PROCEEDINGS OF
The Institute of Radio Engineers

CONTENTS

CORRECTIONS

In the paper on "The Piezo-Electric Resonator," by W. G. Cady, which appeared in the April, 1922 issue of the PROCEEDINGS, page 83, the following corrections should be made:

Page 87, equation (6), for y read y_ν.

Page 97, third line from the bottom, for "low" read "high."

Page 98, first line, for "lead" read "lag."

Page 98, line 22, for X read x.

Page 106, line 12 from bottom, for $4 l^2 f^2$ read $2 lf$.

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RADIO TELEGRAPHY*

By

Senatore Guglielmo Marconi, G.C.V.O., D.Sc., LL.D., Etc.

The first occasion on which I had the honor of speaking before the members of the American Institute of Electrical Engineers was of a very festive nature.

It is over twenty years ago, to be exact on January 13, 1902; (there was not then any Radio Institute in existence) and on that date, memorable for me, I was entertained by over 300 members of your Institute at a dinner at the Waldorf-Astoria in this City. I was offered that dinner following my announcement of the fact that I had succeeded in getting the first radio signal across the Atlantic Ocean.

Many men, whose names are household words in electrical science, were present, men such as Dr. Alexander Graham Bell, Professor Elihu Thompson, Dr. Steinmetz, Dr. Pupin, Mr. Frank Sprague, and many others.

The function was one I shall never forget, and displayed to the full American resource and originality, as only forty-eight hours' notice of the dinner had been given, but what has left the greatest impression on my mind during all the long twenty years that have passed is the fact that you believed in me and in what I told you about having got the simple letter "S" for the first time across the ocean from England to Newfoundland without the aid of cables or conductors.

It gives me now the greatest possible satisfaction to say that, in some measure, perhaps, your confidence in my statement was not misplaced, for those first feeble signals which I received at St. John's, Newfoundland, on the 12th of December, 1901, had proved once and for all that electric waves could be transmitted and received across the ocean, and that long distance radio-telegraphy, about which so many doubts were then entertained, was really going to become an established fact.

You will easily understand my feelings and how very happy I am to have the honor of addressing you again tonight, and when I say that I will always treasure the recollection of the generous encouragement and valid support so heartily extended to me practically at the commencement of my career, when perhaps I most needed it, by such a distinguished and authoritative body as the American Institute of Electrical Engineers.

The subject of my lecture, "Radiotelegraphy," has become so vast and so complex that you will readily understand my difficulty as to where I shall begin and as to when I ought to stop. It would be quite impossible for me to descant at any length on present achievements in a country which in a very short time has made gigantic strides in the scientific development and practical application of the science and art of radiotelegraphy. Moreover, time will not allow me to do more than skim over only a very few of the many problems which have lately been solved, or which there is a good prospect of solving in the near future.

Although we have, or believe we have, all the necessary data for the generation, transmission, and reception of electrical waves, as at present utilized for radiotelegraphy, we are still far from possessing exact knowledge concerning the conditions governing the transmission, or rather the propagation, of these waves through space, especially across long distances.

I propose now to bring to your notice some of the recent results attained in Europe and elsewhere and to call your attention particularly to what I consider a somewhat neglected branch of the art; and which is the study of the characteristics and properties of very short electrical waves. My belief is always that, only by the careful study and analysis of the greatest possible number of well authenticated facts and results, will it be possible to overcome the difficulties that still lie in the way of the practical application of radio in the broadest possible sense.

A very great impulse has been given to radiotelegraphy and telephony by the discovery and utilization of the oscillating electron tube or triode valve based on the observations and discoveries of Edison and Fleming, of those of De Forest and of those of Meissner in Germany, Langmuir and Armstrong in America, and H. W. Round in England, who have also brought it to a practical form as a most reliable generator of continuous electric waves.

As the electron tube, or triode valve, or valve, as it is now generally called in England, is able, not only to act as a detector, but also to generate oscillations, it has supplied us with an arrangement which is fundamentally similar for both transmitter

and receiver, providing us also by a simple and practical method with the means for obtaining beat reception and an almost unlimited magnification of the strength of signals.

A result of the introduction of the triode valve has been that the basic inventions which made long distance radiotelegraphy possible have become more and more valuable.

It may perhaps be of interest if I give some information as to the progress made by the Marconi Company in England, with the practical application of the triode valve.

It has been so far our practice to use a plurality of tubes in parallel at our long distance stations. High power has been obtained in practice up to 100 kilowatts in the antenna by means of a number of glass tubes in parallel, and for the present we are standardizing units capable of supplying 4 kilowatts to the antenna, in the numbers required and sufficient for each particular case.

Some difficulty was at first experienced in paralleling large tubes in considerable numbers, but no difficulties now occur with groups of sixty bulbs working on voltages of 12,000 on the plate.

I am told that no insurmountable difficulty would be encountered if it were desired to supply 500 kilowatts to the antenna from a number of these bulbs. (Figure 1.) The life of the bulbs has been very materially increased and the 4-kilowatt units are expected to have a life, which, based on a great number of tests carried out both in the laboratory and at our Clifden station, should be well in excess of 5,000 hours.

The development of single unit tubes of considerable power is also progressing. We have lately concentrated on the production of high power tubes made of quartz, and two sizes of each bulb are now being made, one for 25 kilowatts to the antenna, and another for 75 kilowatts, but it is not expected that the efficiency of the high power single units will be as good as that of the multiple units, and the work on the large tubes is being considered so far as experimental.

In transmission work a large amount of investigation has been carried out during the last two years on the efficiency of the circuits and in regard to the best way of utilizing the available energy.

Considerable increases in efficiency have been obtained in the aerial or antenna circuits and also in minimizing the losses in the attendant loading coils, and the latest results indicate that it is possible to obtain efficiency of radiation into space as high as fifty per cent. on wave lengths as long as 20,000 meters, when, in

this particular case, towers of a height of 250 meters would, of course, have to be used, owing to the length of the wave.
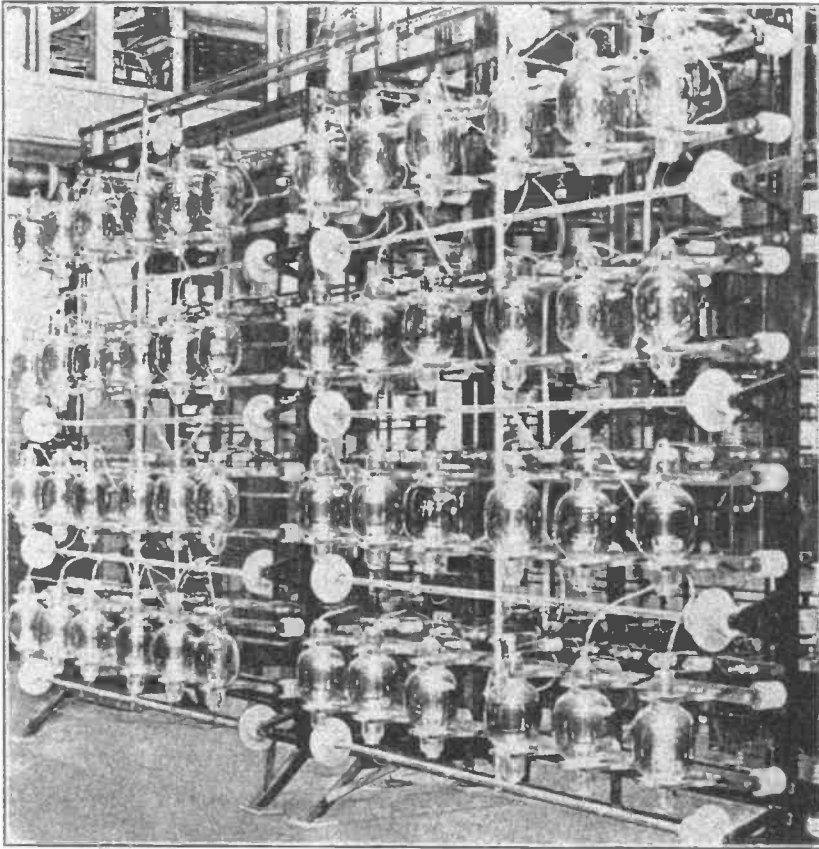
FIGURE 1—Tube Panel at Carnarvon

Very careful investigations have been carried out by Mr. H. W. Round, of all the losses in the loading coils and other parts of the tube circuits, and actual measurements on considerable power have shown that an over-all efficiency from the input power on the plates of the tubes to the aerial of seventy per cent. is possible with a complete avoidance of harmonics, that is, an efficiency from the power input to the plates of the tubes to actual radiation into space of about thirty-five per cent.

On shorter wave stations it is quite practicable still further to increase this efficiency, altho possibly it is hardly worth the extra expense involved. We have at present one station in England working on a 3,000 meter wave length with a height of mast of

100 meters which has an efficiency from plates to radiation into space of 40 per cent.

Aside from the question of efficiency, great attention has been paid to maintaining an extremely constant frequency, and this can now be guaranteed to an extraordinary degree of constancy. Simple and reliable methods of high speed keying have been developed which on the shorter waves can be used up to over 200 words per minute, and on the longer waves to whatever speed the aerial constants will permit.

In high speed transmission, we are maintaining public services at 100 words per minute to two places in Europe, namely, Paris and Berne, using a single aerial transmitter with two wave lengths on the same aerial, and altho the operation uf utilizing a single aerial for two wave lengths is not an advisable one for high power work, it has certain points to recommend it in medium power work, where the consequent loss of efficiency can be made up for by a slight increase of power.

These two waves are working duplex to both Paris and Berne and practically all traffic is taken on printing machinery, altho there are occasions when, because of static, reception has to be done on undulator tape, and in some rare cases, on the telephones, by sound.

The reception at these shorter distance stations is carried out by means of a cascade arrangement of high and low frequency tuned amplifier circuits attached to the directional aerial system of the Bellini type, arranged for unidirectional reception when necessary. Very great care is taken in the receiving circuits to shield them so that the tuned circuits come well into action and to prevent any direct effect or influence of the aerial on circuits other than those intended to be acted upon. The characteristics of all these circuits have been very accurately measured so as to give filter curves suitable to the required speeds of working, and the adjustments are easily performed by the operators. Aside from the protection from interference given by directional reception, a close filtering, and an element of saturation, no particularly sensational methods or ideas in regard to static elimination have been so far introduced into practice.

The careful measurement and study of the constants of all circuits in use and the design of more efficient circuits from the result of those measurements is being systematically carried out, but as a result of these investigations considerable improvements have suggested themselves, which will be applied in the future if certain appropriate means can be devised.

The protection of receivers against the troubles of atmospherics or static can only be, and is likely to continue to be, a relative matter, as it is quite obvious that a static eliminator under certain conditions will cease to be effective, where the static arrives with much greater intensity than had been anticipated, and will also frequently fail when, in consequence of the weakness of the received signals, amplification has to be increased to any considerable extent.

It would be really interesting to know how much the increase in C. W. transmitters, the development in directional reception, and the improvements in tuning that has taken place during the last few years have really increased our speed of readability and reliability over given distances.

As the development has been gradual, the tendency is towards pessimism, but I think we are now able at the same expense to work at about 8 to 10 times the effective speed that we were able to work at in 1912 under the same atmospheric conditions.

Interference from other stations has, of course, enormously increased and this has perhaps somewhat checked the increase of speed, but fortunately prevention of interference from other radio stations is a very much easier problem than the prevention of the disturbances caused by natural electric waves, or static.

Amongst the different types of tube amplifiers used in modern radio receiving stations, the tuned high frequency and audio frequency amplifier is probably the one which excites the greatest technical interest. In fact, its selective qualities, combined with the comparatively better ratio of signal strength to interference which it secures, justifies such interest.

These advantages were fully realized by most radio workers during the war, and I do not think that at the time the Armistice was signed there remained many radio laboratories where some time had not been utilized in experimenting on that type of receiver.

If those researches were generally not quite successful in regard to preparing or fixing the design of practical apparatus, they however indicated that the main difficulty to be overcome was to combine considerable amplification with stability and that the solution of the problem became rapidly more difficult with the increase of the number of tubes used in cascade.

By stability, in this case, I mean the freedom from any sudden generation of oscillations in any part of the circuits of the amplifier.

In 1920, however, an important step was made by Mr. G. Mathieu, as to the path to be followed out in order to obtain a

practical solution of the problem. This consisted in the design of a new type of air-core tuned intervalve transformer arranged in such a manner as to possess only an extremely small electrostatic capacity between the windings, and having its effective primary impedance about equal to the effective internal plate to filament resistance of the tube in use when the secondary circuit was brought into resonance with the frequency of the oscillations to be amplified.

The results achieved during the first tests of these new transformers appeared to be quite amazing, the amplification factor for one tube having passed suddenly from 5 to about 15 for the particular tube tested, whilst the stability proved incomparably better than what had been obtained previously, even when the grid of the tube was kept to a negative potential of 1 or 2 volts.

The same principle has proved quite as successful when applied to the design of iron-core low frequency transformers. In this case, however, it was found necessary to adopt an iron magnetic shunt between the windings so as to provide a sufficiently loose coupling between the primary and secondary circuits of the transformer. Recently, Mr. Mathieu has further improved the design of his high frequency transformer by making it astatic.

One of these new appliances including high frequency and low frequency tuned transformers has been used daily on my yacht during my trip from England to America and the results of the tests carried out on board fully confirm the reliability of the apparatus and its marked superiority over the ordinary type of amplifier.

It has been clearly realized by most radio workers for some years that the science of radiotelegraphy had reached a stage of development where mere guesswork had done nearly all that could be expected from it, and that the improvement and development of commercial telegraphic services over what we once considered exceedingly long distances necessitated some very definite knowledge on the following points:

First: The strength of signals that can be relied upon with given arrangements over these distances, and

Second: The all-important question of the ratio of the strength of signals to that of the natural disturbances and inter ferences acting on the receiving station in various parts of the world.

First of all, suitable and reliable apparatus for the purpose of obtaining the necessary data on both these points had to be

developed. This apparatus is now in systematic daily use in a good many far distant places, with the result that a vast amount of most valuable information is being collected, and is now coming to hand.

At these observation points, the signals from distant stations are measured at all times of the day and night, together with the strength of the interference of static, and also the direction or bearing from which the static appears to be coming.

The measurements are done in such a way that the power that would be required at the transmitting station to give reada-. bility is used as a measure of the static, as this is the actual thing a radio engineer requires for the proper calculation of his transmitting station.

It is a method which gives a very satisfactory and reliable result in practices, and which I think could well be used universally.

In short, this method consists in inducing in the aerial C. W. signals from the measuring apparatus, which signals are made equal to those received from the distant transmitting station. The voltage applied to the aerial can then be directly read off. An aerial of a standard size is used for the purpose, and from this the strength of the signals in microvolts per meter can be calculated. If the signals are then unreadable, due to static, the measuring apparatus is used to send to an operator at a standard rate of 20 words per minute, 5 letter code, and the voltage applied to the aerial from the local sender is increased until complete readability is obtained, thus the ratio of the new voltage applied to the aerial to that of the old voltage equal to that of the signals received gives at once a very correct estimate of how much the power of the transmitting station would have to be increased in order to insure readability. As this variation can be carried out on aerial systems giving direction diagrams the method is obviously of great practical utility.

The question as to whether it would or would not be possible to transmit radio signals right round the world as far as the Antipodes is one which has always fascinated me. In fact the distance to the Antipodes is the greatest possible useful distance that can be covered by radio on this little earth of ours, and from this point of view the question was also important as such a distance included all minor distances between all other places on earth.

Sixteen years ago at a lecture I delivered on the 3rd of March, 1905, before the Royal Institution in London I expressed the belief that if it were proved that transmission to the Antipodes

were possible, the waves ought to go over and travel round different parts of the globe from one station to the other, and perhaps all converge and concentrate at the Antipodes, and in this way I thought it might be possible to send messages to such distant places by utilizing only a moderate amount of electrical energy; and at that lecture I also showed a model globe and tried to explain how I thought the waves would help each other if arriving in proper phase, or in other words, concentrate at places at or near the Antipodes of the sending station.

The results recently obtained and which go to show the relative facility with which radio signals can now be sent from England to Australia seems to indicate that there is something in the idea of the wireless waves traveling round the earth by various ways and reuniting at places near the Antipodes.

But still more interesting and precise data has been obtained during other more recent tests.

Two expeditions, one to Brazil, and the other to New Zealand have carried out a number of most interesting and instructive observations, and although complete reports have not yet been received, I think it will nevertheless be of interest if I give you the results of some of their important tests.

The expedition to Brazil of which Mr. H. H. Beverage, of the Radio Corporation of America, Mr. N. W. Rust, of Marconi's Wireless Telegraph Company of England, and Mr. W. Eichkoff and Dr. A. Esau of the Gesellschaft fur Drahtlose Telegraphie (Telefunken) of Berlin formed part, has just completed a series of observations at various points on the Atlantic Coast of South America, where the intensity of the signals from European and other stations has been observed and measured at all times of the day and night, and where also the direction and intensity of atmospherics or static has been equally observed and recorded over considerable periods of time.

Another expedition under the direction of Mr. E. Tremellen, of the English Marconi Company, has just completed its work in measuring signals from all European and American high power stations, on a journey between England and New Zealand via the Panama Canal, and from the mass of information obtained on both day and night signals it should be possible, among other things, to reconstruct the attenuation formula. Incidentally, I may say that the signals exceed greatly in strength what should be expected according to the Austin-Cohen formula, otherwise super-long distance working would not be a practical proposition.

Complete measurements from England to the Antipodes have been made on the Carnarvon, Nauen, Bordeaux, and Hanover signals; and also in Brazil on the American high power stations and on the U. S. Naval station, N. P. O. at Cavite (Philippine Islands).

In both these expeditions to Brazil and New Zealand the fact has been noted definitely and independently, and I think for the first time that signals from stations at very great distances do not always retain their direction along one great circle, but reach the receiver from either way or various ways round the earth.

These important observations were made by means of loop aerial direction finders arranged so as to give the well known heart shape diagram and the very interesting fact has been recorded independently by both expeditions, that on many occasions during what might be called a transition period, when the wave is changing from one way round the earth to another way round, the two or more sets of waves when received on a simple vertical aerial produced fairly slow beats resembling Morse signals, caused by the mutual interference or addition of the two sets of waves, whereas on the direction finder heart shape diagram arrangement, the signals were quite steady and normal when it was turned so as to receive only from one way or the other.

Of course it should be noted that when one is very near to the Antipodes there is only such a slight difference between any of the great circles leading from the sending station that the constancy of direction is not maintained, but this direction seemed to keep definitely true at distances of about 2,000 miles from the Antipodes.

The observers noted American signals from Radio Central and from Tuckerton coming from a direction which indicated that they preferred to travel a distance of three quarters of the way round the earth, rather than come by the shortest way round. Also, according to the reports received from the observers on other occasions at or near the Antipodes of the English or Ger man stations, the direction finder often indicated the signals as coming from directions all round.

Another interesting and rather extraordinary result was noted on several occasions, according to the report of Mr. Tre mellen from Rocky Point, New Zealand, where during last March the signals from Nauen appeared to travel to him via the South Pole, whilst those from Hanover. also situated in Germany, and not very far from Nauen, appeared to prefer to travel via the North Pole.

A much more complete and exhaustive series of observations at fixed stations in Australia is now being made so as to obtain if possible all the variations from one period of the year to the other.

It seems to have been definitely ascertained in a general way that the sources of bad atmospheric disturbances, or static, are situated chiefly over land, but observations in Brazil indicate that a type of static known as "grinder" is a disturbance originating a long way off and coming from a direction which indicates the African Coast and at a time of the day when static there would be at a maximum, whereas a very violent "click" type of static came from a direction indicating its source as being nearby in South America.

During my present journey across the Atlantic, on board the Yacht *Elettra*, we noticed that up to about half way across (apart from the effects of local storms) static interference appeared to be coming mainly from the European and African continents, while at more than half way across they were coming from Westerly directions, that is, from the American continent.

The changing over of the direction of origin of these disturbances has also been noted under similar circumstances by Mr. Tremellen in crossing the Pacific.

It is very fortunate for the North Atlantic trans-Atlantic radio service, carried out at stations in North America and Europe, particularly for those in Western Europe, that this strong nearby type of static comes from directions which greatly differ from those from which one has to receive, and that the continents which lie in the direction of the sending stations are so far distant and sufficiently temperate as not to project troublesome static to the receiving stations on the other side of the ocean.

Another fact which can be fairly well deduced from these tests over very great distances is that transmission from West to East is apparently easier than from East to West, and shows the necessity for qualifying or modifying the transmission formula for great distances.

A scientific paper giving the results of measurements and of all the work carried out and observations made in these two expeditions will shortly be published.

I shall now deal with another and most important branch of the science of radiotelegraphy; a branch which I might say has been for a long time most sadly neglected. It concerns the use that can be made of very short waves, especially in regard to

their application to directional radiotelegraphy and radiotelephony.

Some years ago, during the war, I could not help feeling that we had perhaps got rather into a rut by confining practically all our researches and tests to what I may term long waves, or waves of some thousands of feet in length, especially as I remembered that during my very early experiments, as far back as 1895 and 1896, I had obtained some promising results with waves not more than a few inches long.

The study of short waves dates from the time of the discovery of electric waves themselves, that is, from the time of the classical experiments of Hertz and his contemporaries, for Hertz used short electric waves in all his experiments, and also made use of reflectors to prove their characteristics and to show among many other things that the waves, which he had discovered, obeyed the ordinary optical laws of reflection.

As I have already stated, short electric waves were also the first with which I experimented in the very early stages of wireless history, and I might perhaps recall the fact that when, over 26 years ago, I first went to England, I was able to show to the late Sir William Preece, then Engineer in Chief of the British Post Office, the transmission and reception of intelligible signals over a distance of 1¾ miles by means of short waves and reflectors (Figures 2 and 3), whilst, curiously enough, by means of the antenna or elevated wire system, I could only get, at that time, signals over a distance of half a mile.

The progress made with the long wave or antenna system, was so rapid, so comparatively easy, and so spectacular, that it distracted practically all attention and research from the short waves, and this I think was regrettable, for there are very many problems that can be solved, and numerous most useful results to be obtained by, and only by, the use of the short wave system.

Sir William Preece described my early tests at a meeting of the British Association for the Advancement of Science, in September, 1896, and also at a lecture he delivered before the Royal Institution in London on the 4th of June, 1897.

On the 3rd of March, 1899, I went into the matter more fully in a paper I read before the Institution of Electrical Engineers in London, to which paper I would recall your attention as being of some historical interest.

At that lecture I showed how it was possible, by means of short waves and reflectors, to project the rays in a beam in one

direction only, instead of allowing them to spread all around, in such a way that they could not affect any receiver which happened to be out of the angle of propagation of the beam.

I also described tests carried out in transmitting a beam of reflected waves across country over Salisbury Plain in England, and pointed out the possible utility of such a system if applied
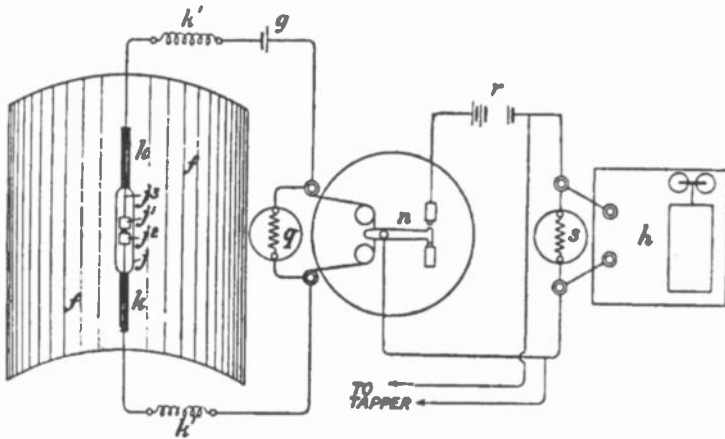

FIGURE 2—Early Short Wave Directional Receiver
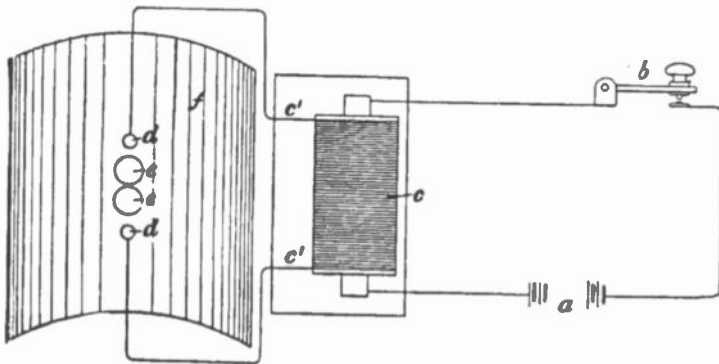
FIGURE 3—Early Short Wave Directional Transmitter

to lighthouses and lightships, so as to enable vessels in foggy weather to locate dangerous points around the coasts.

I also showed results obtained by a reflected beam of waves projected across the lecture room, and how a receiver could be actuated and a bell rung only when the aperture of the sending reflector was directed towards the receiver.

Since these early tests of over twenty years ago practically no research work was carried out or published in regard to short waves, so far as I can ascertain, for a very long period of years.

Research along these lines did not appear easy or promising; the use of reflectors of reasonable dimensions implied the use of waves of only a few meters in length, which were difficult to produce, and, up to a comparatively recent date, the power that could be utilized by them was small. This and the fact of the very high attenuation of such waves over any distance of land or sea, gave results which appeared to be very disappointing.

The investigation of the subject was again taken up by me in Italy early in 1916 with the idea of utilizing very short waves combined with reflectors for certain war purposes, and at subsequent tests during that year, and afterwards, I was most valuably assisted by Mr. C. S. Franklin, of the British Marconi Company.

Mr. Franklin has since then followed up the subject with great thoroughness and the results obtained have been described by him in a paper read before the Institution of Electrical Engineers in London on the 3rd of April, 1922.

Most of the facts and results which I propose to bring to your notice are taken from Mr. Franklin's paper.

The work carried out in experimenting with these waves in 1916, was most interesting, as it was like going back to the very early days of wireless, when one had a perfectly clear field.

The waves used had a length of 2 meters and 3 meters. With these waves, disturbances caused by static can be said to be almost non-existent, and the only interference experienced came from the ignition apparatus of automobiles and motor boats. These machines apparently emit electric waves from near 0 to about 40 meters in length, and the day may come when they will perhaps have to have their ignition systems screened, or carry a Government license for transmitting.

Incidentally I might mention that one of these short wave receivers will act as an excellent device for testing, even from a distance, whether or not one's ignition is working all right. Some motorists would have a shock if they realized how often their magnetos and sparking plugs are working in a deplorably irregular manner.

During my tests in 1916, I used a coupled spark transmitter, the primary having an air condenser and spark in compressed air. By these means the amount of energy was increased and the small spark gap in compressed air appeared to have a very low resistance.

The receiver at first used was a crystal receiver, whilst the reflectors employed were made of a number of strips or wires

tuned to the wave used, arranged on a cylindrical parabolic curve with the aerial in the local line.

The transmitting reflector was arranged so that it could be revolved and the effects studies at a distance on the receiver.

Mr. Franklin has calculated the polar curve of radiation into space (Figure 4), in the horizontal plane, which should be obtained from reflectors of various apertures, by assuming that the waves leave the reflector as plane waves of uniform intensity,

APERTURE   1 WAVE LENGTH — —   3 WAVE LENGTHS   5 WAVE LENGTHS
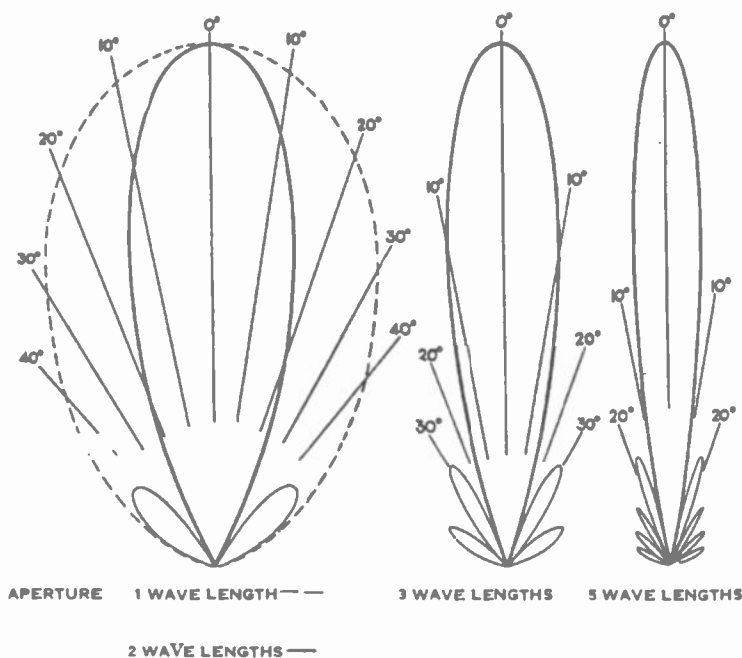
2 WAVE LENGTHS —

FIGURE 4—Calculated Polar Curves of Reflectors

having a width equal to the aperture of the reflector. The calculated curves agree very well with the observed results. In Figure 4 are shown the calculated curves for reflectors having apertures equal to 1, 2, 3, and 5 wave lengths.

Reflectors with apertures up to $3\frac{1}{2}$ wave lengths were tested, and the measured polar curves agreed very well indeed with the calculated values.

The Italian experiments showed that good directional working could always be obtained with reflectors properly proportioned in respect to the wave length employed, and with the apparatus then available the range obtained was six miles.

The tests were continued in England at Carnarvon during 1917. With an improved compressed air spark gap transmitter,

a three meter wave, and a reflector having an aperture of two wave lengths and a height of 1.5 wave length, a range of over 20 miles was readily obtained with a receiver used without a reflector.

In 1919 further experiments were commenced by Mr. Franklin at Carnarvon for which electron tubes or valves were used to generate these very short waves, the object being to evolve a directional radiotelephonic system.

A 15 meter wave was chosen, which could quite easily be generated by the type of electron tube employed.

After overcoming a few practical difficulties, very strong and clear speech was received at Holyhead 20 miles away. Longer distance tests were next undertaken and a receiving set of apparatus was installed on one of the mail boats running between England and Ireland.

During these tests clear speech was received all the way over to the Irish coast and into Kingstown Harbour at a distance of 78 miles from Carnarvon. The important fact was also noticed that there was no rapid diminution of the strength of signals after the ship had passed the horizon line from Carnarvon.

As a result of the success of these experiments it was decided to carry out further tests over land across a distance of 97 miles between Hendon (London) and Birmingham.

It was proved at once that, with reflectors at both ends, good and clear speech could be exchanged at all times between the two places.

The following are some particulars of the arrangements employed at Hendon and at Birmingham (Figures 5 and 6).

The power supplied to the tubes employed is usually 700 watts. The aerial is rather longer than half a wave length and has a radiation resistance which is exceedingly high. The efficiency input to the tubes to aerial power is between 50 and 60 %, and about 300 watts are actually radiated into space.

With the reflectors in use at both ends speech is strong and of very good quality. It is usually strong enough to be just audible with a $\frac{1}{4}$ to $\frac{1}{2}$ ohm shunt across a 60 ohm telephone.

With both reflectors down and out of use, speech is only just audible with no shunt. Average measurements made by Mr. Franklin indicate that the value of the energy received when both reflectors are used is about 200 times that of the energy received without any reflectors.

These figures have been lately confirmed by local measurements taken round the stations.
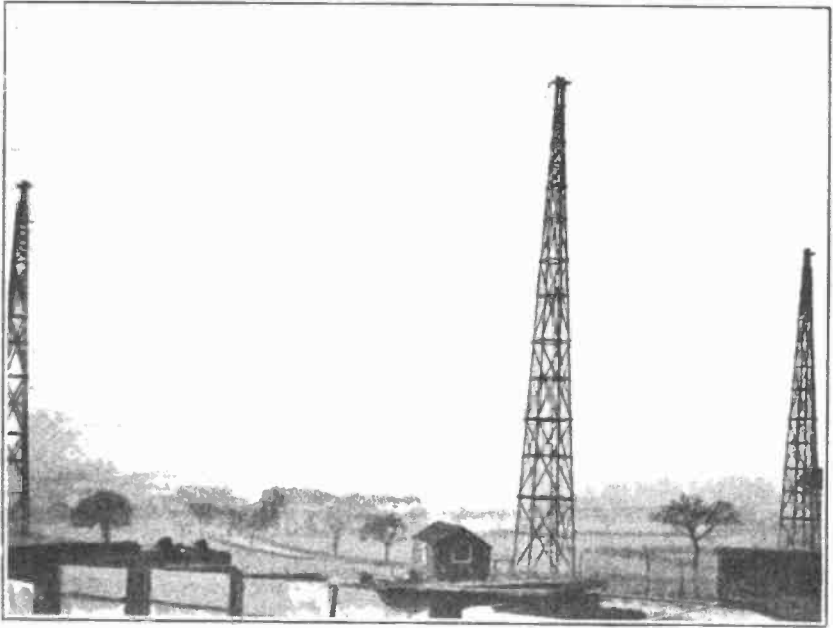
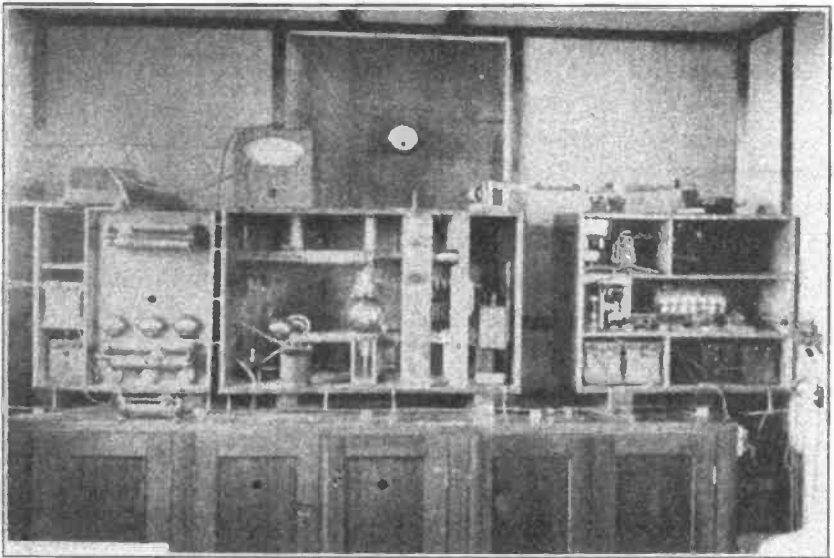FIGURE 5—Directional Transmitter (Hendon)

FIGURE 6—Experimental Short Wave Transmitter and Receiver at Hendon

Figure 7 shows a measured polar curve of the field of Hendon station taken in the vicinity of the reflector. It is rather unsymmetrical in consequence perhaps of the ground being on a slope, and owing to local reflection from trees and wires.

It has occurred to some of my assistants that a polar curve taken locally round the station may not be the same as a curve
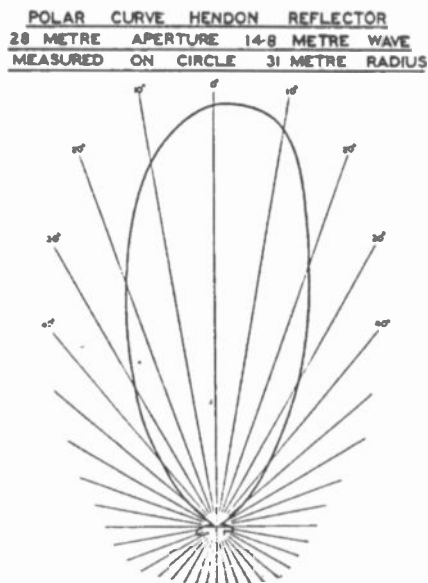

FIGURE 7—Polar Curve of Hendon Reflector

taken at a distance, and that at a distance the directional effect may be lost. I am, however, in agreement with Mr. Franklin that such is not the case.

Experiments carried out with revolving reflectors, which make it easy to read measurements at any distance, prove that the polar diagram for a given reflector and wave length is practically constant at all ranges.

By means of suitable electron tubes or valves, it is now quite practicable to produce waves from about 12 meters and upwards utilizing a power of several kilowatts, and it is also practicable to utilize valves in parallel.

During the continuous wave tests at Carnarvon, it was found that reception was quite possible on the transmitting aerial whilst the transmitter was operating.

This system is being used successfully for duplexing between Hendon and Birmingham, as it avoids all switching.

Reflectors besides giving directional working, and econo-

mizing power, are showing another unexpected advantage, which is probably common to all sharply directional systems. It has been noted that practically no distortion of speech takes place, such as is often noticed with non-directional transmitters and receivers, even when using short waves.

The results between Hendon and Birmingham easily constitute a record for radiotelephony in respect to the ratio of distance to wave length, as Birmingham, it may be interesting to note, is 10,400 wave lengths from Hendon.

We consider, however, that these results represent only what could be obtained from a first attempt, and not what could now be done after the experience gained.

It has thus been shown for the first time that electric waves of the order of 15 to 20 meters in length, are quite capable of providing a good and reliable point to point directional service over quite considerable ranges.

In these days of broadcasting, it may still be very useful to have a practically new system which will be to a very large degree secret, when compared to the usual kind of radio.

The results obtained by reflectors appeared to be so good that I was tempted to try out my old idea of 26 years ago, and test the system as a position finder for ships near dangerous points. This is now being done in Scotland through the courtesy of Messrs. D. and C. Stevenson and of the Commissioners of Northern Lights. Trials are being carried out under the supervision of Mr. Franklin with a revolving reflector erected at Inchkeith Island in the Firth of Forth near Edinborough. The transmitter and reflector revolving, act as a kind of wireless lighthouse or beacon, and, by means of the revolving beam of electrical radiation, it is possible for ships, when within a certain distance to ascertain, in thick weather, the bearing and position of the lighthouse.

The experimental revolving reflector was erected and the first tests were carried out with the S. S. *Pharos* during the autumn of 1920 (Figure 8)

With a 4-meter wave spark transmitter, a reflector, and a single tube receiver, suitably tuned, on the ship, a working range of 7 miles was obtained.

The reflector was caused to make a complete revolution every two minutes, and a distinctive signal was sent every half point of the compass. It was ascertained on the steamer that this enabled the bearing of the transmitter to be accurately determined within $\frac{1}{4}$ point of the compass, or within 2.8 degrees.
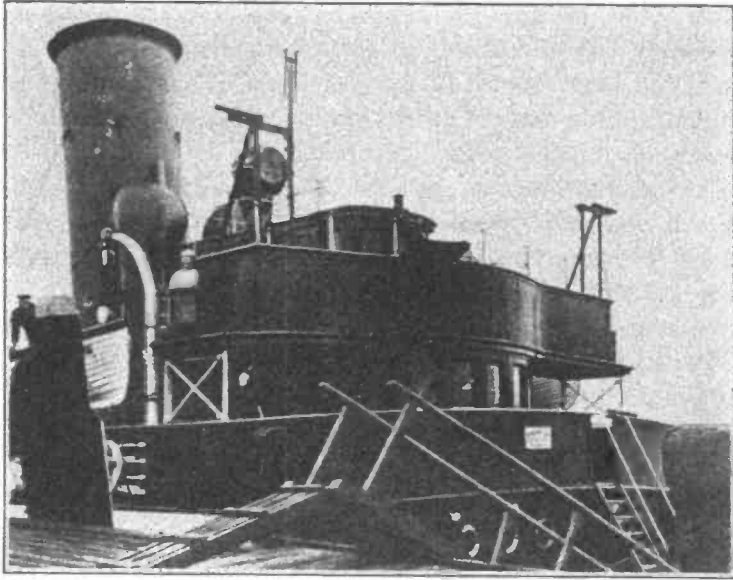
FIGURE 8—Short Wave Receiver on Steamship "Pharos

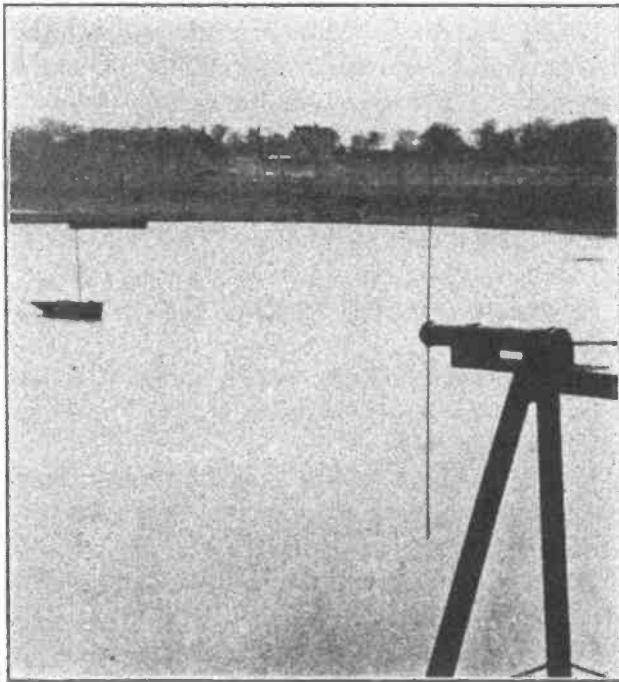At a later date a new reflector was designed and erected and is now being tested (Figure 12).

FIGURE 9—Short Wave Receiver

Figure 10 shows measured polar curves taken recently with the new reflector. The curves were measured at a distance of 4 miles.

With the revolving beam the exact times of maximum signals

POLAR CURVES INCHKEITH REFLECTOR
5·5 METRE PARABOLA 11 METRE APERTURE
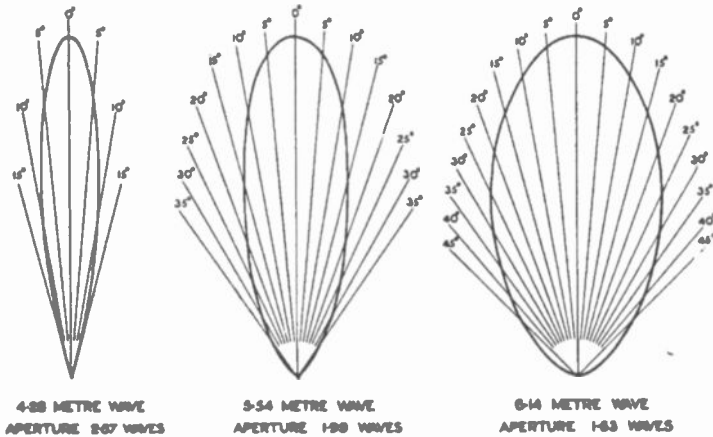MEASURED AT 4 MILES FROM TRANSMITTER.

FIGURE 10—Polar Curves of Inchkeith Reflector

are not easy to judge, by ear, but the times of starting and vanishing are easy to determine, as the rate of rise and fall of the signals is extremely rapid. The time half way between these two times gives, with great exactness, the moment when the beam is pointing to the ship (Figure 11).

By means of a clockwork arrangement a distinctive letter is sent out every two points, and short signs mark intermediate points and half points; and this is done in practice by contact segments arranged on the base of the revolving reflector, so that a definite and distinctive signal is transmitted at every half or quarter point of the compass (Figure 12).

I will now try to show you the working of a roughly constructed 1-meter wave transmitter and reflector.*

The attenuation of these short waves over sea is so surpris-

*At this point, Senator Marconi demonstrated the transmission of 1-meter continuous waves from a parabolic reflector of the type shown in Figure 3, and composed of parallel wires, over a distance of approximately 15 meters to a tube receiver with reflector similar to that of Figure 2. Absorption of the waves by a tuned resonator was also shown—EDITOR.
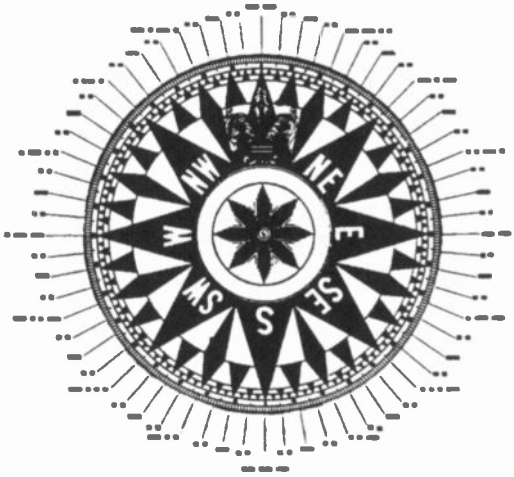
FIGURE 11—Compass Bearings with Letter Designations for Radio Direction Finding

ingly regular that a little experience enables distance to be judged by the strength of signals, and this can be measured by means of a potentiometer.
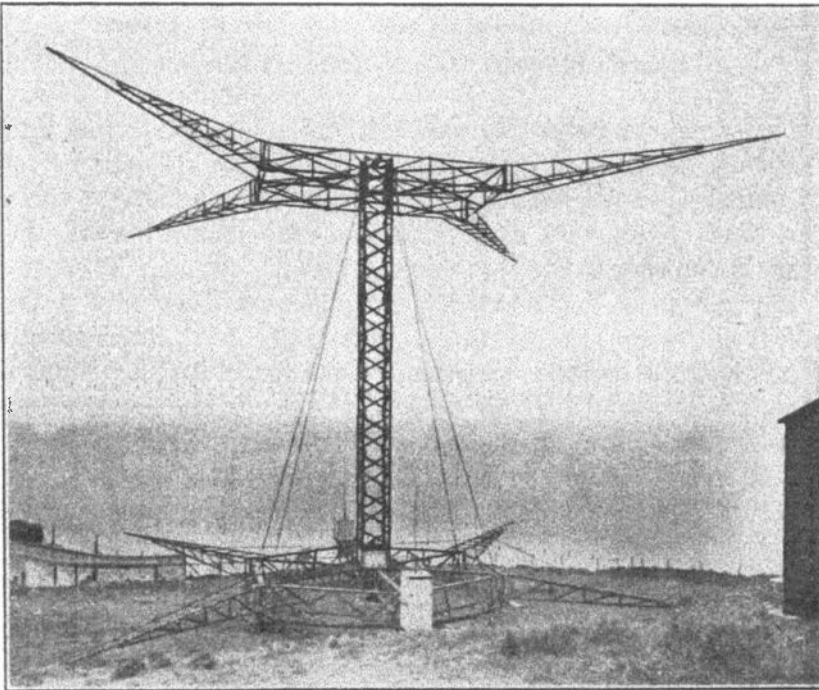

FIGURE 12—Rotating Short Wave Directional Transmitter, Inchkeith

Before I conclude I should like to refer to another possible application of these waves which, if successful, would be of great value to navigators.

As was first shown by Hertz, electric waves can be completely reflected by conducting bodies. In some of my tests I have noticed the effects of reflection and deflection of these waves by metallic objects miles away.

It seems to me that it should be possible to design apparatus by means of which a ship could radiate or project a divergent beam of these rays in any desired direction, which rays, if coming across a metallic object, such as another steamer or ship, would be reflected back to a receiver screened from the local transmitter on the sending ship, and thereby immediately reveal the presence and bearing of the other ship in fog or thick weather.

One further great advantage of such an arrangement would be that it would be able to give warning of the presence and bearing of ships, even should these ships be unprovided with any kind of radio.

I have brought these results and ideas to your notice as I feel—and perhaps you will agree with me—that the study of short electric waves, although sadly neglected practically all through the history of wireless, is still likely to develop in many unexpected directions, and open up new fields of profitable research.

Having referred so lengthily to what is essentially a directional system, that is, a system that does not spread its waves all round, you will perhaps expect a few words from me before I bring this rather lengthy discourse to a close, on the subject of "Broadcasting."

No remarks from me or from anyone else are required to tell you what has already been done with radio in America, as a means of broadcasting human speech, and other kinds of sound which may also be entertaining if not always instructive.

In thousands of homes in this country there are radiotelephonic receivers, and intelligent people, young and old, well able to use them—often able to make them—and in many instances contributing valuable information to the general body of knowledge concerning the problems great and small of radiotelegraphy and radiotelephony.

But I think I am safe in saying that if radio has already done so much for the safety of life at sea, for commerce, and for commercial and military communications, it is also destined to

bring new and, until recently, unforeseen opportunities for healthy recreation and instruction into the lives of millions of human beings.

ABSTRACT

The lecture first deals briefly with the early history of long distance radio communication.

The work carried out by the engineers and experts of the Marconi Company in England with electron tubes or triode valves shows that, according to their experience, greater efficiency can be obtained at present by a number of bulbs used in parallel than by the employment of large single unit tubes.

Information is given in a general way in regard to recent practice in the design and construction of receivers with the object especially of improving selectivity, reducing interference, and concerning the possible speed of working.

The lecture also deals briefly with results obtained at receiving observation stations situated in various far distant parts of the world, where it has been ascertained that radio signals arriving from high power stations situated at or near the antipodes of the observation stations, reach the receivers by various ways around the earth, not always following the shortest great circle route, and also that at such places the electric waves coming round by different ways do in certain cases increase this effect on the receivers whilst in others interfere with each other.

It has also been noticed that apparently transmission is easier from west to east than from east to west, and that it may be necessary to modify somewhat the transmission formula for long distances.

It has also been ascertained that the most troublesome atmospheric disturbances or static usually come from the continents and not from the oceans.

The lecture further deals with a study of short electrical waves and the results which have been obtained with such waves of a length from 1 meter to 20 meters, and describes tests which show for the first time that electric waves of under 20 meters in length, used in connection with suitable reflectors, are quite capable of providing a good and reliable point-to-point, unidirectional system of radio over quite considerable distances.

The application of this system as a direction finder in aid of navigation, and as a method for preventing collisions at sea, is also dealt with.

RECEIVING MEASUREMENTS AND ATMOSPHERIC DISTURBANCES AT THE NAVAL RADIO RESEARCH LABORATORY, BUREAU OF STANDARDS, WASHINGTON, MARCH AND APRIL, 1922*

By

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(UNITED STATES NAVAL RADIO LABORATORY, WASHINGTON, D. C.)

(Communication from the International Union for Scientific Radio Telegraphy)

The observations in the tables, both signals and atmospheric disturbances, were made by comparing the telephone current due to the signal or disturbance, with that due to a known audio frequency emf. impressed on the telephone terminals. In the case of signals, the beat note is brought to the same pitch as the tuning fork vibrator which produces the comparison telephone current. Since this is impossible in the case of the disturbances, these are compared with the known telephone current which can just be heard with the telephones in such a position with respect to the ears that the disturbances are just audible.

The receiving system is frequently calibrated by measuring the telephone currents due to signals of known intensity with the telephone comparator. These known signals are in some cases sent from the Washington Navy Yard with a few milliamperes in the sending antenna, using the regular antenna for reception at the laboratory. In other cases some of the American stations of known effective height and antenna current, such as Marion, Sayville, or Long Island (New York Radio Central), are received on a low antenna. The relative effective heights of the two receiving antennas are determined by thermoelement reception of Arlington's arc. These calibrations indicate that for level country of medium conductivity, and wave lengths above 10,000 m., the attenuation of the signal is practically the same as for salt water, up to at least 400 miles (640 km.).

The average effective height of the regular receiving antenna during March and April was 15.1 m. (50 ft.). The height of the

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Field Intensity of Lafayette Station and Disturbances
($\lambda = 23,400$ m.) in March, 1922, in Micro-volts per Meter

Date	10 A. M.		3 P. M.	
	Signal	Dis-turbances	Signal	Dis-turbances
1	60.0	50	60.0	60
2	55.0	20	46.0	30
3	58.0	40		30
4	50.0	40		20
6	60.0	40	.	30
7	50.0	30	.	50
8	70.0	10	.	30
9	90.0	80	.	100
10	90.0	60	.	40
11	65.0	30		60
13	50.0	750	.	500
14	60.0	50	.	50
15	70.0	50	.	200
16	75.0	50	60.0	40
17	75.0	40	· 70.0	. 50
18	65.0	40	85.0	· 50
20	45.0	400	75.0·	100
21	50.0	30	55.0	30
22	65.0	30	50.0	40
23	70.0	20..	55.0	40
24	90.0	30	50.0	300
25	50.0	40	. . . .	. .
27	60.0	30	55.0	50
28	. . . .	100	35.0	200
29	7 .0	400 .	40.0	300
30	6 .0	30	90.0	650
31	55.0	40	40.0	200
	1663.0	2530	1610.0	3250
Average	64.0	93.7	62.0	125.0

low antenna, used for receiving the stronger stations was 1.2 m.
(4 ft.).   Assuming 480 antenna amperes at Lafayette, and 380

Field Intensity of Lafayette Station and of Disturbances
($\lambda = 23{,}400$ m.) in April, 1922, in Micro-volts per Meter

Date	10 A.M.		3 P. M.	
	Signal	Dis-turbances	Signal	Dis-turbances
1	60.0	30	50.0	50
3	55.0	40	60.0	60
4	55.0	30	45.0	300
5	45.0	300	60.0	500
6	65.0	80	55.0	150
7	75.0	80	45.0	200
8	60.0	100	75.0	150
10	60.0	300	30.0	400
11	90.0	40	75.0	500
12	110.0	20	45.0	30
13	95.0	40	50.0	60
14	20.0	2100	50.0	200
15	60.0	40	55.0	50
17	55.0	100	75.0	150
18	75.0	40	90.0	30
19	95.0	50	75.0	50
20	. . . .	. .	55.0	60
21	80.0	40	75.0	30
22	145.0	40	75.0	40
24	150.0	50	115.0	40
25	130.0	60	60.0	500
26	125.0	60	45.0	500
27	. . . .	. .	50.0	300
28	100.0	300	55.0	80
29	95.0	200	85.0	200
	1900.3	4140	1520.0	4630
Average	82.6	160	60.8	185

amperes at Nauen, the electric field intensity calculated from
our formula (see also PROCEEDINGS OF THE INSTITUTE OF RADIO
ENGINEERS, volume 10, page 158, June, 1922), is:

$$E \text{ (Lafayette)} = 31.5.10^{-6} \text{ volts/meter}$$
$$E \text{ (Nauen)} = 15.3.10^{-6} \text{ volts/meter}$$

Field Intensity of Nauen Station and of Disturbances
($\lambda = 12,500$ m.) in March, 1922, in Micro-volts per Meter

Date	10 A. M.		3 P. M.	
	Signal	Dis-turbances	Signal	Dis-turbances
1	38.0	20	. . . .	. .
2	30.0	15	. . . .	. .
3	26.5	15	26.5	20
4	26.5	8	. . . .	. .
6	34.0	10	26.5	20
7	22.5	8	. . . .	. .
8	34.0	8	34.0	15
9	38.0	30	. . . .	. .
10	38.0	40	30.0	50
11	26.5	10	. . . .	. .
13	30.0	300	30.0	200
14	34.0	20	. . . .	. .
15	30.0	20	38.0	30
16	34.0	40	26.5	20
17	45.0	20	19.0	15
18	26.5	10	. . . .	. .
20	. . . .	. .	. . . .	. .
21	22.5	10	26.5	15
22	30.0	8	26.5	10
23	45.0	8	. . . .	. .
24	49.0	15	38.0	150
25	34.0	15	. . . .	. .
27	26.5	15	30.0	20
28	34.0	20	26.5	50
29	68.0	80	30.0	100
30	34.0	10	. . . .	. .
31	7.8	100	13.0	80
	864.3	855	421.0	795
Average	33.2	32.9	28.06	53.0

Field Intensity of Nauen Station and of Disturbances
($\lambda = 12,500$ m.) in April, 1922, in Micro-volts per Meter

Date	10 A. M.		3 P. M.	
	Signal	Dis-turbances	Signal	Dis-turbances
1	30.0	10	. . . .	. .
3	47.0	8	38.5	10
4	38.5	8	30.0	100
5	21.5	80	43.0	80
6	43.0	20	30.0	40
7	51.5	40	43.0	50
8	38.5	60	34.0	50
10	51.5	60	. . . .	. .
11	56.0	10	. . . .	. .
12	68.5	8	26.0	15
13	98.5	10	30.0	30
14	13.0	1550	32.0	50
15	34.0	15	. . . .	. .
17	30.0	60	. . . .	. .
18	30.0	15	34.0	15
19	38.5	20	30.0	20
20	47.0	30	30.0	30
21	43.0	15	26.0	20
22	43.0	10	. . . .	. .
24	47.0	30	26.	30
25	43.0	30	30.	40
26	.38.	20	30.	80
27	43.	30	26.	80
28	38.	30	26.	80
29	43.0	80	30.0	100
	1076.0	239	594.5	920
Average	43.0	89.7	31.4	48.4

SUMMARY: The daily values and monthly averages of the signal strengths
of the Lafayette station (23,400 m.), and of Nauen (12,500 m.), and the simul-
taneous strengths of the atmospheric disturbances are given for March and
April, 1922.

SOME RECENT DEVELOPMENTS OF REGENERATIVE CIRCUITS*

By

Edwin H. Armstrong

(Marcellus Hartley Research Laboratory, Columbia University, New York)

It is the purpose of this paper to describe a method of ampli fication which is based fundamentally on regeneration, but which involves the application of a principle and the attainment of a result which it is believed is new. This new result is obtained by the extension of regeneration into a field which lies beyond that hitherto considered its theoretical limit, and the process of amplification is therefore termed *super-regeneration.*

Before proceeding with a description of this method it is in order to consider a few fundamental facts about regenerative circuits. It is well known that the effect of regeneration (that is, the supplying of energy to a circuit to reinforce the oscillations existing therein) is equivalent to introducing a negative resistance reaction in the circuit, which neutralizes positive resistance reaction, and thereby reduces the effective resistance of the circuit. There are three conceivable relations between the negative and positive resistances: namely—the negative resistance introduced may be less than the positive resistance, it may be equal to the positive resistance, or it may be greater than the positive resistance of the circuit.

We will consider what occurs in a regenerative circuit containing inductance and capacity when an alternating electromotive force of the resonant frequency is suddenly impressed for each of the three cases. In the first case (when the negative resistance is less than the positive), the free and forced oscillations have a maximum amplitude equal to the impressed electomotive force over the effective resistance, and the free oscillation has a damping determined by this effective resistance. The steady state is attained after the initial free oscillation dies out and continues until the impressed emf. is removed, when the current dies out

in accordance with a second free oscillation. The maximum amplitude of current in this case is always finite; it reaches this maximum amplitude in a finite time, and when the impressed emf. is removed the current dies away to zero. This is the action of the circuits which are now in every-day practical use.

In the second case the negative resistance is equal to the positive resistance, and the resultant effective resistance of the circuit is therefore zero. When an emf. is suddenly impressed in this case, the current in the circuit starts to increase at a rate which is directly proportional to the impressed electromotive force and to the square root of the ratio of the capacity to the inductance of the circuit (for a given impressed frequency). If the force is impressed for an infinite time, then the current in the circuit reaches infinity. If the emf. is impressed for a finite time, then the current reaches some finite value. When the impressed emf. is removed, the current in the circuit at that instant continues indefinitely with unchanged amplitude as a free oscillation. Theoretically, this is the limiting case for regeneration; practically, it is always necessary to operate at some point slightly below this state at which the circuits have a definite resistance.

It is important to note here that altho the circuit of this case has zero resistance, oscillations will not start unless an emf. is impressed upon the circuit; furthermore, that oscillations once started continue with undiminished amplitude indefinitely. This state cannot be attained in practice, because the negative resistance furnished by the tube is dependent on the amplitude of the current and for stable operation decreases with increasing amplitude.[1]

In the third case the negative resistance introduced into the circuit is greater than the positive resistance, and the effective resistance of the circuit is therefore negative. When an emf. is impressed upon a circuit in this condition, a free and a forced oscillation are set up which have some interesting properties. The amplitude of the forced oscillation is determined by the value of the impressed emf. divided by the resultant resistance of the circuit. The free oscillation starts with an amplitude equal to the forced oscillation, and builds up to infinity regardless of whether

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[1] It is very important at this point to distinguish between this purely theoretical state and the state which exists in oscillating tube circuits. In the various forms of self-heterodyne circuits a free oscillation of constant amplitude is maintained in the system and the circuit may be considered as having zero resistance, *but only for that particular amplitude of current*. An external emf. impressed on the circuit always encounters a positive resultant resistance, assuming, of course, that the existing oscillation is stable. This is due to the non-linear characteristic of the tube.

or not the external emf. is removed. This free oscillation starts with an amplitude which is proportional to the impressed force, and this proportionality is maintained thruout any finite time interval (with constant impressed electromotive force).

It is important to note that altho the negative resistance of the circuit exceeds the positive, and the effective resistance of the circuit is negative, oscillations will not occur until some emf. is impressed. *Once an emf. is impressed, however, no matter how small it may be, the current in the circuit builds up to infinity regardless of whether or not the external emf. is removed.*

The fundamental difference between the case in which the resistance of the circuit is positive and the case in which the resistance of the circuit is negative may be summed up as follows: in the first, the forced oscillation contains the greatest amount of energy and the free oscillation is of very minor importance[2] (after a short interval of time), in the second, it is the free oscillation which contains the greatest amount of energy and the forced oscillation which is of negligible importance.

It is, of course, impossible with present-day instrumentalities to set up a system in which the negative resistance exceeds the positive without the production of oscillations in the system, since any irregularity in filament emission or impulse produced by atmospheric disturbances is sufficient to initiate an oscillation which builds up to the carrying capacity of the tube. It is, however, possible, by means of various expedients, to set up systems which avoid the production of such a paralyzing oscillation and which approximate the theoretical case in the use of a free oscillation to produce amplification.

The first use of the free oscillation in a regenerative system for the amplification of signals appears to have been made by Turner[3] in his valve relay system. Briefly, Turner prevented the regenerative circuit from producing oscillations when no signals were being received by placing a negative potential on the grid of sufficient value to hold it just below that point on the characteristic curve at which self-oscillation would start. The impressing of a small electromotive force of sufficient value would carry the potential of the grid over the "threshhold" value and a free oscillation would start which would build up to the limiting

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[2] This is strictly true when dealing with continuous waves which we have been considering. It is not true in the regenerative reception of spark signals, particularly of short wave length, large damping, and low spark frequency. In this case the energy in the free oscillation exceeds the energy in the forced oscillation.

[3] British Patent, 130,408.

value of the tube. The system was returned to its initial sensitive state by means of a relay operated by the increase in the plate current of the tube. This relay short-circuited the feedback coil, thereby cutting off the supply of energy and permitting the potential of the grid to drop back below the "threshhold" value. As Turner explains, the device is a relay with a low limit (as distinguished from an amplifier), but it appears to be the first device in which the free oscillation set up by an impressed electromotive force produced the magnified result.

Bolitho[4] contributed an important improvement by replacing the mechanical relay of Turner which operated only upon the receipt of a signal by a valve relay which was continuously operated by independent means. Briefly, this was accomplished by connecting a second valve to the oscillating circuit of the Turner arrangement with a reversed feed-back connection and supplying the plate circuit of this second valve with alternating current. When the "threshhold" value of the first tube was overcome and a free oscillation started in the system, the reversed feed-back of the second tube comes into action and at that time when the voltage supplied to the plate is positive, damps out the free oscillation and permits the grid of the first tube to return below the "threshhold" value. This represents the second step in the utilization of the free oscillation for the production of amplification.

It is the purpose of this paper to describe a principle of operation based on the free oscillation which is quantitative and without a lower limit. This new method is based on the discovery that if a periodic variation be introduced in the relation between the negative and positive resistance of a circuit containing inductance and capacity, in such manner that the negative resistance is alternately greater and less than the positive resistance, but that the average value of resistance is positive, than the circuit will not of itself produce oscillations, but during those intervals when the negative resistance is greater than the positive will produce great amplification of an impressed emf. The free oscillations which are set up during the periods of negative resistance are directly proportional in amplitude to the amplitude of the impressed emf. The variation in the relation between the negative and positive resistance may be carried out by varying the negative resistance with respect to the positive, by varying the positive resistance with respect to the negative, or by varying both simultaneously at some frequency which is generally rela-

[4]British Patent, 156,330.

tively low compared to the frequency of the current to be amplified.

These three methods of producing the super-regenerative state are illustrated respectively by Figures 1, 2, and 3, which figures indicate the general scheme of the system and the methods of varying the relation between the negative and positive resistance. Figure 1 shows a method of varying the negative resistance produced by the regenerative system by varying the voltage of the plate of the amplifying tube by means of a second tube, the grid of the second tube being excited by an emf. of suitable frequency.

Figure 2 illustrates a method of varying the positive resistance of the circuit with respect to the negative. This is accomplished by connecting the plate circuit of a vacuum tube in parallel to the tuned circuit of the regenerative system and exciting the grid by an emf. of suitable frequency. Figure 3 illustrates a combination of these two systems in which simultaneous varia-
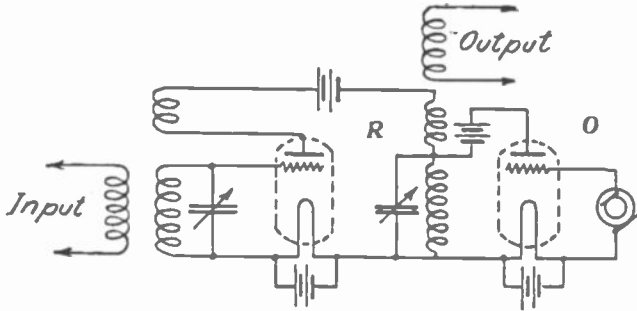
FIGURE 1

tions are produced in both the negative and positive resistances and provision made for adjusting the relative phases of these two variations.

A general idea of the phenomena occurring in these systems when an emf. is applied to the input circuit will be obtained from the diagram of Figure 4 which applies specifically to the circuit of Figure 1. This figure illustrates the principle relations existing in the system in which the positive resistance is constant and the variation is introduced into the negative resistance. It will be observed that the frequency of variation appears as a modulation of the amplified current so that the output circuit contains currents of the impressed frequency plus two side frequencies differing from the fundamental by the frequency of the variation.

Oscillograms of the essential current and voltage relations existing in the systems of the type illustrated by Figures 1 and 2
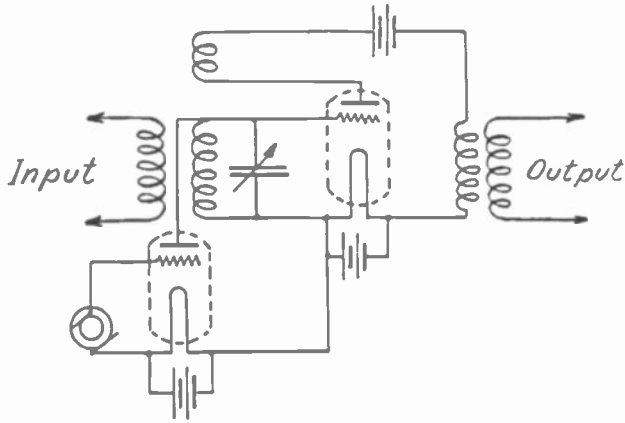
were obtained with the set up of apparatus illustrated in Figures 5 and 6, respectively. In the arrangement of Figure 6, in order to produce sufficient variation in the positive resistance of the tuned circuit, which was of large capacity and low inductance, it
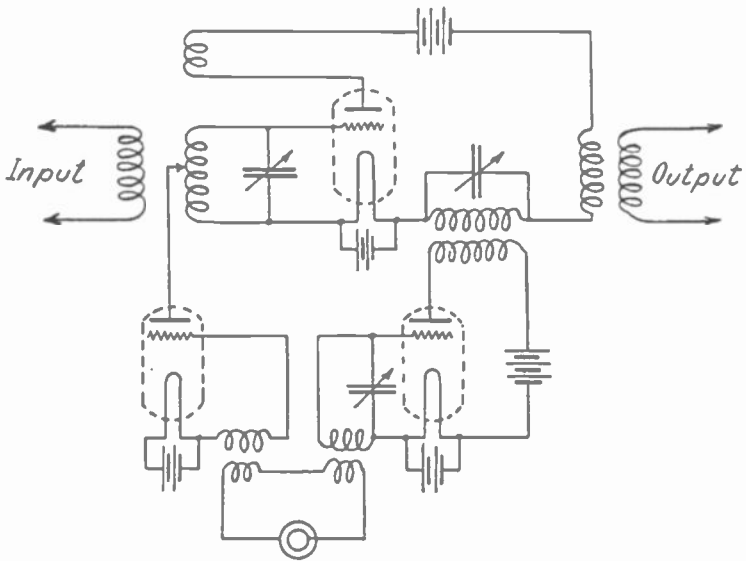
was necessary to use a two-electrode tube in series with the auxiliary emf.

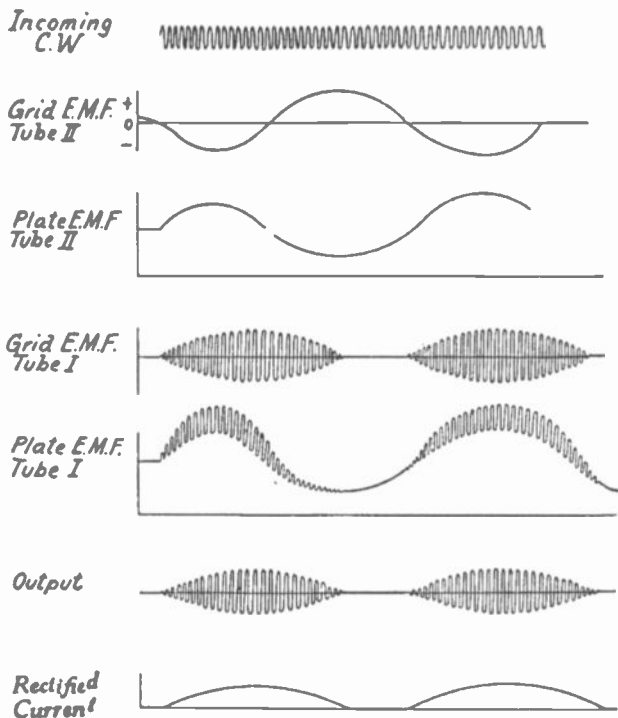Figures 7 and 8 are oscillograms respectively for a negative resistance variation and a positive resistance variation. The signaling emf. was impressed about half way along the film, the

FIGURE 4
Tube I refers to R in Figure 1
Tube II refers to O in Figure 1

exact point at which the key was closed being indicated by the arrow. These oscillograms show phenomena which are in accordance with the explanations already given, but, in addition, show evidence of self excitation. It has been stated in the preceding pages of this paper that the basis of super-regeneration was the discovery that a variation in the relation between the
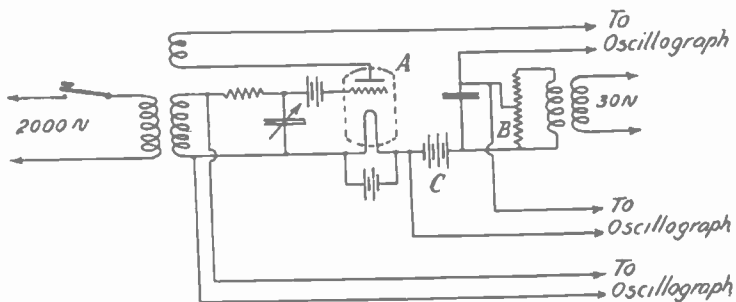
FIGURE 5
A-4 Western Electric Type L Tubes in parallel
B-AC Voltage = 100 Volts
C-DC Voltage = 160 Volts
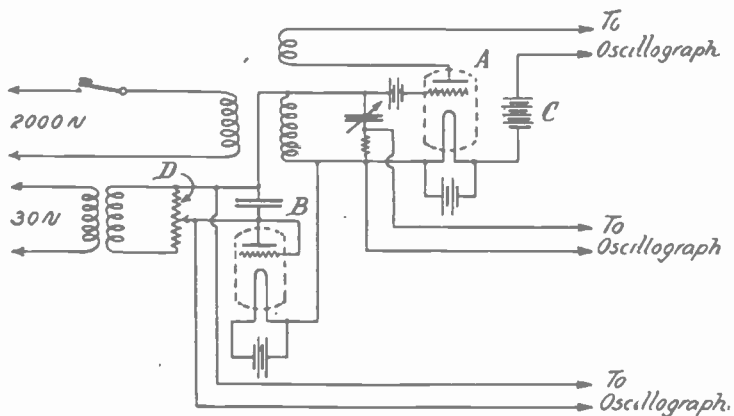
FIGURE 6

A-4 Western Electric Type L Tubes in parallel
B-1 Western Electric Type L Tubes with grid and plate in parallel
C-DC Voltage = 160 Volts
D-AC Voltage = 30 Volts

negative and positive resistances prevented a system which would normally oscillate violently from becoming self-exciting. An
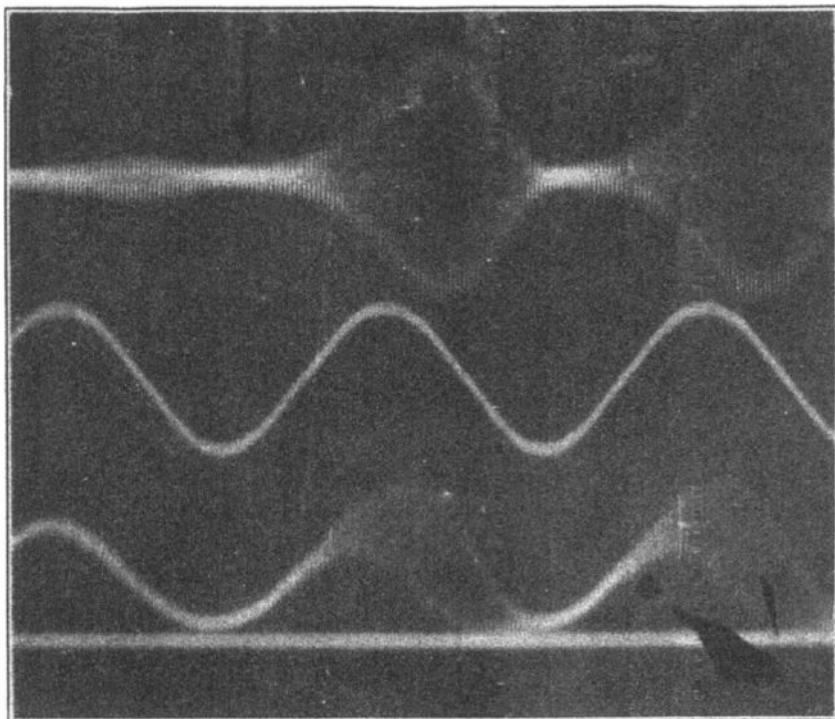
FIGURE 7

examination of the oscillograms will show that this is not strictly true, as a free oscillation starts every time the resistance of the circuit becomes negative. It will be observed however, that this free oscillation is small compared to that produced by the signal, and therein lies the complete explanation of the operation of the system. The free oscillations produced in the system when no signaling emf. is impressed, must be initiated by some irregularity of operation of the vacuum tubes, and must start at an amplitude equal to the amplitude of this disturbance. This initial value is of infinitesimal order, and hence, in the limited time interval in which it can build up the locally excited oscilla-
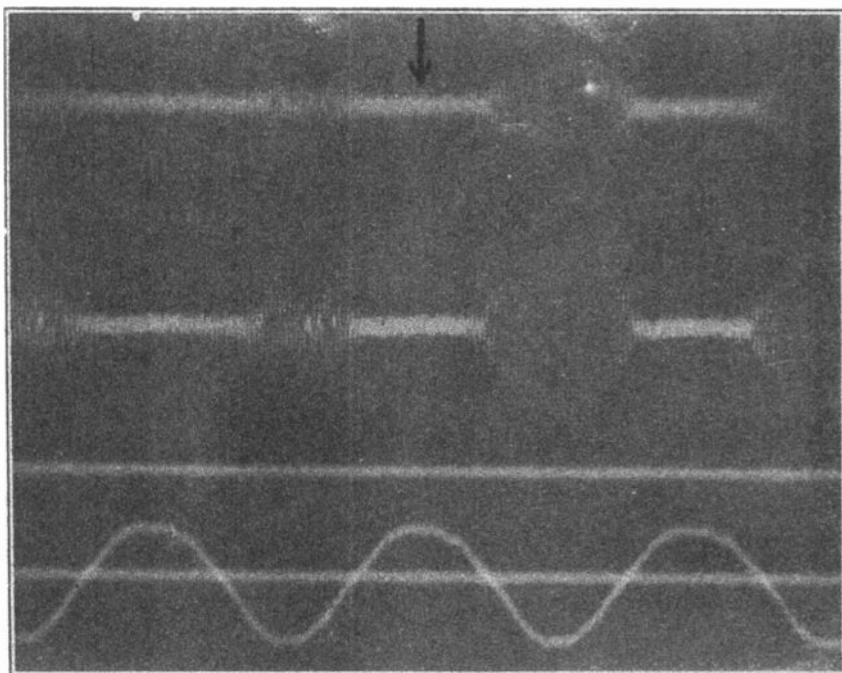
FIGURE 8

tion, never reaches an amplitude comparable to the oscillation set up by a signal of any ordinary working strength.

There is a second point of interest which is most evident from the curves of Figure 7. It will be observed that there is a decided lag in the maximum value attained by the free oscillation set up by a signal and the maximum value of plate voltage (negative resistance) of the amplifying tube. This is most evident from the plate current curve. It is a point of considerable interest, and the phenomena involved will be analyzed in a later part of the paper.

The rate of variation in the relation between the negative and positive resistance is a matter of great importance. It may be at sub-audible, audible, or super-audible frequencies. In radio signaling, for the reception of telephony, the variation should be at a super-audible frequency. For modulated continuous wave telegraphy and spark telegraphy, to retain the tone character- istics of the signals, it must be well above audibility; for maxi- mum amplification a lower and audible rate of variation should be used. In continuous wave telegraphy, where an audible tone is required, the variation is at an audible rate; where the opera- tion of an indicating device is required, a sub-audible frequency may be best. The choice of frequency is a compromise, partie- ularly in telephony, since obviously the lower the frequency the greater the amplification, and the higher the frequency the better the quality.

Some practical forms of circuits are illustrated by Figures 9, 10, and 11, which illustrate respectively the three types of variation. Figure 9 shows a method of varying the plate voltage of the amplifying tube R by means of the vacuum tube oscillator O coupled into the plate circuit. In this arrangement a third tube D acts as a detector. This is essential when an audible frequency is employed; when a super-audible frequency is used the telephones can be placed directly in the plate circuit of the amplifying tube.

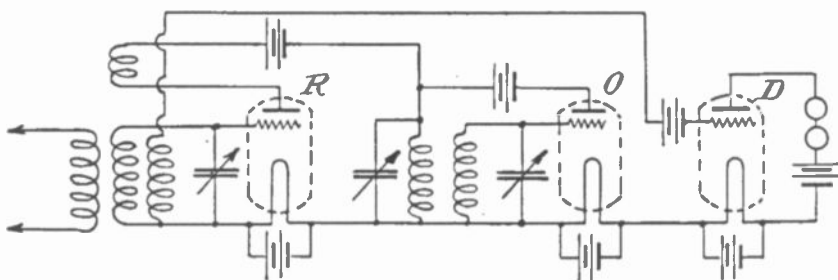Figure 10 shows the second case in which the variation is

FIGURE 9

introduced into the positive resistance of the tuned circuit. This is done by means of an oscillating tube O, the grid circuit of which is connected thru the tuned circuit LC of the amplifying tube R. The variation in the resistance of the circuit is effected thru the variation in potential of the grid of the oscillating tube. During that half of the cycle, when the grid of the oscillating ube is positive, energy is withdrawn from the tuned circuit in

the form of a conduction current from the grid to the filament of the oscillating tube, thereby increasing the effective resistance of the circuit. During the other half of the cycle, when the grid of the oscillating tube is negative, no conduction current can flow thru the grid circuit of the oscillating tube, and hence no resistance is introduced into the tuned circuit of the amplifying tube. In this case the amplifying tube serves also as the detector for any frequency of variation, as the tuned circuit forms a sufficiently good filter even for an audible frequency to prevent a disturbing audible tone in the telephones.

Figure 11 illustrates the case of a simultaneous variation in both positive and negative resistances. This is accomplished by providing the amplifying tube R with a second feed-back circuit L_1C_1 and L_2C_2 adjusted to oscillate at some lower frequency, thereby introducing a variation in the negative resistance thru the variation of the plate potential of the amplifier and a varia-
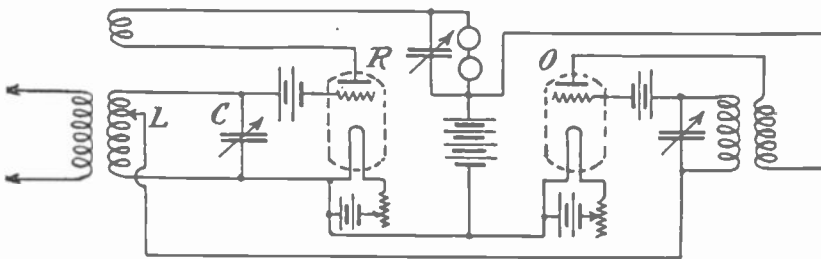

FIGURE 10

tion in the positive resistance by means of the variation of the grid of the amplifier. The proper phase relations between the negative and positive resistance are obtained by adjustment of the capacity of condensers C_1 and C_2 and the coupling between L_1 and L_2. In operation this system is very critical, and extreme care is necessary in order to obtain the super-regenerative state.

In each of the preceding cases the detecting function has been carried out either by a separate tube or by means of the amplifying tube. When a super-audible frequency of variation is employed, it is sometimes of advantage to perform the detecting function in the oscillating tube, and an arrangement for carrying this out is illustrated in Figure 12. The operation of this system is as follows: incoming signals are amplified bv means of the regenerative action of the amplifier tube R and the variations of potential across the tuned wave frequency circuit LC impressed upon the grid of the oscillating tube 0. These oscillations are
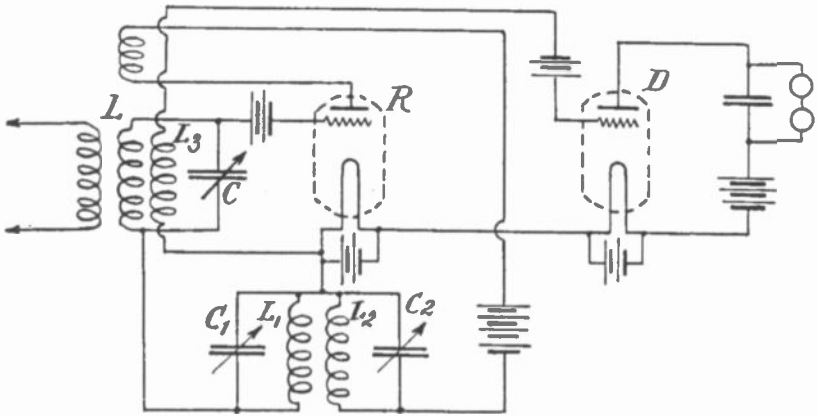
FIGURE 11

then rectified, and two frequencies are produced in the circuits of the amplifier tube. One of these frequencies corresponds to the frequency of modulation of the signaling wave. The other corresponds to the frequency of the variation and contains a modulation in amplitude corresponding to the modulation of the transmitted wave. This second frequency is then impressed upon the circuits of the oscillating tube with which it is in tune, amplified by the regenerative action of the system $L_1C_1L_2O$, and then rectified. The amplification obtainable with this form of
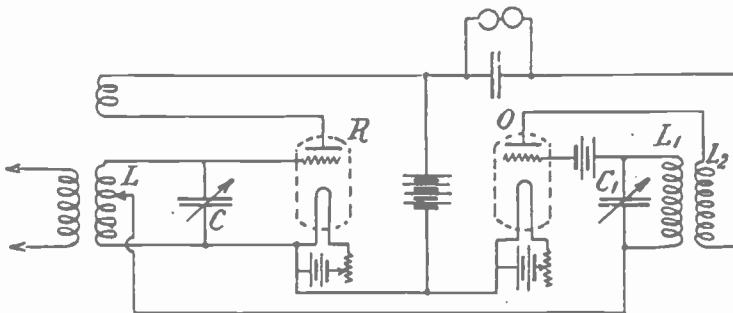

FIGURE 12

system is considerably greater than that of the single amplification circuits, but is naturally more complicated to operate.

When a super-audible variation is employed in a system such as illustrated in Figure 1, it is generally necessary to introduce a certain amount of resistance in the tuned circuit to insure the dying out of the free oscillation during the interval when the resistance of the circuit is positive. This is most effectively carried out by means of the arrangement illustrated in Figure

13, in which a secondary coil L_1 of large inductance and high resistance is coupled to the tuned circuit LC and the energy withdrawn thereby from the oscillating circuit stepped up and applied to the grid of the tube. In the operation of this system, a curious phenomena is encountered. This is the manifestation of an inductive reaction by the plate circuit of the amplifying tube to the auxiliary frequency emf. supplied the plate circuit
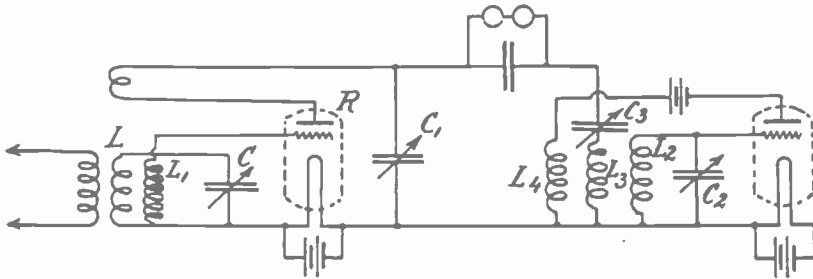

FIGURE 13

by the oscillating tube, which comes about in the following way When the auxiliary emf. is impressed upon the plate of the amplifying tube, a current is produced in this tube in phase with the emf. across the tube. Now suppose the plate voltage is at its maximum positive value. This means that the negative resistance of the circuit is a maximum in amplitude. This in turn means that the average value of the grid is becoming more positive and the current in the plate circuit is likewise increasing. Since the free oscillation in the system will increase in amplitude as long as the resistance of the circuit is negative, it will reach its maximum amplitude after the maximum positive voltage is applied to the plate. Hence the component of current corresponding to the frequency of the variation set up in the plate circuit by the rectification of the radio frequency oscillations lags in phase behind the auxiliary emf. impressed on the plate. Hence the plate circuit of the tube manifests an inductive reaction to the auxiliary emf. It was found that this inductive reaction could be tuned out by means of the parallel condenser C_1 with a great improvement in the stability of the operation of the system and increase in the signal strength. The resonance point is pronounced, and once the other adjustments of the system have been correctly made is as readily found as any ordinary tuning adjustment.

The problem of cascade amplification with these systems is a rather involved one on account of a great number of effects which

are not encountered in ordinary methods of cascade amplification. The principal trouble is the reaction of the second amplifying system on the first, and the difficulty of preventing it in any simple way on account of the high amplification per stage. While this difficulty is not insuperable, a simple expedient may be employed which avoids it. On account of the large values of radio frequency energy in these amplifying systems, the second harmonic is very strong in the plate circuit of the amplifying tube and is of the same order of magnitude as the fundamental if the tube is operated with a large negative voltage on the grid. Hence by arranging the second stage of a cascade system to operate at double the frequency and to amplify this harmonic, the difficulty is avoided. The general arrangement of such a system is illustrated by Figure 14, in which the positive resistance of the circuits LC and L_1C_1 of a two-stage amplifier are varied synchronously by a single oscillator. The circuit L_1C_1 in this case is tuned to the second harmonic of the circuit LC, but the combinations of circuits which may be arranged on this principle are very numerous.

One of the curious phenomena encountered with the super-regenerative system is found when it is attempted to secure
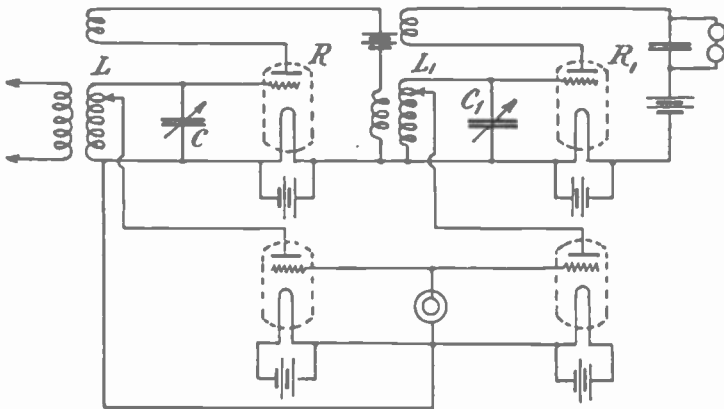

FIGURE 14

sharp tuning by the use of tuned circuits placed between the antenna and the amplifying system. The free oscillations set up in these circuits by the reaction of the amplifying system continue in these circuits during the interval when the resistance of the amplifier circuit is positive, re-excite the amplifier when the resistance becomes negative, and hence the entire system is kept in a continuous state of oscillation. The effect is most critical,

and may be produced with most extremely weak couplings between the amplifier circuit and the second tuned circuit. The simplest solution of the difficulty is to perform the function of tuning at one frequency and amplification at another, and this is best accomplished by means of the super-heterodyne method illustrated by Figure 15. This may be adapted to work on either the sum or difference frequencies, but when the higher frequency is used, care should be taken that it is not near the second harmonic of the local heterodyning current. In the particular arrangement illustrated, *LCD* represents, together with the heterodyne, the usual agency for changing the incoming frequency, and
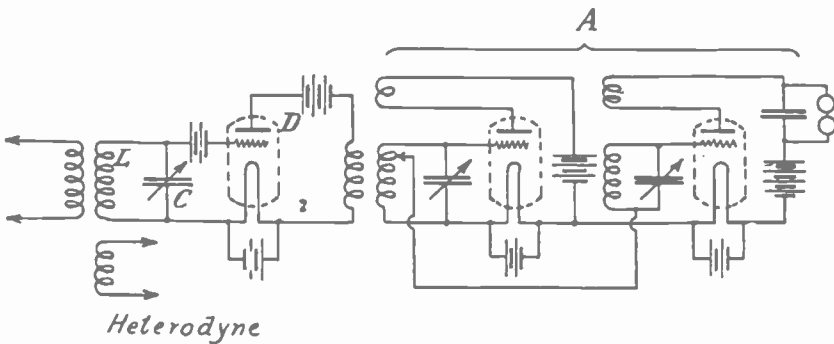

FIGURE 15

A represents the super-regenerative amplifier which may be of any suitable type.

Some of the results obtained in practice with super-regenerative systems compared to simple regenerative systems may perhaps be of interest. In general, it may be stated that the amplification which can be obtained varies with the frequency of the incoming signal and with the radio of the wave frequency to the auxiliary frequency. The higher the signaling frequency and the greater the ratio of this frequency to the auxiliary frequeney, the greater the amplification. Other things being equal, it appears that the energy amplification varies as the square of the ratio of the signaling frequency to the auxiliary frequency. Hence, it follows that for telegraphic signals where an audible auxiliary frequency is used, much greater amplification can be obtained than in the case of telephony, where a super-audible auxiliary frequency must be employed. Using the arrangement of Figure 11 for a signaling frequency of five hundred thousand cycles, an energy amplification several million times greater than that obtainable with a simple self-heterodyne circuit is

readily secured. Where a super-audible frequency is used for the reception of telephone signals, amplification of fifty thousand to one hundred thousand times energy can be obtained.

In a practical way the relative amplification of the new system with respect to the standard regenerative system for reception of telephone signals may be visualized as follows: With a signal so extremely weak that only the faintest of beat notes can be heard in the ordinary regenerative receiver, the super-regenerative receiver will give clearly understandable speech. For signals of sufficient strength to be understandable with the ordinary regenerative system with zero beat adjustment but not audible without local oscillations, the super-regenerative receiver will produce signals loud enough to be heard thruout the room.

Perhaps the most surprising characteristic of the system, apart from the amplification, is its selectivity with respect to spark interference when a super-audible frequency of variation is used. The explanation of this selectivity with respect, for example, to the ordinary regenerative receiver, lies in the periodic suppression of all free vibrations in the system. In the ordinary regenerative system spark interference approximates a form of shock excitation setting up a free vibration in the system which, because of the low damping existing therein, continues for a long period of time. An examination of the character of the oscillation set up will show that the energy existing in the free vibration after the initial impressed electromotive force is removed, is far greater than the forced vibration. In the ordinary system this free vibration may exist for a thousandth of a second or more. In the super-regenerative system this free vibration is damped out before it has proceeded more than one twenty thousandth of a second as a maximum. Hence, the interference from spark signals is greatly reduced. This phenomenon opens up a new field for the suppression of interference produced by shock excitation.

At the present time, on a three-foot loop antenna located twenty-five miles from the station WJZ at Newark, New Jersey, and a system of the type illustrated in Figure 12 with one stage of audio frequency amplification (three tubes in all) the announcements and musical selections are clearly audible five hundred yards from the receiver. With the same loop at the same distance, using the arrangement of Figure 11 without the separate detector tube, that is, with the telephones directly in the plate circuit of the amplifier tube, it is possible to operate a loud-

speaking telephone so that the program from the Newark station is plainly heard thru a large size room. The signals with the arrangements of either Figures 11 or 12 are still heard loudly if the loop is discontinued from the receiver, the coils and wires of the receiver itself collecting sufficient energy to produce response.

While the new system does not amplify the ordinary spark signal with anything approaching its efficiency on continuous wave signals, one example of spark reception may be of interest. During the past winter an amateur spark station located at Cleveland, Ohio, and operating on a wave length of about 340 meters was received nightly at Yonkers, New York, on a three-foot (1 meter) loop and the arrangement of Figure 13 with sufficient intensity to enable the signals to be read thruout the room.

In conclusion, I wish to express my very great indebtedness to Professor L. A. Hazeltine for much valuable aid in connection with the theoretical side and to Mr. W. T. Russell for his assistance thruout the experimental side of this development.

June 2, 1922.   Marcellus Hartley Research Laboratory,
                     Columbia University, New York.

SUMMARY: A system of circuits is described whereby the effective resistance of a regenerative circuit is periodically made positive and negative, tho predominantly positive. Such a circuit will respond to impressed electromotive forces by setting up free oscillations during the negative resistance period, which oscillations are proportional to the exciting emf. The forced oscillations produced by the exciting emf. will be comparatively small. The free oscillations caused by any normal variations in tube operation will also be small.

Means of carrying regenerative circuits thru the requisite resistance cycles are shown, and the practical operation of the system, including the case when extreme amplifications are desired, is discussed.

RESISTANCE AND CAPACITY OF COILS AT RADIO FREQUENCIES*

By

J. H. Morecroft

(Associate Professor of Electrical Engineering, Columbia University, New York)

Contents

Schemes Used for Measuring Radio Frequency Resistance

The available schemes for measuring the resistance of radio frequency circuits have been well analyzed,[1] but there seem to be on record but few reliable determinations of the resistance of such coils as are used in radio circuits. The following results were obtained during the preparation of apparatus for another test; they seem useful enough to warrant publication even tho not as complete as the title of the paper would indicate.

The three schemes ordinarily available for measuring radio frequency resistance are the alternating current bridge, variation of resistance, and variation of reactance; these schemes, using continuous wave excitation, are so much better than any damped wave scheme that such has not been even considered. The bridge has the advantage of being a null method and has been

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used successfully by the writer and others[2] for frequencies as high as about 500,000 cycles a second; the bridge can be balanced at much higher frequencies, but the accuracy of the results obtained is questionable.

For frequencies of the order of a million cycles or more the resistance or reactance variation schemes are available; a substitution scheme is sometimes used, but its accuracy really depends upon one of the two other schemes. Of these schemes the resistance variation is more direct and, for the average circuit, is much more accurate than the others.

In the resistance variation scheme the circuit, the resistance of which is desired, is excited by coupling to a source of variable frequency power, Figure 1. By means of the variable condenser C the test circuit is brought into resonance with the impressed frequency, as indicated by the reading of the thermocouple ammeter, B. The non-inductive resistance R is then increased by a known amount and the new reading of B taken; by a suitable formula the resistance of the circuit can then be computed. The simplest scheme is to increase R until the current is reduced to half of its former value; this value of R is the value of the circuit resistance. If the resistance of B and C are known, the resistance of the coil L is at once obtained.
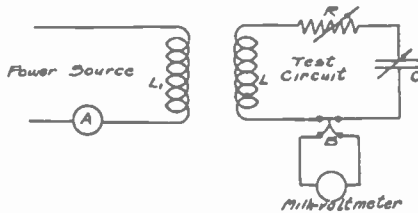

FIGURE 1

In using this method it is necessary that the voltage induced in the circuit being tested is the same for both readings; less power is drawn from the exciting source, however, after R has been increased than before and this will generally affect the current (and possibly the frequency) of the exciting source so that more voltage is induced into the test circuit after R has been increased than before. In such a case the readings of A must be noted for both readings of B, and suitable corrections applied to the calculated value of resistance.

In the experiments reported here, the power source was a 10-watt vacuum tube oscillator, the current in A being between

[2]"Note on radio frequency measurement," Carl Englund, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, for August, 1920.

1 and 3 amperes. The current in the test circuit (measured by vacuum thermocouple) was less than 50 milliamperes and the resistance of the couple heater was 1.3 ohms. With the grid coupling of the power tube adjusted to a considerably tighter value than its critical value, it was found that no appreciable change occurred in the reading of A as the resistance of the test circuit was varied.

In these tests the resistance R was a dial box, built presumably free from skin effect, inductance, and so on. It was found that retuning the test circuit, after R had been changed, was not required unless the coil being measured had less than 50 microhenries inductance. With no resistance in R the coupling between L and L_1 was adjusted to give full scale reading on the millivoltmeter connected to the thermocouple; sufficient resistance was added in R to cut the deflection to nearly $\frac{1}{4}$ full scale and this value of resistance taken as circuit resistance. The millivolt-meter and thermocouple had been previously calibrated on continuous current, so that the proper reading of the millivoltmeter for $\frac{1}{2}$ full scale current was known. The calibration of several thermocouples, of the vacuum type, showed that the reading of the millivoltmeter was very closely proportional to the square of the current thru the heater; unless very accurate work is being done the quarter scale point on the millivoltmeter may be taken as half current thru the heater. It was found that resistance determinations made this way could be duplicated repeatedly to within 1 per cent. of the average.

RESISTANCE OF THE THERMOCOUPLE AND CONDENSER

Because of the high specific resistance of the heater of the thermocouple, and its very small cross-section, its resistance at radio frequency may be considered the same as its continuous current resistance; this was measured and found practically constant from zero to maximum safe current. The condenser used was the best obtainable, having a slow motion adjustment and vernier so that its setting could be duplicated to within 1/25,000th part of its full scale value. The resistance of the condenser was, however, unknown, altho evidently small, as could be told by the constructional features.

To measure the resistance of the condenser an electrically "perfect" one was constructed, meaning by "perfect" one with losses as small as it is possible to make them. The construction was mechanically very crude but electrically the condenser was very good. Two thick aluminum plates, A and B, Figure 2,

were used for the condenser plates; they were 40 cm. (15.7 in.) long and 30 cm. (11.8 in.) wide; the lower one was fastened down to the base board, D, inside a copper pan, C-C. The upper plate was suspended by four oiled silk threads, e, e, the length of which was adjustable. The terminal for the upper plate (which was
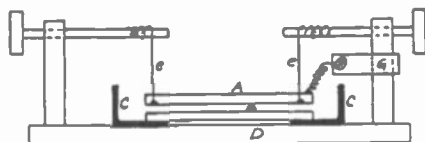
always so connected that it was the high potential plate of the condenser when being used) was a short piece of flexible cable fastened to a clip, F, which was fastened to a quartz slab, G, mounted on one of the upright posts used for supporting the upper plate. As nearly as could be determined, the condenser had no losses. It is impractical for ordinary laboratory use because of the inadequate adjustments, but it served well to measure the resistance of the mechanically good condenser, C, of Figure 1.

The arrangement of apparatus for the test was as shown in Figure 3; C_1 is the standard condenser and C_2 is the one the resistance of which is to be measured; A is a two-pole reversing switch; B is a two-way single-pole switch mounted on porcelain (to keep its losses low) which is fitted with a long insulating handle. The coil N which excites the test circuit is separated from the power supply coil M by an electrostatic shield S, made of a sheet of copper slitted vertically into strips $\frac{1}{4}$ cm. (0.1 in.) wide; these strips are insulated from each other at the top, but
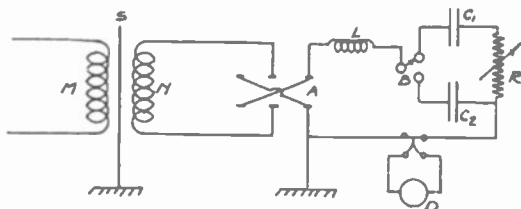

FIGURE 3

are all connected together, and to ground, at the lower ends. The reversing switch A is very necessary if accurate results are to be obtained, and it is also necessary that the high potential

leads (those between L and C_1 and C_2) be kept short and distant from ground connections.

The manipulation requires tuning the test circuit, first using C_2, to the power supply frequency and adjusting the coupling between N and M to get a reading well up on the scale of the galvanometer D; the switch B is then thrown to connect in condenser C_1 and again the circuit is tuned. Resistance R is then varied until D reads the same as it did when C_2 was in the circuit. Presumably the value of resistance in R measures the excess of resistance of C_2 over that of C_1 which we have assumed has no loss.

As the resistance to be measured is very small, it is necessary to have very low resistance in L and in the thermocouple, if accurate results are to be expected. In this case, however, very weak coupling will be required between N and M; that is, a very low voltage will be induced into the test circuit; in the apparatus as used M consisted generally of 10 turns, 10 cm. (3.93 in.) in diameter; N had two turns, and the distance between them was sometimes as great as 30 cm. (11.8 in.). Now it may well be that there is coupling between the power circuit and test circuit other than that given by coils N and M, and, if so, this extraneous coupling will probably be different when switch B is thrown in the two positions; in this case more voltage is induced in the test circuit with one condenser than with the other, resulting in a proportionate error in the resistance determination.

This error may easily amount to 20-30 per cent. unless the wires are arranged carefully. The double throw switch generally enables one to detect an error of this kind. The voltage induced in the test circuit by the coupling of M and N has its phase reversed when A is reversed, but the extraneously induced voltage remains in the same phase it had, so that the total voltage introduced into the test circuit is altered in amount by reversing switch A. The wiring of the experiment must be so arranged that as A is reversed, no change takes place in the reading of galvanometer D. It was found necessary to place the oscillating triode set inside a copper lined box and to make the electrostatic shield S completely surround coil N before the difference in reading of D (when A was reversed) could be reduced to 1 per cent. It is interesting to note that altho the copper used in surrounding the power set was 0.05 cm. (0.02 in.) thick, all joints but the cover being soldered together and grounded, it was possible to read the wave length of the set by putting the wave meter on the top of the closed box, inside of which was

the power set. The copper of the cover was grounded to the rest of the copper used in lining the box at two points, by flexible cable. The induction exciting the wavemeter was evidently coming right thru the copper. The reading of the wavemeter showed that the shielding was only 90 per cent. perfect; the voltage induced in the wavemeter thru the copper was 10 per cent. as much as it was with the wavemeter in the same position with the cover open. The frequency for these readings was about 500,000 cycles.

In carrying out the test indicated in Figure 3, condenser C_1 (which on account of its thread suspension does not permit of very fine adjustment) was set to give a capacity approximately equal to that of the setting of condenser C_2 for which a resistance determination was to be made. The frequency of the power set, by means of its vernier condenser, was adjusted to give resonance with the test circuit. It was found best to have the power set at least two meters (6 feet) from the test circuit; the vernier condenser was fitted with a long wooden handle so that the frequency could be adjusted while the galvanometer D was being observed.

The switch was then thrown to condenser C_2 which, by its fine adjustment, permitted tuning the test circuit accurately to the power circuit, and the coupling of N and M was changed, by means of another long handle, to give nearly full scale reading on D. Then B was thrown back to put C_1 in circuit, and sufficient resistance put in R to give the same deflection as for C_2. This test showed that condenser C_2, which was used in all subsequent tests, had extremely low resistance. With a capacity as low as 75 micro-microfarads at a wave length of 800 meters, it showed 0.5 ohm resistance. This resistance decreased rapidly with increase in capacity for fixed frequency and also decreased inversely as the frequency for a given condenser setting. In the ranges of capacity and frequency to be used later, it showed a resistance less than 0.1 ohm; as this was about the precision obtainable in most of the following tests the condenser resistance was neglected.

Using condenser C_1, which had no appreciable resistance, it was possible to get the resistance of the couple, connecting wires, and coil N, by eliminating coil L and making a resistance determination; this was of course possible only for the short wave lengths because of the low value of inductance in the circuit after L had been taken out. This resistance was less than two ohms, except

for very short waves; by extrapolation the resistance of this part of the circuit for the longer waves was easily obtained.

The Power Set

The oscillating triode power circuit used two 5-watt tubes in parallel, and would give from 1 to 3 amperes in coil M for all frequencies between 100 meters and 4,000 meters. For wave lengths less than 100 meters, it was necessary to set up another circuit as it was practically impossible to construct a coil large enough to give 4,000 meters which, when using one part of it, would oscillate at less than 100 meters. Even tho the coil was built with 0.2 cm. (0.08 in.) air space between layers, and each layer was disconnected from every other, the different parts constitute a group of inductors and capacities which have large losses for wave lengths less than 100 meters. Coil N had two turns and coupling was varied by moving N away from M, the two remaining coaxial. A motion of 30 cm. (11.8 in.) between N and M gave sufficient change in coupling to permit using the same thermocouple and galvanometer for resistances between 3 ohms and 150 ohms.

Single Layer Solenoids. Solid Wire and Cable

The first set of data relate to the resistance of several similar coils as the frequency was varied from zero to nearly 10^6 cycles per second. The coils were single layer solenoids wound upon octagonal forms of dry wood; check tests showed that all of the resistance measured was actual wire resistance, there being negligible dielectric hysteresis and leakage in the wooden reels themselves.

The first set of results (Figure 4) show the resistance variation of four coils made of solid copper wire; the length of each coil was 10 cm. (3.93 in.) and the average diameter was 10.5 cm. (4.12 in.). The size of the wire, number of turns, and so on, of each coil is given on the curve sheet. In a single straight wire the ratio of a.c. to d.c. resistance varies nearly as the square root of the frequency,[3] and it might be supposed that the resistance of coils would vary in nearly the same manner, the rate of increase being somewhat greater in the coils because of the greater potential gradient of the magnetic field of the coil.

Inspection of Figure 4, however, shows that the variation is a peculiar one, the resistance varying rapidly at first, then less so, and finally increasing again more and more rapidly. The first rapid increase (up to about 200,000 cycles) is probably due to

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[3]Cohen, "Calculation of Alternating Current Problems," page 5.

the current shifting to the inside of the coil because in this range of frequency there occurs also a decrease in the self induction of the coil.[4]   Above 200,000 cycles the resistance variation becomes a smooth curve, with no more points of inflection; this smooth curve may be extrapolated into the low frequency range and its equation be determined.   Even with this smooth curve
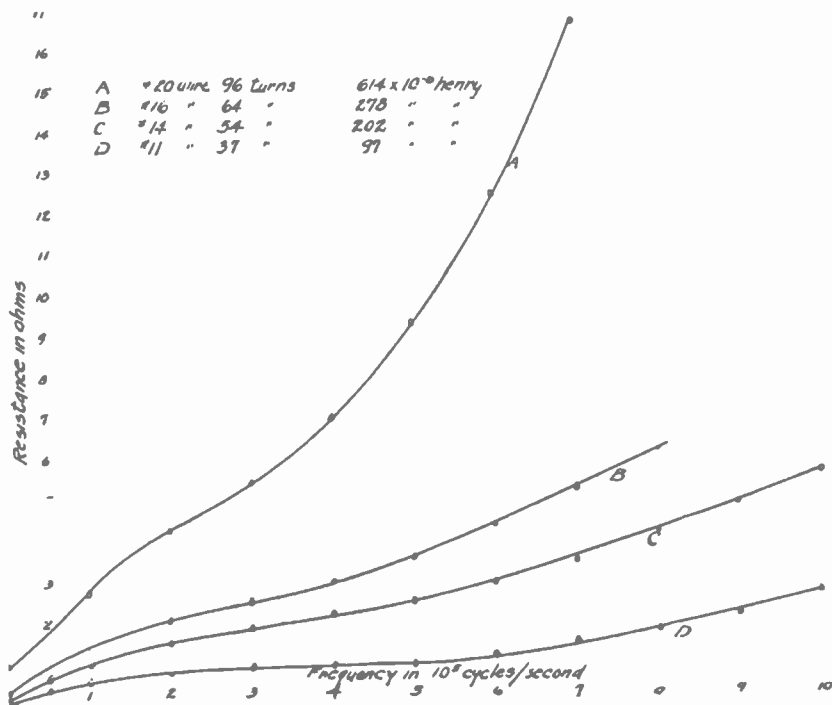

FIGURE 4

the resistance variation is not a simple function of the frequency, however, as it is with straight wires; in the lower frequency range the ratio of a.c. to d.c. resistance is proportional to a low power of the frequency, and at the higher frequencies used, the variation with frequency is nearly ten times as rapid.   Undoubtedly the variation can be expressed in some complicated functions, but the solution so far has apparently not been attempted.   The experimental results lead to an expression for the smooth curve of the form

$$\frac{\text{A.C. resistance}}{\text{D.C. resistance}} = Af^{b\prime}$$

In Figure 5 are shown the comparative resistances of three nearly similar coils, one wound with solid wire and the other two

[4]This re-distribution of the current is pictured in Morecroft "Principles of Radio Communication," page 125.

with radio cable. Two of the coils had very nearly the same resistance for continuous current (direct current) and so serve well to show the relative advantages of cable and solid wire. The superiority of the 42/36's cable over the solid number 20 wire[5] increases rapidly up to a frequency of 200,000 cycles per second, and then decreases again, a result certainly not to be expected; it seems to be the general opinion that the superiority of the cable increases as the frequency increases. At 200,000 cycles, the solid wire has twice as much resistance as the cable, but at 800,000 cycles it has only 36 per cent. more resistance; moreover, the superiority of the cable is evidently decreasing as the frequency increases and it seems as tho at some frequency higher than was possible in this test the solid wire will be as good as the cable. Further evidence on this point is given later in this paper.
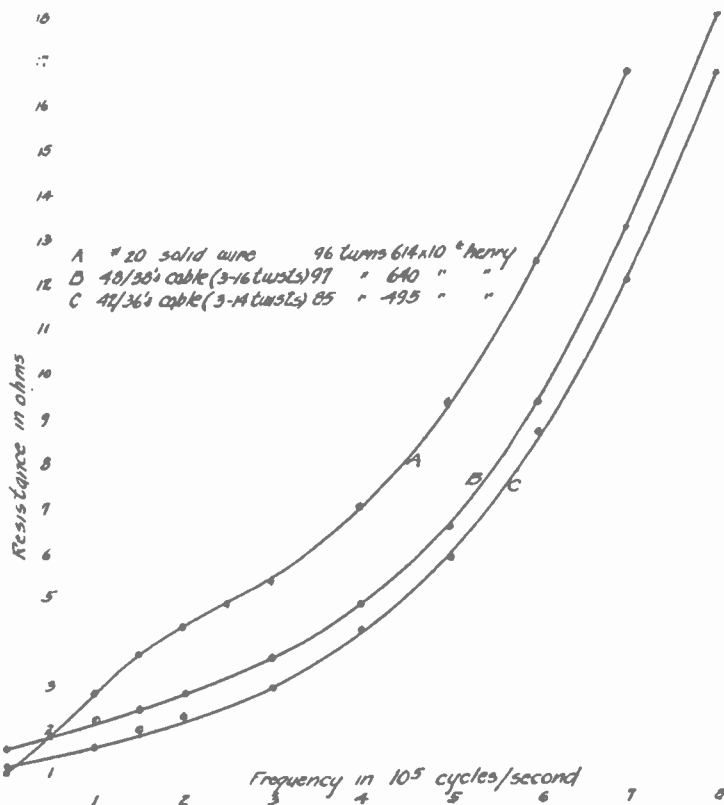

FIGURE 5

It will probably occur to the reader that the rapid increase of resistance in the upper frequency range is due to the internal

[5] 42/36 cable consists of 42 strands of number 36 wire of diameter 0.005 in. = 0.013 cm. Diameter of number 20 wire = 0.032 in. = 0.081 cm.

capacity of the coil, as the impressed frequency approaches the natural frequency. The natural frequency of these coils, however, was nearly 3×10^6 cycles per second, so that even at an impressed frenuency of 10^6 cycles the internal capacity would produce an apparent increase in resistance of only 25 per cent.; the rapid increase in resistance at the higher frequencies shown in Figure 5 is really due to a re-distribution of the current thruout the cross section of the conductor.

Resistance of a Typical Set of Radio Coils

A complete set of cable coils, which had been made up for antenna tuning, was tested; a few of the results are shown in Figure 6. These coils were all made of 48/38's enamelled wire[6] cable (3-16 twists) double and triple layer, banked windings. The coils were all 10.5 cm. (4.12 in.) in diameter, wound on circular forms made of bitumen compound, such as is used for underground conduit. This material was later investigated for dielectric loss and was found to be sufficiently good, so that the effect of dielectric loss on the resistance of the coils measured was negligible. The coils were all thoroly dried and coated with shellac before being measured.
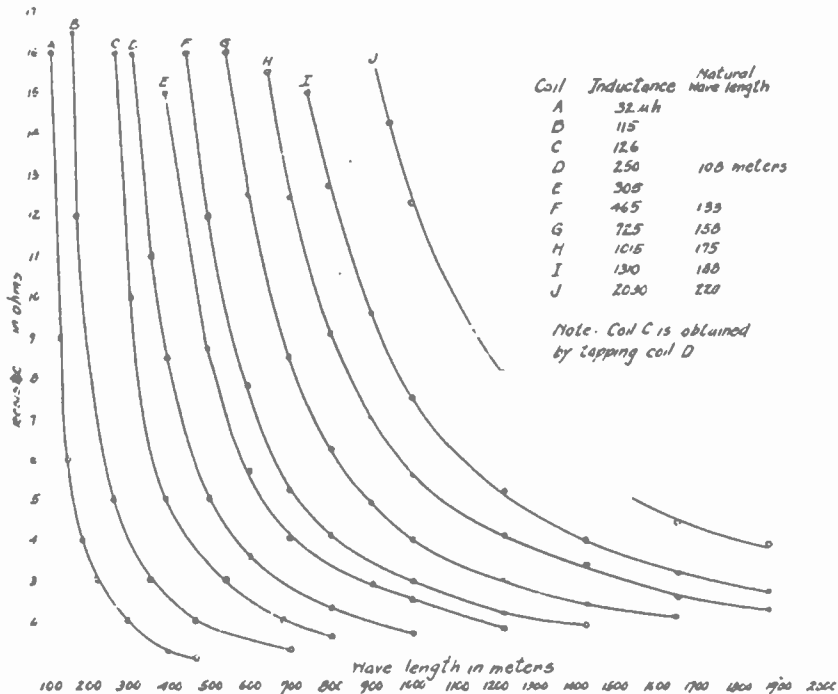

FIGURE 6

[6] 48/38 cable consists of 48 strands (in 3 sets of 16 wires) of number 38 wire of diameter 0.004 in. = 0.010 cm.

As the form and size of these coils are the same as used in the average radio set, they give a fair idea of what the circuit resistance of such sets should be. If a good condenser is used in the set the ratio of reactance of the coil to the total resistance in the circuit should be about as shown in Figure 7, the points of which were calculated from the curves of Figure 6, choosing for each wave length the most suitable coil. It would seem that with carefully constructed coils and condensers, at long wave lengths the reactance of the coil may be 1,000 times as much as its resistance, that is, the power factor of the coil may be as low as 0.1 per cent.
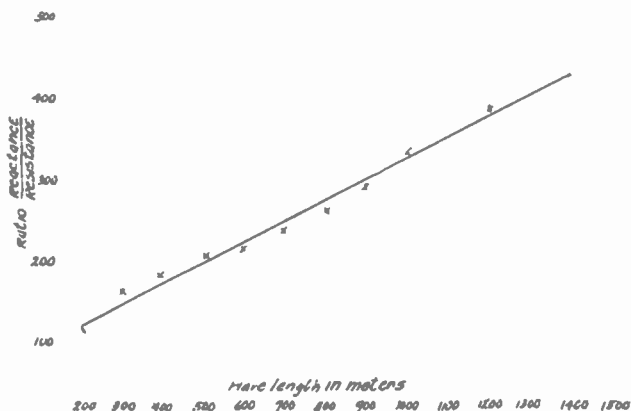

FIGURE 7

It is seen that all of the coils of Figure 6 show a very rapidly increasing resistance at the shorter wave lengths; as mentioned before it might be supposed that this increase is due to the closeness of the impressed frequency to the natural frequency of the coils; that such was not the case is evident when the natural wave lengths of the various coils, which are given on the curve sheet, are compared to the frequencies at which the resistances begin to rise rapidly.

The apparent resistance of a coil departs from its real resistance (in the neighborhood of its natural frequency) by an amount indicated by the fraction $1/(m^2-1)^2$ in which m is the ratio of the impressed frequency to the natural frequency. For example, if the impressed frequency is equal to $\frac{1}{3}$ of the natural

frequency the effect of the internal capacity would be to give an apparent resistance 128 per cent. of the actual resistance.[7]

RESISTANCE OF A TAPPED PORTION OF A COIL

It is well known that it is inadvisable to tap off a small portion of a large coil if less inductance is desired. Thus a coil having one millihenry might be tapped at about 1/5 of its length to get 100 microhenries as indicated at the terminals a-b, Figure 8. The coil is then an auto-transformer, the unused portion of the coil b-c being excited by the magnetic coupling with the used portion a-b. The potential variation of point c with respect to a will be between 5 and 10 times as much as the potential variation of point b; this large variation of potential will evidently cause undesired resistance and dielectric losses in the winding b-c, which losses will cause a proportionate increase in the resistance of that part of the coil which is being used.

A coil should never be tapped at less than ½ of its total inductance; if less than this amount of inductance is desired, a separate coil should be made. To illustrate this point, the set of curves in Figure 9 were obtained; these curves give the reactance/resistance ratio of a coil of 32 turns, tapped at 22 turns
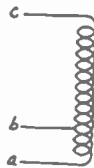

FIGURE 8

and on the same curve sheet is shown the reactance/resistance ratio of a coil of only 22 turns. The size of coil and kind of wire used were the same in the two cases.

EFFECT OF NEIGHBORING COILS

Sets are frequently put on the market with a wide wave length range, for example, 150-3,000 meters. Of course several separate coils must be used in such a set, the coil for the longest wave length having perhaps 30 times as many turns as that for the shortest. If the various coils are all mounted in the same cabinet, the larger coils, by their proximity to the smaller ones, may in-

[7]These remarks about the internal capacity of a coil follow from the ordin, ary conception of the internal capacity of coils; it seems to the writer, however- that the effect of the internal capacity may make itself felt at a wave length 50 per cent. greater than that predicted by the ordinary theory.

troduce hundreds of ohms of resistance into the smaller coils, and this in spite of the fact that the larger coils are completely disconnected from the smaller ones. This effect is illustrated in Figure 10; two coils A and B were wound on the same piece of tubing, about 15 cm. (5.9 in.) apart; coil B had about 20 times as much inductance as had coil A. The resistance of coil A, when measured, was about as indicated in the curve in the lower

A - 32 turn coil
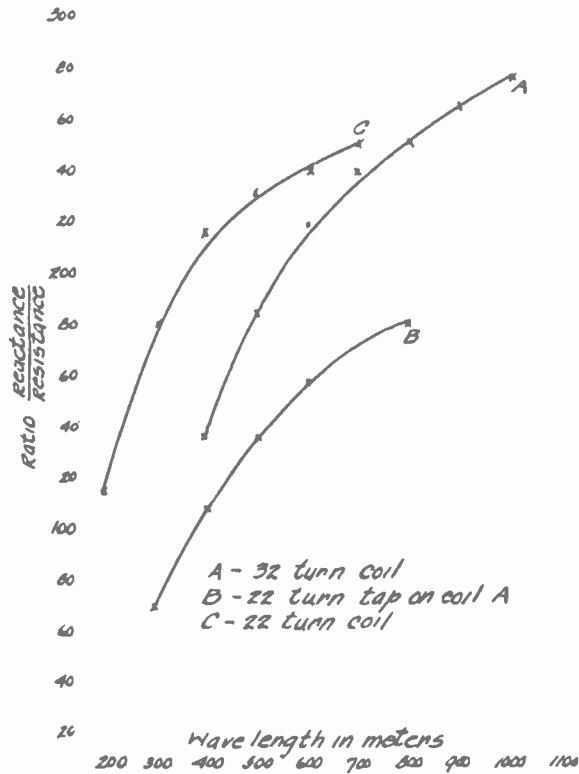B - 22 turn tap on coil A
C - 22 turn coil

FIGURE 9

part of Figure 10. Further test showed that coil B had its natural wave length at 158 meters and even tho the coupling was very loose the free coil B introduced nearly 90 ohms resistance into coil A at this frequency. The writer has seen certain receiving sets which showed this effect to a marked degree; at certain frequencies the incoming signals were nearly inaudible, whereas if the signal frequency was changed slightly, the signals came in loudly.
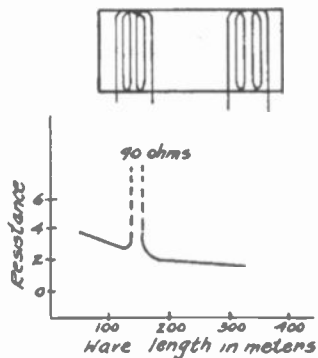
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FIGURE 10

EFFECT OF TERMINAL CONNECTIONS ON RESISTANCE

A 40-turn coil, wound on a bitumen spool had its two end connections (about 20 cm. (7.9 in.) long) covered with oiled linen tube and the two ends were twisted around each other several times; no appreciable change in resistance was noted.

A similar coil was tested for resistance first with its ends free and then with them connected to two clips mounted about 2 cm. (0.79 in.) apart on a small bakelite block. The resistance with and without the terminal block are shown in Figure 11; it is seen that the resistance of a coil may be quite appreciably increased by the effect of its end connections, especially if there are many taps on the coil, brought out to a multi-point switch, mounted in such material as bakelite.
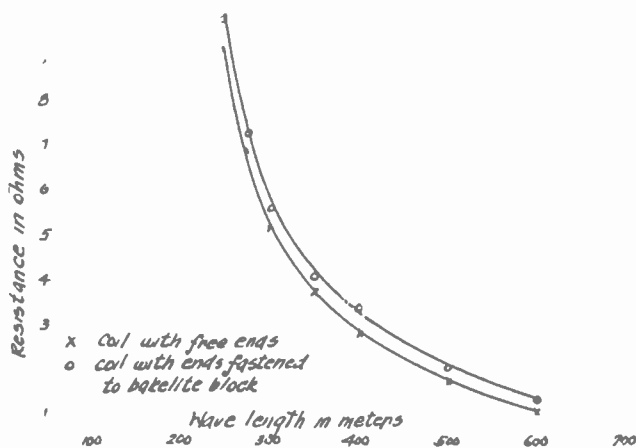

FIGURE 11

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By means of a continuous wave power source the natural frequency of a coil may be measured with almost any degree of precision desired. The coil, the natural wave length of which is desired, is held on a string or stick and brought near the power oscillator. With very loose coupling between the coil and the oscillating set (less than 5 per cent. was required for most of the coils tested) the frequency of the power set is slowly varied. At a certain frequency the ammeter in the power set (either plate ammeter or high frequency hot wire meter) shows a sudden "dip." If the plate ammeter is used there may be a sudden rise instead of a dip, depending upon the type of oscillating circuit. The dip occurs when the power set and coil are tuned; reading the wave length of the power set for this adjustment gives (probably) the natural wave length of the coil.

By natural frequency is meant that frequency which sets the coil into its fundamental mode of vibration, that is, one potential node occurring at the middle and a potential loop at each free end. It may be that the coil is set into vibration at about three times, or five times, this frequency. The writer has found it very convenient to test for this condition by use of a small glass tube filled with neon at low pressure (such as are sold for automobile ignition testers). As the tube is moved down the length of the coil the potential nodes and loops are easily located.

In Table 1 are given the natural wave lengths of several coils tested in this fashion; the coils were of various shapes and sizes and wound on different kinds of spools. It will be seen that for the single layer coils of a given size and form the natural wave length varies nearly proportionately to the number of turns, that is, proportional to the square root of the inductance of the coil. For multi-layer, banked winding coils, the natural frequencies are much lower than for a single-layer coil of the same inductance.

INTERNAL CAPACITY OF COILS

Every part of a coil acts in conjunction with every other part to set up an electric field in and around the coil when excited, thus giving what is called the internal capacity of the coil. It is generally assumed that the internal capacity is constant, independent of the frequency; upon this assumption its magnitude is found from the measured natural wave length and the inductance of the coil measured at low frequency. Recently a note[8] has

[8]"Distributed Capacity of Coils," G. Breit, "Physical Review," August, 1921.

Table 1

	diameter in cms.	length in cms.	no. of turns	L in 10⁻⁶ henries	R_0 in meters	C_0 in 10⁻? farads
single layer solenoids on bitumen spools. this coil fitted with multi-point switch on paper spool	11.7	2.3	20	79	37	5.15
	11.7	4.8	40	200	60	4.70
	11.7	7.5	60	374	78	4.44
	11.7	17.8	141	1140	122	3.6
	11.9	3.3	30	144	53	5.5
	12.	42.3	931	26000	625	4.2
	11.7	7.4	126	214	213	6.0
	14.7	17.6	296	7560	370	5.1
single layer solenoids on wood spools	10.5	10	361	8490	388	5.0
	10.5	10	290	5540	323	5.30
	10.5	10	138	1290	153	5.12
	10.5	10	96	614	104	5.01
	10.5	10	64	278	69	4.83
	10.5	10	41	120	49	5.60
	10.5	10	37	97.5	44	5.60
three layer banked windings on bitumen spools	11.4	1.5	36	205	100	16.0
	11.4	2.1	52	465	133	13.3
	11.4	2.7	68	725	158	9.7
	11.4	3.4	84	1015	175	8.5
	11.4	4.2	100	1310	188	7.6
	11.4	5.7	132	2030	225	7.0
	11.4	7.3	169	2880	263	6.8
	11.4	9.8	232	4220	297	5.9

appeared, showing how to calculate this internal capacity. For short single-layer solenoids, surrounded by air and free at both ends, the theory yields a capacity in micro-microfarads equal to 0.44r, where r is the radius of the coil, in cm. In Table 1 are given the capacities of the various coils calculated from the above formula as well as the values determined from the measured natural wave length and known inductance of the coils. The agreement is evidently not good; in trying to find the reason for this discrepancy the effect of various factors entering into the coil construction was noted.

Effect of Moisture, Shellac, Spool, and so on, Upon Resistance and Capacity of Coils

It was noticed during the tests that the resistance of a coil made of cotton or silk insulated wire, not covered with varnish

or shellac, varied as much as 30 per cent. on different days, and by check tests it was concluded that this was due to internal leakage thru moist insulation; by heating the coil for an hour or so the resistance always returned to its proper low value, and if the coil was coated with shellac while hot and dry, and then thoroly dried out, the resistance was constant from day to day. No appreciable effect of moisture on the natural period of the coil could be determined. To find the effect of spool and shellac on the natural period, various coils were built of exactly the same winding data (11.8 cm. (4.65 in.) diameter, 4.8 cm. (1.89 in.) long, 40 turns). One was wound on thin paper tube, without shellac, and was measured for natural wave length and found to give 49 meters; when coated with shellac and dried it gave 51 meters. The same winding on a bitumen spool, thoroly impregnated with shellac, gave for λ_0 (natural wave length) 58 meters. In these tests the ends of the winding were about 8 cm. (3.15 in.) long. In another coil with 15 cm. (5.9 in.) ends left free the value of λ_0 was 52 meters; when the 15 cm. (3.9 in.) ends bent near together so that for 10 cm. (3.9 in.) they were parallel, 1 cm. apart, λ_0 was found to be 56 meters.

The magnitude of the effect of the end connections on the natural wave length is well shown by the behavior of a coil 17.7 cm. (6.97 in.) long, 7.5 cm. (2.88 in.) diameter, on which both terminals of the winding were fastened to clips mounted on a wooden block fitted in one end of the spool. This arrangement of terminals is indicated in Figure 12; one end of the winding ran from end to end of the coil thru the inside of the spool. The value of λ_0 for this coil was found to be 117 meters; removing the clips to which the ends of the winding were connected, reduced λ_0 to 93 meters; arranging the wire that ran thru the inside of the spool as nearly central as possible reduced λ_0 to 86 meters. Pulling out the long end so that the two ends of the winding were on opposite ends of the spool reduced λ_0 to 71 meters. By this re-arrangement of end connections the internal capacity of the coil had been reduced from 13.7 micro-microfarads to 5.05 micro-microfarads.
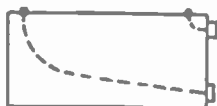

FIGURE 12

All of these internal capacities are much larger than theory (by Breit) would indicate, and evidently end connections,

shellac, spool, thickness of insulation, and so on, have appreciable effects on the internal capacity, making it generally about twice as much as the theoretical value. In only one coil did the measured internal capacity approach the theoretical value; this one was wound on paper just thick enough to support the wire, the insulation on the wire was thicker than ordinary, the ends were cut off close to the coil. In this case the measured internal capacity was 2.55 $\mu\mu$f, whereas the theoretical value was 2.4 $\mu\mu$f.

From Table 1 it will be seen that the capacity of banked winding coils is very much greater than for single-layer solenoids, and also that the capacity varies greatly with the length of the coil, becoming smaller as the coil increases in length.[9] The large decrease in internal capacity can be readily explained when the distribution of electric field inside the coil is examined. This is indicated in Figure 13; *a* shows one side of a short single-layer solenoid and *b* shows one side of a three-layer banked winding. The electric field (which determines the internal capacity) may be divided roughly into two parts:—that close inside the winding, and that completely outside the winding. The capacity of the coil insofar as it is determined by the outside field, will not vary much with coil length, but that inside the coil, where the turns come close together, will vary inversely as the length of the coil. In a multi-layer coil, the inside capacity constitutes a much greater part of the total capacity than it does in the single layer coil, and so we may expect the capacity of multi-layer
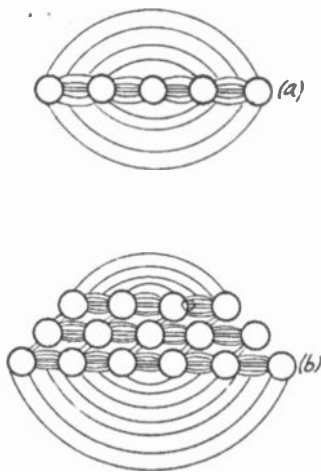

FIGURE 13

[9]In a recent editorial ("Radio Review," December, 1921), it has been stated that experiment shows the capacity of coils to be independent of length; the results given here seem to show that such is not the case.

coils to decrease with increase of length to a greater extent than it decreases for the single-layer coil.

This is seen to be the case in the results of Table 1; for single-layer coils of constant diameter the capacity decreased to about 70 per cent. the value it had for the shortest coil as the length was increased 8 times, whereas in the 3-layer coils the capacity decreased to about $\frac{1}{3}$ its value with the same change in coil length.

BASIS OF CALCULATION OF INTERNAL CAPACITY OF COILS

As noted previously, the foregoing values of capacity have been calculated on the assumption usually made that the capacity stays constant and that the inductance of the coil is the same at low frequency as it is at the natural frequency of the coil. It is also assumed that when a coil oscillates at its natural frequency, the voltage and current distribution along the coil are sinusoidal.[10] It seems to the writer that neither of these assumptions is justified when one gets a mental picture of the electric and magnetic fields as they exist at low frequency and at very high frequency.

The inductance or capacity of a circuit in which the current and potential distributions are non-uniform can be conceived most readily from the standpoint of the energy in the respective fields. Thus the co-efficient of self-induction of a circuit is equal to twice the magnetic energy divided by the square of the current in the circuit. When the current varies in the different parts of the circuit, the value of current to be used in calculating L becomes more or less indeterminate; it seems reasonable, however, to use the maximum value of current occurring in the circuit. (In case the minimum value were used for a coil oscillating at its natural frequency, the value of L obtained would be infinite).

From this viewpoint, it is evident that the L of a coil changes very much from low to high frequency; in Figure 14 an attempt is made to show this. In Figure 14 a the field distribution of the solenoid is shown for uniform current thruout the coil, as is the case for low frequency and in b is shown a comparative field distribution for a distribution of current such as occurs when the coil is oscillating at its natural period, the current in the center turns of the coil having the same value as that occurring thruout the whole coil for the case shown in a. The energy in the magnetic field for case b is only about $\frac{1}{2}$ as much as for case a, so that we may say that the L of the coil is only $\frac{1}{2}$ as much in one case as in the other. As the current distribution of the coil changes with

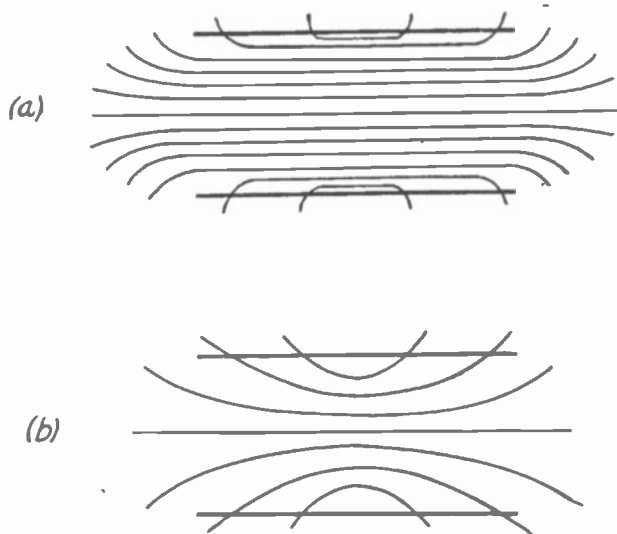[10]Editorial, "Radio Review," December, 1921, and other articles.

(a)

(b)

FIGURE 14

frequency, so must the electric field change its configuration, and hence a change in capacity is brought about.

The reason for assuming a sinusoidal distribution of current and potential is not evident. If a conductor having uniformly distributed inductance and capacity is oscillating at its natural period, the current and potential distribution are nearly sinusoidal, but in the case of the solenoid of appreciable length the inductance per unit length is nearly twice as much at the center of the coil as it is at the ends; the capacity of the coil per unit length is also greater at the center than at the ends of the coil. Such being the case the natural oscillation of the coil cannot be sinusoidal with respect to space altho it is so with respect to time.

COMPARATIVE MERITS OF CABLE AND SOLID WIRE

It has been long appreciated that to keep the resistance of wire low at high frequencies, it must be so built that the current is forced to divide equally between the various elements of cross-section. This is accomplished by constructing the wire of a large number of small wires, each insulated, and so interwoven therein that each individual strand is equally on the inside and outside of the cable. This was originally done by braiding together the various small wires, but a much simpler method is to make the cable of several smaller cables, each of which is made by twisting together several of the small insulated wires. This construction accomplishes practically the same thing as braiding.

But little experimental material has been given, showing how solid wire and cable compare at various frequencies. The follow-

ing results show that a cable is preferable to a solid wire of the same diameter (that is, laying the same number of wires per cm.) in the ordinary range of radio frequencies, having about one-half the resistance of the solid wire for wave lengths about 1,000 meters; as the frequency increases, however, the superiority of the cable becomes less and rapidly disappears for wave lengths less than 300 meters; at frequencies higher than this, the solid wire is actually better than the cable. This effect is indicated in the curves of Figure 5; to bring it out more clearly several sets of coils were made and tested, there being in each set some cable coils and some of solid wire.

As mentioned before in comparing resistance at high frequencies, the internal capacity may play an important role and lead to incorrect conclusions; to eliminate the possibility of this effect nullifying the comparative value of the data of the various coils, solid wire and cables were used which wound the same number per cm., this making the capacity effects nearly the same for all coils. All coils had the same diameter, 11.8 cm. (4.65 in.); the lengths varied with the number of turns in the coil.

For single-layer coils four sets were measured having 10, 20, 40, and 60 turns each; these coils are typical of those used in short wave receiving. In each set the A coils were of solid wire (number 20 double cotton covered); B coils were braided (32 strands of number 36 enamelled wire); C coils were twisted cable (three cables twisted together, each consisting of 16 number 38 enamelled wires, twisted together); D coils were twisted (three cables twisted together each consisting of 40 number 40 enamelled wires twisted together).[11] All of these coils were wound on bitumen spools; coil E was wound on very thin paper tubing, coated with shellac. Three sets of banked winding coils were also tried to see if the conclusions reached for the single-layer coils could be applied to multi-layer coils.

All resistance values together with dimensions and construction of coils are given in Figures 15-18. It will be noticed that altho the cable coils have a continuous current (d.c.) resistance nearly twice as much as the solid wire, thruout most of the frequency range tested their resistance is only about one-half as much as the solid wire, showing that the stranding has made the cross-section four times as effective in one case as in the other.

[11]Diameter of number 20 wire =0.032 in. =0.082 cm.
Diameter of number 36 wire =0.005 in. =0.013 cm.
Diameter of number 38 wire =0.004 in. =0.010 cm.
Diameter of number 40 wire =0.003 in. =0.008 cm.

For wave lengths less than 400 meters the cable resistance in-creases more rapidly than the solid wire, and for wave lengths less than about 250 meters the solid wire has less resistance than the cable.
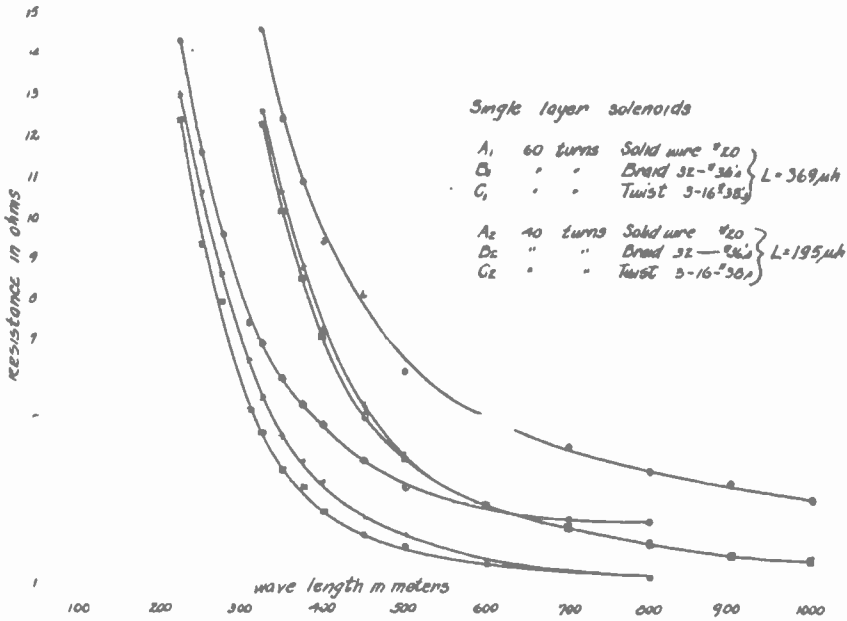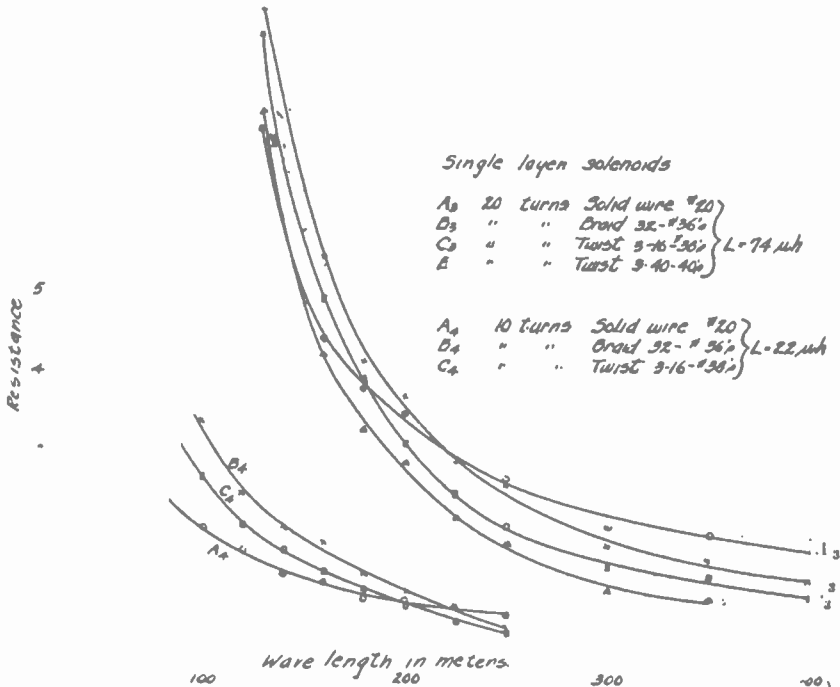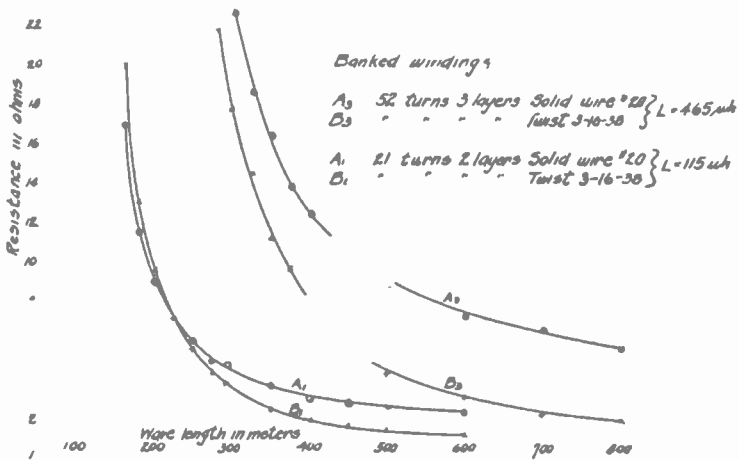

FIGURE 15

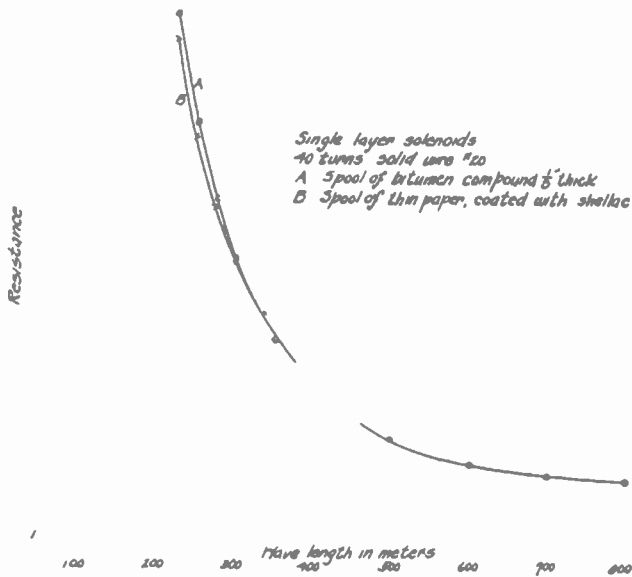Resistance in ohms

Banked windings

A_3 52 turns 3 layers Solid wire #28 ⎫ L = 465 μh
B_3 "   "   "   "   Twist 3-40-38 ⎭

A_1 21 turns 2 layers Solid wire #20 ⎫ L = 115 μh
B_1 "   "   "   "   Twist 3-16-38 ⎭

Wave length in meters

100   200   300   400   500   600   700   800

FIGURE 17

Resistance

Single layer solenoids
40 turns solid wire #20
A Spool of bitumen compound ⅛ thick
B Spool of thin paper, coated with shellac

Wave length in meters

100   200   300   400   500   600   700   800

FIGURE 18

To find the effect of possible losses in the bitumen spools, a pair of coils of exactly the same winding data, one on a bitumen spool of 0.3 cm. (0.12 in.) thick and the other on a very thin paper tube, were compared for resistance; the results, given in Figure 18, show that the spool has a nearly negligible effect on the coil resistance.

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From all the results given, including those of Figure 5, it is evident that but little advantage is to be gained in using cable in ordinary receiving sets designed for wave lengths of 400 meters or less, unless the component wires are much finer than those used in these tests, and even then the superiority of the cable is much less than would be expected. Curve E of Figure 16, for the coils made up of number 40 wires, shows itself better than the solid wire for wave lengths greater than 150 meters, but it must be noticed, in comparing its behavior with that of the other cable coils, that it had considerably greater cross section of copper.

It is quite likely that the reason for the peculiar change in the comparative merits of the solid wire and cable is due to the dielectric losses in the enamel of the strands of the cable. In Figure 19 are illustrated two strands of a cable, each weaving in and out from the center of the cable to the outside. The two
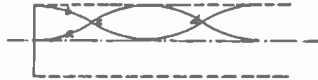
FIGURE 19

strands are soldered together at the end of the cable and hence must have the same potential at this point. Where they cross at c, however, they do not have the same potential, because the IX drop in filament a has been greater than that in filament b due to the greater flux surrounding a, this excess flux being that inside the cable. The enamel, at the point of crossing of the strands, will be subjected to high frequency dielectric loss and further, at very high frequency the current will not divide equally between the strands but will travel more thru the outside strands, that is, at points of crossing, as at c and d, current will tend to leave one filament and go into another, always leaving that filament which is going towards the inside of the cable for that one going toward the outside. At extremely high frequency the inside of a cable will carry but little of the current, even tho the individual strands are perfectly insulated from one another; due to the condenser action at the points of crossing, the current will always pass to the outside strands.

The dielectric loss at each crossing will be proportional to the square of the potential difference of the two strands at the crossing point; for a given frequency this will be proportional to the distance between crossings. As the number of crossings

varies inversely with the distance between them, the total internal loss will vary directly with the distance between crossings.

At high frequencies the loss tends to increase with the square of the frequency, because of the increasing difference in the IX drop in the inner and outer filaments. In a twisted cable the potential gradients occurring in the enamel, due to this cause, are likely to be not as great as in a braided cable, so that a twisted cable, altho theoretically inferior to a braided one, may actually show lower resistance at high frequency.

If many ends are to be made and soldered on radio cable coils, much time may be consumed in cleaning each individual strand, as each must be cleaned if the resistance of the cable is to be kept low. The writer has found that a concentrated solution of potassium bichromate in concentrated sulphuric acid, when brought near its boiling point, removes the enamel in a few seconds and leaves the ends in fine condition for soldering. The end should be dipped in a soda solution, after the enamel has been dissolved, to prevent further action by the adhering acid.

Resistance of Receiving Sets

From the curves given in this paper, a reasonable resistance for a receiving set, at any wave length, may easily be obtained. Thus a small antenna, of capacity 0.0003 microfarad, to receive a 300 meter wave length, requires an inductance of 84 microhenries and for 600 meters it requires 336 microhenries. The resistance for 300 meters should be about 3.5 ohms, and for 600 meters about 6.3 ohms. These values are obtained from the curves of Figure 5, by interpolation. If the antenna had the more likely value of 0.0006 microfarad, the required resistances would be 2.3 ohms for 300 meters and 2.5 ohms for 600 meters.

A first-class commercial receiving set was measured to see what values of resistance were introduced into the antenna circuit for various adjustments and wave lengths; the results are given in Figure 20. With an antenna capacity of 0.0001 microfarad, the resistance of the circuit in the receiving set, from antenna post to ground post, varies from 52 ohms to 45 ohms as the received wave length varies from 250 to 600 meters. If the receiving antenna has a capacity of 0.0008 microfarads, the set, when adjusted to receive 250 meters, has a resistance of 24 ohms, and if adjustment is changed to receive 600 meters, the resistance is 15 ohms.

Other receiving sets were tested, with the same results; the resistance of the average set with coils mounted in a cabinet,
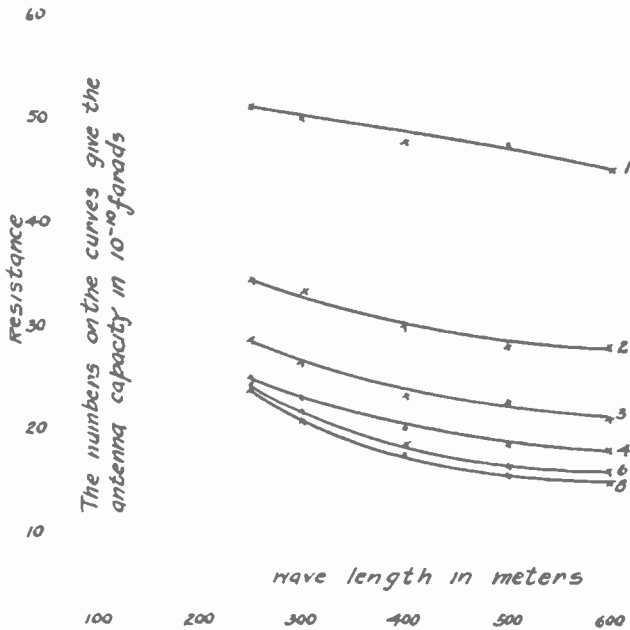
FIGURE 20

attached to multi-point switches, condensers, variometers, and so on, is from five to ten times as much as is actually required by a single, untapped, coil of the right inductance for tuning. The increase in resistance over the requisite amount is the price paid for ease of adjustment and flexibility of operation.

SUMMARY: The various practical methods of determining the resistance of coils at radio frequencies are described, and their conditions of maximum usefulness given.

The resistances of various forms of coils on different mountings are determined at various frequencies, and the laws of variation of resistance with frequency are considered. Measurements are also made of the internal capacity of coils at radio frequencies, and the physics of this capacity is investigated.

The effects on its resistance and capacity of various methods of terminating the coil, mounting it, and varnishing it are experimentally investigated. Finally, solid wire and stranded cable are compared at various frequencies; and numerical data are given on the possible resistances obtainable in actual receiving sets.

DISCUSSION

G. Breit (by letter): Professor Morecroft considers my calculations on the distributed capacity of coils and finds them inapplicable in his work. In particular under "Effect of Moisture, Shellac, Spool, and so on, Upon Resistance and Capacity of Coils," just after Figure 12 we find the paragraph: "All of these internal capacities are much larger than theory (by Breit) would indicate, and evidently end connections, shellac, spool, thickness of insulation, and so on, have appreciable effects on the internal capacity, making it generally about twice as much as the theoretical value. In . . . coil. In this case the measured internal capacity was 2.55 $\mu\mu$ f, whereas the theoretical value was 2.4 $\mu\mu$ f."

I quite agree with Professor Morecroft that the leads have an appreciable effect, and that the other influences cited may be also marked. The most essential factors, however; have been investigated in previous work, as I shall proceed to show.

The effect of the dielectric constant of the spool or insulation is considered in my formulas (22), (27). The capacity according to these formulas is proportional to the dielectric constant—K. If K is not a constant, a mean value must be used. This value becomes unity only if the space occupied by the spool and insulation is negligible. This effect has been demonstrated by Drude (See P. Drude, "Annalen der Physik, 9, 1902, pages 293-339). On pages 302-307, we find the verification of the effect of the core, and on pages 308-310, the effect of the insulation is discussed.

The effect of the leads is mentioned in my paper on page 669, line 1. ("The formulas . . . are . . . in agreement with experiment if capacity of leads is taken into account and the effect of condenser shields is made negligible.") The leads may be considered a part of the condenser with as much right as a part of the coil. For this reason I preferred treating the leads separately.

As a matter of nomenclature, it does not appear to me correct to call the capacity of the leads and clips as part of the *internal* capacity as Professor Morecroft does.

The lead effects discussed in the paragraph just preceding Professor Morecroft's Figure 12 are of the same kind as the effects of condenser shields which have been warned against on. my page 669, line 21. In my measurements I avoided bringing the leads close to any part of the coil except the part to which the particular lead is connected.

Professor Morecroft's experiment demonstrating the effect of shellac is open to criticism because paper tubes warp when coated with shellac and wires are frequently shifted in the act of coating. Granting the absence of these errors, the change from 49 meters to 51 meters would amount to 8.2 per cent in the capacity, which is not very much for a capacity of 2.5 $\mu\mu$f. If a larger coil were painted with a coat of shellac of the same thickness, the percentage of the effect would be smaller.

So far as the effect of length on the capacity of multi-layer coils is concerned, it is of interest to recall the results of Pietz (W. Pietz—"Ueber die Kapazität von Spulen," "Annalen der Physik," 41, page 543, 1913. Especially pages 559 and 566). It appears that Pietz found an increase in the capacity with length instead of a decrease as Professor Morecroft does.

Professor Morecroft's experiments as to the relative advantages of stranded and solid wire are in agreement with the measurements of Lindemann and the considerations of M. Wien, cited by Lindemann. (See R. Lindemann, "Berichte der Deutschen Physikalischen Gesellschaft," 1909, page 682 and, in particular, page 696 and Figure 4) as well as the theoretical work of Butterworth ("Phil. Trans. Roy. Soc.," A596, volume 222, pages 57-100), and Howe ("Roy. Soc. Proc.," A, volume 93, page 468, 1917), which explains the general effects observed.

The displacement currents between strands which are considered by Professor Morecroft could not be pronounced in the experiments of Lindemann, for if they were, the increase in resistance would not be proportional to the square of the frequency.

National Research Fellow, U. S. A.
April 24, 1922.   The University, Leyden, Holland.

J. H. Morecroft (by letter): I am in agreement with Mr. Breit in practically all his comments on my paper on "The Resistance and Capacity of Coils at Radio Frequencies." The paper pretends to be but a slight contribution of experimental results to a field which is extremely bare; the fact that the only references given by Breit are to German periodicals is sufficient evidence on this point, and he must remember that such matter is not available to the average American engineer.

Instead of endeavoring to disprove Breit's formula, as one might judge from his comments, I really did my best to prove it, and my results show that his formula is correct (within the experimental error of my work) when the extraneous effects are elimin ated. The shellaced coil, to which he makes allusion, was meas

ured for inductance before and after coating with the shellac, and as no appreciable change was observable, it is reasonable to assume that no displacements, such as he infers, occurred. The fact that my results show internal capacity decreasing with length of coil, that Howe assumes the internal capacity independent of length, and that one of Breit's references found it to increase with length, is further evidence that there is still room for the publication of accurate experimental results in this field; this fact was further evidenced by the discussion which followed the presentation of the paper.

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

ISSUED MAY 2, 1922–JUNE 20, 1922

BY

JOHN B. BRADY

(PATENT LAWYER, OURAY BUILDING, WASHINGTON, D. C.)

1,414,629—M. M. Dolmage, filed July 15, 1918, issued May, 2, 1922.

RADIO DUPLEX SIGNALING SYSTEM, wherein the transmitting apparatus is normally connected with the antenna. An auxiliary current is provided and a second circuit arranged for balancing the transmitting current circuit on receiving signals. The receiving apparatus is normally connected to the antenna system. A control relay is placed in the auxiliary circuit and arranged to render the receiving apparatus inoperative when the system is used for transmission whereby periods of transmission or reception can take place without manual operation of switches.

1,415,179—E. T. Jones, filed July 21, 1920, issued May 9, 1922

RADIO CONTROLLING DEVICE, for transferring the connections of an antenna system from transmitting to receiving apparatus or vice versa. An electrical switch is described having a central shaft and blades extending on opposite sides of the shaft. The shaft may be rotated by a large knob at one end hereof to move the blades into contacts on either side of the support upon which the shaft is mounted. The switch may be utilized with a broadcast receiver to cut in the filament circuits of the electron tubes simultaneously with the connection of the antenna to the receiving apparatus, while on reverse motion of the switch the filament circuit may be broken and the antenna shorted to ground for protection against lightning.

1,415,220—H. F. Causebrook, filed June 18, 1921, issued May 9, 1922.

ELECTRICAL CONDENSER, comprising a continuous strip of

dielectric material formed with bends or folds therein along its length forming pocket-like receptacles for individual armatures of the condenser. The condenser is assembled by inserting the conducting sheets or armatures oppositely in the folds of the continuous strip and terminals taken from the extending edges of the condenser plates.
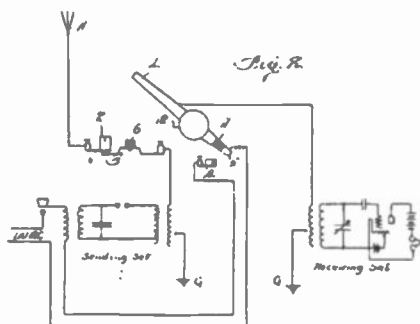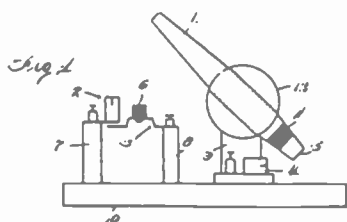
NUMBER 1,415,179—Radio Controlling Device

1,415,382—J. W. Milnor, filed January 17, 1918, issued May 9, 1922. Assigned to Western Union Telegraph Company.

AMPLIFIER. This invention relates to an amplifier and is described particularly in connection with a cable circuit. The amplifier comprises an electron tube connected to oscillate at low frequency with a tuned vibrating relay operated by the amplifier in synchronism with such oscillations, and arranged to rectify the oscillatory current for operation of a responsive device. Another circuit shows a pair of tubes, one adapted to amplify positive current pulses and the other negative current pulses.

1,415,534—H. P. Donle, filed December 15, 1921, issued May 9, 1922. Assigned to Connecticut Telephone and Electric Company, Incorporated.

VARIABLE RESISTANCE. The patent shows a pair of resistance coils mounted one on the front of an insulated member and

the other on the rear thereof with concentric shafts for moving contact arms independently over the resistance coils. The two shafts are operated from separate knobs which may project thru the face of a panel.

1,415,845—M. I. Pupin and E. H. Armstrong, filed February 10, 1916, issued May 9, 1922.
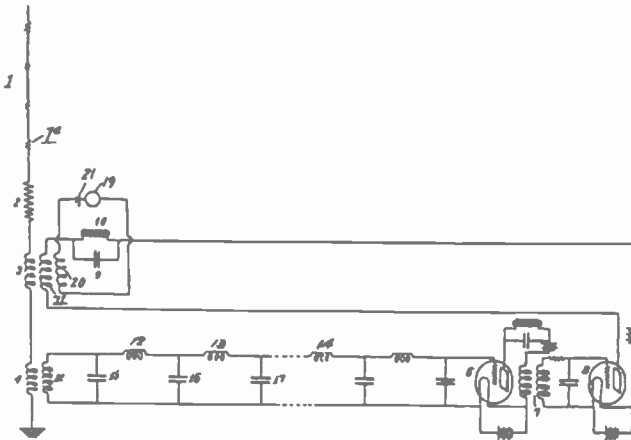
Number 1,415,845—Selectively Opposing Impedance to Received Electrical Oscillations

SELECTIVELY OPPOSING IMPEDANCE TO RECEIVED ELECTRICAL OSCILLATIONS. The invention relates to a circuit arrangement for a radio receiver in which the time necessary for an electrical action impressed upon the antenna is prolonged before arriving at a local power source or resistance compensator. By the re-action between the incoming signals and the resistance compensator, a negative resistance is produced in the antenna system whereby actions impressed upon the antenna which last a time shorter than the time of their transmission to the local power source will not be aided by the power source. The inter-action between the local power source and the antenna system is not instantaneous and therefore the local power source will not be excited to aid an electrical action of a duration shorter than a fixed minimum time interval. When an electrical pulse is impressed upon the antenna it is communicated, as is well known, to the exciting circuit of the resistance compensator 6, 7, 8, thru the mutual inductance 4, 22. This action will be transmitted from 22 to the local energizing circuit over the artificial line, and its time of transmission is determined by the total inductance,

capacity and resistance of the line. Let L, C, and R be the total inductance, capacity and resistance of the artificial line, then the time of transmission t_1 will be approximately

$$t_1 = 10^{-3}\sqrt{LC} \text{ seconds}$$
$$L = 6 \times 10^{-2} \text{ henrys}$$
$$C = 12 \times 10^{-2} \text{ microfarads}$$
$$t_1 = 8.4 \times 10^{-5} \text{ seconds.}$$

If, then, the time of action of the pulse upon the antenna and the process of discharge of the energy deposited by the pulse upon the antenna is less than 8.4×10^{-5} seconds, the local source of power cannot give any assistance to the pulse or the subsequent process of discharge of the energy deposited by it. Any pulse will set up in the artificial line free oscillations, the duration of which, in the example given, may exceed 8.4×10^{-5} seconds, altho their amplitude will be greatly reduced by the uncompensated high resistance of the antenna. These oscillations can always be adjusted in such a way that their frequencies will be very different from the signaling frequency to which the resistance compensator is selectively adjusted. In the example given above, the highest natural period will be less than 23,000 periods per second if the line consists of six equal sections; and oscillations of this frequency will not be assisted by a resistance compensator selective to a signaling frequency of 25,000 periods per second.

1,415,992—L. M. Clement, filed March 22, 1918, issued May 16, 1922. Assigned to Western Electric Company, Incorporated.

RECEIVING STATION. The patent relates to a receiving apparatus with an arrangement of switches within the circuits of the electron tubes whereby the receiver can be made efficiently responsive to different kinds of signals by quick manipulation of switches. The system is adapted to receive damped waves, or plurally modulated waves or undamped waves with heterodyne reception. Switching arrangements are provided so that single or plural stage amplification may be had.

1,415,999—A. M. Curtis, filed November 1, 1916, issued May 16, 1922. Assigned to Western Electric Company, Incorporated.

STATIC REDUCER FOR RADIO SIGNALS. This invention makes use of the properties of various rectifying crystals which lose much of their rectifying action when the impressed oscillations

become strong. A carborundum-to-metal contact 8 is employed in the receiving circuit preceded by radio frequency amplifier 5 and followed by audio frequency amplifier 14. The carborundum-to-metal contact 8 in this invention has a characteristic wave similar to Figure 1 showing a symmetrical resistance for large impressed voltage, but asymmetrical for low voltage. If,
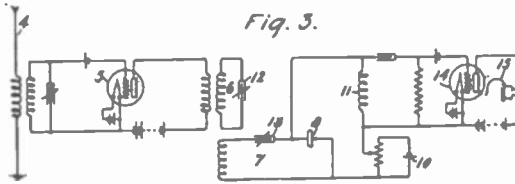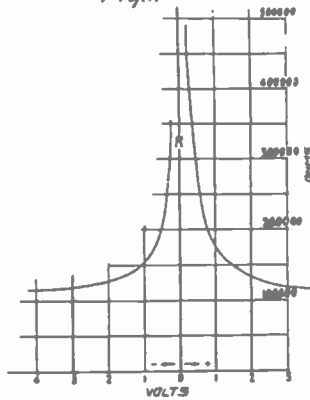

Fig. 3.

Fig. 1.

NUMBER 1,415,999—Static
Reducer for Radio Signals

for example, the instantaneous impressed alternating voltage is three volts, the positive and negative values of the resistance are very nearly the same, namely, 119,000 ohms for the positive value and 120,000 ohms for the negative value. But if the instantaneous voltage is small, say 0.5 of a volt, there is asymmetry of resistance, the positive value being 300,000 ohms and the negative value 200,000 ohms. In the first case there can be no rectification over the portion of the voltage wave which gives equal resistance values for both polarities. What little rectification does occur will be for that fraction of the voltage wave in which the voltage values are all below the minimum value for symmetrical resistance values; if the instantaneous value is large, as illustrated by the first example, that part of the voltage wave which does give rectification will be only a small fraction of the total wave, so that what rectification does occur may be said to be very inefficient. But impressed signals of

smaller voltage values would be rectified during the complete cycle, as is shown by the latter-mentioned case. Thus, if a small alternating voltage is impressed on a contact of this class, there will, in general, be rectification dependent for its amount on the polarizing voltage; but for alternating voltage high enough to bring the resistance down to the point where it becomes constant and equal for both polarities, the rectification will be relatively much smaller. By a suitable adjustment of a rectifier containing a carborundum-to-metal contact of this type, it is possible to cause relatively strong undesired signals to be very much reduced in most cases, while not affecting materially the strength of the weak signals that are to be read.

1,416,061—M. I. Pupin and E. H. Armstrong, filed December 18, 1917, issued May 16, 1922.

Fig. 1
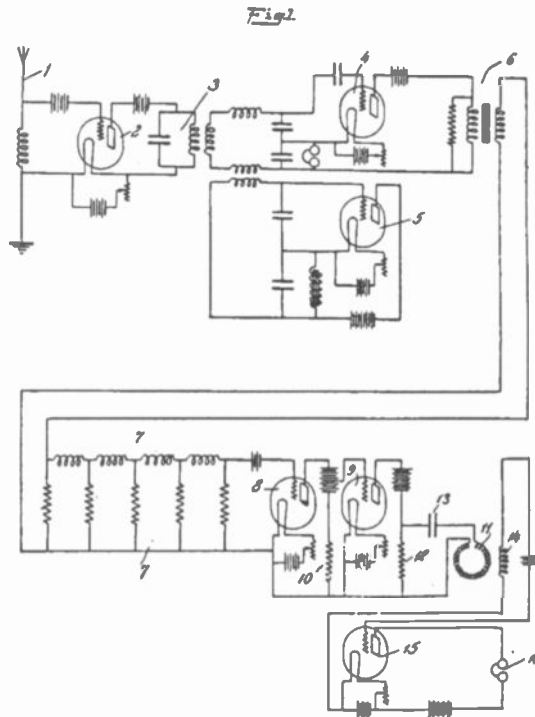
NUMBER 1,416,061—Radio Receiving System
Having High Selectivity

RADIO RECEIVING SYSTEM HAVING HIGH SELECTIVITY. Designed for the purpose of separating received signals from natural atmospheric disturbances as well as artificial radio disturbances

originating at the sending stations of other systems. In the drawing a receiving circuit is shown having a radio frequency amplifier 2 and a regenerative amplifier and detector 4. A local oscillator 5 is employed whereby received oscillations are combined with the local oscillations to produce beats of an audible frequency, usually of about one thousand cycles per second in present practice, but in this invention of a beat frequency of about one hundred cycles per second. These low frequency pulsations are passed thru a wave filter 7 designed to pass such frequencies and, preferably, all lower frequencies, but to attenuate and suppress frequencies of substantially higher range, as frequencies of two hundred or over. These low frequency pulsations are passed thru amplifiers 8 and 9 and energize the rotor 11 of an induction motor. The stator of the induction motor is shown at 14 connected to the input circuit of audio frequency amplifier 15, giving as a result pulsations of 1,100 cycles and 900 cycles frequency in the telephones 16.
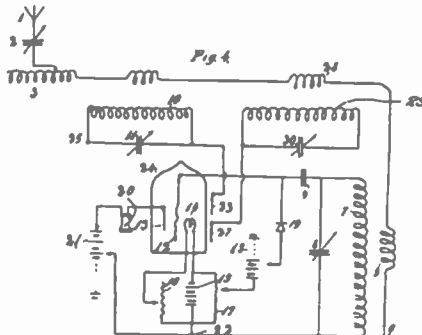
1,416,077—De Witt C. Tanner. Filed March 8, 1919, issued May 16, 1922. Assigned to Western Electric Company.
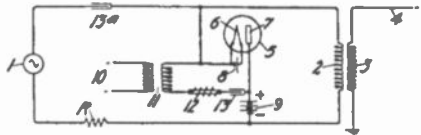
NUMBER 1,416,077—System for Electrical Signaling

SYSTEM FOR ELECTRICAL SIGNALING, in which modulation of high frequency oscillations is secured by use of a two-electrode fube.
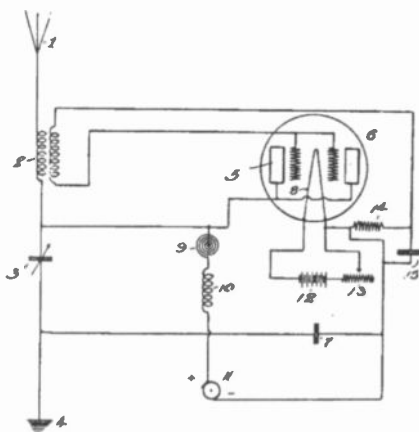
1,416,774—C. Bardeloni, filed April 17, 1920, issued May 23, 1922.

NUMBER 1,416,774—Device for Receiving Radio Signals

DEVICE FOR RECEIVING RADIO SIGNALS. The patent shows a circuit arrangement designed for reduction of interference and strays in radio reception.

1,417,662—L. De Forest, filed June 16, 1917, issued May 30, 1922.

NUMBER 1,417,662—Radio Signaling System

RADIO SIGNALING SYSTEM. A circuit is shown in this patent for connection of an electron tube with an antenna ground system. In the drawing 1 designates the antenna which is connected thru inductance 2 and variable condenser 3 to the ground 4. The plate electrode 5 of the oscillion 6 is connected to one terminal of the condenser 3 and the other terminal of the condenser 3 is connected thru a condenser 7 to the filament electrode 8 of the tube. The plate electrode 5 is also connected thru impedance coil 9, inductance 10 to the source of plate potential 11 back to the filament. A tickler circuit is formed with the grid and filament thru condenser 15 shunted by high resistance 14. The tickler circuit is inductively associated with the inductance 2 of the antenna system. The circuit is particularly designed for electron tube transmitting circuits.

1,417,912.—P. C. Hewitt, filed June 24, 1916, issued May 30, 1922.

VACUUM ELECTRIC APPARATUS, comprising a tube having two surfaces substantially parallel and facing each other with a narrow space between them in which are mounted one electrode in the form of a filament and at least one electrode serving as an

anode. Means exterior of the flat surfaces are provided for controlling the reactions within the tube such as an adjacent transmitter mouthpiece by which sound vibrations are directed against the flat walls of the tube or a magnetic field adjacent the flat walls of the tube.

1,417,913—A. Heyland, filed July 28, 1914, issued May 30, 1922.

APPARATUS FOR GENERATING HIGH FREQUENCY ELECTRIC CURRENTS of the rotor and stator alternator type. The patent relates to a pole and armature system for a machine of this character wherein the magnetic pieces are surrounded by connected electrically conducting metal adapted to bridge the pole tips of opposite polarity.

According to this invention the active rotor iron is disposed solely at the surface of the rotor and always in that segment which bridges the slot separating the pole tips of two stator poles, the segments underneath the stator poles being inactive. The stator field is closed tangentially over the corresponding rotor segments.

1,418,022—E. Reisz, filed June 5, 1915, issued May 30, 1922.

Fig.1
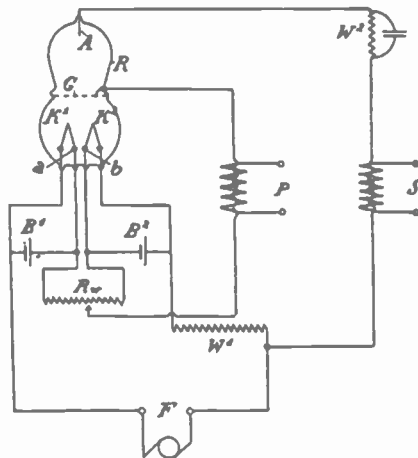
NUMBER 1,418,022—Discharge Tube Relay for Undulatory Currents

DISCHARGE TUBE RELAY FOR UNDULATORY CURRENTS, in which the cathode is divided into two parts, the circuits being separated by a resistance $R_{\iota r}$ and the plate circuit including

resistances W^1 and W^2. A difference of potential between the two parts of the cathode is secured by which strong ionization is produced.

1,418,066—T. R. Bunting, filed June 2, 1920, issued May 30, 1922.
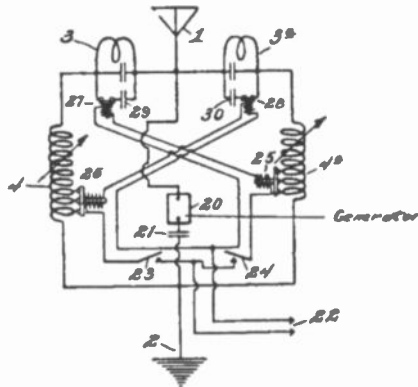
NUMBER 1,418,066—Radio Transmitting System

RADIO TRANSMITTING SYATEM, for duplex operation permitting two messages to be transmitted simultaneously and independently by one antenna. The system includes two parallel radiating circuits consisting of the same antenna and ground, between which are two electrical circuits each of which includes a tuning inductance and an impedance circuit composed of an inductance shunted by a capacity, each impedance circuit to be tuned to the frequency of the opposite radiating circuit, and the two radiating circuits to be tuned to oscillate at frequencies sufficiently different to render negligible the impedance of each impedance circuit to the oscillating current of the radiating circuit of which it is a part.

1,418,285—J. R. Carson, filed October 10, 1918, issued June 6, 1922. Assigned to American Telephone and Telegraph Company.
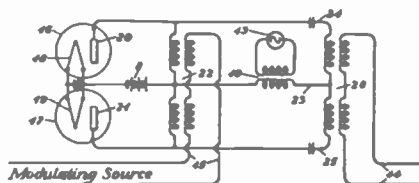

Fig. 2

NUMBER 1,418,285—Translating Circuits

299

TRANSLATING CIRCUITS, for modulating high frequency oscillations in which two electrode vacuum tubes or equivalent devices having unilateral conductivity are employed.

1,418,518—E. F. Bell, filed September 20, 1920, issued June 6, 1922.

QUENCHING ROTARY SPARK CAP. comprising an enclosed casing, a set of separated stationary electrodes mounted in the casing, and a rotor carrying moving electrodes which may be brought adjacent the stationary electrodes forming sparking surfaces. A spring is provided to prevent the rotor from moving longitudinally upon its bearing.

1,418,729—A. A. Oswald, filed April 25, 1919, issued June 6, 1922. Assigned to Western Electric Company, Incorporated.
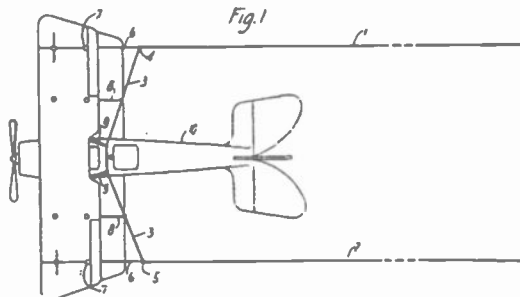
NUMBER 1,418,729—Portable Radiating System

PORTABLE RADIATING SYSTEM for Aircraft or Moving Vehicles.
The invention employs a plurality of trailing wires supported from the outer portions of the wings of an airplane. The wires are connected in parallel and form the antenna system against the metallic structures on the airplane which form the counterpoise. The use of a pair of trailing wires in lieu of a single trailing wire reduces the directional property of the antenna and permits shorter trailing length of the antenna, reducing the possibility of entanglements and breaking away of the antenna.

1,418,739—E. O. Scriven, filed June 4, 1917, issued June 6, 1922. Assigned to Western Electric Company, Incorporated.

OSCILLATION GENERATOR, having in the input circuit of the tube a path of high impedance for the direct current from the source of voltage of the output circuit and a path of low imped-

ance for the resultant oscillations. The object of the circuit arrangement is to provide means for generating oscillations, the intensity of which is independent of small changes in the impedance between the output electrodes of the evacuated vessel, so that approximately similar tubes may be used in the oscillation generator without producing any change in the high frequency output.

1,418,788—J. H. Hammond, Jr., filed July 14, 1913, renewed October 9, 1915, issued June 6, 1922.

SYSTEM FOR CONTROL OF BODIES BY RADIANT ENERGY.

1,418,789—J. H. Hammond, Jr., filed July 14, 1913, renewed May 2, 1922, issued June 6, 1922.

SYSTEM FOR CONTROL OF BODIES BY RADIANT ENERGY.

1,418,790—John H. Hammond, Jr., filed August 14, 1913, renewed July 11, 1917, issued June 6, 1922.

RADIO DYNAMIC CONTROL OF GYROSCOPES.

1,418,791—John H. Hammond, Jr., filed June 22, 1914, renewed May 3, 1922, issued June 6, 1922.

SYSTEM FOR CONTROL OF MOVING BODIES BY RADIANT ENERGY.

1,418,792—John H. Hammond, Jr., filed August 6, 1914, renewed May 3, 1922, issued June 6, 1922.

SYSTEM FOR CONTROL OF MOVING BODIES BY RADIANT ENERGY.

1,418,793—John H. Hammond, Jr., filed December 20, 1915, renewed March March 12, 1919, issued June 6, 1922.

SYSTEM OF TELEDYNAMIC CONTROL FOR DIRIGIBLE BODIES.

1,418,794—John H. Hammond, Jr., filed April 8, 1913, renewed September 22, 1916, issued June 6, 1922.

SYSTEM OF TELEDYNAMIC CONTROL.

1,418,795—John H. Hammond, Jr., filed January 12, 1916, renewed March 14, 1918, issued June 6, 1922.

LAUNCHING MECHANISM FOR TORPEDOES.

1,418,796—John H. Hammond, Jr., filed July 15, 1913, renewed December 13, 1918, issued June 6, 1922.

TELEDYNAMIC CONTROL.

1,418,797—John H. Hammond, Jr., filed March 29, 1913, renewed January 30, 1919, issued June 6, 1922.

SYSTEM OF SUBMARINE-MINE LAYING.

1,418,869—John H. Hammond, Jr., filed November 20, 1913, renewed February 9, 1918, issued June 6, 1922.

TELEDYNAMIC CONTROL.

1,418,870—John H. Hammond, Jr., filed August 14, 1913, renewed January 30, 1919, issued June 6, 1922.

RADIODYNAMIC TORCH LAUNCHING MECHANISM.

1,419,376—J. H. Hammond, Jr., filed November 27, 1909, renewed November 6, 1915, issued June 13, 1922.

RADIO CONTROL APPARATUS. The patent shows a mechanism arranged for control of a vehicle or vessel such as a torpedo boat or dirigible torpedo from a distance.

1,419,377—J. H. Hammond, Jr., filed August 1, 1913, renewed March 19, 1919, issued June 13, 1922.

RADIODYNAMIC OCCULTING SYSTEM for cutting off and concealing the emissions of a searchlight by radio control from a distance. The patent shows a searchlight having a swinging shutter and a compressed air mechanism for operating said shutter. A rotary valve is provided operated by reciprocatory magnetic means controlled by the radio receiver from the distant control station which permits the access of the compressed air to operate the mechanism controlling the swinging shutter.

1,419,460—F. Lowenstein, filed November 29, 1918, issued June 13, 1922.

COMBINED KEY AND SWITCH, for a radio transmitting system. The key for closing the transmitting circuits is carried by a lever arm which is pivotally mounted to swing over wave changer contacts. The unit combines the key and a wave changer switch, the key knob serving both for code manipulation and as a handle for operating the switching lever.

1,419,528—H. W. Weinhart, filed October 25, 1918, issued June 13, 1922. Assigned to Western Electric Company, Incorporated.

ELECTRON DISCHARGE DEVICE, in which provision has been made for the expansion of the electrodes under the influence of heat and electron bombardment to which the tube is subjected. Loose guiding connections are provided for the electrodes slidably mounted on rigid electrode supports whereby distortion of the electrodes under increase in temperature is eliminated.

1,419,530—W. Wilson, filed August 12, 1918, issued June 13, 1922. Assigned to Western Electric Company, Incorporated.

THERMIONICALLY ACTIVE SUBSTANCE for use in electron tubes. The invention describes a treatment of ductile metals of the iron group, such as iron, nickel or cobalt, whereby their thermionic activity is increased and made comparable to that of oxide coated platinum filaments. The filament of the invention comprises a core of a ductile metal of the iron group subjected to a coating of strontium and barium oxides.

1,419,547—C. D. Ehret, filed November 12, 1918, issued June 13, 1922.

FIG. 2.
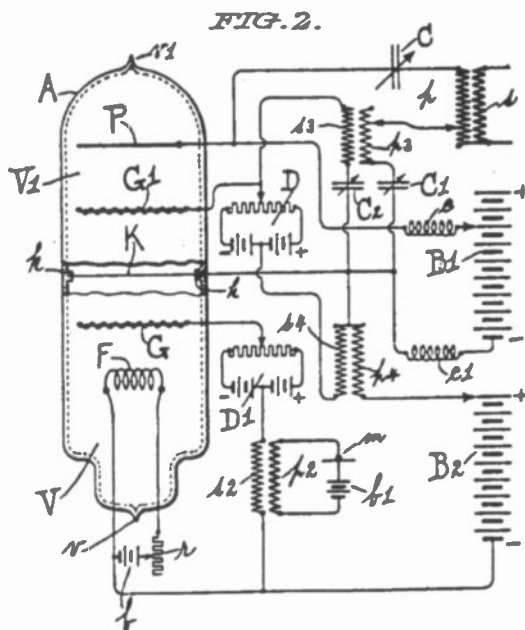
NUMBER 1,419,547—Electronic Apparatus

ELECTRONIC APPARATUS, comprising a tube A divided by cathode K into two chambers V and V_1, both of which and particularly V are preferably closed to the outer atmosphere. The cathode K is in the form of a thin plate sealed thruout its periphery at k, whereby it completely seals chambers V and V_1 from each other and forms a wall common to them.

The body F emits electrons which bombard or impinge upon the cathode K which in consequence becomes an electron-emitting body. The number of electrons so re-emitted may greatly exceed the number of electrons emitted by body F, and so permit or cause a large current between anode P and cathode K. That current may be caused to vary in amplitude or fluctuate by varying the potential of electrode or grid G_1, which may be connected to cathode K thru transformer secondary s^1 and the potentiometer D which serves in known manner normally to hold grid G^1 at any suitable potential. When a telephonic, oscillating or other varying or fluctuating current is passed thru transformer primary p^1, the potential of grid G^1 and therefore, the large current in the circuit of anode P, is correspondingly varied. And that current in transformer primary p may induce an alternating or fluctuating current similarly varying in the secondary s.

1,419,562—R. V. L. Hartley, filed September 29, 1919, issued June 13, 1922. Assigned to Western Electric Company, Incorporated.
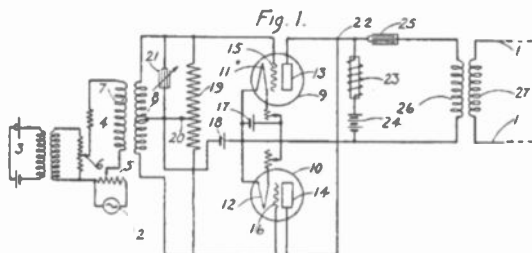

NUMBER 1,419,562—Modulator or Detector

MODULATOR OR DETECTOR, having a balanced circuit made up of a pair of three electrode tubes. The cathodes of the separate tubes are connected directly together. A circuit is provided for causing equal and opposite instantaneous variations of the potentials of the grids of the separate tubes to effect modulation of a sustained source.

1,419,797—E. F. W. Alexanderson, filed February 13, 1919,

issued June 13, 1922. Assigned to General Electric Company.
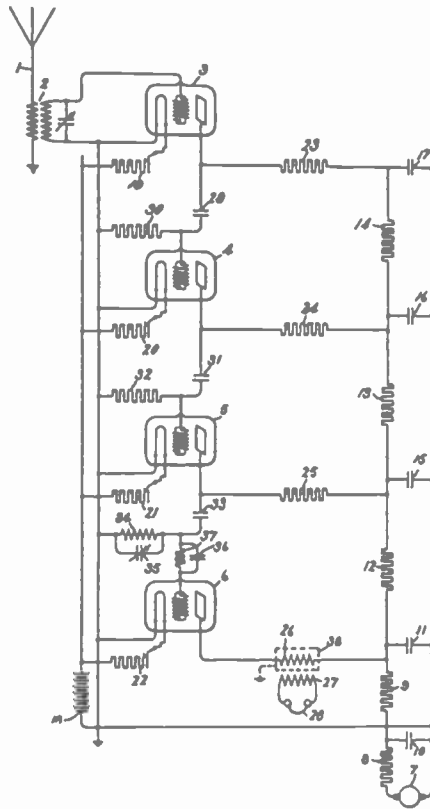
Number 1,419,797—Amplifying System

AMPLIFYING SYSTEM, provided with filter connections between the successive amplifiers of the system. The object of the invention is to provide means for supplying the operating current to the plate circuits of the amplifiers in such a way that a source of current of somewhat variable potential may be employed without injuriously affecting the operation of the amplifiers. Another object of the invention is to provide a connection which will prevent the transmission from one amplifier to another of potential variations of undesired frequency, which may be set up in any of the circuits. Still another object of the invention is to provide connections which will eliminate the tendeney of the amplifiers to act in such a way as to generate oscillations.

1,420,055—H. W. Nichols, filed December 18, 1920, issued June

20, 1922. Assigned to Western Electric Company, Incorporated.

Fig 3
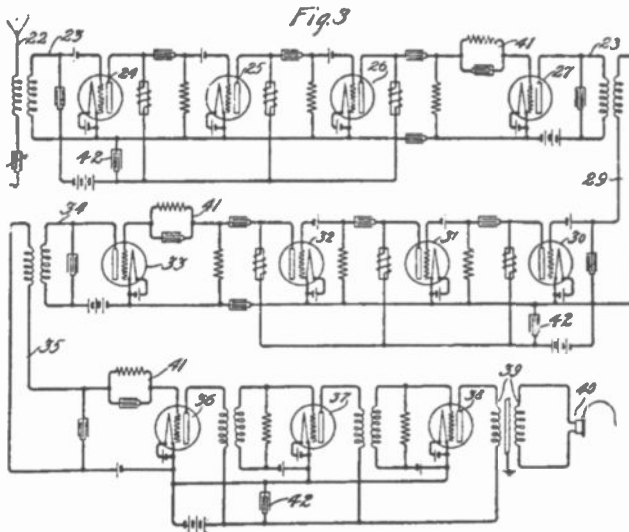
NUMBER 1,420,055—Selective Receiving System

SELECTIVE RECEIVING SYSTEM, which involves detecting
incoming modulated signal waves, selecting a harmonic frequency
of said waves, detecting the said waves of the selected frequency
and then observing the signal.   In Figure 3 of the patent the
receiving circuit is shown comprising antenna system 22 asso-
ciated with a resonant circuit 23 tuned to the frequency of the
incoming signal modulated waves. The high frequency current
is amplified by a three-stage amplifying system including the
amplifiers 24, 25, and 26 and detected by the detector 27, which
includes in its output circuit the circuit 28 tuned to the first even
harmonic frequency of the incoming waves. The latter circuit
is inductively associated with the circuit 29 selective of the same
frequency, whereby the selected oscillations are transmitted
thereto and impressed across the input circuit of the amplifier 30.
The variable current in the output circuit of the tube 30 is ampli-
fied by devices 31 and 32 and impressed across the input circuit
of the detector 33, the output circuit of which includes the cir-
cuit 34 tuned to the first even harmonic of the current traversing
its input circuit, that is, the second even harmonic of the carrier
frequency.

The current selected by the circuit 34 is transferred to the
resonant circuit 35 tuned to the same frequency which is con-

nected across the input circuit of the detector 36. After amplification by the amplifiers 37 and 38 this current is transmitted through the transformer or repeating coil 39 to the receiver 40.

1,420,257—J. H. Hammond, Jr., filed January 21, 1910, renewed December 7, 1918, issued June 20, 1922.

SYSTEM AND APPARATUS FOR AUTOMATIC WAVE SELECTION, wherein signals are transmitted in a predetermined order on different wave lengths and received on a receiver which is rendered responsive to the signals on the succeeding sections of wave length in the same order in which they are transmitted.

1,420,189—A. R. Goodwin, filed September 8, 1921, issued June 20, 1922. Assigned to Chelsea Radio Company.

VARIABLE GRID RESISTANCE. The leak resistance is provided at different steps with switch points and a blade which moves over said points and selects pre-determined value of leak resistance. In this way the grid leak may be made variable from, for example, one-half million ohms to five million ohms in steps of approximately one-half million ohms.

1,420,254—J. H. Hammond, Jr., filed May 20, 1912, renewed December 12, 1917, issued June 20, 1922.

ELECTRIC WAVE TRANSMISSION system employing a fluid stream as a radiating antenna which stream is automatically and irregularly varied, changing its capacity accordingly. Continuous oscillations are superposed on the antenna system, and groups of waves of constantly and irregularly varying amplitude radiated.

1,420,255—J. H. Hammond, Jr., filed February 27, 1913, renewed October 23, 1918, issued June 20, 1922.
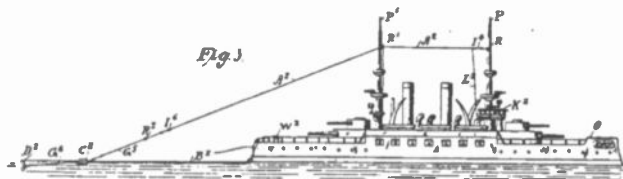
No. 1,420,255—Antenna for Radio Transmission Systems

ANTENNA FOR RADIO TRANSMISSION SYSTEMS, comprising a towing anchor which may be attached to the antenna conductors and extended out from a vessel. The antenna may be extended

to much greater length than is possible to obtain upon the vessel proper, and in this way secure an increase in antenna capacity.

1,420,256—J. H. Hammond, Jr., filed February 25, 1913, renewed October 24, 1918, issued June 20, 1922.

SYSTEM OF TELEDYNAMIC CONTROL, wherein a radio transmitter is arranged to emit a continuous train of waves increased and decreased in amplitude at a pre-determined periodicity. Means are provided selectively to vary this periodicity. At the receiver, means selectively responsive to the variation in periodicity are provided connected to the mechanism to be distantly controlled.

1,420,258—J. H. Hammond, Jr., filed September 3, 1913, renewed April 14, 1919, issued June 20, 1922.

SYSTEM FOR THE RADIO CONTROL OF MOVING BODIES, such as a torpedo ship, land vehicle or an aeroplane. The patent shows mechanism employed at the transmitter and at the receiver for securing the distant control.

1,420,295.—R. W. Tait, filed October 12, 1921, issued June 20, 1922.

COMBINED KNOB AND DIAL FOR RADIO APPARATUS. This patent shows an insulated knob and a dial arranged upon an instrument shaft or spindle. A plurality of resilient jaws are provided which engage and grip the shaft when the knob and dial are screwed together as a unit.

1,420,485—G. F. Johnson, filed May 18, 1920, issued June 20, 1922.

VARIABLE ELECTROSTATIC CONDENSER, having a spring acting against a shoulder formed on the shaft carrying the rotary plates and pressing the rotary plates into accurate center spacing with relation to the stationary plates of the condenser.

The following partially complete list of registered trade-marks will be of interest to the members of THE INSTITUTE OF RADIO ENGINEERS, as showing the character of marks being registered in the Patent Office covering the sale of radio apparatus:

Registration Number 113,751—"Lenzite" for detector crystals.
Registration Number 129,698—"Radio Amateur News" for periodicals.
Registration Number 140,120—"Radio News" for periodicals.

Registration Number 133,313—"Radiophone" for radio apparatus.

Registration Number 133,314—"Radiofone" for radio apparatus.

Registration Number 150,948—"Radiotron" for electron tubes.

Registration Number 152,961—"Radiola" for radio apparatus.

Registration Number 153,172—"Radio Mfg. Co." (Mark arranged within a triangular ornamentation) for radio appaatus.

Registration Number 153,238—Representation of Magnavox loud speaker with lion head protruding from horn, for loud speaking telephones.

Registration Number 157,518—"Vocaloud" for loud speakers.

Registration Number 159,777—"Air O Phone" for radio apparatus.

NOTE—The following patents should be considered as included with the preceding digests.

1,407,147—Wm. N. Goodwin, Jr., filed July 27, 1916, issued February 21, 1922. Assigned to Weston Electrical Instrument Company.
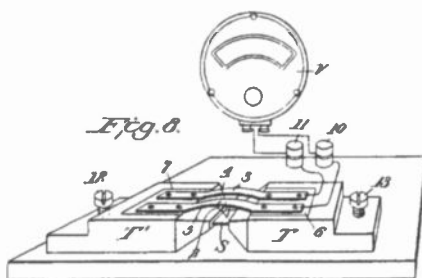
NUMBER 1,407,147—Thermal Ammeter

THERMAL AMMETER, for measurement of alternating currents designed especially for measurement of high frequency currents. An indicating instrument is employed to measure the current passing thru a conductor or "hot wire" connected to its terminals by the difference in the temperatures (produced by the passage of the current) between the mid-portion, preferably the center and ends of the conductor, the conditions being so controlled that this temperature difference will be dependent principally upon the thermal and electrical conductivities of the material of which the heating conductor is made, and only to a slight extent upon external or other influences.

The development of the present form of thermal-ammeter is based upon the principle, as demonstrated by mathematical analysis, that if a conducting strip or wire of uniform cross sectional area, carrying a current, is cooled only by conduction thru the body of the strip itself and not directly cooled by the surrounding air, the difference in temperature between any two points along the strip, in general, or, in particular, between the center of the strip and the terminals to which the strip is joined, is dependent upon the difference of electrical potential between these points and upon the thermal and electrical conductivities of the material of which the conducting strip is made. The relation between these four quantities as found is exhibited in the following equation.
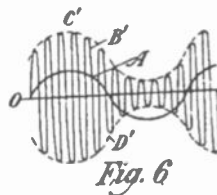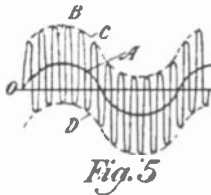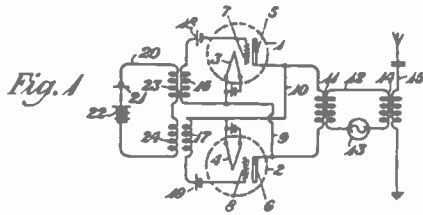
$$T = \frac{V'^2}{8K\rho}$$

where
T = temperature difference between center of strip and terminal.
V = difference of potential between the terminals,
K = thermal conductivity of strip material, and
ρ = specific resistance of the strip material.

1,410,890—J. R. Carson, filed August 8, 1918, issued March 28, 1922. Assigned to American Telephone and Telegraph Company


Number 1,410,890—Method of and Means for Modulating Carrier Oscillations

METHOD OF AND MEANS FOR MODULATING CARRIER OSCIL-LATIONS. wherein both halves of the carrier wave is modulated

in accordance with the signal. Oscillations from the source 13 are simultaneously impressed upon the antenna 15 and the output circuits of the tubes 1 and 2, the half-wave of one polarity flowing from filament 3 to plate 5 of tube 1, and the half-wave of the opposite polarity flowing from filament 4 to plate 6 of tube 2. The amount of energy diverted from the antenna 15 to the tubes 1 and 2 will depend upon the conductivity of the tubes which is determined by the potential on the grids 7 and 8. Since the potential of these grids with respect to the corresponding filaments is the same and varies in accordance with the variation in current flow in the circuit 20 produced by the transmitter 21, the amount of energy diverted thru the tubes will vary in accordance with the signals produced by the transmitter and the amount of energy radiated by the antenna will be modulated in accordance with the signals. Furthermore, since the conductivity of the two tubes at any given instant is the same, both the positive and the negative halves of the transmitted oscillations will be modulated alike. Altho the tubes are unilaterally conductive, and hence only half waves flow thru each tube, their conductivities or impedances are equal with respect to positive plate-filament potentials, since the grid-filament potentials are equal.

1,413,732—R. A. Heising, filed October 2, 1916, issued April 25, 1922.
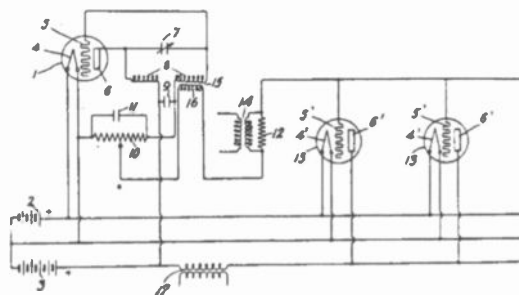
NUMBER 1,413,732—Electric Discharge
Apparatus

ELECTRIC DISCHARGE APPARATUS, in which the necessity for polarizing grid batteries is eliminated and negative potential supplied thru the action of an oscillator. The system is particularly adapted for aircraft sets in simplifying the apparatus and reducing its weight.