PROCEEDINGS OF
The Institute of Radio Engineers

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CONTENTS

GENERAL INFORMATION

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37 West 39th Street
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INSTITUTE ACTIVITIES

New Members and Transfers

At the April Board meeting 185 Associates and 14 Juniors were elected. The following Associates were transferred to Member grade: Paul F. Johnson, Francis M. Ryan, Harry B. Coxhead, Raymond F. Yates, Reginald P. Lyman, Lewis A. Terven, John C. Strobel, Jr., E. C. Hansen, B. S. McCutchen, John C. Warner, H. M. Lewis, Harry Sadenwater, J. F. J. Maher, George E. Oliver, W. A. Peterson, W. A. MacDonald and R. L. Duncan.

Those approved for direct election to Member grade are: R. S. Glasgow, R. R. Ramsey, C. H. Thompson, W. H. Frasse, E. R. Stoekle, G. C. Furness, C. Wright, Thomas Walmsley, R. T. St. James, R. Highleyman, P. A. Greene, G. J. R. Fisher, H. T. Tisshaw, H. T. Tisshaw, C. E. Scholz, F. W. Dane, F. T. G. Townsend, Harold Roess, P. J. Schwartzhaupt, H. P. Corwith, A. C. Lescarboura and J. Joseph.

Eighteen applications for admission or transfer to Member grade were disapproved.

Messrs. Frederick K. Vreeland and E. T. Fisk were transferred to Fellow grade.

Sections

In accordance with the provisions of the new Section By-Laws, remittances have been made to each Section covering the per-member rebate due for the first quarter of 1926. This financial assistance to the Section already has given new impetus to Section activities.

Headquarters Offices

The new and enlarged offices now occupied by the INSTITUTE at 37 West 39th St., New York, are well organized so that the business of the INSTITUTE may be carried on on a larger scale and all matters attended to promptly. A considerable amount of new furniture and equipment has been added to the plant.

Membership Committee

The membership Committee held a meeting at headquarters on April 5. The following were present: H. F. Dart, chairman, and Messrs. R. H. Marriott, M. Berger, W. G. H. Finch, A. R. Nilson, E. R. Shute, and President McNicol, ex officio. The committee has worked out a construction program having in view gains in membership, including all those who are eligible and who desire to avail themselves of the advantages of membership in the INSTITUTE.

Seattle Section

The Seattle Section at its March meeting had a paper by Mr. T. M. Libby, on "Some Studies on Radio Broadcast Transmission," and a paper by Mr. John Greig, entitled "High Frequency Beam Transmission." Regular meetings of the Section are held in the rooms of The City Electric and Fixture Company, 218 James St., Seattle. Members of the INSTITUTE who visit Seattle are invited to get into touch with the chairman or the secretary, whose address may be found on a preceding page of this issue of the PROCEEDINGS.

The April meeting of the Section had for consideration a paper by Albert Kalin, on the subject: "Construction and Design of Transformers."

Chicago Section

The Chicago Section held its April meeting in the rooms of the Western Society of Engineers, Chicago, on which occasion Prof. R. R. Ramsey, of Indiana University, presented a paper on "The Resistance of a Radio Condenser at Radio Frequency."

Chicago has the largest of the Section units, and the work is being well handled by Chairman Montford Morrison, Secretary L. R. Schmidt and Treasurer W. W. Harper.

The March meeting of the Section had for consideration a paper by C. M. Jansky, Jr., on the subject: "Collegiate Training for the Radio Engineering Field."

Changes of Address

Members of the INSTITUTE who change their mailing addresses are requested to advise the Secretary of such change. If this is done promptly delay will be avoided in receiving the issues of the PROCEEDINGS and other Institute publications.

Vice-President Bown in England

Dr. Ralph Bown, vice-president of the INSTITUTE, has been in England during the months of April and May, on official business, in connection with Trans-Atlantic radio telephone development.

Standardization Committee

The Standardization Committee held a meeting at INSTITUTE headquarters on March 25, the following being present: L. E. Whittemore, chairman, and R. H. Marriott, C. B. Joliffe, L. A. Hazeltine, R. H. Manson, H. M. Turner, and President McNicol, ex-officio.

Admissions Committee

The Admissions Committee holds monthly meetings for the purpose of passing upon all applications received for direct election to Member grade, and for transfer to Member and Fellow grade. The committee's recommendations in each case go to the Board of Direction, which meets on the first Wednesday of each month.

Meetings and Papers Committee

The Meetings and Papers Committee, under the direction of Mr. R. H. Marriott, chairman, holds regular monthly meetings, in addition to which a continuous correspondence is carried on by the chairman during the month. At the April meeting of the committee the following were present: R. H. Marriott, D. K. Martin, Carl Dreher, W. W. Brown, L. E. Whittemore, R. A. Heising, L. A. Hazeltine, H. F. Dart, and President McNicol, ex-officio.

Photostats of Pages of PROCEEDINGS

Some of the early issues of the INSTITUTE PROCEEDINGS are out of print and are not available. However, photostat copies of pages desired can be supplied to members or others at a cost of twenty-five cents per page. The time required is one week in addition to time of mail travel.

Members Elected

At the May meeting of the Board of Direction the report of the Admissions Committee was approved, covering the transfer to Member grade of: J. K. Henney, J. M. Clayton, Sylvan Harris, H. Stewart Price, J. W. Milnor, C. F. N. Wade, J. G. Swart, J. C. Van Horn, Chester W. Rice, Alfred Crosley, Minton Cronkhite; direct election to Member grade of: H. M. McClelland, H. J. Vannes, W. K. Wing, Meade Brunet, Frank A. Brick Charles Horton, G. C. Southworth, and transfer to Fellow grade of Mr. E. H. Colpitts.

Institute Medal Award for 1926

The INSTITUTE Medal for 1926 has been awarded to Mr. Greenleaf W. Pickard for his contributions as to crystal detectors, coil antennas, wave propagation and atmospheric disturbances. The Medal will be presented to Mr. Pickard at the June meeting of the INSTITUTE in New York.

Washington Section

At the February meeting of the Washington, D. C. Section a talk was given by Major J. O. Mauborgne, of the Signal Corps, on the subject: "The Influence of the 1925 International Telegraph Conference at Paris, on the Coming International Radio Conference at Washington."

At the March meeting a talk was given by Eugene Sibley, of the Air Mail Service. Mr. Sibley described the problems involved in maintaining communication with the Postal airplanes, and in directing their course by radio. The various direction-finding methods tried, culminating in the adoption of the interlocking system—which appears most promising, were described.

At the April meeting Mr. Marcus C. Hopkins presented a paper on: "The Translation of Electro-Mechanical Movements into Sound Vibrations."

The monthly meetings of the Washington Section are held on the second Wednesday at 8 P. M., in the Department of Commerce Building, 19th and Pennsylvania Avenue, N. W.

Additional Sections

Correspondence is now under way looking to the establishment of INSTITUTE Sections at Cleveland, Ohio; Detroit, Michigan, and Winnipeg, Manitoba.

Papers Available in Pamphlet Form

The following papers are available in pamphlet form, copies may be obtained free by members by applying to the Secretary. Price to non-members, 50 cents per copy.

x "Radio Station KDKA." By D. G. Little and R. L. Davis.

— "Dry Cell Radio Batteries." W. B. Schulte.

x "The Present Status of Radio Atmospheric Disturbances." By Louis W. Austin.

x "The Shielded Neutrodyne Receiver." J. F. Dreyer and R. H. Manson.

✗ "The Polarization of Radio Waves." By Greenleaf W. Pickard.

"Servicing Radio Broadcast Receivers." By Lee Manley and W. E. Garity.

✗ "New Method Pertaining to the Reduction of Interference in the Reception of Wireless Telegraphy and Telephony." H. De Bellescize.

✗ "Recent Advances in Marine Radio Communication." By T. M. Stevens.

✗ "Main Considerations in Antenna Design." By N. Lindenblad and W. W. Brown.

✗ "Transmission and Reception of Photoradiograms." By R. H. Ranger.

✗ "Portable Receiving Sets for Measuring Field Strengths at Broadcasting Frequencies." Axel G. Jensen.

✗ "Maintaining a Constant Reading on an Ammeter in the Filament Battery Circuit of a Thermionic Triode." By E. H. W. Banner.

"Uses and Possibilities of Piezoelectric Oscillators." By August Hund.

"A Radio Field Strength Measuring System for Frequencies Up to Forty Megacycles." By. H. T. Friis and E. Bruce.

"Precautions for the Radio Inventor." By Everett N. Curtis.

"Collegiate Training for the Radio Engineering Field." By C. M. Jansky, Jr.

✗ "Sources of "A," "B," and "C" Power." By W. E. Holland.

Standardization Committee

A meeting of the Standardization Committee was held on March 25, at the offices of the INSTITUTE.

At the invitation of the U. S. National Committee of the International Electrotechnical Commission it was agreed to give that Committee active assistance in its work looking toward the adoption of standard graphical symbols for radio.

After some discussion of the field of work which the Standardization Committee of the INSTITUTE should undertake during the present year, it was agreed that the full activity of the committee should be devoted to the formulation of methods of expressing and measuring the characteristics of radio receiving apparatus and associated circuit elements and devices.

It was agreed to organize five subcommittees to undertake this work. The subjects assigned to the subcommittees are as follows:

1. VACUUM TUBES—L. A. Hazeltine, Chairman.
   - Methods of measuring characteristics.
   - Life testing methods.
2. CIRCUIT ELEMENTS—Professor H. M. Turner, Chairman.
   - Methods of measuring:
     - Resistance.
     - Inductance.
     - Capacity.
     - Power fractor, phase angle or decrement.
     - Frequency.
     - Coefficient of coupling.
3. RECEIVING SETS—Dr. J. H. Dellinger, Chairman.
   - (Including amplifiers and audio transformers).
   - Methods of expressing and measuring:
     - Selectivity (including effect of shielding).
     - Amplification or sensitivity.
     - Trueness of reproduction or fidelity.
     - Distortion.
4. ELECTRO-ACOUSTIC DEVICES—R. H. Manson, Chairman.
   - Methods of expressing and measuring:
     - Frequency characteristics.
     - Efficiency.
     - Distortion.
     - Impedance.
5. POWER SUPPLY—R. H. Langley, Chairman.
   - Life testing of batteries.
   - Method of rating batteries.
     - Voltage.
     - Internal resistance.
   - Socket-power units.
     - Voltage-current characteristics.
       - Output circuits of different impedances.
       - Fluctuating input voltages.

The committee considered several other questions which might fall within its scope, but felt that unless members of the committee who were not present felt otherwise, it would be wiser to concentrate the efforts of the present year on the program outlined above.

It was agreed that the subcommittee chairmen would organize their committees promptly and undertake to prepare a draft of a report within the next two or three months. This is desirable in order that the committee members may have drafts for consideration during the summer months and so that drafts may be available for discussion and criticism at the meetings of the associations of manufacturers.

The committees will include in their reports any new definitions or suggested symbols not included in the 1926 report but which they find desirable in the course of their work.

ADDRESSES AT THE FIRST CONVENTION OF THE INSTITUTE OF RADIO ENGINEERS, NEW YORK, JANUARY 18 AND 19, 1926

OPENING REMARKS OF DR. J. H. DELLINGER, RETIRING PRESIDENT

The constitution of the Institute provides that there shall be held an annual meeting of the Institute. In the sense originally intended by the constitution, such a meeting has never been held. It is true that the Institute has a meeting every month and that the first meeting of the year or any other occasion can be considered as the annual meeting. However, this year the Board of Direction decided to have a specifically set occasion which should be considered as an annual meeting to take stock of the affairs of the Institute and mark its progress. That, in brief, is the origin of this, the first convention of radio engineers. I am glad that the large attendance at this opening meeting ensures that the convention will be successful in its purpose of permitting radio engineers to meet one another and to take stock of the part that radio engineering is playing in the human drama.

This Institute has been peculiarly well timed to play this part. Beginning in 1912 at the very time when radio was beginning to exercise an important part in affairs, it has been privileged to grow along with the rise of radio and to play something of a directing part in that rise. This meeting marks an epoch in the growth of the Institute. The past year has witnessed a number of changes in the character of the Institute's activities and points toward rapid progress in the various phases of its activities. I shall report on this more specifically a little later.

This is the day of the radio engineer. In the past three or four years there has been widespread popular mystification over how radio is done. People have been inclined to classify it along with the acts of the conjurer or in some cases to link it closely with the deeds of the Almighty. The miracles of radio, actually and in the truest sense, are produced not from batteries, coils and electrons, but from the brain of the radio engineer, and when the processes of radio are analyzed they are no more mysterious than any other familiar process. This is the day of the radio engineer, in still another sense. Progress in radio has been up to the present by empiricism. Its foundations have now been laid. The outlines of its major forms of service to humanity now appear and the task of perfecting this service and its instrumentalities is the task of the radio engineer. He must and he can apply the principles of science and technology to advance beyond the empirical foundations of the subject and obtain from it, by both logical and laborious procedure, all of its possibilities.

There is no need for me to delay the convention getting under way in order to dilate upon or even to mention the achievements or the status of radio. Suffice it to say that those who work in it belong to a recognized branch of engineering which has a unique responsibility. It has been said that the progress of civilization consists in learning how to better employ and transform energy. Such words as these state the mission of all engineers, but the material with which he works takes the radio engineer beyond even this control of physical energy, for the uses of radio today have vitally to do with the use and control also of human energy. A well-known radio engineer in one of his moments of tribulation said that these days a radio engineer must be all of the following things: an electrician, a physicist, an expert in acoustics, a mechanical engineer, a musician, and a diplomat. It is a fact that radio has become a large subject. A few years ago, within our own lifetimes, it was an apt saying that no one person could know all the sciences. The multiplication and ramification of knowledge has now become so great that, as any of us in our more ingenuous moments will admit, no one person can even know all of radio. I suppose that we can say that this branch of engineering has arrived, when it has become so specialized that a person working in one branch of it can give an intelligent disquisition that his fellow members in the profession are not able to understand.

Radio engineers can take great satisfaction not only in the particular field that lies before them but also in the substantial manner in which progress is going forward. We have perhaps gone beyond the point where the daily newspapers turn to radio for the creation of a daily sensation, but to the engineer who really knows what is being done there are many substantial advances and improvements in active progress at the present time. The uniform forward movement along the whole front of radio problems and activities is a genuine cause for optimism.

and optimism is conspicuously the attitude of all workers in radio whether in its engineering, scientific, commercial or social aspects. I would not be misunderstood as intimating that its problems are solved,—by no means. The existence of a number of healthy man-sized problems is what gives zest to the game.

The chief concerns of radio engineering just now are: perfection of broadcasting, and the penetrating of the mysteries of radio wave propagation. These can be considered as, in a sense, a single problem since the first cannot go very far forward without the second; yet these two comprehend broadly the two major streams of engineering thought and effort at present. There has been great progress and fine achievement in both of them during the past year.

These two things have been chosen as the main themes of this convention; the one, broadcasting progress, will be the subject of our thoughts at tonight's meeting which will be a symposium on the results of the radio conference held in Washington in November, 1925. The other problem, the vagaries of radio waves, is the general theme of the two scientific sessions of the conference.

STATUS REPORT ON INSTITUTE ACTIVITIES

It is my duty to outline briefly the progress of the Institute during the past year. The business matters of the Institute are handled by the Board of Direction, an elected body of twelve members which meets once a month. During this year the custom has been inaugurated of presenting to the membership a regular summary of the business transacted. This has been done through a verbal report by the President at each meeting of the Institute and through the bi-monthly section on "Institute Notes" in the PROCEEDINGS. The work of the Institute is done mainly through five standing committees. These committees have been active and not merely decorative.

The outstanding progress of the year has been the growth of the sections of the Institute at various points throughout the country. At the beginning of the year there were four such sections, those of Boston, Washington, Seattle and San Francisco. There was little outward evidence of activity on the part of some of these Sections. During the year Sections have been organized in Chicago, Philadelphia and Toronto. The Toronto Section is the first section to be established outside the United States although the Institute has always had a substantial membership in foreign countries. The desirability and possibility of organizing overseas Sections is one of the interesting questions which is engaging the thought of the Board of Direction at the present time. In any event there are a number of cities in the United States in which Sections will doubtless be organized in the next year or two. The growth of the Sections is greatly stimulated by the action of the Institute this year in providing a number of special measures, including financial support, for the regulation and encouragement of the local Sections. This progress has been made possible largely through the work of Mr. McNicol, our newly-elected president, who, as chairman of the Sections Committee, made trips to a number of the cities to help organize and stimulate Sections and in other ways has put a large amount of time into this most important part of the Institute's work.

During the year the membership has increased. It should be borne in mind that most persons must join the Institute as Associates. The rather rigid requirements for the grades of Member and Fellow are faithfully observed by the Board, and very careful consideration is given to every application for membership in these grades. This careful work by the Board in the matter of membership which has become a tradition, ensures that election to the Member or Fellow grade is a recognition of professional attainment which is worth something to any radio engineer.

It is a particular pleasure to report that the financial status of the Institute has changed from a deficit at the end of last year to a substantial balance at the end of the year just closed. Effective in 1926, the Institute has found it necessary to raise the dues by a small amount. While such a measure is always unwelcome, it was rendered inevitable by the expansion of activities which the Institute could no longer avoid. Proper stimulation and development of the work of the various local Sections is alone a sufficient cause for this need of increased income. As a partial paliative to the raise in dues, members will receive with the first PROCEEDINGS in 1926 an excellent printed report which gives the result of two years' work by the Committee on Standardization in the way of standard terminology, definitions, and graphical symbols. This will be followed by a Year Book which will include a complete address list, the constitution and section by-laws, and general information about the Institute.

This Standardization Report is a document which is expected to be the basic standard of radio language for the next two years, which is the approximate period allowed before a new edition of the report may be necessary. Radio has now become stabilized to the point where it seems desirable and worth while for the Institute to undertake standardization work of considerably broader scope. It may therefore be expected that the activities of the Standardization Committee during the coming year will progress to questions of measurements, tests, specifications, etc.

The meetings of the Institute during the past year have been marked by a broadening of the scope of subjects treated. As broadcasting has come to absorb the work of a majority of the radio engineers, a much wider field of topics has become available and necessary for the programs of the Institute meetings. This tendency has been recognized in the papers chosen and presented during the year.

This has been in part reflected in the articles published in the PROCEKDINGS. That periodical has maintained its well-known high standard. The interest of the PROCEEDINGS has been heightened by the addition of the section, "Institute Activities," an innovation which has been very popular with the membership. The volume of material offered for publication has been so great than an undesirable number of months intervenes between the submission of papers and their final appearing in print. The Board has therefore given very careful consideration to the possibility of changing the PROCEEDINGS from a bi-monthly to a monthly periodical. While no definite plans can be made as yet, it may be tentatively forecast that the PROCEEDINGS will be changed to a monthly periodical at the beginning of 1927. It has already been necessary to provide additional editorial service. Arrangements have been made during the year with the Editor of the *Journal* of the American Institute of Electrical Engineers for certain assistance in the editing and publication of our PROCEEDINGS.

There is one point concerning the character of papers presented at the meetings and printed in the PROCEEDINGS on which I think it necessary to give a warning. There is considerable temptation for a radio engineer to use such papers for purposes of commercialization. In yielding to this temptation to secure advertising either in the presenting or in publication of a paper tends directly toward the institution of censorship or, shall we say, toward the requirement of severe editing. Either is undesirable both from the viewpoint of those who present papers or of the editorial staff of the Institute. The proper place for commercial expression in the PROCEEDINGS is in the advertisements. It is worth mentioning, incidentally, that special attention has been given to the advertising this past year and an extremely high grade of appearance and character can be observed in the advertisements published in the PROCEEDINGS.

The year has been marked by a broadening of the affiliations of the Institute. It has become an affiliated society of the American Association for the Advancement of Science and is represented on the Council of that institution. It has become a subscribing member of the National Fire Protection Association and as such will participate in the formulation of national electrical codes. The Institute has also been active in the work of the American Engineering Standards Committee, through participation in some of its committees. These include the Sectional Committees on Radio, on Symbols and Abbreviations, on Batteries, and on Drafting Methods.

Symptomatic of the increasing activities of the Institute, a definite overhauling of the constitution is under consideration. This is being done in no hurried manner. It is thought that a revised constitution will be drafted during the coming year. The committee, of which the present speaker is chairman, has this work in hand and will be glad to receive any suggestions from the membership. The office of the Institute has just taken larger quarters and is a hive of activity. This activity is a reflection of the loyal support, enthusiasm, and interest of the Institute's members all over the world. I know of nothing which so fully illustrates this interest and activity as the present convention with its well-laid plans, fine attendance, and every prospect of success.

NEW OFFICERS

It is now my pleasure to present to you the new officers of the Institute. The gentleman whom you have elected president for the coming year is the man who has been responsible for most of the progress made during the past year. He has done anything but fill the usual role of a vice-president. Instead, he has taken it upon himself to be very active, and such outstanding achievements as the organization of the Chicago and the Toronto Sections are to be credited to his zeal. If the new president receives support this year in proportion as he has given it in the past year, he will have very little trouble in carrying the Institute a long way toward its destiny in 1926. I bespeak such support for him. He is a man of very wide experience in engineering organizations. He has been active for many years in both the Institute of Electrical Engineers and the Institute of Radio Engineers. He is known as a friend of the young engineer, and perhaps nothing better can be said of a man who has established himself in his profession. He has a most unusually complete and extensive library covering the whole field of the profession. He is a man familiar with the mechanisms of publicity, having had wide experience in editorial work, which is one of the main factors in the growth of an organization such as this. All who love the Institute and have ideas or plans for activities will find fertile soil for their development this year. I am very glad to present Mr. Donald McNicol, the new president.

ADDRESS OF PRESIDENT MCNICOL

> There may be societies in which the office of President is mainly an honorary elevation, but in the Institute of Radio Engineers the post is a place where the eight-hour-day is in bad standing. The growth of the Institute in the past two or three years has been such that the routine work and the problems of management have enlarged considerably.
>
> It is a credit to past-presidents and to past Boards of Direction that the Institute survived through the hectic years of fundamental invention in radio, and a greater credit still that its prestige and influence have spread widely, always on sound foundations. The most an incoming president may hope for is that he will succeed in maintaining the standards established, while pressing on with a view to further growth and greater usefulness.
>
> The Institute is a clearing house for radio scientific knowledge and literature and its main purpose is to get this information into circulation among the present and oncoming generations of radio engineers.
>
> I am fully appreciative of the honor of serving the Institute as President, following illustrious predecessors such as Dr. Kennelly, Dr. Langmuir, Dr. Pupin, Mr. Marriott, Mr. Pickard, Mr. Hogan, Dr. Alexanderson, Prof. Morecroft, Dr. Pierce, and Dr. Dellinger.

* * * * *

The Institute has elected as its vice president a man who, like the new President, has been active in its service. The vice-president-elect was the chairman of the Standardization

Committee, the excellent fruit of whose labors I have already mentioned. While comparisons are always odious, I believe in rendering tribute where tribute is due, and have no fear of contradiction when I say that the best paper presented to the Institute in 1925 was one by this same gentleman and his associates, a most remarkable contribution to scientific knowledge of radio signal fading. The gentleman whom I am about to introduce has a long record of radio service, having served with distinction in the Army during the war and since then in commercial engineering. Our new Vice-President, Dr. Ralph Bown.

PRESENTATION OF MEMORIAL TO THE SECRETARY OF THE INSTITUTE

In the preceding I have not spoken of the Institute's activities prior to 1925. The new member of the Institute may think that the Institute always existed or that it has been handed down from the dim past, but things like the Institute don't just happen and don't spring suddenly into full-grown life. There has been a period of fourteen years of steady growth, and this growth is but an integral of the work and faith and service of a number of devoted enthusiasts. The Institute is particularly indebted to the pioneers who founded it and built it up in its early years. Such men as Marriott, Stone, Kennelly, Eastham, Simon, Sarnoff, Hubley and Goldsmith are the personalities who should receive the homage of the Institute today for bringing this organization into being. It is a noteworthy fact that the Institute has been developed entirely on voluntary service. Not only have its officers served without reward of any kind but they have contributed substantially to it in more than one sense. Of no person is this more true than of Dr. Goldsmith, who has been Secretary and Editor for many years. In recognition of his conspicuous service to the Institute, the Board of Direction has deemed it fitting to give a definite expression. It is therefore my pleasure to present to Dr. Alfred N. Goldsmith this engrossed testimonial. (Dr. Goldsmith then received a framed testimonial, signed by all members of the Board, containing the following expression:

The Institute of Radio Engineers

To Dr. Alfred N. Goldsmith

in recognition of his service to science in the upbuilding of

The Institute of Radio Engineers

The members of the Board of Direction, as the representatives of the Institute, are happy to give expression to the high honor and esteem in which they hold Dr. Alfred N. Goldsmith, who has served as Secretary of the Institute for the past eleven years and as Editor of the PROCEEDINGS *since the beginning. He has given unstintingly of his time; his substance, his ability and gracious good will to the Institute; has personally built into its structure much of the strength it now has, and has continuously borne the burden of its problems. The Board of Direction therefore takes particular pleasure, at this first Convention of radio engineers, in acknowledging to Dr. Goldsmith their deep appreciation of his far-sighted support and guidance of the Institute, and the service he has rendered through it to the progress of science and engineering.*

PRESENTATION OF LIEBMANN MEMORIAL PRIZE

There was established seven years ago a fund having an income of $500 a year to be used for an annual prize. This is awarded by the Board each year to the engineer who has made the most valuable recent contribution to the art and science of radio.

I mentioned that one of the two main themes of this Convention is radio wave propagation. It is altogether fitting that one event of our program should be an act of recognition of an outstanding event in this field. Beginning in 1920, working first rather as an amateur than as a member of the Westinghouse staff, Mr. Frank Conrad made the bold departure of establishing regular radio communication on frequencies of 2700 and 5000 kilocycles. He made the startling discovery that there was actually better transmission under some conditions, and less fading than on low frequencies. This and related facts are now very familiar, but at that time it was an overturn of all conceptions of wave phenomena to find that the irregularities of transmission did not increase with the frequency. This achievement has been widely heralded. The statement has even been made that the discovery of the potentialities of high frequencies is the greatest step taken in radio since the original invention of radio itself. It is not my function or purpose to weigh the achievement. It is itself a tribute to the amateur, to the Westinghouse Company, to the spirit of experiment and adventure in the human heart, but beyond all this a tribute to Frank Conrad. The previous recipients of the Liebmann Memorial Prize are:

R. A. Weagant, R. A. Heising, L. F. Fuller, C. S. Franklin, H. H. Beverage and J. R. Carson,

And now it is my privilege and pleasure to hand the prize for 1925, in recognition of his achievement in the development of high frequency signaling, to Mr. Frank Conrad.

MAIN CONSIDERATIONS IN ANTENNA DESIGN[*]

By
N. Lindenblad
Radio Corporation of America
and
W. W. Brown
General Electric Company

Introduction

The purpose of this paper is to present the outstanding features which need be considered in choosing the rating of a high power transmitter, with particular reference to the design of the antenna. The fundamental data presented herein pertain mostly to trans-oceanic stations which use long wavelengths, and, to a great extent, these data are not applicable to short-wave, long-distance circuits. The better-known features will be referred to briefly, and the features comparatively new will be explained in greater detail.

Conditions of propagation at long wavelengths have proven to be sufficiently dependable for obtaining practical engineering information. The probable reason is the relation between the physical dimensions of the waves and the conditions in space through which the waves are transmitted. Although phenomenal results have recently been obtained over great distances with short waves and low powers, the long waves and high powers are still depended upon for reliable long distance communication.

Preliminary Considerations of a Projected Transmitter

In choosing the wavelength for a long-distance circuit, data available from various long-wave transmitting circuits is being utilized. Mr. Alexanderson and other experienced investigators have found that, for reliable communication, less than five hundred wavelengths should cover the communication distance. This figure is subject to some variation, depending on the direction and location of the communication points, and can be more definitely established after observations during extended periods

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[*] Received by the Editor, February 15, 1926. Presented before the Institute of Radio Engineers, New York, March 3, 1926.

have been carried out at these locations. On account of congestion at certain wavelength bands, it is often necessary to use other than the optimum wavelength.

The rating of a transmitter is conveniently designated as the product of effective height of antenna and antenna current. In order to predetermine the meter-amperes required to provide communication between two points, it is necessary to ascertain the magnitude of atmospheric disturbances at the terminals of the channels. From this information, and having chosen the relation between signal and disturbance intensity required, the meter-amperes of the transmitter can then be calculated. Extensive work in the field has been done by Mr. H. H. Beverage, of the Radio Corporation of America, and others.

The required meter-amperes can be obtained by a combination of large generating equipment and small antenna, or vice versa. There is one optimum value of cost in which a minimum balance is obtained between the cost of all initial maintenance and operating expenditures of the generating equipment against the cost and maintenance of the antenna structure (Figure 1).[1] After these considerations, which really are the most laborious on account of the many estimates that have to be made, the dimensions of the antenna structure can be decided and the design work started—the most economical mast height and mast spacing having already been determined in estimating the optimum cost of each aerial considered in the estimate.

COMPARISONS OF TYPES OF ANTENNAS

In considering the advantages and disadvantages of various types of antennas, both mechanical and electrical features have to be considered. Theoretical evidence and actual performance data obtained from experience determine the type to be selected.

The broadest classification of the various types of antennas may be obtained in classifying them according to their height. Thus, we have antennas of great height and relatively low capacity, and those of lesser height and large capacity. The former type generally employs a centrally arranged system utilizing a few supports of great height, and usually does not lend itself to multiple tuning. One of the main reasons is that the capacity of the superstructure is low and the effective height will be considerably lowered by introducing a number of downleads. Another disadvantage of the high type structure is the relatively high

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[1] The Electrical Plant of Transoceanic Radio Telegraphy, by E. F. W. Alexanderson, A. E. Reoch and C. H. Taylor. Journal A. I. E. E., July, 1923.

capacity between the antenna and its supports, which results in lowering the effective height. On the other hand, when antennas of moderate heights are used, these are generally built to cover a large area, and the efficiency of such a system can be made comparatively high by multiple tuning. The lower type antenna, which has a large surface, has a large capacity and its effective height is but little influenced by the introduction of a multiple of downleads. This classification applies mostly to large antenna structures. In comparatively small structures, these conditions may be considerably modified.

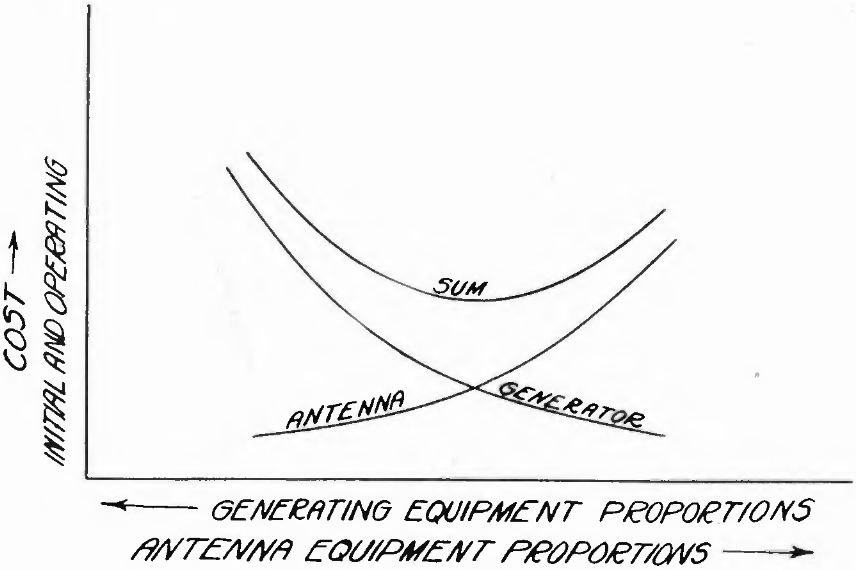


FIGURE 1

GROUNDED OR INSULATED SUPPORTS

The question whether supports for large antennas to be operated at long waves should be grounded or insulated from ground is largely an economical one. The insulators are, of necessity, large and expensive and add appreciably to the cost of the supports. Due to the high mechanical loads which the insulators must carry, a number of units are usually used in multiple, and it is very difficult to distribute the load equally among the several units. Replacing damaged insulators adds to the cost of maintenance. The 860-foot support for the umbrella antenna at the Tuckerton Station in New Jersey was originally insulated, but these have been replaced with metal blocks, due to mechanical failures.

A so-called insulated support is, at best, only partially insulated at radio frequency on account of the electrostatic capacity of the support to ground. However, the current collected by an insulated support is appreciably lower than in a grounded support on account of the high capacitive reactance between the support and ground.

It is essential that antenna supports be either well insulated or well grounded, as a semi-conductive base will introduce relatively high losses. The supports for the antennas at the Radio Central Station on Long Island are built on concrete bases, Figure 2. The resistance of the four bases in multiple for each support is 200 ohms under certain weather conditions. The capacitive reactance from the antenna to a support is approximately 5,000 ohms. At an antenna potential of 100,000 volts, the current collected by one support is 20 amperes. If the concrete bases were not well grounded, the loss would be 80 kw. per support.

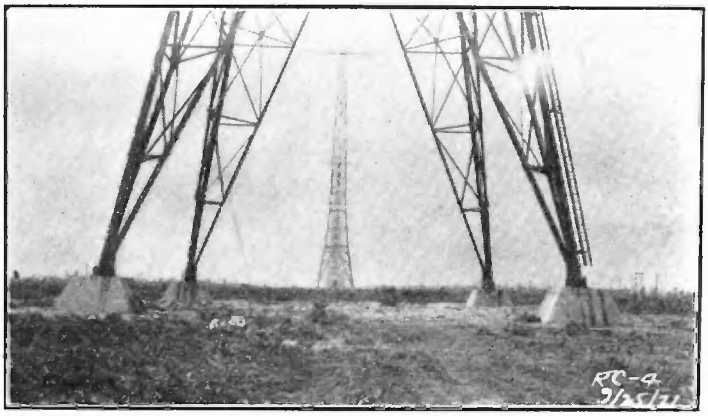


FIGURE 2

For antennas which are to be operated at relatively short wavelengths in which the height of the supports is of the order of a half wavelength or more, the insulation of the supports from ground has certain advantages which do not exist at long waves. At the relatively short wavelengths, grounded supports may cause considerable distortion to the field intensity pattern from the antenna.

CAGES VS. FLAT TOP ANTENNAS

In comparatively small antennas, one or more cages have the mechanical advantage that they are simpler to construct and are less affected by wind than are the flat tops which use spreaders to separate the wires. Electrically, the flat top has a slight advantage in that, for a given average height of conductors, a slightly higher capacity is obtained. This gives slightly greater effective height and efficiency.

Antenna downleads which are subjected to voltage of 75,000 and above are frequently made in cage form, mainly to avoid corona. The diameter of the downleads should not be made of larger diameter than necessary to avoid corona, as the larger the diameter the greater is the capacity of the lead or leads to ground which lowers the effective height and efficiency of the antenna.

MECHANICAL FEATURES OF ANTENNA DESIGN

Mechanical Models—Having decided upon the type of structure and its general dimensions, a mechanical model is often useful to aid in forming a conception of the various mechanical features and is particularly useful to check calculated forces in complicated structures. These models are usually made to a convenient scale, and particular attention is given to making the essential parts to have the correct relative weights. With the model in the normal position, the dead weight stresses are measured by a small dynamometer. By tilting the model, gravity then replaces wind conditions. Light chains or soft lead wire have been found useful in such models.

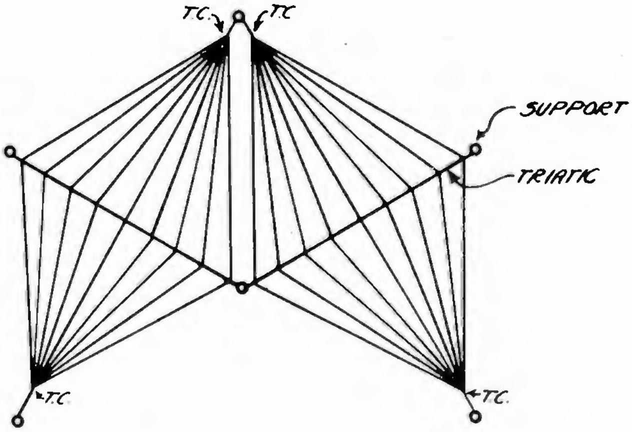
Antenna Supports (Masts, Towers, etc.)—The supports are of two main types: self-supporting and guyed structures. In America, at least, the trend in recent years has been towards the self-supporting type. The self-supporting type, although often of a higher initial cost than the guyed type, offers several advantages. It is less costly to maintain, has less influence on the antenna capacity and, thus, its effective height, and in certain cases, especially at the shorter waves, it causes less complications in tuning phenomenon and absorption. Self-supporting structures can be conveniently constructed with cross arms. These make it possible to arrange the superstructure with considerable width without using pairs of supports, thereby providing a relatively large capacity at an effective height which approaches the physical height.

Wire Material—In selecting wire material for an antenna, the material affording the best compromise electrically and mechanically is chosen. The materials most favorable so far have been found to be silicon bronze and Copperweld steel wires. As more data become available about the latter, it seems to be the better of the two.

One determining factor in choosing the wire material is fatigue and crystallization of the material. It can be said that a large aerial employing long spans is never at rest, and these motions in the system cause fatigue of the material. The natural periods of these motions cover a very wide range from high notes of audio frequency down to oscillations that may take several seconds to complete the cycle. It is thought that of these the ones causing the crystallization are those of the higher order. It was found that solid wires were much more subject to crystallization than stranded wires, and this is, of course, only natural, as the stranded wires afford some damping effects due to their construction. But even stranded wires show the same effects, and it cannot be said that this investigation is finished yet. The slower motions have a great wearing effect upon connections and jumpers, as these are continuously subject to back and forth bendings. Although these are mostly of a minute magnitude, it is surprising how enormous the wear can be during a year of service.

Protection from Excessive Mechanical Loads—In order to protect an antenna structure from damage by the weather elements, arrangements must be made to prevent loads in excess of the elastic limit of any portion of the structure. Often this has been done simply by providing sufficient wire sag. This is detrimental to the electric constancy of an antenna during wind, and various means of permitting small wire sags have been introduced. The nature of such arrangements differs greatly with the various antenna types. For antennas of the "Radio Central" type, it is feasible to use very strong wires having a small sag, as the strain in the wire is at no point taken by the masts, which latter merely support the weight of the wire as in a transmission line. The supports for the Radio Central antennas are of the self-supporting type with cross arms. There is one weak point in this type of support which must be safeguarded. In case one or several wires should break, the cross arms would be exposed to an unbalanced load from the remaining spans of this wire and the supports are subject to dangerous twisting. It was, therefore, found necessary to permit the whole wire to drop in case one should break, in order to avoid such a condition. This is accomplished by means of gripping devices at the supports of the wire that will open when the wire load is unbalanced. In order to safeguard against excessive loads should the stresses be great even under balanced conditions, as, for instance, in case of failure of the sleet-melting equipment during a heavy sleet storm, each wire has at one end been equipped with a tripping device which, by releasing the wire at one end of the antenna will start an unbalance in the wire stress and cause the wires to drop. By adjusting these tripping devices for different loads, it is possible to let the wires causing the most dangerous loads to drop first. This system has been described in detail by Mr. J. H. Shannon in a paper, "Sleet Removal From Antennas," presented before the INSTITUTE OF RADIO ENGINEERS, New York, September 2, 1925. Provisions to melt sleet from antennas is justified by two reasons: (1) It is a form of insurance against long delays which would be occasioned by damage to an antenna by excessive sleet loads. (2) It reduces the initial cost of an antenna by permitting the adoption of a structure of moderate strength.

Wherever feasible, the use of counterweights is a very satisfactory method of safeguarding against excessive stresses in an antenna. For the Radio Central type, this is impracticable, and, therefore, other designs have been tried in which it was attempted to combine the advantages of a long flat top antenna and to employ counterweights. This antenna is designated as the diamond type. One of the antennas at the Tuckerton Station is of this type. Figure 3 shows a plan view. This antenna is multiple tuned at the points designated in the figure and the spans are counterweighted at the same points. Figure 4 shows the arrangement of the downlead at the outside end of a diamond in Figure 3 and Figure 5 shows the arrangement of the two downleads at the inside ends of the diamonds in Figure 3. The antenna de-



PLAN VIEW
"DIAMOND" ANTENNA AT TUCKERTON STATION
TUNED AND COUNTERWEIGHTED AT POINTS "TC"

FIGURE 3

signed for the Pernambuco Station is of the diamond type and is shown in Figure 6. The diamond type requires one extra mast for every two spans, but this is partly compensated for by the greater width that can be used and thus is not so uneconomical. The great advantage of this type is in its mechanical features, in that it can be counterweighted at one end of every span and the counterweight be given such a weight that the elastic limit of the wires can never be reached. The performance of this antenna type has been studied and found to work as expected. During a sleet storm at Tuckerton, the power supply failed and

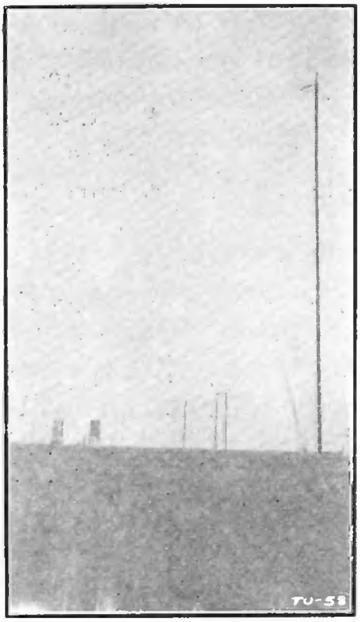


FIGURE 4

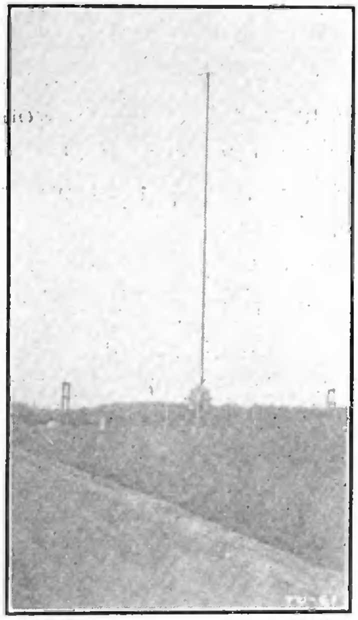
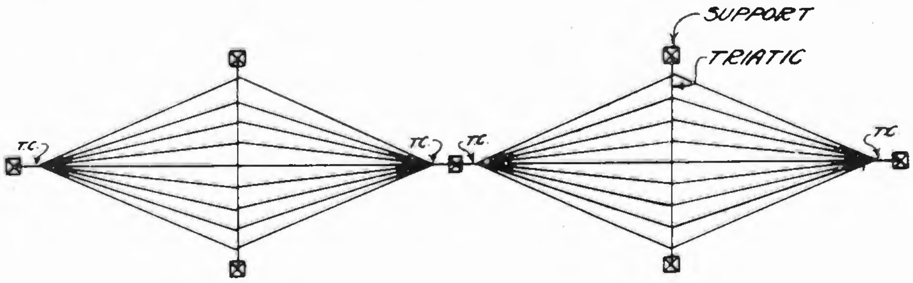


FIGURE 5



PLAN VIEW
"DIAMOND" ANTENNA FOR PERNAMBUCO STATION
TUNED AND COUNTERWEIGHTED AT POINTS "T.C"

FIGURE 6

thus prevented the melting of sleet. The counterweights merely permitted the antenna to assume an enormous sag. Of course, the antenna could not have been used while in this position, even if power had been available. As soon as the power supply was available, the sleet was melted, the antenna resumed its normal position and traffic was resumed without extra delay due to repair work. Counterweights are always used in anchoring downleads, regardless of antenna type.

Electrical Features of Antenna Design

Capacity Calculations and Measurements of Models—In the calculation of antenna capacities, the problems are often so complicated that it is not practicable to attempt a theoretically exact solution, which is possible only for very simple types of antennas. An outline will be given of the methods which have been found most useful and which are sufficiently accurate for practical purposes. The basic principle of the most useful method is to convert the physical arrangement of conductors to such forms that the well-established formulas for the capacity between concentric cylinders and between a cylinder and plate can be used.

Of the several components which constitute the total antenna capacity, the largest component is usually that of the horizontal or top section to ground. This component is again subdivided into wire to plate capacity and plate to ground capacity; these two components are in series. Consider the horizontal section as being composed of a number of wires equally spaced apart and parallel with the ground. The wire-to-plate capacity is determined by considering each wire as being surrounded by a cylinder whose circumference is equal to twice the spacing between the wires. The capacity of each wire to its concentric cylinder times the number of wires gives the wire-to-plate capacity per unit length of the wires. The plate-to-ground capacity is determined by considering the wires to be replaced by a cylinder whose circumference is equal to twice the spacing between adjacent wires times the number of wires. The capacity of this cylinder to ground is equal to the capacity to a concentric cylinder whose diameter is four times the distance from the antenna wires to ground.

In the case of a long flat top antenna of constant width, the conversion to concentric form is simple. In the case of a diamond antenna, the conversion is less direct and the results less accurate, especially when the width exceeds twice the height.

In all cases in which a large number of wires is considered, regardless of the geometrical form, it is well to obtain the plate capacity, which is the capacity of a metal sheet of the same outline as the antenna. If the antenna is low compared to its length and width, the plate capacity and a small factor for edge effect gives the true capacity. As the height increases, the factor for the edge effect increases and this factor can not be estimated unless special data are available.

In order to check calculated capacities, especially in geometrically odd design, it is well to measure models. If models for measuring capacity directly were to be built, these would have to be rather large, and would involve a considerable expenditure of time and money. A method much better and very reliable is the water-box method, which utilizes measurement of resistance rather than of capacity. There is required a water-tight wooden tank with a metal plate covering the bottom, or a metal tank with the inside side-walls dressed with some insulating material and the bottom of this tank uncovered. A standard consisting of a circular disk and surrounded by a concentrically arranged shield ring (Klevin ring) is used. Both the disk and ring are fastened to a plate of some insulating material so that only one side of them is uncovered. If the disk and its associated ring are mounted above and parallel to the bottom of the tank with the metal side facing the bottom, the capacity of the disk can be very closely calculated as it is a straight plate condenser without edge effect, due to the shield ring which always is given the same potential as the disk. The edge effect will thus only appear at the outside edge of the shield ring and not come into consideration. A model of the antenna plate is now made to some convenient scale, comparing in size with the standard. Insulated leads are attached to the model and the disk and ring of the standard. The apparatus is now placed in the tank, which is filled with water. The capacity of the standard is known. The resistance of the standard as well as that of the model can be measured, and thus the only remaining unknown factor is the capacity, which can be calculated from these values, as the current lines radiating from the model have the same physical shape as the electrostatic lines. Thus, the lower the resistance of the model, the higher is its corresponding capacity. This method is very reliable and has been found useful for checking purposes in complicated cases.

In case a model employing wires is used, it is impossible to use wires small enough to correspond to the scale. The smallest practicable wire is used in the model, and, when enlarged to full scale, is considered the outside cylinder around the actual wire.

In order to get an idea of the correct number of wires to be used, it is often advisable to calculate the so-called wire factor which is the ratio of the total capacity of the flat top to its plate capacity. If the supports are strong enough, this factor should be made high. On the other hand, when a support of given strength is available, the factor should be made low, as this means that the wires have been spread apart as much as possible and thus the greatest possible capacity has been obtained with a minimum of wires.

RESISTANCE—REPRESENTATIVE

A segregated list of the various components of resistance of one antenna at Radio Central Station is as follows.[1]

Radiation resistance at 16,500 meters	0.05 ohm
Soil resistance	0.10 ohm
Tuning coil resistance	0.15 ohm
Conductor resistance	0.05 ohm
Insulation and other losses	0.05 ohm
Total	0.40 ohm

With a given arrangement and dimensions of an antenna, the radiation resistance at a given wavelength is definitely established. The other factors which represent losses are subject to considerable variation, largely under control of the designers.

RADIATION RESISTANCE

This element can be calculated by well-established formulas.[2] These formulas contain a factor for the effective height which can also be calculated, but not to the same accuracy as in some simpler problems. After a station has been erected, a check on the calculations of effective height can be obtained by measuring the field intensity at a given distance from the transmitter and by calculating the effective height of the transmitting antenna from these data. Close agreement has been obtained between the two methods of determining the effective height.

SOIL RESISTANCE

This item is usually a larger part of the total resistance than is shown in the segregation which applies to a "Radio Central"

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[2] Transoceanic Radio Communication, by E. F. W. Alexanderson. G. E. Review, October, 1920.

antenna. A careful study of the various factors involved in the arrangement of a ground system and the application of well-established principles is well worth while.

The fundamental principle of keeping the soil resistance low is to provide short paths for the current through the soil. If the resistance of the soil is low, pipes or buried plates may be used to good advantage. If the resistance is high, which is the usual condition, buried wires are preferable. The unit resistance of dry sand is more than 500 times the resistance of salt marsh. Actual measurement of soil resistance is very necessary before a ground system can be properly designed.

The ground currents should be collected according to the area of ground around the point of collection and according to the field intensity at this point. It has been found necessary to arrange the buried wire system so that it can be tapped at a great number of points and the current carried back to the tuning coil center by means of an overhead conductor. To effect an orderly arrangement, the tapping points are generally arranged in symmetrical rows and these rows are connected to a main overhead bus which connects to the antenna tuning coil. As the currents are collected along this bus, the current passing through the bus and the inductive voltage drop along the bus become greater as the tuning coil is approached. If, therefore, it is desired to collect equal currents at each grounding point, it is necessary to insert an inductive reactance at this point which has a value corresponding to the voltage of the overhead bus divided by the current to be collected. This is equally true in connecting up the antenna supporting structures and other structures with the ground return system. The currents collected by these structures are first ascertained, and then the proper reactance in the connecting link is calculated from the voltage of the collecting bus and the current to be collected in order to maintain the natural current distribution, which depends upon the distribution of the electric field from the antenna.

It can readily be seen, however, that in an antenna of great proportions and with the heavy currents that would have to be carried along the busses, or in case of a counterpoise, considerable inductive voltage drop would occur along the conductor. Thus considerable flux would radiate from these busses and cause circulating currents in the ground. Sometimes, when the bus is not too long, the voltage can be neutralized by series condensers inserted in the line. For extended systems, this is an undesirable complication and has the disadvantage of correct neutralization at only one frequency. Regardless of the neutralization of the voltage on such busses, the magnetic field from the current they carry still remains and is a source of considerable loss due to induced circulating currents in the ground

The greatest advancement in the solution of these problems was the development, by Mr. Alexanderson, of multiple tuning.[3] The main object of multiple tuning is to provide shorter paths for the ground currents. This is accomplished by distributing the total antenna current through a number of tuning coils spaced along the length of an antenna, rather than to have the total current flow through one coil. The multiple arrangement makes it possible to obtain a ground-distributing system of reasonable proportions and the soil resistance is thereby greatly reduced.

Excellent results have been accomplished by Mr. Hansell and Mr. Carter, of the Radio Corporation, in investigating the phenomena of conduction of current through soils of different characters. These investigators demonstrated mathematically and by experiment that, for a soil of given character, there is a fairly definite length of wire which gives highest conductivity at a given wavelength. This length is approximately one-quarter of the wavelength at the rate of propagation in the particular soil. The rate of propagation in soil is much slower than in air, in certain soils being 1/20 or less of the rate in air. If the length of wire is extended indefinitely, the conductance will pass through a number of cycles of decreasing amplitude, becoming constant at a value which would obtain with an infinitely long wire.

Another method of reducing soil resistance is by the use of a counterpoise—earth screen—and in some cases a combination of wire ground and counterpoise is justified. On account of the importance of reducing soil loss to a minimum, the outstanding factors will be considered.

First, consider an antenna without a counterpoise, having only a buried wire ground. Figure 7 shows the flux distribution of a long flat top antenna. The electric lines of force from the antenna spread a maximum amount and the radiation resistance of the antenna is a maximum. On the other hand, all of the antenna current returns through the soil and through the contact resistance between the buried wires and the soil. On account of the large spreading of the lines of force, a portion of the current travels long distances through the soil. Therefore, if the resistance of the soil and the contact resistance are high, the radiation

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[3] Transatlantic Radio Communication, by E. F. W. Alexanderson. PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, August, 1920.

efficiency might be low. If a large area under and around the antenna can be covered with buried wires, the soil resistance can be reduced and the radiation efficiency increased.

Second, consider an antenna with a counterpoise only. There is no contact resistance between the soil and buried conductors. The electric lines of force are pulled in toward the counterpoise. The amount of lines which go from the antenna directly to the counterpoise is proportional to the ratio of the direct capacity between the antenna and counterpoise and the indirect capacity from the antenna through the ground to the counterpoise. The potentials on the antenna and counterpoise are in inverse proportion to their capacities to ground. The potential of the counterpoise when no ground connection is used is always of opposite polarity to the antenna potential because when the lines go in the direction antenna to ground, they go, at the same time, in the direction ground to counterpoise. Considering the ground to have zero potential, one must be negative when the other is positive. Therefore, the counterpoise radiation is counter to the antenna radiation.

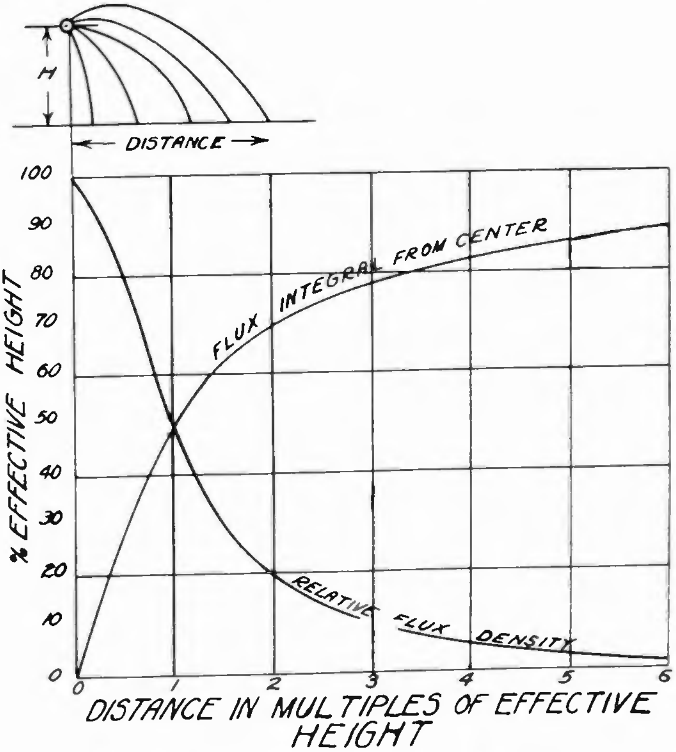

FIGURE 7—Flux Distribution of a Long Flat-Top Antenna

With a counterpoise, the radiation resistance of the antenna is decreased on account of the lines being pulled in toward the counterpoise and on account of the counter radiation. On the other hand, there is no contact resistance and the currents through the soil are smaller. Therefore, for a given area of counterpoise, there is a certain height of counterpoise which gives maximum radiation efficiency. If the ground area for counterpoise is unrestricted, maximum efficiency of the counterpoise is obtained when it extends over a large area. In this case, the height of the counterpoise above ground should be equal to the spacing beteeen the wires, to prevent any of the lines from the antenna from passing through the counterpoise. Of course, there should be a sufficient number of wires so that the counterpoise can be kept low, thereby keeping the counter radiation low.

Following the preceding line of reasoning, we can readily see the conditions which may justify a combination of wire ground and counterpoise. This condition is obtained when the ground area under and around the antenna is restricted and the soil resistance is high. If a sufficient amount of buried wires is used in this restricted area, the soil and contact resistance for currents within the area can be brought to a very low value. If the ground were stony, it might not be possible to install a sufficient amount of buried wires. Regardless of the amount of wires in the restricted area, the ground currents produced by the lines which would fall outside of the area would flow through high resistance soil. Obviously, it would be advantageous to reduce the currents beyond the restricted area, and we have seen that the counterpoise does just this.

Let us now assume that a first-class buried wire system has been installed in the restricted area, and the soil and contact resistance within this area is negligible. Neglecting the coil, conductor and other relatively small resistances, the antenna resistance is determined by the effective height of the antenna and the resistance of the soil outside the restricted area. By knowing the soil resistance, the effective height can be made such that the radiated energy is as large as possible, compared with the energy lost in the soil outside the restricted area.

The same results can be obtained by using only a counterpoise and no buried ground, provided the counterpoise has enough wires (high capacity) and covers the same area as the buried wire ground system.

Either the buried wire system or a counterpoise structure for a large antenna is very costly. The combination of the two sometimes proves to be the most economical, because fewer wires can be used in both, thus reducing the initial and maintenance costs.

It is feasible to use fewer wires in each because the duties of the two are reduced; the total antenna current is divided between the two. If the counterpoise carried the total antenna current, its potential would be high because its area is restricted, the number of wires and the capacity are small. The higher the potential of the counterpoise, the greater would be the proportion of lines from the antenna to the counterpoise as compared with the lines to the soil beyond the counterpoise. This would result in a lower effective height, because the effective height is determined by the flux distribution.

What is the best distribution of current between the buried wire system and the counterpoise? Consider first the circuit of antenna, inductance coil and counterpoise. With the circuit energized, there is a point on the inductance which has ground potential because the counterpoise potential is counter to the antenna potential. If the buried wire system is connected to this point of ground potential, no change in circuit condition will result. If the ground system is tapped down the coil towards the counterpoise, the total antenna current will be distributed between the counterpoise and wire ground.

As the proportion of total antenna current to current in the buried system is increased, the effective height and radiation resistance increases. The soil resistance also increases and the conditions may be expressed mathematically from the fundamental formula:

$$\text{Radiation efficiency} = \eta = \frac{R_R}{R_o + R_R}$$

as

$$\eta = \frac{R_R + \Delta R_R}{(R_o + \Delta R_o) + (R_R + \Delta R_R)}$$

where ΔR is the increase in radiation resistance, and
ΔR_o is the increase in ground resistance.

For a certain adjustment, the above equation will give a maximum value for η, which is the maximum radiation efficiency.

The combination of buried wire and counterpoise systems has proven useful in decreasing the soil resistance at stations which were built at a time the knowledge on this subject was limited. In these cases, the height of the antenna was fixed and the combination provided a means of adjusting the antenna for a relatively high radiation efficiency. In such cases, a check on the calculated optimum proportion of current in the two systems could be obtained by measuring the field intensity for the antenna with different distributions of current, using the same power input to the antenna in each case. The maximum radiation efficiency is not necessarily obtained with minimum antenna resistance.

The tendency of the Radio Corporation engineers has been to adopt the buried wire system in preference to the counterpoise or the combination of the two. The main reason is that the buried system is not subject to mechanical or electrical failures, and, therefore cannot cause interruption of service. Thus, the economical factor enters again and in a broader aspect.

Tuning Coil Resistance

This is the largest item of loss given in the segregation for a representative antenna, and therefore justifies careful consideration in connection with long-wave high-power antennas.[4] In the design of such coils, the two most important factors are reliability and efficiency. As a result of investigations over a period of ten years, improvements have gradually been brought about in the early designs, so that at this time there are two types of coils which embody the factors of reliability and efficiency to a high degree. The two types differ mainly in that one is intended for operation outdoors; the other type is for indoor use.

From a reliability standpoint, of first importance, is a large factor of insulation strength. This is obtained by using porcelain for the supports of the conductor and so arranged that long leakage paths over the surface of the porcelain are provided. From an efficiency standpoint, the kind of conductor, proportions of the coil, absence of metal fittings in the supports and low dielectric loss in the supports are important factors.

Figure 8 shows an assembled coil which operates reliably—outdoors—at 18,000 kilovolt-amperes at higher efficiency than a combination of four coils of an earlier type with the same total kv-a. distributed equally. Figures 9 and 10 show, respectively, a spacing block for the conductor and a detail of the porcelain supports which contain a negligible amount of metal.

Figures 11 and 12 show component parts of the unit type coil, and Figure 13 the assembly of a complete unit. These units are stacked, vertically, to the required numbers. This type is intended for indoor use. There are no metal fittings in the supports, and the conductor is of finely stranded Litz proportioned to reduce eddy current losses to a minimum. Coils of this type

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[4] Designs and Efficiencies of Large Air Core Inductances, by W. W. Brown and J. E. Love. PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, December, 1925.

are operating very satisfactorily at 16,000 kv-a. as antenna tuning coils and at 28,000 kv-a. as antenna uncoupling coils. As uncoupling coils, the potential of one antenna is impressed on the bottom of the winding which requires high insulation strength to

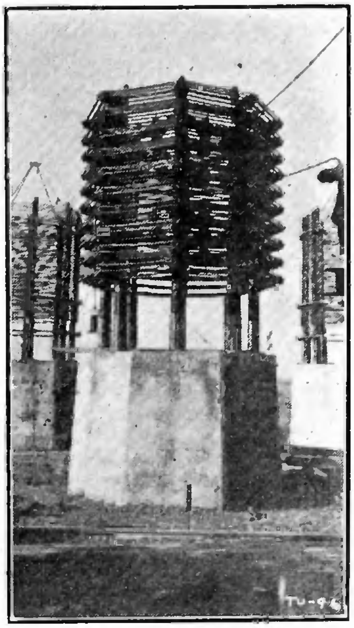

FIGURE 8

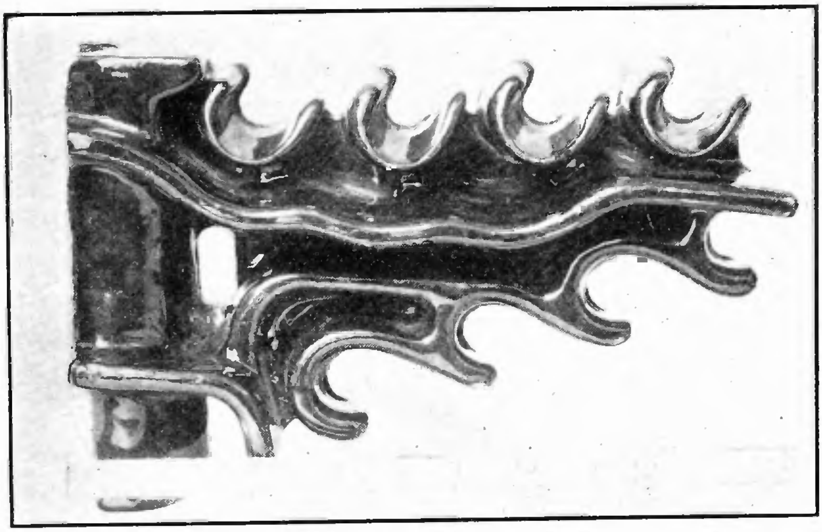

FIGURE 9—Porcelain Spacing Block for the Conductor of Antenna Tuning Coil

ground. This is obtained by using the required number of blank rings between the bottom active section and the concrete foundation.

Each of these types can be proportioned for satisfactory operation at practically any load encountered in connection with high-power long-wave antennas. They are particularly suitable for use with multiple tuned antennas.

Outdoor coils are satisfactory under nearly all climatic conditions, except when so located that salt spray deposits a coating of salt on the coils. This condition necessitates housing around the coils, and other conditions sometimes justify housing. Figure 14 shows a house at the Marion Station in Massachusetts of a size suitable to protect one antenna tuning coil and one uncoupling coil. This house is of frame construction, lined with sheet copper; joints between sheets are soldered, and the roof is also of sheet copper. The effect on the electrical characteristics of a coil

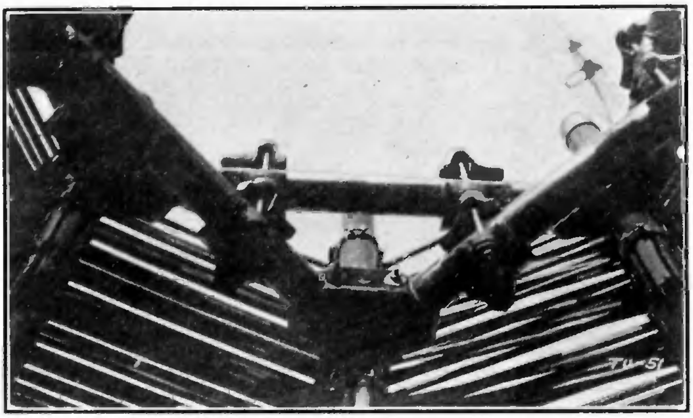

FIGURE 10

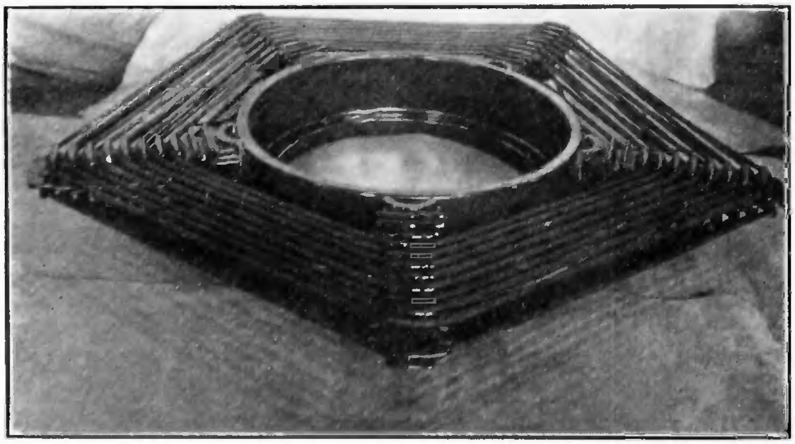

FIGURE 11—One Section of Unit Type High-Power Antenna Tuning Coil

by erecting a house around it is to slightly lower the inductance of the coil. The resistance is not appreciably increased.

CONDUCTOR RESISTANCE

This element is usually relatively small because of the large number of conductors in the multiple and each conductor is of large diameter to avoid corona. For the antenna proper, silicon bronze and copperweld are used almost exclusively. These materials have slightly different resistance at radio frequencies, but the

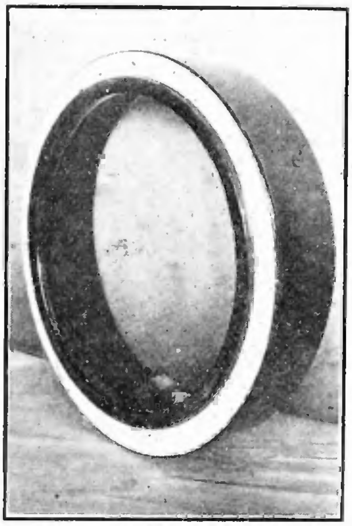

FIGURE 12—Porcelain Cylinder for Unit Type Tuning Coil, 36 in. Diameter

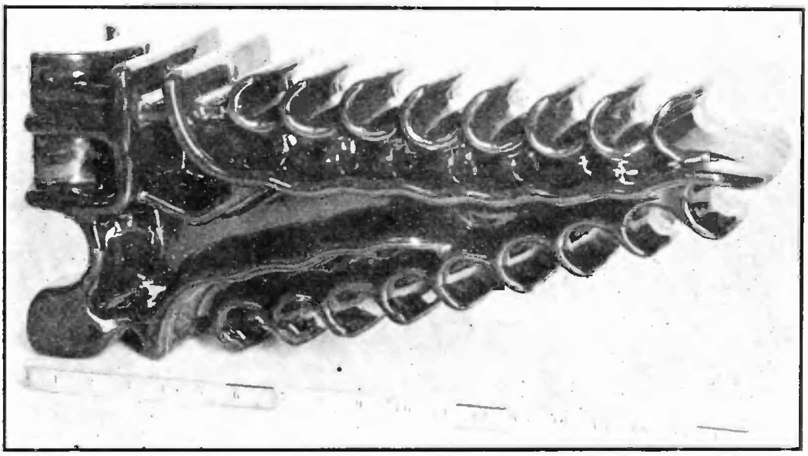

FIGURE 13—Porcelain Spacing Block with 17 Grooves for High-Power Antenna Tuning Coil

choice between them is usually for mechanical rather than electrical reasons.

Insulator Resistance

The type of insulator most satisfactory for insulating high-voltage antennas is in the form of a long cylindrical rod or tube with suitable fittings and shields. Porcelain is the material used almost exclusively, and the designs now in use are the result of development over a period of several years.[5] The dielectric loss in one insulator of this type at 100,000 volts is so small that we were unable to measure it accurately. However, in a large antenna there are frequently 100 or more insulators, so that the total loss becomes appreciable. Correct shielding is very important to obtain satisfactory operation during varying weather conditions.

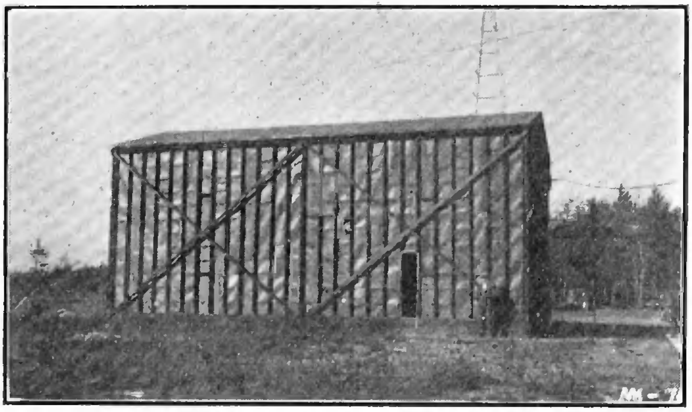

Figure 14

Indoor tuning coils require lead-in insulators. Several forms of these insulators have been used more or less successfully. The type now gaining favor is shown in Figure 15. A large number of insulators of this type of different sizes, having flahsover values from 30 to 100 kv., is in satisfactory use, and a size having a flashover of above 200 kv. is being tested. Larger sizes can be made if required. The mechanical strength of these insulators is in most installations sufficient to withstand the mechanical load of the downlead without additional insulators, which were required before this type became available. Electrically, they have proven satisfactory through the range of long waves to as short as 100 meters.

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[5] Radio Frequency Tests on Antenna Insulators, by W. W. Brown. Proceedings of The Institute of Radio Engineers, October, 1923.

Corona in any appreciable amount must be avoided in order to obtain otherwise possible efficiency. An antenna curve of Resistance vs. Current shows constant resistance through the range of low and increasing current until the corona point is reached at which the resistance increases rapidly. The corona point in a representative high-power antenna is around 175,000 volts, but in many existing antennas is much lower than this value. This, of course, can be raised by providing larger conductors, greater spacing, etc.

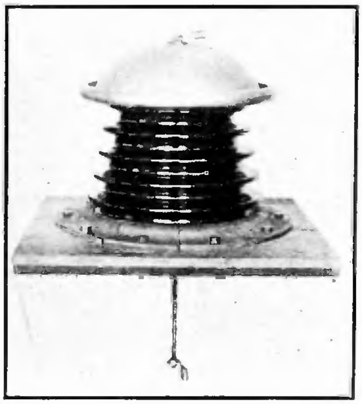

FIGURE 15—Radio Antenna Lead-in Insulator — Nominal Rating 80,000 Volts

EFFECTIVE HEIGHT

As an antenna always consists of members of different heights and as parts of its wire system often are close to the supporting and other structures, it is necessary to take all these factors into consideration in order to estimate their combined influence upon the effective height of a system.

The factor determining the magnitude of the influence of each member is its capacity, and, as the purpose of the investigation is to find the effective height, the effective height of each part of the system should be taken into consideration. The problem is similar to that of finding the center of gravity of a body.

The products of the capacity and effective height of each portion of the system are added up and this sum is then equal to the sum of all capacities multiplied by the combined effective height which is the unknown factor. This problem is relatively simple when the physical dimensions of an antenna are small compared with the wavelength that is used, as the effect of uneven voltage distribution can be neglected. When an antenna is large compared with the wavelength used, a third determining factor is introduced, that of the voltage of each portion considered. This sometimes leads to quite involved complications, depending on the design of the structure.

ANTENNA UNCOUPLING

When two or more antennas are located close together, difficulties are encountered in simultaneous operation of these antennas, particularly if the wavelengths are close together. These difficulties are due to the capacitive couplings between the antennas, and the methods of overcoming these difficulties are referred to as antenna "uncoupling" methods.

Due to one antenna being present in the electromagnetic field of another antenna, energy is in this way transferred from the latter to the former, and the amount of energy transferred depends upon the voltage of the exciting antenna, the combined impedance of the capacity path between the two, and the impedance of the pick-up antenna. It is evident that several conditions can be obtained, depending upon the impedance combinations between the antennas. The energy collected by an adjacent antenna may be helpful or detrimental to a signal, depending upon whether the energy in the pick-up antenna is in phase or out of phase with the energy in the primary antenna.

The conditions may be divided into two main cases:

1. The secondary antenna is tuned to a lower frequency. The impedance across the second antenna is thus capacitive for higher frequencies. As the coupling reactance is capacitive, there is a successive voltage drop first from the primary antenna to the secondary and then across the secondary. The secondary antenna will thus be in phase with the primary.

2. The secondary antenna is tuned to a higher frequency. the impedance across the secondary is thus inductive. As the coupling capacity furnishes a capactive reactance, a successive voltage drop will no longer take place across the combination as in Case 1. Furthermore, there will occur three different conditions in this case:

(a) The reactance of the coupling capacity is smaller than the impedance of the secondary antenna. Then a portion of the inductive impedance will tune the coupling capacitance. However, as the voltage drop along this inductive impedance must be continuous and greater than the voltage drop across the coupling capacity, and as the difference between the two is equal to the primary antenna voltage, then this voltage must be in phase with the primary antenna voltage.

(b) The reactance of the coupling capacity is equal to the impedance of the secondary antenna. Then all energy will be transferred from the primary antenna to the secondary as a tuned short circuit has been formed across the primary antenna by the combination of coupling capacity and secondary antenna.

(c) The reactance of the coupling capacity is larger than the impedance of the secondary antenna. As the voltage drop must be continuous along the coupling reactance and greater than that across the secondary antenna, and, as the difference between the two equals the primary antenna voltage, it follows that the primary and secondary antenna voltage are 180 degrees out of phase.

Condition (1) has no detrimental effect from an energy standpoint.

Condition (2) is undesirable as it may happen that (a) the secondary antenna may constitute too great a branch of the tuned circuit of the primary antenna; (b) the energy dissipation is almost entirely transferred to the secondary antenna; (c) the radiation of the primary antenna is considerably neutralized by out-of-phase currents in the secondary antenna.

Thus it can be seen that while Condition (1) in most cases would be desirable as it corresponds to a greater combined antenna system of consequently lowered resistance, this condition is always accompanied by Condition (2), and thus it is necessary to employ means of neutralizing the effect of the coupling between the antennas.

In long wave transmitters, the methods of controlling the antenna energy for signaling depend at least partially on the principles of detuning. Through this action, the keying of one antenna influences the keying of the other in a detrimental manner.

As the coupling is capacitive, it would be most logical to balance this by another capacitance, but unfortunately, the physical conditions of the circuit prevent this procedure. The capacity of the coupling has, instead, usually been neutralized by paralleling the capacity with an inductance, thus forming a parallel-tuned circuit of high impedance between the two antennas. Another method of uncoupling is to introduce an opposing voltage in one antenna from the other by means of neutralizing transformers. Should it be desirable to completely neutralize for both frequencies, the two methods may be combined. It has been found sufficient to use one of the two methods, and, in America, the shunt tuning of the coupling capacity has generally been used.[6]

Best results have been obtained by having this circuit tuned to a frequency midway between the two antenna frequencies. In this case, the impedance of the uncoupling circuit and the secondary antenna will always be either both capacitive or both inductive and thus insure against opposing phase relations between the primary and secondary antennas. Also, the effect between the two has been greatly reduced, due to the increase in impedance across the uncoupling branch.

Transmission Lines

It is often desirable to locate the antenna at some distance from the transmitter. This is especially true in the case of multiplex stations. Transmission lines will then be required to connect up the antenna with the transmitter. If the physical length of the line is small compared to the wavelength, almost any kind of connecting link forming part of the antenna circuit may be used. The line may either be arranged to feed the antenna in shunt or series. When the physical length of a line becomes great compared with the wavelength used, more specific methods have to be resorted to in order to transfer the energy efficiently and without undesirable tuning phenomena. When a line of these proportions is energized and tuned for the transfer of energy, there is one optimum adjustment at which the transfer takes place with a minimum loss of energy. This adjustment may be called the unity power factor adjustment of the line. At this adjustment—provided we have a perfect line—the current is the same throughout the line, showing the non-existence of standing waves. As is well known, a standing wave of any kind is caused by two waves traveling in opposite directions. In the transient state of charging a line, there are only traveling waves, but, when these reach the end of the line, if they are not perfectly absorbed by correct loading resistance, the remaining energy is stored up magnetically or electrically, as the load resistance is too small or too large to absorb the energy in a given time. This stored energy is then reflected back, due to the electromagnetic pressure caused

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[6] Multiple Antenna Installation, by Dr. A. Meissner. Telefunken Zeitung, January, 1923.

by storing up the energy into the elastic medium surrounding the wires. Thus, in sending the energy back again over the wire, an extra and unnecessary loss takes place. Standing waves occur and, after the steady state has been reached, the line assumes a certain impedance at its ends which depends on its length in relation to the wavelength and often these impedances are of inconvenient magnitudes to fit in with the rest of the circuit. Standing waves can never occur on an infinitely long line as the energy will never reach its end to be reflected. When the load end of a line of finite dimensions is adjusted so that all incoming energy is absorbed and none reflected, this corresponds to making the line infinitely long.

In the case of a perfect line, it may be of interest to conceive the following interesting fact. If a direct-current source be connected to a line of infinite length, a steady current will continuously flow into the line. The amount of current will depend upon the balance between the capacity and inductance of the line. Thus its ability to take a charge and pass it along. If we measure the voltage of the source and the current it delivers into the line, the quotient between the two gives the impedance of the load and this is called the surge impedance of the line. If we were facing four terminals in the laboratory and were told that across two of them was connected a resistance and across the other two was connected a transmission line infinitely long, with no conductor or leakage resistance, it would be a physical impossibility for us to determine by any means of measurements (direct current or radio frequency), to distinguish between them.

The surge impedance of a line without conductor or leakage resistance is the square root of the quotient between inductance and capacity for any length of the line: for a well-built line and of the dimensions conveniently used, this is sufficient for practical considerations. For a line consisting of two wires, each one-quarter of an inch in diameter and a foot or so apart, the surge impedance is of the order of six hundred ohms.

From the previous outline of the principles involved, it is evident that reflection free load of a line is obtained when the load impedance equals the surge impedance of the line as the charge will enter an impedance which is of the same value as if the line were infinitely long. The energy then is received and absorbed at the same rate as it is delivered and no reactive storage of energy takes place.

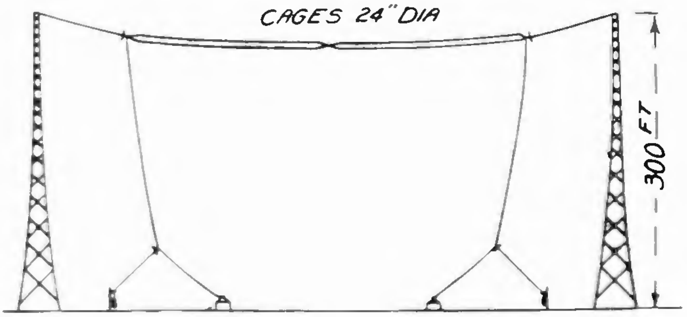
It has been found by Mr. Kroger and Mr. Lindenblad, of the Radio Corporation, that the insertion of a transmission line, whether of natural or artificial form, is an excellent means of coupling circuits, together which, by direct magnetic or capacitive coupling, would separate into two degrees of freedom; that is, assume two tuning points.

In the practical arrangement for connecting up a radio frequency transmission line, it has been found advantageous to employ transformers of high magnetizing reactance and equipped with grounded grid type shields between the primary and secondary windings. This tends to prevent uncontrollable standing waves resulting from electrostatic pick-up. Sometimes, when the field from the antenna is great in the vicinity of the line, it pays to run frequently grounded shield wires above the transmission line. It is not necessary to build a transmission line straight, as practice has proven that negligible disadvantages result from bends, provided they are not too sharp nor too frequent.

The correct impedance from the antenna loading circuit can be obtained in several ways. For instance, the secondary of the line transformer may be tapped to the point on the tuning coil which corresponds to this impedance. Another arrangement which provides a wider range of adjustments is to make the antenna tuning unit in two parallel branches and connect the secondary of the line transformer in series with one of the branches. The inductances may be varied so that the correct impedance is obtained. In adjusting a line after approximate values have been obtained from calculations and test, it is sometimes of value to insert three ammeters in series in the line, and spaced a quarter of a wavelength apart. When the three meters read alike, the line is working at the correct loading. It is readily understood that with two meters at any spacing, equal values can be obtained even if standing waves are present as the meters may accidentally be placed symmetrically in relation to the standing wave.

ANTENNAS AT THE DEVELOPMENTAL BROADCASTING STATION AT SCHENECTADY

The problems in connection with the design of these antennas were very different from those in connection with antennas for a commercial station. One of the main objects in connection with the Developmental Station was to compare the relative characteristics of various wavelengths from 4,000 meters to the shortest for broadcasting purposes. The antenna erected to cover the range from 4,000 to 1,000 meters is shown in Figure 16. The principles which had been found applicable to long-wave antennas were found to be substantially correct for this antenna. The measured values of the essential characteristics checked very closely the calculated values. The antennas at the station which cover the range of wavelength from 1,000 meters to the shortest are of several different types and the fundamentals of these types are being established. Figure 17 shows a plan of the station property and the location of the supports for the various antennas.



ANTENNA No 5
RANGE 3000 TO 1000 METERS
DEVELOPMENTAL BROADCASTING STATION
SCHENECTADY, N. Y.
FIGURE 16

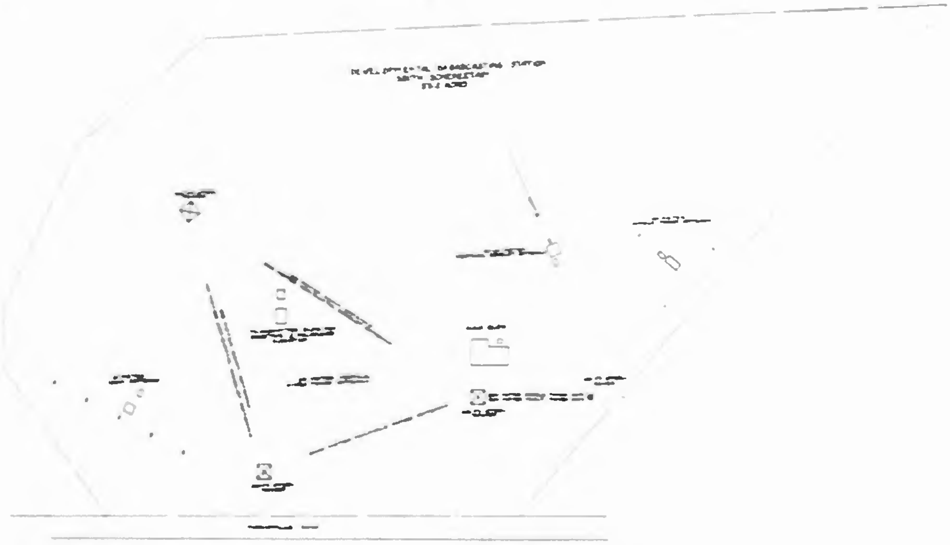


FIGURE 17—Arrangement of Buildings, Towers and Antennas, Developmental Broadcasting Station, South Schenectady

In order to determine the radiation efficiencies and directive properties of these antennas, a portable field intensity instrument, Figure 18, was developed by the General Engineering Laboratory. This operates on the tube voltmeter principle. The instrument is calibrated in the laboratory in a field of known intensity. The scale readings taken in the field times a correction factor for different wavelengths, scale corrections, etc., gives directly the field intensity in microvolts per meter. Provision is made to check in the field the power factor of the resonant circuit, which has been found desirable when field measurements are made in adverse weather conditions. This type of instrument with suitable loop and condenser elements has been used at 1,600 380, 100 and 50 meters.

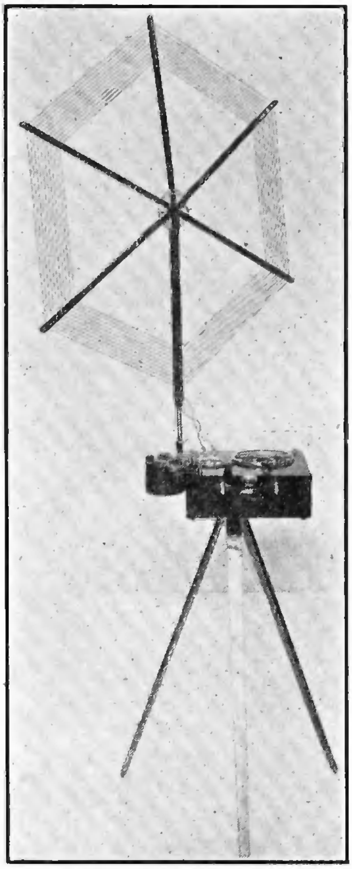
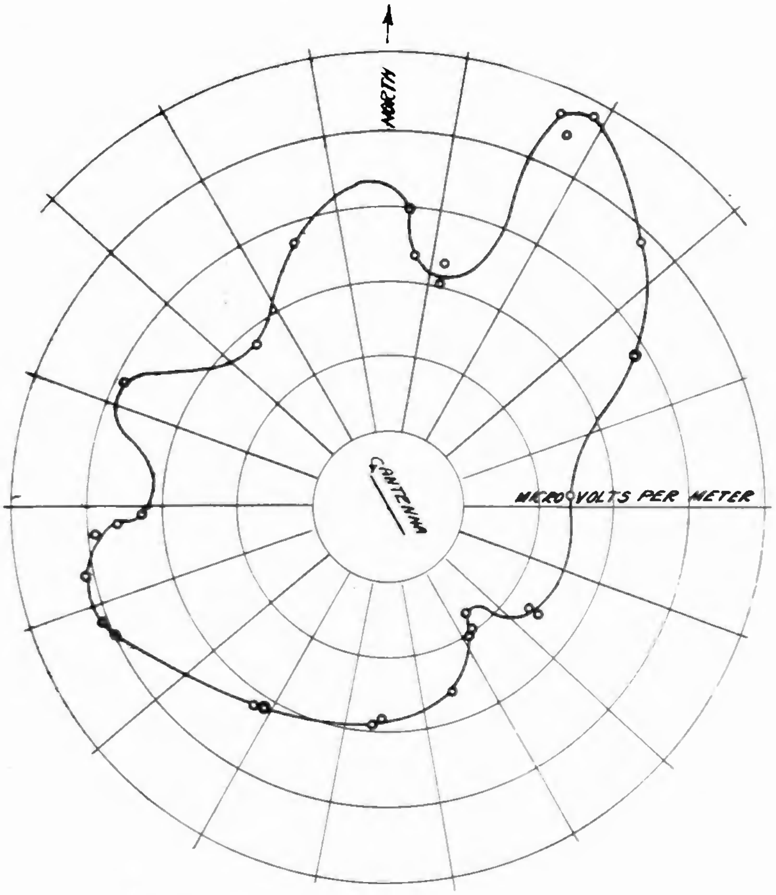


FIGURE 18

In measuring a field intensity pattern of an antenna, a contour map of the surrounding country is invaluable. Circles are drawn on the map at different radii, with the transmitting antenna in the center. The points at which roads cross these circles are chosen as the points at which field intensities are to be measured. It has been found that local conditions at the points measurements are taken influence the field intensities at those points. The most reliable measurements are made in level, open country, at least one wavelength away from power transmission lines, telephone lines, ravines or high banks, buildings, etc.

Figure 19 shows the pattern at 5 kilometers distance from the

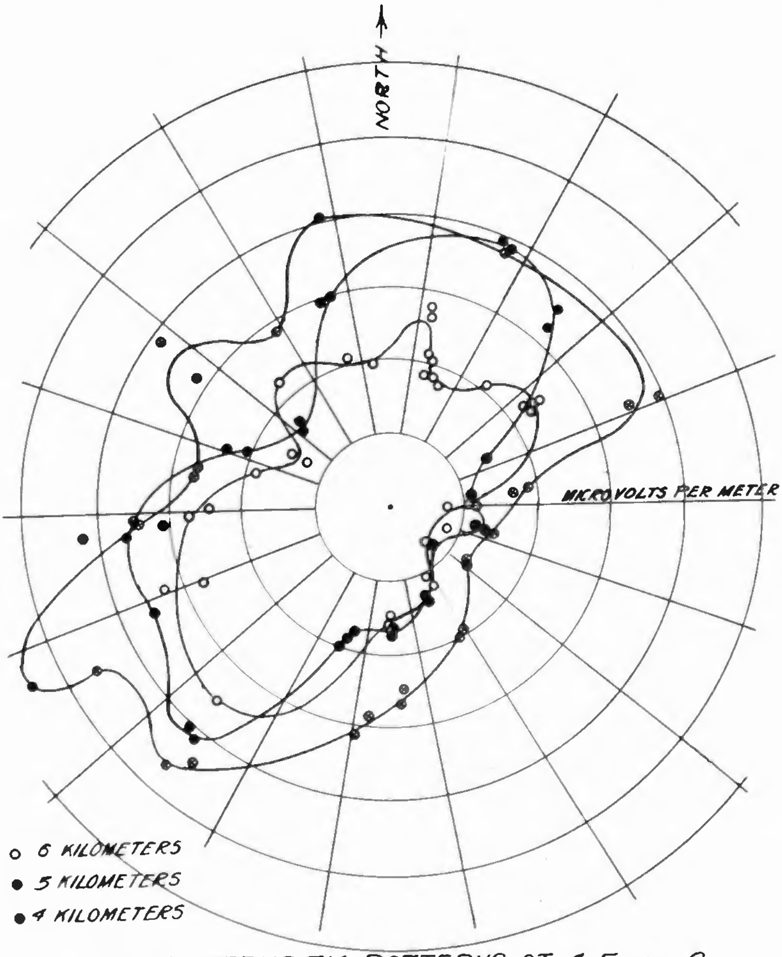


FIELD INTENSITY PATTERN AT 5 KILOMETERS
WGY ANTENNA AT SCHENECTADY, N Y
WAVELENGTH 379.5 METERS

FIGURE 19

antenna regularly used by WGY. The abrupt irregularities are largely due to local conditions at the points measurements are made. The regular pattern, as determined by several series of measurements, is slightly ellipitical with the major axis NE by SW. This is at right angles to the length of the antenna, which is multiple tuned.

Figure 20 shows a family of patterns of field intensities measured at 4, 5 and 6 kilometer distances from Antenna No. 15 at the Developmental Broadcasting Station. These patterns show the effect of local conditions on the intensities measured. The antenna was a vertical cage, operating at 380 meters. The cage was supported by a steel cable suspended between two steel supports, each 300 feet high, which were grounded. The steel cable was sectionalized by insulators.

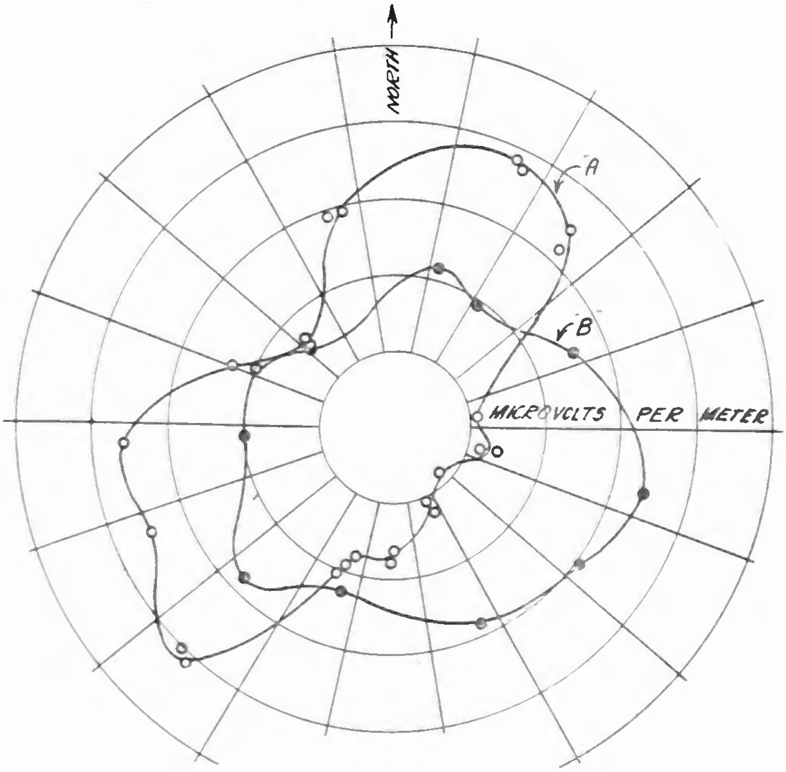


FIELD INTENSITY PATTERNS AT 4,5 AND 6
KILOMETERS ANTENNA NO. 15 AT DEVELOPMENTAL
BROADCASTING STATION, SCHENECTADY, N.Y. λ=379.5 METERS.

Figure 20

Figure 21, Pattern "B," shows the intensities measured at 5 km. from the same Antenna No. 15, the only essential difference being that this pattern was taken with the cage supported by non-conducting manila rope. Pattern "A" in the figure is the same as the 5-km. pattern in Figure 20. This antenna, supported by manila rope, is one which has been used by WGY with super-power.

Figure 22 shows the pattern at 5 km. from Antenna No. 5, which is the antenna used with super-power broadcasting at 1,560 meters. This is a multiple tuned type supported between two 300 foot grounded steel towers, shown in Figure 16.



FIELD INTENSITY PATTERNS AT 5 KMs.
ANTENNA NO. 15 DEVELOPMENTAL BROADCASTING
STATION, SCHENECTADY, N.Y.
λ = 379.5 METERS.

Figure 21

Conclusions

This very general treatment of the complicated problems of antenna design is intended to explain how these problems are attacked and, to a large extent, have been solved. The reduction of resistance of high-power, long-wave antennas to a value considerably less than one-half ohm has introduced two problems: One pertains to a limitation of speed of signaling: the other to the increased sensitivity of tuning. The lower the resistance and power factor of an antenna, the greater is the effect of its electrical inertia, which opposes rapid signaling. This problem is of considerable importance at the present time, and is being investigated. The tuning of an antenna having a power factor of the order of 0.0015 is so sharp that small changes in capacity, due to wind, reduce the antenna current very appreciably. An automatic antenna tuning device has been developed which maintains correct tuning when the changes are not too rapid. This device is being improved to operate more rapidly.

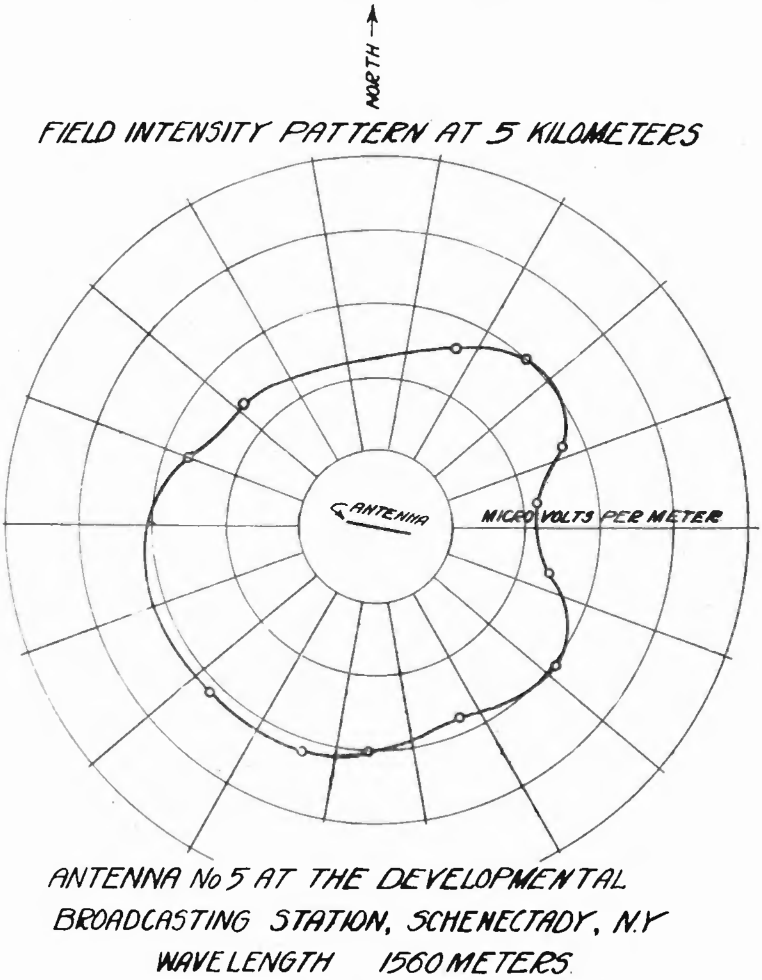


FIGURE 22

In the field of relatively small antennas which operate at powers and wavelengths suitable for marine service, broadcasting, etc., the investigations to determine how accurately the principles applied to long-wave antennas can be applied to these, are well under way at the Developmental Broadcasting Station at Schenectady.

MAINTAINING A CONSTANT READING ON AN AMMETER IN THE FILAMENT BATTERY CIRCUIT OF A THERMIONIC TRIODE*

By

E. H. W. Banner, M.Sc.,

I.—INTRODUCTION

The trouble experienced in determining what is a constant filament current is stated at length in a paper read before the Institution of Electrical Engineers (Wireless Section) on March 16, 1921.—"The Effect of Electron Emission on the Temperature of the Filament Anode of a Thermionic Valve," by G. Stead, M.A. (volume 59, page 427). Most of the speakers in the discussion emphasized the point and no satisfactory solution was arrived at. The present research was undertaken with the idea of supplying a solution to the problem.

11—An Experimental Determination of a Means of Maintaining a Constant Reading on a Filament Ammeter

If the filament of a thermionic triode is connected to a suitable supply, and the grid and anode are both insulated, an ammeter placed in any part of the circuit will read the same current. Figure 1 shows this, and two ammeters are connected, one in the positive and one in the negative lead. When the valve is in use, either oscillating or not, the filament emission causes an alteration in the two ammeter readings, the alteration depending on the method of connection of the anode circuit to the filament circuit.

Figure 2 shows one of the usual methods of connection, in which the two negatives are connected together. Through these tests the grid and anode were connected together in order to obtain a maximum emission from the filament. Figure 3 is a common alternative, showing the anode battery negative connected to the filament battery positive.

It is found that on switching on the anode battery the reading

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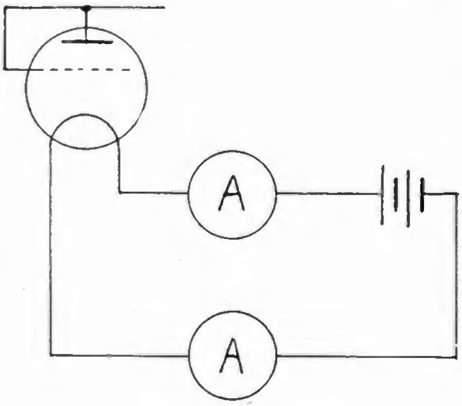

FIGURE 1

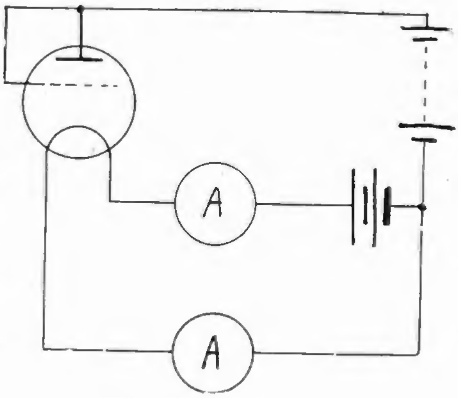

FIGURE 2

of the negative ammeter increases and the positive decreases for both the above methods of connection. Figure 4 is similar to Figure 3 except that the connection is made to the filament side of the ammeter. In this case both readings increase. Lastly, Figure 5 shows the anode battery connected to the filament side of the negative ammeter. Now both readings decrease on switching on the anode battery.

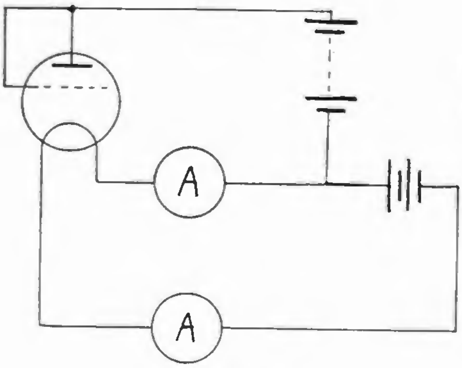

FIGURE 3

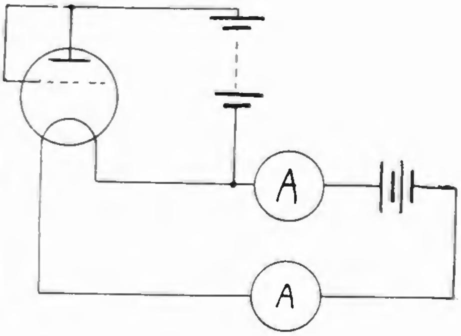

FIGURE 4

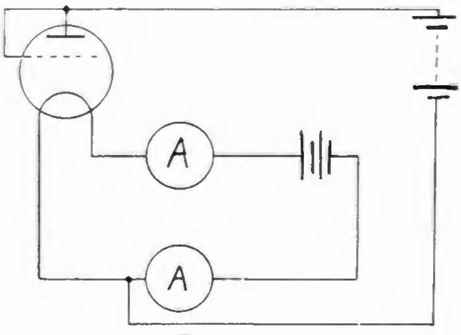

FIGURE 5

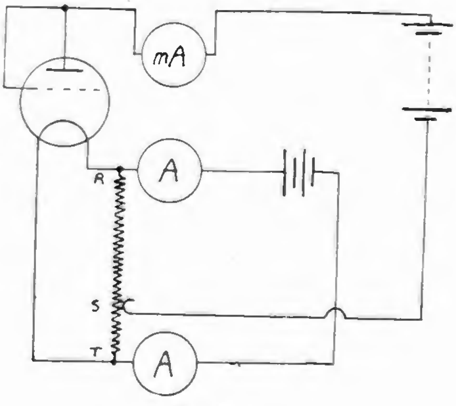

FIGURE 6

This states the case as generally accepted, that the switching on of the anode battery makes it impossible to maintain the filament current constant, and a statement that the filament current was constant during any particular test is void unless the method of connection and the position of the ammeter are stated, at any rate for accurate work.

This investigation was commenced with the object of finding if any position of the ammeter, and a method of connecting the anode battery, was possible, so that the ammeter reading would be unaffected by any variation in the anode circuit.

TABLE I.

Figure 2	Negative ammeter reading increases.	Positive decreases
3	Negative ammeter reading increases.	Positive decreases
4	Negative ammeter reading increases.	Positive increases
5	Negative ammeter reading decreases.	Positive decreases

Comparing the cases shown in Figuers 4 and 5, it is seen that the two extremes are met, and it appeared possible to obtain a mean position between these cases so that both ammeter readings would be constant.

The circuit of Figure 6 was then wired up, using a slide potentiometer-rheostat RT with a tapping at S variable between R and T. When S is at R, Figure 4 is reproduced, and when at T, Figure 5.

A test was then commenced to endeavor to find a position for S so that an ammeter in the circuit would indicate a steady amount. As the anode current for these tests was about 7 milliamperes and the filament current about 0.7 ampere the effect of adding the two is to increase the current from about 0.700 to 0.707 ampere, an increase of 1 percent. This is a small proportion and the usual forms of measuring instrument are too insensitive to indicate a change much less than about 1 percent with ease. In order to be able to state that the filament current is constant it is therefore not sufficient to state that the ammeter reading is constant as a change of 1 milliampere is not shown, and it is necessary to detect a smaller quantity than this in order to state that the current is constant.

It will be seen, therefore, that it is necessary to be able to read a change in current at least of the order of 0.11 percent or 1 in 1,000. No indicating instrument that will read this was available, and so as an indicator a reflecting galvanometer was arranged to project its light spot on to a wall about two meters from the mirror. The terminals were short-circuited by a piece of bare copper wire, the actual length being adjusted by trial. For the test the circuit of Figure 6 included the short-circuited galvanometer in series with one of the ammeters. It must be noted that the galvanometer deflection was not used for measuring current, but only for detecting a change of current. The galvanometer, in effect, is used as in a null test, the steady filament current merely displacing the zero. In this way the various instrument errors are eliminated. The short-circuit was adjusted to give a steady deflection of about two meters on the scale, or rather on the wall, as the galvanometer had been moved back from its normal position to about two meters, and the deflection was off the usual scale. The other ammeters in circuit were only used for approximate readings, as nothing better than a first-grade instrument was available for current measurement in the author's laboratory. The filament was then switched on to a 4-volt accumulator and when the light spot had come to rest, the anode battery was switched on. When the slider was near the negative end, the deflection decreased and when at the other end, an increase was observed. This only confirmed the preliminary rough tests. The slider was adjusted until on switching on the anode battery no change of deflection occurred. It was possible to read a change of 1 millimeter, and as the deflection was two meters, the sensitiveness was of the order of one in 2,000, which is within the limit attempted (1 in 1,000). This means that with the slider at the point found, the change of current for a filament current of 0.7 ampere was not greater than 1 in 2,000×0.7 or 0.35 milliampere. With an even more sensitive arrangement the point of balance might be found still closer, if desired, but the change is very small in the region of no deflection and so a slight alteration in the slider position is negligible.

It was then necessary to find the position of the slider with respect to the filament battery, and so the ratio $\frac{S\,T}{R\,T}$ was measured. This was found to be 0.17, or practically $\frac{1}{6}$. (A later test with a ratio of $\frac{1}{6}$ proved satisfactory.) It was not obvious if this ratio would prove to be constant under different conditions, and so two further tests were carried out. The anode battery voltage was reduced to about half the previous value, other conditions remaining constant. No change in the deflections was observed. Secondly, a reduced filament current was used and finally a different valve. The spot showed no change on switching the anode battery on and off in each case, showing that the ratio of $\frac{1}{6}$ was satisfactory and constant for different conditions of the circuit.

The first test was repeated with the galvanometer in the other lead, and similar results were obtained, as was expected from a study of Figure 6 as the two ammeters are in series with no branch circuits between them and the battery.

III—AN INVESTIGATION INTO THE DISTRIBUTION OF CURRENT IN A TRIODE CIRCUIT

As a further check it was considered desirable to check the currents all round the circuit, and as the author's laboratory was limited in its stock of instruments, the work was concluded at the University of Birmingham with permission of Professor W. Cramp.

The triode was connected up as Figure 7, ammeters being placed in each filament lead and in each battery lead. With the circuit *RT* broken, the four ammeters *A*1, *A*2, *A*3, and *A*4 were in series and their readings were taken for different values of current in order to calibrate the remainder against *A*1, which was known to be the most accurate.

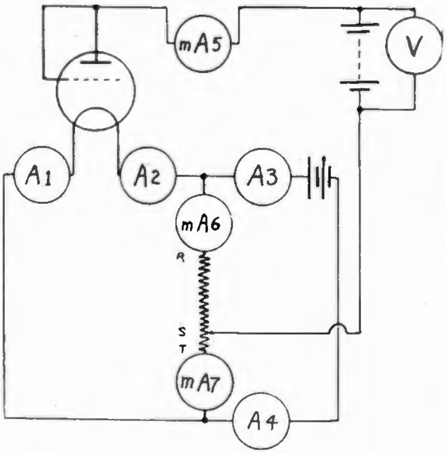

FIGURE 7

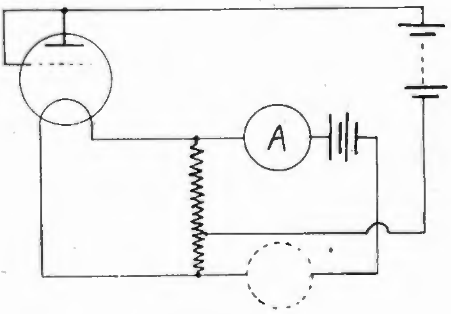

FIGURE 8

The milliammeter in *A*5 read the emission current and was in series with the anode battery. Milliammeters *mA*6 and *mA*7 read the steady current thru the resistance *RT* when the anode battery was disconnected. Finally, an electrostatic voltmeter read the anode battery voltage.

Readings were taken on all instruments under the following conditions:—

(1) Filament Circuit only made.

(2) Filament and resistance *RT* connected.

(3) As (2) with the anode battery on.

(4) As (3) but with ratio changed to $\frac{1}{5}$.

(5) As (3) but with ratio changed to $\frac{1}{7}$.

(6) Tests (2) and (3) with a 6-volt battery and rheostat.

(7) Tests (2) and (3) with reduced filament current.

(8) Tests (2) and (3) with a reduced anode voltage.

The first three tests are the important ones, and a summary of their readings, corrected for instrument errors, is given in Table 2.

TABLE 2

Test—Instrument Readings

Test	*A*1	*A*4	*A*2	*A*3	*mA*6	*mA*7	*mA*5	*V*
(1).......	0.670	0.670	0.670	0.670				
(2).......	0.670	0.676	0.670	0.676	6.52	6.52		
(3).......	0.672	0.676	0.666	0.676	7.53	1.26	6.39	82.5

and {
*A*1 and *A*2 are Filament Ammeters
*A*3 and *A*4 are Battery Ammeters
*A*2 and *A*3 are Positive
*A*1 and *A*4 are Negative

Readings for the subsequent tests are given in Table 3.

TABLE 3

Test	*A*1	*A*4	*A*2	*A*3	*mA*6	*mA*7	*mA*5	*V*
(4).......	0.671	0.676	0.665	0.676	9.00	2.88	6.09	81.0
(5).......	0.674	0.676	0.668	0.676	6.45	0.35	6.09	81.0

(6) No change
(7) *A*1 reduced to 0.400 Ampere. No change.
(8) *V* reduced to 47.0 Volts. No change.

OBSERVATIONS

In test (1) all four ammeters read the same, when corrected for instrument errors, as expected. In test (2) the readings of the battery ammeters increased slightly owing to the current in *RT*. Very careful observation was necessary to detect the change, which was less than 1 percent of the reading. The current through *RT*, as read on *mA*6 and *mA*7 was the same.

Test (3) confirmed roughly the result obtained in the first part of the research, that is, that the battery ammeters maintained a constant reading when the anode battery was switched on. It further showed that the distribution of current thru *RT* was altered on connecting at the point *S*. Tests (4) and (5) were further confirmations of the experimental result found earlier, that the ratio $\frac{S\,T}{R\,T}$ should be $\frac{1}{6}$. Test (6), using a 6-volt battery and a rheostat in series to maintain $A1$ constant as before, showed no change from test (3). For test (7) the current as read on $A1$ was reduced and again no change ensued on $A3$ and $A4$.

Finally test (8) showed that the ratio is independent of the anode voltage used. This may be summarized as follows:

When an ammeter is connected in either battery lead and the anode battery is connected as shown in Figure 7, no change in the ammeter reading occurs after switching on the anode voltage with

(1) Different filament battery voltage.
(2) Different filament current.
(3) Different anode voltage.

The actual resistance of RT may be varied provided the ratio is constant. In the first tests it was 850 ohms, and in the latter 600 ohms. It should be high in order to reduce the loss of power in it and to make the battery ammeter read as little as possible more than that used in the filament-anode circuit. If the resistance is too high, it is possible that the unequal currents at each end may heat up the resistance sufficiently to alter the ratio. This is not likely if the resistance is of the order of a thousand ohms and made of wire, not a carbon line. Figure 8 shows the final connections using one ammeter only. This may be in either the positive or the negative lead, as shown.

SUMMARY: The distribution of current along the filament of a thermionic valve is not constant on account of the emission which takes place from the filament to the anode.

When the valve is not emitting, ammeters in each filament lead read the same value, but when emitting they are necessarily different, and for the usual methods of connection between the anode battery and filament they are also both different from the non-emitting reading.

For accurate tests it is necessary to have a constant reading for comparative tests, and as the filament current cannot be maintained constant, a circuit has been devised in which there is no change on either ammeter reading when the anode battery is switched on.

This is the filament battery current, which, when constant for the cases of non-emitting and emitting, provides a standard for comparison between different tests.

PORTABLE RECEIVING SETS FOR MEASURING FIELD STRENGTHS AT BROADCASTING FREQUENCIES*

By

Axel G. Jensen

(Bell Telephone Laboratories, Incorporated, New York)

In a paper by Bown, Englund and Friis on "Radio Transmission Measurements," there are described several different methods of measuring radio signals and some of the sets for making these measurements are described in detail. The rapid growth and the increasing importance of radio broadcasting has since made it desirable to construct an improved form of measurement set for use in the field, and the purpose of the present paper is to describe such a set which has recently been developed in the Bell Telephone Laboratories and which is now being used by the American Telephone and Telegraph Company for field strength surveys, etc. A portable measurement set for this type of work was in fact described in the above-mentioned paper and several sets of this type have been in use for the last couple of years, but in order to emphasize the improvements made in the latest type of measurement set there is given, in the following, a very short description of this first portable set. The set itself is shown in Figure 1 and a schematic diagram is given in Figure 2.

The receiving set unit is a double detection set provided with a sensitive meter in the plate circuit of the low frequency detector and the first part of a measurement consists in tuning in the signal to be measured and adjusting the gain of the receiving set so as to obtain a suitable signal reading on the detector meter. Next, the local signal oscillator is started and adjusted to the same frequency as that of the signal by zero beating, after which the loop is cut out of the circuit and the input shunt adjusted so as to give the same meter deflection as before, which means that the local signal voltage impressed upon the grid of the high frequency detector is the same as the voltage across half the loop

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†Proceedings of The Institute of Radio Engineers, Volume 11, number 2, April, 1923.

*Received by the Editor, March 15, 1926. Presented at a meeting of the Institute of Radio Engineers, New York, April 7, 1926.

due to the signal. This voltage is equal to the voltage across the entire non-inductive input shunt, as measured by a tube voltmeter, multiplied by the step-down ratio of the shunt; and by dividing this voltage by half the step-up ratio of the loop we obtain the voltage induced in the loop by the signal. The step-up ratio of the loop is given by the ratio of ωL over R, in which L is the inductance and R the resistance of the loop. This ratio is thus a measure of the resonance effect of the loop, giving the voltage E across the loop at resonance as $\omega L/R$ times the voltage e induced in the loop. This loop voltage e gives the field strength on division by the effective height of the loop. The effective height of the loop is a function of its geometrical proportions and the frequency, and may be determined once for all. The calibration of the tube voltmeter will stay constant for a considerable time, but the determination of the loop step-up is inconvenient, especially in a set intended for field use. In order to find the loop-

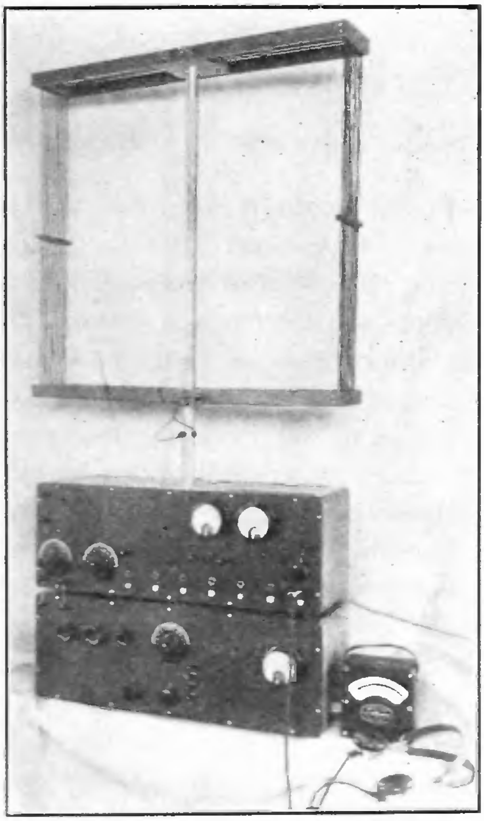

FIGURE 1—Early Model of Portable Field Strength Measuring Set for Wavelengths from 200 to 500 Meters

step-up it is necessary to determine the distributed capacity and the inductance of the loop, and the resistance of the loop as a function of the frequency. The first two quantities will remain practically constant for any given loop, and the resistance of the loop will remain sufficiently constant for a considerable

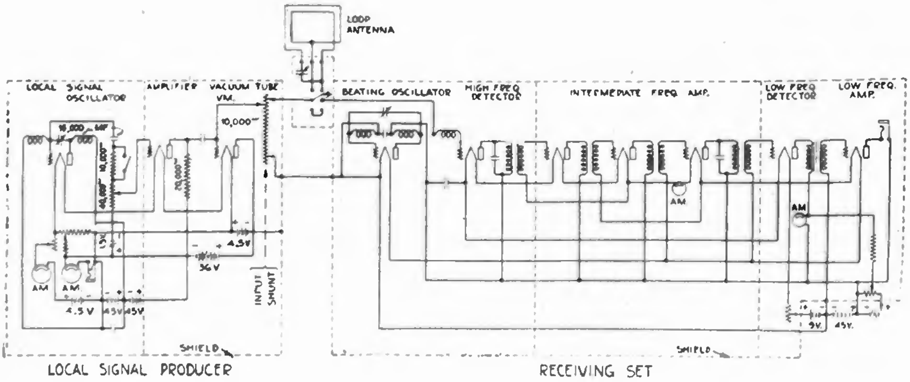

Figure 2—Schematic Circuit Diagram of the Set Shown in Figure 1

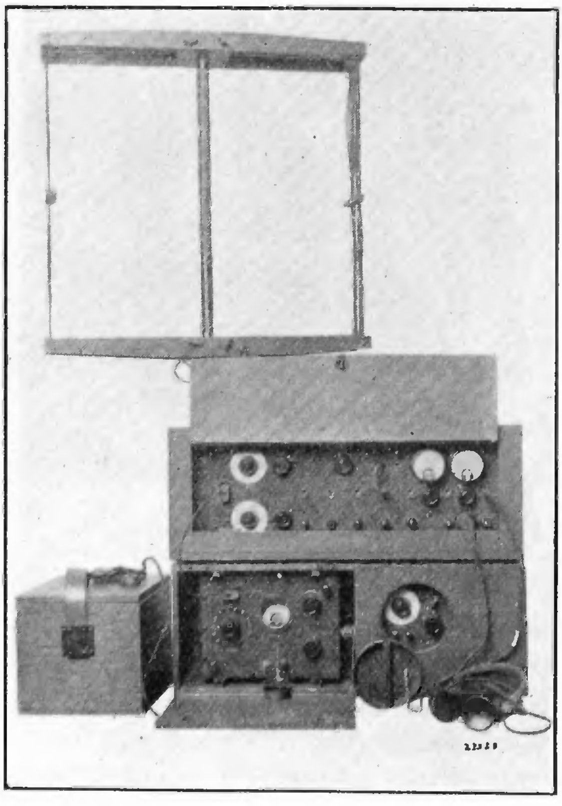

Figure 3—Latest Type of Portable Field Strength Measuring Set

length of time, as long as the set is used only in the laboratory and is not exposed to the weather. In a set for field use, however, it has been found that the loop resistance changes considerably with the weather, so that in order to avoid errors it is necessary to measure this resistance several times a day during the use of the set, especially under bad weather conditions. This is, of course, very inconvenient and causes quite a loss of time, and the main problem in designing the new measurement set has, therefore, been to develop a method by means of which this calibration of the loop might be avoided.

FIGURE 4—Field Strength Measuring Set in Operating Condition in the Field

Such a method, already in use for several years, is described in connection with measurement sets for long wave length in the paper mentioned above, and it was decided to try to adapt this method to shorter waves also.

In doing this it was necessary to modify the input circuit somewhat in order to make the set more compact and also in order to avoid "pick-up" at these higher frequencies, but the general principle is the same as that used in the earlier long wave measurement sets referred to.

The set is shown in operating condition in Figures 3 and 4 and details of the set are shown in Figures 5, 6, 7 and 8, while Figure 9 gives a schematic diagram of the entire set. Referring to this diagram it is seen that, as before, the receiving set is in principle a double detection set provided with a microammeter normally connected in the plate circuit of the low frequency detector and used for indicating the signal received. This meter may, however, also be used for testing the plate current of any of the other tubes by inserting a patch-cord between the meter jack and the plate circuit jack for the tube in question. Also a separate jack marked "meter" is provided for plugging in an external instrument instead of the meter permanently mounted in the set. The plug marked "stage shifter" is always inserted in one of the three jacks, 1, 2 or 3 when the set is in use, the corresponding number of stages of intermediate frequency amplification in operation being 1, 2 and 3, respectively. Finer variations in the gain of the set are obtained by varying the value of the resistance marked "gain control," which is shunted across one of the intermediate frequency transformers. The oscillator coil is wound in toroidal form in order to prevent any direct coupling between the coil and the loop, as such coupling would result in a beating oscillator voltage, impressed upon the grid of the high frequency detector, which would vary with the position of the loop, thereby making the measurements inaccurate.

The potentiometer shown in the diagram directly under the plate current meter is used for balancing out the initial plate current of the low frequency detector, in order that the entire scale of the meter may be made useful for indicating the increase in current due to a signal impressed upon the grid of the detector tube.

The power supply for the filament and plate circuit of the receiving set is a dry cell combination contained in a special battery box, which may be seen in the left part of Figure 3. From the same figure it will be seen that the loop is made with flexible wire and is collapsible in order to facilitate transportation.

A patch-cord is used for connecting the middle terminals of the loop to the terminals on the input box, thereby closing the loop circuit through a known resistance of normally one ohm. This resistance is located in the input box and is further described below in connection with the input potentiometer.

The local signal equipment is shown in the lower part of the diagram in Figure 9, and consists of two separate units, namely, the oscillator unit and the input unit. The input unit is contained in a metal box shown in the left half of the lower box in Figure 3, and the oscillator is contained in a similar metal box, part of which may be seen in the same figure through the hole in the right half of the lower box.

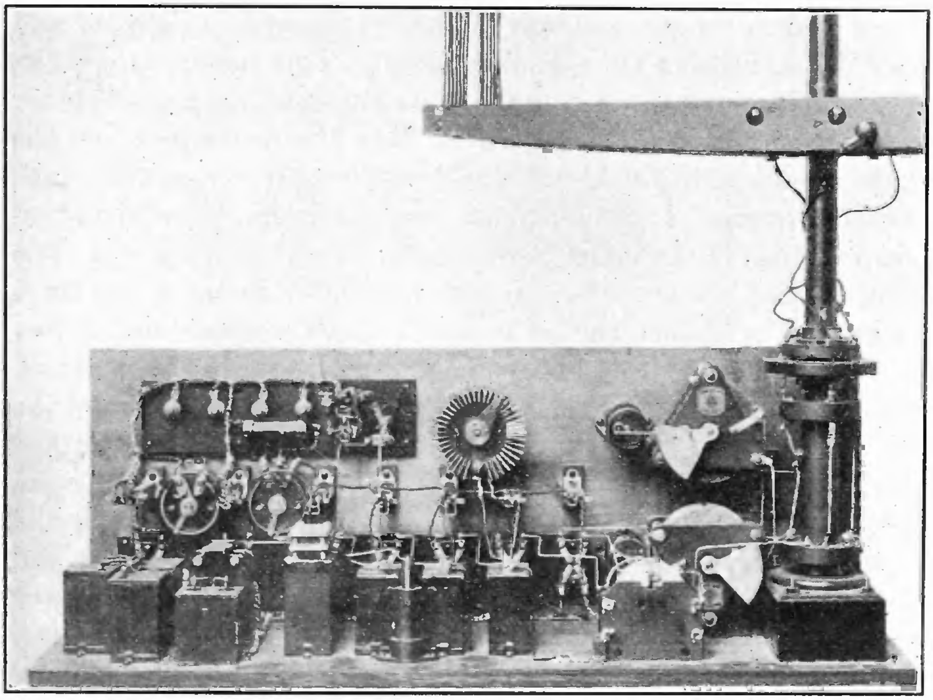

Figure 5—Rear View of Receiving Unit

During an actual measurement this hole is tightly closed by a metal cover, ground to fit, thus completely closing an outer metal box formed by a heavy copper lining on the inside of the compartment containing the oscillator box. The leads from the input unit to the oscillator unit are enclosed in a heavy copper tube connecting the input box with the outer box of the oscillator unit and are connected to the two terminals shown on the oscillator panel. The inner oscillator box is mounted insulated in the outer box and is connected to this only at one point, namely through one of the two leads connecting the input unit and the oscillator unit, this lead forming a direct connection from the inner oscillator box to the input box and thus, through the copper tube, back to the outer oscillator box.

This double shielding of the oscillator unit is absolutely essential in order to avoid any direct "pick-up" from the local signal oscillator by the loop. Without careful shielding this "pick-up" voltage may easily be larger than the voltage to be measured, thus making the measurements worthless. The oscillator coil is, of course, also wound in toroidal form in order to make its external field as small as possible, and the power supply for the oscillator consists of dry cells contained in the oscillator box itself, since any outside battery connections would increase the "pick-up" considerably. This is shown in Figure 6.

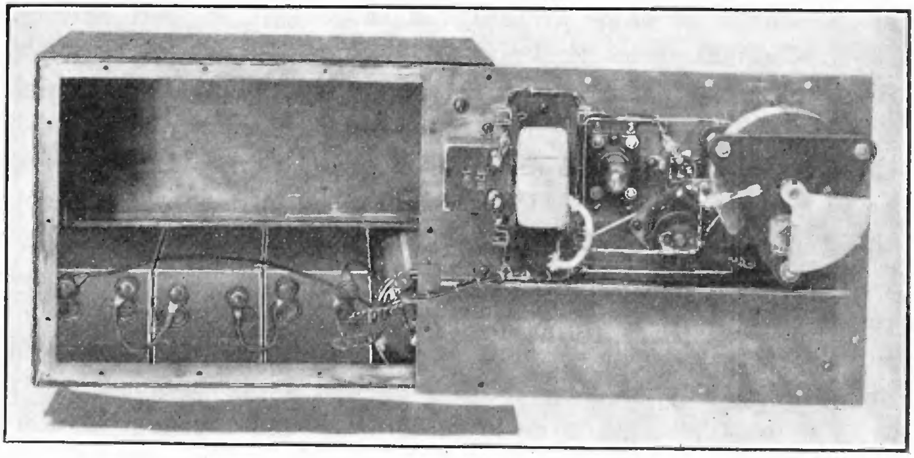

FIGURE 6—Interior View of Local Signal Oscillator Unit

The oscillator is of the Hartley type and the input current is obtained by shunting a high resistance *R* across a small part of the oscillator coil and then tapping across part of the resistance. The current then passes through a smaller resistance *r*, used for fine adjustment, next through a sensitive thermocouple *Th* and finally through the attenuator or current dividing potentiometer *P*.[1]

The values of the resistance in the different units of this potentiometer are given in the diagram, and the units are wound non-inductively (reverse loop-winding) on a hard rubber toroid so that the points *a* and *e* are close together and the points *e* and *c* directly opposite on the toroid, thereby reducing the length of the connecting wires *a b e* and *c d e* to a minimum.

The capacity of such a non-inductive winding is small and the inductance may be calculated by the following formula[2]

$$L = 2l\,(log_e d/p + 1/4 - A)$$

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[1] A description of this potentiometer has already been published in a short note on "Potentiometer Arrangement for Measuring Microvoltages at Radio Frequencies," Phys. Rev. Volume 26, number 1, page 00 July, 1925.

[2] See E. B. Rosa, Bull. Bur. Stand. 4,301 (1907-8).

in which l is the total length of wire, p the radius of wire, d the distance between adjacent turns, and A a constant varying from 0 to 0.45 as the number of turns varies from 0 to infinity. The value of A is 0.25 for a coil of four turns, and it will therefore be safe to disregard the two last terms in the formula, since all the coils in the potentiometer have more than four turns. Applying this formula to the coarsest wire used in the potentiometer, namely No. 36 B & S Advance wire, DSC, we get $d/p=3.5$ and thus an inductance of 2.45 cm. per unit length, while the resistance of the wire is 30 ohms per unit length.

At 750,000 cycles this gives an inductive drop which is 3.5 percent of the resistance drop and thus an impedance which is equal to $\sqrt{1^2+0.035^2}$, or 1.0006 times the pure resistance of the wire. It will, therefore, be seen that the impedance will not be as much as one percent higher than the pure resistance until the frequency is increased to about 3,000,000 cycles.

For the finer wire the relative excess of inductive drop over resistance drop will be still smaller, so that the entire potentiometer will attenuate the current with an accuracy of one percent or better up to frequencies of about 3,000,000 cycles.

The one ohm unit in the output side of the potentiometer consists of a piece of No. 36 manganin wire approximately 3.5 cm. in length and arranged bifilar so that we may use the same formula as before in calculating the inductance. We have here $A=0$ and d/p approximately 5, so that $L=13$ cm. and $\omega L=.06$ ohm at 750,000 cycles. The resulting impedance is thus approximately 1.002 ohm or only 1/5 percent higher than the pure resistance.

The highest current attenuation is obtained with the movable arm of the potentiometer at point f, in which case the output current i is one ten-thousandths of the input current I, and since the thermocouple combination used will measure one milliampere conveniently it is possible to determine voltages down to about 1/10 microvolt with an accuracy of one percent or better.

The following ratios of i/I can be obtained by this potentiometer: .0001; .0002; .0005; .001; .002; .005; 01; .02; .05; .1; .2; .5 and 1.0, and intermediate values of the voltage across the one ohm unit may be obtained by varying the current I. These different ratios were checked, step by step at 750,000 cycles, by using the low-frequency detector in the receiving set as a calibrated tube voltmeter, and in no case was the discrepancy between the calculated value and the measured value found to be more than one percent.

This check shows, at the same time, that direct "pick-up" from the input oscillator to the loop has actually been eliminated.[3] The potentiometer, including the switch, is contained in a separate compartment of the input box, as will be seen from Figure 7, and the potentiometer itself is again enclosed in a separate copper can, which has been removed in Figure 8 in order to show the hard rubber toroid itself. Thus the resistance units are shielded from the switch parts and the one ohm unit in the output is shielded from the rest of the potentiometer. This one ohm unit may be seen in Figure 7 and is connected to the terminals on the panel through a pair of twisted wires. All these precautions in regard to shielding have been found necessary in order to prevent any stray couplings between the different parts of the circuit.

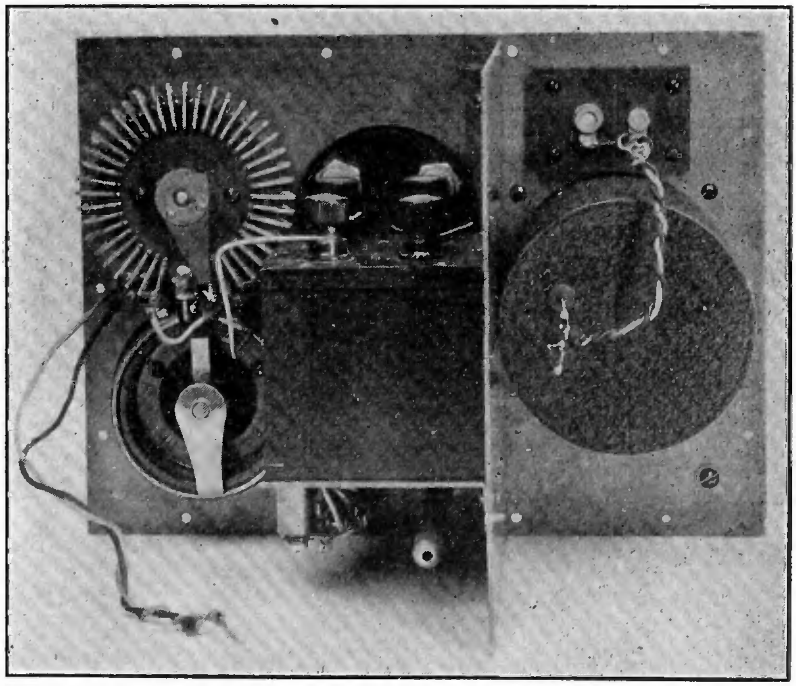

FIGURE 7—Interior View of Input Box Unit

A field strength measurement may now be obtained as follows:

First the signal is tuned in on the receiving set and the gain of the set is adjusted so as to give a suitable reading on the detector meter; next the local signal oscillator is started and by zero

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[3] The increase in resistance due to skin effect is absolutely negligible for the frequencies in question here. Not until the frequency is raised to 15 to 20 million cycles does this increase amount to one percent even for the coarsest wire used in the potentiometer.

beating tuned to the same frequency as that of the signal. Care should be taken here to make sure that the local signal oscillator is not zero beating with some stray signal or with the beating oscillator, and it is found convenient in this connection to watch the detector meter while adjusting the frequency of the local oscillator. When the beat note between the oscillator and the signal becomes very low, *i. e.*, below audibility, the needle on the meter will start moving up and down the scale as the two frequencies pull in and out of phase, thus indicating that the oscillator is being adjusted to the right frequency.

Of course, during this adjustment the input current from the oscillator should be kept low enough so as not to cause any excessive current to flow through the detector meter. The meter deflection is then read, with the local oscillator stopped, after which the loop is turned to minimum position, to eliminate the signal and, lastly, the input current and the attenuating potentiometer are adjusted to give the same deflection on the detector meter as before. We then have an equality between the voltage drop across the one ohm resistance and the voltage induced in the loop by the incoming signal. With a thermocouple current of I amperes and a current ratio $a = i/I$, we thus have for this voltage:

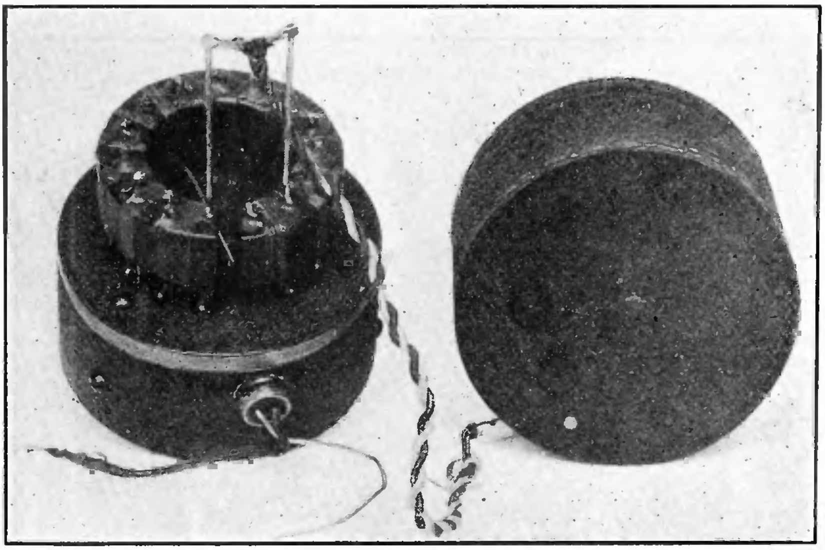

FIGURE 8—Input Potentiometer with Cover Removed, Showing Toroidal Arrangement of Resistance Units

$$e = a \times I \qquad \textit{volts}$$

If the area of the loop is $A\ cm^2$ and the number of turns N, we have for the effective height of the loop:

$$h = \frac{1}{3} \times 10^{-10} \times 2\pi f \times A \times N \qquad cm.$$

f being the frequency of the inductance signal, and the field strength is thus given by:

$$E = \frac{e}{h} = \frac{3 \times a \times I \times 10^{10}}{2\pi f \times A \times N} \qquad volts/cm.$$

or, if we measure the input current I in milliamperes, the frequency in kilocycles and the field in microvolts per meter:

$$E = \frac{a \times I}{f} \times \frac{3 \times 10^{12}}{2\pi \times A \times N} = k \times \frac{a \times I}{f} \qquad microvolts/meter$$

The constant k may be calculated once for all for a particular loop, and the attenuation a is read directly on the potentiometer, so that the only calibrations necessary are a current calibration for the thermocouple and a frequency calibration for the loop condenser or the local signal oscillator condenser. Both calibrations will hold for extended periods, provided the set is not abused or the thermocouple overloaded.

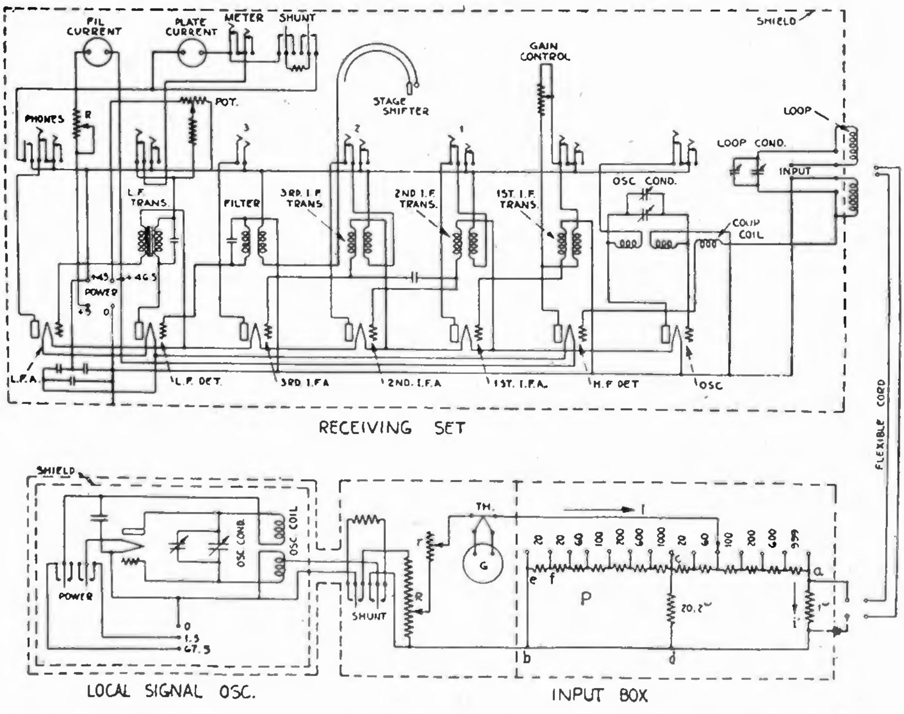

Figure 9—Schematic Circuit Diagram of the Latest Type of Portable Field Strength Measuring Set Shown in Figures 3 and 4

The set in its present form has a field intensity range of about 30,000 to 20 microvolts per meter and a frequency range of approximately 600 to 1,200 kilocycles (500-250). This range may be extended upward to about 150,000-200,000 microvolts per meter by increasing the resistance unit in the output side of the potentiometer correspondingly. A too large value of this resistance will make the potentiometer inaccurate unless the 999 ohms unit is changed also. It would be comparatively easy to extend also the wave length range both ways by making interchangeable oscillator coils, but the potentiometer will not be accurate for frequencies much greater than 1,500 kilocycles (200 meters). It was shown above that the impedance of the one ohm unit at 750 kilocycles (400 meters) is 1/5 percent higher than the direct current resistance; at 1,500 kilocycles (200 meters) this difference will be found to be 1 percent, and at 7,500 kilocycles (40 meters) it has increased to 17 percent. At this latter frequency the impedance of the smallest unit in the potentiometer itself (No. 36 wire) will be about 6 percent higher than direct current resistance, and it is thus seen that the set cannot be used for these high frequencies without making a special frequency calibration of the potentiometer. Furthermore, at such high frequencies great care must be taken to make the switch parts and other metal parts of the potentiometer as small as possible in order to minimize shunt capacities to ground, which would make the current flowing through the potentiometer smaller than the current measured by the thermocouple. Of course, none of these objections arise in extending the range to frequencies below 600 kilocycles.

SOURCES OF "A," "B" AND "C" POWER FOR RADIO RECEIVERS*

BY

WALTER E. HOLLAND

INTRODUCTORY

The purpose of this paper is to describe the various present-day sources of "A," "B" and "C" power for the operation of radio receivers and to indicate the advantages and disadvantages of each. It is too early for anyone to predict which of these sources will prove fittest ultimately and will come into most general use. It is the writer's opinion that as long as the three-element vacuum tube remains the basis of radio there will continue to be substantial fields for storage batteries and dry batteries as well as for battery substitute devices. Considerations of performance, practicability and cost will define the rightful fields of each in time. It is hoped this paper may help clear the ground so that each kind of power source may find its rightful application.

"A" POWER SOURCES

The storage battery, at first, was the only satisfactory source of current for filament heating, and as a 6-volt battery was called for it it is but natural that standard automobile starting-and-lighting batteries were used. These batteries are necessarily made with comparatively thin plates and plate insulators that they may be capable of delivering the high discharge currents needed to crank automobile engines. They were not designed for stationary use at low discharge rates and no special means to prevent spray coming out was provided or thought necessary. Such batteries were soon found to be generally unsuitable for radio use in the home.

It will be a surprise to some to hear that the low-rate discharging and stationary use of batteries in radio "A" service are more wearing to the plates and harder on the battery than the high-rate discharging and vibration to which a starting battery is subjected. The low-rate discharging, especially when inter-

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mittent, allows time for the electrolyte to diffuse in the plates so that relatively great useful ampere-hour capacity is developed and the active material of the plates is worked to a considerable depth instead of just at the surface. Each time the positive active material discharges to lead sulphate and is subsequently charged back to lead peroxide, the coherency of the active material structure is weakened and the active material is softened, resulting eventually in a breaking up into non-coherent particles. The depth or amount of active material that is thus softened is directly proportional to the number of ampere-hours taken out of the battery on each discharge. At the high discharge rates of engine-cranking service a battery will deliver only a small fraction of the ampere-hour capacity that is actually present in the charged plates in the form of potential chemical energy and that can be realized on low-rate intermittent discharge. It will thus be seen that a battery is self-protecting at high discharge rates, whereas at low discharge rates it can be drained of its energy even to the point of injury. The high discharge rates of automobile service work only a very thin layer of active material at the surface of the plates and normally the operation of the car keeps the battery close to the point of full charge all the time, which is good for the battery, provided it is not excessively overcharged at high rates. The vibration in automobile service is also good for the battery as it helps the plates to free themselves of any short-circuits which tend to form across the plate edges by accumulation of active material particles.

Quite early the necessity for thick plates and thick plate insulators or separators in radio "A" batteries was seen and improved types having the general appearance of automobile batteries, were produced. Figure 1 shows a typical "A" battery of this kind as made today.

The thick plates are spaced and insulated with specially prepared thick ribbed-wood separators and between the ribbed side of each separator and the face of the adjacent positive plate is placed a slotted hard-rubber retainer. The function of this hard-rubber retainer is to hold the softened lead peroxide active material in place on the plate and protect the wood from the harmful action of this strong oxidizer. Instead of the old combination of wood case and individual rubber jars, a strong, clean hard-rubber container, molded in one piece with three compartments, is used. Molded hard-rubber covers close the tops of the compartments and these are usually sealed in the container with a special elastic sealing compound and at the cell posts with soft rubber gaskets so mounted as to be held under compression. The cells are connected in series by means of alloy-lead connectors, integrally welded to the posts, and convenient terminals are provided at the open posts of the end cells. Each cell is provided with a chambered vent cap which is removable when rotated a quarter turn.

FIGURE 1—Radio "A" Battery with Charge Tester

The battery shown in Figure 1 is equipped with a charge tester which is built into one of the vent caps. This charge tester consists of a small ball-type hydrometer which, when the rubber bulb at the top is squeezed and released, will indicate by the floating or sinking of the two wax balls of different densities the approximate extent to which the battery is charged or discharged. The tip of the charge tester extends into the battery to the minimum normal electrolyte level so that the tester also serves as a level indicator. If no solution is drawn up into the barrel of the tester when the bulb is squeezed and released, it is at once apparant that the solution level is low and water is needed. The particular merit of this form of tester lies in its convenience and the fact that it does away with the danger of acid dripping where it may do injury, which is always present with the conventional type of hydrometer.

The battery is equipped with a bail handle for convenience in carrying because, in spite of the greater convenience of charging at home and the simplicity and cheapness of present-day chargers, the fact remains that for one reason or another, a large number of users still carry out their batteries for charging.

With a well-designed vent cap and ample gas space above the electrolyte level, this conventional type of battery will keep quite clean and dry externally provided it is charged at suitable charging rates. Batteries of 120 ampere-hours capacity or larger may be safely charged with a 5-ampere charger, but the more common batteries of 50 to 100 ampere-hours capacity should be charged with a 2-ampere charger to give the greatest satisfaction. It is to be deplored that certain charger manufacturers are spending their advertising money in an effort to tell people that 2-ampere chargers are out of date and that rapid charging is desirable. Experience has shown the great advantage of slow charging as a means of preventing spray, extending the time a battery will operate without needing water and prolonging battery life. A 2-ampere charger is adequate to satisfy the needs of the vast majority of broadcast listeners; it is cheaper to buy and to maintain, and, in general, will prove more satisfactory in use than a 5-ampere charger.

Battery and charger manufacturers have for some time advocated the use of switches or plugs and sockets permanently wired to the battery charger and radio set as a very convenient method of operating with batteries. Some manufacturers list suitable switches or plugs and sockets for making these permanent hook-ups. With such an arrangement the charging of a battery is reduced to the mere throwing of a switch or moving of a plug. Charging then becomes so easy that most users prefer to keep the battery well charged by charging frequently. The need for large capacity per discharge then disappears. This has led to the development of small "A" batteries having improved features which were impracticable in the larger batteries. Chief among these features is the use of a transparent container, molded out of glass, which makes possible the use of a built-in charge indicator and high and low solution level lines. Figure 2 shows the construction of a 6-volt battery of this type.

The three cells of this battery are mounted in separate compartments of the one-piece pressed-glass container. The positive plates and the interior negative plates of each cell are mounted in pairs while the outside negative plates are mounted singly. This makes a balanced plate construction in which there are the same number of individual positive plates and negative plates per cell. By mounting the inner plates in pairs, the life advantages of exceptionally thick plate construction are realized and the number of plate separators is reduced to the minimum so that the thickness of each may be made very great. The plates are suspended from the molded hard rubber cover which rests on ledges molded in the jar walls. This does away with the necessity for ribs or plate rests in the bottom of the jar and makes it possible to use separators which extend well below the bottom of the plates and rest on the bottom of the container.

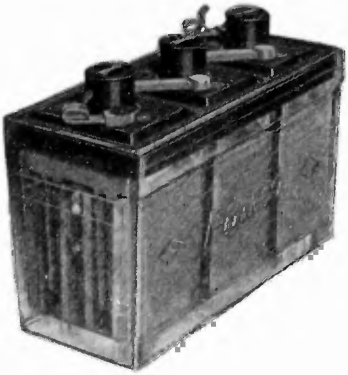

Figure 2—Radio "A" Battery with Built-in Charge Indicator

The vertical edges of the positive and negative plates respectively are staggered or offset with respect to each other, while the width of the separators is such as to fill up the full width of the compartment after they have become expanded by the wetting with electrolyte. The very thick separators reaching to the bottom of the cell and extending beyond the staggered vertical edges and above the tops of the plates provide exceptional security against the possibility of short-circuiting at the plate edges, due to "mossing" or "treeing" of the active material.

Each cover is provided with a novel type of filler-vent, which is designed to thoroughly drain the emitted gas of all acid spray so that nothing but clean, dry gas is given off. The cell posts are molded into the body of the hard-rubber cover, making a perfect liquid-tight joint and the covers are effectively sealed into the container with special sealing compound. The thoroughly tight sealing and the spray-proof vents were designed primarily with a view to making a battery that could be used inside of a radio receiving set without subjecting the corrodible metal or other parts of the set to danger of injury from acid spray. The efficacy of the vent construction can be tested by anyone interested by placing litmus paper or copper gauze over the tops of the vents during a gassing charge of the battery at normal charging rates. Repeated tests of this character together with the use of such batteries in close proximity to the inside works of radio receivers over a period of two years have completely demonstrated the soundness of the design. The upper part of the vent is shaped like a funnel and the internal design is such that water may be added to the cells by pouring it into the funnel-shaped part without removing or loosening the vent. This has the advantage of eliminating the danger of acid dropping from a removed vent cap; and adding water through the vent cap also washes back any acid that may have tended to creep out of the vent openings.

The charge indicator, visible through the glass at the end of the battery, removes the guess work from battery charging and eliminates the sloppy hydrometer. The indicator consists of two wax balls of different densities mounted in a hard-rubber cage which limits the movement of the balls to a pre-determined visible range. The cage is designed to allow free circulation of acid about the balls and at the same time to protect them from becoming coated with particles of active material from the plates. The balls are placed one above the other in the cage, the ball of greater density, of course, being placed below the other. The balls are made different in color for identification in assembly. The heavier ball is white and has a specific gravity of 1.265, while the lighter ball is colored and has a specific gravity of 1.200. At full charge, the normal specific gravity of the battery electrolyte is 1.285, which, of course, will float both balls to the top of the cage. As the battery is discharged, the specific gravity of the electrolyte decreases, as is well known, and if the battery is discharged completely at a low rate, the electrolyte specific gravity will fall to approximately 1.160. During the discharge each ball will drop to the bottom of the cage as the electrolyte specific gravity falls below its specific gravity. The balls will drop at approximately 20 per cent. discharge and 75 per cent. discharge, based on the useful capacity of the battery under average conditions of radio service. As the electrolyte specific gravity rises again during the recharge, the balls will rise one after the other and it will be known to the user that the battery is nearly up to the state of full charge when the second ball rises. For a complete charge the battery is kept on charge for about six hours at the normal charging rate after such time.

In order to protect storage batteries against self-discharge and deterioration during shipment and storage, some manufacturers have developed what are known as "drynamic" or dry-charged batteries and are producing and shipping both "A" and

"B" batteries this way. The plates of these batteries are formed, charged and dried before assembly. The dry-charged plates are assembled with a special form of dry porous separator and made into complete batteries. Since the cells contain no free acid or moisture and are sealed, they may be kept indefinitely without deterioration or loss of charge. When the dealer sells a battery he simply fills the cells with the proper electrolyte. The battery is then immediately ready for use without charging and will deliver from 60 to 80 per cent. of its rated capacity on the first discharge. The battery works up to full capacity with subsequent recharging and use. By this method of shipment, the dealer is saved the expense and time involved in charging batteries before delivery and the user is sure of getting a fresh battery that has not deteriorated on the shelf.

Since radio came in, the old and well-known scheme of making dry or non-spillable storage batteries has been revived and a number of both "A" and "B" batteries have come on the market with jelly electrolytes or with liquid electrolyte held in some form of absorbent filler. The chief objection to all such batteries is that the volume of active electrolyte is greatly reduced so that the battery capacity is also reduced. The free circulation and diffusion of the electrolyte is interfered with and resistance is interposed which causes increased heating of the battery during charge. Such a battery usually requires water more often, due to the reduced volume of free liquid and the increased heating. If the battery is allowed to run too long without adding water, the jelly or paste electrolyte may dry out to such an extent as to shrink and lose contact with the plates. When this happens the battery may be permanently injured by continued use. Jelly electrolytes are apt to cause abnormal softening and expansion of the plate active materials, very often resulting in early failure of the battery. These facts are well known to experienced battery manufacturers.

The storage battery suffers from an unreasonable prejudice against its use in some cases. Some people, usually not engineers, are almost superstitious about it and seem to consider complete battery elimination a goal to be reached at any cost. The storage battery probably inherits this prejudice by reason of the sloppiness and unsuitability for home use of early types. Also, until recently it has been necessary to give thought and go to some trouble to charge a storage battery, and few people like to mix thinking and trouble with their pleasures. These objections are completely met and the prejudice should be overcome by the use for filament current of a small spray-proof battery of the improved design shown in Figure 2, combined with a small charger which is arranged to charge the battery automatically at a low rate during the time the radio set is out of use. Such a power unit is shown in Figure 3.

FIGURE 3—"A" Socket Power Unit

The battery supplies filament current just as does any "A" battery during the operation of the set when the switch that has been developed especially for the purpose is thrown on to ON. With this switch in the ON position, the trickle charger within the unit is disconnected and alternating current is switched on to the receptacle shown at the bottom of the panel in Figure 3, thereby energizing a separate "B" power unit designed to be plugged into the socket when it is desired to use such a device in conjunction with the "A" unit.

When the switch on the "A" power unit is thrown to OFF, the battery current is switched off the filaments, the alternating current is disconnected from the socket which feeds the "B" power unit and is connected to the trickle charger which delivers direct current to the battery. The operation of the radio set is controlled by this switch altogether, the filament rheostats and switch of the set being left in operating position.

The trickle charge rate may be adjusted to the conditions of use by means of three terminal taps marked "Low," "Med." and "High" at the top of the charger. These taps and other internal details are shown in Figure 4. The charge indicator, visible through the round opening alongside the panel (Figure 3), shows whether the proper setting is being used. If the two balls of the indicator are found to be at the top of the opening at the beginning of the day's use of the radio set, the battery is being kept charged. If one ball is up and one down, or if both balls are down at the beginning of the radio day, the battery is not being kept up as it should be. Then, even though there is no noticeable difference in the operation of the set, the next higher tap setting should be used. The charging rate corresponding to each tap setting are approximately: 0.2 ampere for "low," 0.33 ampere for "medium" and 0.6 ampere for the "high" setting. The following table shows the average hours per day sets having different numbers of No. 201-A tubes may be operated on each tap keeping the battery charged:

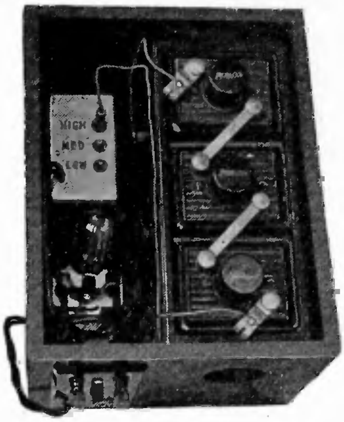

FIGURE 4—Inside View of "A" Socket Power Unit

Filament Current, Amperes	Equivalent Number of No. 201-A Tubes	LOW Tap 0.2 Amp.	MED. Tap 0.33 Amp.	HIGH Tap 0.6 Amp.
.25	1 No. 201-A	10.0	13.1	16.4
.50	2 No. 201-A	6.35	9.00	12.4
.75	3 No. 201-A	4.65	6.86	10.0
1.00	4 No. 201-A	3.66	5.54	8.40
1.25	5 No. 201-A	3.02	4.64	7.24
1.50	6 No. 201-A	2.57	4.00	6.35
1.75	7 No. 201-A	2.24	3.50	5.56
2.00	8 No. 201-A	2.00	3.13	5.10

It is obvious that a power unit of this type must be kept connected to the house socket at all times, except when the radio set is to remain out of use for a week or more, in which case it is advisable to pull the attachment plug from the house socket. The trickle charging rates are so low that the battery will not be harmed by continued overcharging for days or weeks at a time without being used, but it is best to avoid such extended overcharging in order to save current and not to use up unnecessarily the water in the battery. Ordinarily the battery, due to the special design and the low-rate charging, will need water only once in three or four months. Water is then added to each of the three cells through the funnel-shaped vent cap to bring the level to the upper or high level line molded in the glass case.

Figure 5 shows the voltage characteristic of a 30-ampere-hour battery trickle charged at 0.33 ampere, 20 hours per day and discharged at 1.5 ampere, 4 hours per day, compared with a 120-ampere-hour battery discharged at 1.5 ampere, 4 hours per day following a full charge. The trickle-charged battery has a voltage peak lasting about five minutes at the beginning of each discharge period. During the remainder of the 4 hours, the voltage is very steady, dropping less than 2 per cent. The maximum voltage variation is from 6.6 to approximately 6.0 volts, a variation so small as to make filament rheostats unnecessary.

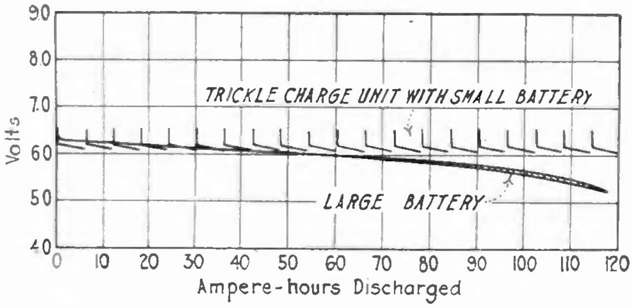

FIGURE 5

It will readily be seen that this type of "A" power unit is applicable to all existing sets using 5-volt tubes with the filaments in parallel. No adaptation or compromise of the circuit is necessary and the radio manufacturer may sell exactly the same set for operation with batteries and from the light socket. Since the alternating current is entirely disconnected from the battery and charger during the periods of use of the radio receiver, all possible complications by which the alternating current or the charger might cause a hum to be heard are avoided. By trickle charging at low current rates during the off periods, the size of the charger is kept to a minimum and the battery is charged in the best possible manner without gassing or heating.

"A" power units have been proposed in which the charger provides sufficient current to light the filaments and some extra current to keep the battery charged, the method of operation being that the charger is switched on only during the time the radio set is in use and both charger and battery are disconnected from the line during the periods of non-use. By this method the battery floats in shunt with the charger and load, where it acts as a smoothing device to keep down the peaks and fill up the valleys of the pulsating rectified current. With this system there must be some method of regulating the charging rate so that it is always a little higher than the current taken by the filaments and the charger must necessarily be comparatively large. Even if such a system would furnish current of a character to give hum-free reproduction of good quality, which it usually will not do, the use of the system is likely to subject the tube filaments to a higher voltage than is good for them, owing to the fact that the charging current passing through the battery will cause the voltage to rise. Figure 6 shows this graphically in the case of a 6-volt, 30-ampere-hour battery connected to a filament load of 1.5 amperes and to a charger delivering 1.8 amperes. The periods of use were 4 hours per day, and it will be noted that the voltage is quite variable throughout the greater part of each period, rising from 6.4 to 7.0 volts.

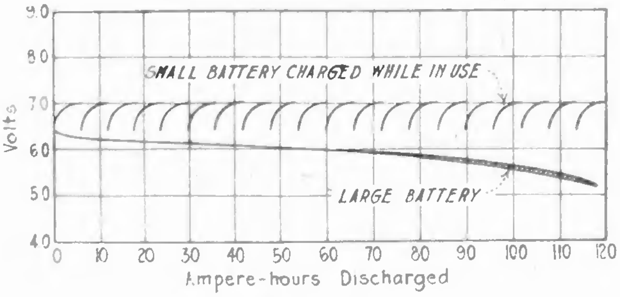

FIGURE 6

With the coming of the high-efficiency tubes, WD-11 and UV-199, the dry primary battery, which hitherto had figured as a source of "B" and "C" current only, entered into extensive use as an "A" source. The fact that this battery is non-spillable and can be placed inside of a set in any position are advantages which go a long way toward offsetting the relatively high cost of frequent replacements. It has not proven practicable to make dry cells larger than the common 6-inch size, and while this cell has proven quite satisfactory for sets having only a few tubes, it has decided limitations as a source of filament current for sets having six or more tubes. The 6-inch cell does not deliver satisfactory voltage and capacity if discharged at a rate higher than 0.25 ampere per cell, and preferably the rate should be kept below 0.2 ampere per cell. Where the filament current runs higher than this, it is necessary to add paralleled groups of cells.

One of the advantages of dry cells that has been much talked of is the convenience of replacement as compared with storage battery recharging. This advantage disappears and the convenience, in the writer's opinion, must be conceded to the storage battery when the filament requirements are such that 9 to 12 six-inch dry cells grouped in series-parallel must be used, necessitating the loosening and remaking of 18 to 24 terminal connections each time the cells are replaced.

One of the serious problems in connection with dry-cell batteries seems to be that of getting fresh cells or batteries to the user. Slow self-discharge commences to take place in a dry cell as soon as it is made, and much of the dissatisfaction with dry-battery operation is, no doubt, due to the use of cells which have deteriorated while standing in stock.

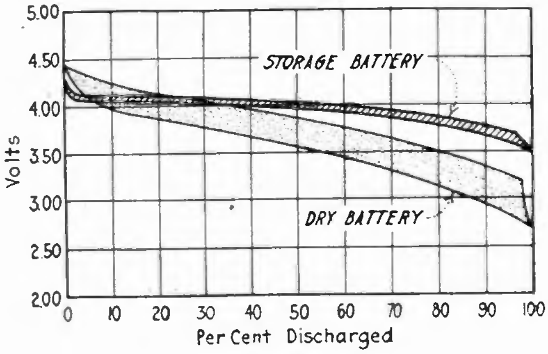

FIGURE 7

Figure 7 shows the voltage characteristics of three fresh 6-inch radio-type dry cells of a representative kind in comparison with a 15-ampere-hour, 2-cell storage battery which occupies somewhat less space than the three dry cells. This little storage battery is shown in Figure 8. The storage and dry batteries were discharged in series at 0.2 ampere, 4 hours per day, and voltage readings were taken at the beginning, middle and end of each discharge period. The curves are drawn so that the vertical width represents the variation in voltage from the beginning to the end of the daily 4-hour discharge periods while the slope of the curve shows the gradual falling off of voltage during the complete discharge cycle.

For more than 0.2 ampere of current, additional groups of dry cells should be connected in parallel to keep the discharge rate per cell below this figure. Even when this is done, the voltage variation during a daily discharge period and from the beginning to the end of the discharge cycle ia so great as to necessitate the re-setting of filament rheostats. The small storage battery, on the other hand, has good voltage characteristics at discharge rates as high as 0.75 ampere and a single battery will satisfactorily operate sets having 8 or 10 No. 199 tubes. The storage battery, however, would have to be recharged more often than the dry cells would have to be replaced, since its ampere-hour capacity is less than that of a single group of three dry cells.

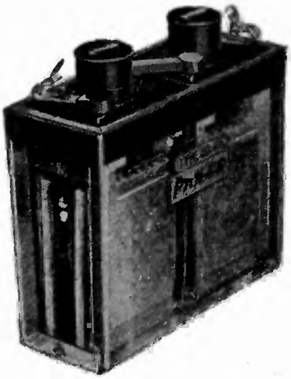

FIGURE 8 — Four-Volt Storage Battery with Built-in Charge Indicator

The charging, however, is taken care of automatically when such a battery is combined with a suitable trickle charger and switch, as is done in the combination "A" and "B" power unit shown in Figure 9.

This unit supplies pure battery current at 4 volts for receiving sets having 3-volt tubes, and when the tubes are turned off by means of the special switch on the power unit, the battery automatically replenishes itself through an electrolytic trickle charger. Three taps inside the housing, marked "Low," "Med." and "High," permit of adjusting the trickle charge rate to the conditions of use, and the charge indicator in the battery, visible

FIGURE 9—Combination "A" and "B" Socket Power Unit for 3-Volt Tubes

through an opening in the front of the housing, shows at a glance whether or not the battery is being kept charged.

The following table shows the average hours per day sets having different numbers of No. 199 tubes may be operated on each tap keeping the battery charged:

Filament Current, Amperes	Equivalent Number of No. 199 Tubes	LOW Tap 75 M.A.	MED. Tap 125 M.A.	HIGH Tap 200 M.A.
0.06	1 No. 199	12.6	15.6	18.0
0.12	2 No. 199	8.60	11.6	14.4
0.18	3 No. 199	6.52	9.20	12.0
0.24	4 No. 199	5.23	7.64	10.3
0.30	5 No. 199	4.38	6.53	9.00
0.36	6 No. 199	3.76	5.70	8.00
0.42	7 No. 199	3.30	5.04	7.20
0.48	8 No. 199	2.94	4.54	6.55
0.54	9 No. 199	2.65	4.12	6.00
0.60	10 No. 199	2.40	3.77	5.54

Special chargers of both the Tungar bulb type and electrolytic type have been developed and applied very successfully to trickle charging purposes. The bulb type has the advantages of compactness and being without liquid while the electrolytic type has better efficiency and longer life at the low current rates usually used. Figure 10 shows the alternating current input in watts at different charging rates for bulb and electrolytic type trickle chargers designed for use with 6-volt batteries.

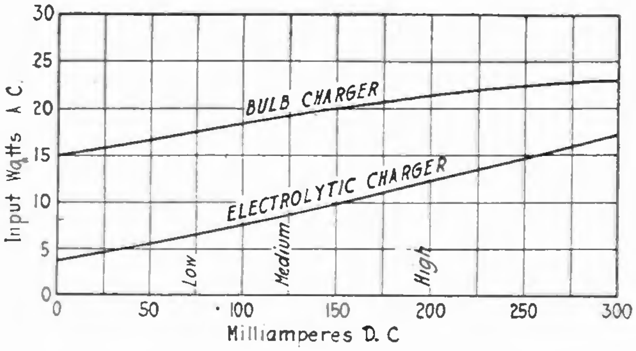

FIGURE 10

The difference in current consumption in favor of the electrolytic type is often sufficient to pay the cost of all rectifier cell renewals. The excess current consumed by the bulb type charger is accounted for principally as cathode-heating current. It will be seen that the two curves converge toward each other as the charging rate increases and at the higher current rates the bulb type charger would seem to have the advantage especially as the electrolytic type becomes bulky and requires the addition of water rather frequently at current rates above 0.75 ampere.

Figure 11 shows a similar comparison of the input watts for bulb type and electrolytic trickle chargers designed for use with small 4-volt batteries. At the very low trickle charge rates applying to receiving sets having the so-called dry-cell tubes, the electrolytic rectifier seems to have the advantages very much in its favor as regards both efficiency and life.

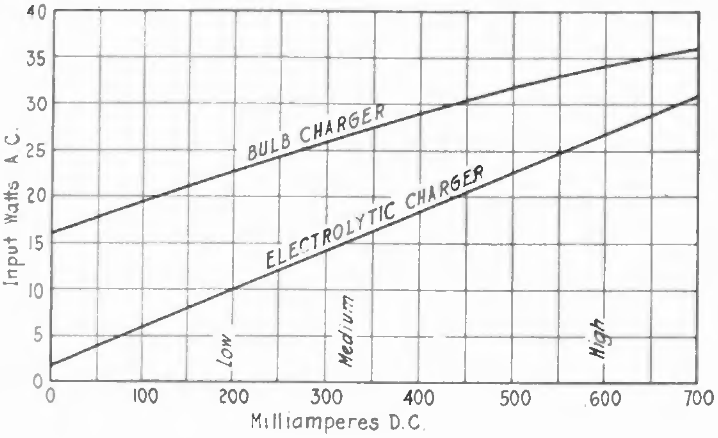

FIGURE 11

Among the methods proposed for heating filaments without the use of a battery may be mentioned the direct use of alternating current in the filament with a voltage-dividing connection and the use of a special type of tube having a cathode which is heated indirectly by conduction or radiation from a separate heating element carrying the alternating current. Neither of these devices has reached the practical stage as yet. There is little doubt that a tube using alternating current for indirect heating of the cathode will be developed and made practical before long, but there is good reason for thinking the performance of such tubes will not fully equal that of present types. Even if such tubes do come in and can be made to sell at a reasonable price, there will still remain a large field for battery-operated tubes in the homes which are not supplied with electric current.

With special circuits in which, as a rule, the tube filaments are all connected in series, some receiving sets are now being operated more or less successfully from alternating current by means of rectifiers and smoothing filters. With the small current required by No. 199 tubes in series, the problem is fairly simple, but for larger currents, even for that required by No. 201-A tubes with the filaments in series, there are numerous difficulties which have seemed almost insurmountable. However, the comparatively recent development of a reliable, long-lived electrolytic rectifier, capable of efficiently delivering the relatively large currents required, has altered the situation and opens up new possibilities. Figure 12 shows several sizes of the rectifier cells referred to.

These rectifier cells employ aluminum as the film-forming or rectifying electrode, but it is only in this respect that they resemble the unreliable aluminum-lead rectifier cells which have been a laboratory curiosity for many years. No lead is used in these cells. An anode of a special corrosion-resisting alloy is used instead with much benefit. The greatest improvement, however, results from the use of a new electrolyte solution. Even the aluminum electrode has been improved both chemically and physically. The result is a thoroughly-dependable, efficient and long-lived rectifier cell having exceptionally good characteristics for radio work. Its only disadvantage of any consequence is that it contains liquid. Chemically, however, this liquid is very mild and much less likely to cause damage than many other liquids used in the household. Ink, for example, has much greater potentialities for harm. Not a single case of damage by the solution has been reported during the more than two years that this electrolytic rectifier has been used extensively in radio battery chargers. The good electrical characteristics, the dependability and the inexpensiveness of this rectifier far outweigh the more or less sentimental objection that it contains liquid.

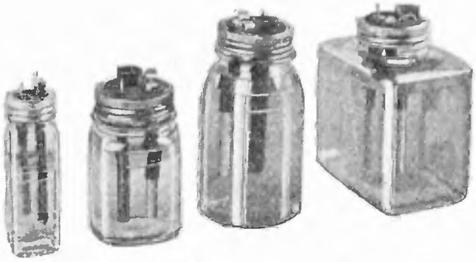

FIGURE 12—Philcotron Electrolytic Rectifice Cells

"B" POWER SOURCES

The dry "B" battery was originally the only source of plate current. With the increasing use of multi-tube receiving sets demanding heavier plate currents, dry "B" batteries have steadily been increased in capacity and size. Some of the original small "B" battery units would not be considered large enough for use as "C" batteries today. With increased volume of production, the dry-battery manufacturers have been able to reduce prices until the largest size 30-cell unit of today may be purchased for less than the price of a comparatively small unit formerly. This saving, however, has been offset by the growing tendency to use three instead of two "B" battery units as standard, and the dry "B" battery remains a relatively expensive, although very convenient, source of current.

Besides being convenient, dry "B" batteries have the advanatge of being clean, non-spillable, and capable of being used in any position.

The problem of getting fresh batteries to the user is even more troublesome with dry "B" batteries than with dry "A" cells, since the self-discharge in small cells goes on at a greater rate in proportion to their capacity. One of the chief reasons for the development of larger "B" batteries has been to provide a margin of capacity to partially offset shelf-deterioration.

The internal resistance of any battery increases as the discharge progresses. The internal resistance of dry batteries is comparatively high, even in fresh batteries, due to the nature of the materials used and to the large number of cells that must be connected in series for the required plate voltages. The internal resistance increases as the discharge progresses and the high resistance of old batteries seems to be responsible for certain imperfections in the radio reproduction with some types of receiving set. Certain frying or crackling noises have also been attributed to corroded or loose connections within dry "B" batteries. It is the writer's opinion that the amount of trouble from this cause has been greatly overestimated and that most of the noises for which dry batteries have been blamed has been merely static or local electrical interference of some sort.

As in the case of dry "A" batteries, the voltage of dry "B" batteries is quite variable both from the beginning to the end of a daily period of use and from the beginning to the end of the useful life of the battery. This is especially true when the plate current required by the set is above the average. Figure 13 shows graphically the voltage characteristics of a representative large so-called 45-volt dry "B" battery in comparison with 20-cell and 24-cell units of storage "B" battery when discharged at 25 milliamperes, 4 hours per day. This test schedule is undoubtedly in excess of average service requirements. However, it represents a requirement which has to be met in thousands of homes in every city and is well below maximum requirements both as to current rate and time.

The vertical width of each curve represents the dropping of voltage during the daily 4-hour discharge periods, while the slope of each curve shows the falling off of voltage during the discharge cycle or useful life. It will be noted that the dry battery falls away from the nominal 45-volts quite early, showing the fallacy of rating this battery in terms of its initial voltage. The storage battery gives fairly constant voltage during the greater part of the discharge. It will be seen that the 20-cell storage battery unit which nominally, as storage batteries are rated, is a 40-volt battery, actually has somewhat higher average voltage than the so-called 45-volt dry battery unit. Most radio engineers are aware of this discrepancy between the nominal and actual voltage of the dry battery and are designing sets for operation at average dry battery voltages rather than at the initial or nominal voltages. It is not surprising, therefore, that a storage "B" battery, made up of 20-cell units, often gives better results than the higher voltage storage battery made up of 24-cell units which has been commonly used heretofore.

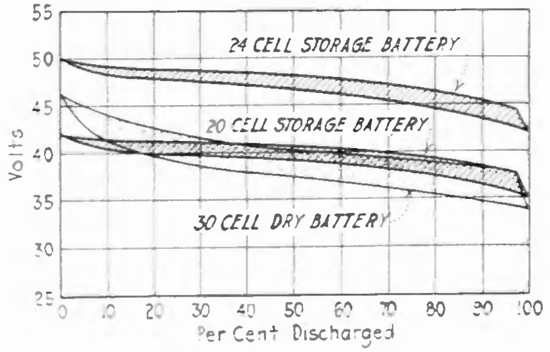

FIGURE 13

Storage "B" batteries give excellent results, due to their good voltage characteristics and low internal resistance, but they are considered objectionable by persons who do not understand their charging and care. Early types also were sloppy, bulky and inconvenient to charge and use. These objections have been largely overcome by improved battery design and the development of convenient chargers. Figure 14 shows a 40-cell storage battery unit made up of square cells of 3,000 milliampere-hours capacity. A similar unit is made with cells of 6,000 milliampere-hours capacity having the same overall width and length but greater height.

The use of the square jars with square sealed covers in the place of round jars with threaded tops and screw covers eliminates waste space both between and within the cells, making the battery more compact. Sufficient acid space is provided above the tops of the plates so that the cells may be used a full year under usual conditions without adding water and the design is such that water may be added conveniently by pouring it in a depression in the cover. Charge indicators similar to those used in the small glass-container types of "A" battery are built into certain front cells so that the state of charge or discharge of the battery is indicated visibly. The battery unit is provided with Fahnestock terminals conveniently located at the front.

Among the many "B" battery substitutes or eliminators that have come on the market during the past year a few stand out as being successful. These power units all operate on the same general principle and consist essentially of a transformer, a rectifier and a smoothing filter. The chief differences among different units are in the kind of rectifier and the details and size of the smoothing filter. The electrical principles upon which these battery substitutes are based are well known to radio engineers and will not be discussed at length in this paper.

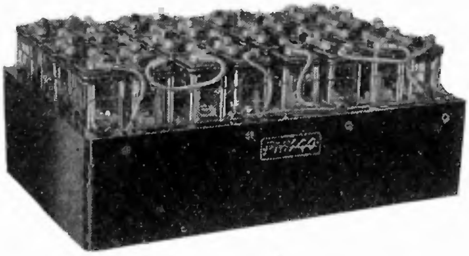

FIGURE 14—40-Cell Unit of Storage "B" Battery

It seems to be important to use a type of rectifier which will pass uniformly-undulating current with a minimum of irregularities or harmonics, and the gas-filled, hot-cathode bulb which is so commonly used in battery chargers does not seem to be well adapted to this purpose. Two general types of rectifier, namely, the vacuum tube and the electrolytic types, have proven most successful. The tube rectifiers used are either of the true thermionic valve type or of the cold-cathode gas-filled type.

Tube rectifiers have the advantage of being compact, dry and clean. They have had the disadvantage in the past of short life, but undoubtedly the life of the new types recently placed on the market will prove satisfactory. The most serious disadvantage of tube rectifiers, whether of the heated or unheated-cathode type, is their high internal resistance or impedance which necessitates the use of a high-voltage transformer. The current consumption is, therefore, relatively high, and usually at least 80 per cent. of it goes to generate heat in the rectifier tube itself. Due to this high impedance characteristic, the voltage of the rectified current will vary greatly with changes in the load current unless some special regulation is provided such as a potentiometer resistance or a regulator tube. Such regulators, of course, increase the current consumption of the device and add to the already-high heat losses, necessitating adequate ventilation.

Two types of electrolytic rectifier are used in "B" power units, one using tantalum as the film-forming or rectifying electrode, the other using aluminum. The electrolyte is sulphuric acid in the tantalum rectifier and a solution containing several substances, chiefly salts, in the aluminum rectifier. The tantalum rectifier in its present stage of development will stand only a very limited voltage per cell and in a 90-volt "B" battery substitute it has been found necessary to use not less than six cells in series for half-wave rectification. The aluminum rectifier will stand at least three times as much voltage per cell as the tantalum rectifier, so that only two cells need be used in series for half-wave rectification under the same conditions. However, there is always some danger that cells in series, connected for half-wave rectification, will not start rectifying at the same moment after a period of idleness, so that the one cell may take the full voltage which should be divided up equally among the cells in the series. When this occurs, the one cell which is taking practically all the load may overheat and break down, thus throwing an excessive load on the remaining cell or cells with probable injury to them also.

A single aluminum rectifier cell may be used for half-wave rectification to charge "A" batteries or 24-cell "B" batteries from a 115-volt secondary or line. In this case, the battery voltage is in series with the supply voltage on the suppressed half-wave which tends to break down the rectifying film so that the film has to withstand a voltage peak of 115 times 1.41 plus 60 volts, or approximately 220 volts. However, when used in combination with the usual smoothing filter, a single aluminum cell should not be used on an alternating current supply voltage higher than 75 volts. The reason for this is that the condensers of the filter circuit charge up to a voltage approaching the peak voltage of the alternating current supply and on the suppressed half-wave this condenser voltage is in series with the transformer or supply voltage. In this case, the voltage tending to break down the rectifying film would approach 75 times 1.41 times 2, or about 230 volts.

For direct-current potentials up to 135 volts in "B" power units, it has been found desirable and practicable to use four aluminum cells connected in a so-called bridge circuit for full-wave rectification, using a transformer designed to give a secondary voltage of 150 r.m.s. volts on open circuit. This transformer voltage must not be exceeded. The perfected aluminum cells referred to in this paper will operate satisfactorily and dependably under such conditions. The loss of voltage in the rectifier cells themselves is so small that 135 volts may easily be obtained at usual loads provided the choke coils used in the smoothing circuit have not more than 700 ohms resistance.

Aluminum rectifier cells should never be used with a center-tap transformer connected for full-wave rectification in the manner that is common with tube rectifiers. Even with tube rectifiers there is a possibility of trouble from unbalancing of the load in such a circuit and there are also good possibilities of burning out the transformer in case of short-circuit in one of the rectifiers.

Figure 15 shows a hook-up that is being used very successfully to supply both "A" and "B" power from the lamp socket under the control of one switch. The bridge hook-up of four aluminum rectifier cells referred to above is shown in this diagram. The entire "A" and "B" supply may be built into a radio receiver or a combination power unit such as that shown in Figure 9, or the "A" and "B" parts may be built into separate units designed to be used either separately or in combination. Figure 16 shows a separate "B" power unit embodying the full-wave rectifying system and filter circuit shown diagrammatically in Figure 15. The four small aluminum rectifier cells used in this unit are designed to snap into special sockets in just one way so that wrong connections cannot be made. One set of four costing

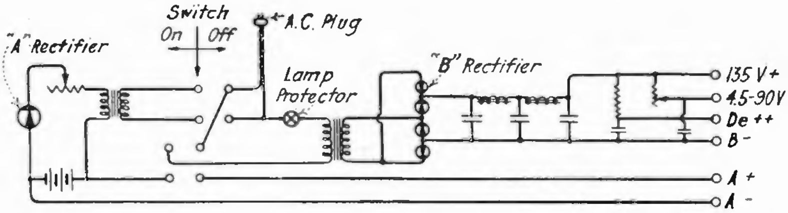

FIGURE 15

no more than a full-wave rectifier tube will operate at least 2,000 hours in average "B" service without any attention whatever. They are so designed that water need never be added. Replacement cells as well as the original cells are shipped filled and corked, ready for immediate use when the corks have been removed and the cells snapped in place of the old ones. There are no delicate parts in these rectifiers and no particular accuracy of manufacture is required, so that there is very little chance of defectives.

FIGURE 16—"B" Socket Power Unit

The lamp protector used in the primary circuit of the transformer which feeds the "B" rectifier cells, as shown in Figure 15, is an important element of this "B" power unit. This protector consists of a standard 115-volt Mazda lamp and its prime function is to protect the rectifier cells and transformer against overload in starting up after a period of idleness as well as when the rectifier cells ultimately break down and pass alternating current. The lamp also serves as a protection in case of short-circuit anywhere in the "B" unit and limits the current obtained at the terminals on short circuit to a value which will not burn out tube filaments if connected to the "A" terminals of the set. The short-circuit current is great enough to burn out one No. 199 tube or even two connected in parallel; but the owner of a set having not more than two such tubes surely would not be using a "B" power unit. Standard tungsten lamps have been found most suitable for the protector on account of their very high resistance-temperature coefficient and also because they offer a convenient means of adjusting the direct current output voltages when required for receiving sets which draw an exceptionally small or exceptionally large plate current. Usually a 40-watt or 50-watt regular Mazda lamp is shipped with the outfit. By changing to a smaller or larger lamp, the voltage applied to the transformer primary is lowered or raised with a corresponding effect on the output voltage. Normally, the filament of the protective lamp is only heated enough to be just visible and the voltage drop therein amounts to only a few volts. In starting up after a period of idleness, however, the lamp burns brightly and the voltage drop in it is high, so that only a low voltage reaches the transformer primary during the few seconds that is required for the film to re-form on the rectifying electrodes. By this means, the initial current which passes through the rectifier cells and the starting load on the transformer are very greatly reduced. The same thing occurs and the same protection is afforded ultimately when the rectifier cells become worn out. The continued bright burning of the lamp at any time is a signal of non-rectification, wrong connections or trouble.

Figure 17 shows the voltage characteristics at the "135-Volt +" post using different lamps in the socket in the primary circuit.

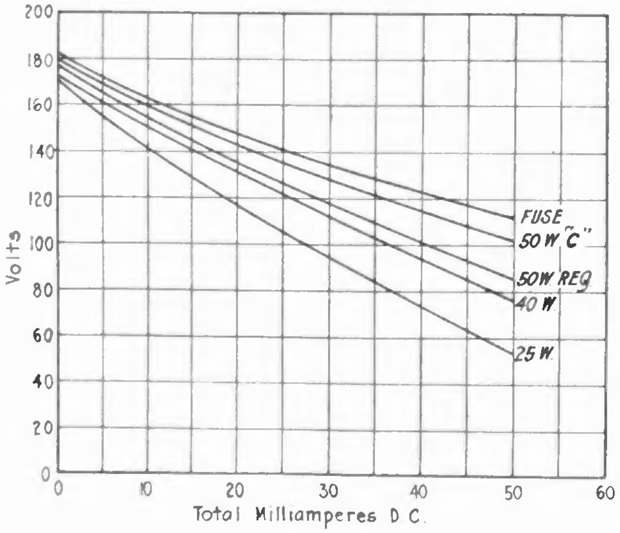

FIGURE 17

The highest curve was made with a fuse in the socket for the purpose of showing the voltage characteristic with no resistance in the primary circuit. But the regular use of the power unit with a fuse in the socket cannot be recommended; in fact, the 50-watt Mazda "C" or gas-filled lamp is the largest that should be used under any circumstances. Where a change of the lamp shipped with the outfit is required, it is usually to a smaller rather than to a larger size.

Referring again to Figure 15, it will be noted that a fixed resistor is used to bring down the high voltage to detector voltage while a variable resistor is used to provide 45 to 90 volts or more at a second amplifier post, which will be referred to as the "B Amp.+" post.

Figure 18 shows the variation in voltage obtainable with different loads up to 50 milliamperes at the "B" Amp.+" post with a constant load of 6 milliamperes in addition at the "135-Volt+" post. These curves were made with a 50-watt regular Mazda lamp in the primary socket. Any voltage within the shaded area may be obtained, over the large current range shown, by adjustment of the variable resistor which is connected between the "135-Volt+" post and "B Amp.+" post.

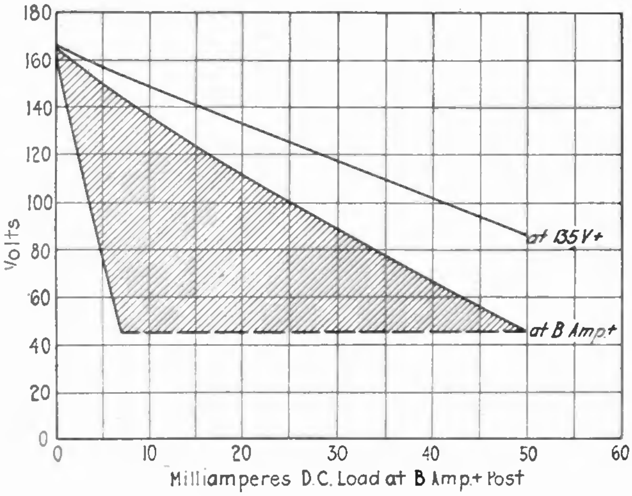

FIGURE 18

In a unit designed to operate with "hard" detector tubes, the detector voltage may be regulated by means of a fixed resistor to a value of 25 to 35 volts. This has been found by practical tests of many radio sets to be the best compromise detector voltage although with most sets using "hard" detectors the voltage may come anywhere between 20 and 40 volts without affecting the results appreciably. With "soft" or gas-filled detector tubes the case is different, and if it is desired to make a "B" battery substitute that will satisfactorily operate sets using "soft" detectors, it is necessary to provide means for adjusting the detector voltage closely to a particular value somewhere between 15 and 20 volts.

Figure 19 shows characteristic curves of a full-wave electrolytic "B" power unit designed to give 90 volts at a load of 40 milliamperes or less in comparison with representative "B" power units using full-wave and half-wave tube rectifiers. The filament adjustment provided in the half-wave tube unit was set to give the normal 5 volts at the filament during the test run. No filament adjustment was provided on the full-wave tube outfit. The very high output voltages of tube-type outfits at low current rates often paralyze the radio tubes so that no sound is heard and the user thinks that the outfit is not operating. Such high-plate voltages, of course, are very damaging to radio tubes having thoriated or coated filaments. The voltage can be reduced to a certain extent by filament adjustment when hot-cathode rectifying tubes are used, but it is rather too much to expect of the average user that he will know by the quality of the reproduction whether or not he is using a plate voltage that will seriously endanger his radio tubes. With the electrolytic power unit the maximum open-circuit voltage is only about half that of the average tube-type unit and the voltage at low current rates can readily be brought down to any predetermined fixed value by the use of a small lamp in place of a 50-watt lamp in the primary circuit.

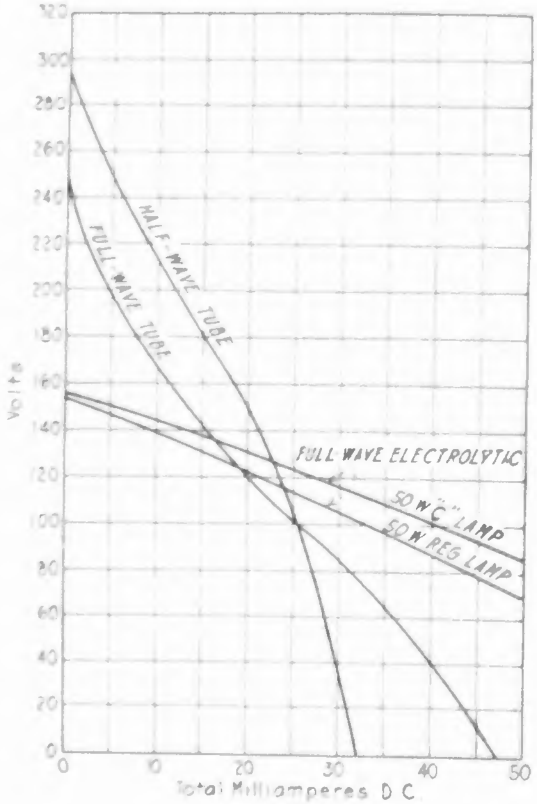

FIGURE 19

The relatively high transformer voltages that must be used with high-impedance rectifiers, such as thermionic and cold-cathode tubes, subjects the condensers of the filter circuit to a severe strain, and it has been a problem to make condensers at a reasonable cost that would stand up in such service. The use of low-impedance electrolytic rectifiers with the comparatively low-voltage transformers thereby made possible solves the condenser problem by removing the excessive strain.

Figure 20 shows the alternating-current watts input in relation to the direct-current load for electrolytic and tube-type "B" power units of the full-wave type. The greater current consumption of the tube-type unit is accounted for by the filament-heating current and the losses due to the high plate-filament impedance of the tube. With regulator or ballast tubes added, the current consumption of the tube-type unit would be considerably greater than is shown in the curve.

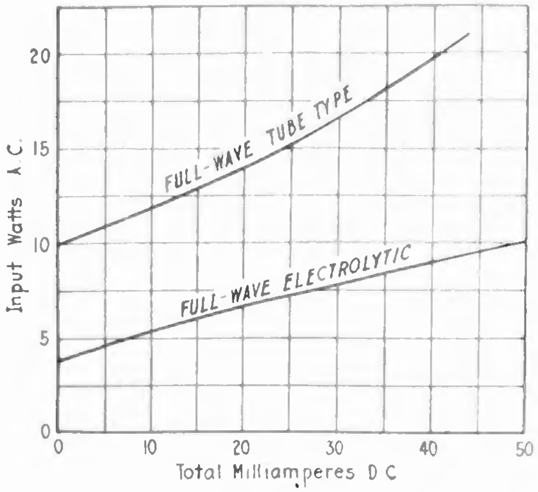

FIGURE 20

"C" VOLTAGE SOURCES

There is some demand for the elimination of "C" batteries, especially where the new UX-120 tube is used in the last audio stage requiring 22½ volts grid bias. The necessary negative voltage can be incorporated in a battery substitute circuit and used successfully where the receiving circuit is adapted to it. It is a question, however, whether battery biasing is not simpler and better.

The writer's experience with dry "C" batteries has been that at least one year's life can be expected of even the smallest of them and that they are no trouble to replace. Certainly there is no need for a storage battery in this service and little need for the complications involved in "C" battery elimination.

It is unfortunate that the little but important "C" battery is sometimes mounted underneath the receiving set or stowed away in some inaccessible place. It is not strange that in such cases the user often fails to renew the "C" battery; that he in fact does not know there is such a thing until eventually he calls in a service man to find what is the matter with the set. It would seem to be good business to place the "C" battery in plain sight inside the set with a special instruction card close by it stating that it must be replaced once a year.

Concluding Remarks

Rectifiers and smoothing filters, which are the basis of all present battery substitutes, are very old devices and were used even in combination long before the days of radio. The old German patent to Koch and Sterzel, dated December 5, 1906, showed such a combination. The successful application of the idea to radio awaited only the development of a suitable rectifier.

There does not seem to be anything very complicated about the design and action of a smoothing filter, notwithstanding the mass of mathematics in the literature on the subject. The condensers appear to act simply as storage tanks which receive the impulses of rectified current and deliver current of smoother form. The choke coil appears to act as a fly-wheel, or perhaps we should say as a turbine having a fly-wheel, which tends to keep the current flowing smoothly in one direction. A double-section filter consisting of two choke coils and three main condensers seems to be more economical of material for a given result than a single-section filter consisting of one larger choke coil with two larger condensers. Good smoothing can be obtained either way. The important thing seems to be to have ample choke coil inductance and condenser capacity.

Naturally, the continuous succession of current ripples from a full-wave rectifier is easier to smooth out than the separate surges of current from a half-wave rectifier. Half-wave rectification necessitates a larger smoothing filter than full-wave rectification for satisfactory results as to hum elimination. Even when no real hum is produced, the use of a half-wave type power unit will often cause a low gurgling or fuzziness in speech or solo voice reproduction, apparently due to current undulations or irregularities at a frequency below the audible range. This form of distortion may not be noticed by the average listener, but it is very objectionable to the critical ear.

Some radio receivers, notably radio-frequency loop sets having one or more reflexed stages, are difficult to operate without hum on an ordinary "B" battery substitute and require some special provision for grounding to eliminate the hum even when the best of smoothing filters is used. In other cases, the receiving set is very sensitive to magnetic induction by the transformer of the power unit, so that the power unit must be placed at a distance from the set, or very heavy shielding must be used. Close cooperation between the set manufacturer and the power unit manufacturer can be the means of eliminating these exceptional difficulties and should bring about a simpler and better use of the principles embodied in present socket power units.

SUMMARY: This paper describes and gives characteristics of the various present-day sources of "A," "B," and "C" power for radio receivers, namely, storage batteries, dry primary batteries, trickle-charge power units and battery substitute devices.

The development of radio storage batteries from the earliest types up to the highly-specialized radio "A" and "B" batteries of today having built-in charge indicators, visible water level and spray-proof construction is traced and information is given on "A" socket power units containing such batteries in combination with newly-developed trickle chargers.

Announcement is made of a perfected aluminum electrolytic rectifier. "B" battery substitutes embodying this rectifier are described and their electrical characteristics are given. Rectifiers and smoothing filters generally and their application to radio uses are discussed.

DIRECTION DETERMINATIONS OF ATMOSPHERIC DISTURBANCES ON THE ISTHMUS OF PANAMA*

By

L. W. Austin

Laboratory for Special Radio Transmission Research

Conducted Jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy.

It has long been known that atmospheric disturbances in general originate over land rather than over the ocean. It is also known that the sources of the tropical disturbances seem to follow the sun in its changing path between the northern and southern hemispheres.[1]

It was therefore to be expected that during the winter in Panama (10° north), the atmospheric disturbances would come chiefly from the mainland of South America, while in summer they might be expected to come from the direction of Central America and Mexico. In addition, during the rainy season, it could be assumed that there would be a considerable amount of local disturbance generated in the low mountain chain which forms the backbone of the isthmus. It was not known, however, whether these local disturbances would outweigh those coming from the larger land masses.

During February and March, 1925, I made directional observations on the atmospheric disturbances at frequencies of 21.4 and 15 kc. (14,000 and 20,000m.) in the U. S. Naval radio receiving stations at Balboa and Colon, at the two ends of the Panama Canal. The measurements were afterward continued by the personnel of the two stations.

The method used in the measurements was first described in 1920.[2]

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[1] DeGroot, The Proceedings of The Institute of Radio Engineers, vol. 5, page 75; 1917. Goldschmidt and Braillard, La T. S. F. au Congo Belge, Hayez 112, Rue de Louvain Bruxelles, 1920. Austin, Journ. Franklin Institute, p. 619; 1921. Round, Eckersley, Tremellen & Lunnon, Journ. I. E. E. (London), vol. 63, page 62; 1925.

*Received by the Editor, April 11th, 1926. Published by permission of the Directors of the National Bureau of Standards of the Department of Commerce.

[2] Austin. Journ. Franklin Institute, page, 619; 1921.

The apparatus shown in the figure consisted of an 8-ft. (2.44-m) coil antenna with 48 turns, which was combined with a small single-wire antenna to form a unidirectional receiving combination. In the measurements the general direction was first found by rotating the coil and adjusting the antenna coupling and resistances until the disturbance maximum was obtained with the antenna reversing switch S thrown in one direction, and the minimum when it was thrown in the other. The absolute direction in which signals were strengthened with the switch in a certain position was determined by observations on a transmitting station in a known direction. When the general direction had been determined, the coil was turned approximately at right angles to the indicated disturbance direction; the switch S was then rapidly reversed, the coil being at the same time slowly moved until the position was found in which the sound of the disturbances in the telephones was of the same intensity with the switch in its two positions. In general there were a certain number of degrees on the coil scale over which the sound equality was maintained. The center of this zone of equality was the scale reading for which the coil was at right angles to the average disturbance direction, since in this position the coil was inactive, the whole reception being from the antenna. By this method good readings can be obtained when no direction at all can be observed on the coil antenna alone.

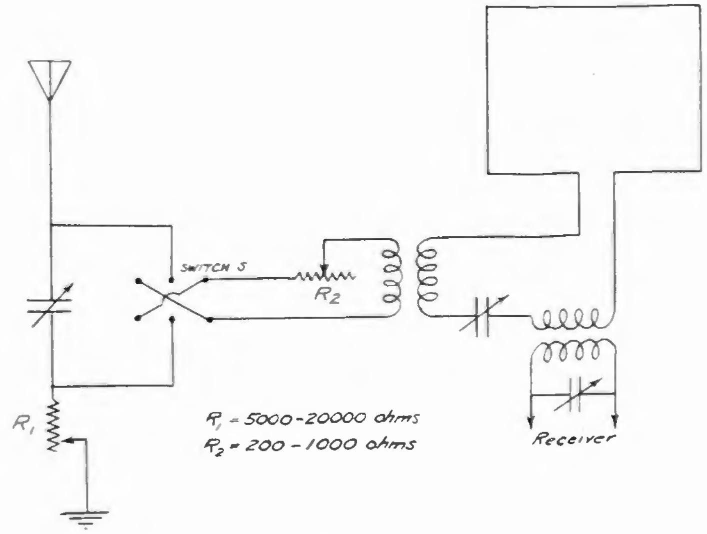

FIGURE 1

The Table shows the results of the observations from February to November, 1925. Those taken from February to the end of June were made by observers who had received personal instruction in the method of measurement and are considered more reliable than those taken later. Owing to changes in the personnel of the stations, the work was apparently entirely interrupted during July and August. During the months in which accurate measurements were generally possible, the bearings in the table are given in degrees, During the more disturbed periods the directions are only roughly indicated.

DIRECTION OF ATMOSPHERIC DISTURBANCES AT BALBOA AND COLON
FEBRUARY TO NOVEMBER, 1925

	BALBOA			COLON		
		No. of Observations			No. of Observations	
	3 P M	10	All (120°-130°)	—	—	—
March	10 A M 3 P M 10 P M	— 25 —	— — — All (125°-135°) — — —	10 A.M. 3 P.M. 10 P.M.	9 9 9	All (120°-130°)** All (130°-140°) All (120°-140°)
April	10 A M 3 P M 10 P M	7 29 7	7 NB*, 20 NB, 7 SE, 1N, 1E 5 NB, 2N	10 A.M. 3 P.M. 10 P.M.	28 25 23	All (120°-145°) All (130°-145°) All (120°-140°)
May	10 A M 3 P M 10 P M	9 31 9	4 NB, 5 (NW-N) 15 NB, 15 (NW-N), 1 NE 8 NB, 1 NE	10 A.M. 3 P.M. 10 P.M.	16 13 3	2 NB, 14 SE 2 NB, 11 SE 3 SE
June	10 A M 3 P M 10 P M	9 30 9	3 NB, 6N 5 NB, 25 N 9 NB	10 A.M. 3 P.M. 10 P.M.	15 14 4	All SE All SE All SE
			No observations in July and August			
Sept	— — —	— — —	— — — — — — — — —	10 A.M. 3 P.M. —	30 30 —	1 NB, 29 SE 1 NB, 28 SE, 1 S — — —
Oct.	10 A M 3 P M 10 P M	31 31 31	26 (NW-NE), 5 SE 3 NB, 23 (NW-NE), 5 SE 25 NB, 5 (W-N), 1 SE	10 A.M. 3 P.M. —	31 31 —	All (130°-140°) All (130°-145°) — — —
Nov.	10 A M 3 P M 10 P M.	30 30 15	19 (E-SE), 8 (NW-NE), 3 (S-W) 1 NB, 20 (SE-S), 3 (SW-W), 6 (NW-NE) 13 NB, 1 SE, 1 NE	10 A.M. 3 P.M. —	30 30 —	All (135°-140°) All (130°-145°) — — —

* NB—No definite bearings.
** The angles are measured clockwise from north.

The data obtained seem to warrant the following conclusions:

1. During the dry season, probaly from January 15 to April 1, the atmospheric disturbances both at Balboa and Colon come almost entirely from the South American continent, from the direction of the high Andes in northern Colombia.

2. When the dry season comes to an end and local storms begin to appear, the local disturbances from the low mountains of the isthmus begin to be prominent. This shifts the prevailing

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

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

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

PRELIMINARY NOTE ON PROPOSED CHANGES IN THE CONSTANTS OF THE AUSTIN-COHEN TRANSMISSION FORMULA*

By

L. W. Austin

(Laboratory for Special Radio Transmission Research)

(Conducted jointly by the Bureau of Standards and the American Section of the International Union of Scientific Radio Telegraphy)

It has been known for a number of years that the Austin-Cohen transmission formula, while satisfactory for moderate distances and wave lengths, gives values at 6,000 km. which are only about one-half of those observed, and that at 12,000 km. the ratio appears to be about one to four.

Our original formula for daylight signals over salt water of 1910-1914[1] was written

$$E = 120\pi \frac{h\,I}{\lambda\,d} \sqrt{\frac{\theta}{\sin\theta}}\, e^{-u} \text{ (volts km. amp.)}$$

where $u = \dfrac{0.0015\,d}{\lambda^{0.5}}$. The constants in u were determined empirically from shunted telephone observations for distances up to 2,000 km. and frequencies between 1,000 kc. ($\lambda = 300$ *m.*) and 80 kc. ($\lambda = 3{,}750$ m.).

Naturally I have been desirous of bringing the formula into better agreement with the observations. Acting on the advice of some of my European colleagues in the URSI, I have given up the idea of altering the Hertzian portion of the formula since this is the portion that rests on a theoretical basis, and have given attention only to possible changes in the values of the constants of the exponential term. These can easily be arranged so as to give excellent agreement for limited ranges of wave length and distance, but in order to give the formula a general character, it should be at least approximately accurate for all frequencies between $f = 1000$ kc. ($\lambda = 300$ m.) and 12 kc. ($\lambda = 25000$ m.)

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*Published by permission of the Director of the Bureau of Standards of the U. S. Department of Commerce. Received by the Editor, February 15, 1926.

[1] Bureau of Standards Bulletin VII, p. 315, 1911, Reprint 159; and XI, p. 69, 1914, Reprint 226.

During recent years a very considerable amount of experimental data on signal field strength has been collected. Long series of transatlantic observations have been taken by the American Telephone & Telegraph Company, The Radio Corporation of America, The Marconi Company, the French Army at Meudon, near Paris, and the Bureau of Standards. The Marconi Company has also collected a vast amount of experimental reception data from various transmitting stations during the voyages of the S. S. *Dorset* from England to New Zealand (February and March, 1922) by way of the Panama Canal, and of the S. S. *Boonah* from Australia to England (June, July, August, 1923) through the Suez Canal. In addition, the Indian Post Office made field intensity measurements at Karachi, India, on several of the European high-power stations from November, 1921, to January, 1923.

All this material now makes it possible to determine the variations of field intensity with varying wave length and distance with some degree of certainty. The relative value of the different series of observations of course differs widely. Those in which the same stations are observed regularly over one or more years are naturally the most valuable. Those which have been taken during the voyages of ships, while important, may show large variations during different parts of the voyage, since in general only one observation is taken at any given distance from the transmitting station, and the results can at best represent the conditions during only limited portions of the year.

The use of much of the experimental material for deriving a formula which must by definition hold for an all-water path is complicated by the fact that in most cases of long distance transmission the waves pass for a considerable distance over land. For example, the shortest great circle distance between Nauen, Germany, and Washington is roughly 25 per cent land, Rocky Point to London twenty per cent., Buenos Aires to Washington more than fifty per cent, while from Karachi, India, to the European transmitting stations nearly the whole path is over land.

The question of the relative land and water attenuation in radio transmission is not at all settled. It is generally agreed that for wave lengths below 5,000 m., land attenuation is much greater than that over water, and it seems probable that there is considerable, though decreasing, land effect from 5,000 m. up to at least 15,000 m. The amount of this effect naturally depends upon the character of the land traversed, and especially on conditions in the neighborhood of the transmitting and receiving stations. Observations at Washington covering more than two years indicate that signals from Bolinas, California, near San Francisco $f=22.9$ kc. ($\lambda=13{,}100$m.) have practically the same attenuation as over water, if the reported effective height of the station is correct. On the other hand, a much more limited number of observations in Washington on San Diego, and in San Diego on the east coast stations indicate nearly twice the water attenuation. This may be due to local conditions near San Diego as this has always been thought by operators to be less favorable for radio work than San Francisco.

Notwithstanding these uncertainties, it has seemed worth while to make use of the accumulated data for obtaining at least tentative constants for a new formula. Up to the present a value of $u=\frac{0.0014\,d}{\lambda^{0.6}}$ seems to give fairly satisfactory results. This may be slightly varied as more and better observational data are obtained. Table 1 gives the ratio of the new to the old values of e^{-u} at various wave lengths and distances, and Table 2 shows a collection of observed intensity values from various sources which are in good, or fairly good, agreement with those calculated according to the revised formula. The observations at Cliffwood and New Southgate[1] were taken by the American Telephone and Telegraph Company and those at Karachi by the Indian Post Office.[2]

TABLE I

RATIO OF NEW AND OLD VALUES e^{-u}

λ km.	*d* km. 500	1,000	2,000	4,000	6,000	12,000
0.3	0.93	0.86	0.72			
0.5	1.00	1.00	1.00			
1.0	1.05	1.11	1.22			
2.0	1.07	1.14	1.31			
3.0	1.07	1.15	1.33	1.77		
5.0			1.32	1.72	2.25	
10.0			1.31	1.62	2.09	4.40
16.0				1.55	1.94	3.75
24.0					1.80	3.25

The series at San Diego[3] was taken by the Bureau of Standards, while the Marion and Nauen observations on the S. S. *Dorset* and *Boonah*[4] by the Marconi Company represent the averages taken from the observation curves of the two ships, one in March, 1922, and the other in July, 1923. Bordeaux

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[1] "Bell System Technical Journal," vol. 4, p. 459; 1925.
[2] "London Elec.," vol. 91, p. 164; 1923.
[3] "Jour. Wash. Acad. Sci.," vol. 15, p. 139; 1925.
[4] "Jour. I. E. E." (London), vol. 63, p. 933; 1925.

changed its wave length from 23,400 m. to 19,000 m., at about the time the *Boonah* sailed from Australia, and this change resulted in such an increase in the efficiency of the station that the observations on the two ships could not be fairly compared.

In a later paper the rest of the available data, both favorable and unfavorable to the formula, will be discussed.

TABLE II

SOME CALCULATED AND OBSERVED FIELD INTENSITIES

Sending Station	Receiving Station	f kc.	λ km.	d km.	E μv/m		
					cal.	obs.	
Nauen	Cliffwood, N. J.	23.8	12.6	6,350	44	42	1922-1923
Marion	New Southgate, Eng.	25.8	11.6	5,280	40	53	1923-1924
Rome	Karachi, India	28.0	10.7	5,230	24	20	Nov., 1921 to
Bordeaux	Karachi, India	12.8	23.4	5,900	60	68	Jan., 1923
Ste. Assise	Bureau of Stds.	20.6	14.5	6,150	53	48	1923
Bordeaux	Bureau of Stds.	12.8	23.4	6,160	67	71	1922
Buenos Aires	Bureau of Stds.	23.6	12.7	8,300	30	37	1924
Cavite, P. I.	San Diego, Cal.	19.3	15.5	11,800	2.7	2.0	Aug. 28-Sept. 22, 1924
Marion	S.S. Dorset & Boonah	25.8	11.6	8,000	11	12	March, 1922 and
				12,000	2.7	3	July, 1923
Nauen	S.S. Dorset & Boonah	23.8	12.6	8,000	21	22	March, 1922 and
				12,000	5.4	5.5	July, 1923
Bordeaux	S.S. Dorset	12.8	23.4	8,000	37	33	March, 1922
				12,000	13	10	

CHOICE OF POWER FOR A RADIO STATION*

By

N. N. Tsiklinsky

and

V. I. Volynkin

(Electrical Engineers, Members of the Russian Society of Radio Engineers, Leningrad, Russia)

The present development of the radio telegraphy is so advanced that the engineer who is designing a radio station has numerous alternative possibilities in solving his problem. He has available three methods of generating continuous waves, these three systems being by the arc, electron tube generator, or radio frequency alternator. The capabilities which these systems offer with respect to power and operating characteristics certainly solve the question of radio communication within the limits of terrestrial distances. There remains only the perfecting of details which do not affect fundamental methods.

The great increase in the available power of generators allows one to solve the problems of radio communication free from narrow technical limitations, as was the case for the earlier spark transmitters. For such spark sets, the constructor was often stopped by the limits of available power, voltage, speed of transmission, and the like, and for these reasons he had to sacrifice economic considerations to technical requirements.

At present the conditions are such that the quantitative design of a radio station can and, therefore, must be considered from an economic point of view, bearing in mind the expenses incurred in the installation and maintenance of the station.

N. Tsiklinsky showed analytically in 1922 that, for a given radio circuit, there is some satisfactory power for which the cost of the radio transmitter is a minimum.[1]

Messrs. E. F. W. Alexanderson, A. E. Reoch, and C. H. Taylor in a paper on trans-Atlantic radio transmission also suggested

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*Presented before the Russian Society of Radio Engineers, Leningrad; in mathematical form by N. N. Tsiklinsky, June 22, 1922, and in final form by V. I. Volynkin, February 24, 1925. Received by the Editor of The Institute of Radio Engineers, July 25, 1925.

[1] "Telegrafia i telefonia bez provodov," number 15, 570-574, August, 1922.

that there is a minimum cost of a radio transmitter for a certain height of the masts and they published two curves of relative cost as a function of the height.[2]

In this paper, an attempt is made to approach this question chiefly from the point of defining that power of the radio station which will give the desired service with the smallest outlay for installation and maintenance.

The cost of a radio transmitter may be looked upon as made up of the combined value of buildings, generating equipment, the antenna with its masts, and the ground connection. Leaving out of consideration the cost of the building as not dependent on the power but determined by other considerations, let us consider the relation between the other three quantities. It is known that the same received signal can be realized by an increase of power of the transmitter and a corresponding reduction of the height of antenna and vice versa. With an increase of power there is an increase in the expenses for machinery and ground connection, but at the same time the cost of the antenna decreases. Combining these components of cost, we can approach a minimum.

For this purpose, one must, of course, have the cost of the chief portions of a radio station as a function of some of its dimensions. These data, which are obtained from usual contractors' estimates, may be presented in the form of a curve $S=f\ (Q)$, where S is the cost and Q the size. For purposes of simplification, one can divide the cost of the whole installation into three principal parts, namely:

GENERATING APPARATUS AND GROUND CONNECTION:
$S_g=f_1\ (P)$ where S_g is cost, P power in the antenna.
MASTS:
Q $S_m=f_2\ (H)$ where S_m is cost and H is height of transmitting antenna.
ANTENNA:
$S_a=f_3\ (P,\ H)$

It is evident that the sum of these quantities is the cost of the whole radio station excluding the buildings and ground, which may, if desired, be included into the equations (Q). In this way, we obtain:

$$S=f_1\,(P)+f_2\,(H)+f_3\,(P,\,H) \tag{1}$$

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[2] "General Electric Review," XXVI, 7, 464, July, 1923.
"Journal of American Institute of Electrical Engineers," XLII, 7, 693, July 1923.

In order to find the minimum of expression (1) graphically, it is necessary to express all the costs as a function of one quantity, for example P, making use of the transmission formula:

$$F = A \frac{h\,I}{\lambda\,d} e^{-a\,d\,\lambda^{-\delta}} \tag{2}$$

where A, a and δ are the correct coefficients for the given case, the choice of which depend on the nature of the transmission path, F is field intensity at receiving end, I the current in transmitting antenna, λ the wave length, d the distance, and h the effective height of transmitting antenna.

Solving (2) with regard to I, squaring it, and multiplying by the resistance R, we obtain an expression for the power of the transmitting station. The resistance of the antenna R is the sum of two quantities: radiation resistance $R_{\mathfrak{z}} = 1580\left(\frac{h}{\lambda}\right)^2$, and the ohmic loss resistance, which we will express in accordance with Mr. Shuleikin's approximate formula[3]

$$R_\Omega = R_o \frac{\lambda}{\lambda_o} \tag{3}$$

where R_o is the loss resistance at the fundamental wave length λ_o, hence:

$$P = a + b\,h^{-2} \tag{4}$$

or, in another form,

$$P = a\left(1 + \frac{R_o\,\lambda^3}{1580\,\lambda_o} h^{-2}\right)$$

where the coefficients have the following values:

$$a = \frac{1580\,F^2\,d^2\,\varepsilon^{2\,a\,d\,\lambda^{-\delta}}}{A^2} \tag{5}$$

$$b = \frac{R_o\,F^2\,\lambda^3\,d^2\,\varepsilon^{2\,a\,d\,\lambda^{-\xi}}}{A^2\,\lambda_o} \tag{6}$$

We may transform the last formulas to be applicable to the case of the optimum wave length for a given distance of transmission, which wave length is given by the known equation

$$\lambda_m = (a\,\delta\,d)^{1/\delta}.$$

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[3] Radiotechnik," number 14, 416, February, 1921.

Substituting this expression for λ in (5) and (6) we get

$$a_m = \frac{1580\, F^2\, d^2\, \varepsilon^{2/\delta}}{A^2}$$

$$C = \frac{R_o\, F^2\, (a\,\delta)^{3/\delta}\, d^{(2\delta+3)/\delta}\, \varepsilon^{2/\delta}}{A^2\, \lambda_o}$$

If we accept Austin's formula, that is:

$A = 377\ \Omega$, $a = 0{,}0015\, km.^{-1/2}$ and $\delta = 0.5$, we get

$$A_{mA} = 0{,}608\, F^2\, d^2; \qquad [W, V, km] \qquad (5a)$$

$$C_{mA} = 6{,}85.10^{-23}\, \frac{R_o\, F^2\, d^8}{\lambda_o}; \qquad [W, V, km] \qquad (6a)$$

$$\lambda_{mA} = 5{,}63.10^{-4}\, d^2 \qquad [km]$$

The effective height of an antenna may be expressed by a coefficient depending on the current distribution (form factor), using any known formula, such as those of Pierce or Shuleikin:

$$h = \gamma\, H$$

where $\gamma = F\,(H.\,\lambda)$ is form factor.

Hence for a given wave length

$$P = a + C\,[H.\,F\,(H)]^{-2} \qquad (4a)$$

Our next step is to transform the function $S_m = f_2\,(H)$ into the function $S_m = \phi_2\,(P)$, keeping in mind the relation between H and P, which is given by equation (4a).

In order to carry out a transformation, we take a sequence of values S_{m1}, S_{m2}, S_{m3} . . . . . ., find their abscissas H_1, H_2, H_3 . . . ., and using formula (4a) we calculate the corresponding values P_1, P_2, P_3 . . . .. which we lay aside as new abscissas for the same ordinates. In this way we obtain a number of points for the needed curve $\phi_2\,(P)$ (Figure 1).

The cost of the antenna depends upon the power and the height of suspension since, for the same power, if the height is increased, we are obliged to use a larger number of wires to secure the required capacity.

Therefore, to reckon the cost of the antenna as a function of P, it is indispensable to ascertain the corresponding heights H, according to formula (4a), and in this way obtaining $S_a = \phi_3\,(P)$.

In order to determine the minimum cost, it is then sufficient to add the three functions $f_1\,(P)$, $\phi_2\,(P)$, and $\phi_3\,(P)$ graphically, and the minimum will be found on the resulting curve (Figure 1).

However, this will not yet prove the full advantage of the corresponding arrangement, since in most cases the designs are made to give the least operating expenses of the projected station and not the minimum first cost.

Only in exceptional cases, where only very limited capital is available, is it desirable to be guided by considerations of minimum first cost while being fully prepared for an increase in the operating cost of the service and the consequent decrease of profits.

Therefore, in general, it is necessary to consider methods of calculating the annual operating charges, or, in other words, the cost per word transmitted and the total traffic. For this purpose, each of the curves $S_g = f_1\ (P)$, $S_m = \phi_2\ (P)$, and $S_a = \phi_3\ (P)$ must be multiplied by its correspoding coefficient, in which are taken into consideron amortization, expenses of maintenance, interest on capital, and other expenses which depend on the total value of the station.

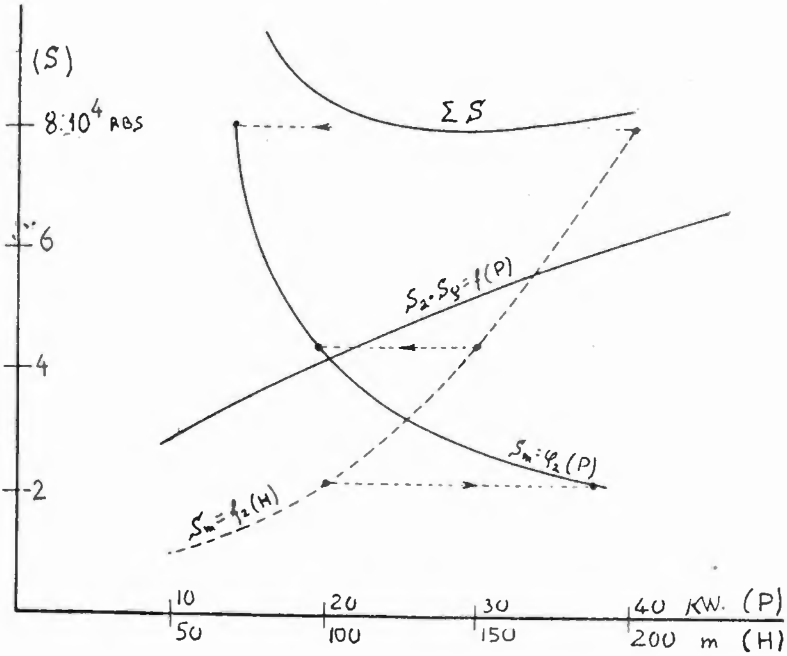

FIGURE 1

If, to the new curves (which differ from the former ones only in scale), we add the curves of annual expenditure for electric power (which is straight line passing thru the origin), and the administration expenses (a straight line of small inclination) and find their sum, we will obtain a curve of annual expenses for the operation of a radio station as a function of power. (The cost of the buildings and ground may also be taken into account.)

The last curve also having a minimum point will, therefore, indicate the most profitable power from the operating profit point of view.

As an example, which illustrates the application of the above method (but which does not pretend to be very precise or strict in treatment), let us determine the relation between the power in the antenna and the height of the masts for a radio station with an effective range of $d = 3{,}000$ km., at the optimum wave length, and with a field intensity at the receiving end of $F = 20.10^{-3}$ v./km.

For this case, we may accept Dr. L. W. Austin's formula, and therefore $\lambda_{mA} = 5.07$ km., and by taking a ratio of 2.5 to 1, as that between the radiated wave length and the natural wave length, of the antenna, we obtain $\lambda_o = 2$ km.

Taking into consideration data from stations already built, we may assume $R_o = 3\Omega$.

Evaluating coefficients a and b according to formulas (5a) and (6a),

$$a_{mA} = 0{,}608 \,.\, (20.10^{-3})^2\, 3{,}000^2 = 2{,}190\ W.$$

$$b_{mA} = 6{,}85.10^{-23}\, \frac{3 \,.\, (20.10^{-3})^2\, 3{,}000^8}{2} = 270\ W.\, km^2.$$

Hence

$$P = 2190 + \frac{270}{h^2} \tag{4b}$$

Let us now take into account the dependence of form factor on the height, according to M. Shuleikin's approximate formula[4]

$$h = H\left(1 - \frac{H}{2\,L}\right) \tag{7}$$

where H is height from the ground to the highest point of the antenna, L the length of the vertical and horizontal parts of the antenna (outward in one direction only). This formula is accurate and can be used when $\frac{\lambda}{\lambda_o} \gg 2$, as is the case.

Substituting (7) in (4b) and calculating a sequence of values of P for chosen arbitrary values of H, we get Table I.

At the same time we must determine the cost of wooden masts of the same heights H. As numerical data for the height from the earth to the highest point of the aerial we take those given by A. Shorin.[5]

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[4] Previous citation, page 408.

[5] "Telegrafia i telefonia bez provodov," number 16, 599-609 (October, 1922).

The results are also tabulated in Table I.

TABLE I

H (meters)	h (kilometers)	P (watts)	S_m (gold roubles)	
50	0.0470	124,400	10,000	2 masts
100	0.0875	37,400	22,500	3 "
150	0.125	19,500	45,000	4 "
200	0.150	14,400	80,000	4 "

Having the curve $S_m = f_2\ (H)$ (Figure 1), and with the aid of Table I, we draw $S_m = \phi_2\ (P)$ inserting for some values of S_m, instead of H, the corresponding values of P.

Further, we will sum up the cost of all generating and radio frequency machinery and of the antenna erection for several values of P, assuming a tube transmitter, and then draw the sum of curves $S_g = f_1\ (P)$ and $S_a = \phi_3\ (P)$. The sum of the three curves $S_m + S_a + S_g$ gives the total cost, which in this example has the minimum value $S = 80{,}000$ roubles, when $P = 30$ kw. and $H = 115$ m. (Figure 1).

If we assume the field intensity instead of 20 μv./m. to be 50 μv./m., the minimum cost will be 90,000 roubles with a power of 46 kw. and a height of masts of 88 m.

As is seen from the example given, near the minimum the cost changes very little with changes of power, which fact gives the designer considerable leeway, and at the same time avoids serious errors due to inaccuracy in the preliminary assumptions, such as is inevitable in such calculations.

To determine the minimum operating expenses, let us take on the average 5 percent for amortization as applied to the curves $(S_g + S_a)$, and for the curve S_m – 10 percent. We also assume interest on capital for all the curves at 6 percent, and repair expenses (including burnt-out tubes), 4 percent. Then the coefficients by which the cost curves are to be multiplied in order to obtain the yearly expenses will have the following values:

for $S_g + S_a$ – 0.15

for S_m – 0.20

We can now calculate the expense of electrical power at the price of 6 copecks kw. hr. for 10 working hours per day at an efficiency of 50 percent.

$$\sigma_p = 365\,.\,(10)0.06\,\frac{P}{0{,}50} = 438\,P \qquad]\mathit{Roubles,\ k}]$$

Let us draw in Figure 2 the curves

$$\sigma_{g,a} = 0.15\,(S_g + S_a),\quad \delta_m = 0.2\,S_m,\quad \text{and}\quad \sigma_p = 438\,P.$$

Summing these up, we get the curve of operating expenses as a function of power (Figure 2); and the curve of administration expenses, being almost parallel to the axis of abscissas, will not have an appreciable influence on the position of the minimum, and, therefore, may, for simplicity, be neglected.

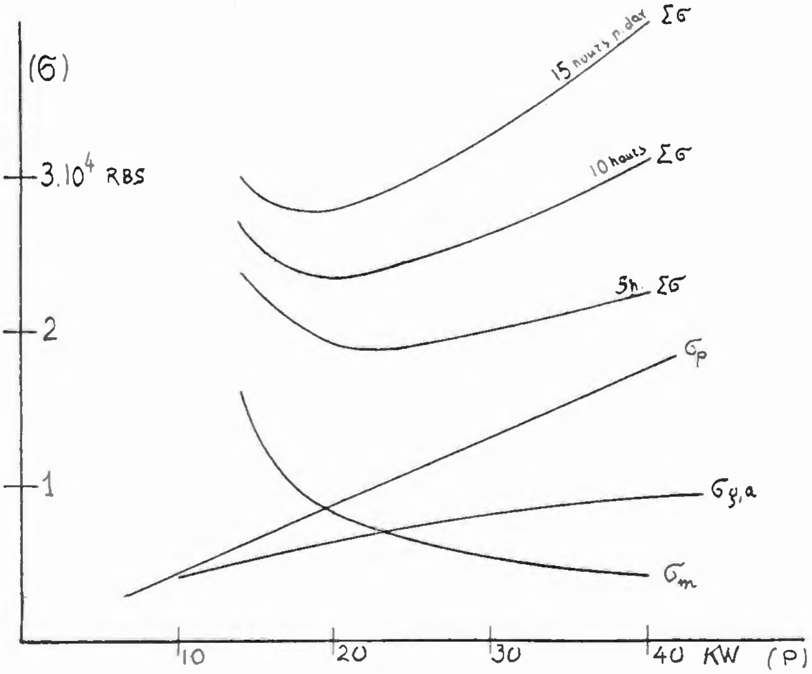

FIGURE 2

For comparison, we have drawn also in Figure 2 the operating expenses if the station works 5 or 15 hours per day. As can be seen, the change in traffic of 50 percent leads to a shift of the minimum point on the average of 10 percent.

In this way, for the case of a tube transmitter, we obtain the following feasible values of power:

30 kw. for minimum first cost, and
20 kw. for minimum operating expenses.

As the curve of cost has a flat minimum and the curve of operating expenses a sharper one, we should select a power kw.

and this will increase the initial expenses only 5 percent above the minimum. And finally, the designer should make similar calculations for the arc generator and the radio frequency alternator, and finally choose the most economical and suitable system.

In conclusion, it is to be noticed that the functions $S_m = f_2\ (H)$ and $S_g = f_1\ (P)$ for the given type of masts and transmitter are applicable with sufficient accuracy in other cases.

Functions $S_m = \phi_2\ (P)$ and $S_a = \phi_3\ (P)$ only are related specifically to the individual case and must be recalculated for different cases of transmission, since they will then have a different form, depending upon the coefficients a and b in formulas (5) and (6).

SUMMARY: The cost of a radio station may be looked upon as the combined value of the buildings, the generating machinery, and the antenna with its masts and ground connection. It is shown in this paper that, for a given radio transmission, the necessary power P in the antenna and the effective height h of the antenna are connected by an equation $P = a + bh^2$. By means of this formula, the cost of the antenna and the masts, as a function of their dimensions, may be expressed as a function of the power, hence all the curves of cost may be combined graphically. The resulting curve of total cost clearly shows that there is some power for which the cost of a radio transmitter is a minimum.

A method is also given for choice of power by which the annual expenses are a minimum.

The methods described above are illustrated by a determination of the power in the antenna and the heights of the masts for a radio station with a range of 3,000 km. and operating on an optimum wave length of 5,070 m. In this instance, the power for the least outlay is 30 kw. and for the lowest annual expenses, 20 kw.

DISCUSSION
ON
"POLARIZATION OF RADIO WAVES," BY GREENLEAF W. PICKARD

BY

E. W. ALEXANDERSON

Mr. Pickard mentions in the introduction to his paper that it has been assumed from the inception of the radio art that if the wave was vertically polarized at its origin it would remain so at all distances and that the measurements of Austin and others confirm this assumption. There can be no doubt about the unanimity of opinion that has existed on this subject, but a number of facts have recently been brought out through work on polarization of short waves which leads us to think that the evidence collected in the past may be given a different interpretation.

Extensive systematic measurements undertaken by A. Hoyt Taylor, Austin, and others have shown that direction-finder bearings on long wave stations show great irregularities during the hours of darkness. It has been assumed that these irregularities meant actual change in the direction of wave propagation. We find now in dealing with short waves that such apparent changes in direction of wave propagation can be reproduced regardless of daylight by controlling the plane of polarization of the radiated wave. When a wave is radiated from a horizontal loop, it is found in the immediate neighborhood of the antenna that a direction finder gives bearings at right angles to the direction where the station really is. In other respects, the instrument responds as if it were receiving an ordinary vertically polarized wave. The loop gives maximum response in the vertical position and nearly zero response in the horizontal position. This evidence may be coupled with the experience in aviation practice, according to Capt. W. H. Murphy, that a direction-finder station on the ground may give false indications on an air-plane as great as 45 degrees or more. The false indications have proven to be the greatest if the antenna is allowed

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*Received by the Editor, February 4, 1926.

to trail horizontally, and if the air-plane is flying at right angles to the direction from which bearings are taken. The antenna is therefore held as vertical as possible by a weight and the personnel is instructed to take bearings only when the plane is pointed towards the observing station. In the light of what we now know, these experiences can clearly be interpreted to mean that an antenna trailing at right angles to the line of observation radiates horizontally polarized waves and that the false indications of the direction finder are due to the wave polarization. The inference from this is also that the apparent changes in direction of long waves observed by Taylor and Austin are due to the presence of horizontally polarized wave components. In fact we may say that this apparent change of direction of propagation is a characteristic by which the horizontally polarized wave may be recognized.

It remains to explain why the horizontally polarized wave is received at maximum intensity with the loop in the vertical position. The reason for this is the following:

The electromotive forces of the horizontally polarized wave are parallel to the ground. However, close to the ground we cannot have any difference of potential because of the short circuiting effect of the ground. However, the horizontal electromotive forces are transformed into currents in the ground. These ground currents are at right angles to the true direction of wave propagation. The fact that the loop gives maximum response in vertical position at right angles to the direction of wave propagation is explained by these currents in the ground which are also at right angles to the wave propagation and therefore inductively related to such a loop. From this reasoning, it can be concluded that the false direction indications are to be expected only in the close proximity to the ground. Some measurements have been made which confirm these conclusions. A set of tests was made exploring the characteristics of a wave radiated from a horizontal loop by making frequent measurements to within ten miles of the station. The composite picture which was obtained from this test was a continuously twisting plane of polarization with alternate points of plane and circular polarization. At intermediate points the polarization was eliptical. The plane polarization was indicated by sharp direction bearings and circular polarization by equal intensity from all directions. The observations indicating plane polarization gave bearings sometimes towards the transmitting station and sometimes at right angles.

Besides these measurements around the vertical axis, observations were made with the loop in the horizontal plane. On flat fields the horizontal position gave nearly zero response. At the top of a steep hill and a high bridge the response in the horizontal plane was equal to the vertical.

These results indicate the presence of a horizontal and a vertical wave component with different velocity of propagation. Whenever the two waves are in phase, they give plane polarization. When they are 90 degrees out of phase they give circular polarization. The observation with the loop in the horizontal position on the top of the hill and the bridge show that even a moderate elevation is sufficient with short waves to reach the point where the horizontal electromotive forces are not short-circuited by the ground.

All this leads me to think that horizontal polarization is not confined to short waves only. Direct observation of horizontal polarization at long waves could be made only at great heights, but indirect observations through the effect of ground currents can be made by ordinary direction finders at any wave length. If this theory is correct it means that the irregularities of direction-finder indications recorded by A. Hoyt Taylor and L. W. Austin on long waves can be explained by the presence of horizontally polarized wave components.

DISCUSSION
ON
"THE SHIELDED NEUTRODYNE RECEIVER," BY DREYER AND MANSON

BY
L. A. HAZELTINE

The paper is largely a descriptive one, giving the final results of an admirable engineering development for which Messrs. Dreyer and Manson were mainly responsible. It has seemed that it might be appropriately supplemented by a theoretical discussion of some of the considerations that enter into the electrical design of a receiver employing tuned radio-frequency amplification. The most basic theoretical considerations are those of *sensitivity*, *selectivity* and *fidelity*. By "fidelity" is meant the degree of uniformity with which a band of frequencies is amplified, this band extending on each side of the carrier frequency sufficiently to cover the useful audio frequencies, so that the latter may finally appear with uniform amplification and may thus faithfully reproduce the modulating wave at the transmitter.

All of the above qualities are best illustrated graphically on a *resonance curve*, in which amplification is plotted against frequency: sensitivity is represented by the amplification at the resonant frequency; selectivity, by the falling off in amplification as we depart considerably from the resonant frequency; and fidelity, by the uniformity of amplification in the immediate neighborhood of the resonant frequency.

Let us first derive the equation of the resonance curve. Figure 1a shows the circuit of a single tuned amplifier stage, and Figures 1b and 1c show simplified equivalents. The circuit constants are as follows:

μ, amplification factor of vacuum tube;
g_p, plate conductance of vacuum tube;
L, self-inductance of secondary coil;
C, capacity tuning secondary circuit;
g, conductance of secondary circuit;

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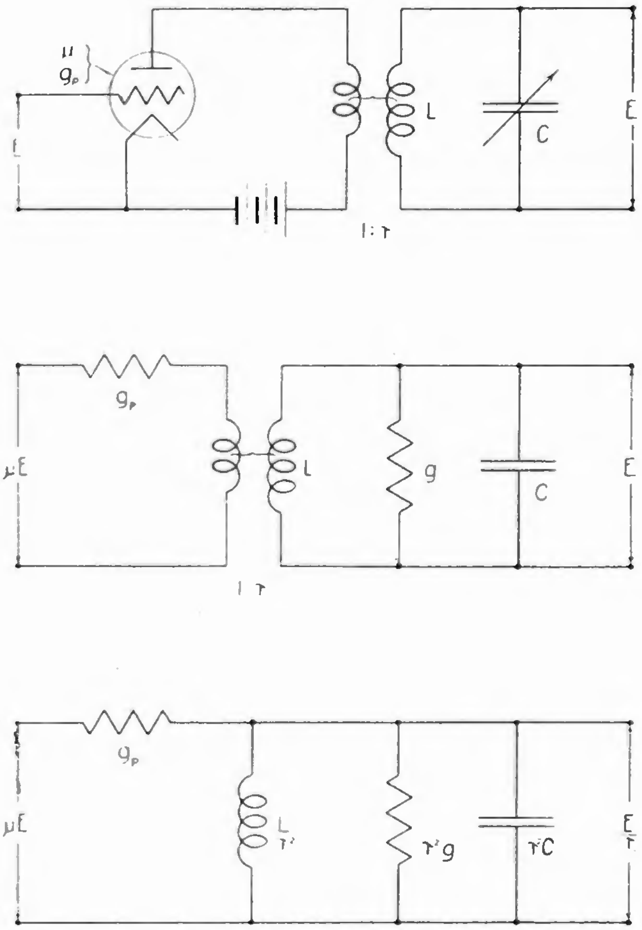
τ, ratio of transformation, secondary to primary;
ω, angular frequency (2π times frequency).*

The amplification is defined as the ratio of the output voltage E' to the input voltage E. If these voltages are expressed as complex quantities E' and E, the amplification is



FIGURES 1a, 1b, 1c—One-Stage Vacuum-Tube Amplifier and Simplified Equivalent Circuits

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*NOTES: It is convenient in vacuum-tube calculations to use conductances rather than resistances, and conductances often vary less rapidly with variations in frequency; if r is the total series resistance of the secondary tuned circuit, then $g = \frac{r}{\omega^2 L^2} = \frac{Cr}{L}$. It is assumed that the primary and secondary coils are closely coupled, in which case τ is the ratio of turns; otherwise τ may be taken as the ratio of secondary self-inductance L to the mutual inductance—that is, to the voltage ratio. It is also assumed that the primary capacity is negligible; otherwise it can be added directly to $\tau^2 C$. The combined effect of the primary capacity (or of g_p) with looseness of coupling, if considerable, requires a more elaborate derivation. It is also assumed that regeneration has been eliminated, by removing or neutralizing all couplings between the input and output circuits, except, of course, the mutually conductive coupling of the vacuum tube.

also a complex quantity A, and includes the phase difference between the voltages as well as the ratio of their magnitudes:

$$A = \frac{E'}{E}. \tag{1}$$

Directly from Figure 1c, since the same current flows through g_p as through the parallel group, L/τ^2, $\tau^2 g$, $\tau^2 C$, we have the ratio of voltages equal to the ratio of the corresponding impedances:

$$\frac{\dfrac{E'}{\tau}}{\mu E} = \frac{\dfrac{1}{\tau^2 g + \dfrac{\tau^2}{j\,\omega\,L} + j\,\omega\,\tau^2 C}}{\dfrac{1}{g_p} + \dfrac{1}{\tau^2 g + \dfrac{\tau^2}{j\,\omega\,L} + j\,\omega\,\tau^2 C}} = \frac{g_p}{g_p + \tau^2 g + \dfrac{\tau^2}{j\,\omega\,L} + j\,\omega\,\tau^2 C} \tag{2}$$

Substituting in (1),

$$A = \frac{E'}{E} = \frac{\tau\,\mu\,g_p}{g_p + \tau^2 g + j\,\tau^2\left(\omega\,C - \dfrac{1}{\omega\,L}\right)} = \frac{\tau\,\mu\,g_p}{g_p + \tau^2 g + \dfrac{j\,\tau^2}{\omega_o\,L}\left(\dfrac{\omega}{\omega_o} - \dfrac{\omega_o}{\omega}\right)} \tag{3}$$

where

$$\omega_o = \frac{1}{\sqrt{C\,L}} \tag{4}$$

is the resonant angular frequency. Instead of the angular frequency ω, let us use as the variable the natural logarithm,

$$x = log_\varepsilon \frac{\omega}{\omega_o}. \tag{5}$$

Then

$$\frac{\omega}{\omega_o} - \frac{\omega_o}{\omega} = \varepsilon^x - \varepsilon^{-x} = 2\,sinh\,x; \tag{6}$$

and

$$A = \frac{\tau\,\mu\,g_p}{g_p + \tau^2\ g + \dfrac{j\,2\,\tau^2}{\omega_o\,L}\,sinh\,x} \tag{7}$$

Ordinarily we are not interested in values of x greater than about 0.1, for which $sinh\,x$ is very nearly equal to x; so to a very close approximation*.

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*The use of natural logarithms for the frequency scale is convenient; for to a high degree of approximation x represents directly the deviation in frequency referred to the mean of the two frequencies,

$$x = \frac{\omega - \omega_o}{\dfrac{\omega + \omega_o}{2}} \tag{9}$$

—that is, a value of x equal to 0.1 means that the two frequencies under consideration differ by 0.1 or 10% of their mean. Equation (8) happens to be

$$A = \frac{\tau \mu g_p}{g_p + \tau^2 g + \dfrac{j\, 2\, \tau^2 x}{\omega_o L}}. \tag{8}$$

The amplification at resonance ($x = 0$) is

$$A_o = \frac{\tau \mu g_p}{g_p + \tau^2 g}. \tag{11}$$

Hence

$$A = \frac{A_o}{1 + \dfrac{j\, 2\, \tau^2 x}{\omega_o L (g_p + \tau^2 g)}} \tag{12}$$

Let us substitute the power factor* of the circuit combination g_p, g, L.

$$p = \frac{\omega_o L}{\tau^2}(g_p + \tau^2 g) = \frac{\omega_o L g_p}{\tau^2} + \omega_o L g = p_p + p_t, \tag{13}$$

where p_p and p_t are respectively the power factors of the combinations g_p, L and g, L. Then

$$A = \frac{A_o}{1 + \dfrac{j\, 2\, x}{p}} \tag{14}$$

The magnitude of the amplification per stage is then

$$A = \frac{A_o}{\sqrt{1 + \left(\dfrac{2\, x}{p}\right)^2}} = \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1 + \left(\dfrac{2\, x}{p}\right)^2}} \tag{15}$$

For purposes of plotting, it is desirable to express amplification on a logarithmic scale — say in transmission units:

Logarithmic amplification per stage,

$$20\, log_{10} A = 20\, log_{10} \left\{ \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1 + \left(\dfrac{2\, x}{p}\right)^2}} \right\}$$

$$= 20\, log_{10} \frac{\tau \mu g_p}{g_p + \tau^2 g} - 10\, log_{10} \left[1 + \left(\frac{2\, x}{p}\right)^2 \right] \text{ T. U.} \tag{16}$$

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exact if x represents the deviation in frequency referred to the harmonic mean frequency,

$$x = \frac{\omega - \omega_o}{\dfrac{2\, \omega \omega_o}{\omega + \omega_o}}. \tag{10}$$

*The writer ventures to suggest that such a quantity as defined by (13) be called the *natural power factor* of the resonant circuit as a whole; for it is the ratio of the conductance to the natural admittance, or of the resistance to the natural impedance. The term is in accordance with the definition of power factor in general, which may be expressed as the ratio of a resistance to an impedance, and should be no more confusing than is the term *natural impedance* as applied to a resonant circuit as a whole.

Figure 2a shows plots of this equation for various values of τ, and with the values of μ, g_p, g and $\omega_0 L$, given in the margin. With $\tau = 1$ (which is equivalent to a direct tuned reactance coupling), we see that the amplification at resonance is 16.1 T.U., which represents good sensitivity for one stage; and the amplification is practically constant up to $x = 0.005$, which means practically perfect fidelity (this corresponds to a side frequency 3 kc. per sec. from a carrier frequency of 600 kc. per sec., or 500 m. wavelength). But there is still considerable amplification (6.1 T.U.) at frequencies 10 per cent off resonance ($x = 0.1$); so the selectivity is poor. When the primary turns are reduced so that $\tau = \sqrt{2}$, the resonant amplification rises to 17.5 T.U., still with practically perfect fidelity, but with a drop in amplification at 10 percent off resonance to 3.4 T.U. Thus we have gained both in sensitivity and selectivity, without impairing fidelity. The same is true when we raise τ to 2, but beyond this value there is a loss in sensitivity, at first slow and then more rapid. The selectivity increases at first rapidly and then approaching a limit, as the curves approach the same form. The fidelity becomes slightly impaired and likewise approaches a limit. These results are given numerically in Table I.

TABLE I

Summary from Figure 2a. Values in Transmission Units

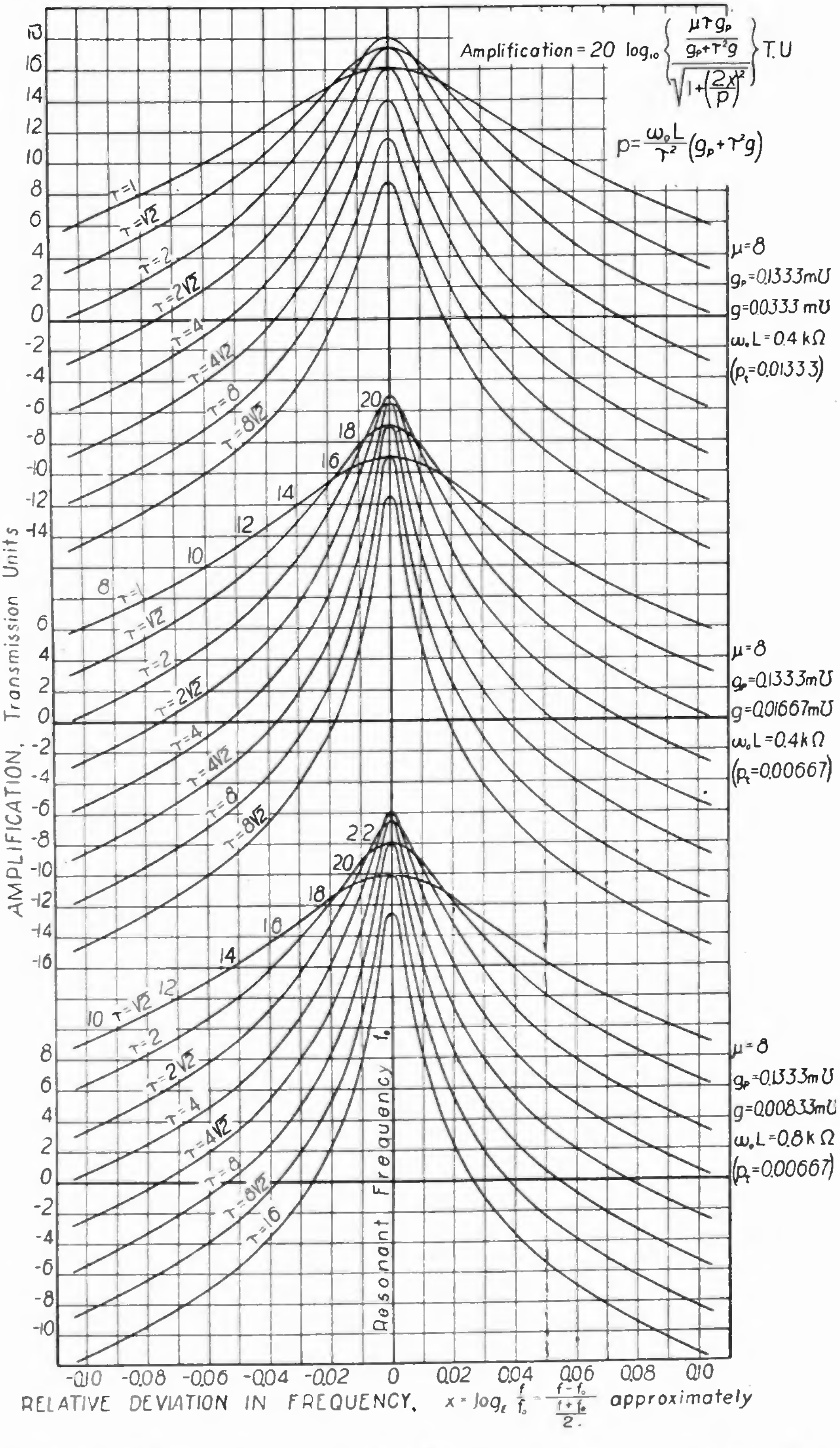
Transformation Ratio,	Sensitivity—Amplification At Resonance	Selectivity—Drop in Amplification 10% off Resonance	Fidelity—Drop in Amplification 0.5% off Resonance
1	16.1	10.0	0.1
$\sqrt{2}$	17.5	14.1	0.3
2	18.1	17.6	0.6
$2\sqrt{2}$	17.5	20.0	1.0
4	16.1	21.6	1.3
$4\sqrt{2}$	14.0	22.5	1.6
8	11.5	23.0	1.8
$8\sqrt{2}$	8.8	23.3	1.85
∞	∞	23.5	1.9

The above results show that there exists a value of τ which gives a maximum resonant amplification A_0. This may be evaluated by differentiating (11):

$$0 = \frac{dA_0}{d\tau} \quad \text{or} \quad 0 = \frac{d}{d\tau}\left(\frac{g_p + \tau^2 g}{\tau}\right) = -\frac{g_p}{\tau^2} + g \qquad (17)$$

or

$$g_p = \tau^2 g \quad \text{or} \quad \tau = \sqrt{\frac{g_p}{g}} \qquad (18)$$



FIGURES 2a, 2b, 2c—Families of Resonance Curves for One-Stage Amplifier with Various Circuit Constants

The maximum resonant amplification is then

$$A_o = \frac{\tau \mu g_p}{2 g_p} = \frac{\tau \mu}{2} = \frac{\mu}{2}\sqrt{\frac{g_p}{g}}. \qquad (19)$$

With the constants of Figure 2a, the turns ratio for maximum A_o is, as indicated by the curves, $\tau = \sqrt{\frac{0.1333}{0.0333}} = 2.$

Under the most common conditions, especially at the higher frequencies and with a small number of stages, the matter of fidelity does not impose a limitation on τ. The best value of τ is then determined as a compromise between sensitivity and selectivity.* Since selectivity increases continuously with increasing τ, while sensitivity passes through a maximum, the best value of τ is higher than that corresponding to maximum sensitivity, and therefore, by (18), is such that the input conductance $\tau^2 g$ of the transformer at resonance is substantially higher than the plate conductance g_p of the vacuum tube. In the table, the best value of τ evidently lies between 2 and 4. The intermediate value, $2\sqrt{2}$, together with the other constants of Figure 2a, corresponds roughly, at the lower broadcast frequencies, to the receiver which formed the subject of the paper under discussion. It is believed that the Neutrodyne receivers were the first to thus obtain increased selectivity by employing fewer primary turns than correspond to maximum amplification at resonance.

Besides the turns ratio τ, the designer has under his control, within certain limits imposed largely by cost and bulk, the self-inductance L and the conductance g of the coil. Figure 2b shows resonance curves comparative with those of Figure 2a, in which g has been halved, by minimizing the sources of loss in the tuned circuit. The two sets of curves are practically identical about 10 percent off resonance, but the resonant amplification has been increased. The result is a gain in sensitivity and in selectivity, but some impairment in fidelity. Also, the turns ratio for maximum resonant amplification has been increased to $2\sqrt{2}$, in accordance with (18).

If in the curves of Figure 2b the lower conductance g causes fidelity to be a limitation, and the turns ratio has to be lowered so as to give the same fidelity as in Figure 2a, then the selectivity will be the same as in Figure 2a, but there will remain some

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*This is on the assumption that stability does not impose a limitation. In designs giving a low power factor p, at high frequencies, the possibility of instability, due mainly to variations in the coupling capacities of vacuum tubes as manufactured, may make it desirable to use fewer primary turns.

gain in sensitivity. However, this gain may be insufficient to offset the greater cost of the low-loss coil, since low losses entail greater bulk. It just happens that at the low broadcast frequencies (in the neighborhood of 600 kc. per sec.), fidelity begins to be a limitation with coils of ordinary size (3 in. in greatest dimension).

In Figure 2c are shown resonance curves for the same transformer power factor p_t, but with twice the self-inductance L and therefore half the conductance g and tuning capacity C. These curves are identical in form with those of Figure 2b, provided comparison is made between curves in Figure 2c having $\sqrt{2}$ times the value of τ for the curves in Figure 2b, but are displaced upward by 3.0 T.U. ($=20\, log_{10}\sqrt{2}$). Thus with the proper increase in turns ratio, there has been an increase in sensitivity with no change in selectivity nor in fidelity. The value of L in practice is determined by the upper limit of the broadcast frequency range and by the minimum tuning capacity, which latter should therefore be kept as low as is feasible, considering the natural capacities of the vacuum tube and the wiring.

The curves of Figures 2a, 2b and 2c illustrate certain other facts to which attention should be drawn. First, the amplification near 10 percent off resonance and beyond is practically independent of the transformer conductance g; for when $2x/p$ is large, equation (15) reduces to

$$A = A_0 \frac{p}{2x} = \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{\omega_0 L (g_p + \tau^2 g)}{2 \tau^2 x} = \frac{\mu g_p \omega_0 L}{2 \tau x}. \qquad (20)$$

The variation of g with frequency consequently has a negligible effect on the resonance curve.

Again, the logarithmic amplification with customary values of the circuit constants falls below zero within the value $x = 0.1$, —that is, each stage of a tuned radio-frequency amplifier actually weakens an interfering signal which is 10 percent or more off resonance. This means that such an interfering signal, as picked up by a small antenna, may reach the detector circuit so attenuated as to be weaker than the signal picked up by the detector circuit directly. The loss in actual selectivity consequent on such direct pick-up in intermediate circuits is one of the important reasons for shielding, as brought out in the paper.

We will now consider the effect of varying the number of stages of amplification. If all stages are alike, the total amplification in transmission units will be directly proportional to the number of stages n, as given by the equation

$$20\, log_{10} A^n = 20\, n\, log_{10} \left\{ \frac{\tau \mu g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1 + \left(\frac{2x}{p}\right)^2}} \right\} T.U. \qquad (21)$$

The amplification relative to that at resonance is also proportional to n:

$$20\, log_{10} \frac{A^n}{A_o n} = -10\, n\, log_{10} \left[1 + \left(\frac{2x}{p}\right)^2 \right] \; T.\,U. \qquad (22)$$

Using the circuit constants of Figure 2c and the turns ratio corresponding to maximum resonant amplification, this relative amplification is plotted for various values of n in Figure 3a; and the resonant amplification is given for each value of n in the left-hand part of Table II. The total amplification would be obtained by shifting each curve upward by the respective resonant amplification.

TABLE II

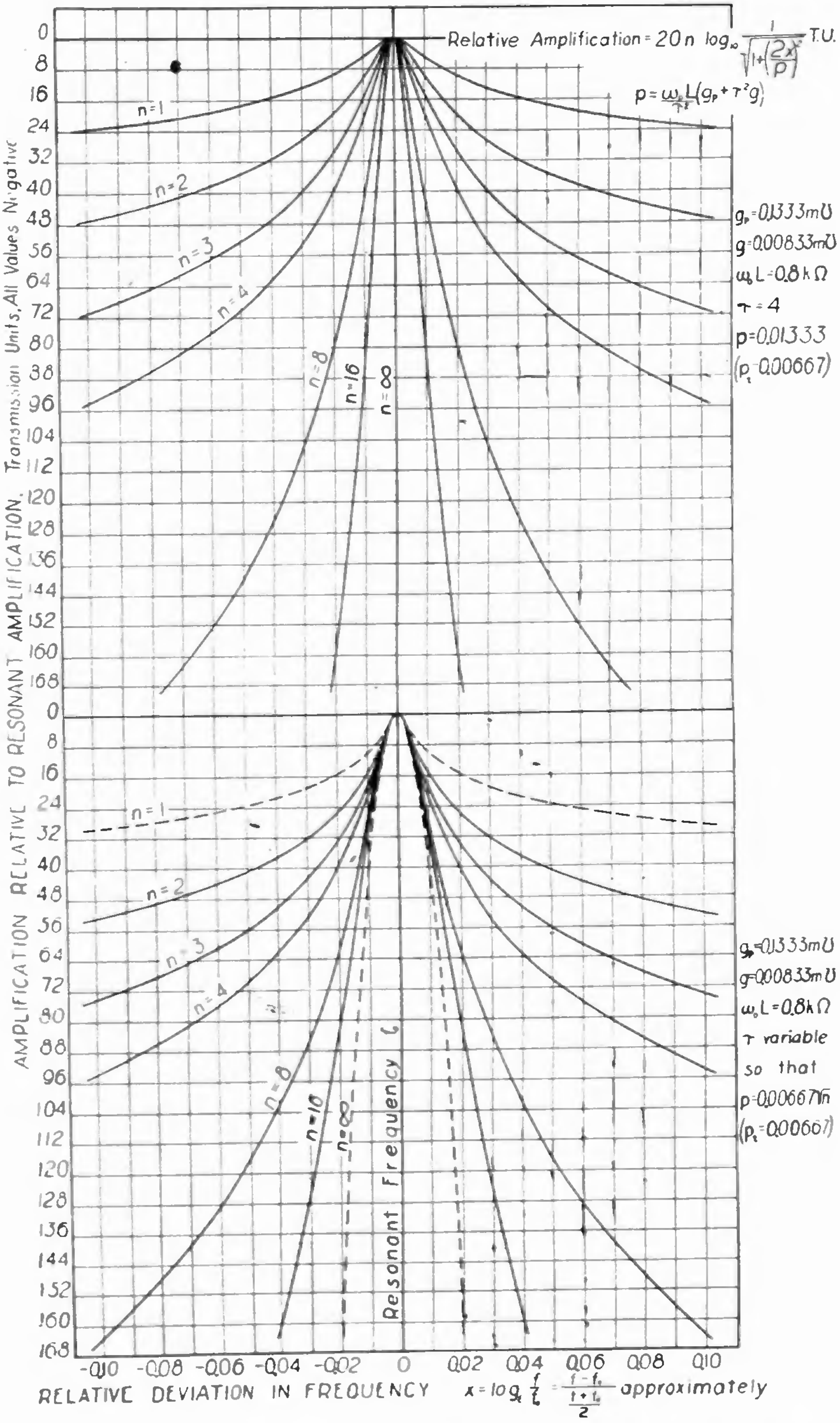
Resonant Amplification, Transmission Units

Number of Stages n	With Constant Turns Ratio, Figure 3a			With Constant Fidelity, Figure 3b		
	Turns Ratio τ	Amplification, Per Stage, t.u.	Amplification, Total, t.u.	Turns Ratio τ	Amplification, Per Stage, t.u.	Amplification, Total, t.u.
1	4	24.1	24.1	∞	– ∞	– ∞
2	4	24.1	48.2	6.21	23.3	46.5
3	4	24.1	72.2	4.67	24.0	71.9
4	4	24.1	96.3	4	24.1	96.3
8	4	24.1	192.6	2.96	23.7	189.6
16	4	24.1	383.3	2.31	22.8	365.6
∞	4	24.1	∞	0	– ∞	– ∞

Examination of Figure 3a shows that increasing the number of stages proportionately increases the selectivity, but with some impairment in fidelity, the curvature of the resonance curves at the origin becoming sharper. If we correct this effect by varying the turns ratio so as to have constant curvature at the origin, the curves of Figure 3b are obtained, the curve for four stages being taken the same as in Figure 3a. Constant curvature at the origin means practically constant fidelity for the lower audio frequencies (the curves practically coinciding for values of x up to 0.003) and nearly constant fidelity for the higher audio frequencies. The proper turns ratio τ for this condition is determined by making the second derivative of (22) equal to a constant at $x=0$;

$$const. = \frac{d^2}{d\,x^2}\left(20\, log_{10} \frac{A^n}{A_o}\right) = -10\, n \frac{d^2}{d\,x^2} log_{10} \left[1 + \left(\frac{2x}{p}\right)^2 \right] \qquad (23)$$

$$= -\frac{10}{2.30} \cdot \frac{8n}{p^2} \cdot x = 0 \qquad (24)$$



FIGURES 3a and 3b—Families of Resonance Curves for Multistage Amplifier, with Like Stages and with Unlike Stages Respectively

Hence, if p_1 is the value of the power factor p that would give the desired fidelity with one stage ($n=1$),

$$\frac{1}{p_1^2}=\frac{n}{p^2} \quad \text{or} \quad p=p_1\sqrt{n} \tag{25}$$

that is, the turns ratio τ must be varied so that the power factor is proportional to the square root of the number of stages; it is given by equation (13):

$$\tau^2=\frac{\omega_o L g_p}{p-\omega_o L g}=\frac{\omega_o L g_p}{p_1\sqrt{n}-\omega_o L g} \tag{26}$$

The resonant amplification by (11) is then

$$A_o=\frac{\tau \mu g_p}{g_p+\tau^2 g}=\frac{\mu}{p}\sqrt{\omega_o L g_p (p-\omega_o L g)}\ \sqrt{\omega_o L g_p (p_1\sqrt{n}-\omega_o L g)}$$

$$=\frac{\mu}{p_1\sqrt{n}} \tag{27}$$

These equations were used to obtain the values of turns ratio and amplification given in the right-hand part of Table II.

The curves of Figure 3b are plotted from equation (22), as in Figure 3a, but with p given by (25):

$$20\,log_{10}\frac{A^n}{A_o^n}=-10\,n\,log_{10}\left[1+\left(\frac{2\,x}{p_1\sqrt{n}}\right)^2\right] T.\ U. \tag{28}$$

It is interesting to note that this equation approaches a finite limit as n approaches infinity, this being evaluated as follows:

$$20\,log_{10}\frac{A^n}{A_o^n}=-\frac{10\,n}{2.30}\,log_\epsilon\left[1+\left(\frac{2\,x}{p_1\sqrt{n}}\right)^2\right]$$

$$=-\frac{10\,n}{2.30}\left\{\left(\frac{2\,x}{p_1\sqrt{n}}\right)^2-\frac{1}{2}\left(\frac{2\,x}{p_1\sqrt{n}}\right)^4+\cdots\right\}$$

$$=-\frac{10}{2.30}\left(\frac{2\,x}{p_1}\right)^2\ T.\ U._{n=\infty} \tag{29}$$

This limit is the dotted parabola of Figure 3b, which the other curves are seen to approach for a greater and greater range as n is increased.

The most important fact illustrated in Figure 3b is that *with constant fidelity the selectivity is increased as the number of stages is increased,* whereas with a fixed number of stages selectivity can be increased beyond a certain point only at the expense of fidelity. With constant fidelity, the selectivity in each stage is decreased as the number of stages is increased, and the possible increase in over-all selectivity has a finite limit, which, however, is far beyond what is attainable with any practicable number of stages (that is, in Figure 3b, the curve for $n=4$, or even that for

$n=8$, differs widely from that for $n=\infty$, except very close to the resonant frequency).

Table II shows that, with any practicable number of stages greater than one, the resonant amplification per stage does not vary greatly with the number of stages, for constant fidelity. It just happens that with the data chosen, the transformer power factor p_t is equal to the total power factor p_1 for one stage; so the number of primary turns approaches zero and the amplification approaches infinite attenuation with one stage. For this reason the curve for $n=1$ in Figure 3b has been shown dotted, as representing a limit rather than a practical condition with the data chosen. With other data, the desired fidelity with one stage might not be even approached ($p_t > p_1$), or it might be attained with finite attenuation or even with some amplification ($p_t < p_1$). As the number of stages is increased above one, the resonant amplification per stage first increases to a maximum (corresponding to the condition of equation (18), and then falls. The total amplification rises nearly in proportion to the number of stages for all practicable numbers, but for very large numbers of stages it also reaches a maximum and then falls, ultimately becoming an attenuation which approaches infinity. That these latter conditions are purely academic is shown by the calculations that the total amplification does not reach its maximum until a few thousand stages are employed and does not become an attenuation until the number of stages passes a million!

Summing up with respect to the resonance curves, equation (21) when written in the form

$$20 \, log_{10} A'' = 20 \, n \, log_{10} \frac{A_o}{\sqrt{1+\left(\frac{2x}{p}\right)^2}}$$

$$= 20 \, n \, log_{10} A_o - 10 \, n \, log_{10} \left[1+\left(\frac{2x}{p}\right)^2\right] \qquad (30)$$

shows that all resonance curves, when plotted to logarithmic scales as illustrated, are alike in form and differ only in scale and in position. Of the three parameters, p determines the horizontal scale, n determines the vertical scale, and A_o determines the position of the curve in the vertical direction.

The above discussion of selectivity refers to selection against interfering signals of fixed frequency, as other broadcasting stations. Interference from damped-wave stations, atmospheric and other strays, is essentially different in that the interfering waves have a wide band of frequencies, and the main interference is due to components *at and near the resonant frequency of the receiver.* In the case of random interference, as from strays, it may most reasonably be assumed that on the average the interfering waves are uniformly distributed in intensity over the narrow frequency band covered by a sharply tuned receiver, and the same is nearly true of damped telegraph waves. On the basis of this assumption, John R. Carson has discussed* the subject of random interference and has derived certain formulas representing relative signal-stray ratios. Carson makes comparisons, in effect, by integrating the square of the amplification with respect to frequency between the side-band limits for the signal and between infinite limits for the strays:

$$\frac{\int_{-x}^{x} A^{2n}\,dx}{\int_{-\infty}^{\infty} A^{2n}\,dx} = \frac{2A_o^{2n}\int_o^x \frac{dx}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}}{2A_o^{2n}\int_o^{\infty} \frac{dx}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}} = \frac{\int_o^{\frac{2x}{p}} \frac{d\left(\frac{2x}{p}\right)}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}}{\int_o^{\infty} \frac{d\left(\frac{2x}{p}\right)}{\left[1+\left(\frac{2x}{p}\right)^2\right]^n}} \tag{31}$$

On the supposition that the fidelity is practically perfect, $(2x/p)^2$ is small compared with unity and the numerator reduces to $2x/p$. The denominator integrates to

$$\int_o^{\infty} cos^{2n-2}\,\theta\,d\,\theta = \frac{1.3.5\ldots.(2n-3)}{2.4.6\ldots.(2n-2)}\cdot\frac{\pi}{2} = \frac{(2n-2)!}{2^{2n-2}(n-1)!^2}\cdot\frac{\pi}{2}$$

Substituting these expressions, (31) becomes

$$\frac{\int_{-x}^{x} A^{2n}\,dx}{\int_{-\infty}^{\infty} A^{2n}\,dx} = \frac{2x}{p}\cdot\frac{2^{2n-2}(n-1)!^2}{(2n-2)!}\cdot\frac{2}{\pi}$$

$$= \frac{2x}{p_1\sqrt{n}}\cdot\frac{2^{2n-2}(n-1)!^2}{(2n-2)!}\cdot\frac{2}{\pi} \tag{32}$$

the last form being useful if fidelity is to remain constant, as discussed in connection with Figure 3b. In this expression $2x/p_1$ has some small value, fixed by the fidelity desired, x being the useful side-band limit. The only variable over which we have control is n. Table II shows how the variable part of (32) de-

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* "Bell System Technical Journal," vol. 2, number 3, p. 28 (1923), and "Trans A. I. E. E.," vol. 43, p. 795 (1924).

pends on n. Evidently, on the basis of Carson's theory, there is no considerable gain in increasing the number of stages above two.

TABLE III

Number of Stages n	Relative Signal-Stray Ratio $\frac{2^{2n-2}(n-1)!^2}{\sqrt{n}(2n-2)!}$
1	1
2	1.41
3	1.54
4	1.60
8	1.69
16	1.73
∞	$\sqrt{\pi} = 1.77$

Let us examine the question of strays in greater detail. Any audio-frequency response may be analysed into components of various frequencies, each of which components is due to beats between radio-frequency waves whose frequencies differ by the audio frequency. When a signal wave is absent, strays will be heard due to the beats between their various components. When a signal wave is present, there will in addition be beats between the strays and the components of the signal wave, mainly the carrier wave.

Under tolerable receiving conditions, beats between the carrier wave and the strays are more important than beats between different components of the strays, as these components, even in the aggregate, will be weaker than the carrier. Those components of the strays whose frequencies are very close to the carrier will result in low-frequency audio disturbances. Components more remote from the carrier in frequency will result in audio disturbances of higher frequency (hisses) or in disturbances beyond the limit of audibility. Carson's theory does not go so far as to consider the relative importance of different audio frequencies, and should be supplemented by the use of a factor equal to the relative sensitivity of the ear at different frequencies. More crudely, we may substitute a factor which is equal to unity up to a certain frequency, about 10 kilocycles per sec., and is equal to zero above this value. This means that the integral in the denominator of (31) should have as its upper limit a value of x corresponding to about 10 kc. instead of infinity. This will make no great difference if the resonance curve is sharp; but with a broad resonance curve it will make the relative signal-stray ratio dependent solely on the ratio of the width of the useful audio-frequency band to the width of the total audible band. Since it is hardly possible to make the resonance curve suitably sharp at all frequencies with the broadcast range, we are led to the conclusion that *the only effective way to minimize strays over the range of a receiver is to so design the audio frequency amplifier and loud-speaker as to pass only the useful audio frequencies and to attentuate all higher audible frequencies.** This is one of the important purposes of the condensers shunting the audio-frequency transformers and the loud-speaker, in the receiver described in the paper. The hissing type of stray is thus largely eliminated; but the low-frequency type is quite unavoidable, as it has no feature to distinguish it from the signal.

The less important mode of occurrence of stray interference, the beats between different components of the strays, is more complicated in theoretical treatment. To find the interference at any particular audio frequency, we should take two resonance curves displaced by that frequency (as in Figure 4a, but using actual, instead of logarithmic, amplification), multiply their ordinates squared, and integrate between infinite limits. This process discriminates against the higher audio frequencies, which confirms the practical observation that the high-frequency hissing strays are less conspicuous in the absence of a carrier wave. Stray interference of this sort can be minimized with respect to *all* audio frequencies by employing sharp resonance curves. Audio-frequency selection is still helpful (though not so important as in the case considered in the preceding paragraph, on account of the lesser importance of hissing strays), but it can no longer make up for broadness in the resonance curve.

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*It may be remarked in this connection that the derivation of the amplification equation given previously applies to audio frequency as well as to radio frequency, provided that the assumptions stated at the beginning hold good. However, the value of x will not be small over the audio-frequency range; so the exact equation (7) must be used instead of (8), giving for the logarithmic amplification with n stages the following expression in place of (21):

$$20\, log_{10} A^n = 20\, n\, log_{10} \left\{ \frac{\tau\, \mu\, g_p}{g_p + \tau^2 g} \cdot \frac{1}{\sqrt{1+\left(\frac{2}{p} sinh\, x\right)^2}} \right\} T.\, U. \qquad (33)$$

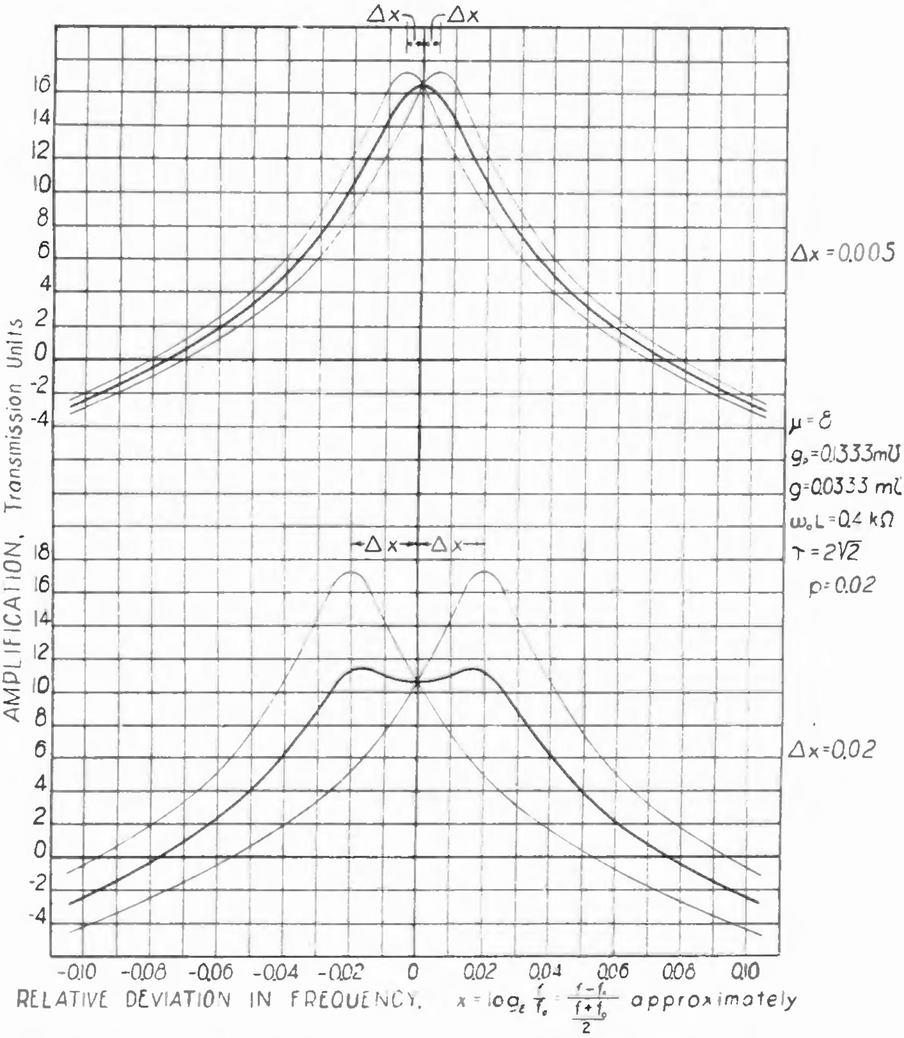
To give a flat curve, p is made large, primarily by employing such a low value of τ that $\tau^2 g$ is much less than g_p. In this case, (33) reduces to

$$20\, log_{10} A^n = 20\, n\, log_{10} \frac{\tau\, \mu}{\sqrt{1+\left(\frac{2}{p} sinh\, x\right)^2}}\ T.\, U \qquad (34)$$

in which p is substantially

$$p = \frac{\omega_o L\, g_p}{\tau^2} = \frac{g_p}{\tau^2}\sqrt{\frac{L}{C}} \qquad (35)$$

We will now consider the effects on the resonance curve of an amplifier of slight lack of resonance in the different stages, due in particular to accidental misalignment of the condensers when a common control is employed, as in the receiver under discussion. If we have two like stages, with resonant frequencies displaced Δx each side of the mean, their resonance curves plotted with their mean frequency as the datum will appear as shown by the light curves in Figure 4a, where $\Delta x = 0.005$. The average amplification per stage is the mean between these curves, as shown by the heavy curve. This evidently is very nearly identical with the original curves except near its peak, which is lower and slightly broader. There is thus some loss in sensitivity and in selectivity, with a slight gain in fidelity.



FIGURES 4a and 4b—Resonance Curves Illustrating Effect of Detuning

The loss in amplification per stage at the mean resonant frequency may be calculated by substituting Δx for x in the expression for relative amplification, and is

$$10 \log_{10}\left[1+\left(\frac{2\Delta x}{p}\right)^2\right] T.\,U. \tag{36}$$

which, for the data of Figure 4a, gives

$$10 \log_{10}\left[1+\left(\frac{2\times 0.005}{0.02}\right)^2\right] = 1.0\ T.\,U.$$

as indicated on Figure 4a. For the very small misalignments that would be tolerated in practice ($\Delta x < 0.005$), the expression (36) may be put in the simpler form

$$10 \log_{10}\left[1+\left(\frac{2\Delta x}{p}\right)^2\right] = \frac{10}{2.30} \log_e\left[1+\left(\frac{2\Delta x}{p}\right)^2\right]$$
$$= \frac{10}{2.30}\left(\frac{2\Delta x}{p}\right)^2 \text{ approx.} \tag{37}$$

which shows that the loss in amplification varies as the square of the deviation in resonant frequency. This expression shows also that the permissible value of Δx is proportional to the power factor p, which is one of the reasons given in the paper for employing a design giving a relatively broad resonance curve, —that is, a relatively high value of p.

With more than two stages and a given maximum frequency deviation Δx, the most adverse condition would be for half of the stages to be at one extreme ($+\Delta x$) and the other half at the other extreme ($-\Delta x$). The average amplification per stage would then still be represented by Figure 4a; and equations (36) and (37) would still apply. If, on the other hand, the misalignments were uniformly distributed between ($-\Delta x$) and ($+\Delta x$), the lowering in the peak amplification would only be one-third as great, one-third being the ratio of the average value to the maximum value with a square-law relation, as in (37). In practice, with a given tolerance, the misalignments will be distributed according to probability laws, and the average lowering in the peak amplification per stage will be less than one-third the value indicated by (37). It should be noted that the percentage deviation in capacity is *twice* the percentage deviation in resonant frequency; so the value $\Delta x = 0.005$ corresponds to capacity deviations 1 percent from the mean, which is much more than is tolerated in the receiver under discussion.

Figure 4b shows the effect of a greater deviation in resonant frequency, $\Delta x = 0.02$, such as might occur in a receiver having separate tuning controls when detuning is employed for volume control of the signal. Here the resultant curve has considerably changed its form, showing two peaks. This affects fidelity in that there is a slight tendency to accentuate the higher audio frequencies in place of the usual and more desirable condition of discriminating against them. With the data chosen, the loss in amplification at the mean of the resonant frequencies is

$$10\, log_{10}\left[1+\left(\frac{2\times 0.02}{0.02}\right)^{2}\right]=7.0\ T.\ U.$$

Evidently in Figure 4b, there has been a large loss in selectivity, so the practice of detuning for volume control is dangerous.

DIGESTS OF UNITED STATES PATENTS RELATING TO RADIO TELEGRAPHY AND TELEPHONY*

Issued March 9, 1926-May 4, 1926

By

JOHN B. BRADY

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

1,575,824—C. H. EIFFERT, filed October 27, 1922, issued March 9, 1926. (Of Roanoke, Virginia.)
RECEIVING ANTENNA FOR RADIO TELEGRAPHY OR TELEPHONY, comprising a device which may be screwed into the usual electric light socket for establishing capacitive connection with the lighting line.

1,575,980—W. S. FERDON, filed August 8, 1923, issued March 9, 1926. (Of Omaha, Nebraska.)
RADIO COMMUNICATION, wherein an antenna device is enclosed in a tube and arranged for the radiation of high frequency current exterior to the tube.

1,576,162—A. F. VAN DYCK, of Schenectady, New York. Filed March 31, 1922, issued March 9, 1926. Assigned to General Electric Company.
HIGH FREQUENCY APPARATUS, wherein electron tubes and associated circuits are housed within a cabinet having a hinged door thereon with apertures through which the controls for various parts of the electron tube circuits pass in such manner that the door of the cabinet may be opened without removing the control knobs.

1,576,324—JAMES B. HOGE and EDWARD E. CLEMENT, of Washington, D. C. Filed August 22, 1922, issued March 9, 1926. Assigned to Edward F. Colladay.
RADIOPHONE BROADCASTING SYSTEM, in which a telephone network is employed for determining from the transmitting station whether or not the receiving apparatus at the different subscribers' stations is operating at resonance with the transmitting frequency.

1,576,667—J. O. MAUBORGNE and GUY HILL, of Washington, D. C. Filed February 9, 1924, issued March 16, 1926.
SYSTEM FOR ELIMINATING INTERFERENCE, in which a wave coil is employed for responding to the transmitted frequency without interference from undesired frequencies.

1,576,783—JOHN B. PITTS, of Winnetka, Illinois. Filed January 31, 1925, issued March 16, 1926.
RADIO DETECTOR of the crystal type arranged to be mounted on and adjusted from the front of a panel.

1,576,829—F. O. JOHNSON, of Chicago, Illinois. Filed August 23, 1924, issued March 16, 1926. Assigned to Reliance Die & Stamping Company.
ELECTROSTATIC CONDENSER of the variable type where the rotor plates are journaled in bushings carried in the end plates of a condenser frame and arranged to be so adjusted as to properly center the rotor plates between the stationary plates.

1,577,108—E. E. CLEMENT, of Washington, D. C. Filed January 21, 1925, issued March 16, 1926. Assigned to Edward F. Colladay.
TRUNKING SYSTEM OF RADIO DISTRIBUTION, where a telephone network is used for the broadcasting of signaling energy to a plurality of subscribers' stations.

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*Received by the Editor, May 17, 1926.

1,577,109—E. E. CLEMENT, of Washington, D. C. Filed January 31, 1925, issued March 16, 1926. Assigned to Edward F. Colladay.
RADIO BROADCAST DISTRIBUTING SYSTEM, where signaling energy is broadcast from a central station to subscribers and the energy properly amplified for serving the various subscriber circuits.

1,577,195—R. C. ROSE, of Osceola, Kansas. Filed October 10, 1925, issued March 16, 1926.
CONDENSER, of the stack type where end plates of glass are provided for securing the stack under pressure.

1,577,443—L. S. BRACH, East Orange, New Jersey. Filed July 21, 1925 issued March 23, 1926. Assigned to L. S. Brach Manufacturing Company.
RADIO RESISTOR COUPLER UNIT, consisting of a condenser and resistance within a casing with an identifying plate on the casing for representing the value of the coupling unit.

1,577,613—F. W. DUNMORE, of Washington, D. C. Filed February 4, 1925, issued March 23, 1926.
RADIO RECEIVING APPARATUS, in which the several tuning circuits of the apparatus are simultaneously controlled by operating condensers by means of cams.

1,577,719—W. H. T. HOLDEN, of Brooklyn, New York. Filed December 30, 1922, issued March 23, 1926. Assigned to American Telephone & Telegraph Company.
ELECTRICAL PROTECTIVE DEVICE, comprising a tube structure which may be connected in an antenna circuit for preventing destruction of signaling apparatus from high potential surges.

1,577,727—F. W. KARGE, of Chicago, Illinois. Filed April 20, 1925, issued March 23, 1926.
COMBINATION FIREPLACE AND CONTAINER FOR RADIO RECEIVING SETS, wherein the receiving set is mounted directly over the fireplace in the home.

1,577,748—D. R. LOVEJOY, of New York City. Filed August 14, 1924, issued March 23, 1926. Assigned to Lovejoy Development Corporation.
ELECTRICAL CONDENSER, where the plates are cylindrical and concentrically arranged one with respect to the other.

1,578,258—A. BLONDEL and M. TOULY, of Paris and St. Cloud, France. Filed May 18, 1921, issued March 30, 1926.
MEANS FOR GENERATING HIGH FREQUENCY CURRENTS by a plurality of electron tube circuits which are retroactively coupled for the production of oscillations.

1,578,288—C. W. HOUGH, of Boonville, New York. Filed September 27, 1922, issued March 30, 1926. Assigned to Wired Radio, Incorporated.
LAMP SOCKET ATTACHMENT DEVICE, by which signaling apparatus may be connected with the electric lighting line through condenser devices for capacitively coupling the receiving apparatus with the lighting line.

1,578,296—A. H. TAYLOR, of Washington, D. C. Filed October 2, 1925, issued March 30, 1926. Assigned to Wired Radio, Incorporated.
MULTI-FREQUENCY CRYSTAL CONTROLLED OSCILLATOR, in which a high frequency signal transmitting system is controlled by piezoelectric crystal devices.

1,578,513—J. H. HAMMOND, JR., of Gloucester, Massachusetts. Filed (Original), March 31, 1914. Reissue filed July 1, 1921, issued March 30, 1926.
SYSTEM AND METHOD OF PRODUCTION OF CONTINUOUS OSCILLATIONS, wherein an oscillator is coupled to an antenna system and the tuning device for varying the frequency of the oscillations directly inserted in the antenna circuit.

1,578,551—C. SCHWARZ, of Charlottenburg, Germany. Filed October 31, 1921, issued March 30, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
RELAY ARRANGEMENT FOR CHANGING THE TUNING OF

RADIO APPARATUS, whereby the transmitting apparatus may be operated on any selected frequency.

1,578,735—H. F HUNTER and L. S. HANNOLD, of Swendensboro, New Jersey. Filed May 8, 1924, issued March 30, 1926.
RADIO WAVE RECEIVING DEVICE, in which a wave coil is used in the reception of radio signals and compactly arranged with the associated apparatus.

1,578,394—H. E. CARLSON, of Minneapolis, Minnesota. Filed May 8, 1924, issued March 30, 1926.
RADIO CABINET, in which the apparatus is compactly mounted within the area of the loop antenna provided in the set.

1,578,396—G. H. CLARK, of Brooklyn, New York. Filed April 26, 1921, issued March 30, 1926. Assigned to Radio Corporation of America.
RADIO SIGNALING SYSTEM, where the oscillations at the transmitting station are varied at an audible rate to permit receivers to respond to the transmitted signals without the employment of a local oscillator.

1,578,490—R. A. WEAGANT, of New York City. Filed April 30, 1920, issued March 30, 1926. Assigned to Radio Corporation of America.
APPARATUS FOR PREVENTING INTERFERENCE IN RADIO SIGNALING, wherein the transmitting station generates two radio frequency currents which must be incident upon the receiver for the production of a beat frequency in order that the transmitted signals may be received.

1,578,832—JOSEPH A. KLAUSE, of Philadelphia, Pennsylvania. Filed March 15, 1923, issued March 30, 1926.
CONDENSER construction, wherein a plurality of condenser units are compactly arranged in a group.

1,578,845—E. L. NELSON, of East Orange, New Jersey. Filed January 16, 1924, issued March 30, 1926. Assigned to Western Electric Company, Incorporated.
MODULATION INDICATING SYSTEM for determining the condition of modulation in a transmitting system.

1,579,117—K. H. KINGDON, of Schenectady, New York. Filed July 1, 1921, issued March 30, 1926. Assigned to General Electric Company.
ELECTRON DISCHARGE DEVICE operating upon the principle of ionization within a vessel with a plurality of electrodes geometrically arranged within the vessel and connected to external circuits.

1,579,156—J. H. SIEMAN, of Brooklyn, New York. Filed May 2, 1924, issued March 30, 1926.
ELECTRICAL CONTACT FOR TERMINALS OF VACUUM TUBES, wherein the pins of the electron tubes have coil springs thereon for establishing contact with the socket terminals.

1,579,168—C. E. VAWTER, of Philadelphia, Pennsylvania. Filed April 28, 1923, issued March 30, 1926. Assigned to Dubilier Condenser and Radio Corporation.
ELECTRIC CONDENSER, wherein pressure is secured upon a stack by a metallic casing which is deformed over the stack.

1,579,209—H. P. CLAUSEN, of Mamaroneck, New York. Filed November 21, 1923, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
VARIABLE CONDENSER, where the rotor plates may be locked in any selected position.

1,579,253—E. SINGER, of New York City. Filed May 21, 1923, issued April 6, 1926. Assigned to Western Electric Company.
RECEPTION OF SIGNALS for securing high selectivity by reducing the frequency of the incoming signals through a series of steps.

1,579,299—J. C. GABRIEL, of New York City. Filed February 1, 1924, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
TWO-WAY COMMUNICATION SYSTEM, in which a solenoid device

is provided for shifting over from transmitting to receiving positions in a radio telephone system.

1,579,482—J. J. JORGENSEN, of Balboa, Canal Zone, Panama. Filed March 19, 1925, issued April 6, 1926.
VARIABLE AIR CONDENSER, where the rotor plates are mounted in an insulated frame spared from the end plates of the condenser by means of conical-shaped insulating devices.

1,579,614—A. W. HORNING, of Chicago, Illinois. Filed March 5, 1925, issued April 6, 1926.
RADIO WIRING SET, where the lengths of leads in a radio set are determined from patterns previously made up in the form of a dummy.

1,579,669—E. A. SPERRY, of Brooklyn, New York. Filed March 12, 1920, (original); divisional filed August 21, 1922, issued April 6, 1926.
RADIO REPEATER SYSTEM for securing simultaneous movement of an indicator at both transmitting and receiving stations automatically.

1,579,894—H. C. SNOOK, of South Orange, New Jersey. Filed May 31, 1922, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
OSCILLATION GENERATOR, in which a tube having a divided space current path is arranged in an external circuit for setting up oscillations.

1,579,895—H. C. SNOOK, of South Orange, New Jersey. Filed June 8, 1922, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
OSCILLATION GENERATOR, where the space current is increased in an electron discharge tube and the intensity thereof controlled by means of s supplemental control electrode arranged adjacent the grid.

1,579,921—H. F. ELLIOTT and J. A. MILLER, of Palo Alto, California. Filed January 9, 1922, issued April 6, 1926. Assigned to Federal Telegraph Company.
MULTIPLE RADIO SYSTEM, where a plurality of arc transmitters may be operated in close proximity to each other without interference.

1,579,930—A. HADDOCK, of East Orange, New Jersey. Filed September 28, 1923, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
RADIO TRANSMITTER, in which a mechanical switching device is provided for changing the transmitting wavelength of the antenna.

1,579,935—R. A. HEISING, of East Orange, New Jersey. Filed August 17, 1920, issued April 6, 1926. Assigned to Western Electric Company, Incorporated.
RESONANCE INDICATOR for determining the frequency of the transmitting system at a broadcasting station.

1,580,057—G. H. LEWIS, of Elizabeth, New Jersey. Filed April 12, 1922, issued April 6, 1926.
ELECTRICAL CONDENSER AND METHOD OF MAKING AND ADJUSTING THE SAME, in which variation in the electrical capacity of condensers may be compensated by changing the area of a number of the plates.

1,580,088—R. M. SANDERS, of New York City. Filed September 2, 1925, issued April 6, 1926. Assigned to Edward R. Tolfree.
REMOTE CONTROL FOR RADIO SETS, wherein the conductors which deliver the audio frequency energy to a reproducer are also used for controlling a relay for putting on and off the filaments of the receiving sets.

1,580,173—J. L. SECOR, of Mountainville, New York. Filed February 2, 1924, issued April 13, 1926.
VARIABLE CONDENSER, where minute adjustment of capacity may be made by selecting the number of stator plates actively in the circuit.

1,580,261—C. V. LOGWOOD, of New York City. Filed July 12, 1919, issued April 13, 1926.
ELECTRICAL SIGNALING SYSTEM, wherein a pair of electron tubes

are connected in balanced relationship for controlling an oscillation system.

1,580,359—C. T. ALLCUTT, of Pittsburgh, Pennsylvania. Filed December 30, 1920, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

RADIO RECEIVING SYSTEM of the heterodyne type where the sensitivity of the receiver is increased by circuit connections between the local source and the receiving circuits.

1,580,409—E. E. CLEMENT, of Washington, D. C. Filed February 14, 1925, issued April 13, 1926. Assigned to Edward F. Colladay.

TRUNKING SYSTEM OF RADIO DISTRIBUTION for transmitting over a line wire system signaling current to a plurality of subscribers from a central station and supervising the operation of the receivers from a central point.

1,580,423—P. E. EDELMAN, of New York City. Filed June 5, 1922, issued April 13, 1926.

VARIABLE CONDENSER, wherein the rotor plates are locked together by means of a locking pin which passes through all of the plate members for securing the plate members in position.

1,580,446—J. SLEPIAN, of Wilkinsburg, Pennsylvania. Filed April 21, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

ELECTRON TUBE, including a cathode and an anode arranged in a vessel which is provided with a restricted portion for the passage of electrons between the cathode and anode through a small cross-sectional area.

1,580,477—J. SLEPIAN, of Wilkinsburg, Pennsylvania. Filed April 21, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

OSCILLATION GENERATOR SYSTEM, in which a pair of two electrode valves are arranged in balanced relationship with an external electrode adjacent one of the valves for controlling the generation of oscillations in the circuits thereof.

1,580,509—D. G. LITTLE, of Edgewood Park, Pennsylvania. Filed June 3, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

COMBINATION OF INDUCTANCES FOR RADIO, for use in radio receiving sets for allowing the tuning of the antenna circuit to be varied without changing the amount of feed-back voltage induced in the grid circuit by the current in the plate circuit.

1,580,536—B. ROSENBAUM, of Berlin, Germany. Filed August 26, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

OSCILLATION GENERATOR, in which a plurality of electron tubes are arranged in co-operative relationship for varying the potential of the control electrode in each tube in accordance with variations of current in the wing circuit of another tube.

1,580,538—C. SCHWARZ, of Charlottenburg, Germany. Filed October 31, 1921, issued April 13, 1926. Assigned to Westinghouse Electric & Manufacturing Company.

CONNECTING ARRANGEMENT FOR HIGH-FREQUENCY TELEPHONY, wherein a calling device is provided at the receiving station and operated from the transmitting station by a control switch for operating the system for inter-communication

1,580,621—G. J. MAHIEU, of Rio de Janeiro, Brazil. Filed March 13, 1925, issued April 13, 1926.

VARIABLE CONDENSER, in which one side of the condenser is formed by a plurality of wedge-shaped plates arranged to be moved into or out of a set of correspondingly shaped plates.

1,580,850—R. M. OTIS and W. F. FUNK, of East Orange, New Jersey and Midland Beach, New York, respectively. Filed June 29, 1925, issued April 13, 1926. Assigned to Bell Telephone Laboratories, Incorporated.

ELECTRON-DISCHARGE DEVICE, of high power construction, wherein a central rod is provided within the tube structure for carrying a corono shield thereon.

1,850,855—R. B. PRINDLE, of Schenectady, New York. Filed April 9, 1925, issued April 13, 1926. Assigned to General Electric Company.
COOLING SYSTEM FOR ELECTRICAL DEVICES, particularly adapted for maintaining the anode of a high power electron tube at uniform temperature under conditions of electronic bombardment.

1,580,873—J. J. WELDON, of Pittsfield, Massachusetts. Filed June 7, 1924, issued April 13, 1926. Assigned to General Electric Company.
STATIC CONDENSER, where a plurality of condensers are each formed in a roll supported from a frame structure.

1,580,898—C. IZENSTARK, of Chicago, Illinois. Filed June 7, 1922, issued April 13, 1926.
CRYSTAL DETECTOR, where a swivel joint carried by a bracket member is provided for securing adjustment of the contact device with respect to the crystal.

1, 580,899—J. B. JOHNSON, of Elmhurst, New York. Filed June 30, 1921, issued April 13, 1926. Assigned to Western Electric Company.
APPARATUS FOR MODIFYING THE WAVE FORM OF ALTERNATING CURRENT, including a vacuum tube having electrodes to be bombarded, the electrodes being of unequal thermal capacity with a source of alternating current connected to the electrodes and circuits so arranged for rendering the energy delivered to one of the anodes greater than that delivered to the other.

1,581,085—J. H. HAMMOND, JR., of Gloucester, Massachusetts. Filed (original), May 13, 1920: renewed August 15, 1924, issued April 13, 1926.
TRANSMITTING AND RECEIVING SYSTEM, in which a selective form of receiving apparatus is employed with a tube having a plurality of sets of grid and plate electrodes with associated circuits regeneratively coupled together.

1,581,133—F. H. MACKENZIE, of Philadelphia, Pennsylvania. Filed February 15, 1924, issued April 20, 1926.
RADIOAERIAL in the form of a coiled spring which may be expended for increasing the effective length and hooked between any suitable supports.

1,581,161—A. S. BLATTERMANN, of Little Silver, New Jersey. Filed April 18, 1921, issued April 20, 1926.
MEANS FOR REDUCING INTERFERENCE AND OBTAINING where the transmitted energy is varied at an inaudible rate and a corresponding variation effected at a selected receiving station.

1,581,219—J. O. MAUBORGNE and GUY HILL, of Washington, D. C. Filed August 6, 1920, issued April 20, 1926.
WAVE METER, employing a wave coil as a resonator by which the energy is picked up from a local emitter and the frequency thereof determined.

1,581,264—R. HERZOG and LEO PUNGS, of Berlin and Charlottenburg, Germany, respectively. Filed August 23, 1921, issued April 20, 1926. Assigned to Lorenz Aktiengesellschaft.
RADIO SIGNALING SYSTEM having means for modulating a transmitting system for radiating only a single wave while maintaining the source of oscillations in stabilized condition.

1,581,296—J. W. SCHMIED, of West Orange, New Jersey. Filed August 26, 1922, issued April 20, 1926. Assigned to Western Electric Company, Incorporated.
MODULATING CARRIER WAVES, by which increased high frequency voltage is impressed upon the transmitting circuit without utilizing a correspondingly increased voltage of the space current supply source of the vacuum tube system which produces the waves to be transmitted.

1,581,356—C. LOFBERG, of Bogota, New Jersey. Filed December 16, 1924, issued April 20, 1926. Assigned to Nelson Tool Company, Incorporated. RADIO CONDENSER, where the adjustable plates are arranged to slide with respect to the fixed plates under control of a rack and pinion mechanism.

1,581,520—P. SCHWERIN, of New York City. Filed March 17, 1921, issued April 30, 1926. Assigned to Western Electric Company, Incorporated. VACUUM TUBE of high power construction, wherein a central stem is provided with arms extending therefrom for supporting the several electrodes of the electron tube.

1,581,649—A. LOPPACKER, of Bloomfield, New Jersey. Filed February 6, 1922, issued April 20, 1926. Assigned one-half to himself and one-half to Frank J. Kent.
DOUBLE-FACED DETECTOR ELEMENT, where the crystal is carried in a metallic sheet covering only the side walls of the crystal.

1,581,701—A. H. TAYLOR, of Washington, D. C. Filed October 24, 1925, issued April 20, 1926. Assigned to Wired Radio, Incorporated.
PIEZO-ELECTRIC CRYSTAL CONTROL SYSTEM, for maintaining the frequency of a high frequency signal system constant.

1,581,992—R. WEBSTER, of Evanston, Illinois. Filed June 23, 1923, issued April 20, 1926. Assigned to Fansteel Products Company, Incorporated, or North Chicago, Illinois.
RADIO DETECTOR OR AMPLIFICATION VACUUM BULB, having means for eliminating end fractions of the gaseous contents of a vacuum tube which consist in the plate element constructed of tantalum which when placed in a magnetic field during the process of manufacture tends to absorb gases within the tube.

1,582,042—F. W. HENNESSY, of Providence, Rhode Island. Filed March 3, 1924, issued April 27, 1926.
RADIO APPARATUS, comprising a telephone and connecting cords with a tip member which includes a rectifier unit. The telephone and connecting cords may be used together as a radio audibility unit, the rectifier being connected in series with the telephone.

1,582,177—J. H. HAMMOND, JR., of Gloucester, Massachusetts. Filed (original), September 25, 1917, issued April 27, 1926.
SYSTEM OF RADIO TELEGRAPHY AND TELEPHONY, in which the transmitting circuit is provided with a saturable core with an alternator for producing pulsations in the transmitting circuit and means actuated in synchronism with the alternator for causing saturation of the core to impress amplitude variations upon the impulses.

1,582,194—B. TRIVUS, of Providence, Rhode Island. Filed April 12, 1925, issued April 27, 1926.
DETECTOR of the crystal type where a metallic contact is carried by a bracket member and is adjustable with respect to a rectified crystal.

1,582,270—H. C. SNOOK and J. B. JOHNSON, of South Orange, New Jersey, and Elmhurst, New York, respectively. Filed March 18, 1922, issued April 27, 1926. Assigned to Western Electric Company, Incorporated.
METHOD OF AND MEANS FOR GENERATING ELECTRIC OSCILLATIONS by means of a discharge tube having an abnormal space charge.

1,582,441—C. H. VOTEY, of Hartsdale, New Jersey. Filed September 14, 1923, issued April 27, 1926. Assigned to The Aeolian Company.
MEANS FOR HOUSING THE RECEIVING LOOPS IN RADIO-SET CABINETS, where the loop is mounted on the cabinet door in such manner that it may be adjustable into any plane for securing desired directive reception.

1,582,460—L. F. FULLER, of Palo Alto, California. Filed June 13, 1922, issued April 27, 1926. Assigned to Wireless Improvement Company.
SIGNALING SYSTEM, utilizing an arc transmitter where an auxiliary ionizing discharge is produced in or about the arc space and this ionized discharge interrupted at the end of each signaling impulse whereby the arc may be intermittently established in accordance with signals.

1,582,519—C. H. HULBERT and W. J. TIDEMAN, of Menominee, Michigan. Filed January 10, 1923, issued April 27, 1926. Assigned to Signal Electric Manufacturing Company.
VARIABLE CONDENSER, having a minimum number of movable parts where the parts are concentrically arranged, one being movable with respect to the other for semi-circular displacement.

1,582,555—E. R. STOEKLE, of Milwaukee, Wisconsin. Filed March 27, 1925, issued April 27, 1926.
DEVICE FOR CONTROLLING AND INDICATING THE TUNING OF RADIO INSTRUMENTS AND THE LIKE, where a plurality of condensers are arranged on the same shaft and each adjustable by means which indicate the relative position of the several rotors of the condensers.

1,582,695—B. ROSENBAUM, of Berlin, Germany. Filed September 2, 1921, issued April 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
RADIO COMMUNICATION SYSTEM for remotely and selectively connecting a plurality of receiving stations which may have time clock mechanism installed therein.

1,582,720—V. K. ZWORYKIN, of Kansas City, Missouri. Filed February 16, 1922, issued April 27, 1926. Assigned to Westinghouse Electric & Manufacturing Company.
METHOD OF TREATING VACUUM TUBES. By subjecting the electrodes of the electron tube to the action of a high frequency magnetic field which tends to heat the electrodes for driving out occluded gases at the same time that a periodically reversing potential is applied to the control electrodes.

1,582,780—P. T. PLATT, of Norfolk Downs, Massachusetts. Filed April 6, 1925, issued April 27, 1926.
RADIO WAVE METER, including an oscillating electron tube circuit with a grid leak and grid condenser arranged to produce a grid choking action for breaking up the radio frequency oscillations into groups at an audible rate.

1,582,826—A. A. KENT, of Ardmore, Pa. Filed May 8, 1925, issued April 27, 1926.
PANEL CONDENSER for mounting within a radio receiver where the rotor and stator elements are supported from the panel structure of the receiving apparatus.

1,582,975—S. B. GARCELLANO, of Charleston, South Carolina. Filed November 7, 1924, issued May 4, 1926.
BREAK RELAY FOR RADIO RECEIVING-SENDING SETS for permitting intermittent transmission and reception without interference of the transmitting set upon the local receiver.

1,583,071—A. A. KENT, of Ardmore, Pennsylvania. Filed May 12, 1925, issued May 4, 1926.
PANEL CONDENSER for mounting with respect to the panel of a radio receiving apparatus cabinet where the stator plates are mounted on a bracket supported from the panel and adjustable with respect to the rotor plates.

1,583,123—L. M. E. CLAUSING, of Chicago, Illinois. Filed August 16, 1923, issued May 4, 1926.
SYSTEM FOR GENERATING RADIO FREQUENCY CURRENTS, by employing a plurality of tubes upon which are impressed low frequency alternating currents for deriving a high frequency oscillating current in the transmitting circuit.

1,583,306—W. W. NEVINS and R. L. WALKER, of College Park and Atlanta, Georgia, respectively. Filed October 7, 1924, issued May 4, 1926. Assigned to A. E. Hill Manufacturing Company.
ELECTROSTATIC CONDENSER, in which alternating conductive and insulated sheets of circular shape are stacked within a metallic container and clamped under pressure.

1,583,414—E. W. B. GILL and E. GREEN, of Oxford, and London, England, respectively. Filed October 31, 1925, issued May 4, 1926.

VACUUM TUBE SHIELD for surrounding an electron tube and confining and serving to control the distribution of electrostatic field therein.

1,583,463—W. G. HOUSEKEEPER, of New York City. Filed July 13, 1920, issued May 4, 1926. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE, of high power construction in which a cooling system is provided for maintaining the temperature of the electrodes at a uniform condition.

1,583,471—A. A. KENT, of Ardmore, Pennsylvania. Filed May 12, 1925, issued May 4, 1926.

PANEL CONDENSER, wherein the rotor and stator elements of the condenser are supported in insulated relationship to a metallic panel of a radio receiving set.

1,583,499—P. M. SMITH and E. M. SQUAREY, of East Orange and South Orange, New Jersey, respectively. Filed April 28, 1924, issued May 4, 1926. Assigned to United States Tool Company, Incorporated.

ROTOR SYSTEM FOR CONDENSERS, where the rotor plates of a condenser are constructed on a single integral sheet of metal.

1,583,503—E. M. SQUAREY, F. KOCH and A. E. BORTON, of South Orange and East Orange, respectively. Filed April 28, 2924, issued May 4, 1926. Assigned to United States Tool Company, Incorporated.

CONDENSER PLATE SYSTEM, where the plates are formed from a single piece of sheet metal with the plates folded and joined by integral tangs at the edges thereof for facilitating the manufacture of the condensers.

1,583,634—T. E. WHITE, of Waterbury, Connecticut. Filed May 17, 1924, issued May 4, 1926.

VARIABLE CONDENSER where the adjustable plates are semicircular in shape and may be varied in relation to stationary plates of circular shape.