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The Institute of Radio Engineers

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GENERAL INFORMATION

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THE COLLEGE OF THE CITY OF NEW YORK

EDITED BY

ALFRED N. GOLDSMITH, Ph.D.

OFFICERS AND BOARD OF DIRECTION, 1921

(Terms expire January 2, 1922; except as otherwise noted.)

THE COLLEGE OF THE CITY OF NEW YORK
NEW YORK N. Y.

AMENDMENTS TO THE CONSTITUTION OF THE INSTITUTE OF RADIO ENGINEERS

The following amendments to the Constitution of the Institute were submitted to the membership for vote, in accordance with the procedure set forth in the Constitution. Having been adopted by the membership by the vote given in each case below the text of the amendment, they are now a portion of the Constitution of the Institute. The attention of the membership is accordingly directed to their text, as here given.

ARTICLE VII

SECTION 1: Six weeks before the annual meeting, the Board of Direction shall submit to the entire membership, excepting Honorary Members and Juniors, a list of candidates (nominees) for the offices of President, Vice-President and two Managers. This list shall comprise at least two names for each office, the names being proposed either by Petition as hereinafter provided, or by a majority of a quorum of the Board of Direction, at one of its stated meetings. The list shall contain no indication as to whether the candidate has been proposed by Petition or by the Board of Direction.

Nomination by Petition shall be made by letter, addressed to the Board of Direction, setting forth the name of the proposed candidate and the office for which it is desired he be nominated. For acquiescence a letter of Petition must reach the Board of Direction on or before October 1st of any year, and shall be signed by at least thirty-five Fellows, Members or Associates in good standing.

The list of nominees shall contain the names of all candidates proposed by formal Petition or by the Board of Direction, but before this list is submitted to the membership for final vote, each candidate shall be consulted and if he so requests, the fact that he has withdrawn from the election shall be stated after his name.

The entire membership in good standing, excepting Honorary Members and Juniors, shall be eligible to vote by written ballots in plain sealed envelopes, enclosed within mailing envelopes marked "Ballot" and bearing the member's signature for the officers whose names appear on the list of candidates. A majority vote received up to the time of the closing of the polls (twenty-four hours before the opening of the annual meeting, the date of which shall be stated in the election notice) shall elect, and no votes by proxy shall be counted. No proxies or ballots within unsigned outer envelopes shall be opened for counting. Ballots shall be checked, opened, and counted by a quorum of the Board of Direction, at a meeting of the Board.

The above amendment was adopted by an affirmative vote of 479 to 8.

SECTION 2: The Treasurer, Secretary, and Editor of Publications shall be appointed by majority vote of a quorum of the entire Board of Direction as soon as practicable after January 15th of each year, for a term of at least one year or until their successors be appointed.

The above amendment was adopted by an affirmative vote of 465 to 22.

RECENT PROGRESS IN RADIO COMMUNICATION IN GERMANY AND AUSTRIA*

By

Dr. Eugen Nesper

(Vienna, Austria)

The radio work of the last years of the World War and of the period immediately following (which has been one of unfortunate scientific depression for the Central European Powers) has been concentrated on vacuum tube transmitters, amplifiers, receivers, and auxiliary beat or heterodyne receiving apparatus. Many different lines of development have been required to meet the very special demands of fixed stations, heavy mobile stations, easily portable stations, and ship and aircraft stations. Reception with a coil or loop antenna provided with a radio frequency amplifier-detector-audio frequency amplifier for the reception of broadcast press messages and of financial and weather reports has found a previously unexpected vogue and usefulness. This mode of receiving without an elevated antenna or ground connection is based on the development of the amplifier which originated in the United States (Lee de Forest). Furthermore, the normal specifications for the construction of stations and equipment in the various countries differed more or less. Considering the then available personnel, it was found, for example, in Germany, that obviously more difficult requirements had to be met in the apparatus than in the same or at least similar English apparatus.

A number of typical instances will be given to show the practical application of the above considerations to the most recently developed equipment.

As a first example, there will be considered a vacuum tube transmitting and receiving set constructed by the C. Lorenz Company, of Berlin. The actual set is illustrated in Figure 1. It can be used for ordinary radio telegraphic transmission, for measurements of wave length in searching for the signals of distant transmitters, for reception with primary circuit only,

* Received by the Editor, July 6, 1920. Presented before The Institute of Radio Engineers, New York, September 1, 1921. Translated from the German by the Editor.

for reception using a secondary circuit, and for radio telephony. This apparatus, therefore, is adapted to a variety of uses, and yet covers a relatively wide range of wave lengths, namely from 350 to 1,800 meters, and for both the primary and secondary circuits. By turning the main control handle *a*, the set can be

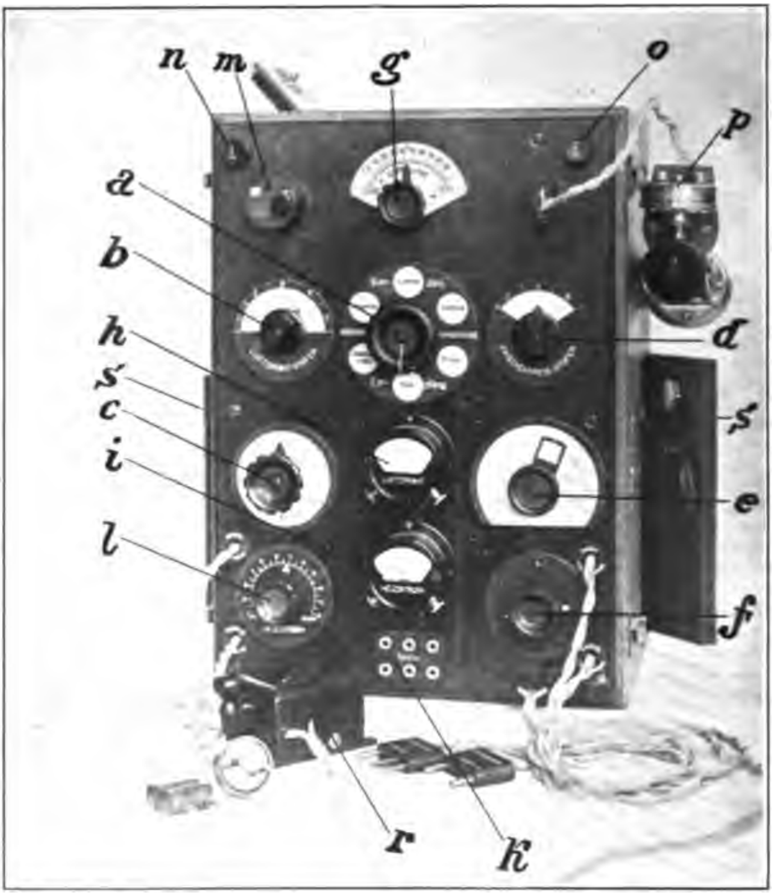

FIGURE 1

readily used in any of the ways indicated above. For operating the apparatus, a number of handles project from the front panel, each handle being provided with a pointer or a window indicator. These pointers or indicators move over appropriate scales graduated in degrees, wave lengths, closeness of coupling, or filament heating current. The upper handles on the left side of the panel control the antenna inductance and the antenna condenser, the handle *b* controlling the steps of antenna inductance and the handle *c* the antenna condenser. The secondary circuit is controlled by handles on the right side of the panel, thus *d* controls the steps of secondary inductance, *e* the main secondary condenser, and *f* a small condenser in parallel with the main secondary condenser and intended for fine tuning when employing beat reception. The handle controlling the coupling between the antenna and secondary circuits *g* is mounted at the middle top of the panel. In addition, the panel carries a small antenna ammeter *h* under which is placed a second ammeter *i* for filament current. Under this latter are jacks *k* for plugging in three telephone receivers or, if desired, a suitable amplifier. In the lower left-hand corner of the panel is the handle *l* which controls the filament current of both the transmitting and the receiving tubes. The buzzer *m* is mounted on the upper portion of the panel, and the antenna and ground connections *n* and *o* are brought to the binding posts at the upper corners of the panel.

A telephone transmitter *p*, adjustable so as to fit the head of the operator, is provided, and can be plugged into the side of the case. The key *r* is similarly provided with cords and a plug so that it can be connected thru the jack at the bottom of the panel.

Small doors *s* are fitted into each side of the case. Mirrors on the inside of these doors enable the operator to see both the transmitting and receiving tubes in the inside of the case, and to note if the filaments burn out. The location of the bulbs in the interior of the case is advantageous in that it keeps the insulation warm and dry, and therefore, in good condition. This is important when the set is used in damp locations.

In the left-hand portion of Figure 2 is shown the transmitting circuit. The transmitting tube *t* is lit by a 12-volt storage battery. Plate voltage is provided either by a 500-volt dry battery assembly *u* or by a small direct current generator. A large condenser is shunted across *u*. The key is *r*, and *d* is the stepwise variable secondary coil. The secondary tuning condenser is *e*. A fixed mica condenser *v* can be connected in parallel to *e*, this being done automatically by the inductance step-control switch *d* of Figure 1. The condenser *w* is the substitute and equivalent of the "tone condenser" *f* (to be described below), and is automatically connected into circuit when changing over from receiving to sending by means of the main control switch *a*.

The internal capacity of the tubes is compensated for by the equivalent capacity of the condenser *x* which is automatically inserted into the circuit across coil *d* when the control switch *a* is thrown over from transmitting to receiving. It should be noted at this point that the secondary coil *d* is used for both transmission and reception, and hence the necessity for the various substitute condensers *w* and *x*.

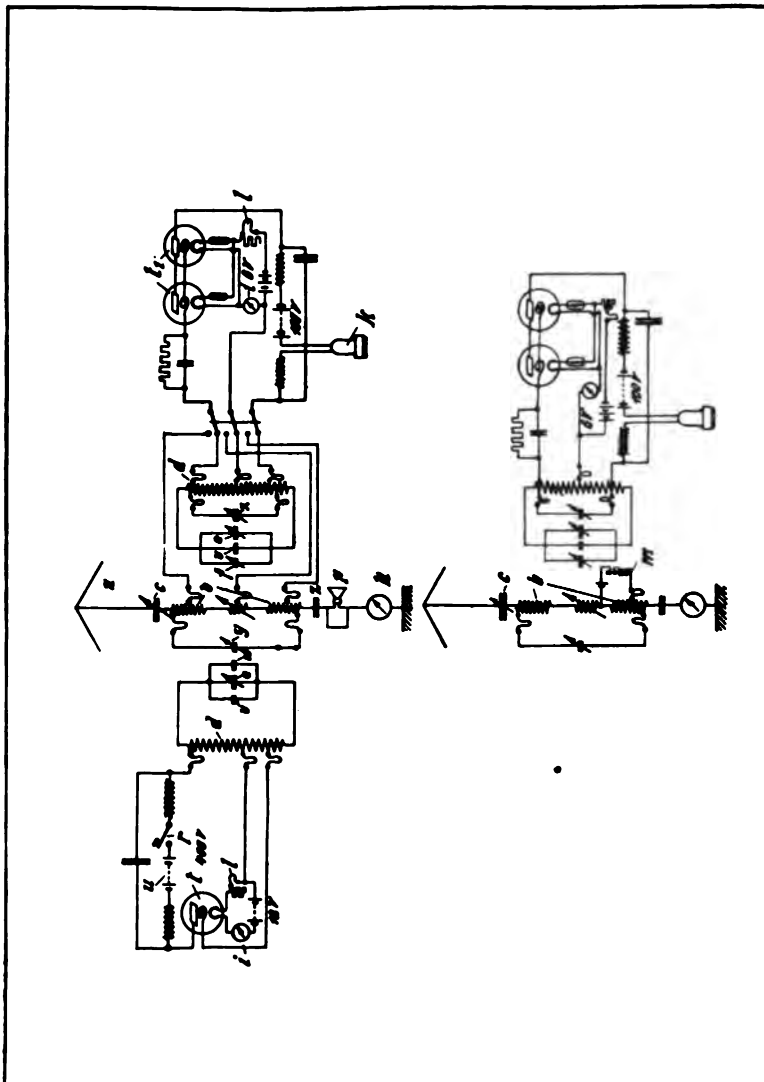

FIGURE 2

The antenna inductance *b* (which is stepwise variable) and the antenna tuning condenser *c* form the main elements of the antenna circuit. In parallel with coil *b* is connected the condenser *y* when sending or receiving with the secondary circuit in use. Condenser *y* compensates for the tube capacity. It is automatically inserted by switch *a*. Transmission using a primary or antenna oscillating circuit alone is not used, because too large a proportion of overtones would be radiated. There are also inserted into the antenna a fixed capacity *z*, the ammeter *h*, and, when required for telephony, the microphone transmitter *p*.

The circuits for reception with the primary alone and also using the secondary as well are shown in the right-hand portion of Figure 2. The receiving tubes t_1 can be directly connected to the antenna circuit *n c b z h*, and the beat reception employed. A filament voltage of 6 and a plate voltage of 100 are then used. The telephone receiver *k* is connected in series with the plate battery.

In changing over from primary circuit reception to secondary circuit reception, the condenser *y*, which is connected at one terminal only to the coil *h* during primary circuit reception, is then shunted across coil *h*, and the secondary coil *d* is inductively coupled to the antenna circuit. The secondary circuit consists of coil *d* and the variable condenser *e*, in parallel with which latter an extra fixed condenser *v* and a "tone condenser" *f* are connected. The beat note is regulated by means of the tone condenser, which is, therefore, a relatively small capacity. The substitute condenser *x* is also connected in circuit in this case. In searching for the signal of a distant continuous wave station, the following procedure is carried out. The main switch *a* is set to primary circuit reception. By varying the inductance step switch *b* and the variable condenser *e*, the beat tone which indicates the approximate setting is obtained. After accurately securing the desired note, the operator switches over to reception with the secondary circuit connection, first setting the handle of the tone condenser *f* to the zero position (neutral zone). By variation of the step control switch *d* and careful adjustment of the secondary condenser *e*, the set is tuned to a resonance maximum. The desired tone is then obtained by adjusting the tone condenser *f*. The coupling between primary and secondary *g* is then adjusted for the loudest signal. In case the transmitting and receiving wave lengths are equal, the operation of the set becomes especially simple. It is then necessary merely to throw the main switch *a* from the "secondary reception" position to the immediately adjoining transmitting position. By operation of the key, and noting from the antenna ammeter *h* that normal radiation is being secured, the transmission may then proceed without any further adjustment.

The measurement of wave length is accomplished as indicated in the lower diagram of Figure 2. The buzzer *m* is started by throwing the main switch *a* into the corresponding position. This sets the antenna into oscillation at the desired wave length provided the inductance *b* and the condenser *c* are adjusted until the secondary circuit indicates resonance. The secondary condenser then gives the wave length of the received signal.

In addition to the typical set just described, vacuum tube transmitters up to a 10-killowatt size have been built in a wide variety of forms. From these numerous types, one built by the former Lorenz Company of Vienna is chosen as an illustration of convenient portability and carefully chosen electrical design. Furthermore this set is intended for transmission and reception on unusually short wave lengths, namely 50, 60, 70, 80, 90, and 100 meters. In Figure 3, this set is shown with the cover of the cabinet removed. For transmission, a larger type of tube (which is behind the window at the right, but is not visible in

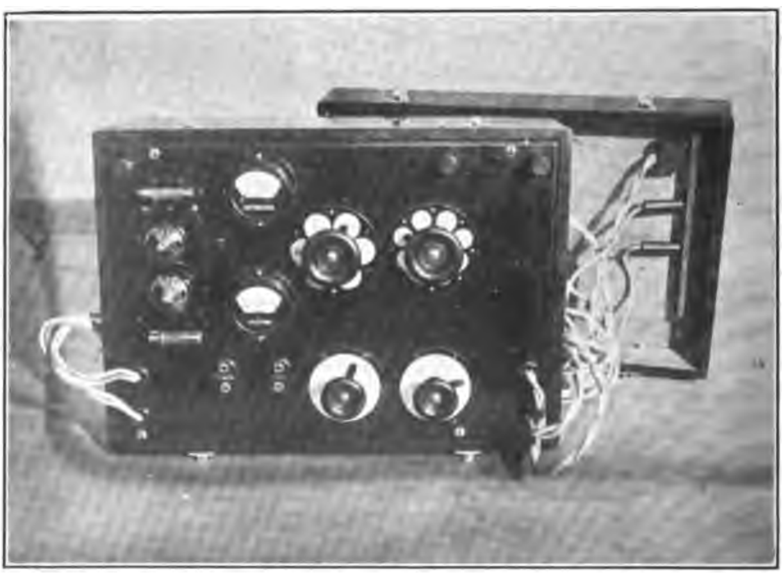

FIGURE 3

the illustration) is employed; while two small bulbs are used for reception to ensure reliable beat reception particularly at such short wave lengths. The set is so constructed that it is largely independent of the size and type of antenna between wide limits. This is arranged for by providing a variometer adjustment for maximum antenna current, in addition to the stepwise adjustment of antenna inductance.

Both transmitting and receiving tubes are arranged so as to heat the interior of the apparatus (thus minimizing the effect of moisture on the insulation), and are also placed so that their light is available for writing or reading messages. The antenna and ground are connected to the right-hand binding posts. The control handle underneath them provides for changing from sending to receiving. In addition, this handle can be set to "Off," or to a position in which the transmitting tubes are not burning at full brilliancy. The adjoining handle controls the switch whereby any of the six fixed wave lengths can be chosen. Thereafter maximum antenna current is secured by adjustment of the variometer in the antenna circuit. The handle of this variometer is at the bottom right. To its left is the control handle for varying the note in beat reception. The two jack pairs at the left are for the insertion of plugs connected to the telephone receiver and the key. The twin-conductors serve for connection to the filament and plate batteries, those at the left being for the receiving tubes and those at the right for the transmitting tubes.

The apparatus next to be described is intended either for receiving purposes or for making radio measurements.

The very great importance of amplification in radio reception has been recognized for many years. As a result a considerable number of mechanical amplifiers have been devised, which however, proved to be unpleasantly sensitive to vibration, shocks, and mechanical injury. It remained for a number of investigators, particularly in America with (Lee de Forest as the pioneer) to meet the needs of the situation by the use of vacuum tubes. Practical tubes of this type were produced by Irving Langmuir and others, and they were found to be very satisfactory amplifiers since they were practically uninfluenced by mechanical disturbances and, being almost instantly responsive in their action, permitted radio frequency amplification as well as audio frequency amplification.

Taking an audio frequency amplifier first, the physical phenomena will be explained in connection with Figure 4. Radio

frequency amplification will be considered in connection with the use of loop receivers.)

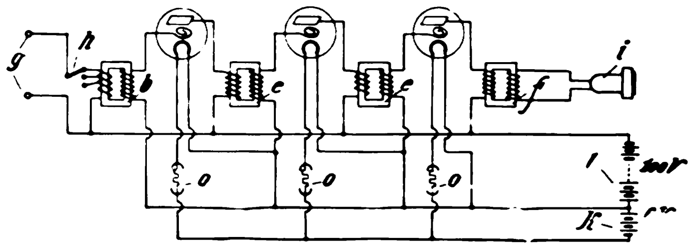

FIGURE 4

The energy which is to be amplified, for example, that received from the detector, is led to the terminals *g* of the amplifier, and then thru a small iron core transformer *h b* to the grid circuit of the first tube. The function of the amplifier is to obtain as high a potential variation as possible on this grid. Since various forms of detector supply their output energy at different voltages, the primary *h* of the transformer is sometimes provided with three taps controlled by a suitable switch. In general, however, a fixed primary is provided and the switch eliminated. An energy amplification of the order of ten times is obtained in the plate circuit of the first bulb, the energy being supplied by the plate battery [illegible].

A second transformer is inserted in the plate circuit of the first tube, and the secondary of this transformer is connected to the grid circuit of the second tube, which, since it produces a ten-fold energy amplification, has an energy output one-hundred times the original input approximately. The same effects are produced by the third tube, so that a total amplification of energy of the order of a thousand times is to be expected. This is transferred by the [illegible] transformer *f* to the telephone receiver *i*.

[illegible] of all the tubes are fed from the battery *k*. [illegible] in an atmosphere of hydro- [illegible] excessive current [illegible].

[illegible] the preceding circuit [illegible] is shown in Figure 5. [illegible] panel in a wooden [illegible] are placed the iron-in-hydrogen ballast resistances which can be readily interchanged in view of the clip-contact mountings. The fine internal iron wires are at a dull red heat when they are functioning properly. On the front of the box may be seen two sliding doors which permit access to two switches. One of these has two positions:

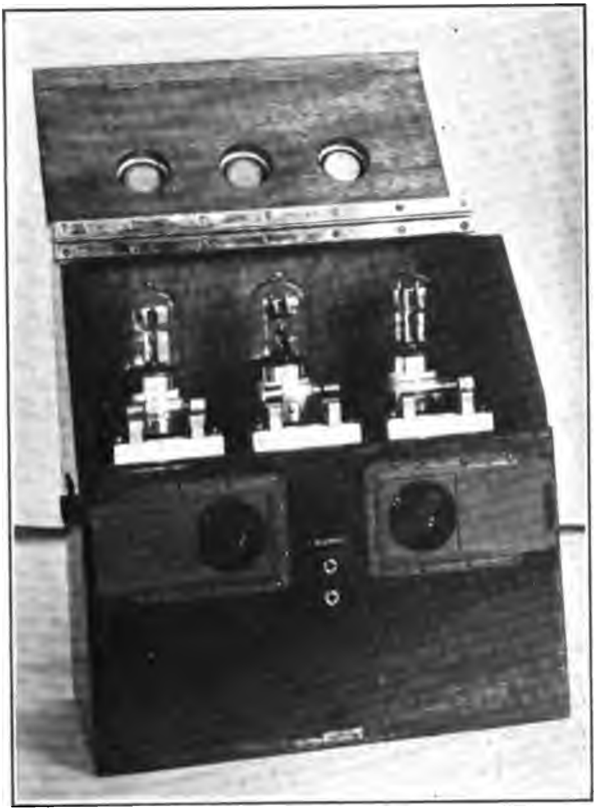

FIGURE 5

"On," meaning that the amplifier is in use, and "Off," meaning that the telephones are connected directly to the input or detector circuit without the interposition of the amplifier. At the left side of the box is a plug pair which permits connecting the amplifier to the energy input circuit. On the right side of the box, but not visible in the illustration, are two pairs of terminals, one for the 100-volt plate battery (usually of dry cells), and the other for the 6-volt filament battery (usually a storage battery). When the amplifier is in use, the top of the box is generally closed, and the holes in the top permit the operator to note whether the bulbs are lit or not.

Probably the greatest changes in the radio field, at least as regards reception, have been brought about by the development of the amplifier. It has thus become possible to increase the strength of the received signals to almost any desired limit, and indeed to dispense with large elevated antennas and, even for reception from long distances, to accommodate loop antennas of convenient dimensions inside ordinary rooms.

The most common arrangement is given in the diagram of Figure 6. The loop antenna *a* consists of several turns of insulated copper wire which may be fastened to one wall of the receiving room. In other cases, when it is desired to vary the direction of best reception at will, the loop can be mounted on a light wooden frame which can be rotated and which may be suspended from the ceiling of the room or otherwise mounted.

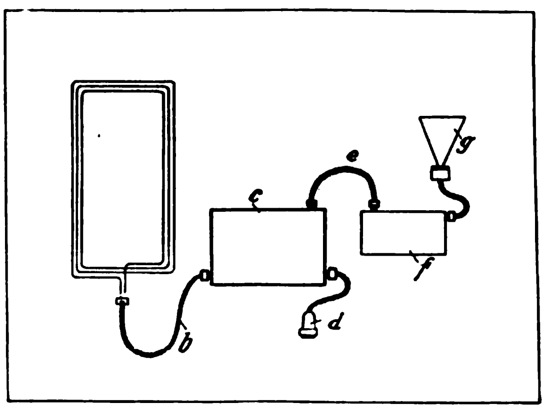

FIGURE 6

From the terminals of the loop antenna a twin conductors cord, terminated by appropriate plugs *b*, leads to the terminals of the special receiver *c*. The construction of this receiver is described below in connection with Figure 7 which shows a type built by the former J. Berliner Company of Vienna. By means of the loop receiver, naturally tuned to the appropriate wave length, and using the telephone *d*, reception from such distant stations as Paris, Lyons, Petrograd, or any other large stations in Europe, and sometimes even North America, can be accomplished.

In case, however, the loudness of signals thus obtained is not sufficient, or in case it is desired to obtain such loud signals that a large group of auditors can hear them, a further amplifier *f* is used which is connected by the conductors *e* and plugs to the receiver *c*. This particular amplifier feeds a loud-speaking receiver or "Megatelephone" *g*. If a large horn is used with this latter, the signals become easily audible thruout a large room. As an alternative, in place of the loud-speaking receiver *g*, an ordinary receiver may be used connected to the amplifier *f*. This is desirable when the received energy is very small, as in reception from very great distances or using very small loops.

The arrangement of the loop receiver shown in Figure 7 permits of obtaining very loud signals even without beat reception auxiliary apparatus (external heterodyne oscillator) or further amplifiers. In all, seven tubes are used, which can be seen in the middle of the apparatus. The circuits are so arranged that the first four tubes are used for radio frequency amplification, the fifth tube is used as a detector, and the last two tubes for audio frequency amplification.

The tuning elements, inductances and condensers, are built into the cabinet in this piece of apparatus. The inductances are mounted behind the glass-covered calibration chart at the right. The variable condenser is visible in the middle of the bottom. The wave length can be varied continuously between 200 and 24,000 meters. The stepwise regulation of the coils—there are three coils in all—is carried out by the control handle mounted directly over the variable condenser handle. The filament current can be read by means of the small ammeter to the left of the condenser handle. To the left of this are two more handles, the lower one of which controls the filament current rheostat, and the upper one of which enables turning the filament and plate currents on and off.

In the left bottom corner can be seen a small block carrying jacks for the insertion of two telephone receivers and also for the filament and plate batteries. The movable handle directly over this block serves to control a resistance inserted into the plate lead of the fourth tube ("regeneration control resistance"), thus obtaining beat reception in the upper portions of its range of motion and ordinary detection in the lower portions. The antenna is connected to the two binding posts in the upper right-hand portion of the case.

The coupling between each tube and the next consists of a high resistance, with the exception of the fifth and sixth tubes and the coupling to the telephone receiver. For the former cases step-up transformers are used; for the latter case a step-down transformer.

FIGURE 7

By thus combining radio and audio frequency amplification, the available sensitiveness of the apparatus is such that with a loop antenna of 30 turns and 1.5 square meters area (4 feet square) reception from America can sometimes be accomplished. However, it is generally advisable when working with such small loop dimensions to have an external heterodyne oscillator which may be coupled to the receiver in a variety of ways, and most simply by placing it in the neighborhood of the receiver.

The physical phenomena in this case are the following: A minute portion of the energy electromagnetically radiated from the distant station is received by the loop antenna *a* (Figure 8), and is carried by the conductors *b* to the tubes of the receiver *c*. The first three of the tubes in *c* act as pure radio frequency amplifiers so that the extraordinarily small input energy is markedly increased by them. The third tube output will accordingly represent about one thousand times the energy received by the loop *a*. This increased energy is then transferred to the fourth and fifth tubes, which partly produce further amplification, but at audio frequency, and partly produce so-called rectification which enables the incoming energy to actuate the telephones. It is also possible by adjustment of the regeneration

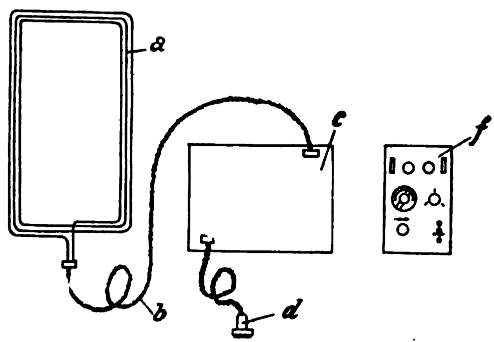

FIGURE 8

control resistance to produce beat reception without additional apparatus, so that, when receiving continuous waves, a clear tone is heard in the telephones in correspondence with the Morse signals sent from the distant station. Since the amplitude of the local oscillations can be varied by means of this same resistance, it is possible to select the best ratio between the amplitude of the incoming signal current and the locally generated oscillating current, in this way securing a maximum signal strength on various wave lengths and for various intensities of the incoming signal. Above a certain value of the resistance, the local oscillations cease, and ordinary detector reception of damped waves becomes possible.

Loop antennas with such a receiver therefore constitute a complete substitute for:

1. The earlier types of complicated receivers with secondary circuit and many adjustments.

2. Former equipment for receiving press news, financial reports, and similar information in the long wave range from 2,500 to 20,000 meters.

3. Apparatus for receiving time signals (in connection with the regulation of clocks).

The advantages of the loop antenna are in its considerable reduction of those atmospheric disturbances of reception which, with high antennas and ordinary receivers, frequently hold up all traffic during the warmer months of the year for hours at a time. Furthermore, increased selectivity is obtained in that the same receiver discriminates between damped and continuous wave stations and, by utilizing the directional characteristics of the loop, enables picking one station signal to the more or less complete exclusion of a number of interfering stations.

In those cases where the strength of the incoming signal is ample for effective amplification, it is desirable to use an external heterodyne oscillator for beat reception.

The general arrangement of such an external oscillator used in conjunction with a loop receiving set of the former J. Berliner Company of Vienna is shown in Figure 8. Here *a* is the suspended rotatable loop, the received energy from which is connected by *b* to the receiver *c*. The telephone receiver is plugged into jacks in *c*. The external oscillator *f* is loosely coupled to the receiver *c*, for example, by placing *f* and *c* close to each other on the table. The intensity of the signals can be brought to the best value within limits by moving *f* on the table.

The external appearance of such an oscillator with its cover removed is shown in Figure 9. At the top are seen two ordinary amplifier tubes which are inserted into their sockets in the usual way. Besides these are the iron ballast resistances in hydrogen which tend to maintain constant filament currents. Below the tubes, and to the right is a rotary switch handle which permits choosing any one of three ranges of wave length extending in all from about 2,500 meters to 22,000 meters. The fine tuning to the desired wave length is done with the variable condenser placed at the left of the last-named switch. The handle of the variable condenser has two attached window indicators, one of which reads wave lengths on calibrated scales, and the other of which reads from 0° to 180°.

A switch for turning the filament current of the tubes on and off is placed below the condenser, and to the right of this switch are jacks for the plate and filament current batteries.

The loop-receiving set previously described enables covering the wave length range from 2,200 to 34,000 meters. Inasmuch as all tuning circuits, radio and audio frequency amplification circuits, detector, and regeneration control are included in the same apparatus, an unusually favorable combination is obtained both as regards portability and ease of operation.

It is not always necessary to cover so long a wave length range, and sometimes the separate parts of the set are desired. Thus, in Figure 10 is shown the exterior of a four-step radio frequency amplifier which is one of the component portions of the loop receiver. The whole receiving set can, then, be built up out of the following parts: loop, tuning means (generally merely a variable rotary plate condenser), four-step radio frequency amplifier, audio frequency amplifier, and such additional parts as storage batteries, high voltage battery, telephones, and so on.

FIGURE 9

In the four-step amplifier of Figure 10, the first three tubes act as radio frequency amplifiers, and the fourth as a rectifying detector. The circuit is so arranged that no external oscillator is required for beat reception of continuous wave stations. This amplifier can be used with ordinary tuned-secondary receivers working with elevated antennas. In the amplifier shown in Figure 10, the windows in front of the four tubes are seen at the top, these tubes being inserted by lifting the top of the case. To the right, directly under the fourth tube, is a switch which not only turns the filament current on and off but regulates its value. The voltage across the tubes is indicated on the voltmeter to the left. Depressing the button under the voltmeter connects that instrument across the plate battery and permits measuring the plate voltage. To the right on the panel is the handle controlling the resistance for beat reception or plain detection, which handle also permits adjusting the local oscillations till optimum signal is obtained. The telephones are connected into the double jack at the right of the panel, the filament and plate batteries into the triple jack, and the connections to the tuning circuit are made from the double jack at the left of the panel.

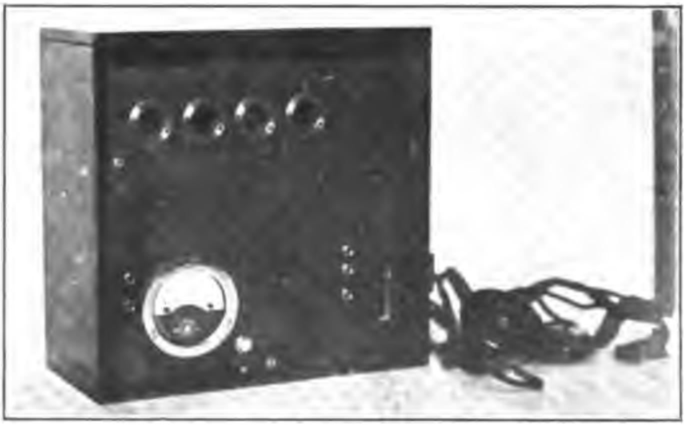

FIGURE 10

Directional receivers or radio goniometers were used in the World War on airplanes and otherwise. But their commercial applications are sure to increase in the future. For example, with the increasing use of aircraft, reception on the plane should also serve to guide the flight and permit safe descents to the landing field. Optical and accoustic means of positively locating the landing field have not proven adequate for the purpose.

The solution of the problem of finding the direction of the incoming waves at a receiving station is most easily and reliably attained by using two directional antennas in conjunction with a receiving goniometer. The type of goniometer built by the former Lorenz Company of Vienna is intended for use with two closed triangular antennas (loops) which can be very readily erected by the simplest means, and which gives greater accuracy in direction and freedom from locally produced errors than other methods.

The general arrangement is shown schematically in Figure 11. In this Figure, a_1, b_1 and a_2, b_2 are the pair of triangular antennas. The mast which supports them is only 9 meters (27.45 feet)

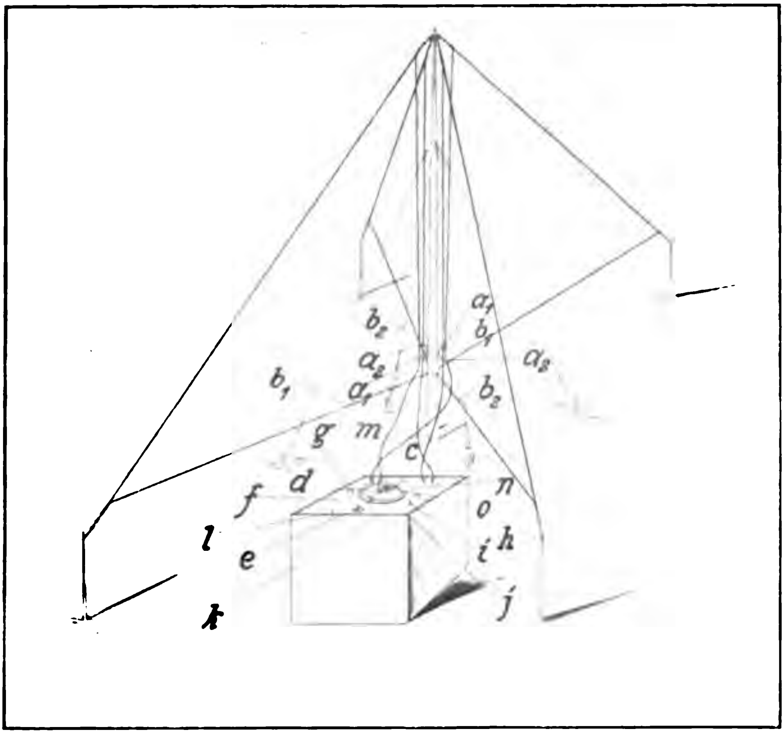

FIGURE 11

high. The four small outer masts are 2 meters (6.1 feet) high and at a distance of 15 meters (45.75 feet) from the foot of the central mast. The planes of the two antennas must be perpendicular to each other, and it is convenient to arrange them in the East-West and North-South directions. The terminals a_1 are connected to the North-South binding posts of the goniometer and the terminals a_2 to the East-West posts of the goniometer. If the ends b_1 and b_2 are left open, a wave length range of from 150 to 760 meters can be covered in three steps. If the two ends b_1 are connected to each other, and the two ends b_2 similarly connected to each other, the wave length range is extended to 1,700 meters. If longer waves than 1,700 meters are to be received, there is connected between the terminals b_1 and b_2 a special piece of auxiliary apparatus, which has also been worked out by the former Lorenz Company, Limited, of Vienna.

The goniometer of the Lorenz Company of Vienna is worked out as a double receiver, with the necessary tuning elements permitting directional receptions of wave lengths between 150 and 750 meters embodied in the apparatus. Figure 12 shows the goniometer removed from its protecting case. It will be seen that there are two cylindrical coils, one mounted at right angles to the other and underneath it. The length, diameter, number of turns, and taps are so chosen that as uniform a field as possible is obtained, so that the cosine law of variation of induction with angular rotation is obtained for the short detector coil within each of the larger field coils. In order to secure the best value of coupling in each case, there is a detector circuit coil mounted within each cylindrical (field) coil. Both the detector coils are rigidly mounted on a common shaft which projects thru the top panel and carries the pointer *o* (Figure 11) which moves over a 0°-360° divided scale. It is, therefore, clear that when one of the detector coils is most closely coupled to its corresponding field coil, the other detector coil has practically zero coupling to its field coil. Inside the handle controlling the pointer *o* is a switch control enabling the choice between two detector couplings, and provided with a pointer designating "close" and "loose" coupling.

The ends of the detector coils are connected to the detectors *m* and *n*, either one of which can be selected for use by means of the switch *g*.

The telephone receivers or the input terminals of an amplifier can be plugged into the jacks *j*.

Any one of three wave length ranges can be chosen by means of the handle *c*. This handle controls a switch which connects all four antenna terminals to the correct conductors leading to the three windings on each of the cylindrical field coils. Dependent on the setting of switch *c*, the following wave length ranges are obtainable: 150 to 300 meters, 250 to 460 meters, and 410 to 760 meters.

Fine tuning is secured by the air condensers *e* which are mechanically coupled so that both antennas are simultaneously and correspondingly tuned. Small differences in their tuning may be compensated for by means of the condenser *f*. A switch *h* enables changing over the antennas from the upper to the lower cylindrical coils, according as the switch is set in positions I and III. In position II, the antennas are both grounded thru an

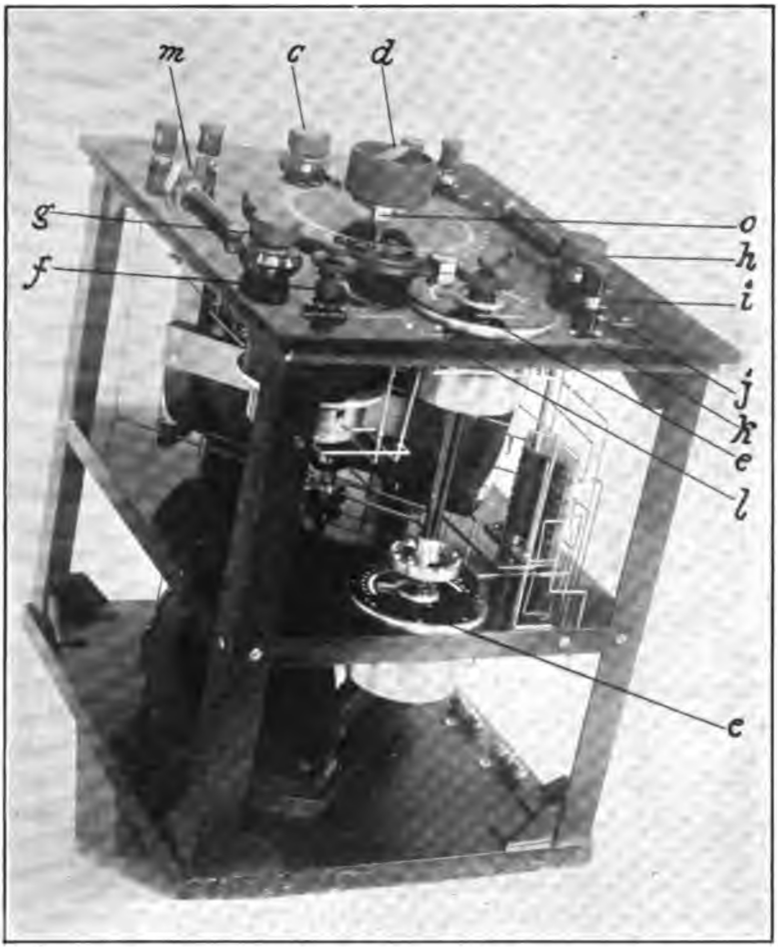

FIGURE 12

earth connection to the binding post *i*, this being done when atmospheric disturbances threaten to injure the receiver or the detectors. If it is desired to extend the wave length range, additional condensers can be connected in parallel with the tuning condensers at the jacks *l* and *k*.

Radio measurements have recently assumed much increased importance. Thru the introduction of vacuum tube generators of radio frequency alternating currents and the use of beat reception, it has become possible to give to such measurements a very satisfactory precision.

The best way of meeting the various requirements for such measurements is to use high vacuum tubes (pliotrons) with appropriate circuits. It thus becomes possible to generate radio frequency currents which, being sustained, permit the obtaining of sharp resonance effects. These same currents remain quite constant over long periods of time. The use of expensive rotating machinery, with constant attendance, for the production of radio frequency energy is thus avoided.

The following assembly of apparatus for measuring purposes is built by the former Lorenz Company, Limited, from the designs of the author and Paul Floch. It is based on the possibility of combining all the necessary oscillating circuits and auxiliary apparatus required in conjunction with a tube for the important radio frequency measurements in one piece of apparatus of small dimensions. There is combined with this a calibrated secondary circuit which contains a calibrated inductance and capacity-free resistance.

Besides being used for measurement purposes, this apparatus can be employed as a continuous wave transmitter.

Both pieces of apparatus are shown in Figure 13. To the right is the tube generator or primary circuit, to the left the secondary or measuring circuit which can also be used in transmitting or receiving circuits when connected to the antenna.

The primary circuit consists of a three-electrode tube *a*, which receives its filament current from a battery connected to the binding posts *b*, and its plate circuit energy from a generator connected to the binding posts *c*. The variable air condenser *d* and the inductance *e*, the tapped sections of which can be inserted into the circuit thru a switch *g*, constitute the oscillating circuit. By varying *g* and the condenser *d*, the wave length of the oscillator for measurement, transmitting, or receiving purposes can be continuously varied from 150 meters to 1,200 meters.

A small secondary coil is mounted inside the cylindrical coil *e*. It can be rotated by means of the small handle *f*, which is provided with a graduated scale. The energy picked up by this small coil is used either to excite the secondary circuit or else the antenna. For this purpose the energy is transferred thru the conductors *h*. A small rotary switch *i* is provided with three settings, whereby the primary circuits is adapted to "Transmit," "Receive," or "Measure." The current thru the filament of the tube *a* is controlled by the handle *k* of a continuously variable resistance. A small hot wire ammeter *l* is provided, which meas-

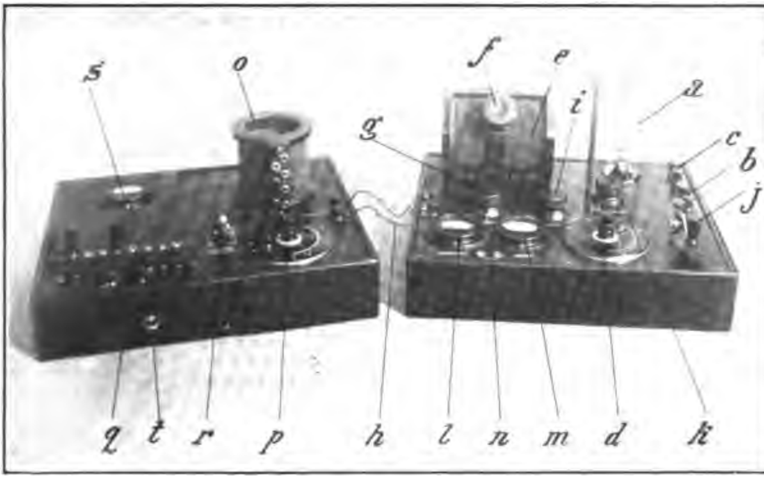

FIGURE 13

ures the radio frequency current in the closed primary circuit. The filament current is measured by the moving coil ammeter *m*. At *n* are two jacks for plugging in a telephone receiver. A key *j* is provided which is used when the apparatus is employed as a continuous wave transmitter.

The secondary circuit is connected to the primary circuit by the previously mentioned conductor *h*. It consists of a tapped coil *o*. Two plug connections lead from this coil to the variable air condenser *p*, to a calibrated tapped resistance *q*, which may be plugged in as desired or short-circuited by means of the knife switch *r*, to a small hot wire meter *s*, and to a sensitive galvanometer, and three terminals behind the coil *o* which can be either partly short-circuited or connected to the oscillatory circuit under investigation, for example, the antenna system. The galvanometer and three terminals last mentioned are not shown in Figure 13. A small aperiodic circuit, not shown in the Figure, and containing an adjustable thermo-detector, is also provided to permit exact decrement measurements of relatively slightly damped systems (resonance circuits, antennas of low decrement, and so on). This circuit and detector can be connected by flexible conductors to the sensitive galvanometer. The aperiodic circuit itself is placed either on the resistance *q*, or, when very close coupling is desired, on the coil *o*. The energy transferred to the detector, and consequently the galvanometer deflection, may therefore be controlled between wide limits.

This assembly of apparatus consequently carrying out many of the measurements of radio telegraphy, can be used as a continuous wave transmitter, or for detector or beat reception, thus amplifying the effect of incoming continuous waves. Finally, the apparatus can be used for radio telephony, tho naturally only for short distances since the available energy is limited. Among the measurements which can be carried out are: measurement of the wave length and decrement of closed and open circuits, measurements of the constants of coils, condensers, insulating materials.

The development of small radio stations for use in trenches, airplanes, and so on gave rise to a considerable demand for a small, light, easily portable, and yet physically exact measuring apparatus. In view also of the long range of wave lengths now used in radio transmission, a continuous variation over this entire range is required.

These requirements have been met by the "pocket wave meter" shown ready for use in Figure 14. This was built by the former Lorenz Company, Limited, of Vienna, from the designs of the author. The outside dimensions of each of the small cases is 20 by 7 by 10 cm. (7.85 by 2.75 by 3.93 inches). They are therefore, about the same size as a cigar box. Nevertheless, the circuit elements are constructed in a physically satisfactory way inasmuch as the condenser has rotary plates in air, and the coils have been chosen as to their dimensions and number of turns to give a minimum decrement. Furthermore, the continuous wave length range of this meter, either for reception (measurement of wave length) or for sending with small energy (buzzer circuit of Eichhorn) extends from 50 to 6,000 meters. In addition, each wave meter is provided with a small aperiodic detector circuit, shown in the Figure, consisting of a coil, adjustable detector, and telephone which is plugged into place. This fits into the wave meter case, and is particularly useful when the wave meter is used for decrement measurements. This circuit may be coupled as loosely or closely as desired to the wave meter inductance, It is also possible to plug the antenna and ground into jacks on the wave meter and receive signals with primary circuit alone. In general, the resonance indicator used

FIGURE 14

in this apparatus consists of a small hot wire "watt meter," which is provided with a special fuse to protect it against being burned out. If the energy available lies below certain limits, the aperiodic detector circuit and telephone receiver is used for locating the resonance setting. The wave meter is coupled to the system under investigation thru any one of the five available inductances.

Vienna, June 2, 1920.

SUMMARY: After describing the general trend of radio development in Central Europe during and immediately after the war, there are described in detail a low power tube radiophone transmitter and receiver; a very short wave tube telegraph transmitting and receiving set; an audio frequency three-step amplifier; a complete loop antenna and receiving set having a four-step radio frequency amplifier, detector, and two-step audio frequency amplifier; an external heterodyne oscillator; a four-step radio frequency amplifier; a complete radio goniometer receiver; an assembly of apparatus for radio frequency measurements; and a portable wave meter.

RADIO TASTE RECEPTION*

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I. INTRODUCTION

Practically all reception of radio telegraphic signals of a practical nature which has been done up to the present time has been accomplished thru the sense of hearing of the operator. Some slight amount may have been done by using the operator's sense of sight, but this has never been found sufficiently satisfactory to warrant its use in practice. It was suggested by Mr. Arthur A. Isbell, that under certain operating conditions, for example, in places where there is great interference due to exterior noises, as in the case of the operator on an airplane, there might be a certain advantage in employing the operator's sense of taste rather than his sense of hearing in receiving signals. The object of this paper is to describe some tests made to determine the feasibility of reception of radio telegraphic signals by the sense of taste.

II. PRELIMINARY TESTS USING DIRECT CURRENT AND 60-CYCLE ALTERNATING CURRENT

1. TESTS USING DIRECT CURRENT

(*A*) APPARATUS

(*a*) ELECTRODES

The fact that a stinging taste sensation may be produced by placing the two wires of a low potential electric circuit on the tongue is well known. The first problem met with in investigating taste reception was to design a pair of electrodes which

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could be kept in the operator's mouth for a considerable length of time. It was, of course, necessary to choose for the metal of these electrodes some material which would not form injurious salts of the metal in the mouth of the operator. This limited the available metals to gold, platinum, or silver. Because of the prohibitive cost of the first two, silver was selected for use in these tests.

Two electrodes were made of sheet silver about 0.016 inch (0.04 cm.) thick, 0.5 inch (1.27 cm.) wide, and 2 inches (5.08 cm.) long. They were separated by a piece of insulating material about 0.25 inch (0.63 cm.) thick. The construction is shown in Figure 1. It was intended that the tongue should be placed between the electrodes. Wires were brought from each electrode so that they might be connected to a source of potential.

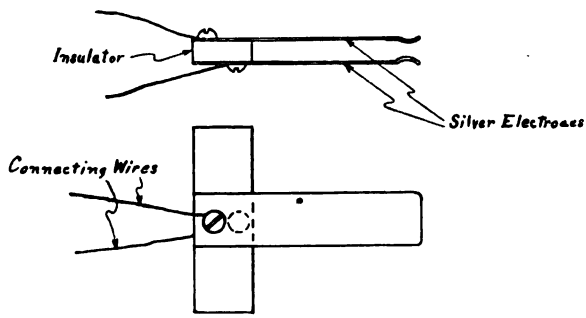

FIGURE 1

A few tests were made to determine the best position, pressure, and size of contact for the electrodes. It was found that placing the tongue between the electrodes as originally intended did not give the most satisfactory results. For the tests using direct current and 60-cycle alternating current, it was found better to have the electrodes slipped over the upper front teeth rather than the tongue. In this way one contact touched the inner part of the upper lip, while the other could be conveniently touched by the tip of the tongue. All the taste sensation was then confined to the tip of the tongue, which was found to be by far the most sensitive region in the mouth. The electrode touching the upper lip acted merely as a means for connecting that side of the circuit to the mouth.

In later tests made when using signals from a buzzer source, and signals from an antenna, it was found that the arrangement of electrodes just described was apt to cause painful sensations in the operator's front teeth. In an effort to prevent this, another disposition of the electrodes was tried. This was to have the ends of both contacts touch the tip of the tongue. This arrangement was found to give very good results. It had been tried previously when using the direct current and 60-cycle alternating current sources of potential, but had been found unsatisfactory, probably because of the relatively higher current and lower potential values common to such sources.

In all cases the best pressure between tongue and electrodes was found to be a firm, but by no means heavy pressure.

The electrodes should be small and should be close together so as to confine the taste sensation to a small area of the tongue and thus concentrate it. Two pieces of number 16 silver wire[1] 0.5 inch (1.27 cm.) long, separated about 0.125 inch (0.31 cm.) and partially imbedded in some insulating material would make very satisfactory electrodes for actual signal reception. The taste sensation should be obtained with the tip of the tongue, for this organ becomes increasingly insensitive toward its posterior portion.

(*b*) Direct Current Circuit

The circuit and instruments used in the d. c. tests are shown in Figure 2. Storage cells were used as the source

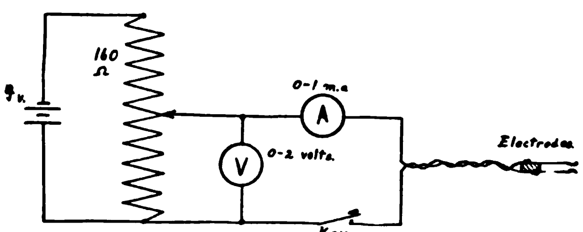

Figure 2

of potential. The potentiometer was a 160-ohm sliding contact resistance connected as a potentiometer. The voltmeter had a range of 0-2 volt, and the milliammeter had a range of 0-1 milliampere. The contacts of an omnigraph could be substituted for the key shown in the figure.

[1] Diameter of number 16 wire = 0.05 inch = 0.013 cm.

(B) Observations

The first test that was made was to determine the constant potential necessary to produce the least noticeable taste sensation. It is quite probable that this potential would vary with different individuals, and possibly with the same individual at different times. The value necessary for the observer was $V=0.4$ volt. For this potential, the current thru the tongue, as indicated by the milliammeter, was 0.01 milliampere. Tests were then made at higher potentials, the results obtained being as follows:

$V=0.75$ volt. The tests made indicated that signaling would be impossible at this potential. The element of fatigue was strongly noticeable at this voltage. It was found that if the key were kept depressed for 5 seconds, it was impossible to detect the opening and closing of the key immediately after the continuous current period. In fact, it was generally necessary to rest for about 10 seconds before the opening and closing of the key could be again clearly noted. The current at this potential was about 0.02 milliampere. On first closing the key it is probable that the current was of the order of 0.1 milliampere for a short time. It fell quickly, however, to the lower value. This effect was probably due to the polarization phenomena which will be described later.

$V=1.0$ volt. Using this potential it was found that the opening and closing of the key could be detected after an almost indefinite period of continuous current. It should be noted here that while it is stated that the opening and closing of the key could be noted, it was really only the closing that produced a noticeable sensation. With the potentials used up to this point, it was not possible to note the actual opening of the key by noticing the cessation of the taste sensation. The current at this potential was approximately 0.05 milliampere. On first closing the key it was probably about 0.2 milliampere.

$V=1.5$ volts. Using this potential it was just possible to note the time of opening the key after a period of continuous current due to the cessation of the taste sensation. The current at this potential was approximately 0.1 milliampere. On first closing the key it was probably 0.2 milliampere. It would be possible to transmit signals very slowly (about 2 words per minute) at this potential.

$V=2.0$ volts. The taste sensation obtained with this potential was considered sufficient for the practical transmission of signals. The probable speed of transmission would not be over

10 words per minute, and possibly no higher than 5 words per minute. The current at this potential was approximately 0.25 milliampere, and slightly higher than this on first closing the key.

(C) Notes on Taste Sensations

It is proposed to give herein the physiological effect of this method of reception on the operator, and to discuss certain electro-chemical phenomena in connection with the mouth electrodes.

It was noted that the taste sensation was more pronounced on first closing the key than after the key had been held down for some length of time. This was probably due to fatigue of the taste nerves on continuous excitation, and also to a partial polarization of the cell formed in the mouth. This latter effect would cause a decrease in the current, and thus a weaker sensation of taste. The fact, noted before, that the current was apparently higher on first closing the key seems to indicate that polarization was the deciding factor in this phenomena. This leads to the suggestion that alternating current might give better results than direct current as the source of potential, as the former would be free from polarization effects. It was found that the positive mouth electrode became blackened by a coating of oxide where the tongue made contact with it. As the other electrode did not become blackened at all, the nature of the polarization is clearly shown.

It will be remembered that in these preliminary tests one electrode made contact with the upper lip and the other was touched with the tongue. In the tests made so far, the latter had been connected to the positive pole of the battery. To determine whether the polarity of the tongue electrode would make any difference in the characteristics of the taste sensation, the polarity of the source of potential was reversed. It was found that the sensations were slightly less distinct when the negative pole was connected to the tongue electrode.

After this test the polarity of the electrodes was changed back to the original arrangement, and it was found that a much larger current now flowed in the mouth electrode circuit than had been obtained previously, using 2.0 volts potential. The current now obtained was 0.4 milliampere instead of the 0.25 milliampere previously recorded. On keeping the current on continuously it was found that the meter indicated a slow fall in the value of the current until the former value was approached. From this we conclude that the polarity of the electrodes had been reversed until the polarization of the cell in the mouth was such that it assisted the flow of current. After the current had flowed for a time, however, the polarity of the mouth cell became again reversed, and by opposing the battery potential, caused the value of the current to fall.

In connection with the increase in current just described, a peculiar effect on the sight of the operator was observed. On closing the key the operator noticed an effect which, at first, made him think that the lights in the room were flickering. On further investigation, however, it was noted that the apparent flicker of the lights occurred only when the key was closed. As nearly as could be determined, the effect of this relatively large current passing thru the mouth was to cause the iris of the operator's eyes to contract momentarily, thus giving the effect of a flickering of the lights in the room. A slight effect of a similar nature was noted on opening the key.

In connection with the reading of signals by taste, it was noted that the greatest difficulty was experienced in reading dots which were immediately preceded by dashes. The letter "c" (—.—.) was especially difficult to receive for this reason.

2. Tests Using 60-Cycle Alternating Current

(A) Apparatus

The source of potential used was a 110-volt, 60-cycle generator. The circuit used is shown in Figure 3. The potential was impressed across the 160-ohm non-inductive resistance shown as R' in the figure. As the potentials needed in these tests were of the order of 1 or 2 volts, a second resistance, R'',

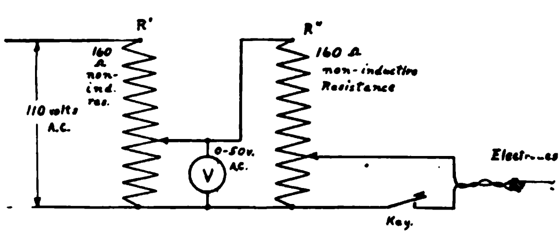

Figure 3

was shunted around a portion of R'. As there was no a. c. voltmeter available for this work, which could be used to measure 1 or 2 volts, the potential impressed across R'' was measured by an a. c. voltmeter having a range of 0-50 volts, and the potential impressed on the mouth electrodes was calculated. As R'' was just 15 inches (38 cm.) long (actual resistance wire winding), a potential of 15 volts was impressed across it. Thus there was a potential drop of one volt per inch of length along the winding. R'' was wound non-inductively like R'. As the amount of current taken by the mouth electrode circuit was small (not more than 0.5 milliampere) and as great accuracy as to the value of the potential was not essential, this method gave a value which was sufficiently exact for our purpose. No attempt was made to measure the current in the mouth electrode circuit.

(*B*) Observations

Tests were first made to determine the lowest alternating potential with which it was possible to obtain a taste sensation. This was found to be with approximately $V = 0.5$ volt.

$V = 1.0$ volt. Using this potential it was found possible to note the time of opening the key after a period of continuous current, by the cessation of the taste sensation. It would be possible to transmit signals very slowly at this potential. The definiteness of the signal in this case was about the same as that obtained using 1.5 volts d. c. It is hard to compare the two directly, for as will be described later, the nature of the taste is rather dissimilar for the two types of current.

$V = 1.5$ volts. The taste sensation obtained using this potential was considered sufficient for practical transmission at a rate of 5 words per minute.

Higher speeds than this (10 words per minute) might possibly be obtained by using higher potentials. It is probable, however, that this increase in speed would be due to the operator's ability to read by muscular reaction instead of the sense of taste. As will be described later, this phenomenon of muscular reaction was quite noticeable at the higher potentials.

(*C*) Notes on Taste Sensations

The taste sensation accompanying the use of an alternating current source of potential differed from that obtained using direct current in the following ways:

1.—The element of fatigue did not seem to be so noticeable when using a. c. This may have been due to a slight variation of the taste with the alternations.

2.—The taste sensations did not appear to be any stronger than those obtained using the same potential d. c. However, it is probable that at the peak of each wave a larger current flowed than was the case with the d. c. The lack of any polarization phenomena with a. c. would lead to the belief that a somewhat larger current would be passed. The taste sensation was more continuous in its intensity when using a. c. than when using d. c.

3.—Combined with the taste sensation was the natural muscular reflex common to a. c., which was felt as a trembling in the tongue. At the higher voltages this was more noticeable than at the lower voltages. At 0.5 volt it was almost unnoticeable. It is probable that this muscular reaction was the principal reason for the taste sensations seeming to be more constant in intensity with a. c. than with d. c.

The more constant character of the taste sensation, combined with the slight muscular reaction obtained with a. c., made it possible to read signals, using a lower potential than was required with the d. c.

At higher potentials (2.0 to 3.0 volts) the same effect on the operator's eyes was noted that has been mentioned under the section on d.c. tests. As in the former case, the phenomenon was due to large values of current thru the mouth electrode circuit. In the a. c. tests a slight difference in the effect was noted. The operator not only noted a quivering of the eyes on first closing the key, but also a constant quivering as long as the key was held down. It was also noted that, for the same potential, the effect on first closing the key was not so marked as with d. c.

(*D*) Remarks on Signals Received Using 60-Cycle Alternating Current

The highest speed which the operator found it possible to receive by taste reception was 5 words per minute, and in order to do this it was necessary to become accustomed to this method of receiving, for it is quite dissimilar to audio-reception. It is possible that with sufficient practice an operator might be able to receive at a rate of 10 words per minute by taste reception. It is doubtful, however, if the speed could be increased much above that. The reason for this is what might be called the "lag" of the taste nerves. It has not been possible to determine whether this is due to an actual sluggishness in the nerves, or a mechanical inertia of the liquids in the mouth. It should be noted that a certain time is required for the chemicals which cause the taste sensation to form between the electrode and the tongue, and then that a further small period of time is necessary for them to be dissipated after the forming current has ceased. Regardless of the exact nature of the phenomenon, however, the fact is easily demonstrable that a fraction of a second elapses between the time the circuit is closed and the moment when the sensation of taste is first noted. Furthermore, a similar period may be noted after the current has ceased, when the taste sensation still persists. As nearly as could be ascertained, this time lag is from 0.25 to 0.5 a second. The effect of this is to slow down the permissible speed of signal transmission. It also necessitates a special type of sending. The dots and dashes must be of greater length than in ordinary transmission, and the spaces between the dots and dashes of a single letter must be longer than usual. As a consequence, of course, the spaces between letters and words must be correspondingly increased. All of these requirements limit the possible speed of reception.

3. Calculations to Determine the Practicability of Taste Reception from an Energy Standpoint

To determine whether it would be possible to use the taste receiver for the reception of actual radio signals, calculations were made on the basis of the data obtained in the d. c. and a.c. tests, to ascertain if the amount of energy ordinarily available in a small receiving antenna could be sufficiently amplified to be used for taste reception.

It has been found that the current in a 25-ohm antenna, necessary to produce unit audibility in the telephones, using a crystal detector, is 5 microamperes. As a basis for calculation, a signal giving an audibility of 1,000 was selected. The current in the antenna system for such a signal would be approximately 30 times that necessary for unit audibility, or 150×10^{-6} amperes.

In order to determine the voltage and energy amplification required to permit such a signal to be tasted, it was now necessary to ascertain the potential and energy available in the secondary or detector circuit.

Calculation showed that such a signal corresponded to an energy in the secondary circuit of approximately two-tenths of a micro-watt.

In the tests using direct current and 60-cycle alternating current it was found that about 2.0 volts potential was necessary for workable taste signals. The measurements made with d. c. indicated that this potential produced a current of about 0.25 milliampere in the mouth electrode circuit. In other words, the energy necessary for readable taste signals was about 500 micro-watts.

Comparing these values with those of the actual signal as found above, it is seen that the necessary voltage amplification is 50 times, and that the energy amplification is 2,500 times. As it is possible in practice to obtain voltage and energy amplifications of this order, there was justification for further investigation of the taste receiver, using actual signals as the source.

III. Tests Made with Radio Frequency Signals

1. Using Signals from a Buzzer Source

(*A*) Apparatus

(*a*) Circuits

It was decided to try signals from a buzzer source first, as these could be easily obtained and controlled. Accordingly, the circuit shown in Figure 4 was set up.

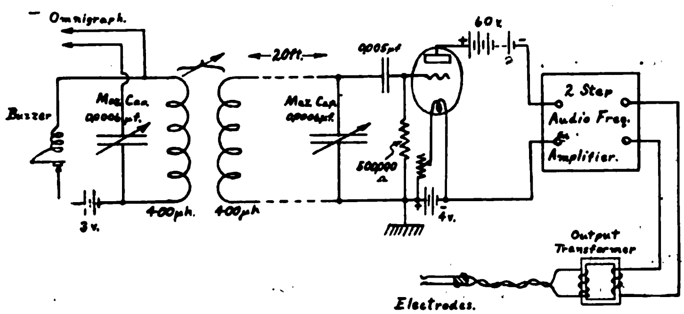

Figure 4

The circuits were tuned to a wave length of approximately 600 meters. The detector used was a vacuum tube. The plate potential employed was 60 volts. The capacity of the grid condenser was 0.005 μf., and the leak resistance between the grid and the plus side of the filament battery was 500,000 ohms. The amplifier used was a two-stage transformer-coupled amplifier giving a total voltage amplification of 150 times. The transformer between the amplifier and the mouth electrodes will be described later. An omnigraph was used in the usual way in the buzzer circuit to produce signals.

It was found necessary to ground the plus terminal of the filament battery to prevent the amplifier from howling. The amplifier bulbs were lit from the same battery as the detector bulbs. Separate plate batteries were used, however.

It was necessary to place the buzzer circuit across the room from the detector and amplifier circuits, because when placed nearby, the buzzer induced strong audio frequency currents in the amplifier circuits. The inductance coil of the receiving circuit was coupled to the buzzer inductance, and twisted leads were run across to the receiver circuit.

In these tests, the electrodes were placed about 0.125 inch (0.3 cm.) apart and touched to the operator's tongue. This was found to give better results for the reception of radio frequency signals than the method employed in connection with the d. c. and a. c. tests.

(*b*) Output Transformer

It was of course, impossible to connect the taste electrodes across the output terminals of the amplifier as the d. c. plate current of the last amplifier bulb would then pass thru the operator's tongue. It was, therefore, necessary to find a suitable transformer so that only the audio frequency a. c. would be obtained in the taste electrode circuit.

The following transformers were tried after consideration of the requirements:

Century Telephone Company, Air Core Transformer, number CAC 1013A.

Federal Telegraph and Telephone Company, Type 226W Transformer.

Western Electric Company, number 5 Induction Coil.

Western Electric Company, number 26A Repeating Coil.

In testing these transformers the following facts were noted:

A step-down ratio of transformation was necessary from the last step of the amplifier to the taste electrodes.

In the detector circuit, or with only one stage of amplification, a 1-to-1 ratio was best. As would be expected, the higher the amplification, the greater the necessary lowering of the voltage for proper reception.

The requirements of the taste receiver seemed to necessitate the use of a power transformer, that is, one capable of handling considerable energy while acting as a potential transformer.

The following figures give the relative strength of the taste sensation obtained, using the four transformers mentioned above, taking the intensity given by the Federal Company's transformer as 5:

Western Electric Company, number 5 Induction Coil (reversed)	0
Century Telephone Company, number CAC 1013A (step-down)	1
Western Electric Company, number 26A Repeating Coil (step-down 3-to-1)	4
Federal Telegraph and Telephone Company, Type 226W (step-down)	5

As the Type 226 W Transformer of the Federal Company gave the most satisfactory results, it was used in the tests which are described below.

(*B*) Observations

The coupling between the buzzer circuit and receiving circuit inductances was increased until a taste sensation was obtained which was of the proper strength for signaling. Measurements were then made of the audibility of the signal in the detector circuit by the usual shunted telephone method. In making the measurements a pair of Western Electric Company Type P-11 telephone receivers were used. These telephones have an impedance of 22,000 ohms at 500 cycles. A decade resistance box was used to shunt the telephones. It was found that the signal of the proper intensity after two stages of amplification to permit of reception by taste, had an audibility of 500 in the detector circuit.

It was thought that a possible increase in the intensity of the taste sensation might be brought about by tuning the mouth electrode circuit to the audio-frequency tone of the buzzer. Values of capacity from 0.05 μf. to 4.0 μf., were tried in series with the transformer winding and mouth electrodes. With a condenser of 1.0 μf. capacity in series, the taste sensation was of the same intensity as when no capacity was in the circuit. With all other values, however, the insertion of the condenser decreased the intensity.

2. Using Signals from an Antenna

(*A*) Apparatus

For the purpose of receiving outside signals, an ordinary inductively coupled vacuum tube receiver was employed. The antenna used was a single wire, 150 feet (45.8 m.) high and 180 feet (54.9 m.) long. It was found necessary to use four stages of audio-frequency amplification in order to get taste sensations of the proper intensity. Two sets of two-stage transformer-coupled amplifiers were connected in cascade. By separating them about ten feet (3 m.), it was possible to get rid of the howling tendency sufficiently for the purpose of taste reception, provided the operator, who was connected to one amplifier, did not go too near the other. The reason for needing a greater amplification in this test than in the tests using buzzer signals was probably that the antenna used had a very high resistance, and thus altho the voltage amplification obtained with a two-stage amplifier would have been sufficient, the actual energy available at the end of the second step was not sufficient for taste reception.

(*B*) Observations

With four stages of amplification it was possible to get taste sensations from all signals, the audibility of which in the detector circuit was 500 or more. The higher the audibility of the signal, the stronger was the taste sensation produced. The strongest signal received had an audibility of 5,000 in the detector circuit. The taste sensations resulting from this signal were not strong enough to cause discomfort for the operator. Whether or not a signal might be obtained of sufficient intensity to cause discomfort to the operator, would depend on the amount of energy which the last stage of the amplifier could handle.

As the signals received were commercial messages, their speed prevented them from being read by taste reception, but the intensity was sufficient to permit of their having been read had the sending been slower. It was found possible to tune in a station by noting when the intensity of the taste sensation was greatest. It was also noted that a slight difference existed between the taste sensation produced by a 240-cycle spark transmitter and a 500-cycle spark transmitter. The difference was not sufficient to permit of one being received thru the other, as could be done with audio-reception. It would be impossible to read thru interference with the taste receiver unless one signal was quite strong and the other almost unnoticeable. Strong strays would probably cause signals to become unreadable.

IV. Conclusions

1 Electrical Aspects

From the point of view of electrical operation, taste reception is possible. It is possible to amplify sufficiently a signal having an audibility of 500 in the detector circuit, to cause it to produce taste sensations. It is possible to read signals by the sense of taste if they are sent at a slow speed (about 5 to 10 words per minute).

2 Mechanical Aspects

At best, the mechanism of taste reception is unpleasant for the operator. A pair of head telephones which may be adjusted snugly to the ears are greatly superior in point of physical comfort to a pair of electrodes which must be held in the mouth, pressed against the tip of the tongue. There is also the disadvantage of the slow speed of transmission necessary for taste reception.

3 Physiological Aspects

The nerves of taste become fatigued by continued stimulations, and this will necessitate an increasingly higher amplification of energy if the operator is to be on duty for any considerable length of time. The effect on the operator's eyes of contracting the iris when very strong signals are received would be very disadvantageous, especially in airplanes. The taste sensation is a sour stinging taste which is far from pleasant. With high amplification and strong signals or strays, the taste sensations might be so strong as to be distinctly objectionable.

4 Psychological Aspects

Since the time when the progenitors of the human race began to communicate with each other by different sorts of sounds, the natural mode of communication between individuals has been by means of sounds. Thus the ear has become the organ which is developed from babyhood for the especial purpose of receiving intelligence. It is only natural, therefore, that this sense should be easily adaptable to the receiving of telegraphic signals. Its highly developed power of selectivity enables it to read only one of a number of signals or noises which may be heard at the same time.

The other sense by means of which intelligence is communicated, that is, sight, is valuable particularly because of its development in reading. In this way it often may be used to partially take the place of the sense of hearing, as in the case of lip reading employed by deaf persons. For the purpose of mechanical signaling it is useful in its ability to read from a tape record, and possibly also from the flashing of a light.

The sense of taste is naturally unfitted, because of lack of previous training along such lines, for the task of associating impulses sent to it with the necessary accurate motor responses required for the copying of transmitted intelligence. In making the tests which have been described, it was noted that great concentration of thought, upon the sense in question, was required in order that the nature of the received impulses might be noted. This indicates that the association is a difficult and unnatural one. Furthermore, it should be noted that if great concentration is necessary in order to receive by this method, it certainly would be impracticable in an airplane where the noise would effectively prevent concentration.

With the amplifications and signal intensities used in the tests on taste reception, it would be possible to read signals by audio-reception in spite of any strength of interfering noise which the ear of man could endure.

In conclusion we wish to thank Mr. Carl Dreher of this Laboratory for his assistance in making the signal speed tests.

Research Department,
Radio Corporation of America,
December 31, 1919.

SUMMARY: The purpose of this research was to determine the feasibility of reception of radio telegraphic signals by the sense of taste.

Electrodes were made which could be placed against the tongue in such a way as to cause a taste sensation when a source of potential was connected to them. Tests were made, using low potential direct current and 60-cycle alternating current to ascertain the amount of energy and potential necessary for taste reception.

Tests were then made, using signals from a buzzer source. By employing a two-stage transformer-coupled audio-frequency amplifier it was possible to obtain taste sensations from a signal having an audibility of 500 in the detector circuit. The possible speed of transmission appeared to be limited to a maximum of about 10 words per minute because of the characteristics of the taste organs.

Finally, the reception of actual signals from an antenna was tried. It was found possible by using four stages of amplification to obtain taste sensations from all signals the audibility of which was greater than 500 in the detector circuit.

The results obtained thus indicate that from an electrical standpoint it is possible to receive radio telegraphic signals by the sense of taste. When compared to the sense of hearing or even of sight, however, the sense of taste is much inferior as a means for receiving intelligence.

DISCUSSION

Greenleaf W. Pickard: Messrs. Goldsmith and Dickey have undoubtedly broken new ground in their work on physiological reception of radio signals, and altho the results thus far obtained do not indicate that their method will generally replace aural reception or the more recent Hoxie recorder, it is certainly within the bounds of possibility that some such form of reception may develop into a practical thing for special cases of reception. The suggestion of physiological reception is one of some antiquity. In 1894 Lodge said[1] "It is just conceivable that at some distant date, say by dint of inserting gold wires or powder in the retina, we may be enabled to see waves which at present we are blind to." Some eight years later, A. F. Collins stuck platinum needles into the brain of an etherized cat, which then twitched synchronously with the excitation of a near-by Hertzian oscillator.[2]

In discussing the pioneer work of this character, one is tempted to go beyond the confines of the paper itself, and to consider the possibilities of physiological signal reception by the various senses. At the outset, one is impressed by the fact that the peripheral sense organs of sight, hearing, taste, and smell are very similar in size and appearance.

In Figure 1, I have shown the peripheral sense organs of sight, hearing, taste and smell. In each case the sense organ consists of a cell-body *a*, with a nucleus *b*, a peripheral process *c*, which in the sense organs of hearing, taste and smell terminates in one or more hair-like filaments, and a central process *d* thru which the sense organ is connected to the nervous system. The stimulus is in each case received by the peripheral process *c*, and then, by some as yet unknown mechanism, it is transformed into an equally unknown pulse which travels rather leisurely—about 30 meters (100 ft.) per second—thru the nervous system. The transmission of a nervous impulse appears to be a chemical process; a sort of sudden evanescent increase in the normal metabolism of the nerve.

Whatever the mechanism of the action, the amount of energy required for a perceptible sensation is impressively small. In Figure 2, I have given a table for the four senses under consideration, and in the second column of this table is the "threshold" value of the stimulus energy required to excite the sense.

Sight appears to be our best sense, so far as energy relations go, and it is interesting to note that it is exactly on a par with the

[1] "London Electrician," June 22, 1894, page 204.
[2] "Electrical World and Engineer," February 22, 1902, pages 335-338.

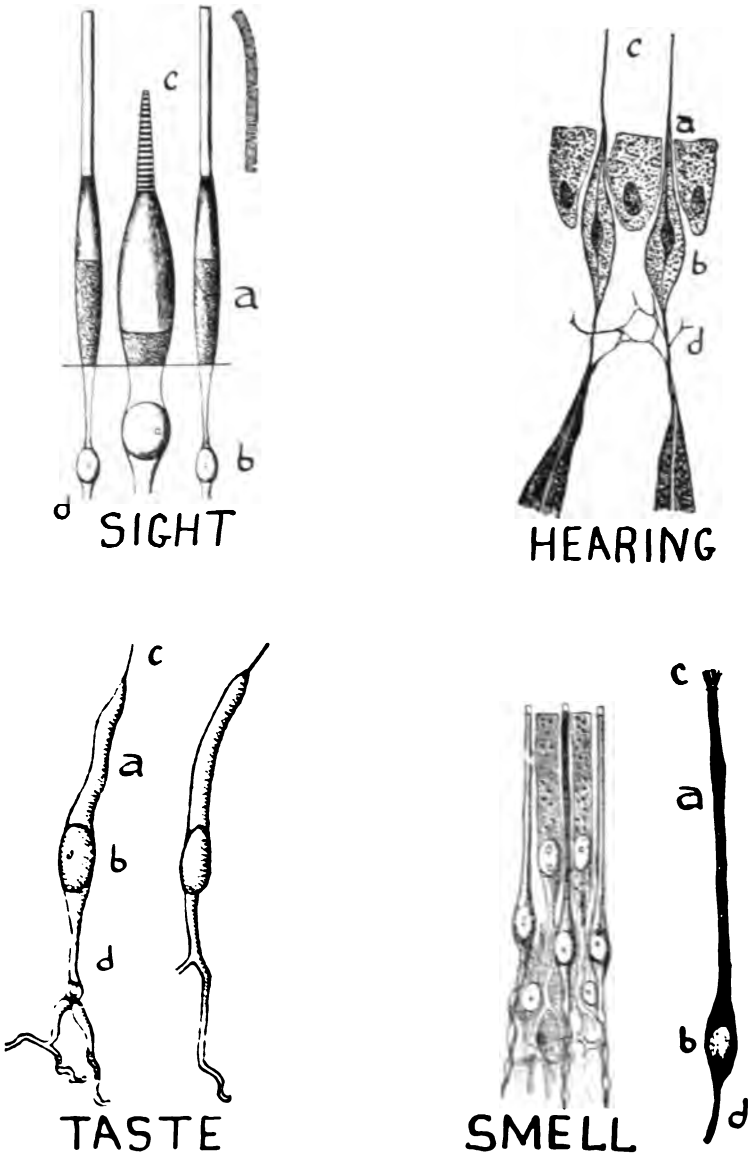

FIGURE 1

Sense	Minimum to Excite Sense	Perception Interval	Words per Minute
Sight[3]	10^{-9} erg/sec.	0.1 sec.	9 to 13
Hearing	10^{-8} "	0.007 "	30 to 40
Taste	10^{-2} "	1?	2?
Smell	10^{-2} "	1?	1?

FIGURE 2

oscillating audion as a detector, which also requires 10^{-9} erg/sec. for unity audibility. Taste and smell, similarly, are of the same order of sensitiveness as the crystal detector, altho our measurements of their sensitiveness are far less accurate than with sight or hearing. If, therefore, we could effectively use our received signal energy to stimulate our senses, they would be surprisingly good detectors *per se*. It is within the bounds of imagination at least that investigation will solve the problem of effectively applying the energy, preferably without a major surgical operation, or even Lodge's suggested retinal stitching and powdering. The sense organ of the ear is unfortunately rather deeply buried, otherwise one might speculate on the possibility of direct physiological reception in radio-telephony.

During the discussion, Mr. George Clark has pointed out that the actual speed of reception by light signaling is often greater than that given in my table. But the higher speeds of visual reception are only obtained by moving the image point about on the retina, thus spreading out the dots and dashes into a string of after-images, which may be interpreted at leisure—the word "leisure" here being used in a strictly relative sense, meaning merely the few tenths of a second that the after images last. Where the image of the signal light falls steadily on one spot on the retina, I do not believe that a greater speed than about ten words per minute can be obtained. Similarly, my table gives the approximate speed in words per minute for pure taste reception, as determined on my tongue with alternating sweet and bitter tastes. In the work described in this paper, I believe that the sensation utilized must have been in reality a complex of taste and electrical shock. The few tests which I have so far made with signal reception by pure shock indicate that the speed is quite high, perhaps of the order of ten words per minute or

[3] "Speeds in Signaling by the Use of Light," W. E. Forsythe, "Physical Review," July, 1920, pages 62-64.

more. It has been mentioned in the discussion of the paper that some form of physiological reception involving the tongue was used by telegraph operators during our Civil War, and at speeds approximating those of ordinary wire working. I have no doubt but that this was principally a matter of electrical shock, as the potentials involved were certainly high enough, when directly applied to wet and sensitive tissues.

In conclusion, it occurs to me that a form of local energy (not the heterodyne) might be applied to physiological reception. Some years ago Professor Fessenden suggested the use of a Poulsen telegraphone as a detector, in which the steel wire carried a continuous audio-frequency record, which was obliterated by the received signals, so that by sending inverted morse, that is, the spaces instead of the characters, a reversed and readable record was obtained. It is possible that something of this sort might be applied here. It seems that high frequency currents act rather to dull and inhibit the action of nerve and muscle than to stimulate, so that by superposing the signal upon some form of continuous local stimulus (not necessarily electrical), it might be possible to increase the speed and sensitiveness of the method.

A SYSTEM FOR MEASURING THE AMOUNT OF STATIC*

By

Austen M. Curtis

(Western Electric Company, New York)

It is necessary in studying systems for the elimination of static to have some means for measuring the relation of static to signals. The method of estimating the efficiency of various receiving systems by the percentage of errors in reception caused by static is not particularly accurate, as different operators do not have the same ability to read thru static. Large momentary variations in the intensity of static make its measurement by the shunted telephone method of doubtful value. The following method of time integration was devised in an effort to measure the average amount of static.

The circuit used is shown in the accompanying sketch. An audiofrequency transformer is connected in series with or in place of the telephones of any type of receiving set. The static, which has been converted into audible frequency waves by the detector, is passed into a vacuum tube valve or combination of valves at an increased voltage, and completely rectified. The resultant direct current pulses are used to charge a very large condenser, which is discharged slowly thru a galvanometer in series with a high resistance. If the condenser and the resistance are large enough, the static will cause a reasonably steady deflection of the galvanometer. This deflection will depend on the average intensity and frequency of occurrence of the static during a time which is short compared to the time constant of the galvanometer circuit. For instance, if 100 microfarads and one megohm are used, the deflection produced by a single crash of static will drop to about one-third its initial value in one hundred seconds. Where the usual static, which occurs in crashes every few seconds, is concerned, smaller capacities and resistances will give satisfactory measurements.

With a pivot galvanometer giving one division for two micro-

* Received by the Editor, May 19, 1920.

amperes, a capacity of 40 microfarads and 500,000 ohms resistance, it is possible to make satisfactory readings of the static on a receiving system with several stages of amplification. With a galvanometer of higher sensitivity, the time constant may be made larger and steadier readings obtained. A practical limit is put on the attainable time constant by the leakance of commercial paper condensers, which is of the order of 2,000 megohms per microfarad.

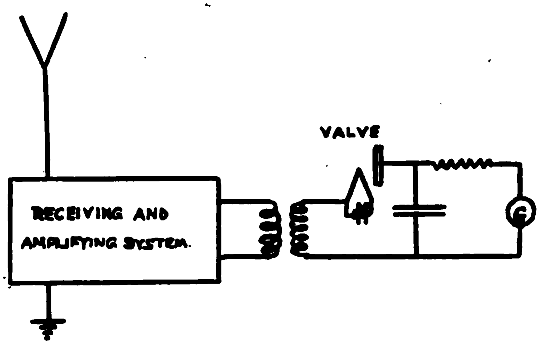

FIGURE 1—System for Measuring the Quantity of Static

It seems probable that the use of this system of static measurement would enable a reliable determination of the direction from which static comes to be made on a single loop receiving system. It would, of course, be necessary to listen in every minute or two, to see that the readings were not influenced by signals of an intensity comparable to the static.

It is also possible to standardize static measuring systems of this type and establish a basis for comparison of the amounts of static received at different stations at the same time. It would be necessary to apply to the detector of each station, at various frequencies, a wave modulated in a known amount at a known voltage. The amplification at each station might then be adjusted until the same deflection was produced in the static measuring system of each station by a given voltage applied to the detector, or the ratios of the detector voltages necessary to produce the same deflections at the same wave lengths in the various stations might be used to reduce the static readings to a common basis. The calibration might be made by an ordinary oscillating circuit excited by a carefully adjusted buzzer, preferably of a low vibration frequency.

SUMMARY: Amplified and rectified energy from static is stored in a large condenser in the output circuit of a vacuum tube. The condenser discharge current thru a high resistance and sensitive galvanometer will, under given conditions, be a measure of the average static. The experimental arrangements are described, as to calibration and actual use.

ON THE POULSEN ARC IN COUPLED CIRCUITS*

By

P. O. Pedersen

(Professor in the Royal Technical College, Copenhagen)

1. Introduction

The Poulsen arc generator in connection with coupled circuits has been used by V. Poulsen[1] at a comparatively early date. Rather close coupling was often used by him in his radio telegraphic tests,[2] whereas he usually employed comparatively loose coupling in the series of tests by which long distance radio telephony[3] was, for the first time, shown to be feasible.

Arc oscillations in coupled circuits have been the subject of a number of laboratory investigations as well as of theoretical studies. In this connection may be mentioned the investigations on musical (audio frequency) arcs by E. Taylor Jones,[4] E. Taylor Jones and M. Owen,[5] E. Taylor Jones and D. E. Roberts,[6] and S. Subkis;[7] and on radio frequency arcs by P. O. Pedersen[8] and Hidetsugu Yagi.[9]

The author himself carried out a series of investigations on the Poulsen arc in coupled circuits in the autumn of 1918. He employed for these investigations, among other arrangements, the one shown in Figure 1 where L_1 is considerably larger than

*Received by the Editor, April 10, 1920.

[1] See U. S. Patents, numbers 789, 449 and 793, 608; filed June, 1903.

[2] V. Poulsen: "Ein Verfahren zur Erzeugung ungedämpfter Schwingungen und seine Anwendung in der drahtlosen Telegraphie," "Elektrotech. Zeitschrift," pages 1040-1044, 1906 (Figure 8).

[3] V. Poulsen: "La téléphonie sans fil." "Rapport officiel au Congrès international des applications électriques," Turin, 1911.

[4] E. Taylor Jones: "Electrical Oscillations in Coupled Circuits," "Phil. Mag.," (6), volume 17, pages 28-43, 1909.

[5] E. Taylor Jones and M. Owen: "Musical Arc Oscillations in Coupled Circuits," "Phil. Mag.," (6), volume 18, pages 713-722, 1909.

[6] E. Taylor Jones and D. E. Roberts: "Phil. Mag.," (6), volume 20, pages 660-663, 1910.

[7] S. Subkis: "Der Einfluss der Koppelung bei langsamen ungedämpften Schwingungen," "Jahrbuch d. drahtlosen Telegraphie," volume 5, pages 507-513, 545-563, 1912.

[8] P. O. Pedersen: "Beiträge zur Theorie der drahtlosen Telephonie," "Jahrbuch d. Drahtlosen Telegraphie," volume 5, pages 449-498, 1912.

[9] Hidetsugu Yagi: "Arc Oscillations in Coupled Circuits," Proceedings of The Institute of Radio Engineers, volume 4, pages 371-388, 1916.

L_2', and he obtained a current I_2 in the secondary circuit 2 to 3 times larger than the current I_1 in the primary circuit (arc-circuit), whereas I_1 at the same time kept its normal value $\sqrt{\frac{1}{2}} I_o$, where I_o is the supply current.[10] (During these tests the wave-length was $\lambda = 7,700$ m., the resistance $R_2 = 3$ to 4 ohms, and the capacity $C_2 = 32,000$ cm. or 0.036 microfarad.) These tests were discontinued in order that some investigations on the arc generator proper might be carried out, and it is hoped to get the opportunity later on of publishing, in another paper, the results thereof. Before discontinuing the above-mentioned

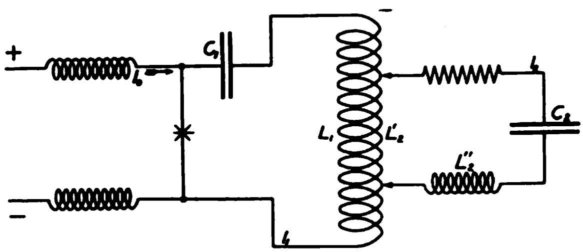

FIGURE 1

tests, there had, however, been carried out a series of investigations on a special arrangement of coupled circuits which is shown in Figure 2 and which, as far as I am aware, has been introduced by L. F. Fuller[11] and by Hartenstein[12] independently of each other.

2. Investigation of the Circuit Shown in Figure 2

The distinctive feature of this diagram is that a condenser C_2 is inserted next to the arc, in series therewith and with the aerial, and further that the arc and C_2 are shunted by another condenser C_1. In the following treatment, C_1 is at times called the "shunt condenser" and C_2 "series condenser." If C_1 be disconnected, the diagram is reduced to the usual and simple

[10] P. O. Pedersen, (a) "On the Poulsen Arc and Its Theory," PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, pages 255-316, 1917. (b) "Supplementary Note," volume 7, pages 293-297, 1919.

[11] L. F. Fuller, U. S. Patent, number 1,179,353, filed April, 1913.

[12] H. Rein, "Lehrbuch der drahtlosen Telegraphie," second edition, pages 182-183, 1917.

one merely containing an extra condenser C_2 inserted into the antenna. The wave-length λ_o is, in this case (in meters):

$$\lambda_o = 6\pi \cdot 10^8 \sqrt{LC} \cdot \sqrt{\frac{C_2}{C_1+C_2}} \qquad (1)$$

By connecting the shunt condenser to the circuit the wave-length will assume a new value λ being determined by the condition that the radio frequency circuit between A and B must be in resonance for that wave-length.

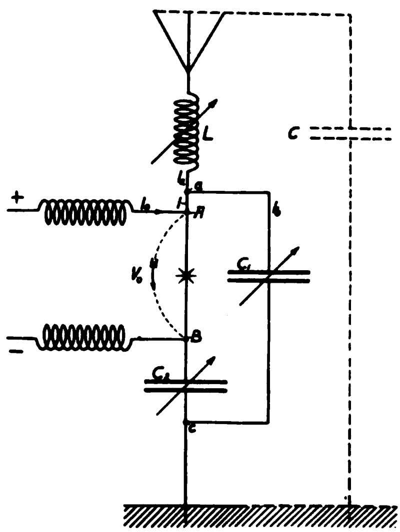

FIGURE 2

We will use the following symbols: $n \cdot \lambda = 3 \times 10^8$; $2\pi n = \omega$; $\sqrt{-1} = j$; the antenna capacity $= C$; the impedance of the radio frequency circuit between A and $B = Z$; the admittance of the circuit $a\,L\,C\,c = Y_a$; the admittance of the circuit $a\,C_1\,c = Y_b$.

We have consequently

$$Z = j\,\frac{C+C_1+C_2-\omega^2 L \cdot C \cdot (C_1+C_2)}{\omega\, C_2 \cdot (\omega^2 L\,C\,C_1 - C - C_1)} \qquad (2)$$

The circuit is in resonance for $Z=0$, from which it follows that

$$\omega = \sqrt{\frac{C+C_1+C_2}{L\,C\,(C_1+C_2)}} \qquad (3)$$

The length of the radiated wave in meters is, therefore, determined by

$$\lambda = 6\pi \cdot 10^8 \cdot \sqrt{LC} \cdot \sqrt{\frac{C_1 + C_2}{C + C_1 + C_2}} \tag{4}$$

which, in combination with (1), gives

$$\frac{\lambda}{\lambda_0} = \sqrt{1 + \frac{C \cdot C_1}{C_2 (C + C_1 + C_2)}} \tag{5}$$

It is evident that λ is always larger than λ_0, which, it seems, has not always been taken fully into consideration.

In the above calculations no regard is paid to the resistances in the radio frequency circuits, because these resistances are of very small importance in the determination of the wave-length; furthermore, the calculations would be very much complicated if the resistances were taken into account.

We have carried out a series of measurements of sets of λ and λ_0 in order to make sure that the above considerations hold good. The results of these measurements are shown in Table 1 below.

TABLE 1

C cm.	C_1 cm.	C_2 cm.	λ_0 m.	λ		$100\frac{\lambda-\lambda_0}{\lambda}$	
				measured m.	calculated m.	measured	calculated
7,300	1,250	14,600	3,440	3,490	3,487	1.45	1.35
7,300	14,600	14,600	3,810	4,200	4,225	10.3	10.9
6,400	7,400	12,500	3,800	4,060	4,066	6.85	7.0
13,800	13,050	39,600	6,860	7,080	7,090	3.2	3.3
13,800	600	14,600	5,400	5,500	5,455	1.8	1.0
13,800	1,200	14,600	5,400	5,560	5,503	3.0	1.9
13,800	2,000	14,600	5,400	5,620	5,567	4.1	3.1
13,800	2,400	14,600	5,400	5,660	5,594	4.8	3.6
13,800	4,400	14,600	5,400	5,800	5,735	7.4	6.2
13,800	5,600	14,600	5,400	5,900	5,805	9.3	7.5
13,800	7,600	14,600	5,400	5,980	5,913	10.8	9.5
13,800	10,350	14,600	5,400	6,100	6,048	13.0	12.0
13,800	13,250	14,600	5,400	6,120	6,160	13.3	14.1

Taking into account that the values given above for the capacities of the condensers may be wrong by about 0.5 per cent., the measured values of λ may be considered to agree quite satisfactorily with the values as calculated from equation (5). There can, consequently, be no doubt that the above calculations are correct, and that it therefore is possible to calculate in the usual way how the radio frequency arc current (wave-length λ) divides itself between the two circuits (a) I_a in $aLCc$ and (b) I_b in aC_1c. If, as before, the resistances are not taken into account we obtain by means of (3)

$$Y_a = \frac{j\omega C}{1-\omega^2 LC} = -j\frac{1}{\omega L}\frac{C+C_1+C_2}{C} \tag{6}$$

and

$$Y_b = j\omega C_1 = j\frac{1}{\omega L}\frac{C+C_1+C_2}{C}\frac{C_1}{C_1+C_2} \tag{7}$$

Furthermore,

$$Y_a + Y_b = -j\cdot\frac{1}{\omega L}\frac{C+C_1+C_2}{C}\frac{C_2}{C_1+C_2} \tag{8}$$

From the above, we derive

$$\frac{I_a}{I} = \frac{Y_a}{Y_a+Y_b} = 1+\frac{C_1}{C_2} \tag{9}$$

$$\frac{I_b}{I} = -\frac{Y_b}{Y_a+Y_b} = \frac{C_1}{C_2} \tag{10}$$

and

$$\frac{I_b}{I_a} = -\frac{Y_b}{Y_a} = \frac{C_1}{C_1+C_2} \tag{11}$$

We note that I and I_a are in phase, whereas I_b is of opposite phase to I and I_a.

It may not appear to be correct to disregard the resistances when the calculation deals with the distribution of the currents between the two circuits. The resulting error is, however, small; which may be shown as follows:

In the above calculations the impedance Z_a of the circuit $aLCc$ has been taken as

$$Z_a = j\omega L\frac{C}{C+C_1+C_2}$$

whereas the real value is

$$Z_a' = R + j\omega L\frac{C}{C+C_1+C_2}$$

If, in these equations, we take $\omega = 400{,}0C0$, $L = 10^{-3}$ henry, and $\frac{C}{C+C_1+C_2} = \frac{1}{4}$, we have

$$Z_a = j\cdot 100 \quad\text{and}\quad Z_a' = R + j\cdot 100$$

Assuming $R = 5$ ohms (which is a comparatively high value) we obtain the ratio of the absolute values of the impedances

$$\frac{Z_a'}{Z_a} = \frac{100.1}{100} = 1.001$$

The difference between the true value of Z and the value used in the calculations is therefore only 0.1 per cent.

If, therefore, the total radio frequency current is of the wave-length λ, that is, if no harmonics or other oscillations of a wave-length differing from λ are present, it must be expected that the current will distribute itself according to equation (11).

In Figure 3 are plotted the results of a series of measurements of the simultaneous values of the currents. Curve *A*

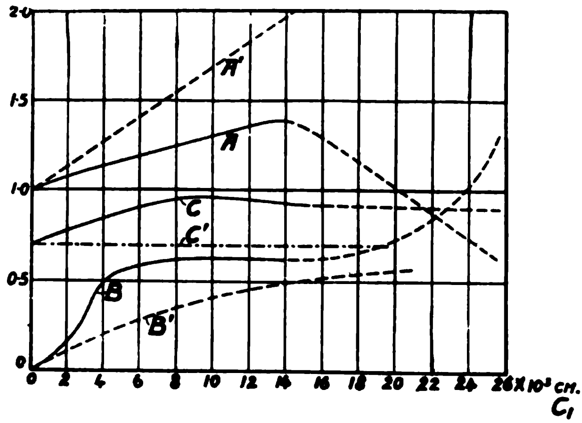

FIGURE 3

shows the ratio $\frac{I_a}{I}$ between the antenna current and the arc radio frequency current; curve *B* shows the ratio $\frac{I_b}{I_a}$ between the shunt current and the antenna current, and curve *C* shows the ratio $\frac{I}{I_0}$ between the arc radio frequency current and the arc direct current. The curves are plotted as functions of the capacity of the shunt condenser. (The other constants were: $\lambda_0 = 5{,}400$ m.; $C = 13{,}800$ cm.; $C_2 = 14{,}600$ cm.; and $R =$ about 3 ohms.) The corresponding theoretical curves, as based upon the equations (9) to (11), are indicated by the curves A', B', and C'.

It will be seen that the measured curves differ to a considerable extent from the theoretical curves, the antenna currents being much less and the shunt currents comparatively much greater than what they should be. The reason for this is, that in addition to the fundamental oscillation of wave-length λ, a series of oscillations with shorter wave-lengths are created, these latter being partly the higher harmonics of the fundamental oscillation and partly the fundamental of the circuit arc—AaC_1c-C_2B—arc. We have hitherto not taken the inductance of this circuit into our calculation; this omission is permissible only to a certain extent. The circuit will always contain some inductance and will, consequently, always have a definite fundamental oscillation. The wave-length of this oscillation was about 420 m. in the tests from which the curves in Figure 3 are plotted.

The proof of the presence of these superfluous and, consequently detrimental oscillations of wave-lengths smaller than λ is:

(1) That the ratio $\frac{I}{I_0}$ between the arc radio frequency current and the arc direct current is larger than $\sqrt{\frac{1}{2}}=0.7$, this being the value of the ratio when only one oscillation is present.[13] Figure 3 shows values of $\frac{I}{I_0}$ up to 0.9 and more; the arc radio frequency current I is therefore far from being a sine curve.

(2) The existence of oscillations of shorter wave-lengths than λ is evident also from the following observation:

During certain tests, a safety arrangement was inserted across the leads connecting the choke coils with the switchboard, the safety arrangement consisting of two sets of carbon filament lamps, each set in series with a condenser, the two condensers being connected to each other and to earth. When the capacity of C_1 was diminished, the lamps ceased glowing, or at any rate glowed very dimly, whereas the brilliancy increased with increasing C_1.

(3) A further proof is that $\frac{I_b}{I_a}$ is very much larger than what would be expected from formula (11); and this fact indicates especially that the fundamental oscillation of the shunt circuit, as mentioned above, is of great importance in this connection.

(4) That the statement in the latter part of (3) is correct is finally proven by the oscillographic analysis of the voltage of the arc as set forth below.

Oscillograms of the arc tension e_1 have been taken by means of the method previously employed by the author.[14] The oscillograms thus obtained showed the features indicated in Figure 4. Besides the normal peaks A (the extinction voltage)

[13] P. O. Pedersen, previous citation, (a).
[14] P. O. Pedersen, previous citation, (a), page 285.

and B (the ignition voltage), a third peak C appeared, which latter, no doubt, is due to the arc current again decreasing to zero shortly after the ignition has taken place, or in any case decreasing to a very small value. That this is so is without doubt due to the free oscillations in the shunt circuit of the short wave-length λ_2, these oscillations being set up at the moment the discharge thru the arc commences anew. The correspond-

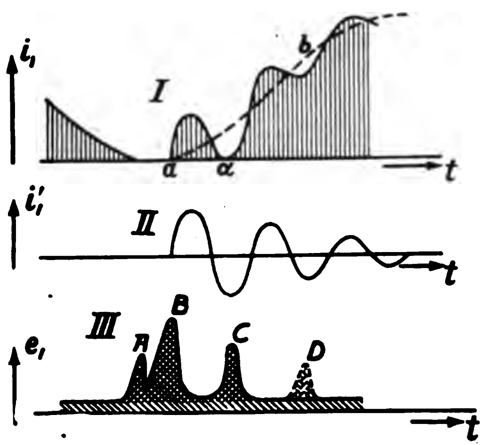

FIGURE 4

ing current i'_1 is also plotted in Figure 4. The arc current is composed of the direct current (supply current) $I_0 +$ the radio frequency current of wave-length λ and of the corresponding higher harmonics (the sum of these latter is shown as the dotted line ab in Figure 4) + the current i_1' of wave-length λ_2. The arc current i_1 resulting from all these currents is shown in Figure 4 and fully explains the reason for the appearance of the extra peak C.

The above described course of the arc tension is the simplest one of those observed. Several peaks may appear as shown by D in Figure 4, III; also C may divide itself in two by analogy to A and B. This latter condition takes place if the current at α (Figure 4, I) remains zero for some time, because in this case another separate extinction voltage and ignition voltage are created.

Figure 5 shows one of the arc voltage oscillograms obtained.

We have now in the main explained the action of the diagram (Figure 2). This diagram may evidently be considered as a transformer arrangement, because the two circuits (1) arc$-Aa\,C_1C_2-$arc and (2) arc$-Aa\,L\,Cc\,C_2-$arc are coupled together by means of the arc and the series condenser C_2.

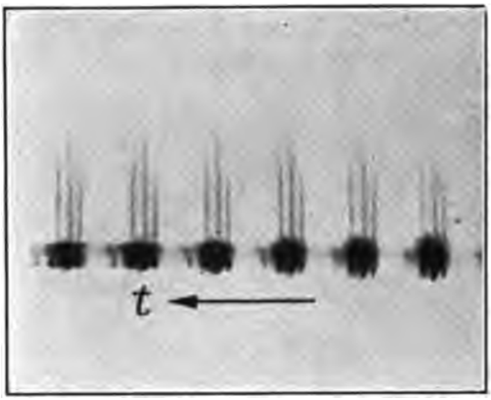

FIGURE 5

3. Comparison of Figure 2 with the Simple Diagram (Without the Shunt Condenser C_1)

It is evident from Figure 3 that the ratio $\frac{I_a}{I}$ between the antenna current and the arc radio frequency current may become somewhat larger than 1 by applying the arrangement shown in Figure 2. Some other effects, however, are introduced in connection therewith, which, at any rate, partly counteract the advantage in question. We will consider especially that:

1. The necessary direct current voltage across the arc increases very considerably.
2. The wave-length increases.

Tables 2, 3, and 4 below show this clearly.

TABLE 2

(Diagram and indications refer to Figure 2.) $C_1=13{,}800$ cm. (0.0153 μf.), $C_2=14{,}600$ cm. (0.0162 μf.), wave-length for $C_1=0$ is equal to 5,400 m.; R=about 3 ohms; $P_o=I_oV_o$ is the energy supplied to the arc; C_1 is variable; and $(C_1=0)$ attached to any of the symbols means that the value of the latter is measured when $C_1=0$, that is, when the simple circuit connection, without the shunt condenser, is used.

1	2	3	4	5	6	7	8	9	10
C_1	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	I	I_a	I_b	λ	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{\frac{I_a^2}{P_o}}{\frac{I_a^2}{P_o(C_1=0)}}$
cm.			amps.	amps.	amps.	m.			
0	1.0	1.0	9.8	9.8	0	5,400	1.00	0.70	1.0
600	0.964	1.0	9.2	9.6	Small	5,500	1.033	0.68	1.03
2,400	0.857	1.29	9.2	10.2	2	5,660	1.11	0.767	0.982
5,600	0.714	1.61	9.4	10.8	6.5	5,900	1.15	0.94	1.06
7,600	0.750	1.61	9.3	11.6	7	5,980	1.245	0.885	1.17
10,350	0.672	1.73	9.4	12.2	8	6,100	1.298	1.00	1.33
13,250	0.693	1.77	9.2	12.7	8.6	6,160	1.38	0.95	1.37
25,750	0.571	2.03	7.1	4.5	6		0.635	0.89	0.187

The results of these measurements are partly represented by Figure 6. Curve *A* shows the figures of column 10 of Table 2; that is, the ratio $\frac{\eta}{\eta_o}$ between the apparent efficiency with shunt condenser and without the same. The curve shows that this ratio is a maximum for a value of C_1 between 12,000 and 14,000 cm. (0.0133 and 0.0156 μf.), further that the maximum η is about 1.37 η_o. It must, however, be noted that the wave-length increases simultaneously, as previously mentioned, and as shown by curve *D* in Figure 6. The increase of the wave-

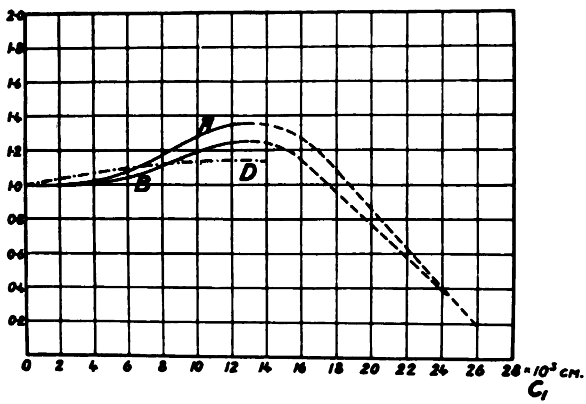

FIGURE 6

length in itself produces a higher efficiency; this increase amounts to about 1.12η, according to tests. The antenna current is, as previously mentioned, not quite a sine curve when the condenser C_1 is inserted, and this is especially the case for values of C_1 as large as 12,000 to 14,000 cm. (0.0133 to 0.0156 μf.) The antenna current in the ordinary arc circuit, for which $C_1 = 0$, is practically a sine curve when everything is properly adjusted. It is impossible to indicate definitely what fraction of the antenna current is due to "harmonics" of various kind. Three per cent. is very likely much too small a figure when $C_1 = 12{,}000$ cm. (0.0133 μf.). Curve *B*, Figure 5, is based upon the above corrections. It will be seen from this curve that the effective increased value of the efficiency η cannot be reckoned to be more than about 1.2 η_o.

It might be that a more advantageous result could be obtained by choosing another ratio between the inductance and the capacity. In order to ascertain whether this be so or not, a series of tests were carried out (Table 3) in which the capacity of the condenser was kept constant, whereas the inductance was varied in such a way that the corresponding wave-lengths covered the range from 6,430 m. to 3,120 m. In no case were better results obtained than those shown in Table 2.

TABLE 3

(Data refer to Figure 2).

$C_1 = 13{,}800$ cm. (0.0153 μf.), $C_2 = 14{,}600$ cm. (0.0162 μf.), R = about 3 ohms; $P_o = I_o V_o$ = energy supplied to the arc. The inductance L is variable; L has the same value in each two related tests.

Tests were also carried out by varying the series condenser C_2, and a few of these tests are tabulated in Table 4. But none of these tests gave better results than the ones in Table 2.

TABLE 4

(Data refer to Figure 2)

$C_1 = 13{,}800$ cm. (0.0153 μf); $R = 1.6$ ohms; $P_o = I_o V_o$. The inductance in the first two tests was about 30 per cent. larger than in the two last tests.

We have thus, by applying the shunt circuit, been unable to increase η_o to more than about 1.25 η_o. This increase in efficiency was, however, in all our tests accompanied by a considerable unsteadiness of the arc. It proved very difficult to keep the arc burning as steadily as desirable when C_1 has the large capacity necessary for increasing the efficiency by the above-mentioned value. Furthermore, a good many frequencies are created—as set forth above—which are of no use at all, and might cause interference. We are, therefore, of the opinion that the advantages obtained by applying the shunt circuit are, as a whole, not of any great value. This, of course, does not exclude the possibility that the shunt circuit may be of advantage under certain other conditions of a special nature.

I wish to acknowledge my indebtedness to Messrs. J. P. Christensen, H. Erichsen, and A. Teglbjerg for the valuable assistance rendered during the above investigations.

Royal Technical College,
Copenhagen, February. 1920.

1	2	3	4	5	6	7	8	9	10
C_2	$\frac{I_a}{I_o(C_1=0)}$	$\frac{V_a}{V_o(C_1=0)}$	I	I_a	I_b	λ	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{\frac{I_a^2}{P_o}}{\frac{I_a^2}{P_o(C_1=0)}}$
cm.			amps.	amps.	amps.	m.			
12,000 0	0.674 1.0	2.15 1.0	9.6 10.0	12.2 10.0	8 0	6,430 5,610	1.27 1.00	1.01 0.709	1.03 1.0
12,000 0	0.738 1.0	1.89 1.0	9.5 10.0	13.9 10.0	8.2 0	6,140 5,360	1.465 1.00	0.913 0.709	1.39 1.0
12,000 0	0.686 1.0	2.04 1.0	9.6 10.2	14.0 10.2	8 0	5,840 5,140	1.46 1.00	0.99 0.714	1.35 1.0
12,000 0	0.653 1.0	2.29 1.0	10.1 10.5	14.0 10.5	9.2 0	5,160 4,730	1.385 1.00	1.03 0.70	1.19 1.0
12,000 0	0.715 1.0	2.09 1.0	9.7 10.5	13.8 10.5	8.2 0	4,430 3,890	1.425 1.00	0.898 0.696	1.16 1.0
12,000 0	0.734 1.0	1.88 1.0	10.0 10.2	12.6 10.2	9 0	3,610 3,120	1.26 1.00	0.95 0.713	1.11 1.0
12,000 0	0.662 1.0	2.29 1.0	9.9 10.3	14.1 10.3	7.8 0	6,400 5,640	1.425 1.60	1.03 0.71	1.23 1.0
12,000 0	0.667 1.0	2.04 1.0	10.7 10.5	14.0 10.5	15 0	3,620 3,180	1.31 1.00	1.07 0.70	1.31 1.0

1	2	3	4	5	6	7	8	9	10	11
C_2	C_1	$\frac{I_o}{I_o(C_1=0)}$	$\frac{V_o}{V_o(C_1=0)}$	I	I_a	I_b	λ	$\frac{I_a}{I}$	$\frac{I}{I_o}$	$\frac{\frac{I_a^2}{P_o}}{\frac{I_a^2}{P_o(C_1=0)}}$
cm.	cm.			amps.	amps.	amps.	m.			
14,600	12,000	0.731	2.12	10.0	13.8	8.4	6,400	1.38	0.943	1.21
14,600	0	1.0	1.0	10.1	10.1	0	5,640	1.00	0.702	1.0
39,600	12,000	0.798	1.68	13.2	11.2	9.8	5,820	0.85	1.15	0.899
39,600	0	1.0	1.0	10.2	10.2	0	5,600	1.00	0.709	1.0

SUMMARY: A bibliography of oscillating arc investigations with coupled circuits is given. A special form of circuit, wherein the arc and the antenna circuit are coupled electrostatically thru an arc "series condenser," and a "shunt condenser," is studied analytically. Experimental results on the same circuit are given, and the practical usefulness of the circuit discussed.

DISCUSSION

Leonard F. Fuller (by letter): A preferred form of circuit in which C_2 of Professor Pedersen's Figure 2 is omitted and C_1, shunted directly across the arc terminals, is the only local condenser used, is shown in United States Patent 14,760, of November 25, 1919. This is a re-issue of my original patent number 1,179,353, and was used at Arlington and Tuckerton for some time. It increases antenna current about as effectively as the connection shown in Figure 2, and saves considerable equipment in a large station. Both circuits are only a means of improving an arc which is not operating under the best conditions and will cause no appreciable increase in the antenna current delivered by a well-designed arc operating with "tuned fields" in the proper atmosphere. For these reasons they have fallen into disuse in recent years.

It seems likely that the arc Professor Pedersen used in his experiments was operating with the air gap flux density, B_g, below the tuned value, for he states that "the increase of the wave length itself produces a higher efficiency." Such a change in efficiency is the natural consequence of operating an arc "underfield."

It would have been very helpful if the observations had been made with tuned fields, as arc performance data rarely permit of quantitative comparison if they are taken with untuned fields. A great amount of experimental work has had its value very seriously reduced by failure to appreciate this fact.

I heartily agree with the conclusion that circuits such as these are hardly worth while, but this is because of our present knowledge of tuned fields and the other factors effecting arc performance which enable us to accomplish the same desirable results in better ways and without fostering the harmonics mentioned by Professor Pedersen.

THE EQUIVALENT CIRCUIT OF THE VACUUM TUBE MODULATOR*

By

John R. Carson, Ph.D.

(Research Engineer, American Telephone and Telegraph Company, New York)

It is a well-known fact[1] that if an emf. E is impressed on the input terminals of the three-element vacuum tube amplifier of amplification constant μ and external or load impedance z, its behavior as an amplifier may be correctly described by postulating an emf. μE impressed on the load impedance z thru a resistance R_o, where R_o is the "internal resistance" of the tube and is given by the formula

$$\frac{1}{R_o} = \frac{\partial I}{\partial E_b} \tag{1}$$

Here I is the plate current, and E_b the steady plate-filament potential difference.

This law has led to the concept of the equivalent circuit of the vacuum tube amplifier, indicated schematically in Figure 1, which has proved a very valuable aid for interpreting the behavior of the device and in designing the associated circuits. The value of such a physical picture of the phenomena does not need

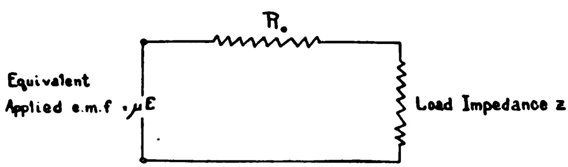

Figure 1—Equivalent Amplifier Circuit

*Received by the Editor, April 30, 1920.

[1] The recognition of this valuable principle appears to be due to van der Bijl; see his papers: "Physical Review," September, 1918, and the Proceedings of The Institute of Radio Engineers, April, 1919. Strictly speaking, van der Bijl's statement of the law is limited to the case where the load impedance is a pure resistance; its extension to the case where the load impedance is unrestricted is however a very simple matter; see my paper in the Proceedings of The Institute of Radio Engineers, April, 1919.

to be pointed out to the engineer actually engaged in the development of the device and its simplicity as a working guide in interpreting and predicting results far outweighs the fact that it is necessarily incomplete and approximate only. On the other hand, in using such a physical conception, he will be wise to recognize clearly its limitations and guard against employing it under circumstances where it ceases to be a reliable guide.

The purpose of the present note is to point out the fact that the device when functioning as a modulator[2] may be represented by an "equivalent circuit" of almost equal simplicity, and the resulting physical conception may be used with considerable advantage and profit in interpreting the behavior of the device and in correctly designing the associated circuits for optimum performance. The equivalent modulator circuit may be inferred at once from the following theorem:

If a voltage E is impressed on the input terminals of a three-element vacuum tube feeding into a load impedance z, the operation of the device as a modulator may be correctly described by postulating an emf.

$$M\left(\frac{\mu R_o}{R_o+z} E\right)^2 \tag{2}$$

impressed on the load impedance z thru a resistance R_o. M is the *modulation factor*, a physical parameter of the tube, and is given by the equation.

$$M=\left(\frac{1}{2R_o}\right) \cdot \left(\frac{\partial R_o}{\partial E_b}\right) \tag{3}$$

The equivalent circuit is shown schematically in Figure 2.

The law formulated by this theorem and the character of the approximations involved are easily deduced from the treatment of the problem developed in my PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS' paper (April, 1919); the proof will be supplied in an appendix to the present note.

It should be remarked that the foregoing law and the equivalent modulator circuit to which it points are, of course, approximate only. It is important, however, to observe that the approximations underlying the concept of the equivalent modulator circuit are of precisely the same character and substantially the same order of magnitude as those involved in the equivalent amplifier circuit, which has proved so useful in the

[2] The following discussion applies equally well to the operation of the device as a detector in the arrangement where it functions by virtue of the curvature of the characteristic.

engineering development of the amplifier. This will be evident from the proof given in the appendix.

A simple problem will now be dealt with to illustrate the application of the concept of the equivalent modulator circuit in deducing certain principles which have a direct and important bearing on the design of the associated circuits.

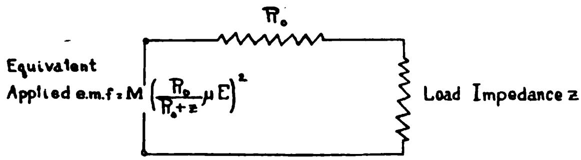

FIGURE 2—EQUIVALENT MODULATOR CIRCUIT

Let the impressed emf. E be the sum of two sinusoidal functions; thus

$$E = E_1 \sin p_1 t + E_2 \sin p_2 t \qquad (4)$$

To fix our ideas, the first component of E may be regarded as the carrier wave and the second the signal wave. In substituting this expression for E in (2), to evaluate the fictitious emf. acting in the equivalent modulator circuit it is essential that E be written down as a complete real time function, since the operation of squaring is in effect a frequency transformation. From (4) we have:

$$\frac{\mu R_o}{R_o+z} E = \mu R_o \left(\frac{E_1}{Z(p_1)} \sin(p_1 t - \theta_1) + \frac{E_2}{Z(p_2)} \sin(p_2 t - \theta_2) \right) \qquad (5)$$

where $Z(p_1)$ and $Z(p_2)$ are the absolute values of the impedance R_o+z to currents of frequencies $p_1/2\pi$ and $p_2/2\pi$ respectively, and θ_1 and θ_2 are the corresponding phase angles. By aid of (5), formula (2) becomes after simplification and rearrangement

$$\frac{M}{2}\Big\{ V_1^2 [1 - \cos(2 p_1 t - 2\theta_1)] + V_2^2 [1 - \cos(2 p_2 t - 2\theta_2)] + V_1 V_2 [\cos[(p_1 - p_2)t - (\theta_1 - \theta_2)] + \cos[(p_1 + p_2)t - (\theta_1 - \theta_2)]\Big\} \qquad (6)$$

where

$$V_1 = \frac{\mu R_o E_1}{Z(p_1)}$$

$$V_2 = \frac{\mu R_o E_2}{Z(p_2)}$$

This is the effective emf. acting in the equivalent modulator circuit and the current corresponding is calculated by usual methods. The modulated output current is evidently that corresponding to the term in $V_1 V_2$ of (6); it consists of the following two components

$$\frac{M}{2}(\mu R_o)^2 \frac{E_1 E_2}{Z(p_1)\cdot Z(p_2)}\cdot\frac{1}{Z(p_1-p_2)} \text{ of frequency } \frac{(p_1-p_2)}{2\pi} \qquad (7)$$

and

$$\frac{M}{2}(\mu R_o)^2 \frac{E_1 E_2}{Z(p_1)\cdot Z(p_2)}\cdot\frac{1}{Z(p_1+p_2)} \text{ of frequency } \frac{(p_1+p_2)}{2\pi} \qquad (8)$$

Now suppose that by a proper design the load impedance acts like a pure resistance R at the frequencies corresponding p_1, p_2, (p_1-p_2), and (p_1+p_2). Then the modulated currents are proportional to

$$\frac{R_o^2}{(R_o+R)^3}$$

and the modulated energy W_1 delivered to the load impedance is proportional to

$$\frac{RR_o^4}{(R_o+R)^6}$$

This expression is a maximum when $R=\frac{R_o}{5}$ and when this condition is satisfied becomes

$$\frac{\left(\frac{5}{6}\right)^6}{5R_o} \qquad (9)$$

Now consider a second arrangement, where the load impedance acts like a pure resistance R at the frequencies corresponding to p_1, (p_1-p_2), and (p_1+p_2), but acts like a short circuit to currents of the signal frequency $\frac{p_2}{2\pi}$. This condition is substantially realizable at least when the carrier frequency is sufficiently large in comparison with the signal frequency. In this case the modulated currents are proportional to

$$\frac{R_o}{(R_o+R)^2}$$

and the modulated energy W_2 is proportional to

$$\frac{R R_o^2}{(R_o+R)^4}$$

This expression is a maximum when $R = \frac{R_o}{3}$, and when this condition is satisfied becomes

$$\frac{\left(\frac{3}{4}\right)^4}{3 R_o} \tag{10}$$

Comparison of (9) and (10) shows that for the same applied emf.'s, the modulated energy outputs W_1 and W_2 are related by

$$\frac{W_1}{W_2} = \left(\frac{3}{5}\right)\left(\frac{4}{3}\right)^4\left(\frac{5}{6}\right)^6 = 0.635$$

$$\text{or} \quad W_2 = 1.575\, W_1.$$

It follows at once that a proper design of associated circuits to satisfy the conditions laid down in the second case results in a gain of 57 per cent. in the available modulated energy as compared with the first arrangement. Another immediate deduction from formulas (7) and (8) is that, altho we are concerned only in transmitting radio frequency modulated currents, it is necessary to provide a low impedance path in the output circuit for the low frequency signal currents $\left(\frac{p_2}{2\pi}\right)$; otherwise a serious loss in the available modulated energy results.

The foregoing simple example has been worked thru to illustrate the application of the concept of the equivalent modulator circuit and to exhibit the utility from an engineering standpoint of a simple physical picture which, in its large outlines, is a faithful likeness of the actual phenomena.

Appendix

The deduction of the equivalent amplifier and equivalent modulator circuits follow from the general operational solution of the vacuum tube circuit problem as given in my paper in the April, 1919, Proceedings of The Institute of Radio Engineers. Inasmuch as it will be impossible to repeat here the course of the argument it will be assumed that any reader who is interested in the problem will consult that paper for the details of the solution.

The method of solution is one of successive approximations. The output circuit current J and the potential difference v across the load impedance are written down as the expansions

$$J = J_1 + J_2 + J_3 + \cdots \tag{1}$$

$$v = v_1 + v_2 + v_3 + \cdots$$

It is hen shown that the assumed expansions satisfy the conditions of the problem if the successive terms are related and defined by the scheme

$$\begin{aligned} J_1 &= P_1\,(\mu\, e+v_1) \\ J_2 &= P_1\, v_2+P_2\,(\mu\, e+v_1)^2 \\ J_3 &= P_1\, v_3+2\, P_2\,(\mu\, e+v_1)\; v_2+P_3\,(\mu\, e+v_1)^3 \end{aligned} \tag{2}$$

Here e (following the notation of the previous paper) is the emf. impressed on the input terminals, and P_1, P_2, P_3 are differential parameters of the tube which appear in the power series expansion.

$$J=P_1(\mu\, e+v)+P_2(\mu e+v)^2+\cdot\;\cdot\;\cdot$$

so that

$$\begin{aligned} P_1 &= \frac{1}{1!}\left(\frac{\partial I}{\partial E_b}\right) \\ P_2 &= \frac{1}{2!}\left(\frac{\partial^2 I}{\partial E_b^2}\right)=-\frac{1}{2}\frac{1}{R_o^2}\frac{\partial R_o}{\partial E_b}=\frac{M}{R_o} \end{aligned} \tag{3}$$

Now from (1), (2), and (3)

$$\begin{aligned} R_o\, J_1-v_1 &= \mu\, e \\ R_o\, J_2-v_2 &= R_o\, P_2\,(\mu\, e+v_1)^2 \\ &= M\,(\mu\, e+v_1)^2 \end{aligned} \tag{4}$$

Writing $v_1=-z J_1$ and $v_2=-z J_2$,—relations which follow at once from physical considerations,—equations (4) become

$$(R_o+z)\, J_1=\mu\, e \tag{5}$$

and

$$(R_o+z)\, J_2=M\left(\frac{R_o}{R_o+z}\,\mu\, e\right)^2 \tag{6}$$

Equation (5) is simply the equation for the current J_1 in a circuit of impedance R_o+z in response to the impressed emf. μe, and therefore, identifying J_1 with the amplification current, it leads at once to the law of the equivalent amplifier circuit. Similarly (6) is simply the equation for the current J_2 in a circuit of impedance R_o+z in response to the impressed emf.

$$M\left(\frac{R_o}{R_o+z}\cdot\mu\, e\right)^2$$

As shown in the paper, the component current J_2 is that which represents the modulated or detected output current; consequently equation (6) is simply a statement of the law of the equivalent modulator circuit.

It will be evident from the foregoing that the concepts of equivalent amplifier and modulator circuits are approximate, and that from a mathematical standpoint they represent simply first and second order approximations to infinite series. Experience, however, has shown that the convergence of the series is so rapid in the usual range of values occurring in practice as to make the deductions from these approximations useful engineering guides. Furthermore the mathematical theory enables us to recognize conditions where the approximations fail to be reliable and to make the necessary corrections under these circumstances.[3]

Department of Development and
Research, American Telephone
and Telegraph Company.

February 8, 1920.

SUMMARY: The author starts from the consideration of the equivalent circuit to a three-electrode vacuum tube *amplifier*. After pointing out the engineering usefulness of such an equivalent circuit, there is derived the equivalent circuit to a three-electrode vacuum tube *modulator*. The resulting theory is applied to a practical example in modulator design and its usefulness demonstrated.

[3] Since the foregoing was written the writer's attention has been called to the fact that the law of the equivalent circuit of the vacuum tube amplifier was first published by Dr. John M. Miller, in the June, 1918, issue of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS. The writer regrets that this had escaped his notice, and takes this opportunity of giving to Dr. Miller due credit for the first published recognition of this valuable principle

VACUUM TUBE AMPLIFIERS IN PARALLEL*

By

R. V. L. Hartley

(Western Electric Company, New York)

It is occasionally desirable to operate a number of vacuum tube amplifiers in parallel, that is, with all of their grids connected together and all of their plates connected together.

Very often the tubes are not uniform in their amplification constants and plate resistances. It is therefore of interest to express the effective values of these quantities for the group in terms of those for the individual tubes, and to compare the power output of the group with that of the tubes operated individually.

If we assume a straight line characteristic it is well known that for a single tube,

$$i = \frac{1}{r}(\mu e_g + e_p) \tag{1}$$

where e_g is an alternating emf. applied to the grid; e_p, the alternating plate voltage; i, the alternating plate current; μ, the amplification constant; and r, the internal alternating current plate circuit resistance.[1] If the external impedance in the plate circuit is Z, then

$$\left.\begin{aligned} e_p &= -Zi \\ \text{and} \qquad i &= \frac{\mu}{r+Z} e_g \end{aligned}\right\} \tag{2}$$

For n tubes in a common circuit, that is, the same e_g, e_p, and Z, the current in the output circuit can be expressed as

$$\bar{i} = \frac{\bar{\mu}}{\bar{r}+Z} e_g \tag{3}$$

The problem is to evaluate $\bar{\mu}$ and $\bar{r}$ in terms of $\mu_1, \mu_2, \cdots \mu_n$ and $r_1, r_2, \cdots r_n$, the constants of the individual tubes. For any one tube

$$i_j = \frac{1}{r_j}(\mu_j e_g - Z\bar{i})$$

* Received by the Editor, September 1, 1920.

[1] It is assumed that the frequencies are such that no account need be taken of the effect of internal capacities in the tube or of connecting leads.

since $e_p = -Z\bar{i}$.

Then

$$\bar{i} = \sum i_j = e_g \sum \frac{\mu_j}{r_j} - Z\bar{i} \sum \frac{1}{r_j}$$

Whence

$$\bar{i} = \frac{\dfrac{\sum \frac{\mu_j}{r_j}}{\sum \frac{1}{r_j}}}{\dfrac{1}{\sum \frac{1}{r_j}} + Z} e_g$$

Comparing with (3)

$$\bar{\mu} = \frac{\sum \frac{\mu_j}{r_j}}{\sum \frac{1}{r_j}} \tag{4}$$

and

$$\bar{r} = \frac{1}{\sum \frac{1}{r_j}} \tag{5}$$

It is at once evident that $\bar{r}$, the effective output resistance of the combination, is equal to the resistance of all of the tubes in parallel.

To arrive at a physical picture of $\bar{\mu}$, consider a single tube, constants μ_1, r_1, operating as a voltage amplifier with an external resistance r_o in its plate circuit. As is well known, the voltage developed across r_o is

$$r_o i_1 = \frac{r_o}{r_1 + r_o} \mu_1 e_g \tag{6}$$

(4) may be written

$$\bar{\mu} = \frac{\mu_1}{r_1 \sum \frac{1}{r_j}} + \frac{\mu_2}{r_2 \sum \frac{1}{r_j}} + \cdots + \frac{\mu_n}{r_n \sum \frac{1}{r^j}}$$

The first term may be written

$$\frac{\mu_1}{1 + r_1 \sum_2^n \frac{1}{r_j}} = \frac{\dfrac{1}{\sum_2^n \frac{1}{r_j}} \mu_1}{r_1 + \dfrac{1}{\sum_2^n \frac{1}{r_j}}}$$

Comparing this with (6) we see that r_o is replaced by $\frac{1}{\sum_2^n \frac{1}{r_j}}$ which is the resistance of all the tubes except the first in parallel. We may, therefore, say that $\bar{\mu}$ is made up of the sum of n terms, each of which, when multiplied by e_g, represents the voltage which one of the n tubes would develop across an external resistance in its plate circuit equal to that of the remaining (n-1) tubes connected in parallel.

Certain special cases are of interest.

Let $\mu_1 = \mu_2 = \cdots = \mu_n = \mu$

Then $\bar{\mu} = \mu$

$$\bar{r} = \frac{1}{\sum \frac{1}{r_j}}$$

That is, if μ is the same for all the tubes, the effective value for the combination is the same as that of each tube. The effective resistance is still that of the individual resistances in parallel.

Again let the resistances be alike and the amplification constants different.

Putting $r_1 = r_2 = \cdots = r_n = r$

$$\bar{\mu} = \frac{1}{n} \sum \mu_j$$

$$\bar{r} = \frac{r}{n}$$

That is, the amplification constant of the group is the arithmetic mean of those of the individual tubes and the group resistance is that of a single tube divided by the number of tubes.

These equivalent constants furnish a basis for comparing the maximum power output per unit voltage input of the tubes as a group with the sum of their individual maximum outputs. This is equivalent to comparing the power output of the group of dissimilar tubes with that of a group of similar tubes each of which has a power output equal to the average of the individual outputs of the dissimilar tubes.

For this we shall take e_g as unity and assume that in each case Z is equal to the plate resistance of the tube or group of tubes in question. This is the condition for maximum power in Z. For a single tube this power is given by

$$p_j = \frac{\mu_j^2}{4\, r_j} \qquad (7)$$

and for the group

$$\bar{p}=\frac{\bar{\mu}^2}{4\,r} \tag{8}$$

A measure of the relative efficiency of a group of n tubes is then given by the ratio

$$\rho=\frac{\bar{p}}{\sum p_j} \tag{9}$$

From (4), (5), and (8)

$$\bar{p}=\frac{\left(\sum\frac{\mu_j}{r_j}\right)^2}{4\sum\frac{1}{r_j}} \tag{10}$$

Then

$$\rho=\frac{\left(\sum\frac{\mu_j}{r_j}\right)^2}{\left(\sum\frac{1}{r_j}\right)\left(\sum\frac{\mu_j^2}{r_j}\right)} \tag{11}$$

The conditions for making ρ a maximum are given by the $2n$ equations of the types

$$\frac{\partial\rho}{\partial\mu_j}=0 \tag{12}$$

$$\frac{\partial\rho}{\partial r_j}=0 \tag{13}$$

The equation

$$\frac{\partial\rho}{\partial\mu_1}=0$$

reduces to

$$\mu_1=\frac{\sum\frac{\mu_j^2}{r_j}}{\sum\frac{\mu_j}{r_j}}$$

From symmetry, it follows that the other equations of the type of (12) lead to the relation

$$\mu_1=\mu_2=\cdots=\mu_n$$

The equation

$$\frac{\partial\rho}{\partial r_1}=0$$

reduces to

$$\left(\sum\frac{1}{r_j}\right)\left(\sum\frac{\mu_j}{r_j}\right)\mu_1^2-2\left(\sum\frac{1}{r_j}\right)\left(\sum\frac{\mu_j^2}{r_j}\right)\mu_1+\left(\sum\frac{\mu_j}{r_j}\right)\left(\sum\frac{\mu_j^2}{r_j}\right)=0.$$

The other equations of this type differ only in the subscript of μ, and hence from symmetry they can all be satisfied only if

$$\mu_1 = \mu_2 = \cdots = \mu_n.$$

Under these conditions

$$\rho = 1$$

regardless of the values of r_1, r_2, and so on.

We may conclude, therefore, that the total power that can be drawn from a group of tubes, per unit input voltage, is the same in a common circuit as in individual circuits when, and only when, the amplification constants of all the tubes are equal. When this condition is met it is not essential that the resistances be equal.

However, a very large fraction of the total power of the individual tubes is available when they are connected in parallel, even tho the tubes differ widely in amplification constant and internal resistance. To illustrate, two tubes the amplification constants of which are in the ratio of two to one, and the resistances of which are equal, give 0.90 as much power in a common circuit as they do in individual circuits. If, with the same ratio of amplification constants, the resistance of the first is twice that of the second, the power ratio is 0.89, and if the resistance of the first is half that of the second the ratio is 0.926.

Research Laboratories of the American
Telephone and Telegraph Company
and the Western Electric Company.

May 10, 1920.

SUMMARY: The general theory of the power output of a number of dissimilar vacuum tubes operated in parallel is given. The equations obtained are applied to the case when all the tubes have the same amplification constant, and also the case when the tubes all have the same internal resistance. Some practical examples are given.

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

GRANTED FEBRUARY 22, 1921—APRIL 12, 1921

BY

JOHN B. BRADY

(OURAY BUILDING, WASHINGTON, D. C.)

The object of this section of the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS is to make available in convenient form for research engineers and others interested, brief information on the radio patents which are granted each week by the Patent Office. The rapid developments in this art emphasize the importance of radio research engineers being familiar with patent literature in order to eliminate as far as possible the duplication of research effort. It is not the purpose of this section to explain radio inventions fully, but merely to indicate the general nature of the patents in order that those of particular interest to individuals concerned with certain problems may be selected, and copies of the patents obtained for complete study. Copies of the complete patents may be obtained at ten cents each by addressing the Commissioner of Patents at Washington, D. C.

1,369,281—Oscar C. Roos, of Brooklyn, New York.
Electromagnetic-Wave-Transmitting System—Patented February 22, 1921.

This patent relates to a transmitting system in which an arc is shown as a source of sustained oscillations. The object of the invention is to provide a circuit for absorbing one or more of the higher harmonics of the fundamental of the antenna system so that the transmitted electromagnetic waves will have the frequency of such fundamental and will be substantially simple harmonic. Parallel branch circuits are provided adapted to absorb the undesirable or parasitic frequencies, while the remaining oscillations are transmitted as electromagnetic waves. The

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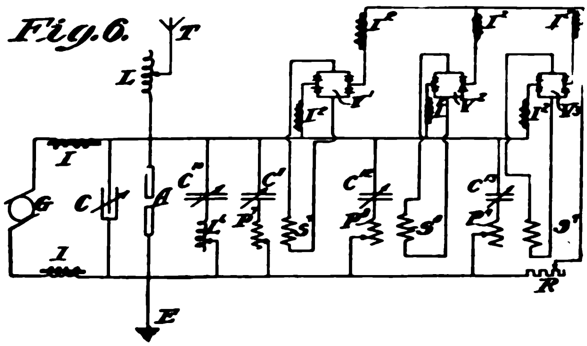
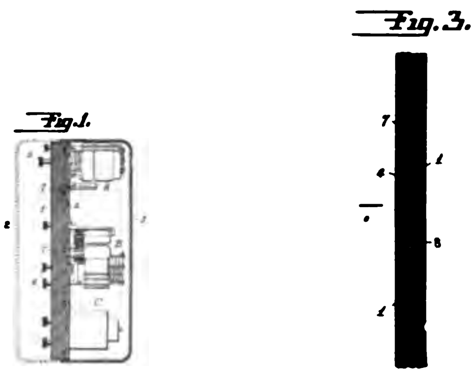
While great care has been taken in the preparation of these Digests, THE INSTITUTE OF RADIO ENGINEERS assumes no responsibility for their correctness or completeness, or for possible omissions of particular patents.—EDITOR.

branch circuits are arranged to rectify the absorbed oscillating energy and return it to the generator circuit to assist in feeding the arc.



NUMBER 1,369,281—Electromagnetic-Wave-Transmitting System

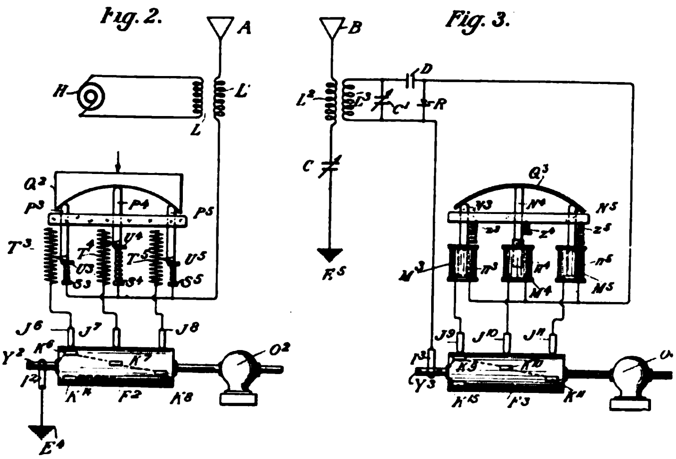
1,370,093—George B. Crouse and Isaac H. Mills, of Brooklyn, New York, Assignors to the Sperry Gyroscope Company, of Brooklyn, New York, a corporation of New York. Receiving-Panel—Patented March 1, 1921.



NUMBER 1,370,093—Receiving-Panel

This patent relates to a construction of panel for mounting radio apparatus. The panel is made up of insulating material and a metallic shield embedded therein which forms a barrier to stray magnetic and electrostatic fields which might affect radio apparatus supported and enclosed by the panel.

1,370,504—John Hays Hammond, Jr., of Gloucester, Mass.
Telestereotypy—Patented March 1, 1921.



NUMBER 1,370,504—Telestereotypy

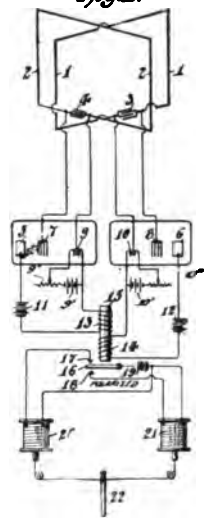
This patent is directed to a system for transmitting and reproducing forms and shapes of objects and solids at a distance by radio transmission. The transmitter is energized by a suitable source of oscillations and an apparatus connected in circuit with the antenna for successively varying the amplitude of the oscillations in accordance with the shape of the object at the transmitter station. The receiving station contains an apparatus synchronized with the apparatus of the transmitter whereby the variation in amplitude of the received oscillations cause a reproduction of the shape of the object at the distant station.

1,370,688—John Hays Hammond, Jr., of Gloucester, Mass.
System of Radio-control—Patented March 8, 1921.

This patent relates to a system for controlling a torpedo, a boat, or aircraft by radio. Two loop antenna, arranged in different planes are employed, each connected to separate vacuum tube detectors which mutually control a relay which is connected to regulate the position of the steering gear.

1,370,735—Charles Samuel Franklin, of London, England, Assignor to Radio Corporation of America, of New York, N. Y., a corporation of Delaware.

Fig. 1.



NUMBER 1,370,688—System of Radio-control

Aerial System for Wireless Signaling—Patented March 8, 1921.

Fig. 1

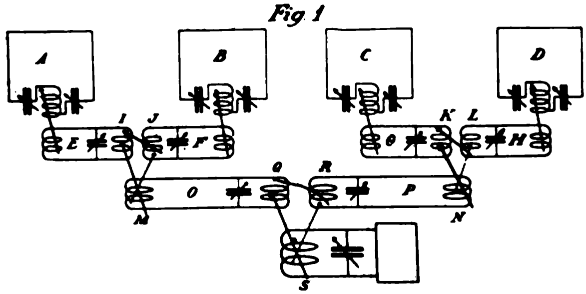
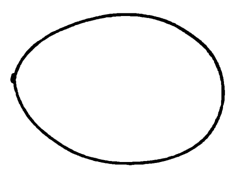


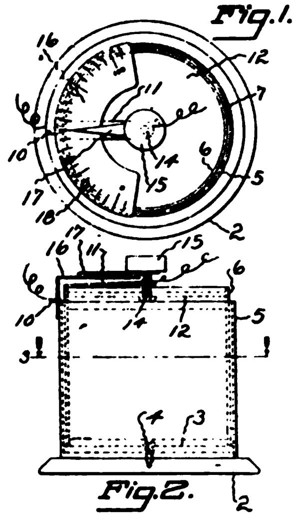
Fig. 3



NUMBER 1,370,735—Aerial System for Wireless Signaling

The object of this invention is to secure a more complete cancellation of signals in a direction opposite to that in which reception is desired. A plurality of antennas are employed, each separated a fraction of a wave length, and circuits arranged for combining the antennas to secure a plurality of directional systems. The systems are effectively separated a fraction of a wave length and the energy superimposed upon a common receiver. The patentee points out that the resulting polar curve for the combined systems is much better than can be obtained from each system alone. The curve is sharper in the direction toward the distant transmitting station and gives nearly complete cancellation in all directions, both vertically and horizontally, at the back of the station.

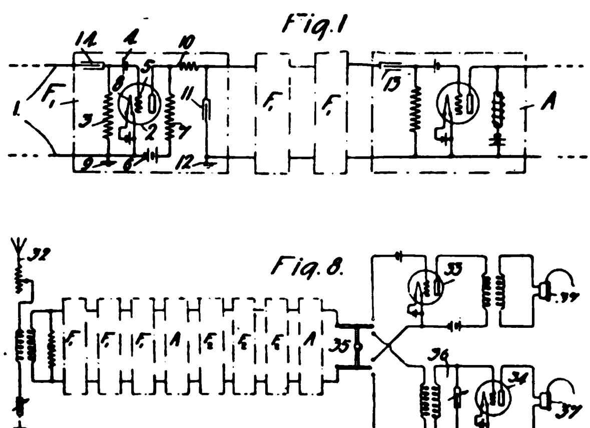
1,371,061—Clarencc D. Tuska, of Hartford, Connecticut.
Condenser—Patented March 8, 1921.



NUMBER 1,371,061—Condenser

This patent relates to a form of variable receiving condenser made up of paper stock and metal foil.

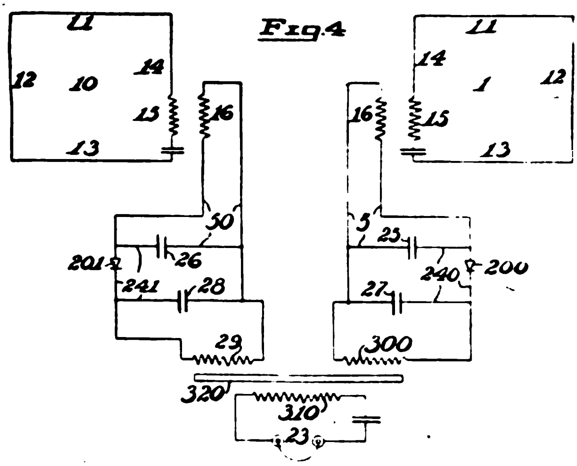
1,371,228—Austen M. Curtis, of Brookl}n, N. Y., Assignor to Western Electric Company, Incorporated, of New York, N. Y., a corporation of New York.
Reduction of Static Interference in Radio Receiving Stations—Patented March 15, 1921.



NUMBER 1,371,228—Reduction of Static Interference in Radio Receiving Stations

This invention relates to a wave filter for use in radio receiving systems for the purpose of reducing the effect of static or atmospheric disturbances.

1,371,567—Robert H. Marriott, of Bremerton, Washington. Radio Receiving System—Patented March 15, 1921.



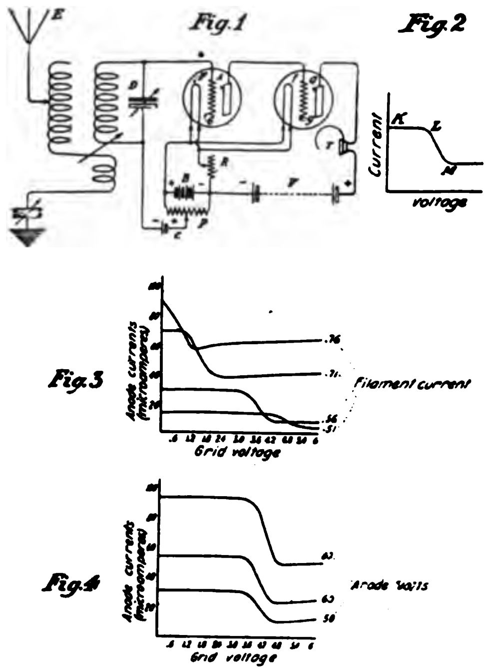
NUMBER 1,371,567—Radio Receiving System

This invention relates to a receiving circuit designed to dissipate or neutralize undesirable disturbing currents. A plurality of receiving circuits are employed connected to a neutralizing circuit and a circuit which contains rectifiers acting as frequency changing devices.

1,371,757—Ernest Walter Brudenell Gill, of Oxford, England, Assignor to Radio Corporation of America, of New York, N. Y., a corporation of Delaware.

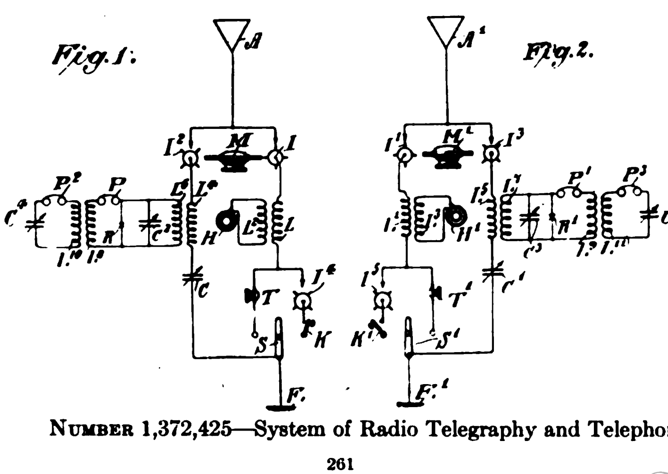
Wireless-Telegraph Receiver—Patented March 15, 1921.

This patent pertains to a circuit arrangement for vacuum tube receivers wherein the voltage of the first grid is adjusted so that the current in the plate circuit of the second tube may decrease as the voltage of the first grid increases and increase as the voltage of the first grid decreases. The plate current of the second tube varies inversely with the potential of the grid of the first tube thru a portion of a cycle. The purpose of this arrangement is to obtain a response of equal strength for all signals over a particular strength and to provide more marked discrimination between signals received from different types of transmitters such as Telefunken and British Navy spark sets.



NUMBER 1,371,757—Wireless-Telegraph Receiver

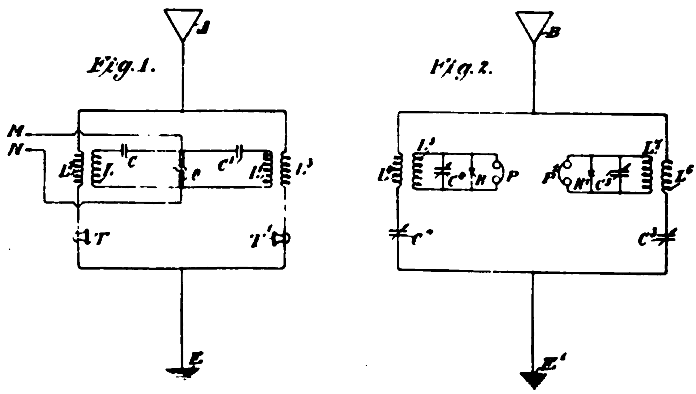
1,372,425—John Hays Hammond, Jr., of Gloucester, Mass. System of Radio Telegraphy and Telephony—Patented March 22, 1921.



NUMBER 1,372,425—System of Radio Telegraphy and Telephony

This invention relates to a system for simultaneously transmitting and receiving in radio telegraphy and telephony. The invention further contemplates the reduction in interference of two transmitting stations in the same neighborhood. The principle involved is that the antenna of each station is simultaneously connected with the transmitter of that station, and the receivers at this same instant are disconnected, so that neither station receives during the instant that either transmitter is connected for operation.

1,372,426—John Hays Hammond, Jr., of Gloucester, Mass.
Multiplex Radiotelephony—Patented March 22, 1921.

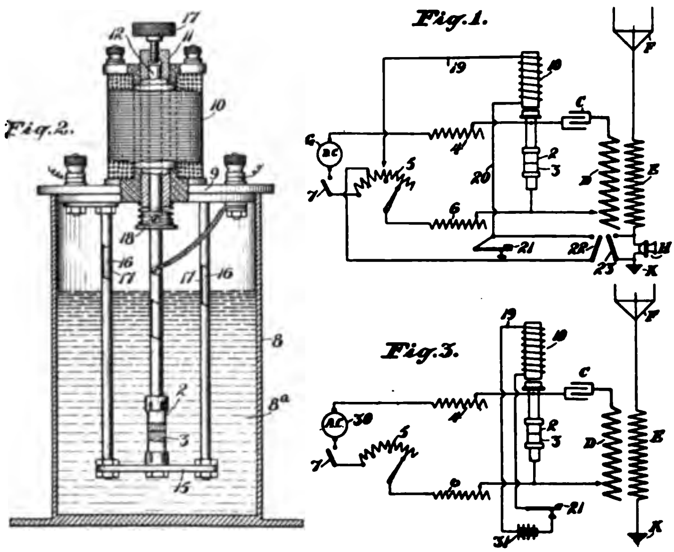


NUMBER 1,372,426—Multiplex Radiotelephony

This patent relates to a system for transmitting and receiving two or more radio telephone conversations simultaneously. Figure 1 represents a transmitting station wherein two conversations may be transmitted on different wave lengths and Figure 2 shows a corresponding receiving station wherein the conversations may be received on different wave lengths.

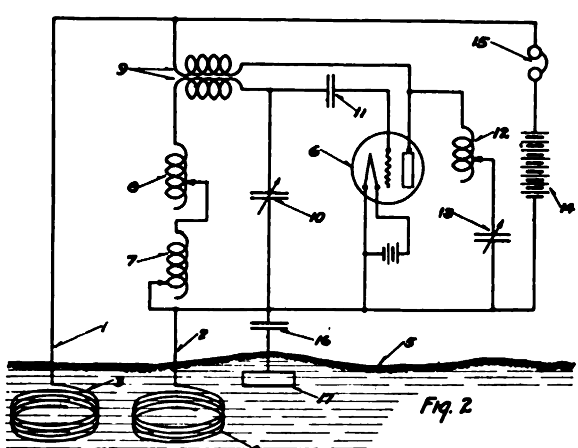
1,372,808—Alphonsus L. Golden, of Oakland, California, Assignor to National Radio Company, of San Francisco, California, a corporation of Arizona.
Apparatus for the Production of Intermittent or Continuous High-frequency Oscillations—Patented March 29, 1921.

This patent shows a construction of oscillator comprising a spark gap having electrodes submerged in distilled water. The oscillator may be arranged in circuit for telegraphy or telephony forming a continuous arc when employed for telephonic conversations and an intermittent make and break when used in telegraphing.



NUMBER 1,372,808—Apparatus for the Production of Intermittent or Continuous High-frequency Oscillations

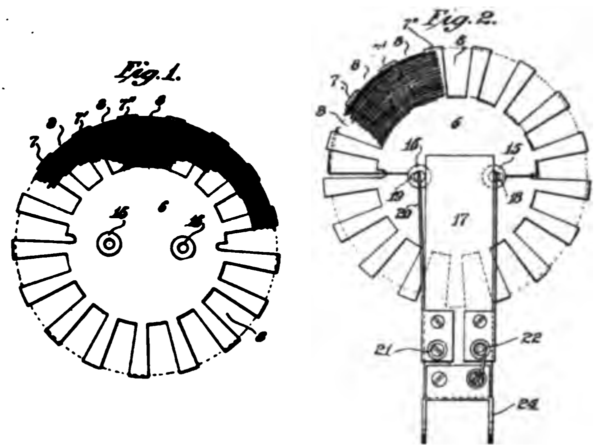
1,372,658—Edward Thomas Jones, of New Orleans, Louisiana. Underground or Underwater Antenna System—Patented March 22, 1921.



NUMBER 1,372,658—Underground or Underwater Antenna System

This patent shows an underground or underwater antenna system comprising a pair of concentrated free ended coils of insulated cable which are submerged in water, or buried in the ground a relatively short distance apart and connected to receiving apparatus.

1,372,850—Eugene T. Turney, of New York, N. Y.
Inductance Device—Patented March 29, 1921.



NUMBER 1,372,850—Inductance Device

This invention relates to a construction of inductance formed by a winding on a flat disc with radiating arms. The wire is wound spirally on the flat arms.

1,373,504—Harry W. Hitchcock, of New York, N. Y., Assignor to American Telephone and Telegraph Company, a corporation of New York.
Electrical Measuring Apparatus—Patented April 5, 1921.

This patent relates to an arrangement for variable condensers in which a fixed capacity is adapted to be connected in parallel with any desired portion of the variable capacity. By this circuit arrangement the desired maximum capacity and also the desired intermediate capacities between the minimum of the variable condenser and the maximum of the two condensers in parallel may be obtained.

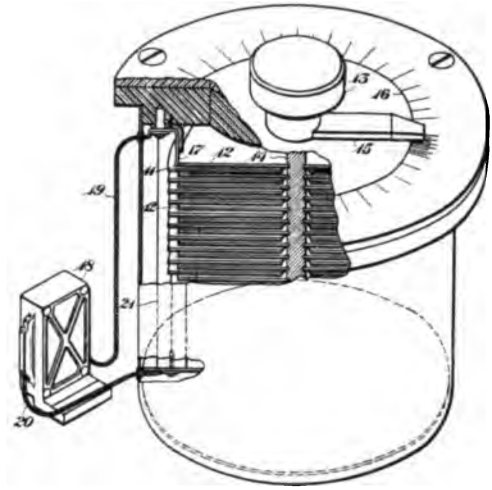


Fig. 1

Number 1,373,504—Electrical Measuring Apparatus

1,373,612—Earl C. Hanson, of Washington, District of Columbia Underground Loop-Antenna—Patented April 5, 1921.

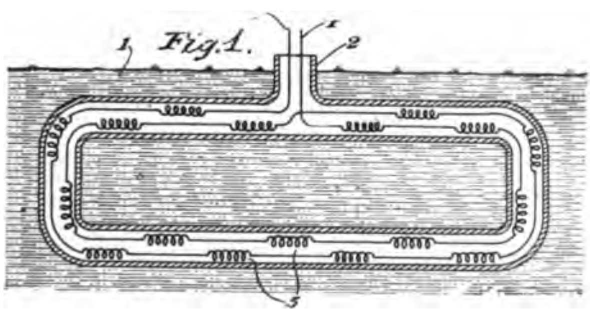
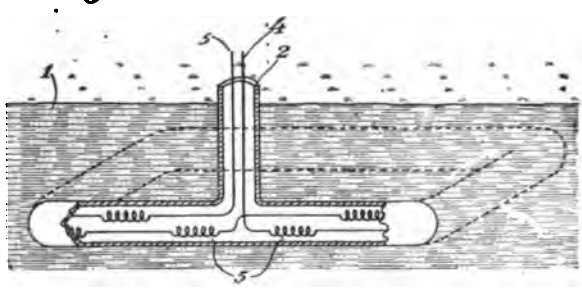


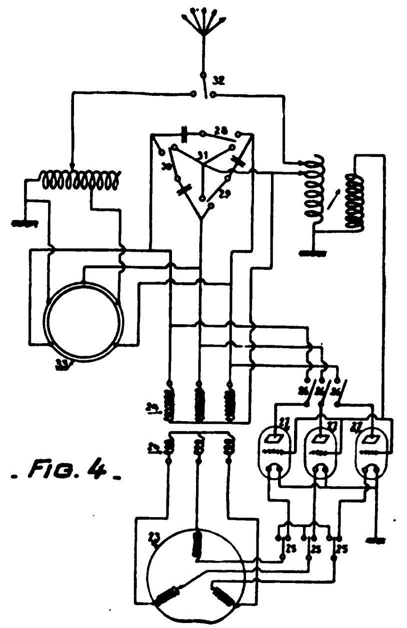
Fig. 2



Number 1,373,612—Underground Loop-Antenna

This patent shows an underground antenna system for radio signaling in which a looped coil is enclosed in a conduit and buried beneath the earth. The coil is provided with filter coils at intervals in the turns in the loop for the purpose of reducing response to shock impulses.

1,373,710—Victor Joseph Francois Bouchardon, of Lyons, France. Generator of High-frequency Oscillations for Wireless Telegraphy—Patented April 5, 1921.



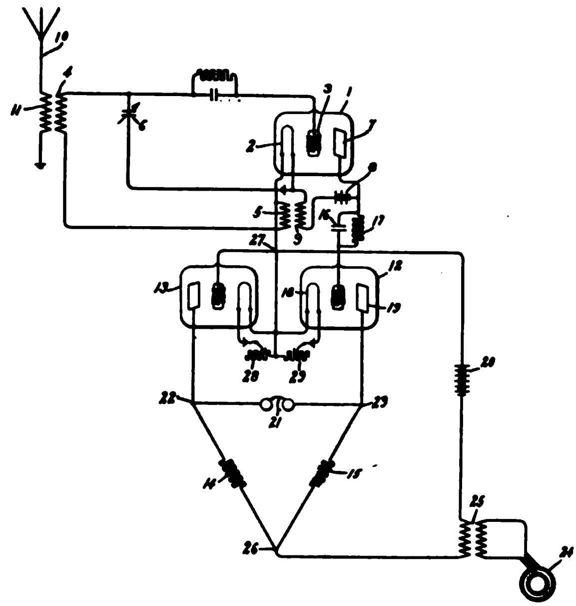
-FIG. 4-

NUMBER 1,373,710—Generator of High-frequency Oscillations for Wireless Telegraphy

This patent relates to a transmitter in which a rotary spark gap set or a continuous wave vacuum tube generator set may be employed. Three phase supply is employed to energize the vacuum tube set wherein three tubes are shown star connected to form an oscillating circuit.

1,373,931—Ernst F. W. Alexanderson, of Schenectady, New York, Assignor to General Electric Company, a corporation of New York.

Radio Receiving System—Patented April 5, 1921.

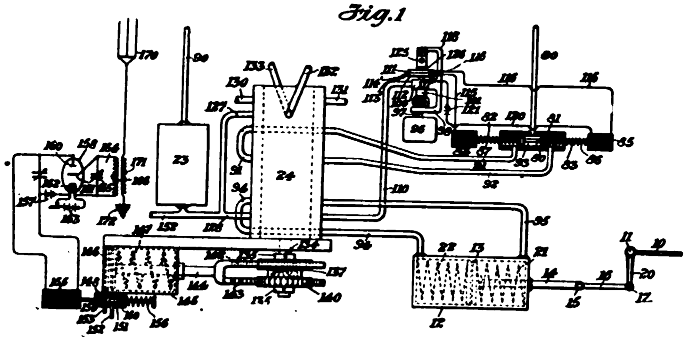


NUMBER 1,373,931—Radio Receiving System

This patent relates to a receiving circuit in which a radio frequency oscillator at the receiving station is adjusted to be normally inoperative. It is arranged so that when signals of a desired frequency are received in the system the local oscillator will be set into operation and produce oscillations of the same frequency as the signaling oscillations.

1,374,124—Albert D. Trenor, of New York, N. Y., Assignor to John Hays Hammond, Jr., of Gloucester, Mass.
System for the Control of Dirigible Devices from a Distance —Patented April 5, 1921.

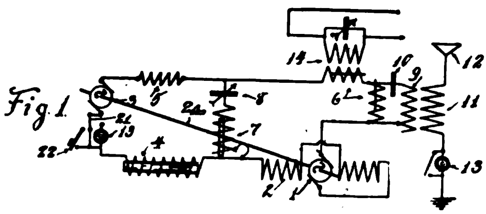
Fig. 1



NUMBER 1,374,124—System for the Control of Dirigible Devices from a Distance

This patent relates to a system of engine valve control by the reception of radiant energy. The valve mechanism is arranged for distribution of motive fluid to a plurality of different actuating devices.

1,374,170—August J. Kloneck, of New York, N. Y.
Generating System for Electric Currents—Patented April 5, 1921.



NUMBER 1,374,170—Generating System for Electric Currents

This patent relates to a generating system for radio frequency currents, and shows a circuit arrangement for a radio transmitting station.

1,374,293—Reginald A. Fessenden, of Chestnut Hill, Mass.
Wireless Direction-Finder—Patented April 12, 1921.

This invention relates to a method of determining the direction of signals from a receiving station. The method consists in taking a plurality of observations at the observing station at different wave frequencies transmitted from the radiating station and noting the amount of the discrepancies between the observations thereby determining the amount of wave bending to obtain the true direction of the radiating station from the observing station.

1,374,679—John B. Pratt, of Schenectady, New York, Assignor to General Electric Company, a corporation of New York.
Degasifying Process—Patented April 12, 1921.

This patent pertains to the pre-treatment of thermionic vacuum tubes during the process of manufacture. Gas is removed from the electrodes by a method of heating the metallic masses to an elevated temperature by electric induction. By driving out the gases from the conductive parts, the later slow evolution of gases is substantially reduced. A radio frequency magnetic field is employed to produce the induced heating current.

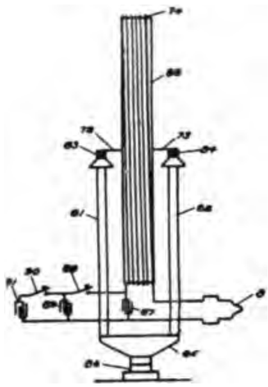


Fig. 1.

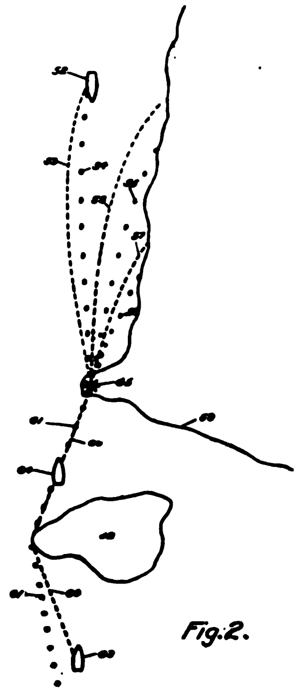
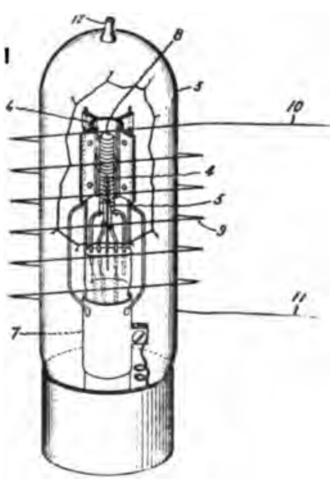


Fig. 2.

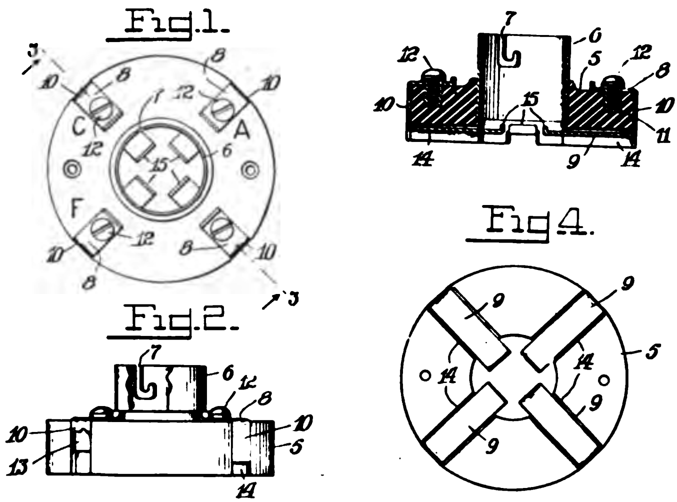
NUMBER 1,374,293—Wireless Direction-Finder

Fig. 1



NUMBER 1,374,679—Degasifying Process

1,374,832—Harold Potter Doule, of Meriden, Connecticut. Assignor to the Connecticut Telephone and Electric Co., Inc., of Meriden, Connecticut, a corporation of Connecticut Vacuum-Tube Base—Patented April 12, 1921.



Number 1,374,832—Vacuum-Tube Base

This patent shows a socket for a thermionic vacuum tube.