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Volume 14 August, 1937 No. 2

THE SURFACE WAVE IN RADIO PROPAGATION

BY

CHARLES R. BURROWS*

Delivered before the Radio Club of America
February 11, 1937

Mr. Burrows opened his paper with a discussion of the concept of the surface wave and its relation to radio propagation. He pointed out that by surface wave is meant a wave that is guided by a surface in generally the same manner that a wave is guided by a pair of wires or by a concentric tube transmission line or even by a hollow pipe. These were given as examples of what is termed one dimensional surface waves. A two dimensional surface wave can be thought of as that which would result from transmission between a pair of planes. In the one dimensional case, the energy is attenuated exponentially by absorption and thus results in the familiar expression of attenuation in decibels per mile. In the two dimensional case, however, in addition to the exponential attenuation factor, due to power absorption there is a decrease in the energy density in the wave as a result of the spreading of the wave over an ever increasing area as it advances. This reduces the energy density inversely with the distance and the field strength therefore varies inversely with the square root for the distance.

The concept of the surface wave was introduced into studies of radio propagation over the surface of the earth in 1907 when Zenneck showed that the interface between earth and air could support a plane surface wave that was exponentially attenuated in the direction of propagation and decreased exponentially with increase in distance from the surface both upwards and downwards. Zenneck did not show that an antenna could generate such a surface wave but because it offered a plausible explanation of radio transmission to great distances it was generally accepted.

Two years later Sommerfeld considered the problem of the spreading of electromagnetic waves from a short doublet antenna located in the interface between earth and air. He expressed his result as the sum of two components, one of which he identified as a cylindrical surface wave which at great distances was equal to Zenneck's surface wave. This theoretical work of Sommerfeld seemed to prove that the surface wave was an important component of the radiation from an antenna on the surface of the earth.

Ten years later Weyl reconsidered the problem and obtained an expression for the radiation from an antenna on the surface of the earth which did not explicitly contain the surface wave. From this he concluded that the separation of the field by Sommerfeld into two components, one of which was called the surface wave, was merely mathematical fiction and had no physical counterpart. He was, however, apparently of the opinion that his results agreed numerically with those of Sommerfeld.

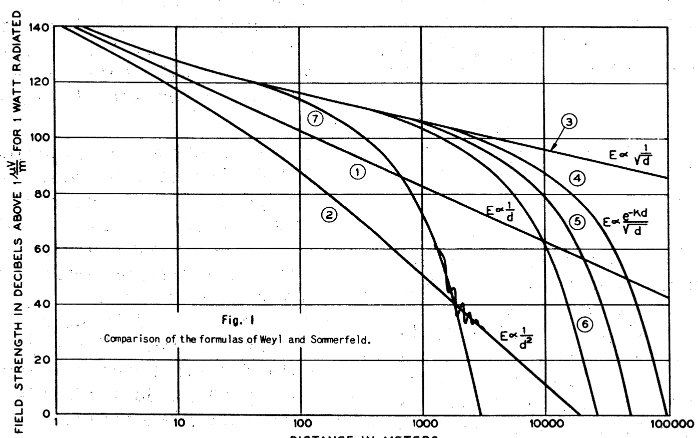

Fig. I
Comparison of the formulas of Weyl and Sommerfeld.

Mr. Burrows here pointed out that a careful comparison of the results of the work of Weyl and of Sommerfeld shows that they differ by precisely the surface wave component in question which was the subject of his paper. The comparison of the formulas of Sommerfeld and Weyl are indicated by Figure 1 where the field strength is plotted as a function of distance both scales being on logarithmic. From this figure it was pointed out that for transmission over a perfectly conducting plane the field strength varies inversely with the distance as shown by curve 1. Curve 2 was de-

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scribed as a plot of Weyl's formula for transmission over a dielectric plane. This shows the field strength varying inversely with the square of the distance at the greater distance. Curve 3 is a plot of the surface wave for propagation over a perfect dielectric showing the field strength varying inversely with the square root of the distance at the greater distances. Where the dielectric is not perfect but has appreciable conductivity the surface wave decreases exponentially with distance as indicated by curve 4. Curves 5, 6, and 7 having been plotted for increasing values of conductivity show that as the conductivity is increased the marked influence of the exponential factor sets in at shorter and shorter distances. The Sommerfeld-Rolf curve results from adding the surface wave component to the Weyl curve. The interference of these two components produces oscillations in the curves where the two components are approximately equal. Under the condition where these two components are equal and out of phase at the same distance the theory of Sommerfeld predicts zero field strength at a finite distance as pointed out by Rolf.

Thus, Mr. Burrows stated, resort to experiment was indicated as being desirable in order to decide which of these two curves is correct. In making such an experimental investigation, however it is highly desirable to make transmission tests under conditions where the received field strength predicted by these two formulas differ greatly. This occurs for propagation over a perfect dielectric and since fresh water is the nearest approach to a perfect dielectric available in sufficient volume and area for a test of this kind the locale of making the tests was largely determined by this fact.

The departure of these two formulas from one another increases also with the frequency so that a most revealing test would comprise a determination of the variation of the field strength with distance over fresh water in ultra high frequency transmission. Thus a frequency of two meters was chosen as a convenient and useful frequency for the work reported by Mr. Burrows.

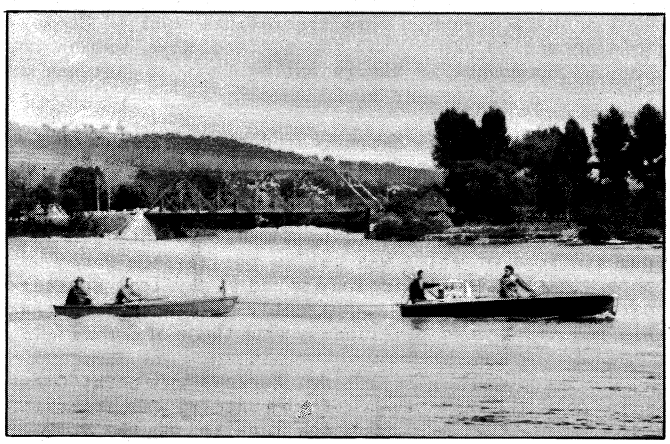

Fig. 2

Experimental arrangement for determining the variation of the received field strength with distance.

During the summer of 1936, Messers Burrows, Decino and Hunt took some two meter measuring equipment to Seneca Lake, New York State and there made these tests. Figure 2 shows a picture of the experimental arrangements. The transmitter was carried in a rowboat towed by a motor boat containing the receiver. The antennas were loaded quarter wave doublets whose midpoints were a quarter wave-length above the water's surface. The experimental procedure was to drive these boats along path 1 of the Figure 3 at a fixed distance apart for a sufficient length of time to make certain that there was no fading such as might be produced by reflections from the bottom of the lake. The distance between the transmitter and receiver was measured by a fishline under a fixed tension.

For distances between receiver and transmitter greater than 150 meters, it was necessary to alter the experimental procedure. For these distances the receiver was located at the end of a pier at Hector Falls and the

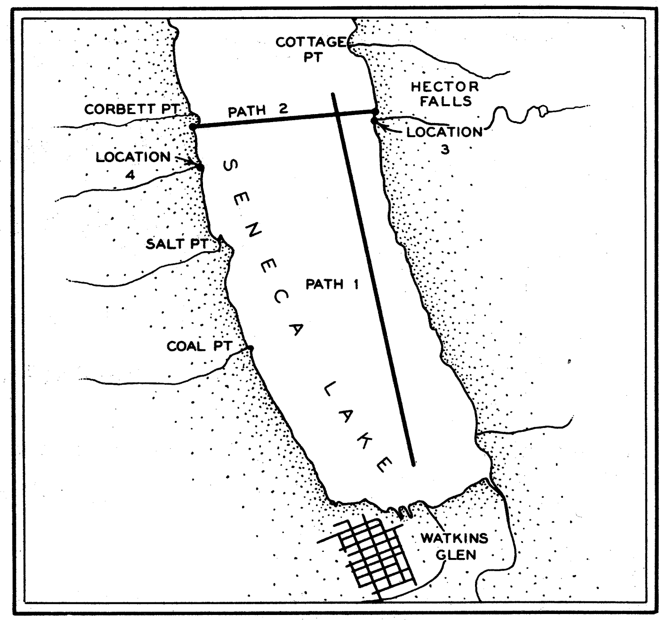

Fig. 3

Map of part of Seneca Lake showing the location of the experiment. Path 1 shows the location of the two-boat experiment. Path 2 the one-boat experiment. Locations 3 and 4 indicate the positions of the terminals for the variable height test.

transmitter was located in the motor boat which was driven along path 2 of Figure 3. This, of course, introduced considerable difficulty in measuring the distance between receiver and transmitter. To minimize the error in this measurement, it was reported by Mr. Burrows that three independent methods were used. First, the motor boat was driven at constant speed in a fixed direction between two points a known separation. Second, the distance between the transmitter and the receiver was measured by means of a transit located at the receiver and a stadia rod carried by the boat. Third, a sextant was used to measure the angle subtended at the boat by two poles located on the shore, one near and the other at the receiver. To complete the measurement the angle between the line joining the two poles and the direction of the boat was measured by the transit.

Figure 4 shows the experimental data so obtained. The solid circles represent data obtained when using the two boats and the open circles those obtained when the receiver was located on the end of the pier. Curve 1 shows the inverse distance variation that would result from transmission over a perfectly conducting plane. Curve 2 is a plot of the Weyl's formula for transmission calculated for water of the characteristics of that of Seneca Lake. Curve 3 is a plot of Sommerfeld's formula for transmission over Seneca Lake water. Curve 4 is a plot of Sommerfeld's formula for transmission over a perfect dielectric.

It will be noted that the experimental data is in good agreement with values calculated by Weyl's formula which as Mr. Burrows reiterated *does not* contain the surface wave component.

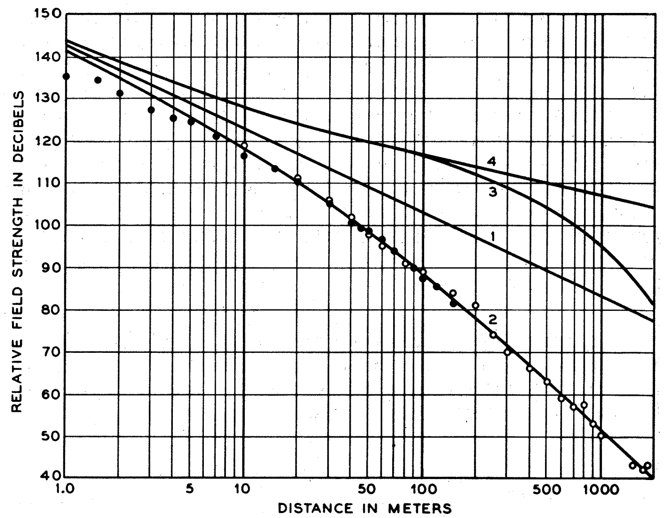

Fig. 4

Comparison of experiment and theory.

The values shown by the theoretical curves depend, of course, upon the distance, wavelength, dielectric constant and conductivity all of which, therefore required evaluation. The methods used in measuring the distance between transmitter and receiver have already been described. The measurement of the wavelength with the required precision introduced no difficulty and since the dielectric constant of water is a known function of its temperature the evaluation of the dielectric constant required, simply, the measuring of the water temperature. The conductivity was determined by laboratory measurements of samples of the water.

Then, leaving the matter of the variation of field strength with distance, Mr. Burrows pointed out that there is another property of a surface wave that might, with interest, be observed experimentally. This is the variation of the field strength with height above the earth's surface. That is, if the field strength is measured over a range of antenna elevations at distances where the surface wave, if any, would be large as compared with the remaining component, there is afforded additional experimental information indicating whether or not the surface wave exists. Accordingly, portable antenna masts were erected at opposite sides of Seneca Lake. The received field strength was determined as a function of the antenna height for two antenna heights at the other terminal as shown in Figure 6. The solid

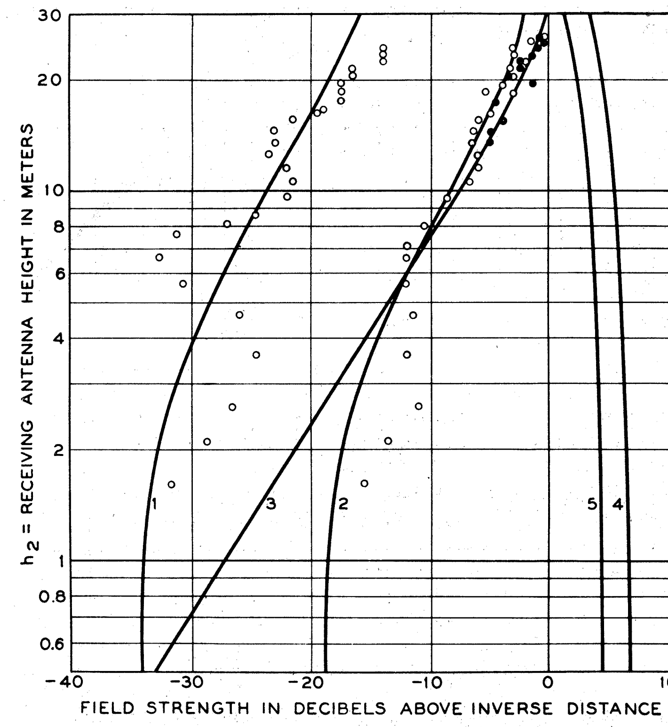

Fig. 6

Variation of received field strength with antenna height.

circles represent data taken on horizontal polarization with one antenna at 24.8 meters above the surface of the water. Since there is no uncertainty in the formula for the field strength with horizontal antennas these points may be used as a calibration of the equipment. Curve 3 is a plot of the formula for the received field strength with horizontal antennas. When this curve is made to fit the experimental data the locations of curves 1, 2, 4 and 5 are fixed. Curves 1 and 2 show the variation of received field strength with vertical antennas that would result if there were no surface wave for the two transmitting antenna heights. Curves 4 and 5 are plots of the surface wave for these two conditions. It will be noted that there is no semblance of agreement between that data and curves 4 and 5. The experimental data does, however, agree with that of curves 1 and 2. These latter are, of course valid only if there is *no surface wave component* either in absolute magnitude or in the variation of magnitude with antenna heights.

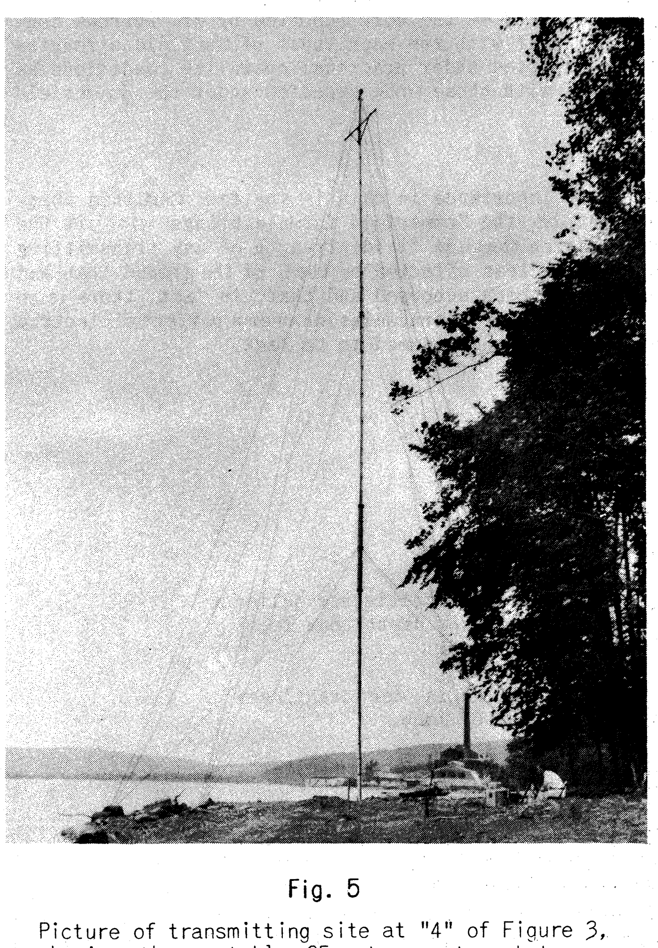

Fig. 5

Picture of transmitting site at "4" of Figure 3, showing the portable 25-meter mast and transmitting antenna.

Mr. Burrows called attention to the fact that the oscillations in the experimental data are presumably due to reflections from the hills and cliffs which line the

Lake and from trees near the receiving antenna. He pointed further that this experimental evidence proves conclusively that simple antennas *do not generate a surface wave* and therefore the Sommerfeld-Rolf formulae and curves require revision for all conditions where the dielectric constant cannot be neglected.

To further indicate the departure between the two sets of concepts discussed by him, Mr. Burrows showed figure 7 which compares the Sommerfeld-Rolf curves with

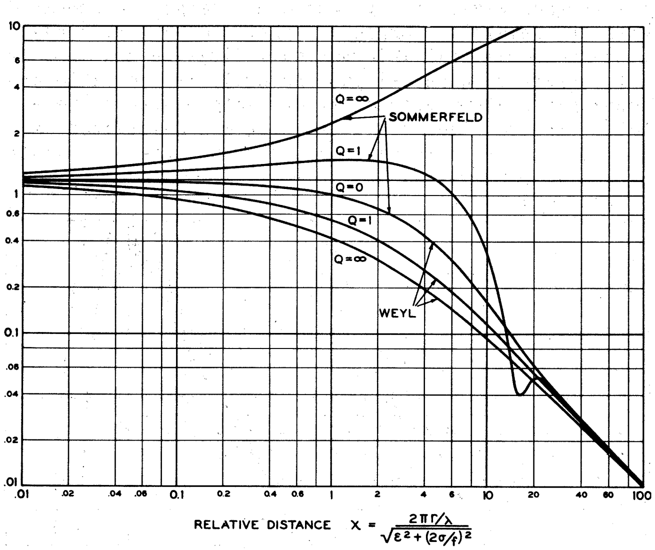

Fig. 7

Comparison of Sommerfeld-Rolf curves with the Weyl-Norton curves.

the new Weyl-Norton curves the validity of which were established by the experimental work which he described. The attenuation factor is plotted against the relative distance. In this the attenuation factor is defined as the factor by which the field strength that would result from transmission over a perfectly conducting plane must be multiplied to give the field strength under the conditions of interest.

For transmission over an imperfect conductor in which the conduction current is large compared with the dielectric amount the two formulas agree as indicated by the curve marked Q = 0.

When the conduction current is equal to the dielectric current (Q = 1) the Sommerfeld formula indicates an attenuation factor greater than unity up to a certain distance, while according to the Weyl formula the attenuation factor is somewhat less than that for the conductivity case. For transmission over a perfect dielectric (Q = oo) the Sommerfeld formula indicates that the attenuation factor is always greater than unity and increases indefinitely with increase in distance, while the Weyl formula indicates the attenuation factor is only slightly less (up to about 10 db.) than that for the conductivity case.

In conclusion Mr. Burrows stated that the validity of the Weyl formula has been unquestionably established by the work reported in his paper as against the previously generally accepted Sommerfeld formula.

The discussion that followed the reading of the paper brought to light much that was of interest to the membership. It was the first reaction of those in attendance that it was to be assumed from Mr. Burrow's conclusions that the concept of the radio wave as being a wave moving forward with its "feet in the ground" would have to be abandoned and it was quite evident from the comments that the attendants were by no means completely willing to abandon this old and generally useful concept unless something more useful could be supplied in its stead.

No alternate concept was offered and, indeed, it was not insisted that this simple concept need be abandoned even in view of the apparent need for abandoning the conclusions usually drawn from the Sommerfeld formulae. Instead it was repeated that the important aspect of the conclusions from the work reported by Mr. Burrows concerns itself with the magnitudes of the field strengths to be expected under practical operating conditions as compared with those to be expected under the Sommerfeld formula.

Of major importance in this is the fact that this abandonment of the Sommerfeld formula brings with it the realization that the field strength of any transmitting station is less effected by the Q of the ground than had heretofore been supposed and that, in fact, there is no great advantage in transmission over a perfect dielectric as has long been assumed to be fact.

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EXPERIMENTS IN GENERATION, DETECTION AND MEASUREMENT AT ONE METER WAVELENGTHS

BY

PAUL ZOTTU*

Delivered before the Radio Club of America
March 11, 1937

Mr. Zottu introduced the subject of his paper by pointing out that the problem of developing oscillators, amplifiers and the like for use at extremely high frequencies - below a wavelength of one meter - is commonly thought of as being largely one involving the development of circuit elements which will provide impedances of sufficiently high value. Thus, the first step in the development of ultra-uhf equipment is the development of high impedance coupling circuits. He disposed of the possible usefulness of conventional types of tuned circuits by pointing out that while they held considerable promise, at the moment the use of lines of various types recommends itself as being the obviously and immediately useful type of arrangement for oscillator stabilization, etc. He limited his further discussion to the closed quarter wave line as being the obviously useful type for providing high impedances and high Q for tube couplings. In this he defined the Q of a quarter wave resonator as F. E. Terman defines it in his article of July 1934 in Electrical Engineering, that is, by analogy with the Q of a lumped circuit. This gives an expression for the Q of such a line as

$$Q = \frac{2\pi Z_0 f}{RC}$$

where R is the resistance per unit length of the line, C is the velocity of light, Z_0 is the characteristic impedance of the line and f the frequency at which it is excited.

Mr. Zottu then proceeded to a discussion of the theoretical factors operating in the choice of dimensions of both open wire and concentric lines for maximum or optimum end impedance and Q. These provide certain optimum dimensional proportions, the optimum relationship between conductor spacing, diameter and wavelength in the case of open lines and the ratio of conductor diameters and wave length in the concentric lines being only approximately equal for maximum end impedance and for maximum Q. In this it was suggested that some difference of opinion exists between the speaker as the result of his experimental work and other workers in this field as the result of their analytical work, as to the influence of radiation resistance on these optimum relationships in the case of concentric lines. There was much discussion of this point after the paper, which might well be mentioned here: the point being that while it was obvious that in the case of open wire lines radiation must be taken into consideration since, as the lines are spaced further and further apart in order to get higher surge impedance and lower attenuation, the radiation resistance increases as a result of the increasing amount of power lost through radiation as the spacing is increased, so that one comes ultimately to a spacing between conductors beyond which the increase in power loss through radiation more than offsets the increase of surge impedance and reduction of assymetrical current distribution in the conductor, i.e. skin effect.

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Figure 1 indicates the magnitude of both the purely resistive end-impedance and the Q of open wire lines of optimum dimensions. From this it appeared that Q's of about one thousand and end impedances of several hundreds of thousands are readily possible at 100 M. C. when using open wire lines.

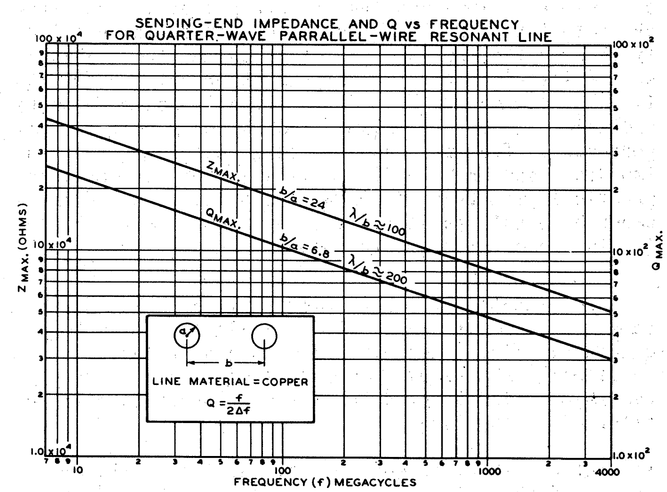

Fig. 1

Similar reasoning, including the consideration of radiation loss, if any, provided the basis for the determination of optimum proportions for concentric lines. Figure 2 shows the maximum end impedance and maximum Q over a wide range of frequencies - 1. to 400. M. C. - for optimum proportions. This indicates that end-impedances and Q's are about ten times as great as those of open lines. On the matter of radiation loss within a closed

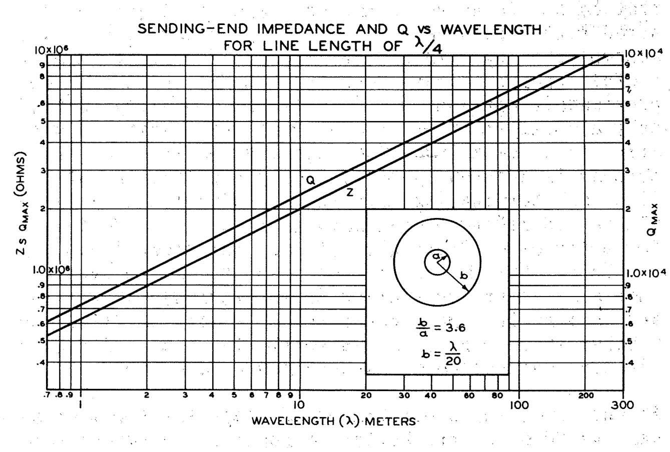

Fig. 2

concentric line, the later discussion, as invited by Mr. Zottu's comment, waxed hot and heavy: the point being that Mr. Zottu had limited his analytical work to such dimensions of conductors that the radiation factor proposed by certain other unnamed workers in arriving at the optimum relationship was negligible notwithstanding the fact that he was unconvinced of the rationality of the assumptions basic to this point. The point at issue here appearing to reside in the fact that as the ratio of the diameters of the conductors of a concentric line gets great and as the difference between them gets to be an appreciable portion of the wavelength, the assumption of the instantaneity of the building up of the radial flux within the line introduces an increasing error and one which would doubtless limit the ratio of diameters to some finite value if valid correction is made for it. Mr. Zottu felt that such correction as proposed does not however meet the needs of the problem.

It might here be pointed out in passing that from the purely analytical viewpoint the lack of instantaneity of development of flux within a concentric line results in a departure from the precise in-phase or quadrature relations indicated by the analysis of the properties of loss-free lines and thus probably contributes to the characteristics of the line under consideration precisely as does the presence of losses in the line. Whether such a loss-like relationship in the properties of the lines discussed by Mr. Zottu actually means loss by radiation or otherwise appeared of only academic importance. The influence of this factor on the end-impedance and on the Q of the line is, however, of major practical importance from the view point of Mr. Zottu's paper but, unfortunately, was not completely included in his presentation of the problem.

It was brought out in a later section of Mr. Zottu's paper that in the case of an oscillator including a concentric line closed at both ends and including within itself all circuit elements including the tube, he was able to find no evidence of radiation or other fields external to the line.

Mr. Zottu next proceeded to a discussion of the application of the relations shown by his graphs. He indicated that a quarter wave line at any but the highest frequencies requires far more space than is likely to be available under practical conditions. Thus, as he pointed out, in the broadcast band for nearly optimum dimensions something like a pair of smoke stacks, something over three hundred feet high, would be required for the stabilizing of a broadcast transmitter by means of an "open wire line" while a pipe, sixty feet in diameter and three hundred feet long, would be required to serve as the outer conductor of a suitable concentric line. This pointed the obvious limitations of simple quarter wave lines and introduced the compromises that he has found he could make and still get the desired high impedances and high Q. In general, this was accomplished by two different means. The first and most useful appears to have been the use of a line of approximately optimum cross sectional dimensions but of only a small fraction of a quarter wave length terminating in a capacity. The capacity required for this purpose is secured by putting a cap over the end of the line and terminating the inner conductor in a large flange and making the cap movable relative to the flange for purposes of "tuning". It was not pointed out by Mr. Zottu, but it is in fact a moot question whether such a structure consisting of an extremely short line and terminating in a capacity is really a "line" or whether it is merely an extremely low loss and conveniently constructible inductor and a capacitor.

At any rate, the short line with capacity termination was one form that Mr. Zottu's circuit arrangements took in order to secure high impedance for the tube couplings.

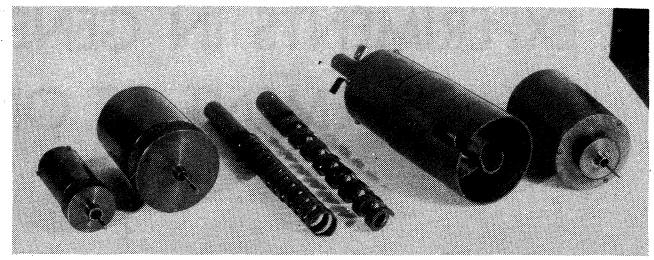

Fig. 3

The second form which was shown, Figure 3, is a concentric line in which the inner conductor consisted, not of a simple cylindrical member, but of a spiralled conductor of rectangular section; this, in the interest of raising the surge impedance, decreasing the axial velocity of propagation and hence, making a quarter wave line short enough to be useful. Because of its greater complexity this type of line was not much used.

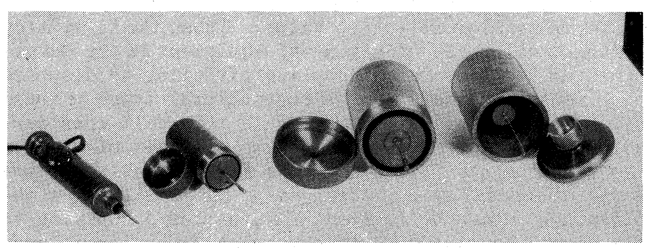

Fig. 4

Samples of a number of different sizes and types of these several forms of shortened lines as shown in Figure 4 were available for inspection after delivery of the paper.

In these forms of circuit construction provision has to be made for the coupling to the tubes or associated circuits. Such coupling was necessarily made variable so that "matching" would be readily possible. In general, this was accomplished by providing slots in the outer conductor near the low potential end through which conductors terminating on the inner conductor could pass for connection to the tube or other circuits. Where used with tubes this provided either for "back-coupling" of grid and plate circuits in the case of oscillators or plate-circuit-to-grid circuit coupling in the case of amplifier arrangements. In these practically useful forms of short lines provision for tuning was in each case made by an adjustment knob at the low potential end either for shorting portions of the spiralled inner conductor or varying the capacity at the remote end of the line, or for varying the effective length of the line itself as is shown in the figures.

After an extended discussion of these details, Mr. Zottu showed an oscillator consisting of eight tubes arranged radially on a circular metal plate, each tube carrying its own plate and grid circuits each consisting of a single loop of wire and coupled into a rather unusual form of short concentric line. This line consisted of an inner conductor of what was termed a concentric line, lacking however, the outer concentric conductor: the latter being replaced by three cylindrical standards of small diameter supporting the end plates of the line, one of the end plates comprising one of the plates of the line terminating condenser. The connections between the tube circuits and the line which acted as a single tank circuit for all eight tube circuits being provided by taps on the inner conductor connected through coupling condensers - either adjustable or fixed - to the single loop plate or grid circuits of each tube.

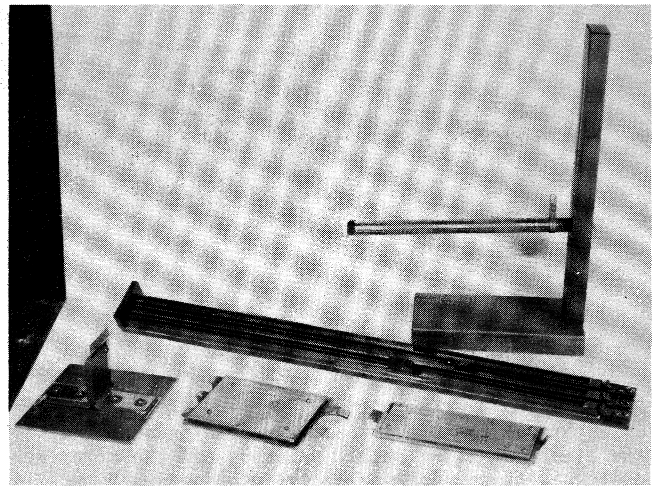

Fig. 5A

This was reported to give a power output of the order of 80 watts at about one meter.

Mr. Zottu explained at some length how this radially symmetrical structure might be extended by the use of a line tank circuit not so greatly foreshortened so as to provide for its being fed by a number of levels of radial tube generators and suggested further extensions of this scheme of symmetrical layout in the interest of making it possible to use tubes as oscillators at frequencies near the upper limit imposed on their operation by their individual impedances and thus, avoiding the paralleling of their capacities and impedance and the consequent limitation on the upper frequency of their operation. It was pointed out that one could, by the arrangements shown, operate an almost unlimited number of tubes all feeding into a single tank and thence to a single dissipator at the same high frequency as that at which the tubes would operate individually.

Mr. Zottu then reviewed the acorn tube oscillators, shown in the B. J. Thompson papers of sometime ago. In this he brought out a distinction between the original Thompson tubes and the now commercially available acorn tubes - the 955, etc. - by referring to the original and still experimental tubes, as "shoe button" tubes.

This portion of the paper stressed some of the details of the design of circuit elements such as the inclusion within the tube mounting of the required bypassing capacities by the simple expedient of mounting the socket elements on separate metal plates which were separated from the datum metal plate base of the assembly by thin dielectric in the interest of getting high bypassing capacity. Additionally, various combination current and voltage supply leads were shown in which thin sheets of dielectric were used between the strip or thin plate leads in the interest of getting by-passing.

In addition to bypasses, Mr. Zottu showed an interesting

METHOD OF MOUNTING AND BY-PASSING ACORN TUBES

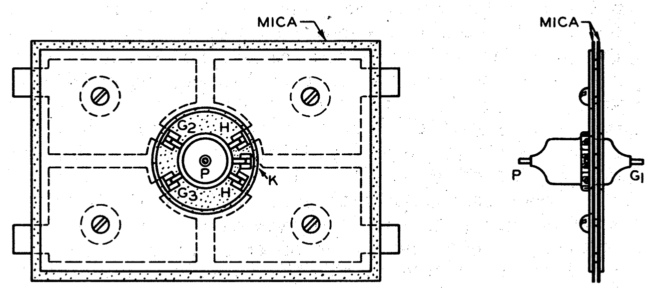

Fig. 5B

"universal" choke coil the operating range of which was from about two meters down to one half a meter. It consisted of a single layer solenoidal coil of small diameter - about half an inch in diameter - and about four to six inches long wound with a single layer of wire, of either copper or higher resistance material. The theory of its usefulness being that a coil of a sufficient number of wavelengths long and of sufficient attenuation will provide so little reflection from the receiving end back to the transmitting end that, as viewed from the transmitting end, it would offer only its own surge impedance at all frequencies. In addition, other forms of lines of use as chokes were shown, amongst them simple adjustable lines comprised of a small channel section as the outer conductor and having a concentric wire as the inner conductor and a slider to provide H. F. short-circuiting of the line to the channel section and thus to provide the adjustability necessary for making the end impedance of the line high and largely resistive. These as shown in Figures 5A and 5B and other similar devices were found necessary in oscillator and amplifier designs to maintain filaments and other elements requiring D.C. excitation at potentials determined by the H. F. requirements of the circuit and independent of the potential of the current and voltage sources.

Several other forms of oscillator were shown: amongst them one, shown in Figures 6A and 6B in which an acorn tube was mounted within the concentric line and provision made for changing the coupling of the line to the tube through the shifting of the line as a whole relative to the tube and for tuning the line by means of a break in the inner conductor which was closed through a dielectric adjustable as to capacity from outside the closed line.

Mr. Zottu then proceeded to a discussion of such measuring methods and devices as had been devised for work in this field. It was pointed out that with the means for measuring voltage and power available, most desired characteristic data could be secured. There were, therefore, two general types of measuring instrumentalities devised. The first to be described was the thermocouple type of watt meter and the second was the diode rectifier type of peak voltmeter. Of these the first took the form of a number of different types of vacuum

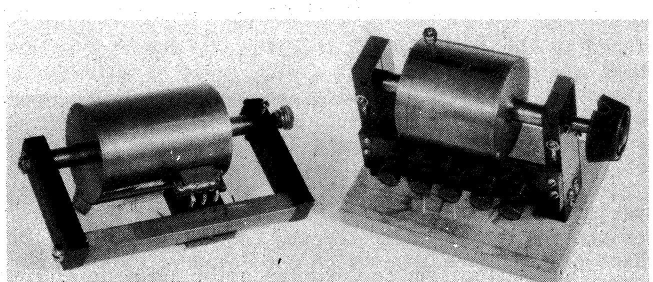

Fig. 6A

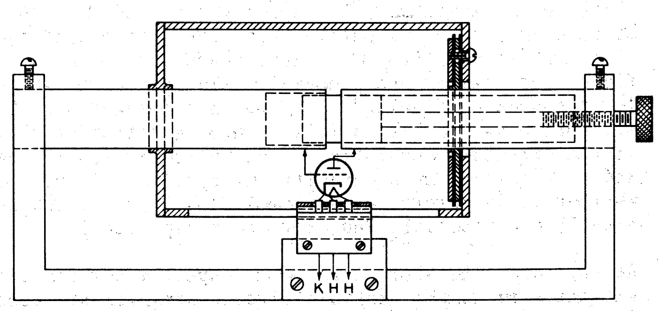

Fig. 6B

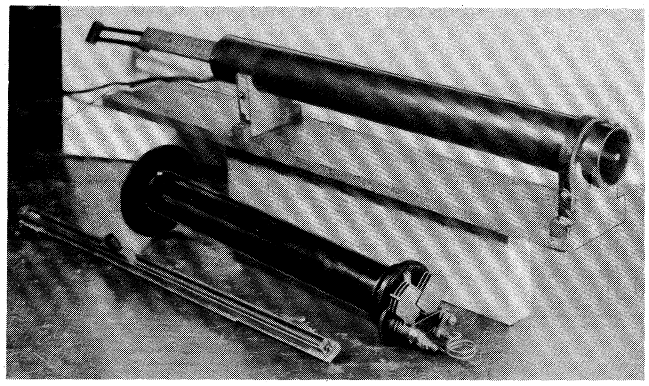

Fig. 7A

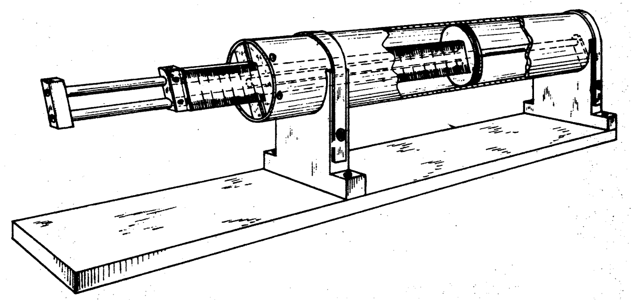

Fig. 7B

type thermocouples in which all the available power was dissipated in a heater and the resulting thermoelectric voltage read externally on a conventional indicating instrument, the arrangements of the heater and couple elements and terminal arrangements being such as to minimize the coupling between the heater and the couple circuits. In order to provide for rather unusually high heater temperatures the heater itself was made of extremely fine tungsten wire, while the nature of the couple conductors was undescribed. Calibration curves of several typical thermocouples were shown indicating that for the most sensitive thermocouple watt meter the system gave full scale deflection at about 40 milliwatts while for the least sensitive couple maximum power indication was gotten at about 40 watts.

Photographs of a number of diodes devised for use as diode peak voltmeters were shown. These were all characterized by extremely small anodes and filaments with microscopic clearances between them. Thus, the smallest of the diodes shown included a cylindrical anode six mils in outer diameter enclosing a filament of unspecified diameter. The circuits used with these diodes are quite conventional in that the diode output circuit comprises a condenser which is charged by the unidirectional electron current to such a potential as to reduce the electron current to a negligible amount. It was pointed out that the minute clearances were made essential by the influence of the electron transit time upon utility of the diode for this purpose. Even the smallest of the diodes shown required correction for frequency at the extremely high frequencies at which they were used. Thus, a calibration curve for this diode was shown in which the 60 cycle calibration departed little from the calibration at one meter.

A brief discussion of the relation between electron transit time - or the phase shift of the diode current and voltage due to transit time - and the current flowing in the diode served to indicate the procedure followed in making the frequency corrections to the diode voltmeter characteristics.

A third type of measuring instrument was shown in the slides: this, of the wave meter type. Two specific types were indicated and are here shown in Figures 7A and 7B. One of them consisted of a few turns of wire connected to a variable condenser of the Remler type presumably in order to secure complete symmetry to ground in the tuned circuit and to maintain a low minimum capacity, the LC combination was mounted at the end of a long dielectric rod or tube with the control and scale mounted at the end remote from the inductive elements. No resonance indicator was included in this type of wavemeter; thus, it was useful only for "absorption" measurements.

The second type consisted of a concentric line in which the effective length of the conductors was made variable through the provision of a sliding member within the line contacting both the inner and the outer conductors with a moving scale carried along with the sliding member and itself sliding under an indicator external to one end of the line, thus indicating wave length directly on the linear scale; the entire assembly being provided with a removable end so that it might act as an open or shorted line, thus providing for two wave length ranges.

Mr. Zottu then proceeded to a discussion of the adaptation of these types of structure to selective receiver circuits in conjunction with acorn tubes. He showed illustrations of several types of receivers already shown on previous occasions, notably in connection with the Thompson IRE papers in which conventional tuning arrangements of small size were used and pointed out that the gains per stage gotten by these means were small even at the lowest of the high frequencies at which the receiver operated; and, indeed, were never in excess of four per stage. This low gain appears to have provided the impetus required for the attempts to adapt the "line" type of tuned circuit to receiver uses and resulted in a three line receiver which was shown both in slides and "in the flesh" after the reading of the paper and is here shown in Figure 8. The problem to be

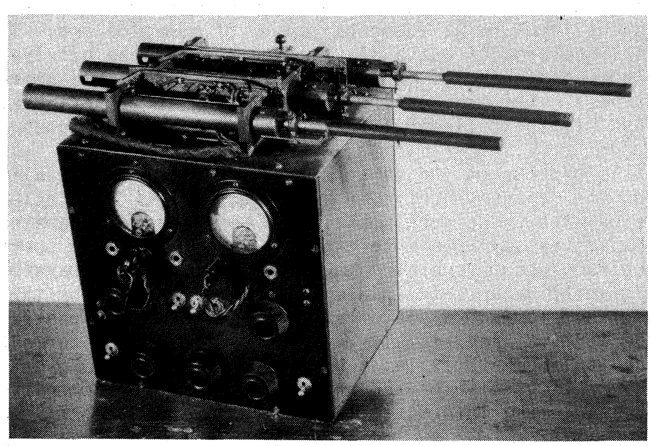

Fig. 8

faced in the design of the receiver was reported to have been one of providing such a wide range of adjustability as to accommodate a wide and apriori unknown range of tube impedances and such a wide frequency range as would determine the ultimate limits of the receiver's effectiveness. Thus, not only were the lines made adjustable as to length for a wide range of frequency variation but adjustable with respect to the point of connection along their lengths to the tube elements. Each of the three assemblies consisted of a yoke carrying a sliding line the tube being mounted on the former while a sliding member within each line provided for the adjustment of the effective length of each of the three lines to suit the desired frequency of operation. Thus, the tube in each one of the three assemblies comprising an amplifier stage could be connected to its own line on the plate side at the proper point along the length of the line by the sliding of the line within its yoke and to the adjacent line at the proper point along the length of that line by the sliding of the adjacent assembly, including the yoke and all and, in addition, the frequency of operation of each of the three stages was adjusted by sliding the short circuiting member within the line housing.

Mr. Zottu pointed out that, as was to be expected, when coupling the tube plate circuit to such a high impedance as was provided by the line, it was found necessary to make the plate-to-line connection relatively close to the low potential end of the line in order to secure low enough coupling to give the desired selectivity of operation but, as was not so definitely expected, it was found necessary to make the grid-to-line connection also near the low potential end and, even less expectedly, found necessary to make this connection even nearer the low potential end than the plate connection if anything approximating a desirable degree of selectivity was to be obtained. Thus the tuned R. F. receiver comprising the tubes and lines consisted of three sharply tuned circuits coupled loosely out of the tube plate circuits and even more loosely coupled into the tube grid circuits.

It was pointed out that the unhappily low input impedance was not due, as is sometimes suggested, to the capacitive reactance of the tube input but in large measure to the low value of the input resistance - or high conductance - which, in turn is due to the relatively high ratio of the electron transit time to the period of the circuits. In fact, it was shown that at a point in the range of the receiver *not* close to the upper limit of its frequency range, the input resistance of the tubes became so low that the gain of the receiver was reduced to unity.

Mr. Zottu's conclusion to his most interesting and instructive paper indicated that the solution to the problems that so seriously limit the development of suitable radio receivers, oscillators and other radio devices employing vacuum tubes for use at extremely high frequencies has been shown by the work reported in this paper *not* to reside in the design or construction of the circuit elements but rather in the design and production of vacuum tubes. Indeed, one understood from the paper, that further progress in the field reported on by Mr. Zottu was unquestionably and completely dependent on the development of new and suitable types of vacuum tubes.

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