PROCEEDINGS OF
The Institute of Radio Engineers

Volume 14 | AUGUST, 1926 | Number 4

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GENERAL INFORMATION

The Proceedings of the Institute are published every two months and contain the papers and the discussions thereon as presented at the meetings and at the Sections in the several cities listed on the following page.

Payment of the annual dues by a member entitles him to one copy of each number of the Proceedings issued during the period of his membership.

Subscriptions to the Proceedings are received from non-members at the rate of $1.50 per copy or $9.00 per year. To foreign countries the rates are $1.60 per copy or $9.60 per year. A discount of 25 per cent is allowed to libraries and booksellers.

It is understood that the statements and opinions given in the Proceedings are the views of the individual members to whom they are credited, and are not binding on the membership of the Institute as a whole.

PUBLISHED BY
THE INSTITUTE OF RADIO ENGINEERS, Inc
37 WEST 39TH STREET, NEW YORK, N. Y.

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INSTITUTE ACTIVITIES

Elected and Transferred to Member Grade

Members elected and transferred at the June 2nd meeting of the Board of Direction. The report of the Admissions Committee for May was approved, authorizing the election or transfer to grade of Member of the following: Zeh Bouck, Axel G. Jensen, H. T. Friis, H. H. Beverage, O. G. Mauro, D. F. Whiting, I. S. Bobrovsky, H. H. Bouson, E. E. Freeman, L. S. Hawkins, Coke Flannigan, F. J. Kahn, P. H. Boucheron, R. S. Kruse, Harris J. Rogers.

Washington, D. C., Section

A meeting of the Washington Section was held in the Department of Commerce building at Washington on April 14th, 1926. A talk on "The Translation of Electro-Mechanical Movements Into Sound Vibrations," was given by Mr. M. C. Hopkins. Mr. Hopkins demonstrated with apparatus the possibility of reproducing the deep base notes sometimes lacking in radio reception.

The Section also held a regular meeting on May the 12th, at which a talk was given by Mr. George Clark on the subject "The Evolution of Radio."

Rochester, N. Y., Section

A meeting of the Rochester Section was held on April 21st, jointly with the Rochester Engineering Society. Seventy-five members and guests were present. A talk was given by Mr. Harry Sadenwater who described the Broadcasting Stations WGY, KOA, and KGO, also the fifty-kw. transmitter at Schenectady. A meeting was held on May 21st, a talk being delivered by Mr. L. C. F. Horle on the subject "New Developments in Radio." A paper was read also on the subject of "Design of Radio Amplifier Circuits," by Mr. K. Henderson.

San Francisco Section

The San Francisco Section held a meeting on May 20th in the auditorium of the Pacific Gas and Electric Company, San Francisco. Mr. C. W. Latimer gave a talk dealing with the High Power Trans-Oceanic System of the Radio Corporation of

America, illustrated with motion pictures and slides. Mr. R. E. Mathes gave a detailed explanation of the operation of the system of Photo-Radio Transmission employed by the Radio Corporation of America. The talk was illustrated by lantern slides. Fifty-two members were in attendance.

Philadelphia Section

A re-organization meeting was held by the members of the Philadelphia Section on May 21st. Very interesting talks were given by Stuart Ballantine, W. L. Sayre and David P. Gullette. A meeting was held on July 12th, at which 100 members were present. A paper, illustrated with slides was read by W. E. Holland, on the subject "A, B and C Power from Alternating Current Sources." The next meeting of the Section will be held about September 15th.

Proposed Section at Detroit

A preliminary meeting was held by Institute members in Detroit, Michigan, on May 22nd, twenty-seven being present. The purpose of the meeting was to consider the proposal to establish a Section at Detroit. Temporary officers were elected as follows: W. A. Pedersen, temporary chairman; E. H. Clark, temporary vice-chairman; W. R. Hoffman, temporary secretary-treasurer.

As soon as the plans are completed the Section will be placed on a permanent basis and will hold regular technical meetings. At the preliminary meeting thirty-four members were present.

Proposed Section at Hartford, Conn.

A meeting was held in Hartford, Connecticut, on May 26th, with the object of determining whether or not a Section of the Institute can be established and operated to advantage with headquarters at Hartford. Among those who attended the preliminary meeting were: Dr. W. G. Cady, Dr. K. S. Van Dycke, H. P. Maxim, R. B. Bourne, K. B. Warner, A. L. Budlong, A. A. Herbert, F. E. Handy, F. C. Beekley, C. B. Rodimon, J. M. Clayton, H. P. Westman, R. S. Kruse.

A second meeting was held at Scott Laboratory, Wesleyan University, Middletown, Connecticut, on June 22nd, at which Dr. Cady and Dr. Van Dycke discussed the theoretical and practical aspects of the Piezoelectric Crystal with special reference to radio applications.

Employment

At Institute headquarters occasional calls are received for radio engineers and technicians. The Institute does not maintain an employment bureau, but the headquarters staff will be glad to receive inquiries from employers concerning their staff needs. The technical experience of those looking for employment is a matter of regard at headquarters and such information can be given to employers when so authorized by applicants for employment.

Toronto Section

The Toronto Section held a meeting on May 5th at which a paper was read by Mr. D. Hepburn on the subject of "Resistance, Reactance and Inductance." The officers elected to serve during the coming year are: Honorary Chairman, Professor T. R. Roseburgh; Chairman, D. Hepburn; Vice-Chairman, George F. Eaton; Secretary, C. C. Meredith; Assistant Secretary, C. I. Soucy; Treasurer, A. L. Ainsworth.

The Canadian Section is planning having one or two summer outings, possibly at Niagara Falls, to which all members of the Institute in Ontario and Quebec, as well as Northern New York State will be invited to attend.

The Section proposes to hold meetings in a lecture room of the Electrical Engineering Department, University of Toronto, once a month, except June, July and August. The number of Institute members in Canada continues to increase satisfactorily.

Meetings and Papers Committee—Note on Illustrations

Illustrations should be deep black on white on separate sheets. Letters and numerals should be as large as practical. A wiring diagram and a curve or family of curves is usually quite plain when reduced to very small dimensions; however, the numerals and letters nust be relatively large to remain readable. More coordinate lines than necessary interfere with reduction. Sheets much larger than the curves are a waste of space.

The cost of cuts is proportional to their area and the cost of publications is proportional to the number of pages.

If the illustrations are not suitable, either the Institute must pay for reducing, or other illustrations must be requested from the author.

Illustrations that make the important points plain at a glance are very desirable because they save the time of the reader, but illustrations which do not add anything or embody confusing non-essentials irritate the readers and add useless cost to the PROCEEDINGS.

Papers Available in Pamphlet Form

In addition to the list of papers available in pamphlet form given on page 277 of the June PROCEEDINGS, we have available in this form a paper on "Some Measurements of Short Wave Transmission," by R. A. Heising, J. C. Schelleng and G. C. Southworth, and a paper on "Combined Electromagnetic and Electro Static Coupling and Some Use of the Combination," by Edward H. Loftin and S. Young White. Copies of these papers may be procured free by members by writing to the Secretary.

New Members and Transfers

Associates transferred to the grade of Member at the meeting of the Board of Direction on June 30th were E. W. Dannals, H. O. Horneij, R. W. Augustine, W. P. Powers, S. W. Dean, A. E. Harper, G. E. Burghard and A. T. Murray. Direct election to Member grade: A. J. Carter, J .D. Relyea and H. A. Oleson.

No New York Meetings in July or August

There are no technical meetings held in New York in July or August, but the offices of the Institute are open continuously for the transaction of business.

Work of Standardization Committee

A meeting of Subcommittee No. 1 on Vacuum Tubes was held on May 28th in New York under the chairmanship of L. A. Hazeltine. A preliminary report describing methods of measurement of the important characteristics of vacuum tubes has been prepared by the Subcommittee and will be given further consideration at a meeting to be held within a few weeks.

COLLEGIATE TRAINING FOR THE RADIO ENGINEERING FIELD*

By

C. M. Jansky, Jr.

(Assistant Professor, Radio Engineering, University of Minnesota)

Every discovery in the field of abstract science is quickly followed by the adaptation of the new knowledge gained to the benefit of civilization. We have grown to expect this. The average individual today takes his radio receiving set and the programs it gives him very much for granted, just as he does his electric lights and his telephone. The engineer has developed

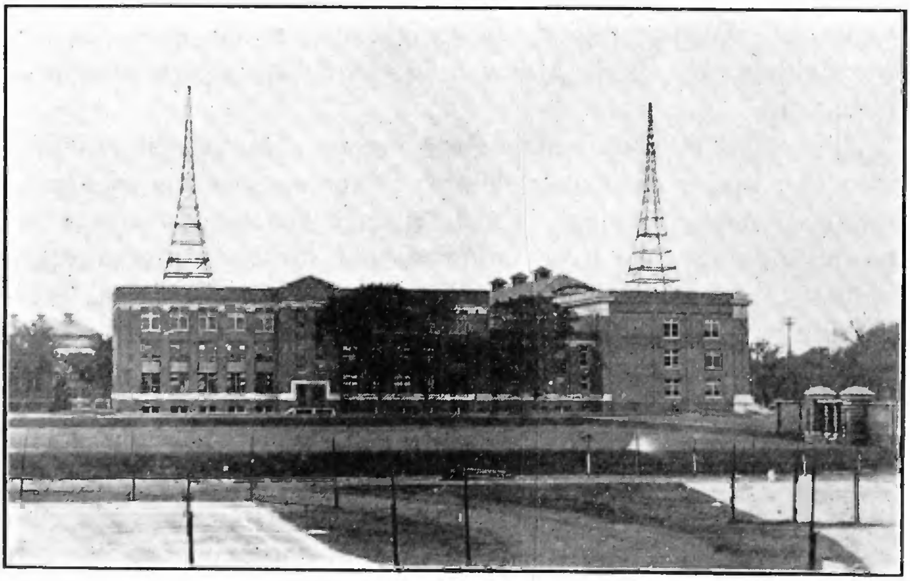

Figure 1—Electrical Engineering Building—University of Minnesota
(The Communication Laboratories occupy the third floor of this building)

these instruments of usefulness to a point where neither knowledge nor effort is required to operate them. As a result we must not be surprised to see a general lack of appreciation by the public of the intricacies of modern electrical apparatus and the work of those who have developed it.

*Received by the Editor May 5, 1926.
Presented before the Chicago Section, Institute of Radio Engineers, March 4, 1926, and at the New York meeting June 2, 1926.

Scientific development may be classified under two heads; that which increases our knowledge concerning fundamental physical phenomena and that which concerns itself with the development of apparatus and equipment the operation of which is based on these phenomena. Those studies which increase our knowledge concerning the nature and behavior of electricity belong to the field of physics. Those studies which have as their aim the development of apparatus and equipment utilizing fundamental electrical phenomena belong to the field of electrical engineering. An extreme physicist may be defined as one who, when he sees a practical application of his work, shies as far away from it as he can. An extreme "practical engineer" might be defined as one who, if he cannot see a practical application of a particular line of study, leaves it to others. As a matter of fact the most abstract theoretical physical investigations have often turned out to be of the greatest practical value, which proves that the distinction is not always an easy one to make. A striking illustration of this is the immense practical value of the theoretical investigations made over half a century ago by Clerk Maxwell in the field of electromagnetic radiation.

The field of electrical engineering may be roughly divided into two major divisions: electric power engineering and communication engineering. Until recently the magnitude of the power industry has overshadowed that of the communication industry. As a result, most collegiate courses in electrical engineering have been and in fact are today primarily courses designed to train men for the power field. By this I mean that in courses required of all students the fundamentals of electrical theory are taught by the aid of problems and illustrations which are almost entirely drawn from the power field. An analysis of the textbooks and laboratory manuals used in such courses will substantiate this statement. The fact that elective courses devoted entirely to the communication field are open to electrical students in addition to their required work does not alter the situation. A course of training which required of students a knowledge of the power field and leaves as optional a knowledge of the communication field will give the graduate a very lopsided view of electrical engineering in general. It is not difficult today to substantiate the statement that the communication industry is as important a factor in our civilization and offers as great opportunities to the graduate of electrical engineering as the power industry. Any discussion of the training of men for the field of communication engineering which does not take account of this fact will fail of its purpose.

It is easy to say, and has often been said, that a course in electrical engineering should be based upon fundamentals. There is, however, often a wide difference of opinion as to what are and what are not fundamentals. Since physical knowledge is a basis for electrical engineering, and therefore radio engineering, it is obvious that a thorough course in physics should be an essential part of any training for the radio engineer. It is difficult to see how an understanding of complex radio phenomena can be obtained without the aid of a thorough knowledge of such physical concepts as force, mass, power, work, etc. Yet although courses in physics are an integral part in the training of all electrical engineers, I have yet to meet a group of senior students who did not have a hazy idea concerning these obvious fundamentals. More emphasis could well be placed on them.

A second obvious fundamental subject essential to any course in radio engineering is mathematics. Mathematics to the engineer is a tool which permits him to carry a number of variable quantities through transformations which enable him to check experiment or predict results. The engineer is at times inclined to look askance at the mathematician who studies his science for its own sake. Here again we must not forget that the most abstract investigations in mathematics may lead to the development of extremely practical tools which may be of great assistance to the graduate engineer. Examples of this are as plentiful in the field of pure mathematics as they are in the field of physics.

The importance of thorough training in physics and mathematics for engineers has been the subject of so much discussion by writers on education that the subject has become hackneyed. Yet no one will deny that many of our educational institutions continue to grind out graduates woefully deficient in this respect. The answer I presume is that to acquire a knowledge of these subjects, the student must cease to become a mere receptacle for information poured into him and must think for himself. It is much easier both from the standpoint of the teacher and the student to fill a student's head than it is to teach him to use it.

There is one other group of course incorporated in the curricula of most of our technical colleges, which I would designate as fundamental. This group includes those courses designed to increase the ability of the student to express himself either on paper or before an audience by word of mouth. The business of a lawyer requires that he analyze situations and present his analysis to others with conviction. The engineer deals with highly technical and intricate developments. To leave presentation of those developments to the general public to others with less knowledge than himself, is to rob himself of the rewards which are justly his due. To command public attention, the engineer must be able to present his developments forcefully to those outside his profession. Mathematics is a useful tool, but its use is limited to those who understand it. The written and spoken word is the universal tool of civilized man.

Those of us in educational work are constantly charged with teaching too much application and not enough fundamentals. The cry of many in the industry is "give your students a knowledge of the fundamental physical sciences; leave the teaching of application to us. We can teach application better than you." Now if this be true, then why does not the industry turn a cold shoulder to electrical engineering graduates and draw its recruits entirely from those who have had training only in the field of abstract science, because, after all, electrical engineering is only applied physics. Yet even those who insist that the teacher should confine his attention to fundamentals, hire more engineers than they do physicists.

This leads to the question: what is the difference between a training in abstract mathematics and physics and a training in electrical engineering. The difference is that the student in electrical engineering has been taught to apply his physics to concrete engineering problems. It is entirely possible and even probable that the concrete problems used for illustrations will never be of any use to the engineer after he has graduated. This is not important. However, the ability to apply abstract science is as essential to the success of an electrical industry as is a knowledge of it. No one will, I think, argue that the teaching of the methods of applications should be left entirely to the industry itself. It it should, then courses in Electrical Engineering should be abolished.

The manufacturer who hires electrical graduates is very likely to analyze one of his recruits as he would the raw product he expects to use in his factory. For his purpose the graduate should have certain characteristics which would best fit him for work in his organization. Having told educators what characteristics he desires in his recruit engineers, why, he asks, does not the educational institution turn its attention to turning out a product which will have these characteristics. This might be possible were it not for the fact that the engineering student is not a piece of material, but, on the contrary, is a human individual. During the entire period of his scholastic training the average student is trying to answer the very important question, "In just what kind of work and in what branch of engineering will I be happiest and most successful?"

No one can deny that the initial selection of a job made by the young graduate is of great importance. It is, therefore, the duty of the educator to give to the student as great an insight into the problems and opportunities of the various fields of electrical engineering as possible to the end that the graduates' initial choice may be a wise one. The presentation of engineering problems to the student which have been drawn from all branches of the industry, and which, in so far as possible, give the student some realization of what may lie beyond, is an admirable way of assisting the student in his efforts to select his life work wisely.

A serious criticism of an electrical engineering curricula which in its required courses draws all of its illustrative problems from the power field, is that graduates will select work in this field to the exclusion of all others. Men are loath to enter a line of work the problems and opportunities of which they know nothing. The communication industries have in the past found it very difficult to obtain engineering recruits for this reason. Men who have had a thorough training in courses drawing illustrations from the electric power field, may make as good communication engineers as anybody else, but in most instances the communication industry will never get them.

A properly-balanced course in electrical engineering in some good college or university undoubtedly offers the best training for the average prospective radio engineer. If the required work of this course does not give the student the fundamentals of electricity as applied to the communication problems, then the student should take elective courses designed to give him these fundamentals. The fact that these courses may be elective and may be titled "Telephony and Telegraphy" or "Radio Communication," does not necessarily mean that they are any more specialized than his required courses or that the teacher is concerned only with the application of fundamentals learned elsewhere. On the contrary, they are probably as fundamental and basic as any other courses he may be required to take, and may provide the only means of giving the material necessary to an understanding of the fundamentals of electricity as applied to the communication field. The theory of the vacuum tube, the theory of coupled circuits, the radiation of electro-magnetic waves, distortion of wave form, the theory of circuits containing distributed capacitance, inductance, and resistance, and the meaning and measurements of transmission loss and gain are subjects which are not always sufficiently emphasized in average electrical engineering curricula of today for those who expect to become communication engineers.

One outstanding characteristic of the radio communication field is the number of new problems which are met at every turn.

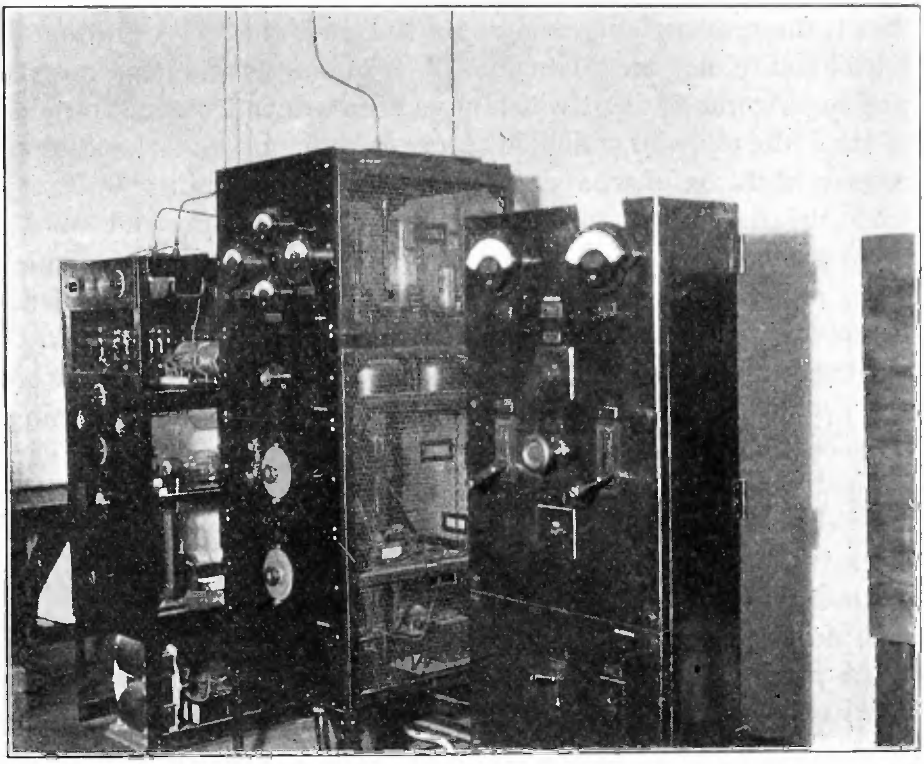

FIGURE 2—Short-wave Radio Telegraph Transmitter and Broadcast Transmitter—University of Minnesota Experimental Radio Station

(The short-wave transmitter was designed and built by students in the Department of Electrical Engineering)

Amateurs and broadcast listeners are continually trying new circuits and apparatus, most of them, it is true, with very little knowledge of what they are doing. The radio field offers an excellent opportunity for individual investigation on the part of the engineering student. Such work should not, however, be undertaken until the student has secured sufficient fundamental knowledge to derive some benefit from his experiments. In colleges having large registration it is difficult to give the student sufficient opportunity to exercise his own initiative. The laboratory work in courses containing a large registration must, of necessity, be largely stereotyped. The student's experiments are outlined for him so that he knows what data to take, how to take it and what conclusions to draw. In an independent investigation the student is given a problem for which he must develop his own line of attack. He must decide upon what data he needs, what conclusions he can draw, and more important than anything else he should criticize his own results and judge their value.

During the past few years the writer has had a number of senior and post-graduate students working under him on individual investigations. The selection of a problem for the student is based on (1) his interest, (2) his ability to get somewhere with the problem, (3)the availability of equipment, and (4), the value of the results expected from the investigation.

In industrial work the last-mentioned point is all important. In educational work, except with candidates for higher degrees, it is of minor importance. The main object is to give the student training in the methods of independent investigation. The progress which I have seen students make in the development of their ability to analyze a problem, to search literature, and to take and draw conclusions from experimental data has been very gratifying and has convinced me of the value of scholastic training of this sort in spite of the amount of work it requires on the part of the teacher.

One of the peculiarities of radio communication is the fact that while man designs and builds the equipment necessary for the transmission and reception of radio waves he has no control and in fact very little knowledge of the transmission system he uses. Radio engineering today concerns itself largely with the design and construction of transmitting and receiving apparatus. Our knowledge of what goes on between transmitter and receiver and what conditions influence the strength and readability of signals at distant points is as yet very limited. This knowledge is largely of a statistical nature based on experience.

In view of the importance of the transmission medium in our communication system it would seem that some contact with it by the prospective radio engineer would at least be desirable. I know of no better method of studying transmitting and receiving conditions than by the actual transmission and reception of radio messages. Many a radio engineer became interested in his field as an amateur or commercial operator.

The American Radio Relay League deserves much credit for the stimulation it has given to amateur operation of radio stations and to interest in non-commercial experimental work. It would seem that a closer alliance between this organization and our educational institutions would help to give students contact with actual radio communication and would in many other ways be mutually beneficial.

At the University of Minnesota Department of Electrical Engineering, we maintain an experimental radio station which serves a number of useful purposes. The station carries on extensive communication by short wave radio telegraphy with other experimental stations and amateur stations located all over the world. All construction and operation is carried on by a staff of student operators under faculty direction. This year the staff has eighteen members. The station is in operation normally about eighty hours each week. Actual transmission is carried on by men who have had extensive amateur or commercial operating experience. Other students not qualified operators are given the opportunity to design and construct equipment. Students may, if they choose, obtain a limited amount of credit towards graduation for work done in the radio station.

It is distinctly not the purpose of this work to train radio operators. Its principal object is to keep both students and faculty in touch with transmitting and receiving conditions as they actually exist. Incidentally, the experimental station yields much valuable information concerning transmitting conditions and also provides an excellent means for testing radio apparatus under conditions which stimulate those met in commercial practice.

Any student activity, the success of which requires respect for authority, systematized procedure, the ability to assume responsibility, co-operation with others, and yet permits an exercise of individual initiative cannot but help to train men to better meet the problems which will confront them when they enter modern industrial work. Radio station operation by students on a basis such as I have described provides such training.

The radio industry has enjoyed a remarkable growth during the past decade. It is not to be expected that such growth would take place without its problems. During the period when any radio manufacturer could sell equipment faster than he could make it regardless of quality it is small wonder that many have seen no necessity for services of well-trained engineers. However, conditions are changing rapidly. The public is already beginning to discriminate in favor of those manufacturers whose apparatus has been designed and constructed under the supervision of competent engineers. This discrimination on the part of the public will do much to stimulate development and improvement. It will also bring about greater rewards to those who have sacrificed time and effort necessary to secure an adequate training in what is the youngest as well as one of the most technical of the electrical sciences.

DISCUSSION
ON "COLLEGIATE TRAINING FOR THE RADIO ENGINEERING FIELD," BY C. M. JANSKY

J. H. Dellinger: I would like to add one point to the very excellent ones brought out in Professor Jansky's paper, and it is a point which it was impossible for him to make. My added point is that we give too little credit to our educators. The honor and credit for the achievement in radio should be divided between the men who make the advances and the teachers who have trained them. Professors, and instructors generally, seldom get their due, and this is an excellent occasion to draw attention to that seriously neglected fact.

The common attitude toward educators and educational courses is one of broad criticism rather than praise. We have an effective offset to this critical attitude in papers like this one of Professor Jansky's which reveal how the educator is thoroughly alive to the problems before him and is capable of giving them as keen and thorough an analysis as any engineer gives an engineering problem. Professor Jansky has set forth a number of important ideas for our consideration and I would like to emphasize the ones which appear to me of particular importance. They are five in number.

First, he points out that in most electrical engineering courses "the fundamentals of electrical theory are taught by the aid of problems and illustrations which are almost entirely drawn from the power field." It is certainly true that the characteristic phenomena of electrical communication give just as valuable a province for instruction as those of electric power. This will unquestionably be given increasing recognition.

Second, it is pointed out as obvious that training in physics is an essential part of the radio engineer's education. While this is often stated and is indeed obvious, it cannot be given too much emphasis. This is proved by Professor Jansky's admission that "I have yet to meet a group of senior students who did not have a hazy idea concerning" the fundamental physical concepts. My own observation of the preparation and technical equipment of radio engineers gives strong emphasis to the need

Received by the Editor June 6, 1926.

for more thorough training in fundamental physics. I have many times been thankful that the gentleman who taught me physics had no illusions as to ability of students to grasp the subject. I came to know some of his philosophy of teaching, and he said that his experience had led him to the conclusion that if he could get even one physical principle thoroughly into the heads of his students so that they really knew it and used it, he felt that the year's teaching work was successful. Fortunately, a principle on which he concentrated was simple harmonic motion. Any student who got through his course without grasping the principle that in simple harmonic emission the force is proportional to the displacement probably was hopeless as far as learning physics was concerned. I believe it is fair to add that when a man has learned this particular principle he has secured a substantial part of the stock in trade of a well trained radio engineer.

Third, it is suggested that courses in expression are of fundamental importance. This point is seldom mentioned or realized. I believe it is of enormous importance, second only to the need of training in physics, that an engineer should be trained in the arts of expressing himself, either in writing or in speaking to an audience. Obviously few engineers spend much of their time in either writing or public speaking; nevertheless, all must do a certain amount of it, and shortcomings in a man's ability in expression all too often weigh heavily against and neutralize ability in his technical work.

Fourth, it is neatly demonstrated that the student of radio engineering must have technical training in his chosen field through the application of his physics and other fundamental work to concrete problems of radio engineering. The argument given on this disposes of the contention frequently made that the teaching of methods of application should be left entirely to a man's experience in the industry after graduation.

Fifth, and finally, we are reminded that students cannot be trained to fit a particular model as a piece of material would be fashioned into an instrument, because of the fact that the student is first of all a human individual. This again disposes of some criticisms leveled against educational institutions. The manufacturer would like to have recruits for the industry with a definite kind of preparation which could be prescribed as the result of analysis of the particular work the man is to do. That this is not in general possible hinges on the fact that by far the great majority of the students are not certain during their college course as to what vocation they will pursue or for what branch of engineering they are fitted. The teacher cannot subordinate the human problem involved to the less important task of creating a mere standardized unit of work.

Of the various points brought out in Professor Jansky's paper, by far the most important is the emphasis on the need of fundamental training. The details of radio engineering or any other branch of engineering are ephemeral, and they have their roots in physical principles. To learn the principles of physics and how to apply them to understand, to modify, and eventually to create engineering processes is much more difficult and far more important to the student than the practical engineering. I would venture to defend the thesis that the responsibility of the position attainable by a man is proportional to his grounding in the fundamentals of his subject. I do not mean at all that opportunity and other circumstances necessarily always bring a man to this position, and, on the other hand, his grounding in fundamentals must be actual and does not mean that he has merely been exposed to knowledge of fundamentals through taking certain courses. There is no way to learn the fundamental facts of a profession and to understand the processes which are vital except by hard work. I believe it to be true that not only the responsibility of the position open to a man but the contribution he can make to his field of work and the satisfaction he can get out of life, are proportional to his grounding in the fundamentals of his vocation.

Alfred N. Goldsmith: It is unquestionably one of the functions of universities to train specialists in professional branches, such as radio engineering. There is not, however, a widespread knowledge of the real qualifications of a radio engineer. The following definition may be proposed: "A radio engineer is an electrical engineer who has first specialized in communication engineering, and then sub-specialized in radio communication." Guided by this definition, it is clear that the fundamental training of a radio engineer is that of an electrical engineer. His first specialization should be in the field of alternating current phenomena at high frequencies and the characteristics which are displayed to such currents by networks and systems having concentrated or distributed electrical constants. If electric courses on advanced transformer design and, under the division of physics, on acoustics are available, the student will do well to choose these.

The sub-specialization in radio engineering will deal with the theory and construction of the specialized circuits used in radio transmitting and receiving apparatus, together with a careful study of that universal device, the triode, or three-electrode tube. A great deal of emphasis should be placed on the laboratory side of the work because the field is new and rapidly changing, and only those who have had direct contact with actual equipment will be spared the continual mortification of embarrassing mistakes based upon too slavish a reliance on narrow theoretical considerations.

There are today relatively few universities giving training in the field of radio engineering which, perhaps, is just as well, since the absorption of trained men in the radio engineering field (despite public interest in this field) is rather limited. It may be added that a radio engineer, on graduation from the university, is qualified to begin his career in a somewhat humble capacity, since he must get experience in the test, design, and manufacturing divisions of a commercial organization of some scope before he can be depended upon to meet the requirements of this fairly difficult profession. However, it is a most interesting field and the workers in it feel that they are in the van of progress.

Arthur F. Rose: Professor Jansky's paper is of considerable interest to all of us who are engaged in communication work, although it applies particularly to the radio engineering field which Professor Jansky has emphasized. His analysis of the time-worn policy of industry urging "emphasis of fundamentals in the engineering curriculum" is a very valuable contribution and will aid in bringing together the viewpoints of those in the field and the educators. The question of what constitutes fundamentals has been the subject of many discussions, all of which result in the conclusions that the same fundamentals form the basis for both communication engineering and power engineering. The difference between the two is only the question of the frequencies and the amount of power involved. In the power field a single frequency and large quantities of power are studied, while in the communication field minute quantities of power but a very large range of frequencies are involved.

The radio engineer or the communication engineer in his design work must study the action of his circuits throughout the frequency range of voice transmission. For instance, the sharply tuned circuits of radio sets react very differently at the different frequencies and may introduce appreciable amounts of distortion if not considered carefully from this standpoint. Therefore, the fundamental conceptions which the student obtains in his early studies should not be restricted to single frequency reactions.

Again in connection with the question of teaching engineering applications in the colleges, Professor Jansky has emphasized the importance of teaching the student how to apply his fundamental knowledge to specific problems. This is, of course, the aim of all education, for as Ruskin says, "All knowledge is lost which ends in knowing, for every truth we know is a candle given us to work by." In some cases, however, the tendency has been to attempt to make the student a finished radio engineer after having taken a course on radio telephony. This, of course, is a mistake, as the text books and problems used in the courses must necessarily lag considerably behind the practical application of the art in the field. In radio engineering particularly, the art is changing so rapidly that it appears futile to attempt to teach detailed application, but better to concentrate on the more fundamental aspects and by practice acquire skill in approaching new problems.

USES AND POSSIBILITIES OF PIEZOELECTRIC OSCILLATORS*

By

August Hund

(Physicist, Bureau of Standards)

Certain crystals [1] which lack symmetry exhibit electrical charges in particular regions when subjected to stress or when heated or cooled. When the electrical charges are due to stress the effect is called piezoelectric, and, when due to heat, pyroelectric. All piezoelectric substances are pyroelectric, and it is doubtful if any pyroelectric effect would be obtained if stresses were eliminated. The effect of stress was discovered by P. and J. Curie.[2]

Though Rochelle salt has the greatest piezoelectric effect, and quartz a comparatively small one, the latter substance, on account of its mechanical properties, is more suitable for the uses and applications here described. Pioneer work in the practical applications of the piezoelectric effect has been described[3] by several experimenters. Prof. Cady and Prof. Pierce have been responsible for most of the applications of value in radio communication.

Quartz has a crystalline structure, as shown in Figure 1, OX being the optic axis. A plate cut out with its surface parallel to the OX axis and either of the other two principal axes, OY or OZ, shows piezoelectric effects which are very pronounced.

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*Published by permission of the Director of the National Bureau of Standards of the U. S. Department of Commerce.

Received by the Editor, November 12, 1925. Presented at a meeting of The Institute of Radio Engineers, New York, May 5, 1926.

[1] Rochelle salt, tourmaline, silicate of zinc, cane sugar, quartz, boracite, etc.

[2] Comptes Rendus, vol. 91, pp. 294 and 383, 1880. Voigt, "Lehrbuch der Kristallphysik," Leipsig, 1910; Graetz, "Handbuch der Elektrizitat und des Magnetismus," vol. 1, Leipzig, 1914. For similar observations consult Gehlers Physikalische Woerterb. Bd. 3, p. 255, 827. W. C. Roentgen, Weid. Ann. Bd. 18, p. 534, Bd. 19, p. 523, 1883. M. G. Lippman, Ann. d. Chemie (5), T. 24, p. 45, 1881. W. Thomson, Phil. Mag., vol. 36, p. 331, 1893.

[3] A. M. Nicolson, Proc. A. I. E. E., vol. 38, p. 1315, 1919; W. G. Cady, Proceedings of The Institute of Radio Engineers, vol. 10, p. 83, 1922; and G. W. Pierce, Proc. American Academy of Arts and Sciences, vol. 59, No. 4, p. 81, 1923.

Axes AB, CD, and EF are known as the piezoelectric axes. Piezoelectric effects are observed when the plate is placed between two metal sheets. The planes of the sheets are then perpendicular to one of the piezoelectric axes and parallel to the optic axis of the crystal. If the quartz plate is compressed, opposite charges will be induced in the two conducting sheets. Elongation reverses the polarity. Hence if the circuit is closed by a conductor connecting the two metal sheets, and the plate is subjected to alternating mechanical impulses, it generates corresponding alternating electric currents. An alternating e.m.f. impressed across the piezoelectric plate will also cause a similar mechanical vibration in it. This is true even if the metal sheets are not quite touching the respective faces of the plate.

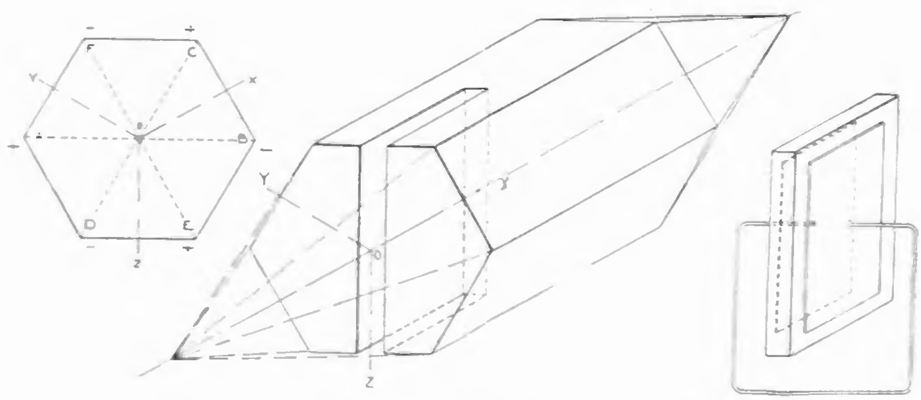

FIGURE 1—Quartz Crystal and Piezoelectric Plate

Piezoelectric Oscillator—From the foregoing it is evident that a plate of quartz can be used for converting mechanical vibrations into electrical oscillations and vice versa. The effects are greatest when the electrical oscillation is adjusted to resonance with a possible natural mechanical vibration of the piezoelectric plate. Using an electron tube circuit it is possible to have the piezoelectric plate control the oscillations which are set up. Such an arrangement is shown in Figure 2 where a quartz plate can be inserted either between the grid and the filament or between the grid and the plate.

The action of the circuit is as follows: Upon closing the circuit or moving certain portions of it, a transient current is started in it whose decay assumes a frequency which is due to a possible mechanical vibration of the piezoelectric plate. Normally such an oscillation would die out before being noticed. If, however, an inductance, L, of proper magnitude is inserted in the plate circuit, it will, by means of the feedback[4] through the tube itself, render the circuit regenerative, that is, produce the equivalent of a negative resistance between the grid and the filament, and sustain the oscillations due to the piezoelectric element. Whenever this happens, the plate current measured by a d. c. milliameter drops to a minimum value. The output can be increased by using a variable condenser, C, in parallel with the inductance, L, of the plate circuit. With the quartz plate connected between the filament and the grid, the condenser is set at its minimum position and its capacity is gradually increased. For a certain setting, the oscillations begin to build up and while increasing C, the plate current will decrease until the oscillations stop altogether when close to the resonance setting of the C-L circuit. For the quartz plate connected to the anode and the

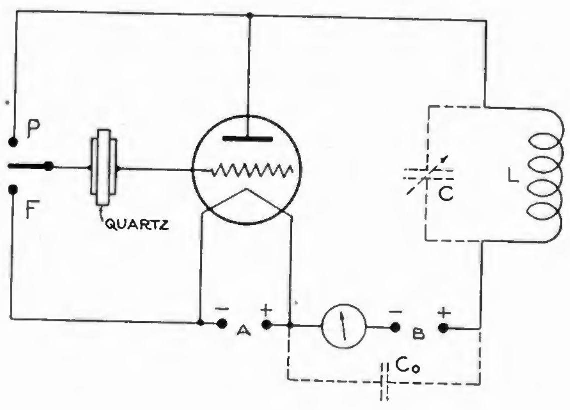

FIGURE 2—Circuit Connections for a Piezo-electric Oscillator

grid, the capacity, C, has to be gradually decreased from the maximum setting in order to start the oscillations. The building up of the oscillations takes place normally in a fraction of a second, but in some cases it may require several seconds, and it is therefore necessary to change C slowly. The slow building-up of the oscillations may be due to either a poor piece of quartz, incorrect value of the inductance L, or the lack of necessary freedom of the quartz plate. When using the quartz plate as an oscillator it is necessary for it to be free to move, while for use as a resonator the conductive layers can

[4] If the piezoelectric element is inserted between the filament and the grid the plate to grid capacity acts as the agency for the feedback of the plate actions into the grid branch. The filament to grid capacity provides the feed-back, if the quartz plate is connected between the grid and the anode.

even be pasted on the piezoelectric plate or clamped against it without disturbing the operation.

Cutting of Quartz Plates Suitable for Oscillator Work.—Figure 3 shows a large piece of quartz which rests on a surface perpendicular to the optic axis along which no "direct" electrical effect is possible. Figure 4 shows another crystal of quartz likewise resting on a plane perpendicular to the optic axis. The lines indicate where a plate is to be cut out. Cuts of this type give a maximum piezoelectric effect with a small temperature coefficient which is either positive or negative. Although there are

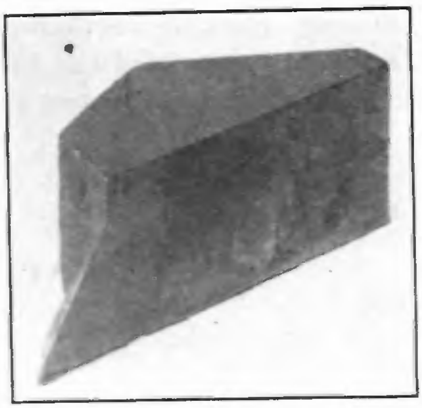

FIGURE 3—Piece of Quartz Resting on a Plane Perpendicular to the Optic Axis and Cut Along an Axis Such as OX, OY or OZ.

FIGURE 4—A Suitable Cut for Obtaining a Plate for Piezo Oscillators

cuts for which the temperature coefficient is zero it has been found more practical to cut as closely as possible along OX, OY or OZ directions (Figure 1) since then three well-defined natural vibrations occur. Figure 5 shows a quartz plate removed from the original crystal while Figure 6 shows several plates cut out from the same block. From such slices either rectangular plates are cut out as indicated on one of the slices or circular plates are cut out by means of a revolving brass tube. The latter shape can be secured more quickly since there are only two faces which need to be made parallel. There are several methods of cutting out slices from the natural crystal. One method is to use a plate of galvanized iron or copper which revolves against the crystal. To this is fed No. 150 carborundum powder mixed with about the same amount (by volume) of water. The work can be done somewhat faster by using a plate of copper whose circumference is finely ribbed and charged with diamond dust, using a steady flow of kerosene against the cutting edge. The faces are ground parallel first by means of No. 60 carborundum and water and then with No. 150 carborundum and water. The finishing is done by means of No. 140 emery powder mixed with water, then No. 302 emery and No. 303 emery in water solution. Most

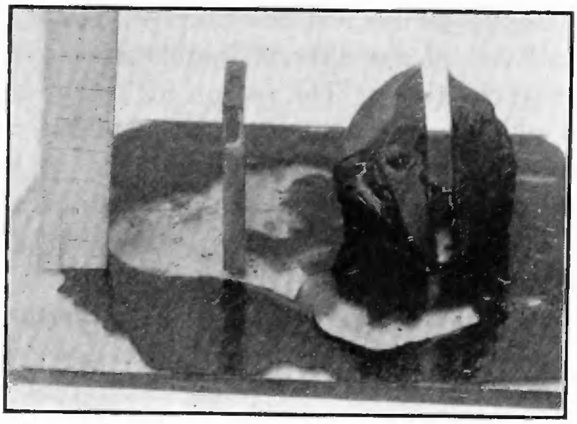

FIGURE 5—Quartz Plate Cut from the Natural Crystal

of the piezoelectric plates at the Bureau of Standards are polished to transparency by means of rouge and the edges somewhat bevelled. A polished plate sometimes has the tendency to chip

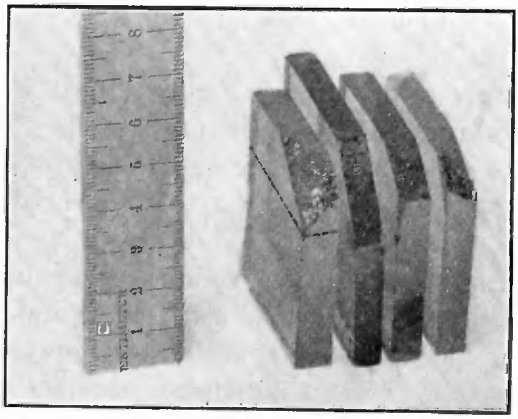

FIGURE 6—Several Piezoelectric Plates Cut from a Quartz Crystal

off near the edges. However, when the two main faces (parallel to the respective conducting layers) are polished, oscillations start more easily and such plates are usually more desirable. The breaking off of the small pieces may be due either to excessive mechanical vibrations in the plate or more probably to strains left near the polished surface, as in the case of Prince Rupert drops.

Important Natural Mechanical Vibrations of Quartz Plates.—When quartz plates are cut out as described above and indicated in Figures 1, 4 and 5, it will be found that in general three fundamental modes of natural oscillations are possible. Several of the many samples tested are described in Table I, from which it is seen that two of the natural frequencies are close together with respect to the third. The reason for this is that the thickness of the plates is small in comparison with the other two dimensions.

When rectangular plates are cut not along planes parallel with either OX, OY, or OZ (Figure 1) but along planes of zero temperature coefficient of frequency or planes closer to directions OA, OD, or OE, either three or more natural mechanical vibrations occur and with frequencies which are not always in agreement with those expected when the normal cuts are employed. For example, a rectangular plate 24.94 × 19.29 × 3.03 mm. gave $f_1 = 105$; $f_2 = 612$, and $f_3 = 924$ kc., that is, two higher frequencies, f_2 and f_3 respectively, in comparison to the third frequency f_1. A normal cut would have given two low frequencies and a high one. In another case four natural frequencies were obtained, the plate having the dimensions 24.775 × 19.92 × 3.04 mm., that is, almost the identical shape as in the first case. These frequencies were $f_1 = 105.6$; $f_2 = 606.5$; $f_3 = 819.5$ and $f_4 = 932.5$ kc.

Using normal cuts as shown in Figure 1, it can be said that three fundamental natural frequencies are possible, irrespective of whether the cut is bounded by a rectangle, square, ellipse or circle, as long as the thickness is small, but not too small, in comparison with the other dimensions. If a thickness is used which is comparable to the other dimensions such as in a cube, it would take a strong electric field to start the oscillations and there would be little gain since the frequencies would be close together. In the same way when the shortest dimension becomes small, less than about 2 mm., special measures have to be employed to start the highest frequency.

In all cases, irrespective of shape, the fundamental vibration due to the thickness can be estimated with a good degree of approximation from the expression

$$f_3 = \frac{2870}{t} \tag{1}$$

when f is expressed in kilocycles per second (kc.) and the thickness t measured in mm. It is therefore seen that the product of the frequency and the thickness is a constant

$$K_3 = f_3 \cdot t = 2870 \tag{2}$$

This is shown by the data of Table I and II.

Data on circular plates used as piezo oscillators, f_1 is the lowest f_2 the medium, and f_3 the highest natural frequency of the quartz plate.

Since for oscillator work the surfaces of the piezoelectric plate are free, it can be assumed that a fundamental vibration has its node at the center of the plate and consequently the thickness is equal to one-half wave length. If v_3 denotes the velocity of propagation along the thickness t, that is, along the electrostatic lines across the plate and λ_3, the wave length, we have

$$v_3 = \lambda_3 f_3 = 2\, t f_3 = 2\, K_3 \tag{3}$$

Hence twice the value of the constant K_3 gives the velocity of propagation, 574×10^3 cm./sec. This result agrees within about 5% with a value obtained from a theoretical formula.[5] This agreement would probably be much better if the appropriate modulus of elasticity were used. The other frequencies which are lower and due to larger dimensions can not be calculated by formula (1). However, for circular plates

$$f_1 = \frac{2715}{d} \tag{4}$$

$$f_2 = \frac{3830}{d} \tag{5}$$

where d is the diameter of the plate in millimeters and the respective frequencies are again expressed in kilocycles. The characteristic constants for these two oscillations are then

$$K_1 = f_1\, d = 2715 \tag{6}$$

and

$$K_2 = f_2\, d = 3830 \tag{7}$$

and the respective velocities of propagation along the diameters are:

$$v_1 = 2\, K_1 = 543 \times 10^3 \text{ cm./sec.} \tag{8}$$

$$v_2 = 2\, K_2 = 766 \times 10^3 \text{ cm./sec.} \tag{9}$$

using similar assumptions as for v_1.

[5] $$v_3 = \sqrt{\frac{\textit{modulus of elasticity}}{\textit{density}}} = \sqrt{\frac{785 \times 10^{11}\, dynes/cm.^2}{2.654\, gn/cc}} = 540 \times 10^3\, cm/cc$$

TABLE I

DATA ON SEVERAL QUARTZ PLATES USED IN PIEZO OSCILLATORS
CIRCULAR PLATES.

Quartz Plate	Shape	Dimensions in mm.				Natural Fundamental Frequencies in kilo: cycles per second			Corresponding Wave lengths in meters							
		t	d	a	b	f_1	f_2	f_3	λ_1	λ_2	λ_3	f_3t	f_1a	f_2b	f_1d	f_2d
A	Circular plate	6.307	36.15			75.05	105.91	454.2	3995	2831	659.8	2871			2715	3815
B	Circular plate	4.782	39.17			69.36	97.625	600	4354	3070	499.5	2874			2700	3827
C	Circular plate	6.0	57.97			46.80	66.27	475.25	6405	4523	631	2854			2715	3841
D	Circular plate	5.78	49.3			55.115	77.82	492.8	5445	3860	608.5	2852			2717	3831
E	Circular plate	4.87	49.27			55.23	77.76	583.6	5425	3855	505	2893			2727	3831
F	Circular plate	6.075	49.3			55.01	77.715	470	5445	3860	638	2857			2717	3831
G	Circular plate	3.4325	49.58			54.88	77.375	843.7	5461	3880	355.2	2899			3725	3831
H	Circular plate	3.4975	58.38			46.5	65.675	822	6445	4560	364.7	2879			2717	3836
I	Circular plate	4.277	39.37			68.5	97	670	4376	3090	447.5	2868			2700	3822
J	Circular plate	8.805	21.84			124.8	175.5	326.75	2401	1708	917.5	2882			2727	3836
K	Circular plate	8.28	29.2			93.4	131.8	346.25	3210	2273	866	2876			2727	3856
						Rectangular Plates										
L	Rectangular plate	3.12		31.855	25.155	79.925	105.41	924.57	3752	2843	324.2	2887	2549	2655		
M	Rectangular plate	4.909		39.005	30.295	70.69	102.42	587	4240	2928	510.5	2886	2759	3099		
N	Rectangular plate	7.177		42.08	39.62	66.05	85.43	404	4538	3508	742	2901	2786	3390		
O	Rectangular plate	3.264		36.82	25.2	80.485	106.67	873.5	3725	2810	343.4	2854	2967	2691		
P	Rectangular plate	7.59		44	35	64.6	83.4	382.8	4640	3595	783.5	2907	2846	2921		
Q	Rectangular plate	6.83		48.5	37.5	59	78.8	417.4	5080	3805	718	2855	2866	2956		
R	Rectangular plate	5.04		39	30	70.7	102.2	569.5	4240	2932	527	2871	2762	3067		

f_1 is the lowest, f_2 the medium, and f_3 the highest natural frequency of the piezo oscillators. t is the thickness of the rectangular plate, d the diameter of the circular plates, a and b are the length and breadth of the rectangular plates.

The optic axis is along a line which is parallel to the circular planes of the plate and so one diameter is parallel with the optic axis. Along a diameter perpendicular to the optic axis the modulus of elasticity is, as given in footnote 5, 7.85×10^{11} dynes/cm.^{2} and with the density value given in that formula confirms exactly the velocity, v_1, of equation (8). The value, v_2, is high and even if it is assumed that the vibration occurs along the direction of the optic axis for which the modulus would be 10.3×10^{11} dynes/cm.^{2} the theoretical velocity is only 623×10^3 cm./sec., which is about 22 percent low. The mechanism for this oscillation is

TABLE II
DATA ON CIRCULAR PLATES USED AS PIEZO OSCILLATOR

Quartz Plate	Natural Fundamental Frequencies in Kilocycles per second			Corresponding Wave lengths in meters			$f_1.d$	$f_2.d$	$f_3.t$
	f_1	f_2	f_3	λ_1	λ_2	λ_3			
A_1	74.95	105.5	452.5	4000	2842	663	2710	3814	2856
A_2	75.05	105.91	454.2	3995	2831	659.8	2713	3829	2865
A_3	74.9	105.15	454.25	4003	2853	660	2707	3800	2868
A_4	75.4	106.0	457.0	3976	2828	656	2726	3830	2873
A_5	74.75	105.35	454.5	4011	2847	659.5	2700	3810	2869
A_6	75.0	105.75	454.5	3997	2835	659.5	2710	3828	2869
A_7	75.1	106.25	453.75	3991	2822	661	2713	3840	2861
A_8	74.8	105.5	457.25	4007	2842	655.5	2703	3814	2887
A_9	75.25	106.5	453.25	3984	2815	661.5	2720	3850	2860
A_{10}	74.75	106.0	454.25	4011	2828	660	2700	3830	2868
A_{11}	74.8	105.95	453.25	4007	2829	661.5	2703	3830	2861
A_{12}	74.95	105.55	454.25	4000	2840	660	2710	3819	2868
A_{13}	74.7	105.55	454.5	4013	2840	659.5	2700	3819	2869
A_{14}	74.75	106.1	454.5	4011	2827	659.5	2700	3835	2869
A_{15}	75.15	106.0	456.0	3989	2828	657	2716	3830	2869
A_{16}	75.05	105.75	454.5	3995	2835	659.5	2713	3825	2860
A_{17}	74.65	105.15	453.75	4016	2853	661	2699	3800	2860
A_{18}	75.1	106.1	453.25	3991	2827	661.5	2714	3836	2860
A_{19}	74.9	105.35	452.5	4003	2847	663	2707	3810	2856

(Circular Quartz plates all of the same size, diameter = 36.15 mm. and thickness = 6.31 mm. cut from different pieces of quartz as indicated in Figure 1.)

probably more complicated than the other two. Nevertheless this in no way gives any practical difficulties since equation (5) can be used to a fair degree of approximation even though a better explanation cannot be given at the present time.

According to Table I and many other data, it is more difficult to give good approximation formulas for the two low frequencies, f_1 and f_2, respectively, of rectangular plates since some values deviate too much from the average value. The average value of the lowest frequency gives a characteristic constant of about $K_1 = 2785$ and for the medium frequency $K_2 = 2945$. The corresponding velocity values, $v_1 = 2\ K_1$, and $v_2 = 2\ K_2$, are reasonable. It is interesting to note that their average value gives about the value for the constant K_3. From these observations it looks as though the three characteristic vibrations occur along the three main dimensions. This appears to contradict the theory of piezoelectricity, at least at first sight, since one dimension is parallel to the optic axis along which no piezoelectric effect is possible. But since a contraction across a set of small faces perpendicular to the optic axis produces an expansion along this axis and vice versa, there will be a disarrangement of the molecules. The effect of this probably produces the third vibration.

Another explanation would be that the piezoelectric plate acts like a coupled circuit which produces two frequencies, one which is somewhat lower and another which is somewhat higher than the expected frequency. The degree of coupling is dependent on the relative magnitude of the three main axis.

A third explanation makes use of the fact that the vibration parallel to the two conducting layers may be due to both a transverse and a longitudinal wave motion which have different velocities of propagation and so produce two waves of different frequencies.

Experience indicates that it is best to use circular plates. It is essential that the faces be exactly parallel since otherwise the frequency spectrum of the highest frequency may give several values or not appear at all. It happens sometimes that a plate will not oscillate at all, although the faces appear to be parallel. A little grinding which would hardly be noticed with a micrometer brings in the oscillation. This is probably due to the fact that a certain stiffness exists so as to annul the effect. Sometimes after grinding, the oscillation disappears again and further grinding starts another higher oscillation and so on, which somewhat confirms the last explanation. Some plates work exceedingly well because one fundamental oscillation is a multiple of another fundamental oscillation.

Besides the three fundamental oscillations a piezo oscillator (Figure 2) will give a series of harmonics. They are due mostly to the distortion produced by the tube circuit. They should be distinguished from the higher modes of oscillation when the piezoelectric plate is used as a resonator and for which no harmonic relations necessarily exist.

Calibration of Frequency Meters by Means of a Piezo Oscillator

The method, which is due to Prof. G. W. Pierce (see footnote No. 3), is illustrated in Figure 7. Use is made of the three fundadamental frequencies due to the quartz plate, the harmonics of the corresponding electrical oscillations as well as of the harmonics of the auxiliary generator.

The procedure of measurement is as follows:

(1) By means of the inductance L_1 and the variable air condenser C_1 the piezo oscillator is set to one of the three fundamental vibrations of the quartz plate, say for instance, to 80 kc. This is accompanied by using an inductance L_1 which tunes for a certain setting of C_1 to this frequency.

With the piezoelectric plate connected between the filament and the grid, the capacity C_1 is gradually increased until a decrease is noted in the milliammeter in the plate circuit. The capacity of C_1 is further increased until[6] the oscillations stop.

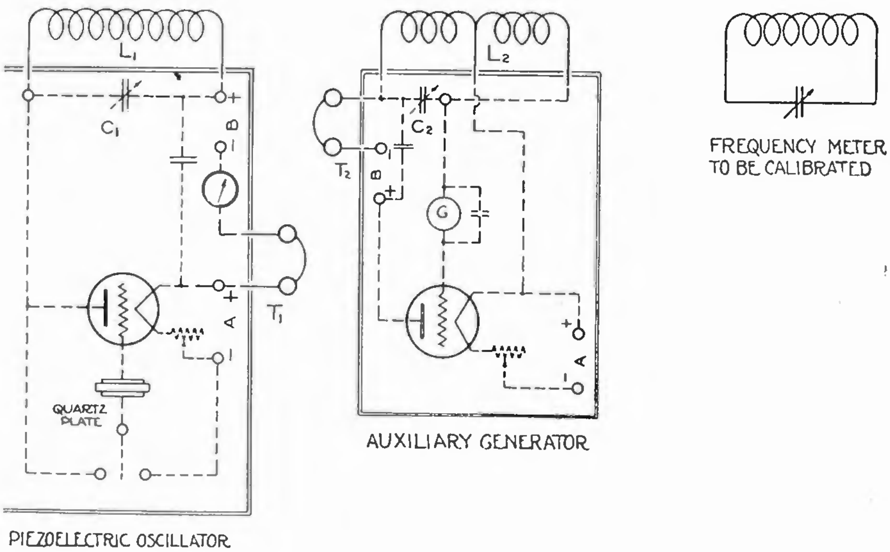

FIGURE 7—Arrangement for Calibrating a Frequency Meter

This happens when the $C_1 - L_1$ branch becomes a capacity reactance and produces a positive resistance between the grid and the filament. The circuit is then no longer regenerative and cannot sustain the oscillations set up by the piezoelectric plate.

The oscillations are started once more by setting the condenser at a point just below the resonance setting. Such a condition will, as a rule, produce a current which is rich in harmonics with a fundamental frequency of remarkable steadiness.[7]

(2) The loosely coupled auxiliary generator is set to the same fundamental frequency by noting the beat note either with the

[6] A milliammeter giving 5 to 10 ma. for maximum deflection is suitable for this work if an ordinary receiving tube is being used with about 80 volts on the plate.

[7] A weight of about 50 grams when resting on a plate vibrating at about 10^5 cycles per second does not change the frequency more than about 10 cycles, and one degree Centigrade change in temperature produces a frequency change of about 20 parts in one million.

telephone receiver T_1 or T_2. Resonance occurs where the critical silence condition (zero beat) within the range of the audible note is secured.[8]

(3) The frequency meter to be calibrated is loosely coupled to the auxiliary generator and its setting varied until the grid milliammeter G of the generator shows a decrease. When this is a minimum the frequency meter is tuned to resonance with the auxiliary generator, *i. e.*, to the fundamental[9] frequency of the piezo oscillator which, for example, is 80 kc.

(4) The frequency of the auxiliary generator is then increased until the next best beat note is heard and the critical silence position adjusted. The grid current decrease produced by the resonance of the frequency meter then gives the calibration for the second harmonic which is for the example 2×80 kc. Without the aid of an amplifier it is possible to go up to about the 20th harmonic. Using one or two stages of audio-frequency amplification for the beat note, it is possible to hear beat notes up to about the 200th harmonic. For ordinary work, the amplifiers can be dispensed with since the twenty harmonics of each of the three fundamental vibrations of the quartz plate give sufficient points. For beat notes due to harmonics of the piezo osillator with the fundamental of the auxiliary generator, it is best to use the receivers T_1 because the beat notes are then louder.

(5) By adjusting the fundamantal frequency of the auxiliary generator to half of the frequency of the piezo oscillator, that is, in the above case to 40 kc., the second harmonic (2×40 kc.) of the auxiliary generator will beat with the fundamental current of the piezo oscillator and the grid current decrease will give the calibration for $f/2=40$ kc., if f denotes the fundamental frequency of the piezo oscillator. In a similar way we get calibrations for $f/3$, $f/4$, $f/5$, etc., and this can be readily carried on at least to $f/20$ without the use of an amplifier. For practical frequencies the telephone receiver T_2 should be used since the harmonics of the auxiliary generator are being utilized. Since there are normally three fundamental frequencies, f_1, f_2 and f_3 of the quartz plate, it is evident that one quartz plate is sufficient to

[8] The beat note passes from a high pitch through a low note, narrow silence region, and again up to a higher note, while the condenser C of the auxiliary generator is being varied. The critical silence position can be set within about 15 cycles per second and even somewhat less by means of telephone receivers. If a still greater accuracy is required, a milliammeter can be used instead of phones for watching any of the slower beats between zero and 15 cycles.

[9] By means of the grid milliammeter, the frequency meter can be coupled very loosely to the auxiliary generator with a negligible effect on the frequency.

check the entire range of frequencies used in radio communication. Figures 8a and 8b show characteristic frequency spectra for a circular quartz plate and a rectangular plate, respectively. The exact values are given in Tables III and IV and are computed from only three primary calibrations, namely from the three fundamental frequencies f_1, f_2 and f_3 of the piezoelectric plate.

Example—Suppose a certain frequency meter is to be calibrated for a range between 10 and 50 degrees of the condenser

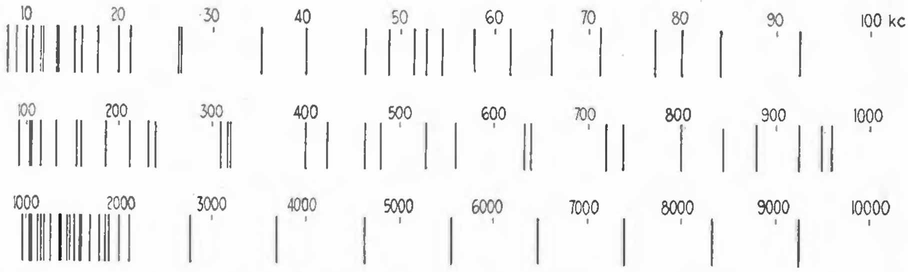

FIGURE 8a—Frequencies Produced by a Piezo Oscillator Using a Circular Quartz Plate 6.307 mm. Thick, and a Diameter of 36.15 mm. The Three Fundamental Frequencies are 75.05, 105.91 and 454.2 kc.

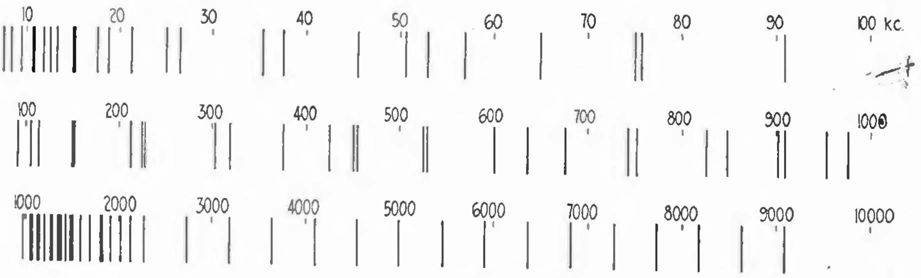

FIGURE 8b—Frequencies Produced by a Piezo Oscillator Using a Rectangular Quartz Plate 3.12 x 25.155 x 31.855 mm. The Three Fundamental Frequencies are 79.925, 105.41 and 924.57 kc.

setting. By means of the auxiliary generator whose settings are approximately known, a few points can be readily found to an accuracy of about one percent. Otherwise the old calibration of the frequency meter can be used or the calibration be estimated from the capacity and the approximate value of the inductance. Suppose that with one of the above procedures it has been found that at 20 degrees the frequency is roughly 226 kc.; at 30 degrees it is 190 kc., and at 40 degrees it is 168 kc. Using the piezo oscillator with the circular plate we find from Table III that 225.15 kc. is closest to 226 kc. and is due to the third harmonic ($3\,f_1$) of the lowest frequency of the piezoelectric plate, while 227.1 kc. corresponds to a setting of the auxiliary generator of half of the frequency ($f_3/2$) of the highest natural frequency of the plate.

TABLE III

FREQUENCIES AVAILABLE FROM PIEZO OSCILLATOR A (Circular Plate)

f_1 = 75.05 kc.	f_2 = 105.91 kc.	f_3 = 454.2 kc.
7.505 = $f_1/10$	211.82 = 2 f_2	1350.9 = 18 f_1
8.3389 = $f_1/9$	225.15 = 3 f_1	1362.6 = 3 f_3
9.38125 = $f_1/8$	227.1 = $f_3/2$	1376.83 = 13 f_2
10.591 = $f_2/10$	300.2 = 4 f_1	1425.95 = 19 f_1
10.7214 = $f_1/7$	317.73 = 3 f_2	1482.74 = 14 f_2
11.7678 = $f_2/9$	375.25 = 5 f_1	1501.0 = 20 f_1
12.5083 = $f_1/6$	423.64 = 4 f_2	1588.65 = 15 f_2
13.2388 = $f_2/8$	450.3 = 6 f_1	1694.56 = 16 f_2
15.01 = $f_1/5$	454.2 = f_3	1800.47 = 17 f_2
15.13 = $f_2/7$	525.35 = 7 f_1	1816.6 = 4 f_3
17.6517 = $f_2/6$	529.55 = 5 f_2	1906.38 = 18 f_2
18.7625 = $f_1/4$	600.4 = 8 f_1	2012.29 = 19 f_2
21.182 = $f_2/5$	635.46 = 6 f_2	2118.2 = 20 f_2
25.0167 = $f_1/3$	675.45 = 9 f_1	2271.0 = 5 f_3
26.4775 = $f_2/4$	741.37 = 7 f_2	2725.2 = 6 f_3
35.3033 = $f_2/3$	750.5 = 10 f_1	3179.4 = 7 f_3
37.525 = $f_1/2$	825.55 = 11 f_1	3633.6 = 8 f_3
45.42 = $f_3/10$	847.28 = 8 f_2	4087.8 = 9 f_3
50.4667 = $f_3/9$	900.6 = 12 f_1	4542.0 = 10 f_3
52.955 = $f_2/2$	908.4 = 2 f_3	4996.2 = 11 f_3
56.775 = $f_3/8$	953.19 = 9 f_2	5450.4 = 12 f_3
64.8857 = $f_3/7$	975.65 = 13 f_1	5904.6 = 13 f_3
75.05 = f_1	1050.7 = 14 f_1	6358.8 = 14 f_3
75.7 = $f_3/6$	1059.1 = 10 f_2	6813.0 = 15 f_3
90.84 = $f_3/5$	1125.75 = 15 f_1	7267.2 = 16 f_3
105.91 = f_2	1165.01 = 11 f_2	7721.4 = 17 f_3
113.55 = $f_3/4$	1200.8 = 16 f_1	8175.6 = 18 f_3
150.1 = 2 f_1	1270.92 = 12 f_2	8629.8 = 19 f_3
151.4 = $f_3/3$	1275.85 = 17 f_1	9084.0 = 20 f_3

TABLE IV

FREQUENCIES AVAILABLE FROM PIEZO OSCILLATOR B (Rectangular Plate)

f_1 = 79.925 kc.	f_2 = 105.41 kc.	f_3 = 924.54 kc.
7.9925 = $f_1/10$	115.567 = $f_3/8$	1264.92 = 12 f_2
8.8805 = $f_1/9$	132.077 = $f_3/7$	1278.8 = 16 f_1
9.9906 = $f_1/8$	154.09 = $f_3/6$	1358.725 = 17 f_1
10.541 = $f_2/10$	159.85 = 2 f_1	1370.33 = 13 f_2
11.4178 = $f_1/7$	184.908 = $f_3/5$	1438.65 = 18 f_1
11.712 = $f_2/9$	210.82 = 2 f_2	1475.74 = 14 f_2
13.176 = $f_2/8$	231.135 = $f_3/4$	1518.575 = 19 f
13.321 = $f_1/6$	239.775 = 3 f_1	1581.15 = 15 f_2
15.058 = $f_2/7$	308.18 = $f_3/3$	1598.5 = 20 f_1
15.985 = $f_1/5$	316.23 = 3 f_2	1686.56 = 16 f_2
17.568 = $f_2/6$	319.7 = 4 f_1	1791.97 = 17 f_2
19.981 = $f_1/4$	399.625 = 5 f_1	1849.08 = 2 f_3
21.082 = $f_2/5$	421.64 = 4 f_2	1897.38 = 18 f_2
26.352 = $f_2/4$	462.27 = $f_3/2$	2002.79 = 19 f_2
26.642 = $f_1/3$	479.55 = 6 f_1	2108.2 = 20 f_2
35.137 = $f_2/3$	527.05 = 5 f_2	2773.62 = 3 f_3
39.9625 = $f_1/2$	559.475 = 7 f_1	3698.16 = 4 f_3
46.23 = $f_3/20$	632.46 = 6 f_2	4622.7 = 5 f_3
48.66 = $f_3/19$	639.4 = 8 f_1	5547.24 = 6 f_3
51.36 = $f_3/18$	719325 = 9 f_1	6471.78 = 7 f_3
52.705 = $f_2/2$	737.87 = 7 f_2	7396.32 = 8 f_3
54.38 = $f_3/17$	799.25 = 10 f_1	8320.86 = 9 f_3
57.78 = $f_3/16$	843.28 = 8 f_2	9245.4 = 10 f_3
61.64 = $f_3/15$	879.175 = 11 f_1	10169.94 = 11 f_3
66.04 = $f_3/14$	924.54 = f_3	11094.48 = 12 f_3
71.12 = $f_3/13$	948.69 = 9 f_2	12019.02 = 13 f_3
77.04 = $f_3/12$	959.1 = 12 f_1	12943.56 = 14 f_3
79.925 = f_1	1039.025 = 13 f_1	13868.1 = 15 f_3
84.05 = $f_3/11$	1054.1 = 10 f_2	14792.64 = 16 f_3
92.454 = $f_3/10$	1118.95 = 14 f_1	15717.18 = 17 f_3
102.727 = $f_3/9$	1159.51 = 11 f_2	16641.72 = 18 f_3
105.41 = f_2	1198.875 = 15 f_1	17566.26 = 14 f_3
		18490.8 = 20 f_3

Either one can be used since the points are rather close together. In a similar way 151.4 kc. $=f_3/3$ requires that the auxiliary generator is set to one-third of the frequency of the highest frequency of the piezoelectric plate corresponding roughly to about 50 degrees on the scale of the auxiliary generator. It is convenient to have a rough calibration for the auxiliary generator used. The accurate calibration is then as follows:

(a) The piezo oscillator is excited to the higher frequency which in this particular case is $f_3=454.2$ kc.

(b) The auxiliary generator is set to a frequency of about 151 kc. according to the rough calibration given on the curve of the coil and the condenser C_2 varied slightly until a beat note is heard and then adjusted to the point of zero beat.

(c) The dip [12] in the grid current produced by the resonance of the frequency meter then gives the calibration for 151.4 kc.

(d) By searching by means of C_2 and for the same vibration ($f_3=454.2$ kc.) of the plate in the neighborhood of 225 kc. for a beat note and setting again to the critical silence point, calibration for 227.1 kc. is secured.

(e) Next, the piezo oscillator is adjusted so that the plate vibrates at $f_1=75.05$ kc., and a beat note found near 225 kc. After securing the critical silence point and obtaining the grid current dip, the calibration for 225.15 kc. is obtained.

Beats Between Harmonics and Their Application

When the coupling between the auxiliary generator and the piezo oscillator is somewhat closer but still loose enough to avoid any objectionable interaction between the respective circuits, it is possible to hear weak beat notes, which correspond to 1.25, 1.33, 1.5, etc., times a fundamental frequency f of the quartz plates of zero beat settings for $f/1.25$, $f/1.33$, $f/1.5$, etc. Such beats are caused by the interference of harmonic currents of the piezo oscillator with harmonic currents of the auxiliary generator. This is evident when we express $1.25f$ by $5f/4$ and note that for a fundamental frequency f of the auxiliary generator and its adjustment to zero beat within the region of such an interference the relation

$$5f\frac{=F}{4}$$

[12] For certain couplings (which are not extremely loose) as the frequency meter gets gradually in resonance with the auxiliary generator a low beat note appears again and disappears as resonance occurs. This method can be used for checking the grid dip.

or

$$5f = 4F$$

holds. Hence the fifth harmonic of the piezo oscillator produces a zero beat with the fourth harmonic of the auxiliary generator. In a similar way the case of $1.33f = \frac{4f}{3}$ shows that the fourth harmonic of the piezo oscillator is beating with the third harmonic of the auxiliary generator and that for $1.5f$ the third harmonic of the piezo oscillator beats with the second harmonic of the auxiliary generator.

Such beats can also be explained by means of beats of beat currents. Suppose the piezo oscillator is excited with a fundamental frequency $f = 80$ kc., and that the fundamental frequency of the auxiliary generator is set to $F = 125$ kc., then an interference takes place between the fundamental currents of the respective high frequency sources. The amplitude variation of the resultant current occurs at the rate of $F - f = 45$ kc., which corresponds to a high-frequency variation which is not audible. Another amplitude variation which is possible is due to the interference between the second harmonic of the piezo oscillator and the fundamental current of the auxiliary generator which produce again a high-frequency variation but of frequency $2f - F =$ 35 kc. But these two high-frequency currents can beat again and with each other producing an audible current of frequency $45 - 35 = 10$ kc. If the auxiliary genenator is, therefore, varied until $F = 120$ kc., then

$$F - f = 2f - F = 40 \text{ kc.}$$

and a zero beat condition is attained which confirms the case of $1.5f = 120$ kc. According to this explanation the so-called "spurious" beat notes are due to beats between beat currents, which accounts for the fact that they are, as a rule, weaker than the beat notes giving the settings as expected directly from the theorm of Fourier. The first explanation by means of the interference between the harmonics of each circuit confirms the law

$$a.f = b.F \tag{10}$$

where a and b are whole numbers and is perhaps the most direct way of explaining the phenomenon.

For ordinary work, it seems best to utilize only the main harmonics as shown in Tables III and IV; but if more points are required, for example, two more points between 90.84 and 105.91 kc. (Table III), it is possible to secure them by means of the fundamental plate vibration $f_1 = 75.05$ kc. by using $\frac{5f_1}{4} = 93.81$

and $\frac{4f_1}{3} = 99.82$ kc.

Method Used for Grinding Piezoelectric Plates Accuratey to the Required Frequency

It is possible to grind a quartz plate accurately within a small fraction of a desired frequency, even though the desired frequency is of the order of 10^6 cycles per second. An ordinary standard frequency meter does not have the resolving power to indicate such accurate settings, but the beat method, with a visual beat indicator, can be used. The principle of this method is as follows: An auxiliary generator is required, which can be set at the desired frequency and can maintain it constant for some time. The piezoelectric plate, after first being ground to the approximate frequency according to the frequency formulas given in this paper, is connected as indicated in Figure 2. The holder for the plate is shown in Figure 9b and provides an air

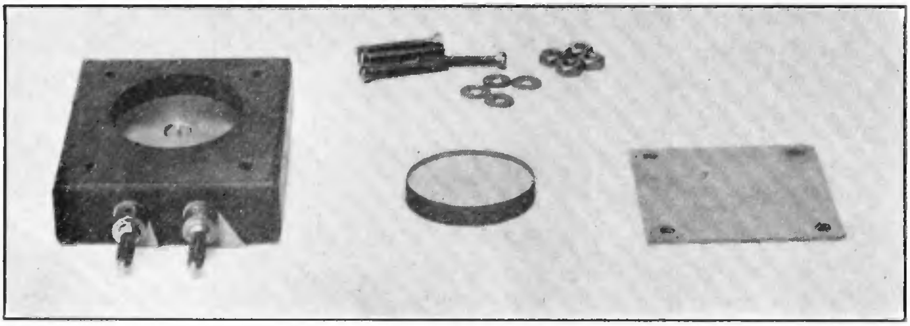

FIGURE 9a—Quartz Plate and Holder for Piezo Oscillator

gap of about one-third mm. between the upper face of the plate and the brass cover. Figure 9a shows the holder open. The plate rests on a polished brass plate. A note will be heard in the telephone receiver of the piezo oscillator, since the frequency of the plate is somewhat off. The plate is taken out of the holder and moved slightly over a grinding plate, using fine emery with water and tried again and again until the note becomes so low as to be difficult to hear. This indicates that the frequency difference is about 15 cycles, the exact frequency depending on the observer. By using a portable galvanometer instead of the phones, the slower beats between 15 and zero cycles can be indicated. It is convenient to connect a portable galvanometer using about 1 to 2 ma. current for the maximum deflection in series with a crystal detector and a coil coupled loosely to both the piezo oscillator and the auxiliary generator. When the pointer swings to and fro twice in one second, it indicates that the frequency is off by two cycles per second; and if the pointer moves once in two minutes, the frequency is only off by 1/120th of a cycle per second. Accuracies of such a nature are seldom required, and the grinding, according to the formulas given here, is usually sufficiently accurate.

Rough Test for Suitable Piezoelectric Materials

For a rough test of material to determine the suitability for piezo oscillators, a plate or disk is cut from the material which

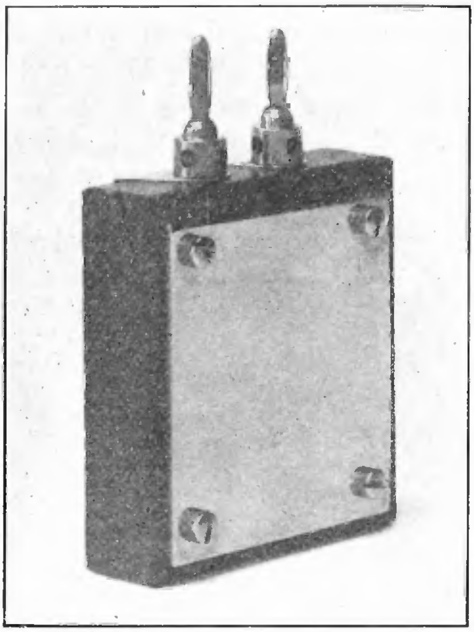

Figure 9b—Quartz Plate Holder for Piezo Oscillator Assembled

does not need to be exactly parallel), and this plate is inserted between the plate and the grid of an auxiliary generator which has a telephone receiver in the plate circuit. If the sample is suitable it will give several distinctive absorption noises while acting as a resonator. The frequency of the generator is gradually varied and a click will be heard for the different modes of resonator actions.

Method for Controlling Power by Means of Piezoelectric Plate

Since it is not possible to generate much power[13] in the circuit in which the quartz plate is connected, an amplifier which is free from self-oscillation must be used. An arrangement is shown in Figure 10. The piezo oscillator is set for maximum output so that its fundamental current is almost sinusoidal and pronounced. This is done by varying the capacity of C (circuit as in Figure 2), until the oscillation is about to stop. The amplifier tube (50-watt tube) as well as the power tube (250 watts) use negative grid voltages so that they deliver no plate current at times when the piezoelectric plate is not vibrating. These tubes are therefore only loaded at such times as they are required to deliver power. Experiment shows that there is no transfer of power back to the piezo oscillator, and that the arrangement does not generate but merely amplifies the current of the first circuit. This can be demonstrated by keying the switch K. With the

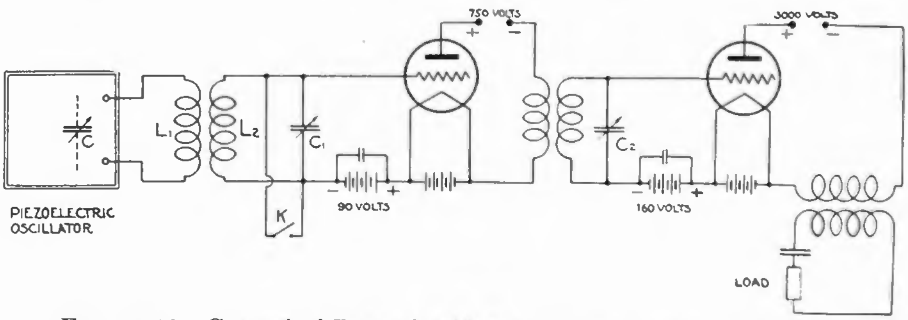

FIGURE 10—Control of Power by Means of Piezoelectric Oscillator

switch open, incandescent lamps consuming 250 watts in place of the load burn brightly; with the switch closed they are extinguished. The arrangement indicated works well. To control more power, one or more stages may be added. The control of power is of special interest for high-frequency work (2,000 kc. and above), where the constancy of the frequency is otherwise greatly impaired by body capacity, etc. Special means have to be used then to produce the very high-frequency oscillations. One is, for instance, by using a suitable auxiliary voltage in the grid circuit of the piezo oscillator. If an appropriate choke coil is used instead of the auxiliary voltage in the grid branch, care muct be taken that the tube does not produce oscillations which are due to the constants of the circuit.

Audio-Frequency Currents from Piezo Plates of Moderate Size

Since the frequency in kilocycles of a quartz plate is roughly 3,000 divided by the dimension in mm. along which the vibration occurs, it is evident that a very large plate has to be used for producing audio currents. Audio frequencies can, however, be obtained when the interference vibrations of two high frequencies are produced, giving beats of audio frequency. There are three methods for accomplishing this.

(1) Use of two piezo oscillators. Suppose one marked A has a fundamental frequency of 100 kc. and another marked B a frequency of 99 kc. Each plate is connected in a separate piezo oscillator as shown in Figure 2. The two circuits may be coupled to a third circuit with a detecting device and will give an audio frequency current of 1 kc. Either of the two circuits may be used also as a detector, and the audio frequency taken directly from one of them. For ordinary work this gives the audio-frequency currents readily. However, one circuit has the tendency to affect the other, that is, by adjusting the amplitude of one high-frequency component the frequency of the audio current varies somewhat, often as much as 10 to 20 cycles per second. This is a disadvantage when a high precision is required unless the circuit is calibrated and used only for certain amplitudes (condenser settings of the respective piezo oscillators).

(2) Use of two quartz plates in the same circuit. The two plates A and B may be connected in parallel but in separate plate holders and in the same circuit which gives directly the audio-frequency current. The audio-frequency oscillation is then a little harder to start since both high frequencies are produced by the same tube. It may happen that one of the two high-frequency vibrations builds up faster than the other and uses all of the available power and annuls the effect of the other oscillation. This is sometimes accompanied by a short whistle during which period both oscillations exist. Sometimes there is no whistle at all, in which case only one oscillation starts up.

By using frequencies in the neighborhood of 100 kc. and higher, it is easy to find a plate inductance which starts both frequencies and produces the desired audio-frequency current. If it is done properly the audio frequency can be produced for a range of condenser setting (about 10 to 20 degrees) and adjusted to a point for which maximum loudness exists. This is the point for which the oscillator should be calibrated and used.

(3) Use of a single quartz plate. A single piezoelectric element may be used for producing the audio-frequency current directly. To accomplish this a plate is ground first for producing the component vibration A and then a small step ground in it[14]

[13] Not more than about 6 watts for a plate of average rating.

[14] The height of the step is exceedingly small so that the quartz has still the shape of a plate to the eye and can be used in an ordinary plate holder with an air gap of about 1/3 mm.

as indicated in Figure 11 in order to superimpose on it the high-frequency vibration B. The plate is used in the ordinary way, (Figure 2) and works well. The oscillogram of Figure 12 shows the beat current which produces an audible note. Figure 13

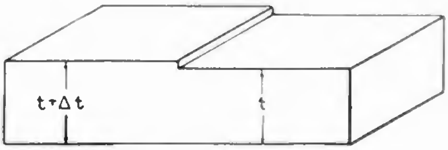

FIGURE 11—A Piezoelectric Plate with a Minute Step in it for Audio Frequency Currents

gives an arrangement using a plate as indicated in Figure 11, when more output is required. It is an arrangement which is self-starting, that is, a fixed condenser is used in the piezo circuit and the audio frequency current will start upon closing it. The

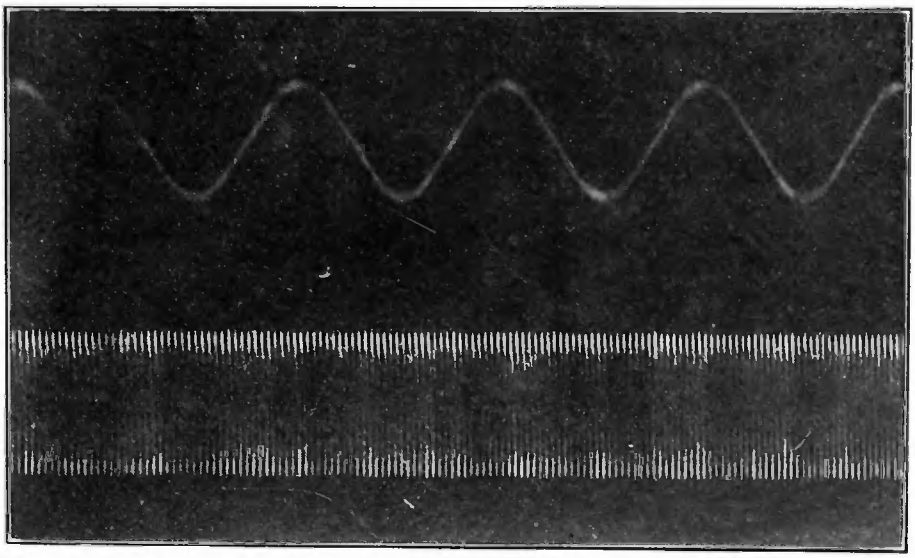

FIGURE 12—Beat Current Produced by a Single Small Piezoelectric Oscillator. (f . . 1912.1 Cycles per Second, Upper Oscillogram is the Timing Wave.)

arrangement of Figure 13 was used for producing the wave shown in Figure 12. For the oscillographic work and other applications it is also possible to use the piezoelectric plate circuit directly in the output circuit as long as not more than about 6 watts are required. It is to be noted that the output of an audio-frequency oscillator is somewhat smaller than when only one component current is flowing. It is not necessary always to use a load resistance across the output branch as indicated in Figure 13. Any amplifier circuit arrangement will be satisfactory.

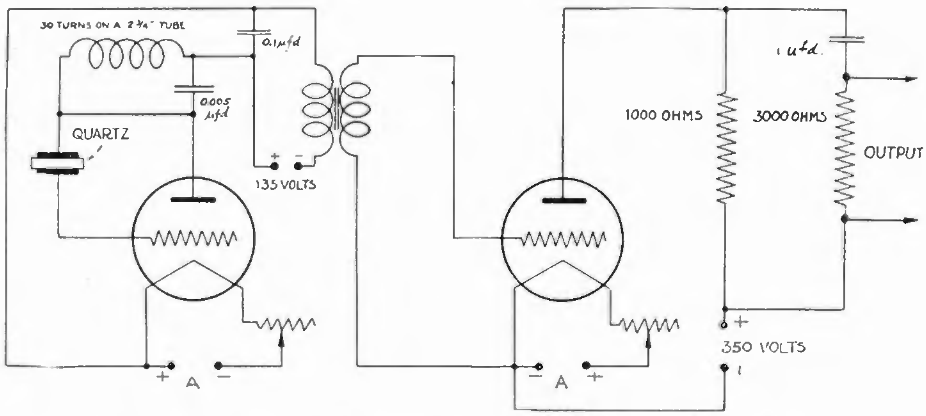

FIGURE 13—Audio-frequency Oscillator Which is Self-starting

MISCELLANEOUS APPLICATIONS

By using the method herein described, it is possible to grind a plate to any suitable frequency. It is, therefore, possible to design the equivalent of a second pendulum or any other timing device. The disadvantages described in connection with the first method for producing audio-frequency currents can be used to advantage for making a radio or audio-frequency generator whose frequency can be varied somewhat without regrinding the piezoelectric plates.

A change of a few cycles and less in a plate for radio frequency currents is due to a change in dimension which can not be noted with a micrometer. It can, therefore, be used for measuring very small variations in the thickness of piezoelectric materials.

Using a sphere of quartz the optical axis can be roughly determined electrically (no direct electrical effect along it) as well as the main piezoelectric axis by placing the sphere between two cup-shaped electrodes and noting the strength of any resonator effects when placed along different diameters of the sphere.

Working backwards, using the electrical data (frqeuency), and the dimensions, it gives a means for finding certain mechanical properties of the substance such as its elasticity from the velocity and the density.

Using a vibrating piezoelectric plate in front of a fine slot or another vibrating plate, a shutter can be designed which opens and closes at a very high rate. This may open up a new field in experimental optics for direct and reflected light rays, and give a means of determining the velocity of light.

Conclusions

(1) Experiments with quartz plates have shown that they can be used in an electron tube circuit for producing radio-frequency currents of fixed frequencies bearing a definite relation to the dimensions of the plate.

(2) The piezo oscillator can be used together with an auxiliary generator for standardizing a frequency meter.

(3) A single piezoelectric plate can be employed as a standard for the entire range of frequencies used in radio communication.

(4) By using special arrangements a small plate can be employed for producing audio-frequency currents.

(5) Methods are given for grinding a plate accurately to a given frequency.

(6) Formulas are given for designing plates to a desired frequency to a fair degree of accuracy.

(7) Other miscellaneous applications are described.

SAFEGUARDS FOR THE RADIO INVENTOR*

By

Everett N. Curtis

(Member of New York Bar and Lecturer on Patent Law at Columbia University)

My topic assigned for this evening concerns the safeguarding of the inventor who, ignorant of patent law, may neglect the taking of those steps or precautions which he may at some time find of infinite value in the preservation of his rights. The inexperienced inventor as a rule is the victim of his own imagination or his own unfounded suspicions, in that he is usually watching for some patent pirate just around the corner whom he fancies is looking for the opportunity of swooping down upon him and of taking away the coveted prize. He is, therefore, fearful of disclosing his invention to anybody. He is suspicious even of his friends. It may be in rare instances his friends are such as to warrant such suspicions, but more often the inventor's secretiveness results in his neglecting to preserve proper evidence of his date of conception and his reduction to practice, so that in case of a contest as to who is the prior inventor of a certain invention, he is unable to offer good and sufficient proof of the actual facts, and loses the contest, not to a pirate but to a rival inventor with the requisite evidence.

Some inventors have the idea that patenting an invention is a sort of marathon race to the Patent Office. They go to a motion picture house and see a fearsome drama, in which the inventor after undergoing and surviving many perils, finally races up the steps of the Patent Office one jump ahead of the villain and deposits his patent application just in time to save the day. In the same drama, with the same marvelous speed, unknown in practice, the Patent Office immediately examines the application and prior art, and the next day issues the patent. As most of you know, nothing could be further from the truth than this. While it is of advantage to be the first to file an application in the Patent Office, a prior inventor if he be diligent in

*Received by the Editor March 11, 1926. Presented by title only at the New York meeting of The Institute of Radio Engineers June 2, 1926.

reducing to practice and in filing his application will, nevertheless, prevail even though his filing date is subsequent to his rival, but not two years or more prior to the issue date of his rival's patent. Furthermore, getting a patent is not a speedy process. Ordinarily it is several months before a patent application is reached by the examiner and several years before the patent actually goes to issue.

It sometimes happens that where two or more men have been working to bring an invention to a successful issue, it is determined by them to file an application for a joint invention. The central idea may have been the creation of one of them, but the others have contributed time, effort, and mechanical skill, and it seems only just, all things considered, that the application should be filed in the names of all of them. This is often a snare and a delusion. Joint inventors are those who jointly create a single invention. If the creation of the invention is the product of a single mind, no amount of co-operation of others in reducing the same to practice can change the original individual creation into a joint invention. It is rarely that two or more persons can unite together in creating a single invention. In many cases, where so-called joint inventors are subjected to cross examination, it develops that there was but one inventor and that the others were not inventors at all and the patent is declared void for this reason. Great care should, therefore, be taken where an inventor deems himself a joint inventor. He should carefully sift the whole situation to determine whether or not after all there was really joint invention, and only after mature consideration should a joint application be filed.

It is of great importance to the radio inventor to keep and preserve careful records. He should have note books in which to make sketches of such inventions as may occur to him from time to time, together with notes of explanation. These should all be dated. If he thinks that any of these are of material importance, he should secure the signature of witnesses, and also have made up dated drawings by a competent draftsman fully illustrating his construction. Another method is that of a drawing and affidavit clearly describing the same and setting forth the fundamental features of the invention. Still another method is that of writing dated letters disclosing the invention to a relative or to a friend, particularly where the envelope bearing the postmark is preserved. It is also of importance to save if possible any models or full-sized machines together with working drawings, bills for parts, and records of actual tests. All these matters go to show the date of invention, the date of disclosure and the date of reduction to practice.

It is not the date of filing an application for patent which controls in a contest as to who is the first inventor. It is he who can show by a preponderance of the evidence that he first conceived the invention and with due diligence reduced it to practice, that will be declared the first inventor and entitled to the patent.

Thus, for example, in the well-known litigation over the Armstrong Feed-Back Patent in the Federal courts in the second circuit, Armstrong was able to prevail over all other alleged inventors making claims to his invention by reason of the decisive character of his proofs establishing the fact that he was the first inventor. The inventor's mere assertion, standing alone, that he invented his device on a certain day amounts to nothing No court will ever find the date on invention to be established on the uncorroborated testimony of the inventor. It is, therefore, of the utmost importance that this evidence be secured and preserved as heretofore indicated or the inventor will have to bear the penalty of his neglect. So also must the inventor's reduction to practice be fully substantiated. If sufficiently early in point of time the date of the filing of the application may be relied upon as a constructive reduction to practice, but it is better, all things considered, to try out and demonstrate at the earliest possible moment under the conditions of actual commercial use the operativeness of the invention. It is evidence of the tested reduction to practice which counts most heavily with the courts, and the one which most effectively disposes of the contention of abandoned experiment.

An inventor cannot afford to sleep upon his rights. If he has made an invention it is his duty to reduce it to practice at the earliest possible moment and to apply for a patent. The theory of reward to an inventor by the grant of patent is based upon some obligation in his behalf. A patent is a contract. In consideration of the enjoyment of the exclusive right of the invention for the period of 17 years, the inventor makes a full disclosure to the public in order that at the end of this period the public may have thrown open to it the full knowledge of and right to make, use and sell the invention. In other words, an inventor must play fair with the government. If he makes an invention and takes no steps toward reducing it to practice or demonstrating its practical use until a rival inventor enters the field, he may lose his right. If he stands idly by and permits others to use his invention without protest, his acts may be construed as a constructive abandonment, and his rights to a patent are forfeited. Where this right is once abandoned by the inventor, it cannot afterward be resumed at pleasure, as where gifts are thus made to the public, they become absolute.

Another important matter neglected by inventors is the necessity of making a full disclosure of the invention in the application as originally filed. While the fullest opportunity of amendment both of the specification and claims is permitted in elucidating, amplifying and correcting the same, it is not permitted to incorporate new matter. The inventor, therefore, should not rely too much upon his attorney for this original disclosure. He should read and re-read the specification and claims as drafted by his attorney to make sure that his invention is fully and correctly set forth. It is better by far to say too much than not enough. Too much may easily be cancelled, but if the inventor says too little, he will be correspondingly limited. The claims are also important. The claims are the life of the patent. The inventor is required by law particularly to point out and distinctly claim the part, improvement or combination which he claims as his invention. Nothing is secured to the patentee unless there be in his patent a valid claim covering it.

What is not claimed is by implication given to the public, so claims should be drafted to give the inventor the broadest possible protection. The broadest claim of the patent is the claim containing the fundamentals of the invention, or the invention reduced to its lowest terms. The inventor should realize this and carefully examine the claims with this in mind. The drawings should be carefully checked, and enough figures should be employed fully to illustrate the invention. Mistakes are likely to creep in. Care must be taken to correct them before the patent is issued. If a drawing is defective, as for example, where an inoperative hoop-up is shown, the effect on the patent may be disastrous and may result in the patent being declared to be void for want of utility. The drawings, specification and claims are all considered together in determining the scope of a patent, and the claims are to be fairly construed so as to cover the invention if possible, and save it especially if it be a meritorious one. Claims are to be construed in the light of the specification and in view of the prior art. If the invention is primary, a broad interpretation is to be given, but if the art is close, the claims are to be narrowly construed.

This brings us to the consideration of the nature of patent rights. For an alleged invention to be patentable, it must be new, it must have utility, and it must involve the exercise of the inventive faculty. What the inventor gets by his patent is a negative right, that is, the right to exclude others from making, using or selling his invention, without his permission. If his rights are infringed, he may obtain relief by a suit at law for damages or by a suit in equity for an injunction, profits and damages.

A patent right is not a natural right. It is entirely the creation of statute. For many years of the earth's history, the inventor had no reward. Patent systems taking the inventor into consideration have been of comparatively recent growth. Even under our own patent laws in the early history of our country there were but few patents granted. Practically all of our great advance in invention has been accomplished within the last fifty years, and is due largely to the encouragement given to the inventor by patent laws the world over. In most foreign countries, the obligation is imposed upon the patentee of working the invention under penalty of forfeiture of the patent. Such obligation has never been imposed by the laws of this country, and this may be one of the reasons why invention here is so prolific and why so many applications for patents are filed in the U.S. Patent Office.

The question of novelty plays a considerable part in determining the scope of a patent, and accordingly the prior art must always be considered in drafting a patent application. It is useless to attempt to cover in a patent that which is old and well known to the art. An inventor is presumed to know or hold to the knowledge of what has gone before, and his claims are limited or avoided accordingly. It is well, therefore, for an inventor to educate himself in the particular art to which his invention belongs. This he may do by reading the literature accessible to him, and by having searches made of the files of the Patent Office at Washington.

The two-year statutory periods are important to the inventor. The patent statute provides that a prior printed publication or patent published in this or in any foreign country more than two years prior to the filing of the inventor's application here, or a public use or sale of the invention in this country more than two years prior to such date, shall operate as a bar to the issuance of the patent. This language not only applies to publications and uses of other persons than the inventor but also to the inventor himself. Care should accordingly be taken by the inven-

tor not to permit these two-year periods to run against him, either by rushing into print or by permitting a public use of his invention and then neglecting to file his application within the time. Furthermore, the inventor, if he contemplates filing applications abroad, must be careful not to publicly publish or use the invention here in advance of the making of such applications or he may lose valuable rights or perhaps all rights relating thereto.

Some inventors have thought that by concealing their inventions, as in the case of a secret process, to delay over a considerable number of years the filing of an application for a patent until it was determined that secrecy could not longer be maintained. The danger of this is that courts have held in a number of cases that such conduct on the part of the inventor constituted abandonment and forfeiture of the right to obtain a patent.

In the absence of a special agreement, inventions made by an employee belong to him personally. But where he is employed in a certain line of work to invent, his inventions belong to his employer. That is, while the mere fact he is employed by another person does not preclude him from making improvements in machines with which he is connected and making application for patents therefor as his own personal property, yet if he be employed to make such improvements the right to such patent belongs to his employer, since he is merely doing what he was employed to do. Even if he be not employed to invent, if he uses the property of his employer, and the services of other employees to develop and put into practical form his invention, and permits his employer to use the invention without protest, a shop right or license may result to the employer. Contracts with employers are usually drawn by the employer, and are construed most favorably to the employee. A contract requiring an inventor to turn over *all* the inventions he may make without limitation to his employer is void as in restraint of trade and against public policy. Such agreements must be limited to the line of endeavor in which the employee is engaged or by the scope of the employer's business, and if it be desired that the employee should turn over such inventions or applications therefor to the employer, words of assignment or the equivalent should be unequivocally set forth. Otherwise, on a suit for specific performance, the court might decline to act because of uncertainty.

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SUMMARY: Precautions for the radio inventor who is not associated with an organization which includes a patent department, with explanation why such precautions are necessary.

"KDKA"

By

D. G. Little and R. L. Davis

Radio Engineering Department, Westinghouse Electric and Manufacturing Company

Introduction

KDKA, up to March 1, 1925, has been described in previous papers before the Institute. It is the purpose of this paper to bring the history up to date by describing the equipment now in use, both for regular broadcasting and for short-wave international broadcasting and relay work. The short-wave transmitter, employed for interworks telegraph service, will also be described.

General

The rapid development of broadcasting, both long and short wave, indicated that the space available at the East Pittsburgh Works would soon become inadequate for further expansion. A place was, therefore, selected about two miles from the old location, on high and relatively level ground, free of buildings and structures that might influence radio transmission, and a building laid out that would house the proposed equipment for all transmission activities. The antennas and buildings cover a space approximately 300 x 500 feet. Figure 1 shows the station building and the antennas. The station building is located in the center of this plot and is a basement and one story brick structure 25 x 65 feet, with a wing on the front 20 x 30 feet. The offices, storerooms, shop, and audio frequency control room are located in the wing; while the radio equipment is placed in the main part of the building, the long wave at the South end, and the short wave at the North end. The power apparatus, such as motor-generator sets for filament heating, transformers, filters, control apparatus, and storage batteries, are placed in the basement, leaving the main floor for the rectifier, modulator, and oscillator vacuum tube frames.

Presented before the Institute of Radio Engineers, New York, September 2, 1925. Received by the Editor October 5, 1925.

Power for the station is obtained through underground cables from two separate substations of the Duquesne Light Company. A substation in the basement of the building transforms this power of 4,000 volts, three phase, 60 cycle, into 220 volts, three phase, which is then distributed to the radio equipment.

The short wave or 64-meter transmission work was moved to the new building during the summer of 1924, and has been in use since that time.

Careful tests were made at the new location before the 309-meter apparatus described in this paper was put in regular oper-

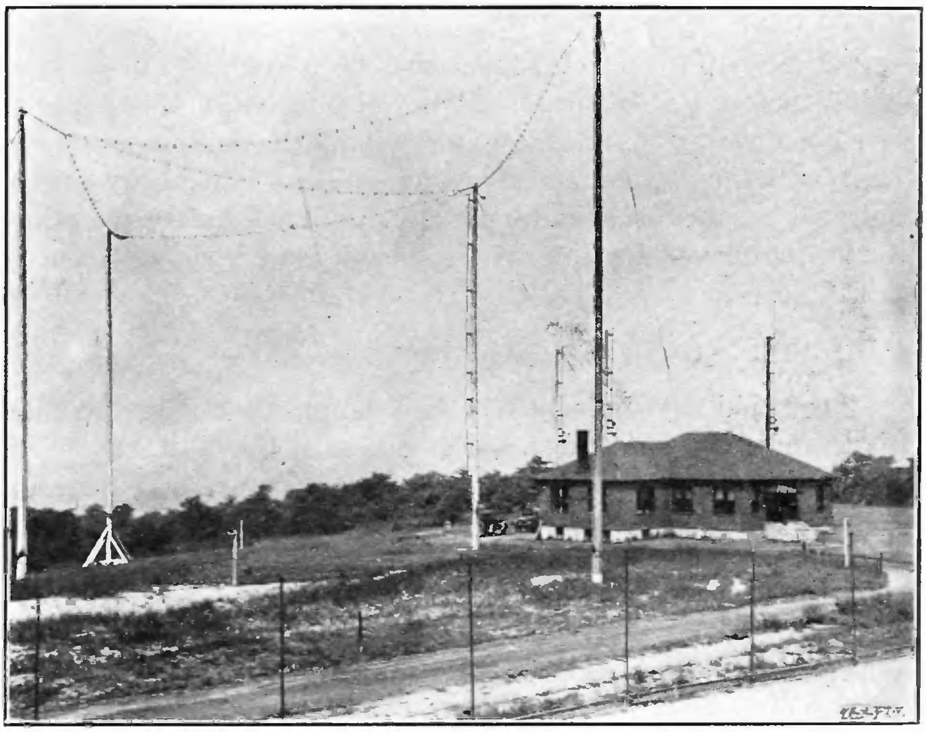


FIGURE 1—General View of "KDKA" Station

ation. On the night of March 19, 1925, alternate numbers of the program were run from the old station at East Pittsburgh, and from the new station. The program selections were numbered and reports requested from Westinghouse representatives in all parts of the United States. The same power was put into the oscillators at the two stations, thus checking both the locations and the antenna systems. The results of this test indicated that the new location was considerably better than the old. The majority of nearly 100 observers reported an increase in the signal strength received, particularly at distances beyond 300 miles; and as the new antennas had an effective height somewhat less than the old, the new location on high, level ground is a considerable improvement over the old location in the valley at East Pittsburgh.

Figure 2 shows in schematic form the layout of circuits.

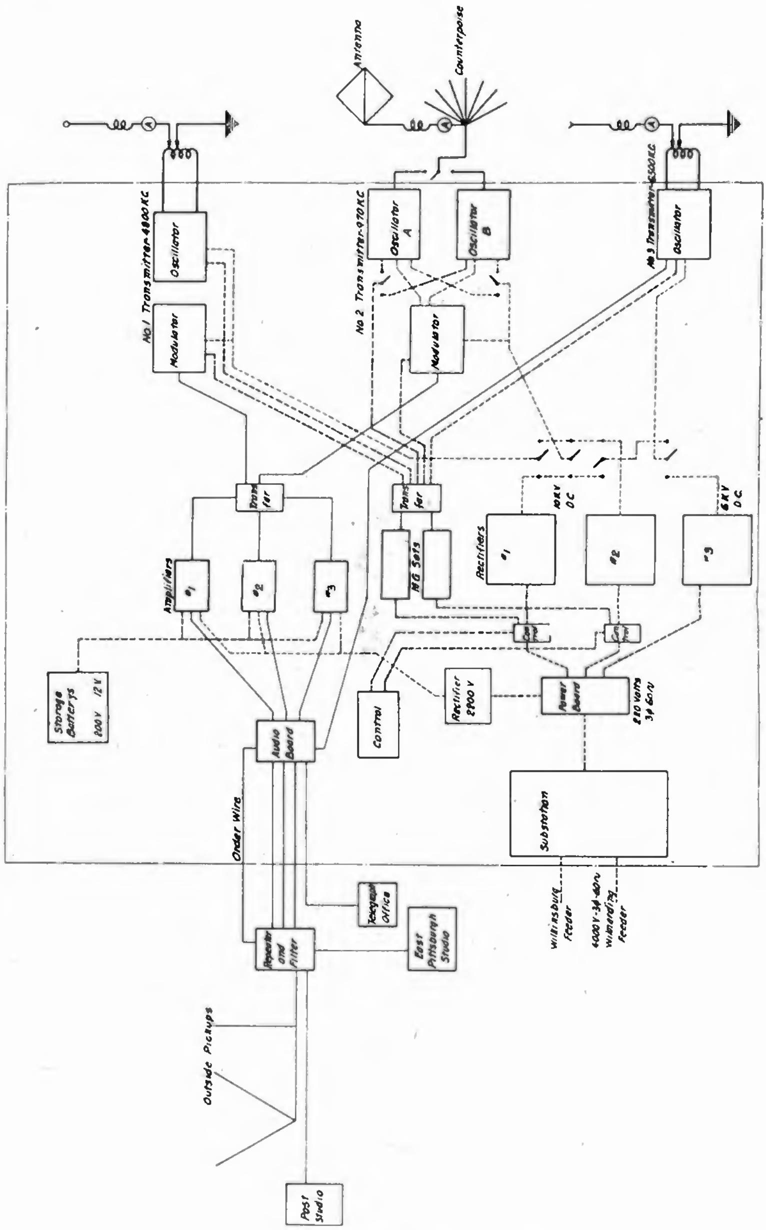


FIGURE 2—Schematic Circuit Diagram

No. 2 TRANSMITTER

The equipment employed for regular broadcasting at 970 kc., 309.1 meters, is known as No. 2 Transmitter, and is here described.

Antenna. The 970 kc. antenna system differs somewhat from the conventional flat-top type. This antenna has been shown in Figure 1. Four spruce poles, 80 feet in height, support five cages, each 100 feet long. The vertical conductor is a 1½-in. diameter copper tube rigidly supported on porcelain pillar insulators by the pole nearest the station building. Three cages are connected to the top of the vertical lead and extend horizontally, with angles of 60 degrees between them, to the remaining three poles, which in turn are connected by two cages. Each cage is made up of eight No. 10 copper wires on micarta ring spacer 6 inches in diameter. This makes an antenna with flat top of low copper loss. The high potential points are near the middle of the two outer cages, so that insulator loss is also minimized. The small loading coil seen in Figure 3, and ammeter, are con-

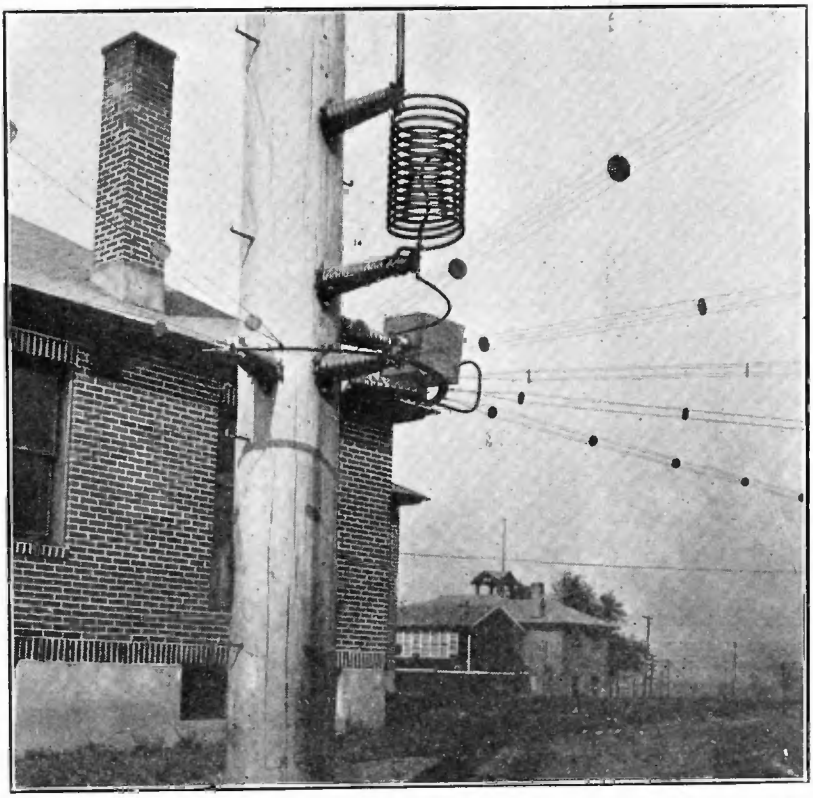


FIGURE 3—Antenna Loading Coil and Ammeter

nected in series to the lower end of the vertical lead, and the current then flows into the counterpoise, which consists of seven cages, spreading in fan shape from the main pole. Each counterpoise cage is made up of four No. 10 copper wires on 3-inch diameter micarta spacers. The copper tube coupling lead to the transmitter is connected just below the ammeter.

The natural period of this antenna structure is 281 meters.

The total resistance measured at 970 kc. is 10.8 ohms and the effective height approximately 20 meters. The resistance curve is given in Figure 6.

Apparatus—Oscillator. There are two oscillator frames, one employed as a spare part. The oscillator frames each provide mounting for eight WO-41 (see Figure 5), 10-kw. water-cooled

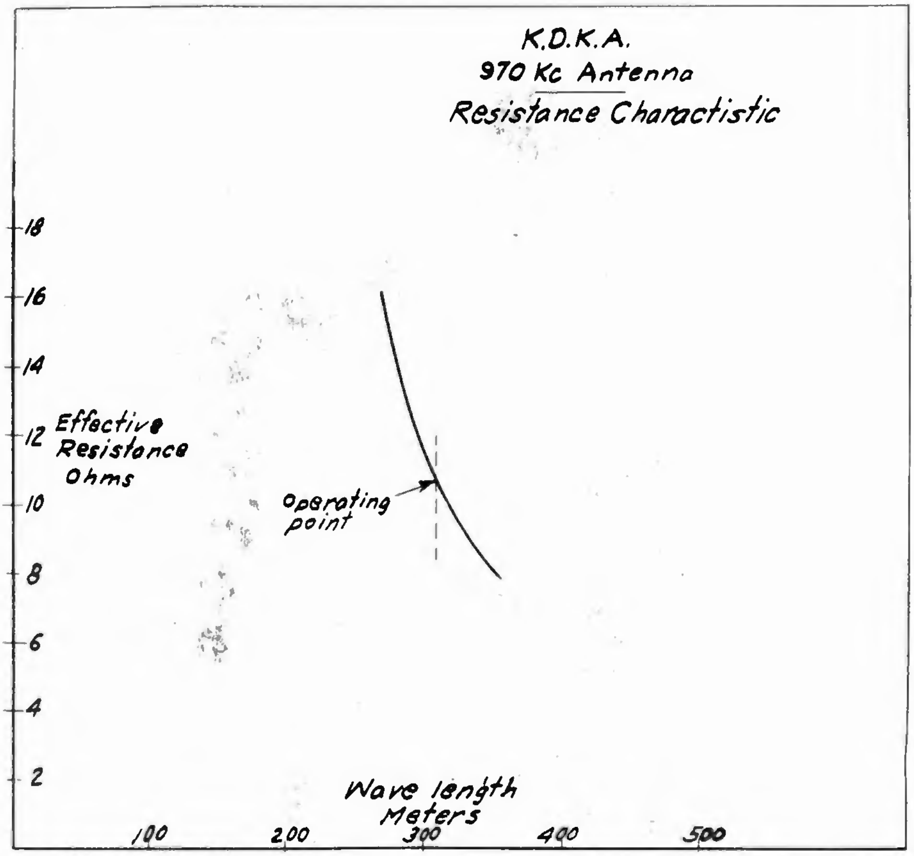


FIGURE 4—970 Kc. Antenna, Resistance Characteristic

tubes in two groups of four tubes. Figure 6 shows the mechanical details. The four tubes are clamped to a common plate support and treated as a unit. All oscillator and modulator tubes are furnished with filament power from the motor generator sets, shown in Figure 7. A filament voltmeter and plate ammeter are mounted on the front of the frame. The primary oscillating circuit is arranged in the rear of the tubes and consists of a 500 $\mu\mu$f. air condenser and a 52 micro-henry inductance mounted above. Fine adjustment of frequency is obtained with a single turn variometer, mounted at the end of the primary circuit inductance. This is adjusted approximately by means of the frequency standard wavemeter, shown mounted on the wall in Figure 6, and exactly to zero beat with a small oscillator provided with a quartz crystal ground to 970 kc. This arrangement enables frequency adjustments of a precision unobtainable in any

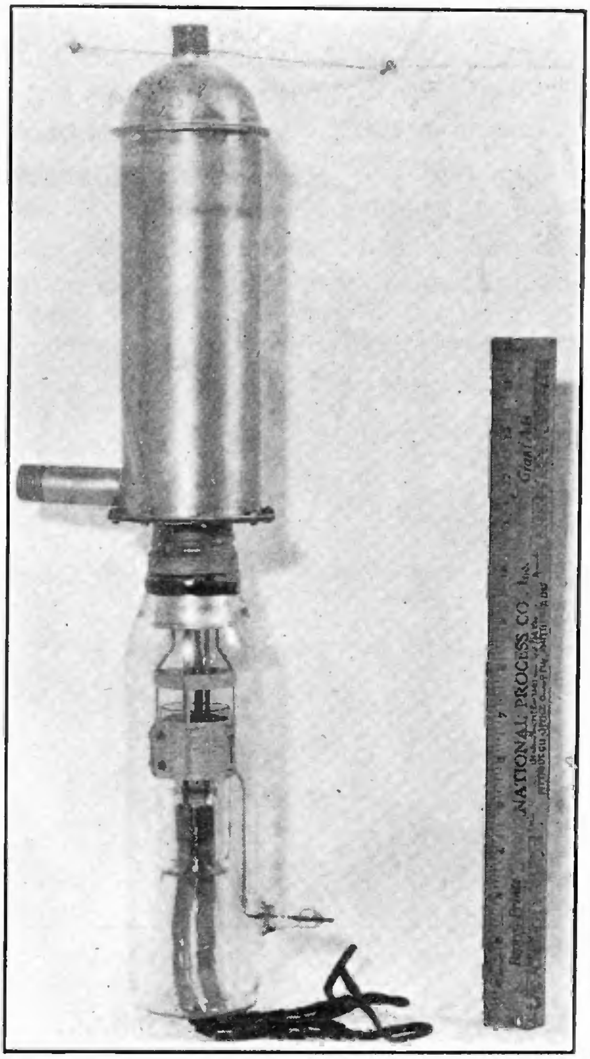


FIGURE 5—WO-41, 10 Kw. Transmitting Tube

other way. Under normal conditions, KDKA should be within 100 cycles of the frequency assigned to it.

Figure 8 shows the connection diagram of the oscillator and modulator circuits as employed at KDKA. The modulation choke is not shown in this diagram, as it is treated as a group with the filter system and appears on that diagram. For clearness, only one oscillator and two modulator tubes are shown

However, during actual normal operation, to which most of the following data applies, four type WO-41 tubes are used as oscillators and nine as modulators.

Plate and grid couplings to the primary oscillating circuit are of a conventional type, which is familiar to radio men.

Antenna coupling to the primary circuit is effected through a single lead, having a choke coil in series with it, and connected, between the two circuits, at almost any convenient point, other

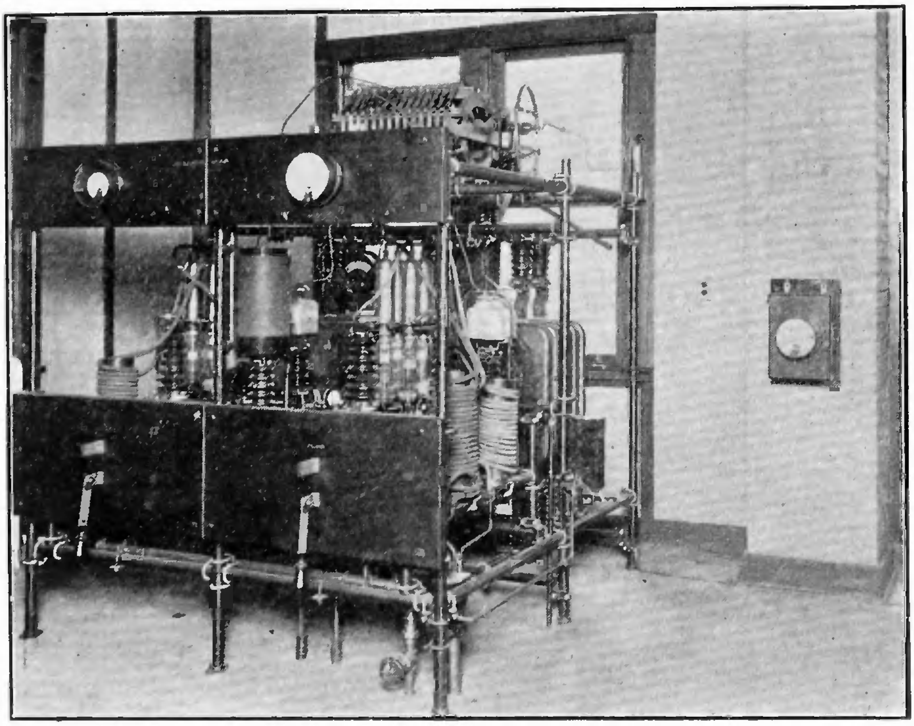


FIGURE 6—970 Kc. Oscillator Frame

than the ground. This coupling method is subject to easy adjustment, and the small coupling lead, since it carries only a small current, can be carried distances which would be prohibitive for the main antenna leads.

The choke also acts to suppress harmonics, as its impedance is proportionally greater for the high frequencies. No ground is used on the antenna itself, as it is thought best to permit it to oscillate freely about its own electrical center rather than attempt to constrain it by an actual ground, location of which is inconvenient and subject to slight changes.

The use of water-cooled tubes permits a simple means to be employed for determining the efficiency and losses of the tubes and connected circuits. By measuring water flow and temperature rise to determine the energy given off under different conditions, and considering this in connection with plate input, grid leak losses and heating of the plates, due to filament alone, valuable data may be obtained. In this manner, the primary circuit losses and antenna input can be evaluated quite accurately. The measurements made by this method for antenna and primary circuit resistance check measured values to a close degree. For example, the antenna resistance measured in a

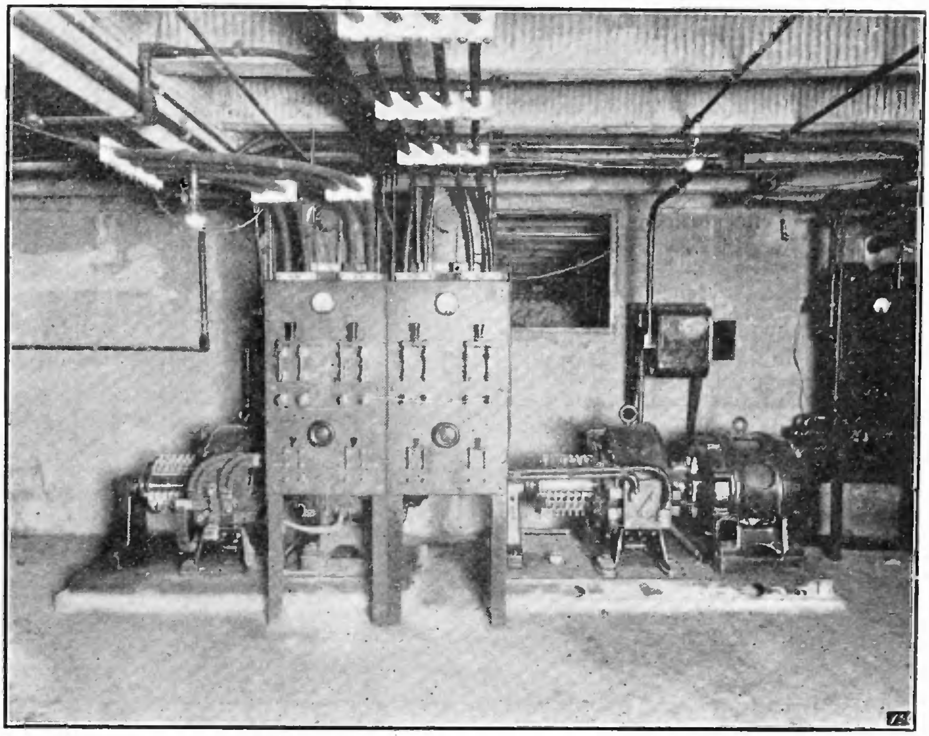


FIGURE 7—Filament Motor-Generator Sets

more conventional manner was 10.8 ohms, and by the heat loss method was 10.73 ohms.

The net oscillator efficiency, considering the direct current input and output to the antenna, obtained from the heat loss method was found to be constant at 67 percent over a wide range. This is as it should be if good modulation is to be obtained, as the whole condition for modulation is based on proportional antenna current and plate volts, which, of course, means constant efficiency.

Gross plate efficiency for the oscillator units is 70 percent, which, with the losses of the grid leak of 200 watts and primary

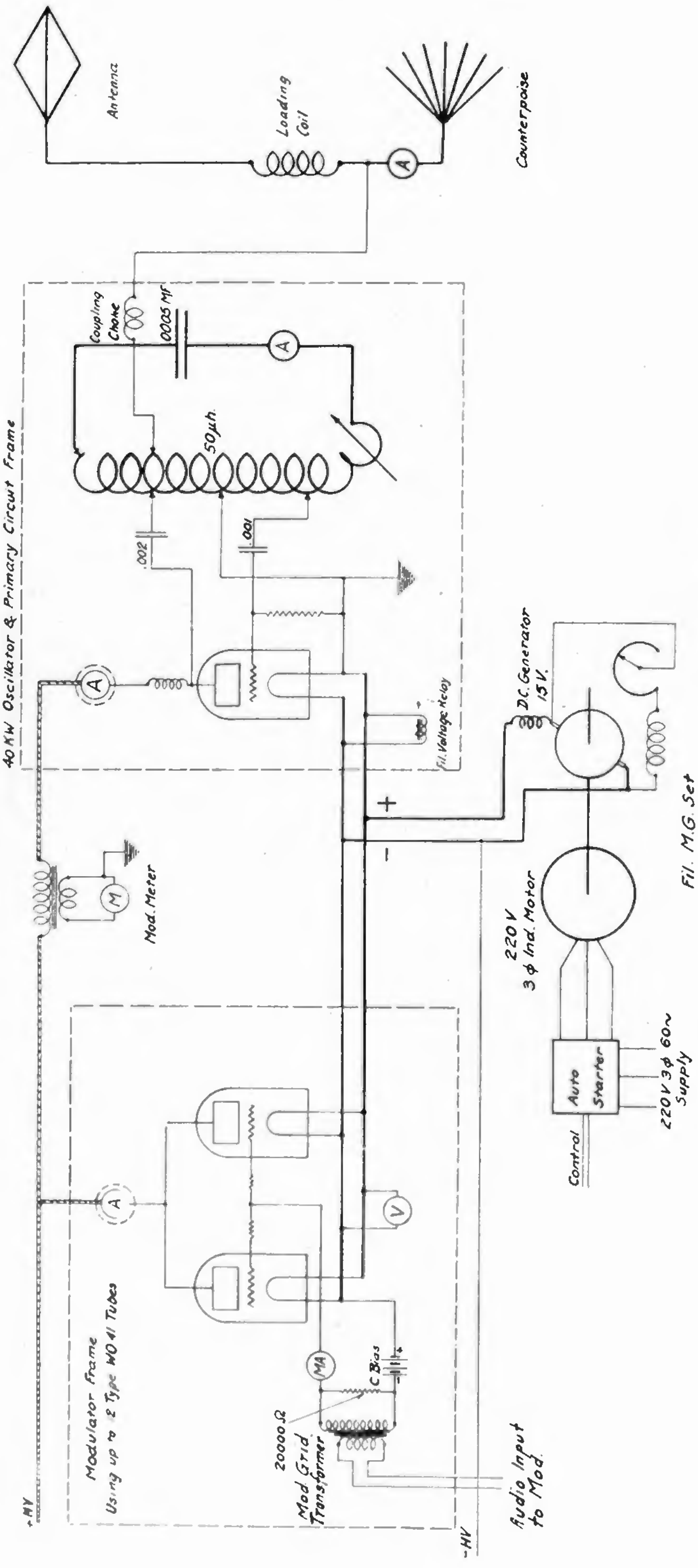


FIGURE 8—Circuit Diagram, Oscillator and Modulator

circuit I^2R loss, brings the net efficiency of the oscillator to 67 percent, as stated before. Direct measurement and heat loss means, both give a primary circuit resistance of 0.3 ohms.

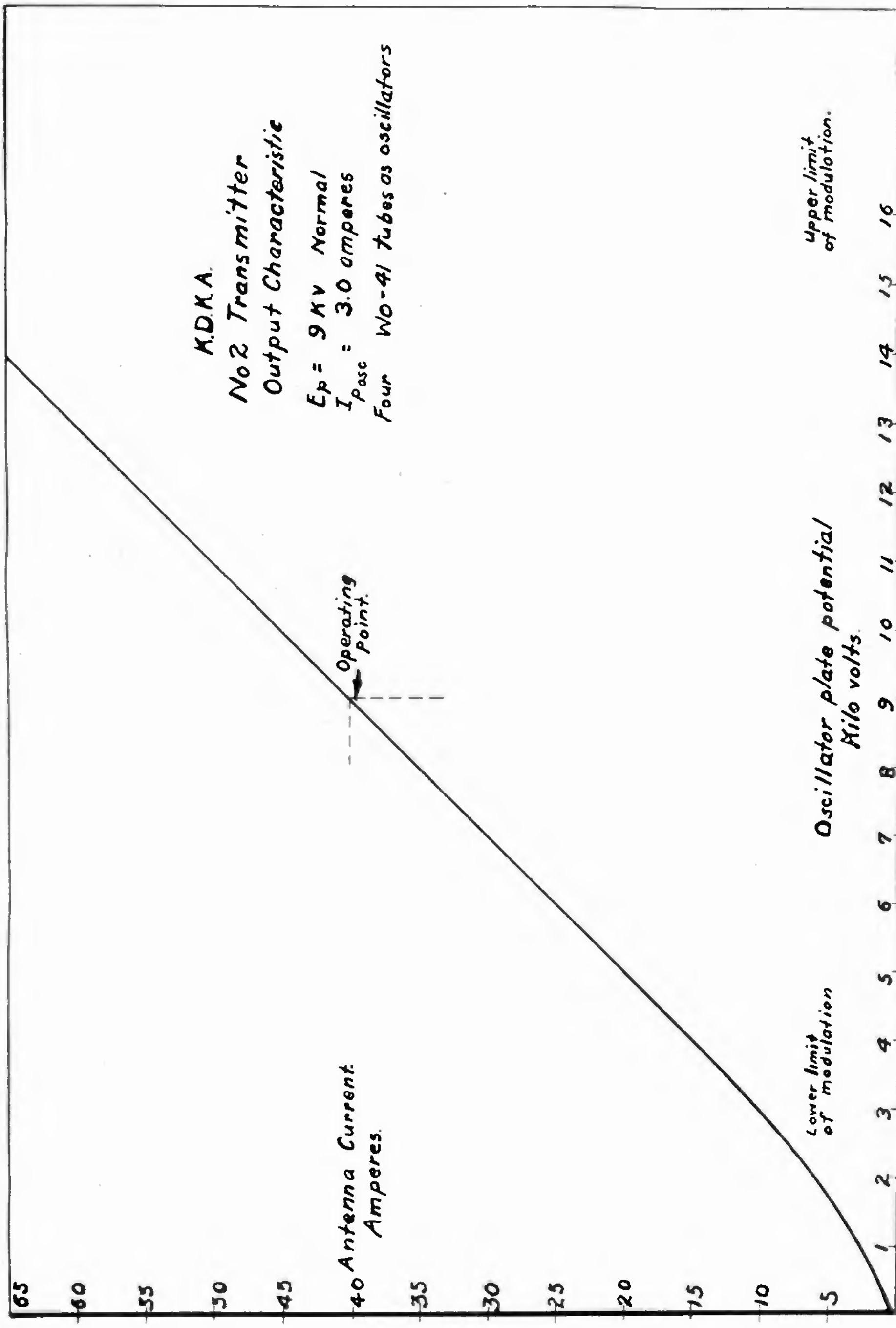


FIGURE 9—Antenna Current—Oscillator Plate Voltage Curve

Another check, showing that the efficiency of the oscillator is constant over a wide range, is obtained from the antenna current plate voltage curve, as shown in Figure 9. This is a straight line over the entire distance, 2,500 to 15,000 volts, at which modulation takes place.

Modulator. Figure 10 gives a general view of the apparatus room with No. 2 set modulator at the extreme left.

The modulators used at KDKA for both 970 and 4,800-kc. units are duplicates, and while not arranged with transfer switches, can, in case of emergency, be cross-connected with jumpers to be used on either set.

The modulator units are designed to provide suitable modulation for oscillators producing 40 kw. of radio frequency power input to the antenna.

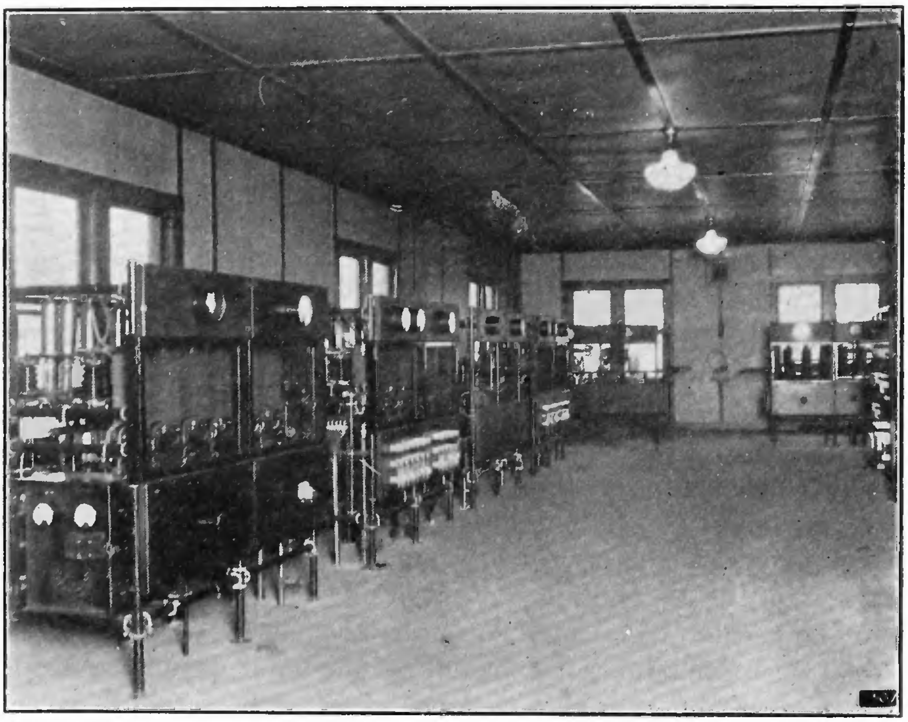


FIGURE 10—General View of Apparatus Room

Each modulator frame provides mounting for 12, type WO-41 tubes, arranged in pairs, the two tubes of each pair are supported on the same tube support plate, with their anodes electrically in parallel. A high-voltage disconnect switch that can be opened under load is provided for each pair, so that groups of tubes can be cut in or out, as desired. Each modulator tube grid lead is provided with a damping resistance, to prevent parasitic oscillations among the tubes. Under normal conditions, this grid lead resistance has no effect, as the modulator is not worked to where grid current is produced.

Bias or "C" battery voltage for the modulator tubes is provided by dry cell "B" batteries, housed in a box at the end of the frame. At the side of this box is an oil-insulated step-up transformer that supplies proper audio grid voltages for modulation. A milliammeter is provided in the main grid lead for indicating grid currents. It is used only as a check on test numbers, together with the modulation meter to determine the limits for modulation. A multi-point switch for adjusting bias voltages and a voltmeter for checking are also provided.

To insure a substantially uniform load for the modulator grid transformer, a resistance is connected across its high-voltage side. Without this, the load on the transformer would vary from approximately zero at low frequencies to an appreciable capacity reactance at the higher ones, thereby altering the effective transformer ratio, which is undesirable.

Normal operation at usual power adjustment employs nine, type WO-41 tubes operating in parallel. Characteristic curves of the modulator as a unit is shown in Figure 11. These are different from the ordinary grid voltage-plate voltage curves frequently used, but are plotted from the same data, and for this purpose are more convenient, as the curves are straight lines, which make interpolation easier.

Figure 12 shows the modulation characteristics of oscillator plate volts versus grid volts applied to the modulator. It is based on the assumption that constant current is being supplied to the oscillator and modulator together at all times, as is the case when a modulation choke of infinite inductance is connected in the common high-voltage supply lead. This curve is seen to be very nearly a straight line, and as such, indicates that the plate voltage variations impressed on the oscillator tubes are practically proportional to the voltage applied to the modulator grid. This is the condition necessary for the modulator to function with the minimum of distortion, and when considered in connection with the oscillator plate volts-antenna current curve, shows that the antenna current modulation will likewise be proportional to the applied modulator grid voltages, and reproduce its variation to a close degree.

Under normal conditions, the plate voltage is 9,000 and the bias 540 volts. Within the grid voltage limits of zero and twice 540 or 1,080, which must be observed if the station audio amplifier output is not to be distorted by the load of modulator grid currents, a variation of plate voltage from 2,500 to 15,000, giving a modulation difference of 13,000 is obtainable. This variation corresponds $\frac{13,000}{2\times 9,000}$, or approximately 70 percent modulation.

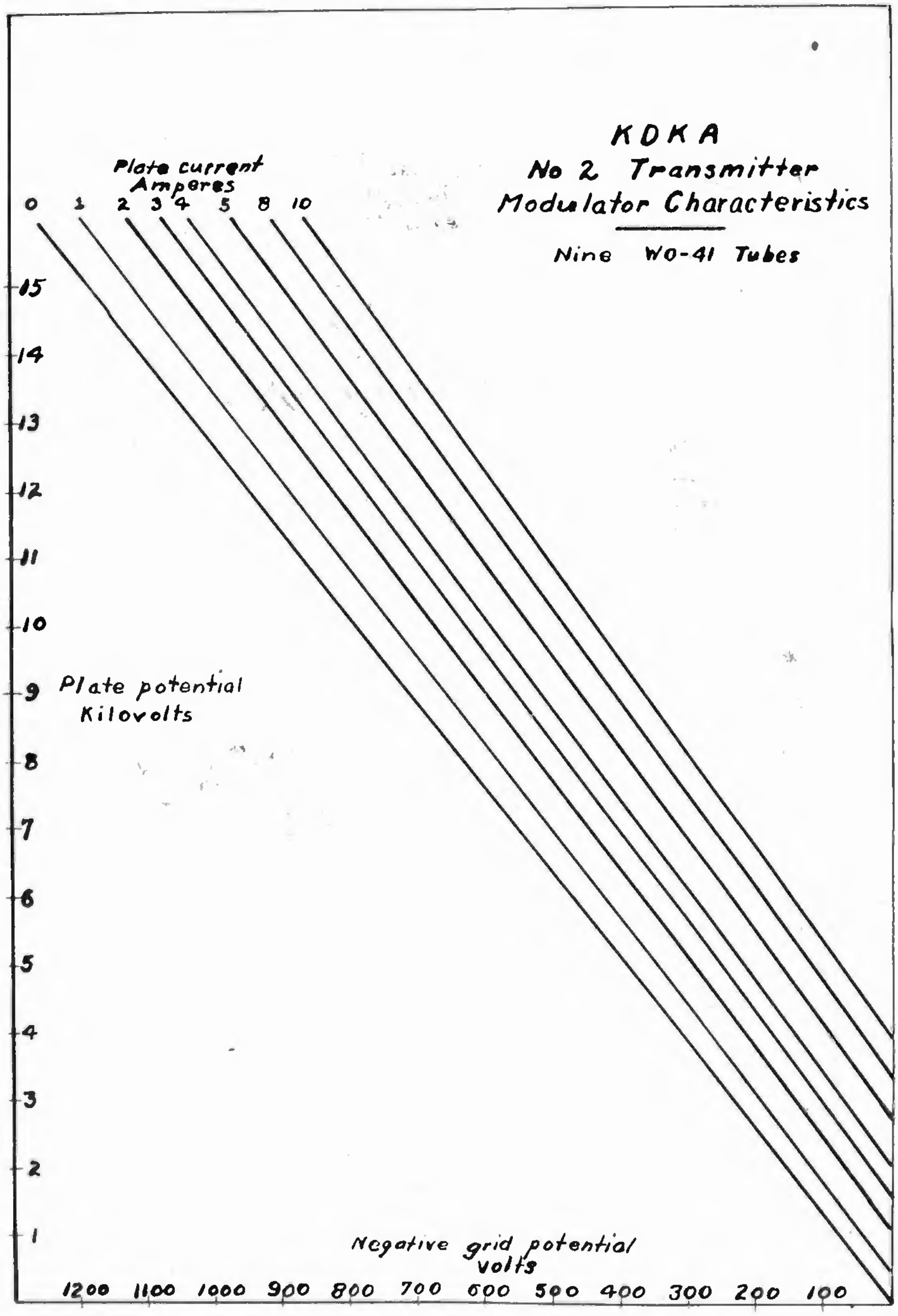


FIGURE 11—Modulator Characteristics, Static Curves

Oscillograms taken of rectifier antenna current bear out these deductions.

The amount of distortion over this range is of the order of 3 percent. This amount is ascertained by noting the departure of the curve from a straight line drawn as shown in Figure 12,

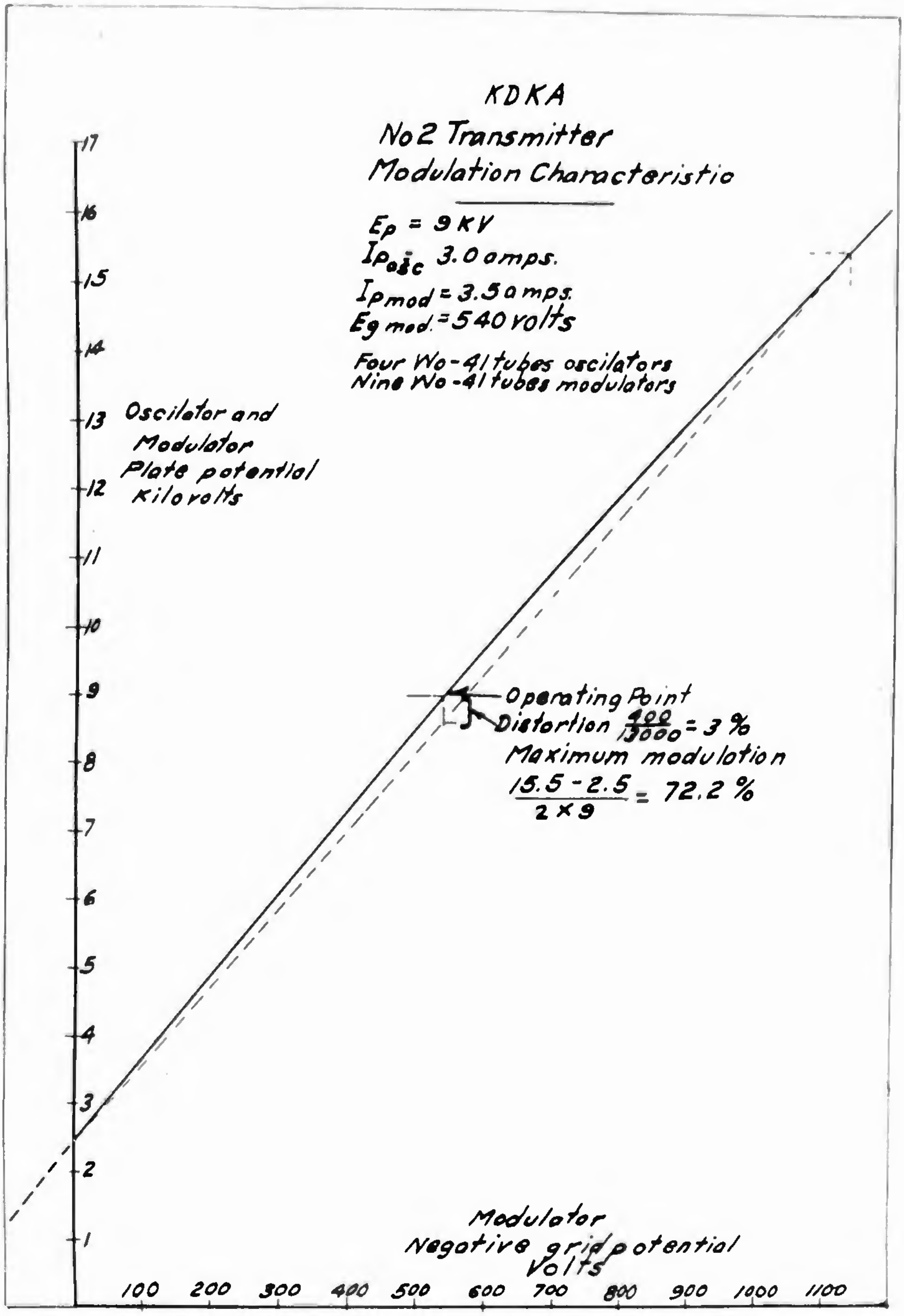


FIGURE 12—Modulator Characteristics, Operating Curve

and in this case, is found to be 400, or 3 percent of 13,000. Also, by plotting the differences, a double frequency curve is obtained, which shows that the distortion is mostly a second harmonic. Because of its nature and small amount, distortion produced by the modulator, as adjusted, is entirely too small to be detected in any way, except by analytical measurements.

Another characteristic of the modulator that is quite important, is that of relative modulation plate voltage, available at the oscillator at different frequencies. When calculating the plate voltage-grid voltage modulation characteristic, it was assumed that there was no leakage in the modulation choke. Actually, this is not the case, particularly at low frequencies. For example, at 100 cycles, the reactance of a 10-henry choke is approximately 6,300 ohms. With the oscillator tubes to take three amperes at 9,000 volts, their average impedance is 3,000 ohms. This would look as if a considerable portion of modulation would be lost, as the modulation choke is practically in parallel to the ground across the oscillator tubes. However, the conditions are not nearly so bad as might seem at first thought, as the choke leakage is mainly at 90 degrees to the current passed into the oscillator, and the relatively low impedance of the modulator unit does not cause much voltage variation to take place, as the external impedance changes.

Considering the function of oscillator, modulation choke, and modulator units reveal that the audio voltage produced in the modulator acting as alternating current generator is impressed across an external impedance made up of the oscillator and modulation choke in parallel, as stated above. Therefore, the solution of elementary circuits, such as shown in Figure 13, will give the relative voltages available at the oscillator for different frequencies. The curves shown are those obtained using modulator impedance of 400 ohms, together with an oscillator impedance of 3,000 ohms, which, as before stated, are in normal conditions of operation. It will be noted that all curves tend to reach a maximum value of 88.2 percent at the higher frequencies. This is the limiting proportion of the voltage generated in the modulator by action of the grid potentials and amplification constants of the tubes that is available on the oscillator when the respective impedances are those stated. At low frequencies, when the choke reactance becomes comparatively low, thereby reducing the load impedance into which the modulator works, the relative available voltage falls below the maximum of 88.2 percent, in a manner shown by the curves. At KDKA, a 10-henry choke is used, and as seen from the curves, gives even at 25 cycles, about 84 percent volts available on the oscillator, which is relatively 95 percent of the maximum available. Therefore, as far as the modulating system is concerned, the output is nearly constant over the full range of musical frequencies. Lack of choke, while not important, as far as speech and general phone trans-

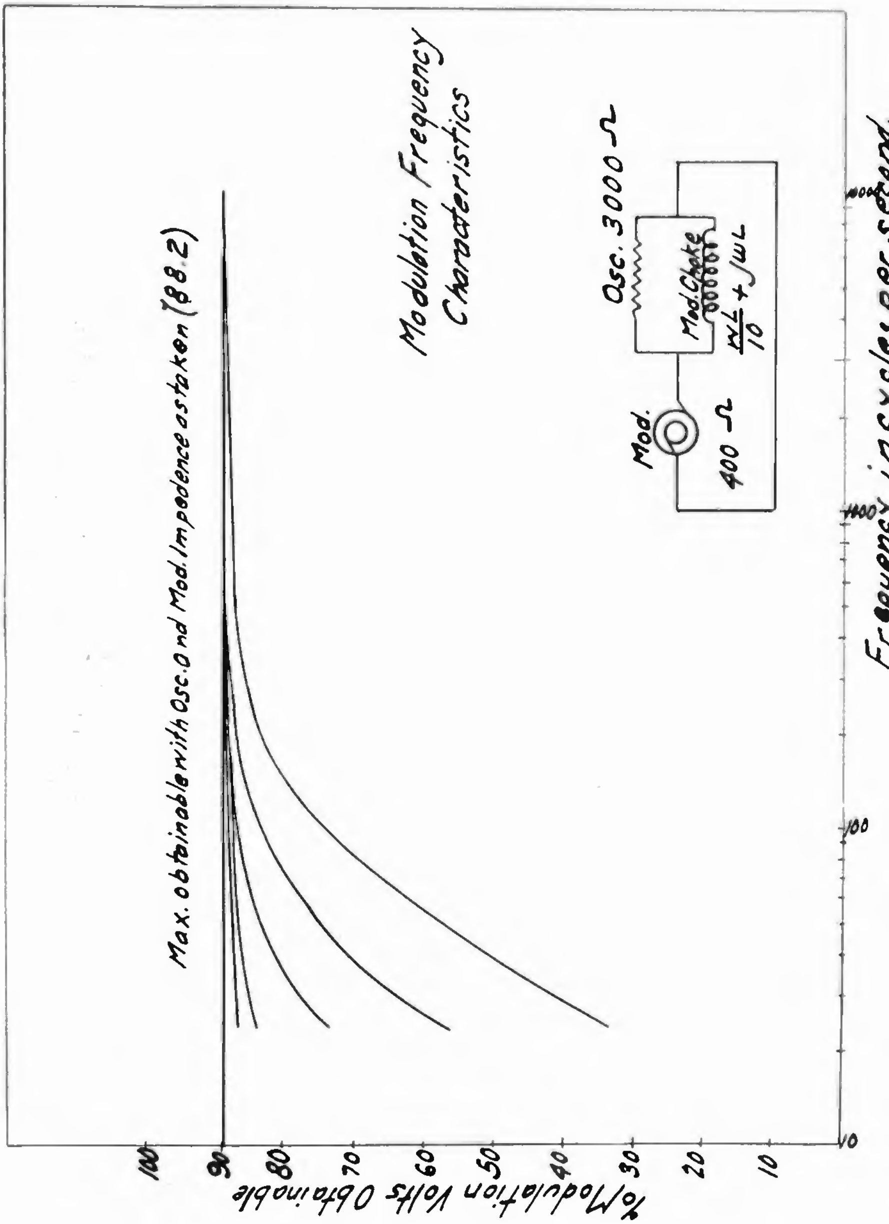


FIGURE 13—Modulator Characteristics, Frequency—Relative Plate Volts

mission is concerned, is not very noticeable, but to bring through the low notes that give the characteristic richness to pipe organ music, heavy choke is necessary, and special attention was given to this matter in constructing the apparatus for KDKA.

In calculating the modulation characteristics, one could not fail to be impressed by the way that low modulator impedance is effective in eliminating distortion. In many cases, we are accustomed to think in terms of maximum output and balance of impedances, whereas, for good quality and minimum distortion, the main requirement is to have the modulator impedance low compared to its load. The latter is the general condition under which all ordinary power apparatus is normally operated. There is a striking parallel in this case to that of the early direct-current generator. It was at first thought that maximum output was important, and when loaded for this condition with external load resistance equal to the machine resistance, voltage regulation was found to be 50 percent and the efficiency correspondingly bad. Further consideration showed, however, that good efficiency and voltage regulation was obtainable by operating where the external load resistance was high compared to that of the machine, and modern machines are built to operate in this manner, although the output is much less than the maximum theoretically possible. Considering the modulator unit, the distortion was roughly comparable to the voltage regulation on the generator, and while actual power output efficiency is not important, the relative voltage output of the oscillator is; therefore, it is highly desirable to keep the modulator impedance low, in comparison to the load with which it is to work. Also, the curvature plate voltage, modulator-grid characteristic is produced by the change in average modulator impedance at different grid voltage amplitudes, and if the total impedance of the circuit is designed to be comprised mostly by the oscillators, which have substantially a constant impedance, the characteristic will be practically a straight line, with slight variations of modulator impedance having little effect. The same consideration applies equally to amplifiers, as a modulator as only a large power amplifier and in the audio equipment, as will be seen later, tubes in parallel are used to reduce the internal impedance, and not because large power output is required.

Audio Frequency Apparatus

Telephone lines from the various places of pick-up come to the telephone exchange works at East Pittsburgh, at which point the audio control is installed. Four lines connect this point with the station, a distance of approximately three miles. These lines terminate on the switchboard in the control room. Three complete station amplifiers are installed (shown in Figure 14). Any one of these may be connected with either broadcasting transmitter. The upper amplifiers (Nos. 1 and 2), have one 5-watt balanced or push-ball stage and one 50-watt balanced stage. (See Figure 15 for diagram.) No. 3 is a single-side design, having two 5-watt tubes in parallel for the first stage and two 50-watt tubes in parallel for the second stage. This unit is impedance coupled, while the balanced units are transformer coupled. Characteristic curve of amplification, versus frequency, is given

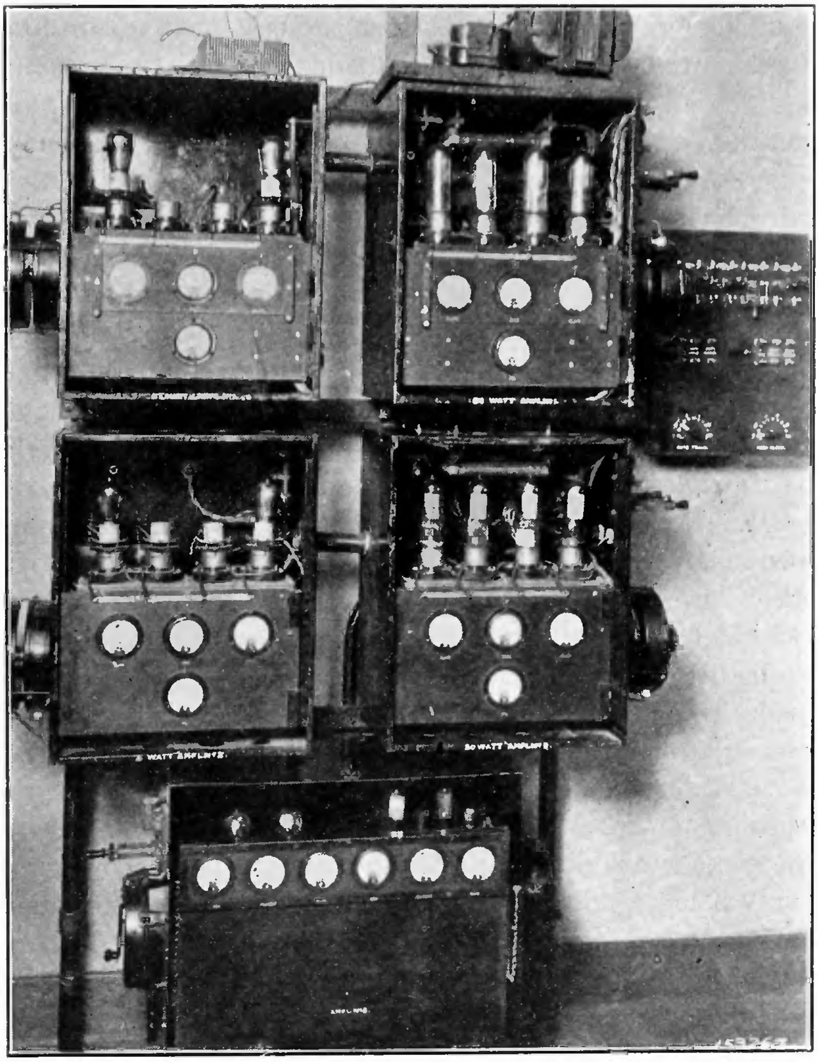


FIGURE 14—Audio Frequency Amplifier

in Figure 16. It will be seen that the amplification is substantially constant from 50 cycles to 1,000 cycles, after which the curve rises gradually to 6,000 cycles. The audio frequency thus amplified is stepped down to the line connecting the amplifiers and the modulator units.

Control of the amount of modulation is nominally in the hands oi the man at the control position in the telephone exchange at East Pittsburgh Works. All line switching is handled from this point and potentiometers and filters are so arranged

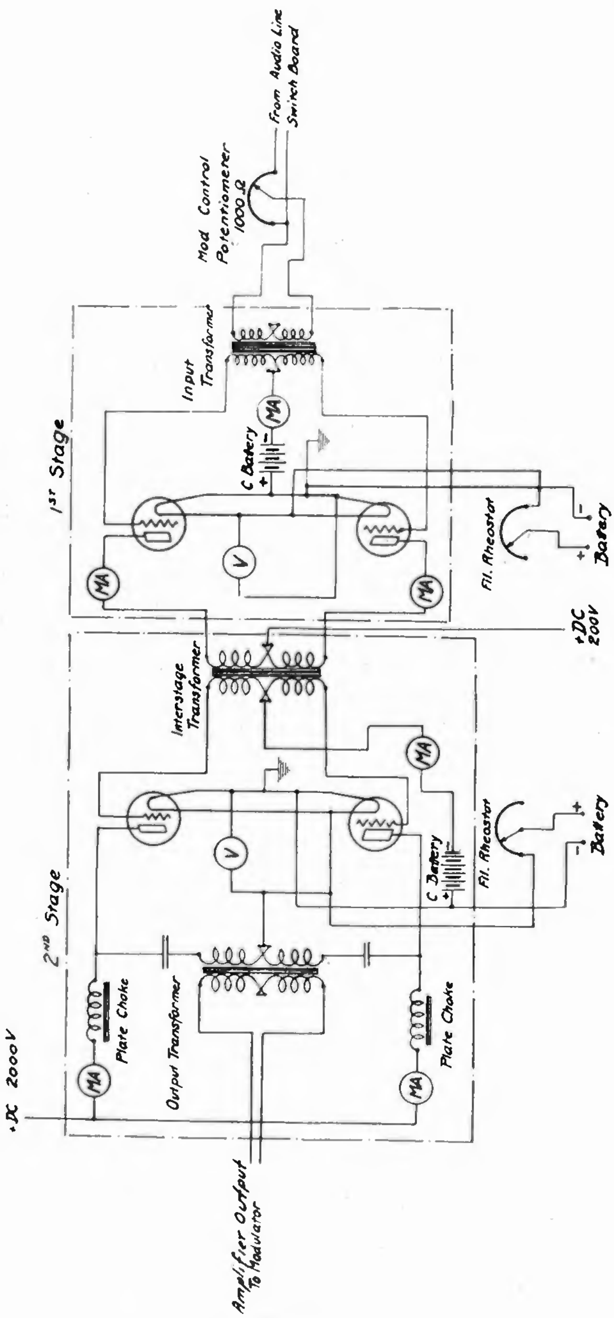


FIGURE 15—Amplifier Circuit Diagram

that by means of a vacuum-tube voltmeter the audio input to the station is held substantially constant at the proper level and line loss compensation is effected. In cases of emergency, the modulation can be controlled by potentiometer at the station which is connected between the lines and the station amplifiers, as shown in diagram, Figure 15. The station amplifiers are furnished with filament power from a 12-volt storage battery, and the 5-watt stages are furnished 200-volt plate power also from a storage battery, while the 50-watt plate energy is obtained from a single-phase rectifier at a voltage of 2,200 direct current. By means of a potentiometer arrangement, this 2,200-

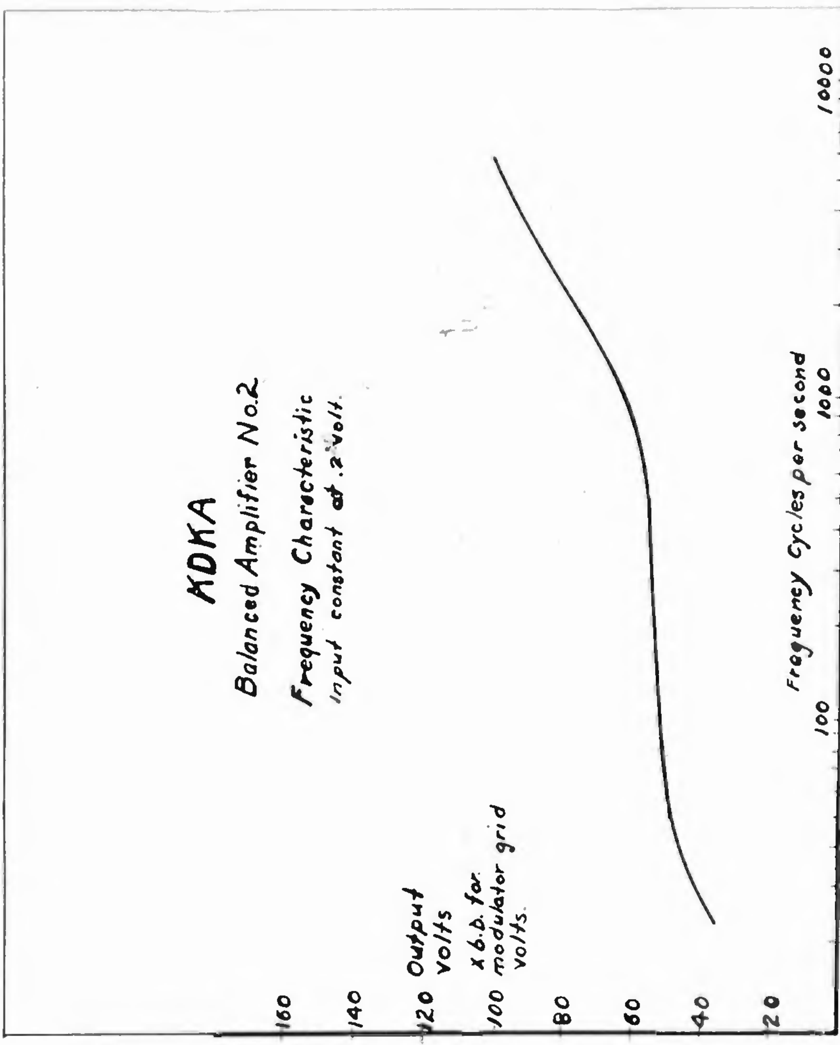


FIGURE 16—Amplifier Frequency Characteristic

volt direct current may also be used for the 5-watt stages, giving a net voltage of 350. Thoriated filament, 5- and 50-watt tubes are employed.

Rectifier. Hot cathode rectifiers are employed for high voltage direct current supply to the radio apparatus. There are three of these rectifiers as shown in the schematic diagram, Figure 2;

two are of the two-phase type, using twelve type WC-61 water-cooled tubes each, and are operated directly from the commercial 220-volt 3-phase 60-cycle power service. The output rating of each rectifier is 10,000 volts 12 ampere direct current, which is conservative. The construction of the rectifier frame is similar to the modulator frames with the tubes mounted in pairs, one pair to each phase. Disconnecting switches, similar to those on the modulators, are provided, by means of which any pair of tubes can be cut out in the case of trouble, thus permitting the rectifier to continue in operation at a slightly reduced output, its overload capacity being sufficient to continue normal in this condition.

The connection diagram of a rectifier and filter is shown in Figure 17. Three single-phase 220-volt to 22,000-volt transformers are employed for plate supply. This arrangement gives greater flexibility as regards replacement than if a single three-phase transformer were used. The direct-current output of the rectifier can be regulated in the 10 percent steps between 50 percent and 100 percent voltage through auto-transformers connected between the power service and the primary of the plate transformers. The high-voltage windings of the plate transformer are connected double star, thereby obtaining six-phase power. Neutral point of the star forms the negative terminal of the rectifier. The positive lead from the rectifier is taken directly off one of the filament busbars. Filament heating energy is obtained from one phase of the main supply, using a specially insulated transformer to give the proper filament voltage. The filament transformer is located in the basement and connected to the tubes through relatively long leads. The filament voltage is shown by a meter on the rectifier frame, the meter being insulated by means of a 1 to 1 voltage transformer. This arrangement is simple and more accurate than measuring voltage on the primary of the filament transformer or of providing a special winding on this transformer when low-voltage leads are long. No filament rheostat is used, as a power supply voltage regulation is good and the adjustment is not critical.

Owing to the exceedingly low resistance of the filaments when cold, which would result in the tubes drawing a heavy rush of current and possible damage if full voltage were applied when starting, a delayed action filament voltage relay is used, which acts to apply full voltage only after the tubes have become well heated by a limited current. The action of this relay is similar to the acceleration relay on a direct-current motor as it speeds up, because of the change in voltage across the filament as the temperature rises.

To prevent voltage surges, sometimes caused by the rectifier

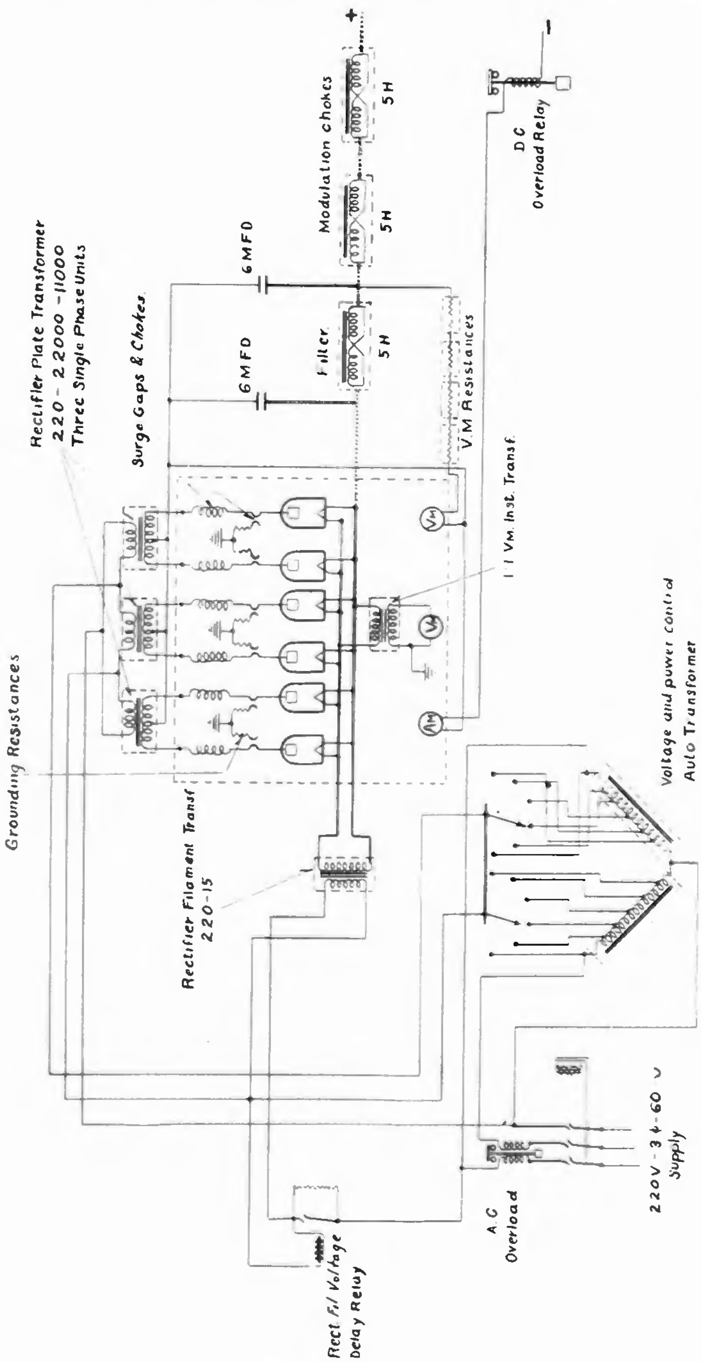


FIGURE 17—Circuit Diagram, Rectifier and Filter

tubes, from injuring the plate transformers, a surge gap and grounding resistor and choke are connected in each high-tension lead.

It has been found possible to conserve cooling water for the rectifier tubes by passing it through three or four tubes in series, since the loss per tube is relatively small and gives only a moderate rise after passing through several tubes.

The filter used to smooth out the ripple left in the direct current from the rectifier, consists of a 5-henry choke coil and 12 μf. of condenser as shown in the diagram, Figure 17. This filter employs standard 10,000-volt condensers in one ½ μf. units which operate without balance resistors and their attendant losses. Figure 18 shows the filament modulator chokes and contactor panel.

The voltage ripple left at the output of the filter is so small that it cannot be seen on an oscillograph using a 3-inch deflec-

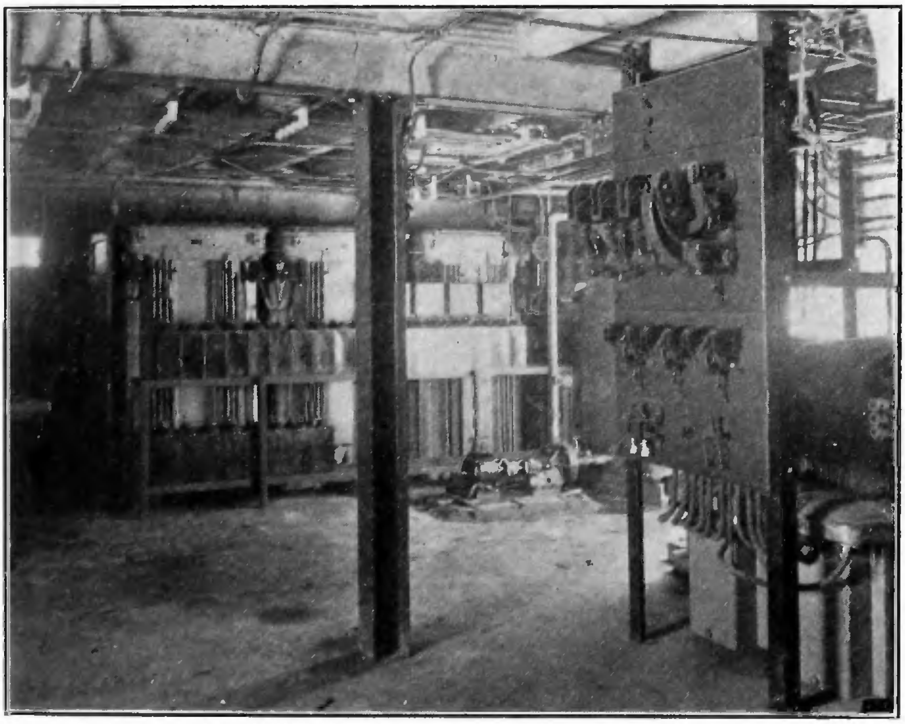


FIGURE 18—No. 2 Transmitter, Filter Control Panel

tion and is inaudible on the receivers used at the station. As a unit with the rectifier filter, and built in with it, is the modulation choke system, consisting of two 5-henry inductances which are duplicates of the filter choke.

Control. All of the apparatus may be controlled by means of push button and signal lights located in the control room, which is separated from the main apparatus room by a glass partition. Figure 19 shows the control desk. At the back of the desk are the control buttons, signal lights, and modulation meters for transmitters Nos. 1 and 2, and buttons and lights for No. 3 transmitter. The audio frequency board, referred to previously, is at the left of the desk and includes a potentiometer for proper adjustment of audio input voltage. The chief operator, who is stationed at the desk, thus has complete control of power and audio circuits. The second operator is stationed

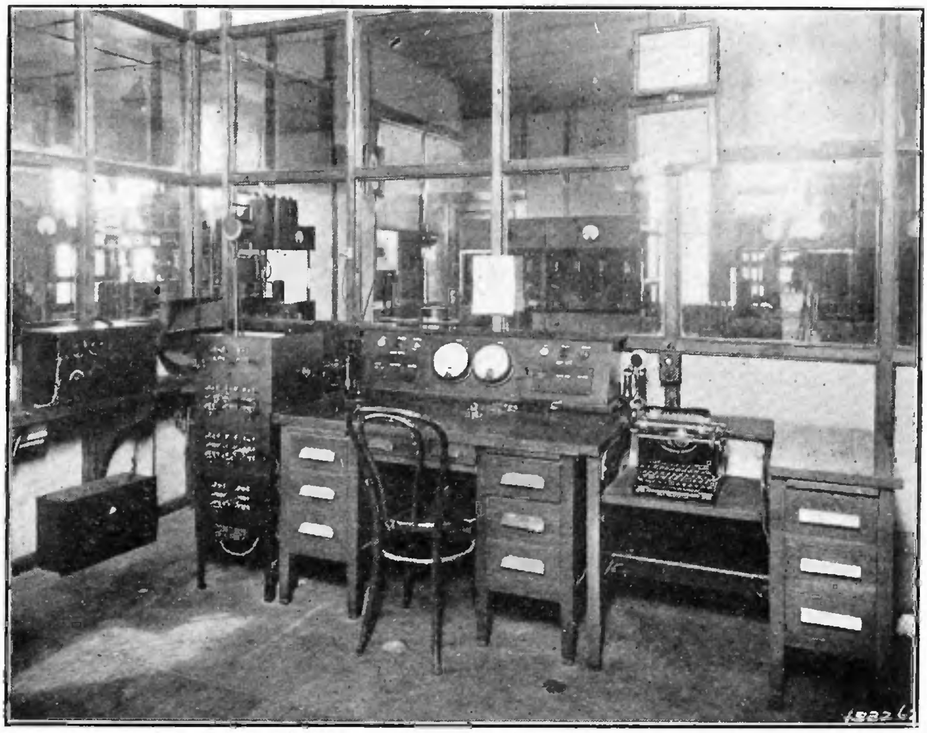


FIGURE 19—Control Desk

in the apparatus room and makes necessary adjustments of filaments, voltages, power output, wavelength, etc.

The power control is associated closely with the rectifier and operates in connection with it. The elementary diagram of the control system is shown in Figure 20. Relays are provided which give overload protection to both alternating-current and direct current-circuits and cut off the plate power in case the safe maximum is exceeded. Water pressure relays are used on all the tube frames, which interlock with the filament control relays and main power circuits to prevent any power being applied to the tubes until the water circulation is satisfactory. Relays are also provided on the modulator and oscillator, which prevent the application of plate power until the tube filaments are up to normal voltage. The push-button control and relays are so interlocked that it is impossible to start filament and high-voltage in any way other than the proper sequence. In case the high-voltage-start button is operated, the filament will be brought up to the proper voltage and the high-voltage then applied automatically. Simultaneously, with starting the radio transmitter, the speech amplifier filament and plate supply may be connected so that the entire set can be placed in

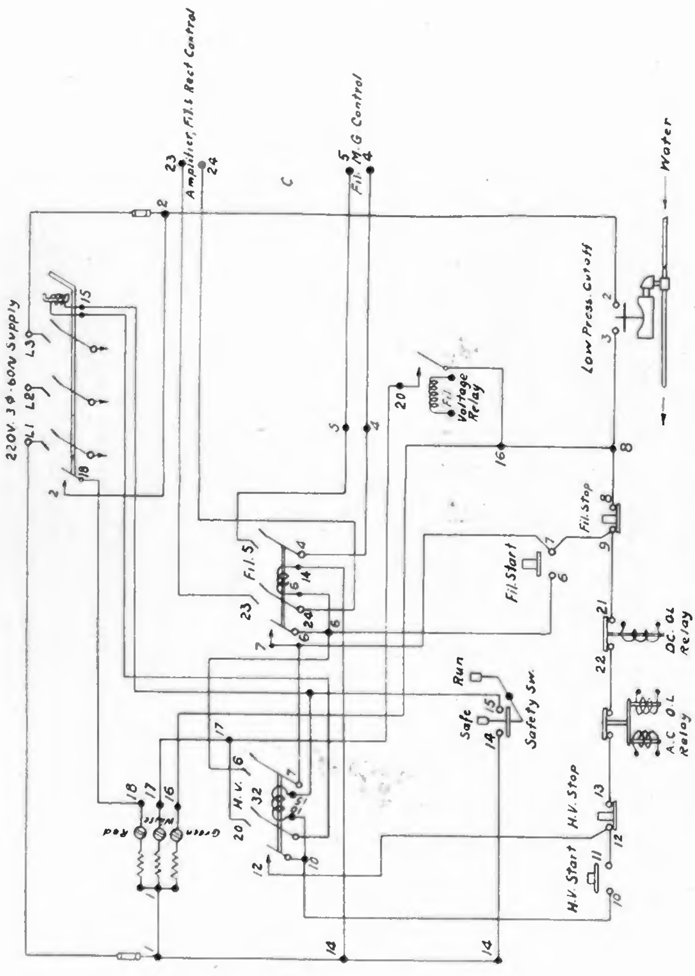


FIGURE 20—Circuit Control Diagram

operation by the pressing of one control button. Signal lights for each transmitter show when the cooling water is flowing, when the tube filaments are lighted and when the plate voltage is on. These lights are in the control room directly in front of the chief operator. Safety lock-out push buttons, which prevent application of high voltage, are provided on the tube frames for the use of the operators when making adjustments or repairs to the equipment.

Cooling water system is of the recirculation type, but no cooling tower is used. Cooling is effected by introducing fresh water into the circulation system as required to keep the temperature below the safe maximum. The supply water is very cold and only a relatively small amount is needed. The heat-dissipating ability of the system allows the operation of the set for a period of 30 to 45 minutes, without the use of outside cooling water. Two circulating pumps are provided, one of which is used as a spare part.

No. 3 Transmitter

No. 3 transmitter is employed for interworks telegraph service. Two WO-41 tubes are used as oscillators on either side

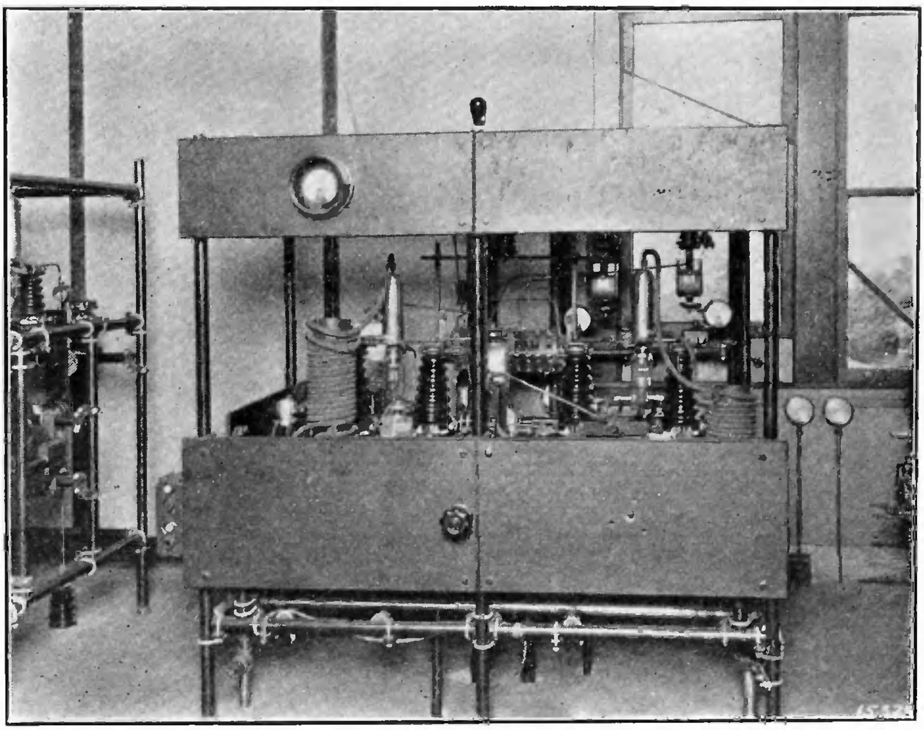


Figure 21—No. 3 Transmitter

of a push-pull circuit. The tubes work self-exciting into the primary oscillating circuit from which a short transmission line carries the power of 6 to 10 kw. to the antenna. Figure 21 shows the oscillator frame. Keying is ordinarily effected by means of compensated wave with a condenser type of relay. Straight keying by blocking with a holding bias, provided by a single tube rectifier, can also be used. Plate power is at 6,000 volts from a single-phase rectifier and filter, Figure 22.

No. 1 Transmitter

The transmitting apparatus, working on a frequency of 4,800 kc. (62.7 meters), is known as No. 1 set, as it was the first set installed in the building. Many changes have been made in this set since it was installed and put into operation last year.

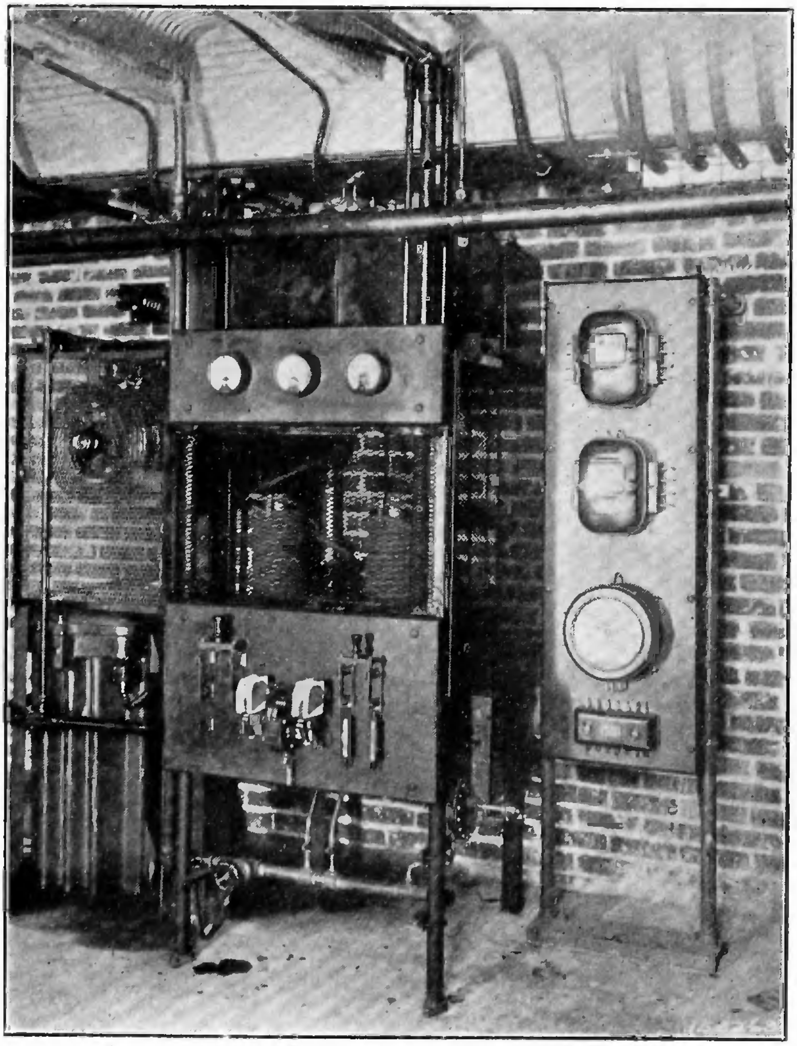


FIGURE 22—No. 3 Rectifier

The present arrangement utilizes one of the six-phase, 10,000-volt rectifiers described above. Modulation is by the constant current system. The radio-frequency apparatus is shown in Figure 23, and is of the quartz crystal controlled type. The crystal controls the frequency of a 5-watt tube and this is amplified through one 250-watt stage, one 500-watt balanced stage, one 10-kw. balanced stage, and one 20-kw. balanced stage. Coupling to the antenna is by means of a short transmission line, the antenna itself being of the grid vertical conductor type. This crystal-controlled equipment may be the subject of a separate paper in the future and it is not thought advisable to say more about the radio-frequency apparatus at this time. The results obtained have been very gratifying. Our transmissions have been relayed in England, France, Germany, South Africa

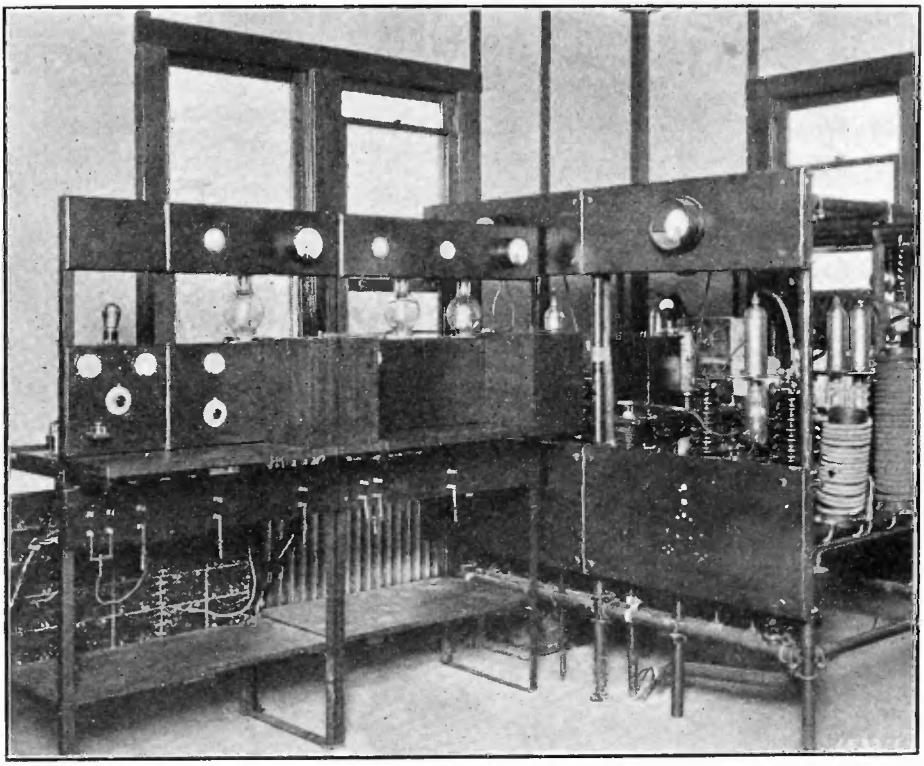


FIGURE 23—NO. 1 Transmitter

and Australia. The use of the quartz crystal as a frequency stabilizer has gone a long way in improving the quality of transmission at short wave lengths.

CONCLUSION

It will be seen from the above description that, with the installation of duplicate equipment and switching arrangements made for the transfer of rectifiers, filament-generators, amplifiers, etc., from one set to another, failure from any cause is guarded against and continuity of service assured. Nothing has thus been spared in making KDKA a station that gives the best quality of broadcasting service.

A RADIO FIELD-STRENGTH MEASURING SYSTEM FOR FREQUENCIES UP TO FORTY MEGACYCLES*

By

H. T. Friis and E. Bruce

(Bell Telephone Laboratories, Inc.)

Introduction

There have been presented to the Institute descriptions of radio field strength measuring equipment which cover frequencies from the lowest in present usage up to and including the broadcast range.† This paper will deal with a new system of measurement which has been used successfully at a frequency as high as forty megacycles. While this frequency has been the extent of our endeavor, it is our belief that the fundamental principles can be employed at still higher frequencies when the occasion demands.

Prior Systems

Previously, the most satisfactory method of radio signal measurement consisted of the substitution, for the received signal, of a known locally-generated e.m.f. at the loop center, identical in frequency to the signal, and of such magnitude as to produce the same receiver output as that resulting from the received signal. Under these simulated conditions, the known locally-generated e.m.f. is equal to the voltage induced in the loop by the signal. The field strength is obtained by dividing this induced voltage by the effective height‡ of the loop.

The magnitude of the locally-generated e.m.f. is usually obtained by passing a known current through a known impedance inserted at the loop center. It is desirable that this known impedance be a pure resistance in order to establish its independence of frequency, also its value should be kept as small

*Received by the Editor, April 29, 1926. Presented at a meeting of The Institute of Radio Engineers, May 5, 1926.

†"Note on the Measurement of Radio Signals," C. R. Englund, Proceedings of The Institute of Radio Engineers, February, 1923.

"Radio Transmission Measurements," R. Bown, C. R. Englund, and H. T. Friis, Proceedings of The Institute of Radio Engineers, April, 1923.

"Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies," A. G. Jensen, presented before The Institute of Radio Engineers, New York, April 7, 1926.

‡The effective height of a loop is defined as the height of an equivalent vertical wire, having the same induced voltage.

as is practical. The minute, known currents are obtained by attenuating measurable currents by known amounts through the use of suitable networks. It is evident that the local oscillator and the attenuating network must be separately and thoroughly shielded from the loop or failure will result.

Difficulties at High Frequencies

As the frequency is increased, the proper construction of the described system becomes more difficult. Unless great ingenuity and extreme caution are exercised, inaccuracies creep into the attenuating networks, due to reactive effects, as well as into the resistance at the loop center. The problem of shielding at very high frequencies becomes considerable by reason of the low field strength values at which high-frequency communication is possible. Since the problem of the authors was to design apparatus for the measurement of signals at frequencies as high as twenty-five times the upper frequency limit of apparatus then available, the economic aspect eliminated existing systems from consideration.

Fundamentals of Proposed System

In reviewing these difficulties, the conclusion was reached that a considerable advantage would be experienced if a voltage of sufficient magnitude to be actually measurable by means of a tube voltmeter were induced into the loop from the local comparison oscillator. In conjunction with this, a voltage attenuator would be located elsewhere in the receiver proper. Thus, instead of placing the attenuation between the comparison oscillator and the loop, with the accompanying danger of undesired "pick-up," comparable in magnitude to the small induced voltage, the attenuation was placed beyond the loop in order to minimize the necessity of elaborate shielding of the oscillator. This simple expedient proved a great constructional economy.

Furthermore, the search for an appropriate location for the voltage attenuator, beyond the loop, revealed the desirability of placing it on the output of the intermediate-frequency detector of a double-detection scheme, with due regard for the limits of overloading of this tube. The importance of this arrangement should be emphasized. It means that the attenuator need operate at only the fixed intermediate frequency. Since this frequency has been selected as 300 kilocycles, great accuracy is possible without elaborate attenuator design, regardless of the signal frequency.

As an illustration, Figure 1 will be of assistance in explaining how these principles may be employed in the measurement of some unknown voltage occurring at a high frequency.

The intermediate frequency detector also serves as a tube voltmeter actuating the d.c. plate circuit meter A_1 shown in the

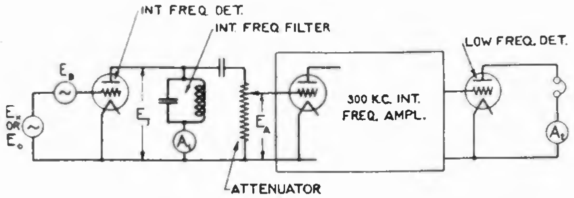


FIGURE 1—Voltage Measurement Apparatus

sketch. The gain control or voltage attenuator is calibrated directly in voltage ratios; thus a reading of 10,000 indicates that the input voltage to the attenuator is 10,000 times larger than the output voltage.

From the modulation theory, it is known that

$$E_I = k\, E_X\, E_B \tag{1}$$

below the overloading limits of the intermediate frequency detector.

Applying the unknown voltage E_X at a frequency f, the frequency of E_B is adjusted to be $f \pm 300$ kc. The attenuator is then regulated until a convenient deflection appears on A_2. Assume this attenuation to be a_1. Then we can write

$$E_A = \frac{k\, E_X\, E_B}{a_1} \tag{2}$$

Suppose we substitute for E_X a voltage E_o, identical in frequency, but sufficiently large to be measurable when using the intermediate detector as a tube voltmeter (E_B turned off). With E_B the same as in (2), the attenuator is readjusted to a_2 where A_2 again reads the same as before. Under these conditions E_A must also be the same as previously. Now

$$E_A = \frac{k\, E_O\, E_B}{a_2} \tag{3}$$

Equating (2) and (3)

$$\frac{k\, E_X\, E_B}{a_1} = \frac{k\, E_O\, E_B}{a_2} \quad \text{or}$$

$$E_X = E_O \frac{a_1}{a_2} \quad \text{which is the desired equality.} \tag{4}$$

We can extend these manipulative operations to the measurement of a radio signal by means of the apparatus shown in Figure 2A. These operations are tabulated below.

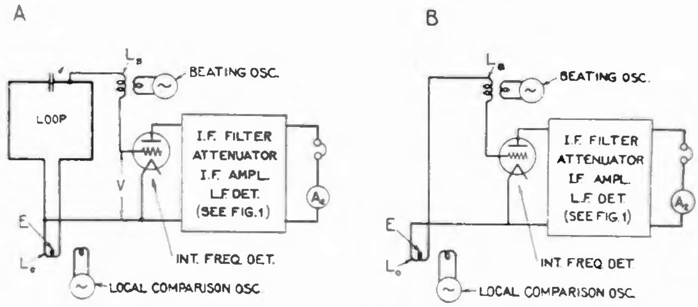


FIGURE 2—Field Strength Measurement Apparatus

TABLE OF PROCEDURE

	Attenuation Ratio of Attenuator
I. The receiving set is tuned to the incoming signal. The attenuator is adjusted until a convenient output deflection is obtained. This deflection is noted.	a_1
II. (1) The local comparison oscillator is started and tuned to resonance with the receiving set.	
(2) The attenuator is adjusted to make the output the same as in I.	a_2
(3) The input V to the grid of the intermediate frequency detector is determined (beating oscillator is off during this measurement).	
III. (1) The grid of the intermediate frequency detector is connected through L_B to the local oscillator input as shown in Figure 2B.	
(2) The attenuator is readjusted to make output the same as in case I.	a_3

From this table we have

Voltage across half of the loop due to incoming signal $= \dfrac{V}{\dfrac{a_2}{a_1}}$ volts

Loop voltage step-up (the ratio of half of the loop terminal voltage to the induced voltage) $= \beta = \dfrac{a_2}{a_3}$

Voltage induced in loop by comparison oscillator $= E = \dfrac{V}{\beta}$ volts

Voltage induced into loop by incoming signal $= \dfrac{V}{\dfrac{a_2}{a_1}\beta}$ volts.

It should be noted here that it is entirely unnecessary for the transmitter of the incoming signal to stop while measurements are being made.

Detailed Discussion

With this explanation of the fundamental principles underlying the proposed system, some refinements in the accurate measurement of the voltage step-up β of the loop may well be discussed.

Figure 2A illustrates the usual arrangement for obtaining the beating oscillator input in double-detection sets and the ratio of attenuations $\frac{\alpha_2}{\alpha_3}$ (as of the previous table) should normally give the effective loop step-up. Unfortunately, however, such a procedure leads to a large error due to a large change in beating oscillator input to the intermediate-frequency detector, as the change is made from connections 2A to 2B. Also a small error due to the voltage drop across L_B is present.

In Figure 2A, the loop resonance frequency differs from the beating oscillator frequency only by the value of the intermediate frequency. At short waves, this proximity is usually very close in percentage. The removal of the loop circuit, Figure 2B, therefore greatly affects the beating oscillator input due to the radical change in the character of the load on the beating oscillator.

Figure 3A shows a balanced beating oscillator input system where the input from the beating oscillator is independent of loop tune. Changing the connections to those of Figure 3B

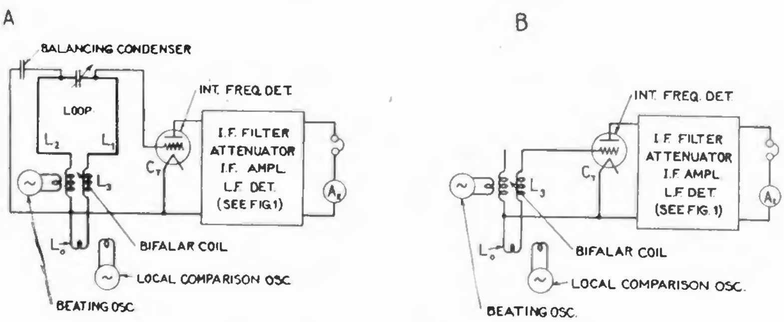


Figure 3—Balanced Beating Oscillator Input Circuit

gives the loop step-up fairly accurately. However, this measurement is still slightly in error but is a great improvement on the method in Figure 2. This error results from the removal of L_1 from the circuit $L_o - L_3 - L_1 - C_T$ through which the current, induced by the beating oscillator, circulates. Since the impedance of L_1 is small compared to that of C_T, the error resulting from the removal of L_1 is small but increases in magnitude at shorter wave-lengths. The voltage drop across L_3 is still responsible for a small error.

Figure 4 shows the methods finally adopted and Figures 5 and 6 are photographs of a measurement set employing this

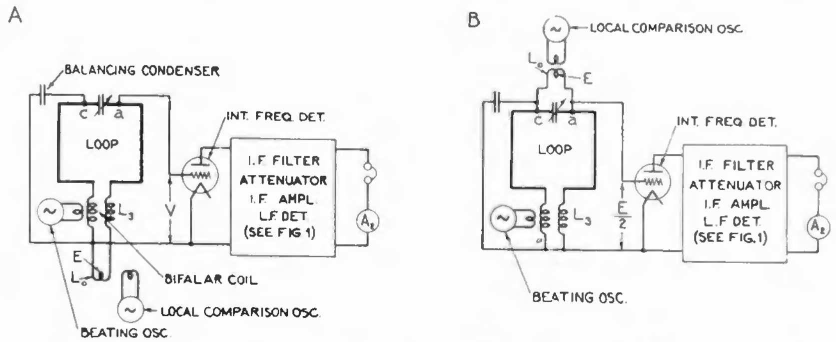


FIGURE 4—Circuit Finally Adopted of Field Strength Measurement Apparatus Employing Grid Modulation

scheme. The local signal voltage impressed on the tube input in Figure 4A is very close to half the loop terminal voltage. (V is over 100 times E and nearly at right angles vectorally).

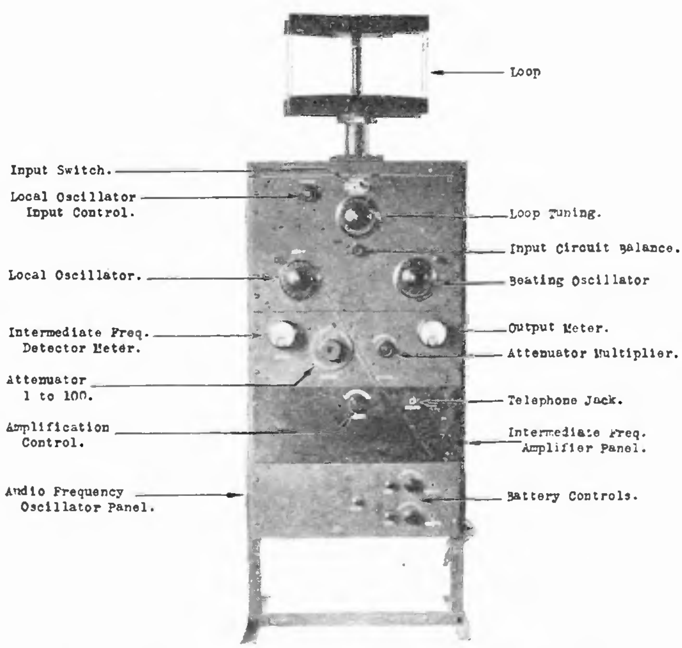


FIGURE 5—Field Strength Measurement Apparatus Employing Grid Modulation

In Figure 4B the coil L_o has been connected across points ac. No change in the beating oscillator input occurs from this change in connections, since there is no potential difference between a and c in respect to the beating oscillator. The impedance of the coil L_o is very small compared with the impedance between points a and c. Therefore the voltage impressed on the tube input by virtue of E is $\frac{E}{2}$. By this method we measure the ratio

$$\frac{V}{\frac{E}{2}} = 2\beta = \text{twice the loop step-up.}$$

This method has been carefully checked by calculation of the loop step-up from the measured frequency characteristic of the loop circuit. These checks have been very satisfactory.

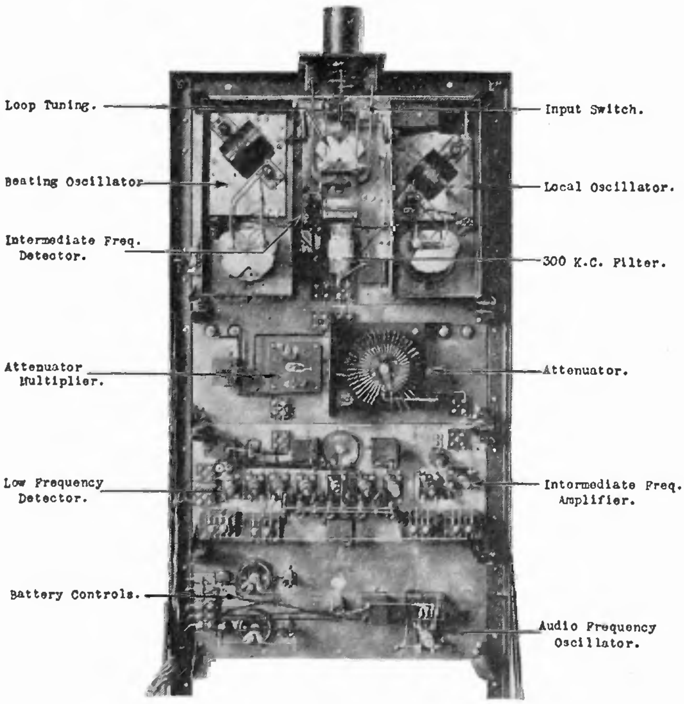


FIGURE 6—Same as Figure 5, with Copper Shielding Boxes Removed

It might be mentioned that possible errors in practice due to spurious capacities to ground do not occur because of the small impedance of the source E. Also it is not absolutely necessary that the loop circuit be accurately anti-resonant in Figure 4B since the loop impedance is large compared with that of L_o.

Figure 7 illustrates the application of the method of measurement in the case of plate modulation of the beating oscillator input. The introduction of the beating oscillator in the plate circuit of the intermediate frequency detector is important because it makes possible the simplification of the input circuit. Balancing is provided so that no appreciable voltage from the beating oscillator appears between the grid and filament of the intermediate frequency detector. Under these conditions changes in the input circuit impedance do not react on the beating oscillator. Here again the use of the anti-resonant circuit in Figure 7B prevents errors due to the low impedance of the grid to filament capacity of the intermediate frequency detector at high frequencies. A measuring set has been constructed

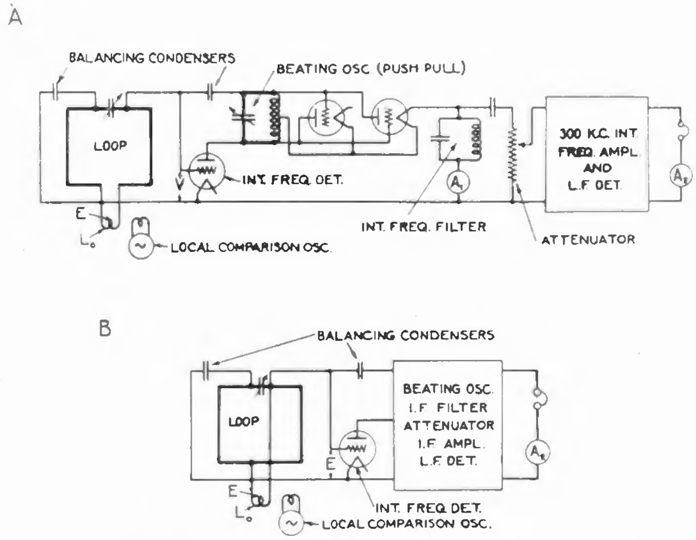


FIGURE 7—Field Strength Measurement Apparatus Employing Plate Modulation—Loop Antenna

employing the plate modulation scheme. This is illustrated by photographic reproductions in Figures 8, 9 and 10.

Since the input circuit for the plate modulation requires no balanced circuits, as does the grid modulation scheme, this system is particularly applicable for operation in conjunction with antenna systems as shown in Figure 11. This provides a means of increasing the sensitivity of the set. It of course is necessary to know the effective height of the signal collector of measuring sets and this can be calculated quite accurately in the case of a loop. When antennas are used, their effective height can be obtained in terms of a known loop by direct comparison, using a small portable oscillator placed ten or more wave-lengths away from the antenna.

This system of measurement is naturally wholly dependent on the calibration of the intermediate frequency detector as a tube voltmeter and the independence of this calibration as to frequency. Direct laboratory measurement has demonstrated this independence for frequencies varying from 60 up to 2,000,000 cycles per second. At higher frequencies, laboratory checks are difficult due to an absence of a suitable standard of comparison. There does not seem to be any reason to believe that the calibration does not hold up to possibly 50 megacycles. It has

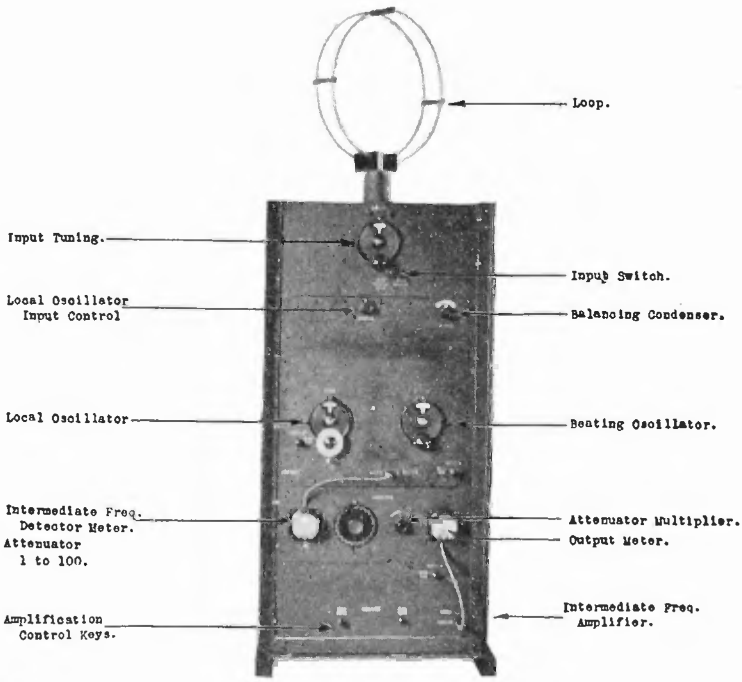


FIGURE 8—Field Strength Measurement Apparatus Employing Plate Modulation

always been found most convenient to calibrate the tube voltmeter at 60 cycles per second.

The statement has been made in connection with Figure 1 that

$$E_I = k\, E_X\, E_B$$

for the intermediate-frequency detector within the limits of overloading. By overloading we mean the region where k is no longer constant. Careful tests have shown that k does not change beyond the limits of tolerance as E_X is varied from 2 volts down to 2×10^{-5} volts, at a frequency of one megacycle, where it is still possible to construct potentiometers of sufficient accuracy.

Circumstantial evidence as to the accuracy of this action at high frequencies is given by the fact that when E_X and E_B at about 40 megacycles are made the same as E_X and E_B at about one megacycle, as indicated by the intermediate frequency detector as a tube voltmeter, the factor k is identical in both cases.

The gain control or attenuator is made of resistance units wound non-inductively (reversed loop) on a thin card. An

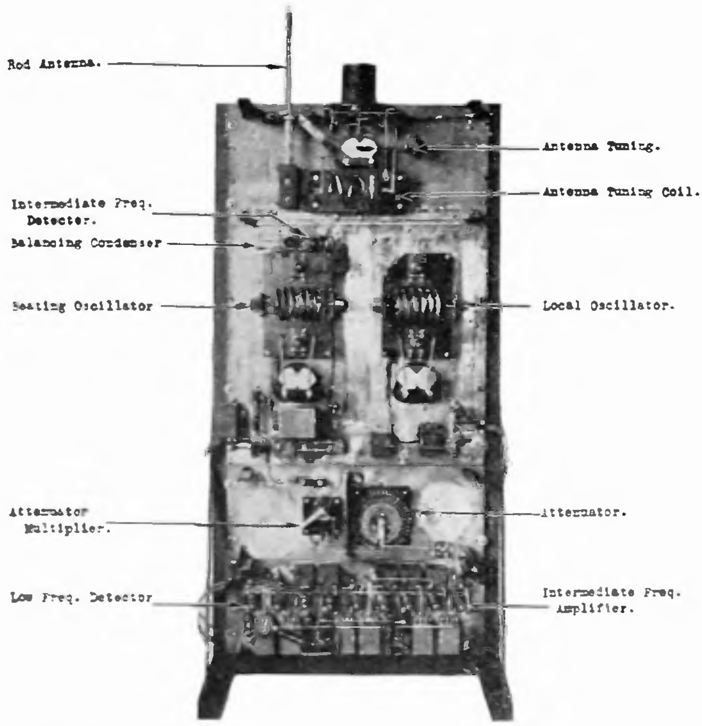


FIGURE 9—Apparatus Employing Plate Modulation with Copper Shielding Boxes Removed

idea of this construction can best be obtained by examining the photographs. Maximum attenuation is 10^{-6} times.

The intermediate frequency amplifier is of fairly standard construction. Its resonant frequency is 300 kilocycles and the band width has been adjusted to about 30 kilocycles. This broad band eliminates "hair line" tuning at the higher signal frequencies.

In regard to the sensitivity of the set, it should be recalled that the voltage induced into the loop by the incoming signal is given by

The field strength in microvolts per meter of the received signal is therefore

$$\frac{\mu v}{m} = \frac{V \times 10^8}{\frac{a_2}{a_1} \beta H}$$

where H is the effective height of the signal collector in centimeters. V is usually chosen as one volt for convenience.

The largest ratio of $\frac{a_2}{a_1}$ is determined by the total amplification of the set and the sensitivity of the output indicator.* For the sets in the photographs, this ratio is close to 5×10^4. The

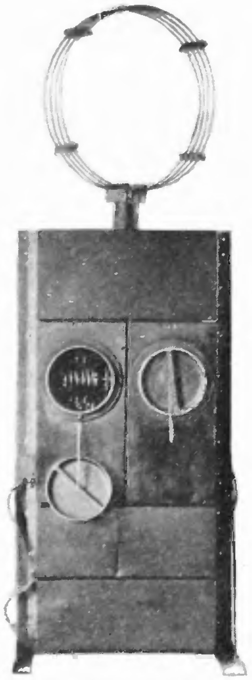


FIGURE 10 — Field Strength Measurement Apparatus Employing Plate Modulation

loop voltage step-up ratio β depends on the construction of the loop. Examples of this ratio are given in the following Table II. These values are for the four-turn loop and the two-turn loop shown respectively in Figures 10 and 8. Assuming that the average product of the loop step-up and effective height is about 500 (see Table II), the minimum field strength measurable when using these loops is about

* A Western Electric "N" Tube (215-A), Plate Curvature, Tube Voltmeter.

$$\varepsilon = \frac{1 x 10^8}{50{,}000 \times 500} = 4 \frac{\mu V}{m}.$$

TABLE II

Turns	Diameter	Frequency	Loop Voltage Step-up β	$\frac{\omega L}{R}$	H cms.	$\beta x H$
4	44.2 cm.	4.9 x 10^6	120	240	6.3	760
4	44.2 cm.	7.8 x 10^6	75	150	10	750
2	35 cm.	8.6 x 10^6	80	160	3.5	280
2	35 cm.	17 x 10^6	60	120	6.8	410

Using an open vertical antenna, constructed of ½ inch copper pipe, as a signal collector, instead of a loop, the set sensitivity can be multiplied from 5 to 10 times. Table III, below, gives

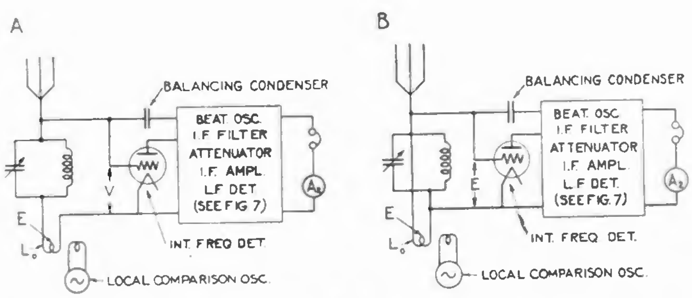


FIGURE 11—Field Strength Measurement Apparatus Employing Plate Modulation—Open Antenna

examples of comparison data on various lengths of pipe, their measured effective heights, and their effectiveness as signal collectors as compared with the previously mentioned loops. In most cases, these antennas make possible the measurement of fractional parts of a microvolt per meter.

TABLE III

Antenna	Signal Strength $\eta v/m$	Frequency	H_{eff} cm.	Relative values of Antenna Outputs
4-turn loop	455	5.4 x 10^6	6.9	1
Rod 80 cm. long	455	5.4 x 10^6	22	4.6
Rod 231 cm. long	455	5.4 x 10^6	80	5
Rod 427 cm. long	455	5.4 x 10^6	152	7.6
2-turn loop	1260	16.1 x 10^6	6.5	1
Rod 80 cm. long	1260	16.1 x 10^6	2.5	5.4
Rod 231 cm. long	1260	16.1 x 10^6	105	4.5
Rod 427 cm. long	1260	16.1 x 10^6		below 1
Rod 10 cm. long	900	30 x 10^6		below 1
Rod 50 cm. long	900	30 x 10^6		2.6
Rod 80 cm. long	900	30 x 10^6		2.6
Rod 150 cm. long	900	30 x 10^6		1

It is interesting to note the existence of optimum lengths of these antennas at a given signal frequency. This is due to the fact that the radiation resistance increases as the square of the effective height while the induced voltage is only proportional to it. Simple calculations show that an optimum value is obtained when the radiation resistance is equal to the circuit resistance.

The frequency range of the set utilizing plate modulation is from 0.7 to 20 megacycles using a loop antenna. With the open vertical antenna the upper limit is raised to 43 megacycles. This large frequency range is made possible by the use of a set of interchangeable oscillator coils, loops, antennas and tuning coils.

In conclusion, it may be well to enumerate the major factors which make this system of short wave measurement possible.

1. The method facilitates the shielding of the local signal oscillator.

2. All the required known attenuations are made at a relatively low and fixed intermediate frequency.

3. The comparison voltage is measured directly by means of a tube voltmeter. This method is more satisfactory than the current-impedance drop method at the very high frequencies.

4. Effective balancing circuits have been devised whereby the input circuits to the intermediate frequency detector do not react upon the beating oscillator input.

5. The completed system is capable of giving the absolute field strength of a received signal within 20 per cent of its true value. Comparative signal measurements can be made with an error of not more than 5 per cent. The prevalence of fading at the high frequencies make these degrees of accuracy quite ample.

SUMMARY: The paper describes field strength measurement sets for frequencies as high as forty megacycles. The apparatus is a double detection receiving set which is equipped with a calibrated intermediate frequency attenuator and a local signal comparison oscillator. The local signal is measured by means of the intermediate frequency detector which is calibrated as a tube voltmeter.

RELATION BETWEEN THE HEIGHT OF THE KENNELLY-HEAVISIDE LAYER AND HIGH FREQUENCY RADIO TRANSMISSION PHENOMENA*

By

A. Hoyt Taylor

The theoretical basis of this paper has been published in the "Physical Review" for January, 1926.[1] The paper referred to was in turn based upon certain experimental data[2] which have been considerably extended since the date of submitting the same for publication.

The present discussion concerns itself solely with waves short enough to show the skip distance effect and one of its main interests lies perhaps in the indication that it may give as to the possible lower limit of wavelength which will be useful in long-distance communication. In reference (1), it has been shown that for the period covered by the data in reference (2) the average height of the Kennelly-Heaviside layer during the daylight hours was 150 miles reduced to the basis of the height of an equivalent reflector. It must be kept in mind, however, that the actual process is not one of reflection. At the same time, fortunately, methods of graphic representation of high-frequency phenomena may be employed based upon an equivalent reflection without introducing any inaccuracy, except that it is important to recognize that the full treatment on the refraction basis is such that in the general case there are four rays coming down after refraction from the layer; two of them being plane polarized and two circularly polarized; and these four rays need not, indeed usually are not, coherent. For the sake of simplicity, the following discussion will be based on a single ray, taking the one which has the smallest refractive index. This means the ray which will first reach the earth after refraction (reflection from layer at equivalent height). In reference (1), for 150-mile layer, it was shown that the shortest wave it would be possible to use in long distance communication would be 14 meters. Extensive

*Received by the Editor, April 29, 1926.

[1] Hulburt and Taylor, "Physical Review," Feb., 1926.

[2] Taylor, Proceedings of The Institute of Radio Engineers, December, 1925.

experiments have not brought forth any evidence contradicting this conclusion, but inasmuch as the Heaviside layer during the middle of the day is lower than at other portions of the day, and is in fact lower in summer than it is in winter, it has been thought worth while to extend the investigations to the study of transmissions between 11 and 20 meters, carried out over long distance in the middle of the day. The results of these transmission studies have shown a very gratifying agreement with earlier work and have permitted some calculations on the height of the layer at various times, which permit to a certain extent, the forecasting of probable results to be obtained at various wavelengths, provided those wavelengths are short enough to show skip distance effects. Practically, this means waves somewhat shorter than 60 meters. The inclusion of the three other waves with different states of polarization and other refractive indices will not in any way change the character of the general results, but will merely serve somewhat to blur or obscure the otherwise sharp boundary between zones of reception and non-reception.

Figure 1 shows the state of affairs when transmitting station S is able to transmit rays at all angles between the vertical and horizontal. The horizontal ray, which can only be transmitted if the station is elevated a considerable distance off the ground (otherwise it would be absorbed) is, afterrefraction (equivalent refraction) from the layer, brought down at a considerable distance from the transmitter. Let the angle of the ray with the horizontal ray be α. The radius of the earth is designated by the latter R, and the height of the layer by h. Let α' be the ray of the highest angle, which can be used and still return to the earth. The line $R+h$ is drawn from the center of the earth to the point on the layer which is struck by this ray. This ray returns to the earth at an angular distance of $\theta°$ from the transmitter S. This angle to $\theta°$ corresponds to the skip distance, that is, $D=2\theta\times 69.8$. What actually happens is that all rays at a higher angle than α, if the wave is short enough, are not sufficiently refracted ever to return to the earth, or, putting it on the equivalent reflection basis, we may say that since we exceed the critical angle, thay will not be reflected. It must be kept in mind that the velocity within the layer is higher than the velocity in free space, due to the presence of electrons within the layer. The angle β is the critical angle. It the ray strikes the layer in such a way as to exceed the critical value of β (which is, of course, a function of the frequency), the ray will not return. This is the physical meaning of the skip distance. It will be seen that for a layer of uniform height, a simple relation exists between β, θ, α', h, R and μ, the refractive index, where α' is the value of α, corresponding to the critical value of β. This relation is

$$\cos(\alpha' + \theta) = \frac{R}{R+h} \cos \alpha' = \sin \beta = \mu.$$

The curve of the refractive indices is shown in Figure 2, the values being calculated as previously in reference (1), using the ray with the smallest refractive index. Knowing the value of

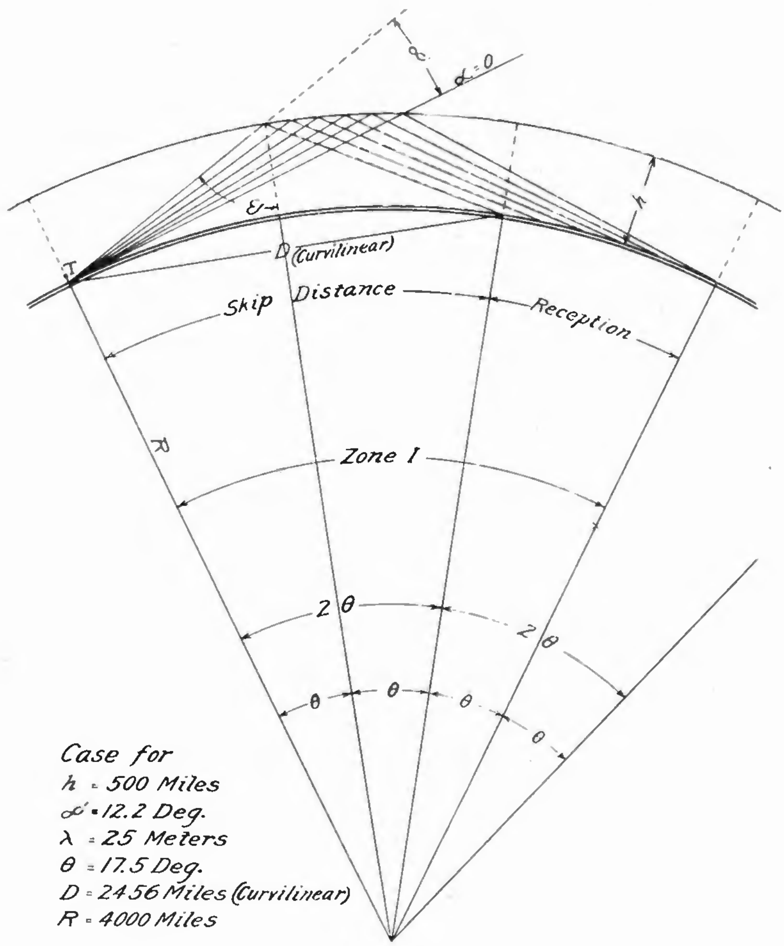


FIGURE 1

the refractive index for any wave, we are in a position to compute the critical value of α, which may be used; in other words, the radiation of the highest angle which is useful in producing a return wave from the sky. Further we can compute the width of the zone of reception for any given cone of emitted rays. If, for instance, the upper limit of our cone is the critical angle, α', and the lower limit is the small angle α, which in the limiting case is 0 (ray horizontal), there will be two values of θ, where θ' corresponds to α' and θ corresponds to α. α' is greater than α, but θ' is less than θ. The breadth of the first zone of reception

$$B = \frac{4\pi R}{360}(\theta - \theta').$$

In general, if B_n is the breadth of the nth zone of reception, then

$$B_n = \frac{4\pi Rn}{360}(\theta - \theta').$$

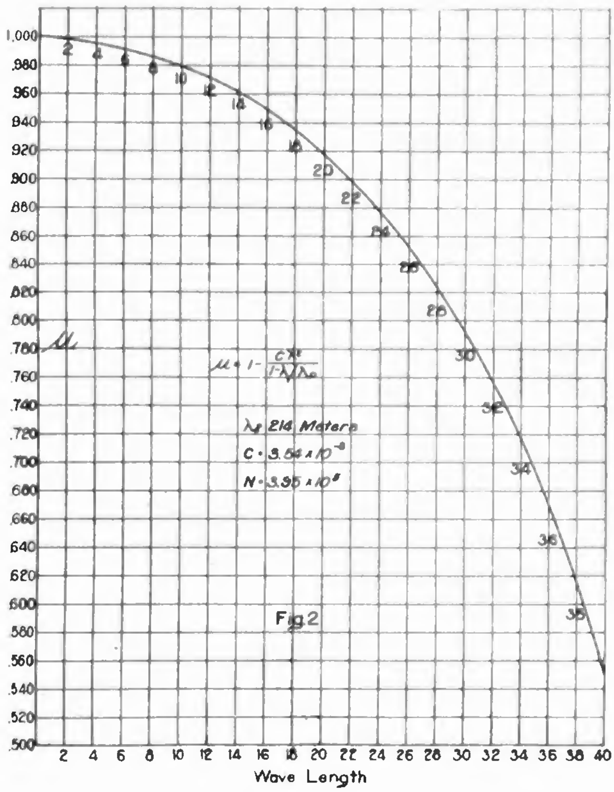


FIGURE 2

The next zone beyond n will have the breadth

$$B_{n+1} = \frac{4\pi R}{360^\circ}(n+1)(\theta - \theta')$$

This is assuming that θ is measured in degrees. The gap or zone of non-reception, lying between any two zones is from the advanced edge of zone n to the rear edge of zone $n+1$, which is

$$G_n = \frac{4\pi R}{360}[(n+1)\theta' - n\,\theta]$$

There will be no gaps when this expression is negative; that is, when $n\,\theta \geqq (n+1)\theta'$, or $n \geqq \dfrac{\theta'}{\theta-\theta'}$.

The following illustrations will show this works out. Case 1—Suppose our cone of rays is limited between the horizontal ray and 10°. θ then is equal to 15° 27′ and θ' is equal to 8°, 20′. The application of the preceding criterion for the existence of gaps shows that a gap does occur between zone 1 and zone 2, and that the gap is nearer zone 1 than it is to zone 2. Case 2—A cone of rays limited between the horizontal and 15°. If this case is calculated we find that θ equals 15°, 27′, θ' equals 6°, 24′, and the application of the criterion for gaps shows that there are no gaps after the first skip distance; that is, there are no gaps in reception following zone 1, but if the nearness of the transmitter to the ground should so absorb the lower rays that our cone is limited between 5° and 10°, the calculation shows that θ will equal 11°, 13′, θ' equals 8°, 20′, and the application of the criterion indicates that the gaps do not disappear until the region of reception is beyond the second zone. The criterion will also show that there is grave danger in the neighborhood of the outer edge of zone 3, since the conditions for no gaps are barely met and a very little variation in the height of the layer will introduce a gap. A limiting case for extremely short waves is where the refractive index is equal to unity. This would give

$$\cos \alpha' = \frac{R+h}{R}$$

This, of course, can only be true if $h=0$; in other words, unless the layer is extremely low down, extremely short waves cannot be used effectively over distances of more than a few miles. It is interesting to see whether these results can be expressed graphically in such a way as to approximate the actual distance of long distance transmission.

Figure A depicts the pattern produced on the earth by different zones of reception and non-reception when there are three different conditions for a Heaviside layer height of 150 miles, and two different wave lengths, which show an initial skip distance of 500 and 1,500 miles, respectively. The figure is drawn to scale and assumes a uniform layer. The transmitter is at W. The ray at the critical angle for the wavelength of 500-mile skip distance is drawn as a solid line. The ray at the critical angle for the wave, which shows the 1,500-mile skip is represented by long dashes separated by a single dot. The horizontal or

FIGURE A

tangent ray is represented by long dashes separated by two dots, and the ray for which $\alpha = 3°$, that is, 3° above the horizontal, is represented by short dashes.

Case 1—500-*mile skip*. The first zone of reception, if we consider the transmitter capable of getting out all rays down to the horizontal, lies between 500 and 2,000 miles. The second zone of reception lies between 1,000 and 2,000 miles; the third between 1,500 and 2,500 miles, etc. It will be seen that there are no secondary skips or zones of non-reception after the first skip distance. The diagram for this ray is, therefore, not carried out beyond 2,500 miles. In the region between 1,000 and 1,500 miles, we have two kinds of rays, one family having suffered one reflection and the other family having suffered two reflections. In the region between 1,500 and 1,750 we have three kinds of rays, and again two kinds between 1,750 and 2,000. Beyond 2,000 there are always three or more kinds of rays, due to the overlapping of the zones. If we take into account a certain amount of absorption in the lower rays, which is usually inevitably the case, and cut off the 3° next to the horizontal, we find that the first zone of reception falls between 500 and 1,750 miles, but that the zones still show a good overlap, so that there is no danger of any missing region developing further out. Now consider a much shorter wavelength showing a 1,500-mile skip. We find that if we include rays at the horizontal, the first zone falls between 1,500 and 2,000 miles; the second between 3,000 and 4,000, leaving a wide gap between. The third zone falls between 4,500 and 6,000, with a somewhat narrower gap between zone 2 and 3, and that after 6,000 miles no further missing regions develop. For this condition the diagram stops at 8,000 miles, it being unnecessary to carry it any further. If, however, we again limit the lower side of the ray by a ground absorption or any other artificial means, sich as the use of a suitably arranged reflector or by special means of tuning the antenna system, we find that the first zone of reception is very narrow and lies between 1,500 and 1,750 miles. For the second zone it lies between 3,000 and 3,500; for the third, 4,500 and 5,250; for the fourth, 6,000 and 7,000; for the fifth, 7,500 and 8,750, and for the sixth between 9,000 and 10,500 miles. In other words, it would be necessary for a ray to travel almost to the antipodes before the condition of alternating regions of reception and non-reception is done away with. This, of course, does not represent an actual case, because the layer could not possibly be even approximately at a uniform height over so great a distance. The discussion shows, however, the general trend of affairs as they exist, and by observing the primary and secondary skips produced by such short wave radiations it has been possible to get certain checks on the general theory. It should also be pointed out that these missing regions will occur at somewhat longer waves if the layer becomes of sufficient height. Experimental data have been collected along these lines, and there is sufficient evidence to indicate that this general conclusion agrees with the facts.

It is possible to analyze the situation graphically in another way which presents, in a clearer way, the varying conditions as the height of the layer is changed. Figure 3 shows the values

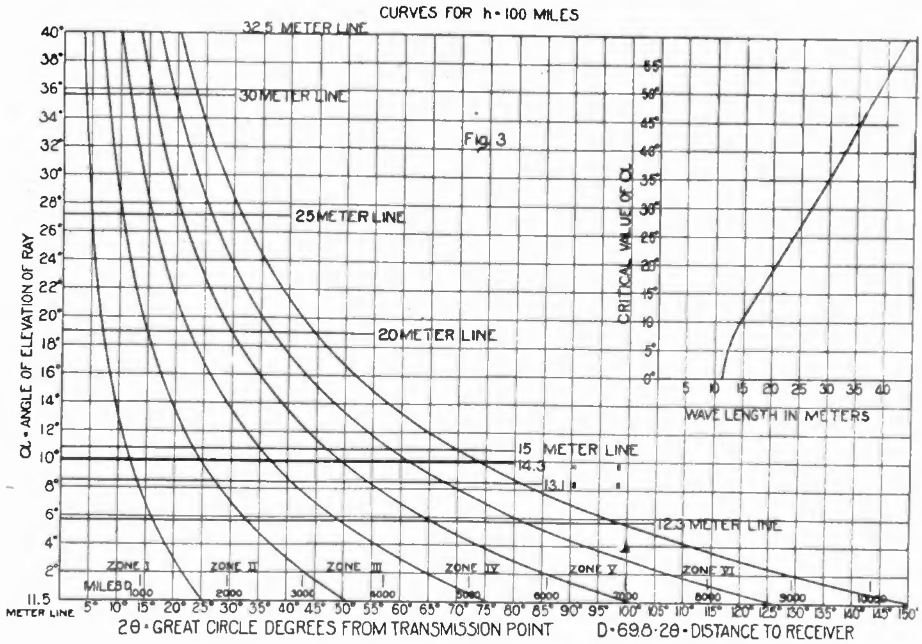


FIGURE 3

of θ corresponding to different values of α for the different zones of reflection, and for rays varying from horizontal to 40° with the horizontal. To find the position on the surface of the earth where any one of these rays come down, it will be necessary to find the value of θ, which corresponds to any given value of α. Assuming that the rays coming down from the sky will be reflected up again at the same angle, which some of them at least will do, if they will strike a sufficiently large piece of horizontal flat ground or water, the zone where the ray comes down after two reflections from the layer is shown by the next curve zone, No. 2, and so on for succeeding zones. Figure 3 is drawn for a Heaviside layer of 100 miles, which corresponds very accurately to the mid-day height over the American continent for the Spring of this year. In order to determine what angles are actually available for useful transmission, it is necessary to take account of the critical values of α, and therefore of the variations of the same with wavelength. The curve in the upper right-hand corner of Figure 3 gives these data and from values taken from this latter curve, we can draw straight horizontal lines corresponding to different wavelengths on the main diagram. All portions above these lines indicate, for that particular wavelength, those higher angles of radiation which are wasted as far as long-distance transmission is concerned. For instance, using a wavelength of 32.1 meters, it is possible to utilize rays of as high an angle as 40°, but when using the 15 meter wavelength, all rays higher than 10.8° are useless. They may be all right for communication with other planets, but they never return to the earth. The limiting angle on the lower side is more difficult to specify as it differs greatly with different antenna installations and the method of exciting antennas. An antenna may be so excited as to exclude rays of a certain angle which will certainly be very disadvantageous on certain wavelengths for reaching certain portions of the earth's surface. On the other hand, an antenna close to the earth is liable to have a few degrees near the horizontal taken out by the earth's absorption. It is, however, certain that the shorter the wave, the nearer we can come to using rays near the horizontal, the amount of absorption depending on the ratio between the height of the base of the antenna above the earth and the wavelength in such a way as to greatly favor the low angle rays for very short waves. Another interesting thing comes out of the diagram, and that is, that it indicates a distinct limit as to the shortest wave possible for any long distance work whatever. That wave for this particular diagram, with a layer 100 miles high, is 11½ meters. In this connection it is interesting to note that while this laboratory has repeatedly communicated with the Radio Corporation station 6XG at Oakland, California, and with the Radio Corporation station 9XA at Denver, Colorado, on 11.8 meters, it has never been possible so far during the month of March to communicate on 11 meters. It is expected, however, that this will be accomplished during May or June—or possibly even during the latter part of April; because the Heaviside layer will be somewhat lower at that time, which will so modify conditions as to make a shorter wave possible. The use of the diagram can best be understood by an actual case. For instance, for 20 meters, we see from the insert curve on the right of Figure 3, that the 20 meter line falls at about 19°. This gives the skip distance of 7.2 great circle degrees and the farthest zone of reception in the first zone extends to 25 great circle degrees. If now we drop the perpendicular from the intersection of zone 2 curve with the 20-meter line to the intersection of that perpendicular with the zone 1 curve, we see that it cuts that curve at 7°. If we are able to utilize radiation between the angle of 7° and 19° with the horizontal, we will never have any other skip regions opening up beyond the first. In other words, there will be no region of non-reception after the first skip. If, however, we drop to 12.3 meters we find that the critical value of α for this wavelength is 5.7°. The initial skip distance is 16.5 great circle degrees, and the limit of reception even for a horizontal ray is 25°. This shorter wave gives a longer skip and a much narrower zone reception. If we take the intersection of the 12.3-meter line with zone 2 curve and drop the perpendicular from there, we see that it does not intersect the zone 1 curve; there is a large gap from 25° to 32.5°, where there is certain to be no reception. This gap has been actually experimentally discovered a number of times. If we take the intersection of the zone 3 curve with the 12.3-meter line and drop the perpendicular we find that it just barely hits the zone 2 curve. Since the rays probably do not actually come quite down to horizontal, it would seem reasonable to expect a gap at 50° (great circle) from the transmitter. Beyond this, however, we would not expect gaps to occur, unless we are working into a region towards darkness where the layer is getting higher. This will be considered as a special case later.

The general nature of the influence of the height of the layer on the lower wavelength limit and the distribution of the zones of reception may be seen in the succeeding Figures 4, 5, 6, and 7, which are plotted for layer heights of 150, 225, 300, and 500 miles, respectively. One hundred and fifty miles represents mid-winter, mid-day conditions or late afternoon conditions in the Spring and Fall. It may also be considered to represent morning conditions at similar seasons of the year. Two hundred and twenty-five miles represents conditions approximately as they exist at midnight: summer nights and 300 miles conditions for the middle of the night in Spring and Fall. Figure 7 for 500 miles represents conditions approximately as they often exist during the middle of the night in mid-winter. The followig points are of particular interest in connection with curves shown in Figures 3 to 7, inclusive. A critical wavelength, below which no long-distance communication is possible, is shown to be:

11.5 meters for a 100-mile layer
14 meters for a 150-mile layer
16.5 meters for a 225-mile layer
19 meters for a 300-mile layer
25 meters for a 500-mile layer

If we take curve 6 as fairly representative of average night time conditions and compare it with curve 3, which actually represents conditions for mid-day in the month of March, this year, some interesting differences in the pattern on the surface of the earth

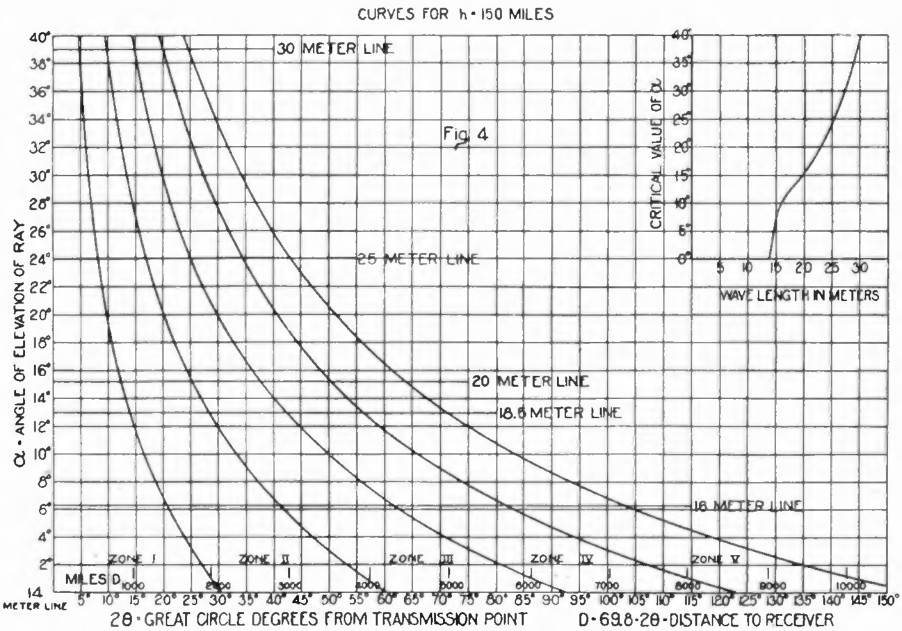


FIGURE 4

produced by the alternating zones of reception and non-reception are to be brought out.

Consider 20-meter transmission. When the layer is at 100 miles, the skip distance is 7° and there are no skip regions beyond the first. Rays of higher angle than 19° are useless, but when the layer is at 300 miles, rays higher than 7½° are useless and the initial skip distance is 30½°, which is somewhat over 2,000 miles. There is a very wide gap from 43° to 61°, that is, between 3,000 miles and 4,250. Following this gap there is a zone of reception up to 6,000 miles and then there is another gap beyond which reception is continuous. A glance at the diagram suffices to show why long distance work in the 20-meter band at night shows marked peculiarities and why communication on still shorter waves is impossible. These remarks must not be interpreted to apply to transient or freak conditions. Some interesting conclusions can also be drawn as to relative strength of signals, if they are received at all, under these two conditions. For a point 5,500 miles away, under conditions shown in Figure 3, reception is only possible after four reflections, whereas under conditions shown in Figure 5, only two reflections are necessary. There is no theoretical reason so far for leading us to believe that there is any mechanism of absorption whatever in the upper layers of the earth's atmosphere for these frequencies, or at any

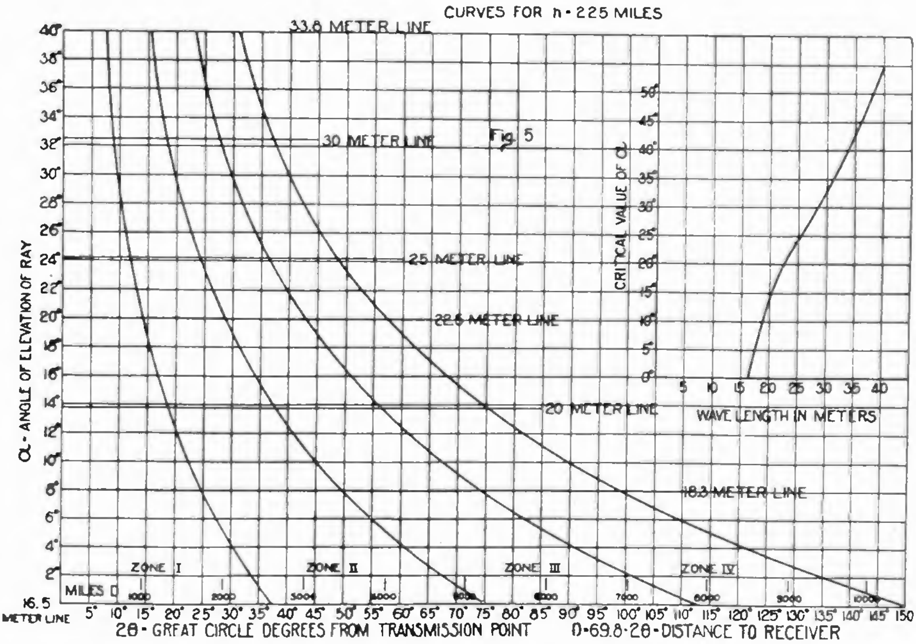


FIGURE 5

rate if such absorption exists, it is exceedingly small. It is true, however, that a great deal of energy is lost after a reflection from the earth's surface. We would expect, therefore, that signals under conditions shown in Figure 6 would be much stronger, and this, as far as information goes, is actually the case. It is also true that many of the nocturnal transmissions on 20 meters have not been observed at points sufficiently remote from the transmitter to get positive results. It follows in general, no matter what the height of the layer, that at points sufficiently remote, a good many different zones take part in the process of reception and many different rays of different life history have been brought down to the same receiver. This, of course, means an averaging out or a reduction in fading effects. This also is strictly in accordance with facts. The main advantage of the short wave is that it is able to reach the desired point with a small number of reflections. It may be argued that the longer wave has the same opportunity, since low angle rays are present, but this is not strictly true since at the lower angle the longer wave rays are taken out by ground absorption much more readily than the shorter rays. The greater height of the layer in winter nights, however, favors all wavelengths above 25 meters, which is the limiting wavelength for that layer height, because it is possible for all waves to take longer jumps under these conditions. At

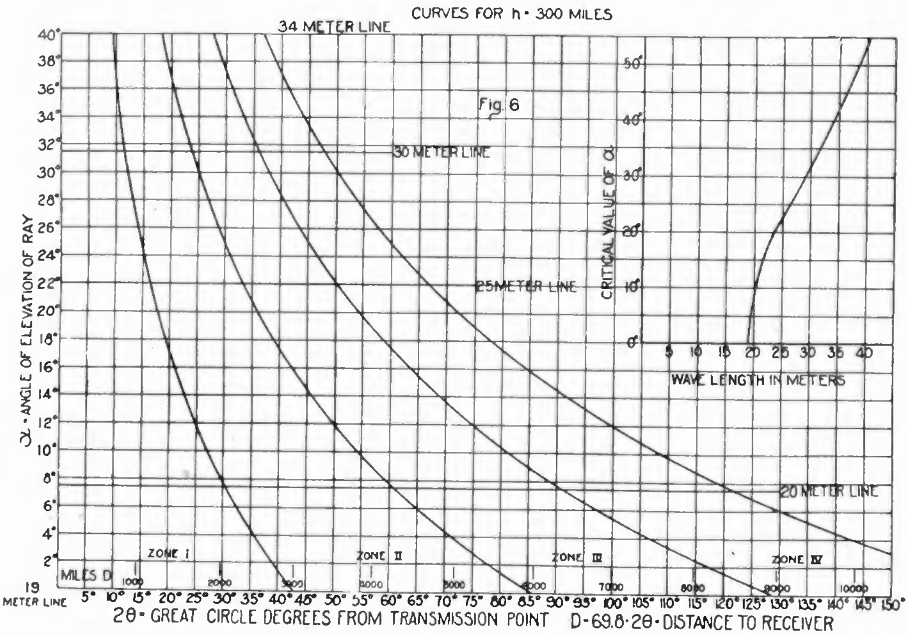


FIGURE 6

the same time a distant point receives energy from a smaller number of zones, as can be seen from an inspection of Figure 7. Therefore, the fading is liable to be somewhat more violent. These conclusions are borne out by practice. Some interesting conclusions can be drawn as to the probable maximum and minimum heights of the layer in this portion of the world. Knowledge of skip distances and their variations with the time of the day and year permit these calculations to be made. Based on the longest observed skips in the 40-meter band, the maximum height of the layer last winter appeared to be 550 miles. In connection with this figure it may also be of interest to note that since signals on 27 meters have not been observed to completely disappear during the winter midnight hours, the layers cannot have been last winter over 706 miles high. On the other hand, 21 meters would repeatedly apparently disappear completely, which would lead to a calculated height of 405 miles. The average between these two extremes is 555 miles, which agrees very well with the height computed from observations in the 40-meter band. This perhaps explains why the height of 500 miles has been chosen to represent mid-winter, midnight conditions. Another interesting point is that the layer would have to rise to 3,300 miles to make a 40-meter wave completely vanish and never be received on the surface of the earth. This seems

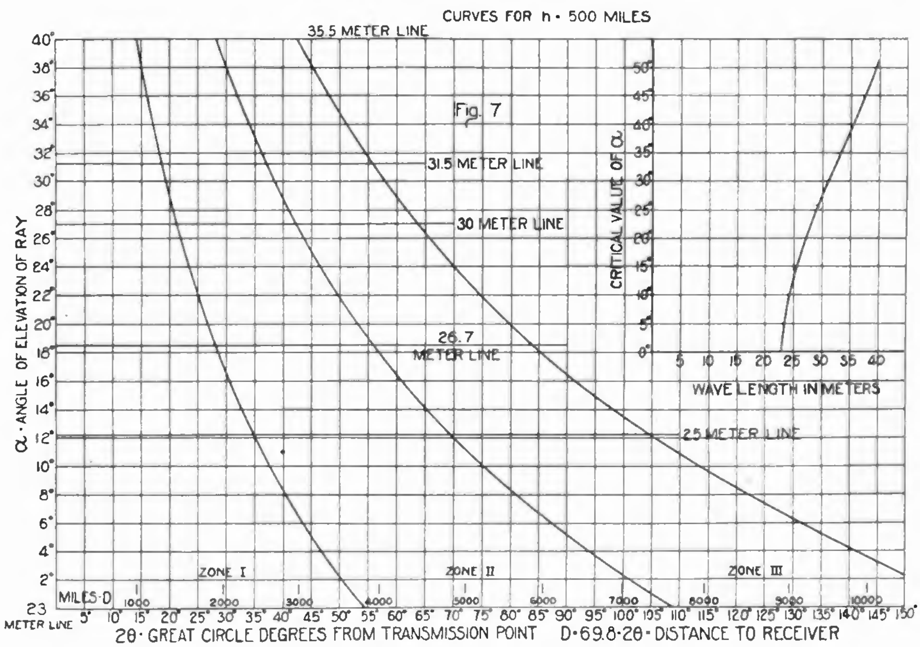


FIGURE 7

extremely unlikely unless perhaps over the polar regions in mid-winter. The evidence from the Polar regions does not indicate complete disappearance, but does indicate a very high layer during the winter and a very low layer in summer. The data are too scanty to warrant calculating the height there. Some observations are also at hand taken during the months of July and August of 1925, at which time, over a period of nearly a week, signals in the 20-meter band showed an abnormally short skip distance and indicated a layer height over this brief period as low as 51 miles. The limiting wavelength for a 51-mile layer would be 7 meters, but the skip distance would have been several hundred miles and the pattern on the surface of the earth would have shown very narrow zones of reception and very wide zones of non-reception. In other words, it would have been quite accidental if communication had been established under such conditions and it would be persistent only for a short time. Even a small variation in layer height would have flickered these zones back and forth so as to give extremely unstable conditions. To communicate on 8 meters would require the layer to come down to an equivalent height of 61 miles and the conditions would be the same to those just described. For 5 meters the height would have to be 41 miles, and it seems extremely unlikely that this will occur for sufficiently long periods to make experimental work worth while. If such work is attempted, it should be done in the middle of the summer and the observers should be scattered out between 300 and 1,500 miles from the transmitting station.

The experimental data obtained during the daily tests in the month of March this year, using waves between 11 and 26 meters, have been made possible by the cooperation of the operators at the Radio Corporation stations 9XA and 6XG, Denver and Oakland. It has been possible to observe the primary skips at Denver and the secondary skips, on different wavelengths of course, at Oakland, and to correlate this information. Since it has been impossible to get successful communication at 11 meters, but has repeatedly been possible on 11.8 meters, we can calculate the upper limit of the layer height to permit communication on 11.8 meters and this comes out to be 116 miles. The information based on primary skips shows the layer height to have been close to 113 miles. The information from Oakland, based on secondary skips, shows the layer height to have been 102 miles, and other information, based on observations at lesser distances by other stations, and on other wavelengths, particularly the twenty-meter band, give a calculated height of 110 miles. This is considered to be a very remarkable agreement. The skip distances observed by Denver were, for some of the waves, also secondary skips and these also calculated to practically the same height. Furthermore, the secondary skips observed by Denver have been checked as primary skips by other observers at half the distance in entirely different directions, notably by 9CXX at Cedar Rapids, Iowa, and 4XE at Winter Park, Florida. It does not appear, then, that the agreement in results is a matter of coincidence. These transmissions will be continued with the expectation that the layer will lower to average mid-day height somewhere in the neighborhood of 75 miles in the approaching summer, which will permit the use of waves down to 9 or 10 meters.

The curves herein presented refer, of course, to an ideal condition, namely, for a layer of unvarying height. It is somewhat difficult to get a graphic solution of the problem for layers of varying height, but as information comes in and more data become available, considerable progress can be made in this direction. The variation in the height of the layer is, of course, particularly interesting for East and West transmission. Figures 8, 9, 10, and 11 constitute an attempt to show the general nature of the peculiarities in East and West transmission which may be expected. The figures are obviously very far from correct

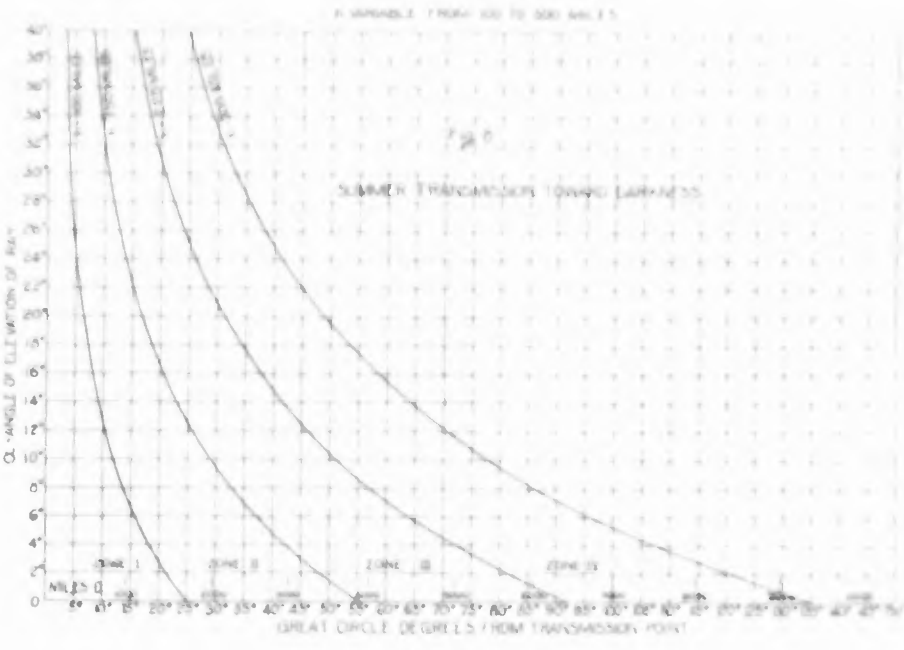


Figure 8

and more accurate figures could be constructed if it were deemed worth while in the light of the present information; nevertheless, they do throw much light on the situation. These curves in Figures 8 to 11 are drawn with differing layer height for each zone of reflection, which is, of course an exceedingly poor approximation, since the energy received in any zone may be reflected from heights not corresponding to that zone, nevertheless, the curve shows a marked peculiarity which should perhaps be called, in a certain sense, a non-reciprocity in transmission and reception. For instance, looking at Figure 8 for summer transmission towards darkness, starting from high noon at the location of the transmitter, we may pick a given wave such as 20 meters and by inspection of Figure 3 we see that rays of as high an angle as 19°

are available. The first region of reception is a broad region extending from 7 to 25°. For zone 2, however, by inspection of Figure 5 we see that rays up to 15.2° may be used so that the second region of reception overlaps the first. However, when we get out to zone 4, inspection of Figure 6 shows that rays up to only 7½° may be used, which do not quite overlap zone 3. However, the pattern is one of nearly continuous reception from 7° outward. There is merely a small gap in the neighborhood of 95°, but if we look at Figure 9, where the transmitter is at midnight, we are obliged to start with rays no higher than 7½° and no

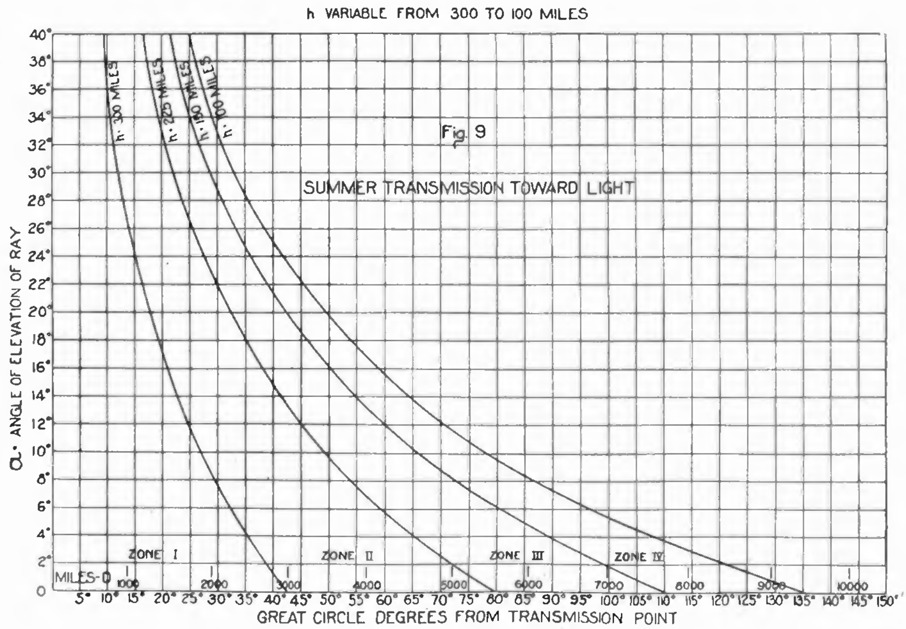


FIGURE 9

reception begins until 31°, which is beyond 2,000 miles. Moreover, rays of higher angle having been cut off at the beginning will not exist thereafter; the result of this is that there occurs a very wide gap between zone 1 and zone 2 of reception, namely: between 33 and 55°. After that there are no gaps. Obviously the zone patterns on the earth are very different for the two cases. It would seem, however, that after a ray actually reaches a given point, it should be possible to put a transmitter at this point and send that same wavelength back in the opposite direction and have it received at the original transmitter. However, we are really dealing with a complex band which is being refracted through an electron atmosphere in the presence of a magnetic field and it seems reasonably certain that the return ray or rays would at any rate, have entirely different states of polarization from the ray which started out. The irreversibility then consists in the different state of polarization and in the different character of the patterns on the surface of the earth made by the zones of reception and non-reception. This sort of thing is, of course, clearly emphasized in winter time as shown in Figures 10 and 11. Obviously, however, for extremely long East and West transmission, one must not use wavelengths which, when they encounter darkness in a high layer, will become lost because they exceed the critical wavelength for that particular

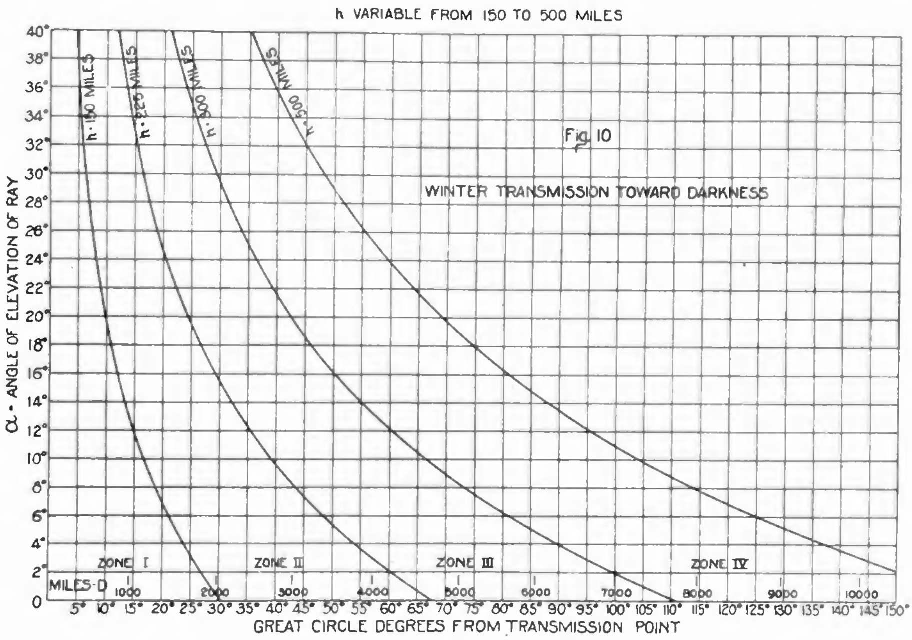


FIGURE 10

layer. If this be true, very long distance work East and West in the winter time should be limited to wavelengths in excess of 23 meters and in summer time to wavelengths in excess of 9.0 meters. At the same time, the waves should be, for strongest signals, fairly close to the limiting ray in order to have the smallest number of reflections and therefore, the least absorption.

As far as North and South transmission is concerned, the limiting cases would probably occur when winter occurs south of the equator, and again when winter occurs north of the equator. At these periods, transmission may not be wholly reciprocal. In the Spring and in the Fall, however, fairly uniform conditions should prevail over the entire distance.

In conclusion it may be stated that there is one station in this country which does not appear to show a skip at all, or at least not at all in line with that shown by Naval transmitters and by other transmitters observed at this Laboratory. That station is 2XS of the Radio Corporation, whose signals are received at points from 200 and 600 miles distant, which, theoretically, they should not reach at all. A number of observations have been accumulated upon this station by this Laboratory, and practically without exception they show this anomaly. Several possible explanations have been advanced and they are given here for what they are worth, none of them, however. must be

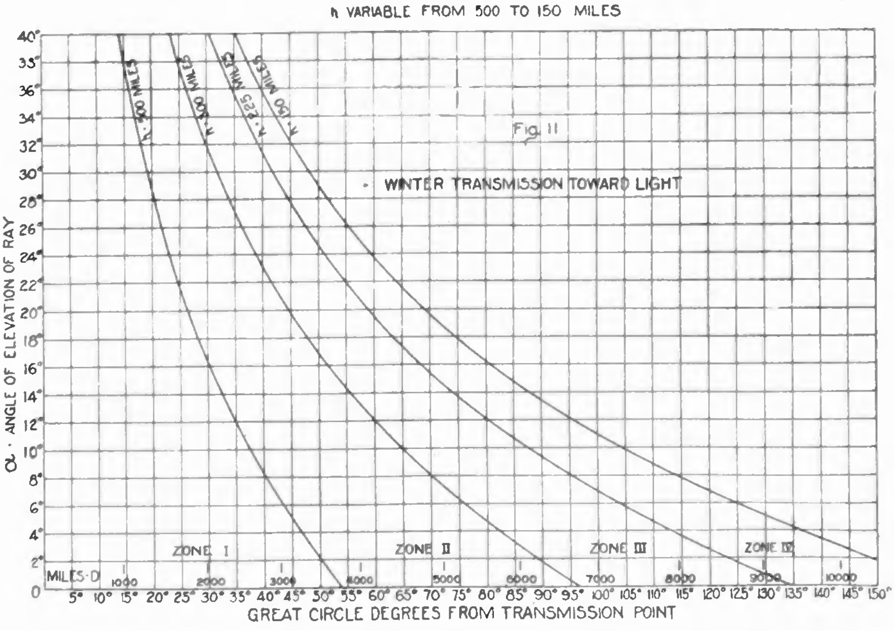
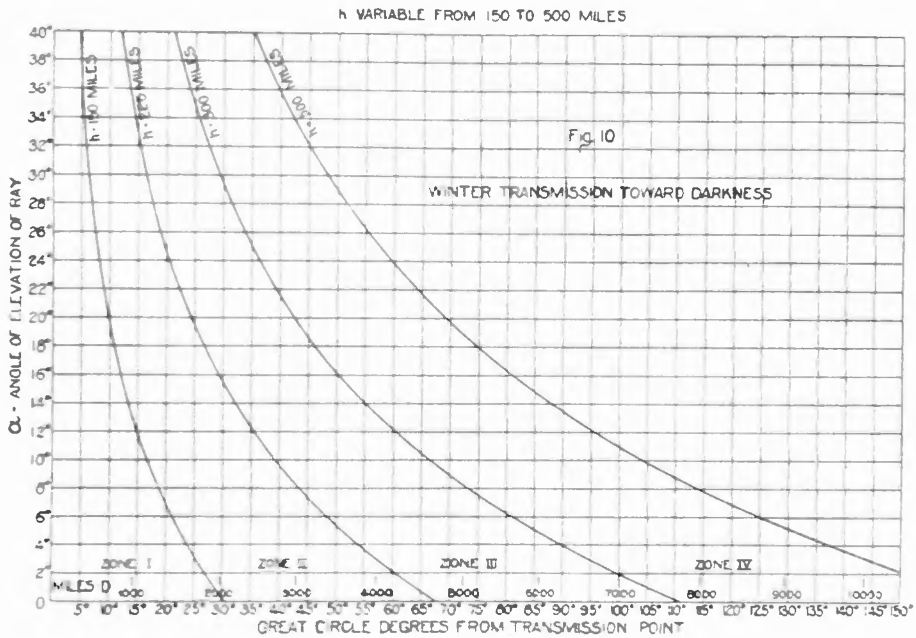


FIGURE 11

taken too seriously. First, that the signals travel entirely around the globe. This seems unlikely, because the signals are too strong. Second, that there may be an effect near 2XS, due to ionization from various sources, which are known to exist in the neighborhood of large manufacturing cities. There is little doubt that such ionization effects do exist, but that the electron density is sufficiently great to account for the refraction and production of a sky wave other than the one from the Kennelly-Heaviside layer, seems difficult to believe. It is understood that the radiator of 2XS is a horizontal polarized doublet, but this does not explain in any way the anomaly. Such doublets have been commonly in use at this Laboratory for a long time and without exception they show normal skip distance effects. The use of the ray or rays would at any rate, have entirely different states of polarization from the ray which started out. The irreversibility then consists in the different state of polarization and in the different character of the patterns on the surface of the earth made by the zones of reception and non-reception. This sort of thing is, of course, clearly emphasized in winter time as shown in Figures 10 and 11. Obviously, however, for extremely long East and West transmission, one must not use wavelengths which, when they encounter darkness in a high layer, will become lost because they exceed the critical wavelength for that particular



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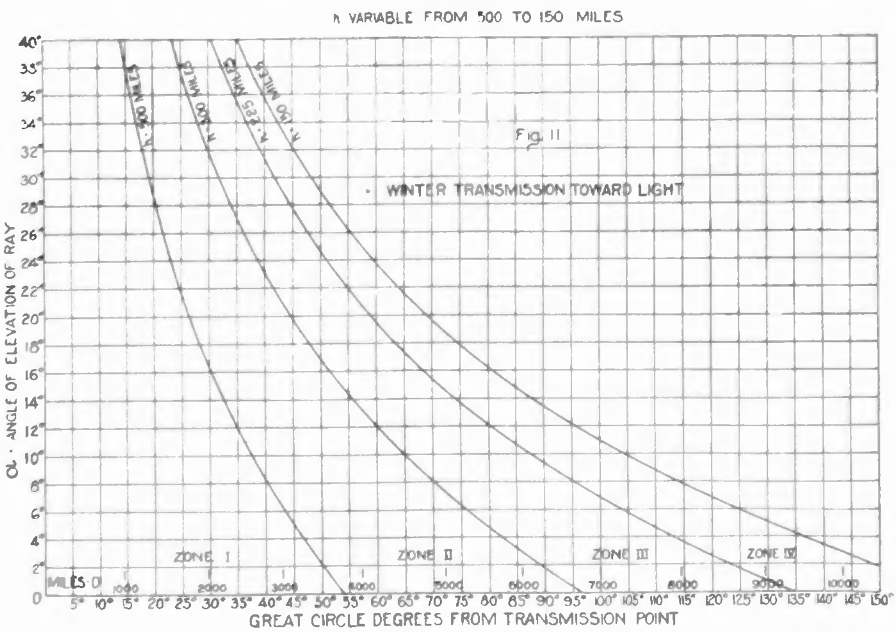

FIGURE 11

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SERVICING OF BROADCAST RECEIVERS*

By

Lee Manley and W. E. Garity

(Radio Corporation of America)

Much has been said and much has been written on the many troubles that arise in radio broadcast receivers as to what causes their failure and how to correct troubles when they occur. The radio sections of our daily papers and radio publications have devoted columns and pages in answering individual problems. These have been of invaluable assistance to the individual, but in nearly all cases have referred to specific conditions.

In this paper we will endeavor to group service problems under general classifications, prescribe methods of diagnosing them followed by a prescription for correcting them.

We believe that general methods may be applied in spite of the fact that there are so many different types of sets on the market, each one claiming individual distinction all its own. All radio sets, no matter what type, which fail to give satisfaction do so for a number of reasons that are fundamental.

In general, there are four basic pick-up circuits in use today: the so-called regenerative detector, the untuned radio frequency, the tuned radio frequency and the super-heterodyne. Any set on the market may be classified as using one of the foregoing types or possibly a combination of one or more. There are two additional types of pick-up circuits which have fallen more or less into oblivion and will not be found in general use in the broadcast receivers of today. They are the crystal detector and the straight audion detector which employs no form of regeneration whatsoever.

Receiving sets consist of a pick-up circuit, a detector circuit and an audio frequency amplifying circuit. In the pick-up circuit radio frequency amplification may be incorporated. The detector may be either a tube or a crystal. In the audio frequency circuit from one to three tubes are generally used. In multi-tube sets employing radio frequency amplifiers, some arrangement of circuit is made to suppress or control the tendency

* Received by the Editor, October 9, 1925. Presented before The Institute of Radio Engineers, New York, October 7, 1925.

of the tubes to oscillate, when the circuits are tuned to resonance.

Any set on the market today may be grouped under one of the foregoing classes as to the circuit employed.

In much the same way that receivers may be grouped under circuit classifications, their failure to operate may be grouped under certain general classes, namely:

Lack of operating experience on the part of the user.
Location.
Defective accessories.
Open circuit.
Short circuit.
High resistance connection.

Lack of operating experience may be the result of not following out instructions carefully enough, or, as is sometimes the case, the instructions are not complete enough and are not entirely clear to the novice. It may be the result of insufficient instruction on the part of the service man who made the installation. Then, too, it may be the result of impatience on the part of the customer. It is a peculiar condition, but a fact nevertheless, that the first night a customer has a set, he feels that he should be able to get Chicago and points west from New York City. The responsibility for this condition rests with either the salesman who sold the set or the service man who failed to correct this fallacy in the customer's mind, or with the manufacturer of the set for over-advertising his product, and being a little too optimistic as to the possibilities of reception. A manufacturer who in New York City receives the Pacific Coast stations on his product is not justified in making a general statement that this can be repeated at will, giving the impression to the reader of the advertisement that that particular receiver will perform likewise in every other locality. That is incomplete advertising and should be discouraged as it has a detrimental effect on the industry as a whole, and results in unnecessary service costs.

Under the caption of location many factors must be considered. The type of building in which the installation is made, the proximity to steel buildings, power lines, trolley and railway lines, and the geological and topographical conditions surrounding the installation are all important factors. Certain areas appear to be "dead" to certain stations, while at the same time particularly good for others. We believe that this is due not to the area being "dead," but to a distortion of the wave front from the transmitting station, causing it to be deflected in such a manner as to render reception of signals from that station very difficult or impossible in that particular location.

Under defective accessories we may include defective tubes, batteries, loud speakers, antenna and ground installations, also improper battery connections. Many sets fail or are returned to the dealer as unsatisfactory because of poor antenna and ground installations. Many a set of good quality and capable of delivering satisfactory results fails because the loud speaker that is used with it does not have the proper electrical characteristics to operate satisfactorily in conjunction with the receiver. Tubes will also cause trouble as they are subject to certain defects incidental to fragility.

Open circuits are generally found in the movable connections of the set such as a condenser pigtail, loop leads, loud speaker leads, and any other connection that is subject to movement or vibration in the normal operation of the set. Open circuits may also result from burned-out transformers or from mechanical failures in telephone jacks, rheostats, and switches.

If a set has been once tested and found to be O. K., short circuits rarely occur. When they do it is the result of a mechanical failure of the moving parts or of tinkering with the mechanism of the set. It will sometimes happen that the pigtail of a moving element of the receiver will break and fall in such a way as to cause a short circuit of that element. This is particularly true of the pigtails of variable condensers. The principal cause of short circuits that occur in the normal operation of a set is in the tubes. If the filament of the tube should break there is a possibility of its falling in such a way as to cause a short circuit between itself and the plate and grid elements of the tube. When such a fracture of the filament occurs the voltage of the "B" or "C" battery, as the case may be, is short circuited through the conductors involved. This type of short circuit is generally of very brief duration as the filament will generally burn out as soon as the short circuit occurs. A contact between the grid and plate element of a tube is a more serious type of short circuit, resulting in the rapid deterioration of the "B" and "C" batteries, and may possibly cause a burn-out of the transformer windings in the circuits involved.

The foregoing troubles are relatively easy to check up as they are immediately apparent or can easily be located by a continuity of circuit test.

The most difficult type of failure to locate is that caused by a high-resistance connection. It is not only difficult to locate, but it is difficult to determine. This condition will cause the set to operate indifferently with rather unsatisfactory results. This condition is sometimes mistaken as location trouble. A high resistance is possible at any connection in the receiver. Soldered connections that are soldered with a corrosive flux that has not been properly treated after the soldering operation are probably the worst offenders. Weak mechanical springs in telephone jacks and switches may also introduce high resistance connections.

Radio sets, like individuals, are very much the same the world over. They fail or succeed according to a few fundamental laws. They are subject, as it were, to the same ills. The doctor can diagnose the trouble in a man's system whether he be well dressed or poorly dressed, whether his name be Smith or Jones, because he knows the fundamental laws governing the human system and is not confused by size or shape or a difference in physical dimensions.

One doesn't have to be a radio engineer or a radio expert to be able to service a radio set, but one does need experience to become adept, and some knowledge of the fundamentals is valuable. One must be, of course, familiar with the various parts that are commonly used in radio receivers such as rheostats, jacks, etc., and must know, in a general way, the function of each.

Given a first-aid manual, the man in the street with an ordinary amount of common sense and an ability to read, might go out and administer first-aid treatment and, if he followed the directions properly, might effect a recovery. A doctor could do no differently. His experience would permit him to handle the case more skilfully and his intimate knowledge of the workings of the human system would permit him to diagnose the case more quickly from the apparent symptoms, but the man with the first-aid manual would produce the same results in a little longer time and yet he knows nothing of medical science.

For instance, what does a doctor do when he is called in to treat a sick person? The first thing he generally does is to feel the pulse and while doing that he starts a series of questions as to the length of time the person has been ill, where the pains are, etc., and he may even go as far as to inquire into the family history. Let that be the practice of the radio service man. Do not immediately get out the tool bag and start pulling the set apart, but try to find out what the difficulty is by questioning the customer. What would one think of a doctor if at the first sight of every patient, he started to operate, and yet you will see a service man start in immediately to pull the set out of the cabinet and look for trouble, and the trouble may be in a battery connection.

What we will attempt in this paper is to outline a first-aid manual for the treatment of "sick" radio sets; that will enable the man who is not a radio engineer and who has only a slight knowledge of the art, to recognize trouble and make the necessary repairs. We have avoided, therefore, all theoretical considerations so far as possible and will treat the subject from a practical viewpoint and refer only to theoretical discussions when absolutely necessary. We have prepared a list of complaints that are most frequently heard, and we will analyze each complaint as to the possible reason for it.

Let us start with a suggestion to the dealer or, for that matter, to anyone who sells a radio receiver. Test all sets before sale. This takes but a very few minutes and will surely pay well in avoiding dissatisfaction as well as time that is sometimes necessary to service a defective set that has been shipped to a customer. A radio receiver that is working properly today does not as a rule go bad tomorrow, and if such an installation does fail, the dealer may feel that the trouble is due to a defective accessory rather than the set itself. When the service man is called on to service such a set he has the confidence that the set is O. K. and he will immediately be able to concentrate on the real probability of failure rather than imaginary ones.

Then, too, if the dealer would acquaint the customer with the limitations of radio reception, what to expect and what not to expect, service problems would be minimized. Acquaint the customer as to the probable length of time his batteries will last. This is quite important, and if followed out, will avoid some very disagreeable service jobs. For example, when a man purchases a radio set he becomes quite enthusiastic and will read all available literature on the subject, and at the end of a month he has absorbed just enough information that may prove dangerous. About this time the signals on his set will start to decrease and he will remember having read somewhere that this might be caused by a defective transformer, and he immediately gets out the tools to make the repair, and then the dealer has a regular service job on his hands. Had the dealer in the first place acquainted the customer with the facts concerning the life of the batteries, the customer would be more than likely to recall such information and take the proper steps to renew them.

The question has been asked at times, "What should the service man's equipment consist of?"

He should carry the necessary tools and apparatus to be able to run a complete test on the set to be serviced and be able to make any minor repair necessary. We would suggest the following items:

Set of tested tubes.
Multi-scale voltmeter of good quality.
Pair of head phones.
Large and small screwdrivers.
Small soldering iron.
Solder and non-corrosive flux.
Spare wire and tape.
Test-leads with clips.
Pipe cleaners.
Large piece of cloth.
Set of B and C batteries (small).

When a service man goes into a customer's home he is usually going there as a representative of a commercial establishment. He should be instructed to be courteous and considerate. If he must take a set out of the cabinet for adjustment he should use the piece of cloth provided in his kit to protect the surface of the table he works on. He should answer all questions asked him no matter how absurd they may appear to him. The customer generally has one question that he would like to have answered, and in his mind the service man must be an expert, in order to be able to do such work, and so he unburdens his mind. The service man should respect this attitude on the part of the customer and should do his best to point out the fallacies tactfully and set the customer right in his ideas about radio. The service man should make the customer enjoy his visit and if this is done the service man becomes a valuable asset to a business and is a potential salesman.

The service man, before he starts to make any adjustments other than turning on the set and trying the various controls, should question the customer as to how it happened, the time, place, and conditions surrounding the failure. Such questions as the following:

How long has the set been in operation?

Was the set operating satisfactorily up to the time of failure?

Were you tuning the set when the failure occurred?

If so, what control were you moving?

Did you make any change in the connection of the batteries, if so, what were they?

Did it suddenly stop operating?

Was there any squeal or howling sound just prior to failure?

Were you moving the loop?

Did the loud speaker fall?

Is the antenna OK?

In short, have the customer re-enact the conditions at the time of failure. Get all the symptons and an astonishing amount of time may be saved in running down the difficulty. If sufficient questions are asked, the customer will generally give you the real cause of trouble or he will suggest something to you in the course of inquiry that will point out just what the cause of failure was. Sets as a rule do not go bad of themselves. The failure usually occurs while some operation is taking place, such as plugging in the loud speaker, turning the condensers or making a change in the battery connections.

The length of time that a set has been in operation will be an indication of various types of trouble. A set that has recently been installed is subject to a certain type of failure, while a set that has been in operation for a year or more, is subject to other types of failure.

If a set has been installed for a period of two weeks or less, outside of the inability of the customer to procure the desired results, there are only a few reasons why the set should fail. They are:

A defective tube.

Defective battery or battery connection.

Loud speaker connection loose in telephone plug.

Burn-out of transformer.

Of course, there may be other reasons, but these are the most common and are given in the order of their probability of occurrence.

If the set has been in operation for a month or six weeks and has been giving satisfactory service for that period, the cause of failure is generally due to the weakening of the batteries.

If the set has been in operation for a period of six months or a year, the possibilities of trouble will increase. If the failure in this type of installation has been gradual, the first thought would be that the tubes were becoming deactivated through continual use.

If the breakdown was sudden, a mechanical failure might be expected in one of the movable connections or pigtails. A burned-out transformer could be expected in difficulties of this sort. If the trouble is due to a noise condition, the failure might be ascribed to dust or dirt accumulations on the condenser plates or other important parts of the receiver. The defect might also be due to a soldered connection. It will require, as a rule, a rather long period of time for a soldered connection to corrode to such a degree as to cause this condition. The local atmospheric conditions under which the set has been operating may have some bearing on the cause of failure. If the set has been operating near the seashore and has been subjected to the action of salt atmosphere it may have caused sufficient corrosion of the connections or other metallic parts to introduce high resistance or leakage path. Moisture may saturate the cheaper grades of insulating material to such an extent as to cause high-frequency short circuits.

If a set has been operating for a long period of time and has given satisfactory results and then develops noises and scratching sounds, one should not look for a loose connection in the wiring of the set, but rather look for an open circuit in the moving parts. Worn mechanical parts are often mistaken for loose connections in the wiring. The wiring is absolutely stationary and it is not at all likely that it will be disturbed in the ordinary use of the set so as to cause a failure due to a loose connection. Vernier drive shafts and vernier plates will wear loose and while apparently they are making perfect contact to the metal surfaces of the condenser when the set is brought into a critical condition, as is the case when receiving distant stations, will cause noises that might be thought due to a loose connection in the wiring.

Another item to be considered in the servicing of radio sets is the cost of the original apparatus. Radio, like any other merchandise, is a matter of price. As a rule, the more you pay for a set, the better should be the quality of the equipment you get and you may reasonably expect longer and more satisfactory service from it. In a high-grade receiver the mechanical failures are less frequent than in the cheaper grades of sets. The same is true of electrical failures. The cheaper grades of sets are much more subject to climatic conditions then are the better grades.

We have compiled a series of complaints in such terms as they are received by the dealer, and we will take each up in turn as to what it suggests as the possible cause of failure.

"The set just stopped operating. It was giving excellent results, but it suddenly stopped." This complaint is quite unsatisfactory from a service man's point of view. It does not suggest anything definite and it may be the result of many factors. Trouble generally occurs when some operation is taking place, whether it be tuning or making adjustments or plugging in the loud speaker, or revolving the loop. The service man should inquire just how the failure took place, just what the customer was doing when the set failed. If the failure occurred when some adjustment was being made, he should look for a broken connection or a mechanical breakdown in the control being used at the time. There are several causes of a set failing completely and suddenly, namely, a burned-out tube, a burned-out transformer, a broken connection, or a short circuit. A broken loop connection will also cause complete failure as well as a burned-out loud speaker. Of course, there are many reasons why a set may fail to function, but the list just given represents the principal causes for a complete and sudden failure.

A burned-out tube will be immediately obvious and should be replaced. A broken battery connection or pigtail may be located by inspection and necessary repairs made. A defective loud speaker may be determined by replacing the loud speaker with a pair of head phones and noting whether the head phones operate satisfactorily.

In making all checks on defective sets, the first thing that the service man should do is to light the tubes to their proper brilliancy and then plug the loud speaker in and out of the jack. If the B battery is properly supplying the tubes in the amplifying circuit, a loud click will be heard in the loud speaker. If there is a jack provided on the detector tube, repeat this, using the head phones. In other words, see that there is a B battery voltage at the plate contact of each tube. In the radio-frequency tubes, if used, measure the voltage across the tube contact springs in the socket. This may be accomplished by removing the tubes from the sockets and making direct contact with the springs. There is another possibility of failure in sets that employ a large by-pass condenser which is connected across the B battery supply. In event of this condenser becoming short-circuited, it will cause the B batteries to drop in voltage very rapidly and if the short-circuit is complete enough, the batteries will heat up. This can be very quickly determined by breaking the connection through the negative B battery. If a heavy spark occurs, it is an indication that there is a short circuit in the B battery supply which may be due to this condenser. In testing this condenser should, by chance, the tubes be lit when the B battery connection is broken, a small spark will be present. The small spark is due to the normal drain on the B batteries and represents the total plate current of the tubes in the set. If the tubes are not lit, no sparking should occur when the battery connection is broken, but if there should be, this is an indication of a short circuit within the set. Of course there is the possibility of a wire breaking free in the set itself and falling in such a way as to cause a short circuit, but this is immediately apparent on inspection. There is also a possibility of a short circuit of the elements in the tubes.

"I cannot get distance," is a general criticism that is met with radio receivers of all types.

The most general cause for this complaint is the inability of the customer to tune the set properly so as to get the most out of it. The obvious remedy for this is to instruct him further in the operation of the set. The service man should spend an evening with him and show him just how to do it, and once the customer knows that the set is capable of receiving distance, he will never admit that he cannot get it.

A defective tube will sometimes prevent distant reception. Perhaps one of the tubes used in the radio frequency circuit is not particularly adapted for that purpose, but will make an ideal detector or audio frequency amplifier. Try interchanging tubes so as to get the best possible combination. Do not make a practice of interchanging tubes after the most satisfactory combination has once been determined. This is particularly applicable to dry-cell tubes. Because of their delicate structure, it is not well to subject them to excessive handling.

Location and local conditions materially affect the ability of a set to receive distant stations. Antenna construction and ground conditions are important factors. If a loop is used, the shielding of nearby metallic bodies will affect the results. In a case of loop sets it is advisable to install the set near a window. This is particularly true in the latest types of homes and apartment houses which employ in their construction metal lathing which acts as an electro-static shield to the incoming signals. In the case of sets employing antennas, it will be necessary to experiment with antennas of different length and in different directions. However, before the service man blames the location for the failure, he should take a set of similar make which he knows operates satisfactorily in another location, and check the results in the doubtful location, comparing results received on the new set with those of the standard set. In some instances, the service man is prone to use location as the cause of failure to receive distant signals, whereas it may be due to a defective part in the radio set.

"The signal comes in loudly and then dies out." This is generally due to the phenomenon of fading.

However, should this condition exist on the local stations, as well as the distant stations we would be inclined to suspect either a defective A battery connection or a defective A battery. A soldered connection in the filament circuit that has become corroded or broken for some unknown reason while not completely open so as to cause the tube's failure to light, but just making contact, will cause this condition. This defective connection, at times, will become highly resistant; sufficiently so to cause a decrease in the filament brilliancy. This condition is generally obvious as the brilliancy decreases at the time of the fading. This condition is rarely met, but it is extremely difficult to locate the defective connection and requires careful inspection of every connection.

This condition may be brought about by a defective dry-cell type A battery. In this case, it is due to a local action within the dry-cell. The internal resistance of the cell will vary, due to this local action, and cause effects similar to that caused by the defective connection just described. In the case of dry cells, it is sometimes necessary to readjust the filament rheostats slightly in order to restore the set to its normal operating condition, and at times, the set will recover itself. In a storage type A battery this condition may be brought about by a so-called "treeing" effect. This condition is generally present only in old storage batteries and is the result of a lead tree building up on the plates in such a way as to penetrate the separator. This lead tree builds up until it touches the opposite plate and causes a momentary short circuit of the plates involved. The short circuit burns off the lead tree and immediately the building up process is started again. When the short circuit occurs there will be a slight decrease in the total voltage of the battery, which will cause a slight decrease in the filament brilliancy resulting in a fading effect. In cases of this type, the fading periods are only momentary and recur at fairly uniform time intervals and are present on all positions of the tuning scale.

A similar condition may be caused on sets employing an antenna, by swinging of the antenna or lead-in. This condition should not be confused with the fading phenomenon and may be identified by the fact that the volume of the signal will not change, but will swing in and out. The particular danger to be encountered is when the antenna is close to a metallic or other conducting body and in swinging, touches the same, causing a momentary short circuit. This is recognized by a click in the loud speaker when the ground occurs.

"I don't get any volume; the signals are weak." If this condition is persistent and investigation shows that good results were never had on the receiver, and the location has been carefully checked by a similar type set, the difficulty would seem to be due to one of the following causes:

Inferior grade of set, not capable of producing good results.

Inexperience, lack of knowledge of tuning.

Defective tubes.

Defective batteries.

Reversed A battery connection.

Poor antenna location or installation.

Defective ground connection.

Defective loud speaker.

These are listed in their order of importance and occurrence. If the receiver is of an inferior quality some advantage may be had by replacing the grid condensers and audio-frequency transformers with similar instruments of better quality. If it is due to lack of knowledge, it is the duty of the service man to instruct the customer more fully. Defective tubes should be replaced. This condition may be checked by replacing the entire set of tubes in the defective set with tubes that are known to be O.K. A defective battery may be located by checking the voltage. It is generally conceded that a B battery whose voltage has dropped 25 per cent. from the normal rating of the battery, should be discarded. If the A battery connections are reversed on receivers employing audio frequency amplification, little or no amplification will be had. This is easily checked by reversing the battery leads. Just when an antenna is defective is very difficult to say, as there are so many local conditions which play important parts in the success or failure of an antenna installation. In general, the antenna should be removed as far as possible from all objects, such as trees and buildings, and metal objects in particular. In general, the higher the antenna, the better will be the results obtained. If the antenna is erected in the vicinity of a high-tension transmission line, it should be erected so that the line of the antenna is at right angles to the transmission line. The antenna should be carefully insulated at all points throughout its length including the lead-in. It will sometimes happen that a set employing an antenna operates quite satisfactorily during periods of dry weather, but during, and after rain storms, the operation of the set becomes rather indifferent. This condition is generally due to a defective insulator which breaks down during periods of wet weather, causing high losses. An opposite condition may be had where the set operated more successfully during periods of wet weather than it did in dry weather. This would indicate that the moisture in the ground enhanced the value of the ground connection by reducing the ground resistance of the circuit. Some care should be exercised in the selection of a ground and the service men should not necessarily use the first ground available. Several ground connections should be tried and an effort made to determine the one giving maximum results, and this one used. In the present day equipment it seems to be customary to use an aperiodic circuit in the antenna, and for that reason defective grounds do not manifest themselves quickly. In antenna sets employing a series antenna condenser, a defective ground will cause the antenna condenser to tune very broadly.

A loud speaker that has been connected into a receiver with the polarity reversed will, after a time, become demagnetized and result in very poor volume and quality.

"The volume was great for a short time, but suddenly started to weaken." This condition generally results from using an excess voltage on the tubes. It is particularly true in the case of sets employing dry cell tubes. The customer sometimes has a peculiar psychology and believes that by turning the rheostats of the tubes on full that he is getting better results. With the tubes used today, employing thoriated tungsten filaments, this is a fallacy. Operating tubes using this type of filament at a greater than normal voltage deactivates the filament very rapidly and decreases its useful life. Under no consideration should a thoriated tungsten tube be operated at a voltage higher than the rated voltage as indicated by the manufacturer. A defective battery that has deteriorated abnormally will also cause this condition.

"I get one station well, but another station is weak and they are both about the same distance away." It is the general belief that this condition is caused by metallic obstructions, such as steel buildings, high-tension systems, railroads, etc., or possibly mineral deposits near on the earth's surface. It is believed that these obstructions cause either an absorption or a deflection of the radio waves which renders certain areas incapable of receiving signals from certain stations. You have probably all heard of the recent investigation carried on by the American Telephone and Telegraph Company, in which it plotted the signal strength of its New York station in different sections of the metropolitan area, and of the peculiar results noted. Certain areas in Central Park were practically dead to signals from this station. There is perhaps no remedy for this condition and it is not the fault of any particular set, as this condition would be true whether a crystal detector or a super-heterodyne be used in such a location. Of course, the super-heterodyne circuit, because of its sensitivity, would respond to an extremely weak signal that would be inaudible in a crystal detector set, but for practical considerations, reception in such an area would not be satisfactory, while at the same time, excellent results might be obtained from other nearby stations.

"The volume used to be O.K., but has been getting weaker and weaker." This condition is generally caused by the normal decrease in voltage of the batteries. It may also be caused by the use of a slight excess voltage on the tubes which will cause a slower deactivation of the filament than described previously.

In the case of a recent installation, defective batteries should be looked for. Should the installation have been made a year previously, the difficulty might be due to the normal depreciation of the useful life of the tube.

"It works O.K. for a while, but suddenly a howl starts which sounds like a siren or a fog horn which can only be stopped by shutting off the set or cutting down the volume." This effect is due to a vibrating air column which is set up between the loud speaker and, usually, the detector tube of the set. The action is similar to that which results when a receiver of a telephone instrument is placed in front of the mouthpiece of the transmitter. This condition is generally caused by a microphonic tube in the detector socket. It may be due also to a loose element in some part of the circuit. A loose transformer lamination or condenser plate might cause the same condition. A popular theory of this condition is that the vibrating air column from the loud speaker causes a vibration of the filament in the detector tube. The vibration of the filament causes a variation of the tube characteristics which causes in turn a variation of the plate current, and an acoustic feed-back results. In loud speakers of the adjustable type, adjustment of the air-gap will sometimes eliminate this howl. In the case of non-adjustable loud speaker units it will be necessary to try interchanging the tubes in the sets in order to eliminate this condition. If interchanging the tubes does not correct it, place the loud speaker so that the bell points away from the set and place either the loud speaker or the set or both on pads of soft felt or sponge rubber. It is because of this effect that it is not advisable to place the loud speaker on the top of the cabinet, unless the tube sockets are sufficiently cushioned.

This condition, however, usually occurs only when the set is operating at maximum output and the radio-frequency amplifiers are set in an extremely sensitive condition. Reduction of the volume will invariably eliminate the howling effect.

"The quality is terrible, we cannot understand a thing that is said." This condition is known as distortion and is due to many factors. As a general rule, distortion occurs only in the audio-frequency circuits. Distortion may be caused by a defective tube, a defective battery, a defective loud speaker, a broken-down by-pass condenser across the output or, what is the most common cause of distortion, overloading of the tubes. A soft or gassy tube will cause distortion, but this defect in a tube is rarely encountered in standard makes of tubes. A weak or defective C battery is also a very common cause of distortion and will be evidenced by a tendency of the amplifiers to squeal. A "B" battery whose voltage has dropped 25 per cent. will often cause distortion and may be accompanied by a continuous high pitched squeal. Audio-frequency transformers of poor quality and design will cause distortion. This is generally indicated by the inability of the amplifiers to reproduce the extremely high and low musical tones. A transformer in which the leads have been soldered with a corrosive flux will cause distortion a short time prior to the time when the corrosive action of the flux causes the winding to open. Overloading of the amplifier tubes is evidenced by a blasting of the loud tones of the program. This is particularly true on local reception. The customer should be instructed to watch the overloading of the tubes and if the blasting does occur, he should detune his set slightly so as to reduce the volume to the point where the tubes will function properly. It is quite possible with the multi-tube sets used today, when installed in the vicinity of a powerful broadcasting station, to impress on the grid of the last tube in a series, sufficient voltage to swing the grid voltage beyond the limits of the straight line portion of the characteristic curve. Increasing the "C" battery potential or voltage on the amplifier tubes will tend to reduce this blasting. But this is not recommended as good practice because of the possibility of increasing the negative potential to such a point as to cause distortion when the tube is operating with normal volume. A great many amplifiers in receiving sets use a fixed condenser, ranging from the values of 0.002 to 0.006, connected across the loud speaker terminals. This condenser is known as a "by-pass" condenser and is subjected in this part of the circuit to considerable peak voltages. Should this condenser fail, a distorted signal will result. If, on servicing, this condition is met and all the foregoing items have been checked with no results, replace this bi-pass condenser, as a potential breakdown in this condenser is rather difficult to test for unless laboratory equipment is available. Both these conditions call for the replacement of the transformers.

"It is loud enough, but very noisy. There is a continuous, cackling, rasping or scratching sound in the loud speaker." This may be the result of any one of many causes. Interference from either atmospheric or local sources is the most common cause of this defect. By local sources we refer to such apparatus as X-ray machines, violet-ray machines, electric railway systems, elevator controls, leaky power lines or transformers, automatic telephone switching lines, telegraph lines, and local telegraph stations in the vicinity of the receiver.

In checking noises in a radio receiver, the first problem should be to determine whether this is being picked up on the antenna or the loop, or whether it is originating in the set itself. In order to check this on a set employing an antenna, adjust the receiver to a point where the interference or noise is present. Then remove the antenna and ground connections from the receiver and note whether or not the noise ceases. If there is a great decrease in the volume of the noise when the leads are disconnected, it is safe to assume that the noise is emanating from an outside source.

If a loop set is employed, disconnect the loop and place a short length of wire, not over four inches in length, in place of the loop. If the noise ceases when the loop is removed, it may be safely assumed that the noise originates at some outside source. However, if the noise persists after the pick-up circuit, either loop or antenna, is removed, it is safe to assume that the noise is originating in the set itself. The noises referred to in the foregoing are those which are present at all times, particularly when none of the controls are being moved. Noises within the set itself may be caused by one of the following items:

A defective tube.
Dirty tube contact.
Defective battery.
Defective loud speaker.
Dirt on loud speaker diaphragm.
Defective battery contact or a loose connection.

The defective tube should be replaced by a tested one. The tube contacts should be cleaned with a piece of emery cloth or fine sandpaper. Make sure to remove all traces of grit before replacing the tube. Make sure the contact springs of the sockets are clean and are making good contact to the contact pins of the tube. A defective battery will also cause many noises in a receiving set. The batteries should be checked in the following manner: Connect a pair of headphones across the outside terminals of each individual battery, and note the sound in the head phones. If there is a boiling or frying sound in the head phones when they are connected in this manner, it is an indication of a defective battery, and batteries showing such defects should not be used in a radio set. A loose or defective battery connection will also cause a set to be noisy. A loud speaker with a defective winding will also cause disagreeable noises. Dust and dirt accumulations on the loud speaker diaphragm will cause the set to appear noisy. A condition might arise where the diaphragm of the loud speaker becomes loosened, causing it to rattle when actuated by the incoming signal. Loud speaker defects generally necessitates a factory repair. A transformer winding which is deteriorating will cause a hissing or a frying sound in the amplifier. A loose connection in any part of the receiver, and the loud speaker, which is subject to vibration when the loud speaker is operating, will also cause the set to be noisy. In order to definitely locate the origin of noises in the receiver, use a pair of head phones and plug them in in place of the loud speaker. This will immediately determine whether the noise is originating in the loud speaker. If the noise persists with the phones plugged in the last stage of amplification, plug into the first stage, if a jack is provided, and repeat the process, plugging into the detector circuit. If but a single jack is provided, and this jack is connected in the output of the audio-frequency amplifiers in order to determine whether or not the noise is originating in the audio-frequency-amplifiers, connect the telephones in series with the detector "B" battery lead. In that way, you may determine whether or not the noise is originating ahead of the detector or in the audio-frequency amplifiers. Once the source of the noise is determined, it requires very careful checking of the various parts and connections in the circuits responsible.

"Set operates satisfactorily except when any of the controls are moved; it is very noisy." This condition indicates directly a defective connection caused by a mechanical failure. A defective tube will sometimes cause this condition, and is apparent when a rheostat is moved or the set is subjected to mechanical vibraareas in Central Park were practically dead to signals from this station. There is perhaps no remedy for this condition and it is not the fault of any particular set, as this condition would be true whether a crystal detector or a super-heterodyne be used in such a location. Of course, the super-heterodyne circuit, because of its sensitivity, would respond to an extremely weak signal that would be inaudible in a crystal detector set, but for practical considerations, reception in such an area would not be satisfactory, while at the same time, excellent results might be obtained from other nearby stations.

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Dirty tube contact.
Defective battery.
Defective loud speaker.
Dirt on loud speaker diaphragm.
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The defective tube should be replaced by a tested one. The tube contacts should be cleaned with a piece of emery cloth or fine sandpaper. Make sure to remove all traces of grit before replacing the tube. Make sure the contact springs of the sockets are clean and are making good contact to the contact pins of the tube. A defective battery will also cause many noises in a receiving set. The batteries should be checked in the following manner: Connect a pair of headphones across the outside terminals of each individual battery, and note the sound in the head phones. If there is a boiling or frying sound in the head phones when they are connected in this manner, it is an indication of a defective battery, and batteries showing such defects should not be used in a radio set. A loose or defective battery connection will also cause a set to be noisy. A loud speaker with a defective winding will also cause disagreeable noises. Dust and dirt accumulations on the loud speaker diaphragm will cause the set to appear noisy. A condition might arise where the diaphragm of the loud speaker becomes loosened, causing it to rattle when actuated by the incoming signal. Loud speaker defects generally necessitates a factory repair. A transformer winding which is deteriorating will cause a hissing or a frying sound in the amplifier. A loose connection in any part of the receiver, and the loud speaker, which is subject to vibration when the loud speaker is operating, will also cause the set to be noisy. In order to definitely locate the origin of noises in the receiver, use a pair of head phones and plug them in in place of the loud speaker. This will immediately determine whether the noise is originating in the loud speaker. If the noise persists with the phones plugged in the last stage of amplification, plug into the first stage, if a jack is provided, and repeat the process, plugging into the detector circuit. If but a single jack is provided, and this jack is connected in the output of the audio-frequency amplifiers in order to determine whether or not the noise is originating in the audio-frequency-amplifiers, connect the telephones in series with the detector "B" battery lead. In that way, you may determine whether or not the noise is originating ahead of the detector or in the audio-frequency amplifiers. Once the source of the noise is determined, it requires very careful checking of the various parts and connections in the circuits responsible.

"Set operates satisfactorily except when any of the controls are moved; it is very noisy." This condition indicates directly a defective connection caused by a mechanical failure. A defective tube will sometimes cause this condition, and is apparent when a rheostat is moved or the set is subjected to mechanical vibration. If the noise persists when any of the other controls are moved, such as condensers and coils, it is an indication that there is a mechanical failure which is causing a defective electrical connection. Dust and dirt accumulations on the condenser plates will cause noises to be heard when the condensers are rotated. The plates should be cleaned with an ordinary pipe cleaner. A bent condenser plate touching the opposite assembly will also cause this condition. Some variable condensers are constructed so that the electrical contact is made through a friction washer or through the friction of the rotor shaft to the bushing. This type of contact is quite satisfactory when the condenser is new, but after a long period of operation the parts wear, decreasing the friction, resulting in an indifferent contact which will at times cause the set to appear noisy, particularly so when the circuits of the receiver are tuned to resonance. Vernier drive shafts that have become worn through use will cause the sets to be noisy when the circuits are in resonance. Weak contacts in telephone jacks will also cause this condition.

"The signal is garbled. We cannot clear up the speech." This is generally caused by a defective oscillation control. Either a defective tube, a defective potentiometer or the neutralizing capacity out of adjustment will generally be found to be the direct cause. Of course, this applies only to receivers employing radio-frequency amplifiers ahead of the detector tube. If this condition is met in a single tube receiver it is generally due to the fact that such signal is too weak fully to actuate the detector tube. In the case of multi-stage radio-frequency amplifiers, this is a rather difficult problem to service. If it be caused by a defective tube, which it rarely is, then matters are simplified.

The balanced or neutralized type of set employs neutralizing capacities for oscillation control. The so-called reflexes and untuned radio-frequency circuits use the potentiometer and in addition introduce losses in the radio-frequency transformers. Some of the straight tuned radio-frequency amplifiers employ a rheostat for each tube, some a single rheostat and a potentiometer; others a variable series resistance in the grid circuit of the first tube. There is another class that employs ingenious arrangements of wiring and parts to take advantage of stray capacities and interlocking stray fields, which have a tendency to prevent free oscillation. Certain other sets, it would appear, leave it entirely to chance and hope that it won't oscillate.

The sets in the latter two groups present very trying service problems.

The effect of this garbling condition is generally only apparent on extremely weak signals. It is generally impossible to eliminate entirely the whistle or carrier wave, and as a result, you receive a combination of voice or music, as the case may be, combined with the lower pitched tones of the carrier wave. Interchanging tubes in the radio-frequency sockets will sometimes lessen the tendency to oscillate, as there is some slight variation in the oscillating characteristics of the tubes, particularly after the tubes have been in operation for any length of time.

In the case of the failure of balanced or neutralized receivers, it is necessary to readjust the neutralizing capacities to their proper values. This particular service is rather difficult and should only be attempted as a last resort. It is not likely that these neutralizing capacities will vary a great deal from the original setting, unless the set has been abused or has been subject to physical damage. In the case of sets employing a potentiometer for oscillation control, this condition is extremely rare except when signals are received that are so weak that their modulated power is not sufficient to actuate the grid of the first tube in the series. It should always be remembered that a carrier wave of a broadcasting station is heard at a much greater distance from the station than is the audio-frequency modulation which is impressed on the wave. Sets employing individual tube control rarely have this trouble. The types of receivers using circuit arrangements and placements may be corrected by adjusting a single wire, but the problem is to find that wire. It is generally a grid wire and is, as a rule, oddly shaped and takes apparently a roundabout way to get where it belongs. Reducing the radio-frequency "B" battery voltage will help correct this condition.

The last type mentioned, where no apparent means are used to prevent oscillation, are generally found in very cheap sets, where the poor grade of material used introduces so many losses that it would be difficult to make them oscillate. Occasionally a set of this type oscillates and causes this condition and the only possible correction lies in tube interchanging and reduction of the radio-frequency "B" battery voltage.

"It is too loud on the loud speaker." This complaint is rare, but is sometimes heard. It is generally due to an effort to reduce the cost of the receiver, with the result that a telephone jack in the first stage of amplification is omitted, and for the same reason no provision is made for volume control. The only remedy for this condition is to reduce the voltage of the audio-frequency amplifiers to a point where satisfactory volume is had.

"When I take my hand away from the set I loose the signal." This effect is known as a "body capacity" effect and is primarily due to poor design, a poor ground connection, or a poor circuit design. All sets should be equipped with grounded metallic shields. In addition, wherever possible, the shafts of the control knob should be electrically connected to this shield. If this is not possible, the low potential side of the various apparatus should be connected to the control knobs. Some sets have poor circuit design which prohibits the use of a grounded shield, and in cases of this kind, body capacity effects are quite disagreeable and persistent. Grounding of the "A" battery will sometimes be helpful in eliminating body capacity effects, but it should be first determined whether or not there is a connection between the ground terminal and the filament circuit within the set itself. For example, if the positive filament circuit is connected to the ground terminal, the "A" battery should be grounded at the positive terminal. If the ground terminal of the receiver is connected to the negative side of the filament circuit within the set, the negative terminal of the battery should be grounded. In sets of proper design in which shields have been incorporated and body capacity is present, we would suspect that the shield has become disconnected from the ground or battery circuit within the set.

"There is a frying sound in the set." This condition may be brought about by a defective battery, defective tube, a ground in the loud speaker, a defective battery connection, a transformer that is burning out or in the case of a set employing a gas type 200 detector tube, an excessive "B" voltage on this tube. The defective tube may be located by replacing the tubes with tested ones. The defective battery should be checked with head phones as described previously. A defective loud speaker may be tested by replacing same by head phones. All battery connections should be tightened. A defective transformer may be determined by a similar test that is used to locate a defective battery, except that a battery that is O.K. is used and connected in series with the telephones and the winding of the transformer under suspicion.

"When I touch the panel there is a ringing sound." This is invariably due to a microphonic tube and may be eliminated to a certain extent by interchanging the tubes until the best combination is had. The detector and audio-frequency amplifier tubes are the principal offenders in this connection. In sets employing dry cell operated tubes such as the WD or WX11 or the UV or UX199, this condition is exaggerated unless the tube sockets are properly cushioned. There is a certain degree of this condition present in all receivers, even under normal conditions, and it is another reason why radio manufacturers are inclining more and more to the cushion type socket suspension

"There is a squealing sound in the set all the time." This condition may be caused by a defective tube, one that has become soft or gassy. It may be due also to a defective "B" or "C" battery that has dropped in voltage more than 25 per cent. A burned-out primary winding of a transformer, or an open telephone jack in the audio-frequency circuit will cause this squealing. Another cause may be the result is the heterodyning of two transmitting stations, or it may be the effect of a nearby receiver interfering with the one in use, however, under the last conditions the squeal will be present at certain definite places on the dial, whereas in the case of a defective battery, tube, transformer or jack, it is continuous throughout the entire scale reading.

"There is a buzzing sound like a motor boat. There is a clicking sound in it." This is a general indication of an open grid circuit. The frequency may vary from one click a minute to a very high pitched note. If the grid leak should become loosened from its clips, this sound will generally result. If a "C" battery is used, a poor connection or broken connection to this battery will give the same result. If none of these conditions appear to be the difficulty, it will be necessary to make a continuity test from the grid contact spring of each socket to the filament circuit.

"When I touch anything on the set a rattling sound sets up or the set will sometimes go dead and a jar will restore it." This is caused primarily by a loose connection either in one of the tubes or in the connection of the circuit. Investigation of every connection and friction contact in the set should be made. It is well to replace the tubes with tested ones in order to eliminate the tube as a factor. A loose shield or a loose venier shaft will give these results; particularly so when the circuit is tuned to resonance.

"It works in the detector jack, but does not operate in the first or second stages." If the A battery connections to the amplifier are properly made, this condition is probably due to a defective telephone jack in the detector circuit or a burned-out primary winding of the auto-frequency transformer connected in the detector circuit.

"It works in the first stage audio-frequency amplifier, but does not operate in the second stage." This is due to a similar reason as previously given. It is caused by a defective telephone jack or transformer in the first audio-frequency circuit.

"The tubes fail to light." This condition may be brought about by a defective A battery, or a defective A battery connection. It may also be due to a faulty battery switch that fails to make proper contact. In the same way a rheostat that does not make proper contact will cause the same effect. Any loose connection in the A battery circuit of the set may cause failure of the tubes to light. If this condition exists only on one or two tubes, it is in all probability due to a burned-out filament. A dirty contact on the tube will sometimes cause the failure of a tube to light. If the contact springs of the socket do not make a firm contact to the tube pins, this condition might also occur. If dry cells are used, check to see that the individual cells are connected in the circuit with the proper polarity. If one or more of the cells are connected with reversed polarity, full voltage will not be had at the tube terminals.

In general, the service men should follow a procedure somewhat along these lines. Light the tubes and tune the receiver to the point where the best local station generally is received. Note the volume on the loud speaker, if one is used. If the volume is weak, tap the tubes with the finger-nail to determine whether or not the audio-frequency amplifiers are operating satisfactorily. If the amplifier is working satisfactorily, a ringing sound will be heard in the loud speaker. If this ringing does not result, check the polarity and voltage of the various batteries, and replace all defective ones. Inspect the connections of the batteries, and if this does not result in satisfactory reception, try replacing the tubes. If no sound at all results, immediately replace the loud speaker with the head phones to determine whether or not the loud speaker is defective. If no results are obtained, turn off the A battery switch and remove the tubes, and by means of a voltmeter, check the voltage between the filament and plate contact springs of each socket. If satisfactory indications are had and no signal is heard, repeat with a similar operation between the grid and filament contacts, using a pair of head phones in series with a 22½-volt battery in place of the voltmeter. Rather decided clicks should be heard, when contact is made in each instance with the exception of the detector grid. Because of the fact that in the detector circuit, a high resistance grid leak is used, the click will be rather weak. One of the foregoing tests will most probably check up the difficulty and the obvious repair should be made.

We will make a brief analysis of the various types of parts that are commonly used in radio broadcast receivers, as to their possible defects. The common practice in tuned radio-frequency circuits today, is to use the air-core type of transformer. These coils are generally wound on some form of tubing. Some manufacturers, depending on the adhesive quality of the binder to hold the wires in shape, do not use any type of tubing for support. These coils are generally wound with a relatively heavy wire, and are not subject to electrical failures. They may be connected into the circuit improperly, but as a unit are not subject to difficulties. Trouble is sometimes experienced with transformers of this type that have no supporting tubing, due to mechanical collapse. In some cases the windings may be wound on cardboard or fibre tubing, which has not been made impervious to moisture, and during the periods of humid weather these absorb enough moisture to cause high resistance short circuits of the winding.

Vario-couplers and variometers are constructed along the same lines, and are subject to similar defects. However, because of the fact that a vario-coupler or variometer has a moving element in it, some form of flexible connection is generally employed to bring out the connections of the moving coil. These flexible connections, because of mechanical movement, are subject to fracture. If no flexible connection is employed, and the contact is made through the friction of the rotor to a bushing on the stator, after long periods of use the friction may decrease, and reduce the effectiveness of the connection. These movable parts should be inspected for mechanical failure. The primary or fixed coil of the coupler is sometimes tapped, and leads taken off. Check to see that these leads are properly soldered, and not short-circuited or open.

A second type of radio-frequency transformer used is the so-called untuned transformer. This consists of a core of either iron or air around which is placed a bobbin with two inductively-coupled windings wound on it; one is primary and one is secondary. Because of the relatively low potentials and weak currents present in the radio-frequency circuits, they are not subject to failure to any great degree. Occasionally one will find a winding of one of these transformers burned out, but the percentage of such failures is rather small.

Audio-frequency transformers are similar in their general construction to radio-frequency transformers. The resistance of the primary winding is about 1,000 ohms, and the resistance of the secondary is from 2 to 6,000 ohms. In order to get the required turns in a limited space the wire used is very fine. Because of the relatively high currents passing through these windings, they are more subject to failure than is the case with the radio frequency transformers. Failures generally occur at the point where the lead wire is soldered to the end of the winding. This is particularly true when a corrosive flux is used in soldering.

Transformers may be tested by measuring the resistance of the individual windings. A quick check may be had by connecting a 22½-volt battery to the windings and noting by the spark at the contact whether or not the circuit is continuous. Because of the high resistance of these windings a short circuit of the "B" battery will rarely cause a burn-out.

Variable condensers are, to our mind, the principal cause of trouble in a radio set. In this case it is particularly true that the troubles increase as the quality decreases. We have covered a good many points of possible failure and for that reason we will make but one addition. Most condensers use an oil or grease to reduce the friction in the bearings. This oil or grease, as the case may be, accumulates dirt and dust very rapidly and in condensers where the electrical contact is made through the friction of this bushing, these dirt and dust accumulations cause poor contact. Any moving part in a condenser that is not making a firm, clean contact will cause the set to be noisy when the circuits are in resonance.

In order to test for a short circuit in a variable condenser it is necessary to disconnect it from the circuit. The quickest test and the most satisfactory is to connect a source of 110 volts in a series with an electric lamp across the condenser. Rotate the condenser to its entire range and note the points of contact. Any short circuit will cause the lamp to light, and the exact point of short will be indicated by sparking.

Should the rotor assembly for any reason get out of alignment so much as to cause the rotor plates to touch the stator plates, it will be necessary to adjust the end thrust bushings so as to re-align the rotor assembly.

Fixed condensers of good quality rarely go bad or break down as the potentials generated in a radio receiver are as a rule far below the breakdown potential of the condensers. Cheap, fixed condensers, particularly those using fibre in their construction, are subject to climatic conditions and absorb moisture very readily. This causes high losses in the circuits in which the condenser is used. To test a fixed condenser it is generally necessary to free it from the circuit, then connect a 90-volt B battery in series with a pair of head phones and make a contact across the terminals of the condenser. The first contact should cause a loud click to be heard. Remove the contact and count ten slowly, and make a second contact. If, on the second contact, little or no click is heard in the phones, such a condenser may be considered as perfect. If the second contact gives the same volume of click as the first contact, there is a high leakage in this condenser and it should be replaced. We might say in this connection that the contactors of the test just outlined should be properly insulated so that they do not come in contact with the hands or any part of the circuit. In testing a grid condenser it is necessary to remove the grid leak, as in most cases the grid leak is connected directly across the condenser, forming a permanent leakage path. The foregoing test is applicable to the testing of variable condensers and the same procedure may be followed. In making such a test the variable condenser should be set at maximum capacity.

Grid leaks are difficult to test without the necessary laboratory equipment and we would suggest that if there be any doubt in the service man's mind he should replace these.

Multi-point switches very seldom give electrical trouble, except when the tension of the contact spring weakens; this may cause a high-resistance contact. If the shaft of the switch is pigtailed, check the pigtail, making certain that it is intact.

Check also the soldered connections to the contact points of the switch, making sure that the contact connections are firm and clean.

Telephone jacks, filament control jacks, and battery switches constructed along the lines of a telephone jack are often sources of trouble. The contact springs may become weakened and dust and dirt accumulate on the contact points causing the failure of the jacks or switch, as the case may be, to close the necessary circuits. Faulty jacks are the cause of a large percentage of the failure of amplifiers to operate properly. To check these, plug the telephones in and out of the jack very slowly and observe just how the springs should function. If the springs do not close the circuits as they should, bend the offending spring down or up as required to insure firm contact. It would be well to draw a fine piece of emery cloth across the contact points to brighten them up.

The principal difficulty which may be experienced with rheostats is that due to a faulty contact between the contact and the resistance winding. Burn-outs of the rheostat are very rare.

Potentiometers are subject to the same difficulty in the matter of contact as is the rheostat. In making any adjustments on receivers in which a potentiometer is used, it is well to set the potentiometer at the half-way mark while making these adjustments. Potentiometers are subject to burn-outs. To check for a burn-out, place a pair of head phones in series with a battery and connect one side of this test lead to the center terminal to the potentiometer which is generally connected to the contact arm. Place the contact arm at the center of the winding and make contact to each of the other binding posts in turn.

Binding posts sometines cause trouble due to loosening of the screws. All binding-post screws should therefore be tried and if found loose, should be firmly seated.

Crystal detectors, which are used principally today in the so-called reflex type of circuit, sometimes fail because of dirt accumulations on the surface of the crystal. Occasionally the crystal may be burned out by an accidental short circuit. To restore a dirty crystal, use a non-alkaline soap and a tooth brush. Scrub the surface of the crystal thoroughly and rinse in cold water, removing all traces of soap.

In this connection we might say that considerable service is experienced on reflex sets that fail to give results, and the crystal is generally found to be the cause. Fixed crystals are not entirely satisfactory.

The foregoing is a brief review of some of the most frequent troubles that may occur in the radio receiver. There may be a few troubles that apply to a single type of receiver which have been omitted, but such will be characteristic of that particular type. In conclusion, we would repeat: Test all sets before sale and be truthful in the matter of results that may be expected. Do not lead the customer to believe that he will be able to receive California any time he desires. Advise him also of the probable length of life of his batteries. To the service man: ask questions and analyze the defects before you commence operations. A few judicious questions will oftimes save considerable work and create a more favorable impression with the customer.