BRADY

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

1,612,835—INTERMEDIATE ELECTRODE IN INCANDESCENT CATHODE TUBE—WALTER SCHOTTKY, Wurzburg, Germany. Filed Aug. 30, 1921, issued Jan. 4, 1927. Assigned to Siemens & Halske Aktiengesellschaft.

1,612,902—RADIOCONDENSER—C. V. BATES, Chicago, Ill. Filed April 16, 1925, issued Jan. 4, 1927. Assigned to Cinch Mfg. Corp.

1,612,952—RADIO RECEIVING APPARATUS—G. H. STEVENSON, New York, N. Y. Filed Aug. 24, 1921, issued Jan. 4, 1927. Assigned to Western Electric Co., Inc.

1,613,032—VARIABLE CONDENSER—C. F. GOUDY, Flushing, N. Y. Filed Oct. 30, 1924, issued Jan. 4, 1927. Assigned to Pacent Electric Co., Inc.

1,613,088—CONDENSER CONTROL FOR RADIOS—W. G. DUNN, Clarinda, Ia. Filed March 3, 1926, issued Jan. 4, 1927.

1,613,333—LOOP AERIAL—J. McW. STONE, Chicago, Ill. Filed Oct. 31, 1923, issued Jan. 4, 1927. Assigned to Operadio Corp.

1,613,503—ELECTRON TUBE—W. DAUMANN, Hamburg, Germany. Filed Jan. 16, 1923, issued Jan. 4, 1927. Assigned to C. H. F. Muller.

1,613,607—COMPENSATING NETWORK FOR CARRIER TRANSMISSION CIRCUITS—H. FLETCHER, New York, N. Y. Filed Sept. 29, 1924, issued Jan. 11, 1927. Assigned to Western Electric Co.

1,613,791—ELECTRON TUBE CONSTRUCTION—M. B. FORRESTER, Philadelphia, Pa. Filed Apr. 11, 1925, issued Jan. 11, 1927. Assigned to J. S. Timmons, Inc.

1,613,612—ELECTRON DISCHARGE DEVICE—ROBERT W. KING, New York City. Filed August 14, 1919, issued Jan. 11, 1927. Assigned to Western Electric Co.

1,613,626—SPACE DISCHARGE SYSTEM—J. J. VAN DER BIJL, New York City. Filed Oct. 30, 1918, issued Jan. 11, 1927. Assigned to Western Electric Co.

1,613,630—VACUUM TUBE—P. M. WATROUS, Jersey City, N. J. Filed Nov. 25, 1919, issued Jan. 11, 1927. Assigned to Western Electric Co.

1,613,709—ELECTRIC SPARK GAP—C. L. A. M. LEBLANC, Paris, France. Filed Apr. 18, 1923, issued Jan. 11, 1927. Assigned to Societe Anonyme Pour L'Exploitation Des Procedes Maurice LeBlanc-Vickers.

1,613,733—RADIO SIGNAL CIRCUITS—A. H. TAYLOR, Washington, D. C. Filed Jan. 7, 1925, issued Jan. 11, 1927. Assigned to Wired Radio, Inc.

1,614,113—ELECTRIC CONDENSER—P. R. FORTIN, Schenectady, N. Y. Filed May 13, 1925, issued Jan. 11, 1927. Assigned to General Electric Co.

1,614,151—ELECTRON DISCHARGE APPARATUS—O. W. PIKE, Schenectady, N. Y. Filed Mar. 2, 1925, issued Jan. 11, 1927. Assigned to General Electric Co.

1,614,428—VARIABLE CONDENSER—F. O. HARTMAN, Mansfield, O. Filed Nov. 5, 1925, issued Jan. 11, 1927. Assigned to Hartman Electrical Mfg. Co.

1,614,458—RADIO RECEIVING SYSTEM—O. E. CURTIS, Pittsford, N. Y. Filed May 3, 1923, issued Jan. 18, 1927.

1,614,459—ELECTRICAL CONDENSER—W. T. DITCHAM, Colchester, England. Filed Apr. 19, 1923, issued Jan. 18, 1927. Assigned to Radio Corp. of America.

1,614,462—THERMIONIC DEVICE—H. M. DOWSETT, Colchester, England. Filed Nov. 12, 1920, issued Jan. 18, 1927. Assigned to Radio Corp. of America.

1,614,481—COLLAPSIBLE LOOP AERIAL—M. MATHIESEN, Chicago, Ill. Filed Aug. 1, 1925, issued Jan. 18, 1927. Assigned to Mathiesen Sandberg Co.

1,614,494—CIRCUIT ARRANGEMENT FOR GENERATING OSCILLATIONS—H. RUKOP, Berlin, Germany. Filed Dec. 27, 1922, issued Jan. 18, 1927. Assigned to Gesellschaft fur Drahtlose Telegraphie.

1,614,671—AUTOMATIC ANTENNA SYSTEM—J. H. HAMMOND, JR., Gloucester, Mass. Original filed July 9, 1920; Division filed Dec. 2, 1922, issued Jan. 18, 1927.

1,614,762—HIGH POTENTIAL ELECTRICAL APPARATUS—J. A. PROCTOR, Lexington, Mass. Filed Dec. 12, 1923, issued Jan. 18, 1927. Assigned to Wireless Specialty Apparatus Co.

1,614,902—VARIABLE CONDENSER—J. SCHOLTZ & G. W. SUNDAY, Philadelphia, Pa. Filed Feb. 13, 1925, issued Jan. 18, 1927.

1,614,990—RADIOSIGNALING ANTENNA SYSTEM—P. O. PEDERSEN, Fredericksberg, Germany. Filed July 21, 1921, issued Jan. 18, 1927.

1,615,093—HIGH VACUUM SPACE DISCHARGE DEVICE AND GAS ACCUMULATOR THEREFOR—F. S. McCULLOUGH, Wilkinsburg, Pa. Filed Sept. 17, 1923, issued Jan. 18, 1927.

1,615,224—CHOKE COIL AMPLIFICATION UNIT—EDWARD E. HILLER, Bloomfield, N. J. Filed Apr. 30, 1926, issued Jan. 25, 1927.

1,615,468—ANTIMICROPHONIC SHIELD FOR ELECTRON TUBES—LESLIE R. McDONALD, Montreal, Quebec, Canada. Filed July 6, 1926, issued Jan. 25, 1927.

1,615,645—COMBINED RADIO SENDING AND RECEIVING SYSTEM—ALEXANDER NYMAN, Wilkinsburg, Pa. Filed July 15, 1920, issued Jan. 25, 1927. Assignee Westinghouse Electric & Mfg. Co.

1,615,808—VACUUM TUBE CIRCUITS—MARIUS LATOUR, Paris, France. Filed Aug. 19, 1921, issued Jan. 25, 1927. Assignee Latour Corporation.

1,615,654—VACUUM TUBE STRUCTURE AND METHOD OF ASSEMBLING THE SAME—M. H. RYDER, of Wilkinsburg, Pa. Filed Nov. 7, 1922, issued Jan. 25, 1927. Assigned to Westinghouse Electric & Mfg. Co.

1,615,660—VACUUM TUBE OSCILLATOR—J. SLEPIAN, Swissvale, Pa. Filed Feb. 26, 1921, issued Jan. 25, 1927. Assigned to Westinghouse Electric & Mfg. Co.

1,615,712—SYSTEM OF NAVIGATION AND PLANT FOR CARRYING IT OUT—W. A. LOTH, Paris, France. Filed Feb. 27, 1925, issued Jan. 25, 1927. Assigned to Societe Industrielle des Procedes W. A. Loth.

1,615,755—LOOP ANTENNA—F. GRAUE, Washington, D. C. Filed Nov. 11, 1925, issued Jan 25, 1927. Assigned to George T. Kemp.

1,615,896—HIGH FREQUENCY SIGNALING SYSTEM—H. A. AFFEL, Brooklyn, N. Y. Filed Dec. 15, 1922, issued Feb. 1, 1927. Assigned to American Telephone and Telegraph Company.

1,615,913—RADIO DIRECTION FINDING SYSTEM—H. S. OSBORNE, Montclair, N. J. Filed Dec. 6, 1920, issued Feb. 1, 1927. Assigned to American Telephone & Telegraph Company.

1,615,958—ELECTRON DISCHARGE DEVICE—P. SCHWERIN, New York, N. Y. Filed Dec. 15, 1923, issued Feb. 1, 1927. Assigned to Western Electric Co.

1,616,010—DESTRUCTION OF THE ELECTRICAL CONDUCTIVITY OF FILMS—C. T. ULREY, East Orange, N. J. Filed Jan. 3, 1923, issued Feb. 1, 1927. Assigned to Westinghouse Lamp Co.

1,616,093—VARIABLE CONDENSER FOR RADIOCIRCUITS—F. W. STEIN, Atchison, Kan. Filed May 2, 1924, issued Feb. 1, 1927.

1,616,176—VIBRATION ABSORBER FOR RADIO TUBES—H. A. BREMER, Chicago, Ill. Filed Nov. 7, 1925, issued Feb. 1, 1927.

1,616,214—VACUUM TUBE—J. L. BROWN, Long Beach, Cal. Filed May 5, 1922, issued Feb. 1, 1927.

1,616,139—ELECTRON DISCHARGE DEVICE—V. L. RONCI, Brooklyn, N. Y. Filed Feb. 21, 1925, issued Feb. 1, 1927. Assigned to Western Electric Co.

1,616,184—ELECTRON DISCHARGE DEVICE—T. R. GRIFFITH, Dover, N. J. Filed Oct. 29, 1923, issued Feb. 1, 1927. Assigned to Western Electric Co.

1,616,622—OSCILLATION GENERATOR WITH AUTOMATIC FREQUENCY CONTROL—J. W. HORTON, Bloomfield, N. J. Filed May 21, 1923, issued Feb. 8, 1927. Assigned to Western Electric Co.

1,616,892—DUPLEX RADIO SYSTEM—L. ESPENSCHIED and DE LOSS K. MARTIN, of Hollis, N. Y., and Orange, N. J. respectively. Filed Aug. 18, 1922, issued Feb. 8, 1927. Assigned to American Telephone & Telegraph Co.

1,616,914—ELECTRON DISCHARGE DEVICE—A. MAVROGENOS, Milwaukee, Wis. Filed Jan. 15, 1926, issued Feb. 8, 1927.

1,616,923—INTERFERENCE REDUCING MEANS FOR RADIO RECEIVING APPARATUS—R. H. RANGER, Brooklyn, N. Y. Filed Dec. 28, 1922, issued Feb. 8, 1927. Assigned to Radio Corp. of America.

1,617,023—AERIAL—J. E. MONTELIUS, Los Angeles, Cal. Filed Dec. 27, 1924, issued Feb. 8, 1927.

1,617,171—METHOD AND APPARATUS FOR THE RECTIFICATION OF ALTERNATING CURRENTS—C. G. SMITH, of Medford, Mass. Filed Oct. 8, 1920, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,172—PRODUCTION OF ELECTRICAL VARIATIONS—C. G. SMITH, of Medford, Mass. Filed Oct. 8, 1920, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,173—PRODUCTION OF ELECTRICAL ENERGY VARIATIONS—C. G. SMITH, of Medford, Mass. Filed Oct. 20, 1920, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,174—ELECTRICAL APPARATUS AND METHOD—C. G. SMITH, of Medford, Mass. Filed Apr. 25, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,175—ELECTRICAL APPARATUS—C. G. SMITH, of Medford, Mass. Filed Apr. 25, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,176—ELECTRICAL APPARATUS—C. G. SMITH, of Medford, Mass. Filed May 3, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,177—PRODUCTION OF ELECTRICAL VARIATIONS—C. G. SMITH, of Medford, Mass. Filed May 3, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,178—ELECTRICAL APPARATUS—V. BUSH, of Chelsea, Mass. Filed Oct. 27, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,179—ELECTRICAL APPARATUS—C. G. SMITH, of Medford, Mass. Filed Dec. 31, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,180—ELECTRICAL APPARATUS—C. G. SMITH, of Medford, Mass. Filed Jan. 3, 1921, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,181—ELECTRICAL APPARATUS—V. BUSH, of Medford, Mass. Filed Apr. 7, 1922, issued Feb. 8, 1927. Assigned to Raytheon Mfg. Co.

1,617,236—PORTABLE RADIO RECEIVING SET—H. CSANYI, of New York. Filed Dec. 7, 1922, issued Feb. 8, 1927.

1,617,240—METHOD FOR RADIO DIRECTIVE SIGNALING—R. A. FESSENDEN, of Chestnut Hill, Mass. Filed Jan. 28, 1922, issued Feb. 8, 1927.

1,617,242—RADIO TRANSMISSION AND RECEPTION—R. A. FESSENDEN, of Chestnut Hill, Mass. Filed Oct. 13, 1924, isued Feb. 8, 1927.

1,616,832—CONDENSER—R. C. SPRAGUE, of Quincy, Mass. Filed Sept. 18, 1925, issued Feb. 8, 1927.

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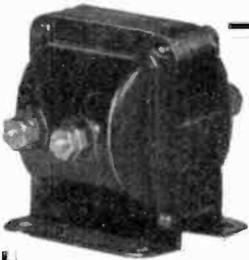

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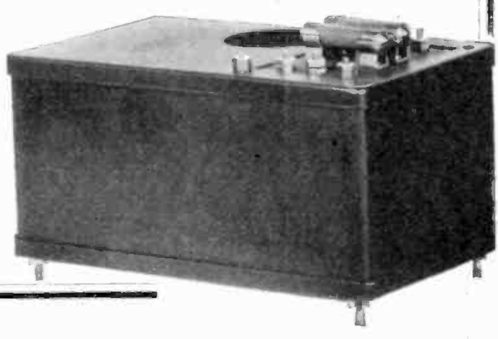

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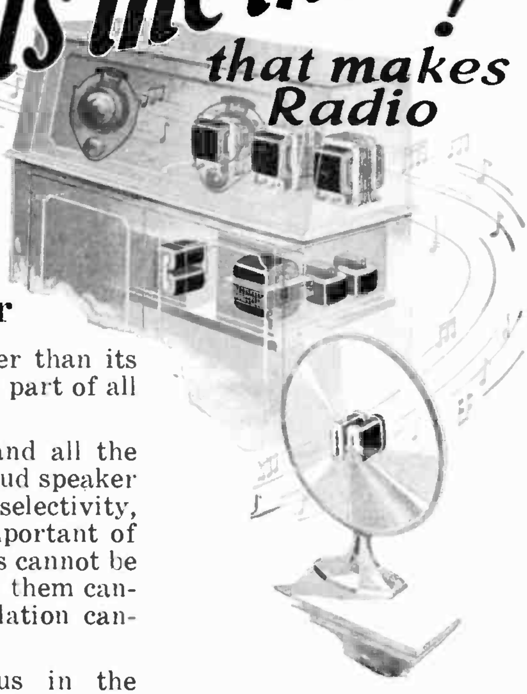

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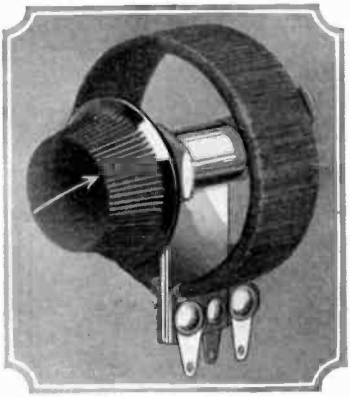

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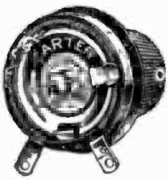

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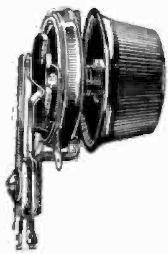

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