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PILOTING VESSELS BY ~~ELECTRICALLY~~ ENERGIZED CABLES*

By

A. CROSSLEY

(EXPERT RADIO AID, NAVY DEPARTMENT, WASHINGTON, D. C.)

Piloting vessels by means of cables energized by audio frequency currents is the result of the work of many scientists, inventors, and engineers, each having contributed some part to the general scheme whereby it is possible at this date successfully to apply the system for piloting vessels thru treacherous channels during inclement weather.

Before entering into a discussion on the general details of this system, there will be given a brief history of the evolution of the system. This history is the result of a thoro investigation of the prior art. The writer does not wish to be quoted officially as to the authenticity of statements made should it be proven later that there are other inventors who claim priority on the hereinafter stated inventions. The writer, therefore, does not desire to cover the system from a patent standpoint, but only desires to bring to the attention of those interested the technical details, and also the possibilities of this new aid to navigation.

GENERAL HISTORY

A résumé of the past history of the evolution of the Audio Piloting System may be briefly stated as follows:

Michael Faraday discovered in 1851 the principle of electro-magnetic induction.

Alexander Graham Bell's invention of the telephone receiver in 1876.

A. R. Sennett's British patent, number 13,415, of 1892, which discloses means of maintaining communication with light vessels by use of a submerged cable from which signals were received on board lightship by means of a multiple turn loop and telephone receivers.

Charles A. Stevenson's British patent, number 5,498, of

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1892, which discloses means for navigating vessels over electrically-energized cables and which shows the use of conduction principle at the receiving end in connection with sensitive galvanometer for recording purposes.

Robert B. Owens' American patent, number 736,432, of 1903, which shows a combination of the Stevenson's cable and Sennett's receiving apparatus in conjunction with special method of tilting receiving coils with respect to cable.

Alexander Chessin's British patent, number 21,610, of 1912, which shows an improvement on Owens' patent with reference to a means of mechanically tilting receiving coils.

July, 1916, issue of "Motor Boating," and also the August, 1916, issue of "Popular Mechanics," in which Earl C. Hanson discloses information on application of vacuum tube amplifier to audio frequency circuits, among which is the proposed use of such a system for piloting vessels thru fogs.

Earl C. Hanson's American patent, number 1,315,197, of 1919, which discloses application of vacuum tube amplifier to audio frequency receiving circuits.

Further work on the application of the amplifier to the Audio Piloting System has been, it is understood, undertaken by the English and German Navies, but full details on this work are not known to the writer.

Expert Radio Aid R. H. Marriott, of the Puget Sound Navy Yard conducted a series of interesting experiments at that place using the same circuits that Hanson had previously employed. Marriott brought to the attention of the Navy Department the results of his tests, and partly thru his efforts the Navy Department decided to make a thoro investigation of the merits of the system.

Having outlined previous work attempted, we will now devote our attention to the experimental work undertaken by the Bureau of Engineering, Navy Department, to determine the feasibility of developing and applying this system for Naval use.

NEW LONDON EXPERIMENTS

Upon receipt of orders from Commander S. C. Hooper, in charge of Radio Division, Bureau of Engineering, the writer proceeded to the Submarine Case, New London, Connecticut, on October 18, 1919, to conduct preliminary experiments. Arrangements were made whereby a sixty-foot (18.3 m.) sailing launch was placed at his disposal for the experiments. A 5,250 foot (1,600 m.) length of 9,000 circular mil (0.076 cm. diameter)

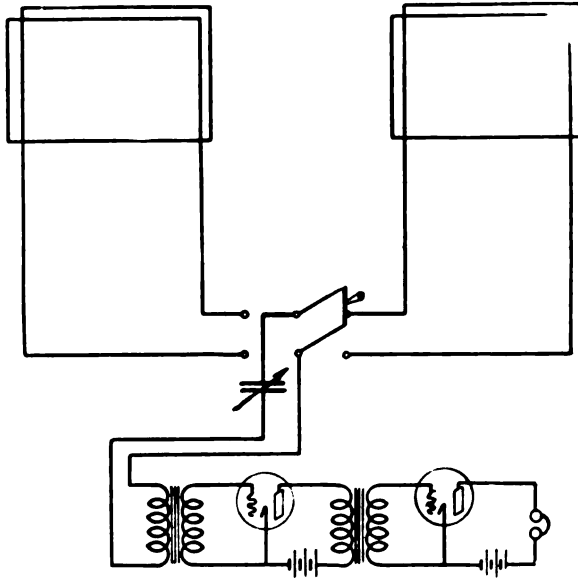
single conductor (Navy Standard) rubber insulated cable was submerged in the channel of the Thames River from the Submarine Base to a point approximately 5,000 feet (1,520 m.) down the river. The extreme end of this cable was grounded to a six foot (1.8 m.) length of 1.5 inch (3.8 cm.) galvanized iron pipe while the shore end of the cable was connected thru a lamp bank of eight 32-candle-power carbon lamps to a 0.5 kilowatt 500 cycle generator on board the submarine "N-4," and grounded to the hull of the submarine. The cable was anchored at 500 foot (152 m.) intervals along the course, but due to the difficulty experienced in handling the sailing launch, this cable was not laid in a straight course.

The receiving equipment consisted of two coils wound on a wooden frame four feet (1.2 m.) square, each coil having 240 turns of number 20 single cotton covered copper wire,* a double pole double throw switch and type SE-1,600 Navy two stage audio frequency amplifier, to which were connected standard telephone receivers. The double pole double throw switch made it possible to connect either coil to the amplifier, and thereby compare the relative received signal strength of the respective coils. A 0.0025 microfarad variable air condenser was connected in series with the input terminals of the amplifier as shown in Figure 1, with a view towards tuning the circuit to resonance; but because of the low inductance of the coil this was not possible, and the condenser was removed from the circuit.

A current flow of 2.3 amperes at 170 volts was supplied to the submerged cable. The input watts as recorded on a wattmeter indicated that the input in the cable was 145 watts or a power factor of 0.37. The poor power factor obtained was due to the fact that it was not convenient to obtain direct leads from the generator without totally dismantling the panel of the radio set of which the generator was a part, and therefore resort was made to connecting the primary of the transformer in series with the cable, thus creating a predominance of inductance in the circuit with the resultant lagging power factor. The receiving apparatus was installed on the sailing launch, one coil on one side, and the other coil on the opposite side of the launch above the water line. The launch was then made to follow a zigzag course over the cable to note the relative signal strength as received from the cable by the respective coils. It was noted that there was no shielding effect between the two coils and resort was made to the use of one coil. Using the single coil in the vertical position it was

* Diameter of No. 20 wire = 0.032 in. = 0.082 cm.

possible to tell within a distance of ten feet (3 m.) the exact location of the cable. The signal received from the cable was of an audibility in excess of 10,000 when the launch was directly over the cable, and of such intensity to be uncomfortable to retain telephone receivers on the observers' ears, while when moving away from the cable the signal strength rapidly diminished until



SE-1600 2 STEP AMPLIFIER

FIGURE 1

it became inaudible at a distance of 600 feet (180 m.) from the cable.

The next experiment consisted of turning the coil at different angles to the vertical plane to note whether a pronounced maximum or minimum signal could be obtained from the cable. It was noted, as expected, that a maximum signal was obtained when the plane of the coil was in line with the cable, and a minimum signal was obtained when the coil was at right angles to the plane of the cable.

Having proved that the single coil could be used to advantage on wooden vessels, arrangements were made with Capt. Oliver of the Submarine Base, whereby the Submarine "G-1" was

detailed for work to prove whether or not a shielding effect was present when a steel hull was interposed between the coils.

The results of experiments conducted on the "G-1" proved that there was a shielding effect between the coils and by use of this effect the Commander of the "G-1" could easily note on which side of the submarine the cable was situated. Strongest signal was always picked up by the coil nearest the cable, while minimum signal was received by the coil which was furthest from the cable. The shielding effect was not as pronounced as it should have been, but this was probably due to the poor shielding effect of the sloping sides and small conning tower of the "G-1."

On sailing down the river and passing over end of cable, it was immediately noted that the submarine had passed over the cable by the sudden decrease in signal strength. This decrease in signal strength was much more pronounced than the decrease noted when passing over and away from cable on a course at right angles to cable. No difference was noted in signal strength when the submarine was at different points along the cable, therefore showing that the attenuation effect along the cable could be neglected from a practical operating standpoint.

Having concluded necessary preliminary experiments at New London, the writer returned to Washington and recommended to the Bureau of Engineering that this system be further investigated wherein resort could be made to the use of a vessel having steel hull with a high superstructure, and that experiments be conducted under conditions which would be representative of its future practical application. Upon receipt of recommendations thus submitted, Commander Hooper decided that New York Harbor would be an ideal place to complete the final experiments.

NEW YORK EXPERIMENTS

Immediately after the decision to conduct further experiments at New York, the writer proceeded to the Navy Yard, New York, conferred with Commander R. F. McConnell, and made arrangements for the future experimental work. The New York Yard then obtained the services of the Mine Planter "Ord" and laid a cable from the Bayview Naval Station to a point approximately 700 feet (210 m.) from the Ambrose Channel Light Vessel. The cable referred to above consisted of 2,000 feet (610 m.) of 9,000 circular mil (0.076 cm. diameter) lead and armored cable, 2,000 feet (610 m.) 9,000 circular mil lead covered cable, and 83,000 feet (25,300 m.) 9,000 circular mil rubber

insulated Navy Standard cable. This cable was anchored at 500 foot (152 m.) intervals with concrete anchors of similar design to the anchor shown in Figure 2, and was laid as close as possible to the center of Ambrose Channel. The extreme end of the cable was grounded to a two foot (0.61 m.) square copper plate while the shore end was connected thru an inductance to a relay key which was actuated by an "Omnigraph"

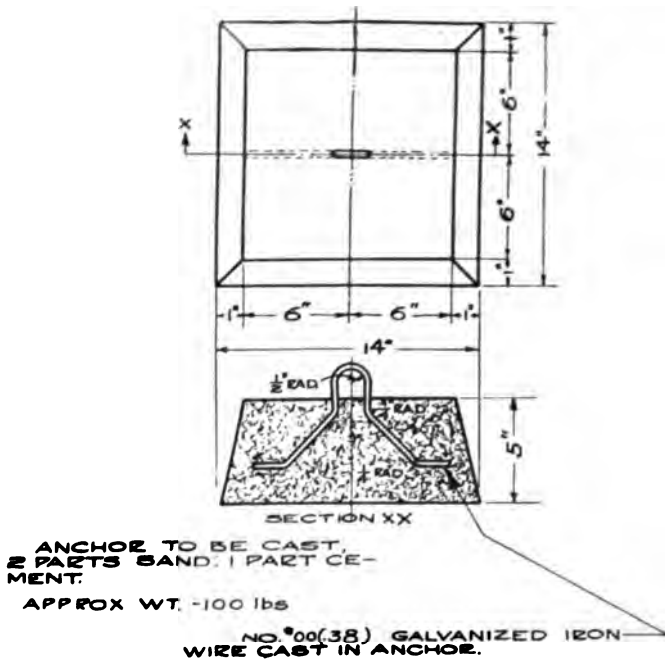


FIGURE 2

transmitter; and from this key, connection was made to one terminal of a 0.5 kilowatt 500 cycle generator: the other terminal of the generator was grounded to a copper plate two feet (0.61 m.) square, which was submerged in the bay.

The destroyer "O'Brien" was detailed to assist the New York Yard in this work and was equipped with two collector coils, four feet (1.22 m.) square, having 240 turns of number 20 double cotton covered wire,* one coil suspended over one side of the vessel and the other coil over the opposite side. Leads from

* Diameter of number 20 wire = 0.032 in. = 0.082 cm.

these coils were led to a double pole, double throw switch on the bridge, this switch being connected to a Type SE-1,600 two-stage audio frequency amplifier with the usual telephone receivers. Leads from the coils to the switch were run in lead and armored cable to prevent these leads from picking up extra signal from the cable and induction from ship's circuits.

A current flow of seven amperes was delivered to cable. The "O'Brien" steered a course from Bay Ridge out the Channel towards the Light Vessel, but lost the signals from the cable when passing a point 1,000 feet (300 m.) from the shore end. Upon noting that no current was being delivered to the cable from the 1,000 foot (300 m.) point to the Light Vessel, a sailing launch was obtained and the cable was under-run and found to be broken at the 1,000 foot (300 m.) point. The broken section of the cable was repaired, but on further investigation covering a period of three months it was found that the cable had been broken in fifty-two different places, and was of no further use. This investigation was carried on during midwinter and was extremely trying to the personnel engaged in this work. It is believed the breaks in the cable were caused by strain put upon it while being laid.

During the period when investigation of the defects in the cable was being conducted, the New York Yard was requested to try different types of cable to note which type would be best suited for this system. This was the original idea when the three different sections of cable were incorporated in the first cable, but as it was not possible to obtain this information due to the defective nature of this cable, experiments were conducted in the Navy Yard to solve this problem. Three cables, one 9,000 circular mils (0.076 cm. diameter) lead and armored, one lead covered 9,000 circular mils, and the other the rubber insulated 9,000 circular mils cable of 150 foot (45 m.) lengths were submerged to the same depths in the East River near Pier H, in the Navy Yard. Each cable was grounded at one end to a copper plate and the other end was connected to a 0.5 kilowatt 500 cycle generator. A current flow of one and one-half amperes was supplied at different intervals to the three cables; and the audibility of the received signal as received by a 240 turn four foot (1.2 m.) coil, a type SE-1,600 amplifier with the usual telephone and audibility meter, from the respective cables, was noted. The audibilities obtained were as follows:

<i>Cables</i>	<i>Audibility</i>
Lead and armored.....	1,000
Lead covered.....	1,000
Rubber covered.....	700

The results of the above-mentioned tests being in harmony with the practical design of future cables, work was immediately started on the design of a standard type cable. After consultation with certain cable manufacturers, specifications were drawn up for the purchase of 87,000 feet (27,000 m.) of the special cable shown in Figure 3. This cable consists of seven strands number 16 tinned copper wire,* a layer of 30 percent Para rubber 0.188 inch (0.476 cm.) thick, one layer of cambric, a layer of jute and an armor of number 12 galvanized steel wire.† This cable was manufactured by the Simplex Wire and Cable Company, of Boston. The cable was delivered by motor truck to the Navy Yard, Boston, in four reels. The Coast Guard Cutter "Pequot" was detailed to lay the new cable in Ambrose Channel and was at the Navy Yard, Boston, to receive this cable. Upon arrival of the four reels at the Navy Yard, representatives of the cable company made necessary cable splices so that it was stowed on board the "Pequot" in one continuous length. This procedure was of great help, as it eliminated the extra work and delay which would have been encountered should splices have been made during cable-laying operations.

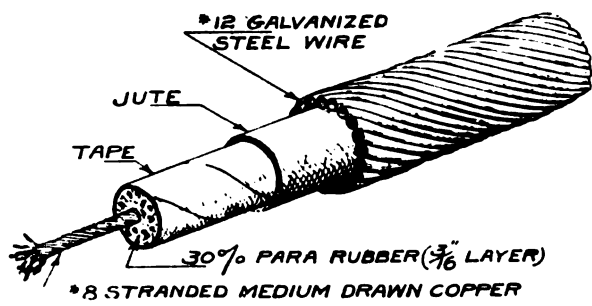


FIGURE 3

While the cable was being put on board the "Pequot," a special connection was made to the end of the cable. Figure 4

* Diameter of number 16 wire = 0.05 in. = 0.127 cm.
 † Diameter of number 12 wire = 0.08 in. = 0.203 cm.

shows sketch of this connection. The connection made between the internal conductor and the armor was for the purpose of eliminating the grounding plate and the attendant mechanical and electrical difficulties encountered when using this plate. It was figured theoretically that the low resistance offered by the large surface of the grounding plate (4 sq. ft. or 0.37 sq. m.) to the return current thru salt water between the plate and the armor was approximately equal to resistance of the short length of the internal conductor (6 inches or 15 cm.) as shown in Figure 4. The brass cap covering the rubber insulation at the end of wire was used to keep the salt water from seeping back into the cable between the rubber insulation and the wire.

The "Pequot" arrived at New York, July 31, 1920. Three days were spent in under-running the Western Union, Army, and Police cables which cross the Narrows between Forts Hamilton and Wadsworth, after which operation the "Piloting" cable

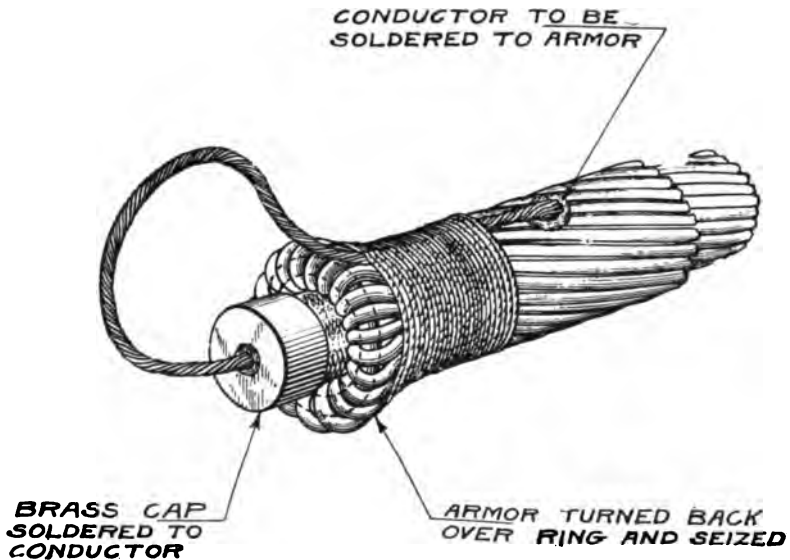


FIGURE 4

was placed under these cables. This was accomplished by hoisting up cables one by one and passing a 60-foot (18.3 m.) sailing launch with 2,000 feet (600 m.) of cable on board under the

cables and then allowing the cables to be released and sink to the bottom. After this operation, the sailing launch carried the remainder of the cable ashore and placed 500 feet (150 m.) of cable on the dock at Fort La Fayette.

When the shore end of the cable was secure, the "Pequot" headed for the middle of the channel and on reaching this point on the course, a cable clamp (see Figure 5) was placed on the cable, and by means of shackles and 0.31 inch (0.8 cm.) chains an anchor was made fast to the cable and lowered over the side. From this point the "Pequot" followed as close to the middle of the channel as was possible on her way out of the Ambrose Channel, passing to the left of the entrance buoy and completing the work of laying the cable when at a point 1,900

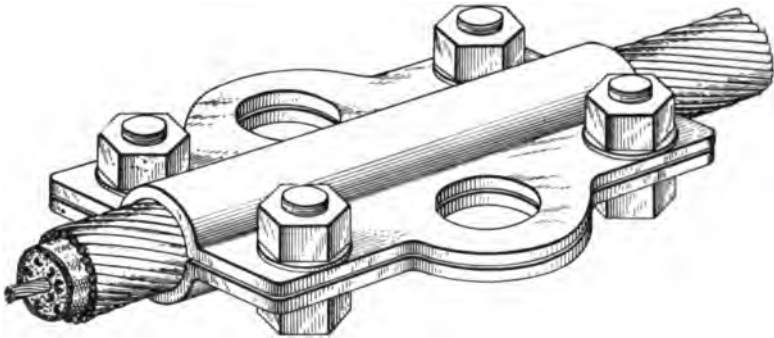


FIGURE 5

yards (1,740 m.) from the Ambrose Light Vessel. The cable was anchored at the two turns and also at the end, as shown in Figure 6. This cable was approximately 16 miles (26 km.) in length and laid in a period of six hours. Upon completion of the cable laying, August 6, 1920, test was made to ascertain whether the cable was in good condition, the result of which test showed that it was possible to obtain a current flow of 3.5 amperes when using 400 volts supplied by a 1-kilowatt 500-cycle generator at Fort La Fayette. Upon noting that the cable was apparently in good condition a power unit was installed at Fort La Fayette for this cable. This unit shown in the schematic diagram Figure 7, consisted of a 2-horse-power two-phase 220-volt 60-cycle induction motor (the current for which was supplied from a commercial source), which was connected by belt

drive to a 1-kilowatt Navy Standard, 500-cycle, 120-volt motor generator. The generator voltage was stepped up to 400 volts

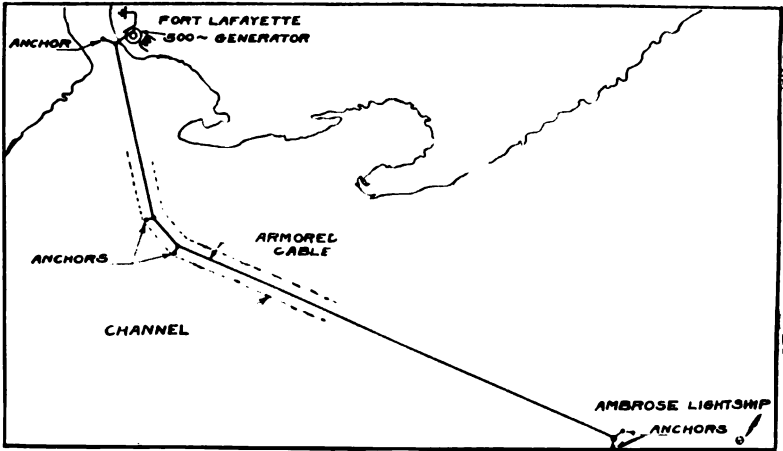


FIGURE 6

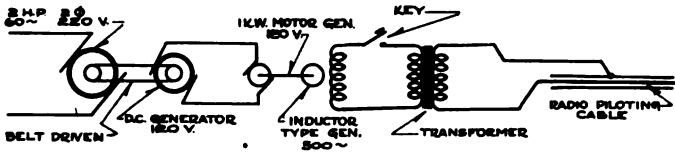


FIGURE 7

by means of a transformer and the output of the transformer supplied direct to the cable. An "Omnigraph" transmitter connected to a Navy Standard relay key was used to send distinguishing signals into the cable. After improving the receiving equipment it was found that the step-up transformer could be dispensed with, thereby simplifying to a certain extent the power unit. A schematic diagram of the simplified circuit is shown in Figure 8.

The cable before being laid was found to have an impedance of 50.2 ohms at 500 cycles and a direct current resistance of 50 ohms. The capacity of the cable measured at 800 cycles was 5.7 microfarad. After laying the cable, it was found that

the impedance of the cable circuit was 123 ohms at 500 cycles, and that there was a lagging power factor, which when measured was found to be 0.80. The inductance (calculated) of the cable was 38.28 millihenrys.

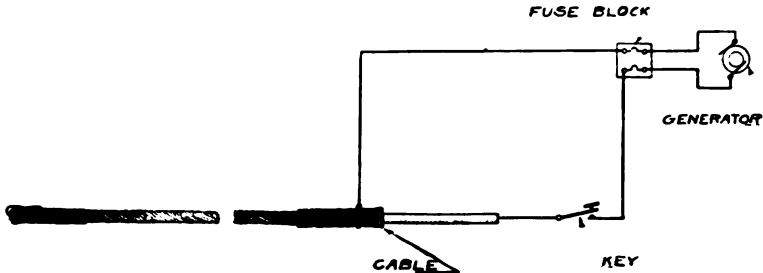


FIGURE 8

Having completed the installation of the power unit, work was started on the receiving apparatus. Three types of coils were constructed, one having 400 turns, one 600 turns, and the other 800 turns, wound on a wooden frame four foot (1.2 m.) square. These coils with the exception of the 400 turn coil, were wound with number 20 Browne and Sharpe gauge double cotton covered copper wire.* The 400 turn coil was wound with number 24 wire† which size wire gave considerable trouble, as it stretched easily. It was, therefore, practically impossible to wind two coils with this wire and have them of the same resistance. It was imperative that both coils have the same resistance and therefore resort was made to re-winding the 400 turn coil with number 20 wire which gave very satisfactory results. The coils were layer-wound, and impregnated with beeswax and boiled linseed oil.

The resistance of the coils are as follows:

<i>Coil</i>	<i>Resistance</i>
400 turn.....	64.3 ohms
600 turn.....	100.2 ohms
800 turn.....	130.9 ohms

Leads from each coil terminated in a watertight junction box on the coil frame, from which portable leads (lead and

* Diameter of number 20 wire = 0.032 in. = 0.082 cm.

† Diameter of number 24 wire = 0.02 in. = 0.051 cm.

armored duplex cable) were led to a double pole double throw switch and from there to a type SE-1,600 two-step audio frequency amplifier and the Navy telephone receivers.

The double pole double throw switch had to be re-designed so that it would at no time completely open the input circuit of the amplifier, as under such a condition the amplifier would howl and deafen the observer. A rotating switch was therefore designed which when rotated made contact with one coil before disconnecting the other coil.

Upon completing work on the receiving equipment, the U. S. S. "Algorma," a large Naval sea going tug, was fitted out with the receiving equipment. The amplifier and switching device was installed in the pilot house and the collector coils were rigged out from the opposite sides of the vessel on a level with the upper deck and approximately amidships. In this condition the coils were about fifteen feet (4.5 m.) above the waterline. The coils were rigged on separate outriggers by use of which the coils could be swung clear of the ship's side in a vertical position to a maximum distance of six feet (1.8 m.).

When all circuits (transmitting and receiving) were found to be in perfect condition the "Algorma" steamed out the Ambrose Channel and conducted preliminary experiments on the system. During these experiments it was found that the steel hull of the "Algorma" had a very pronounced shielding effect on the respective coils, which was not noted during the New London experiments. This shielding was such that it was possible to note easily when approaching the cable the exact location of the cable with respect to the vessel. When the vessel was directly over the cable a signal of the same audibility was received on each collector coil, while if the vessel moved to the right or left of the cable the coil nearest to the cable picked up the strongest signal, while the coil furthest away from the cable picked up a signal of markedly less intensity.

Figure 9 gives an idea of the relative audibilities received by the nearest coil when vessel is at different distances from the cable. It can be seen from this graph that the shielding of the hull of the vessel is responsible for the big decrease in audibility when vessel is directly over cable, and the tremendous increase in audibility when the vessel is approximately 30 feet (9.2 m.) either side of the cable. Further explanation of this point may be given by reference to Figures 10 and 11, which shows apparent effect of the electromagnetic field on the respective collector coils.

This pronounced shielding effect was found to be very helpful since by its use a vessel could keep the maximum signal in the port coil and steer a course which would always keep the vessel on the correct side of the channel.

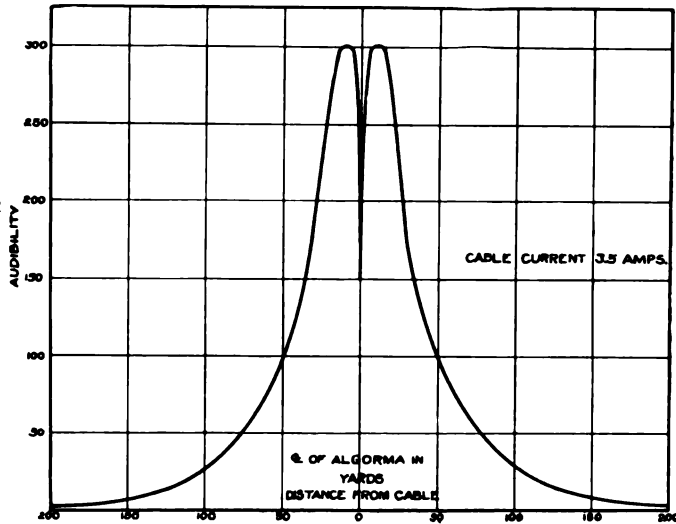


FIGURE 9

After noting the shielding effect, experiments were conducted to ascertain the correct distance that the coils should be from the side of the vessel, the results of these experiments show that the coils should not, for a vessel of the "Algorma" type, be at a greater distance than three feet (0.9 m.) from the side of the

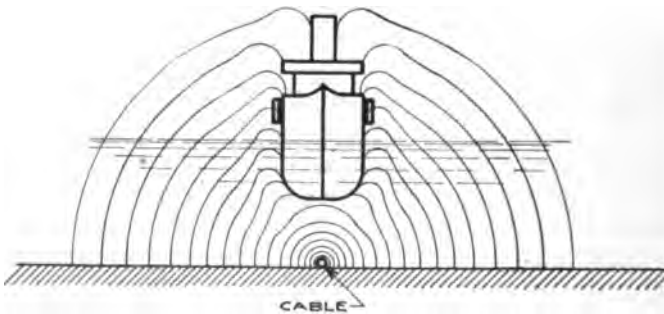


FIGURE 10

vessel. Should this distance be exceeded, the shielding effect of the hull would be annulled to a great extent. It was also discovered that tilting the coil at different angles to the vertical plane was beneficial with reference to increased signal strength.

Before completing the day's work, and on the return trip, the "Algorma" tried various experiments in picking up signals from the cable, chief among which was to approach the cable at right angles to note how far away a vessel could be and still pick up signals from the cable. It was found that the cable could be picked up at a distance of one hundred yards (90 m.), and, by noting the gradual increase in signal strength, the navigator could easily note that he was approaching the cable on a course at right angle to the cable.

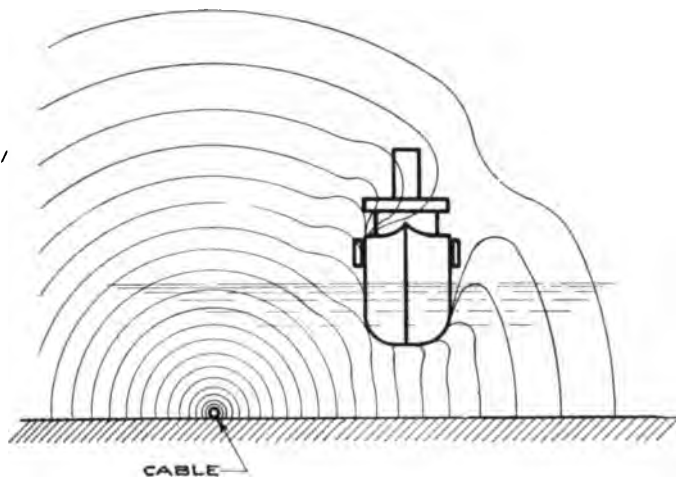


FIGURE 11

Having determined certain major navigational features of the cable on the first trip, the "Algorma" made a second trip on the following day. During the return trip to the city, the pilot house of the "Algorma" was blanked off by means of shutters so that the navigating officer could not see daylight, and by means of the receiving apparatus of the system he was able to bring the "Algorma" thru the Ambrose Channel without receiving aid from any other source. At no time was the "Algorma" more than 50 yards (46 m.) from the cable, except at the 30° turn where the officer deviated 100 yards (92 m.) off his course before

settling on the new course. When consideration is given to the fact that the navigating officer of the "Algorma" was a perfect stranger to the system, having only 'three hours' preliminary instruction, it is to be granted that this new aid to navigation has great possibilities.

During the succeeding tests on board the "Algorma," much information was obtained, chief among which may be given as follows:

A current flow of three amperes into cable is sufficient for all needs in water up to a depth of 200 feet (61 m.).

A collector coil having 800 turns of wire gave twice the audibility as the 400-turn coil, which was to be expected.

It is important that the coils shall have identical electrical constants or else the system will not function properly.

The use of tuned resonant receiving circuits increased the efficiency of system 1,000 percent., under which condition the cable can be picked up at 1,000 yards (920 m.) on either side of the cable, which further increases the possibilities of the system for deep water work.

When using a single tilting coil for determining the location of the cable, the shielding effect of the steel hull of ship blurs both the maximum and minimum signal received by the coil, thereby rendering this method inoperative. Figure 12 shows a graph of signal strength plotted against position of coil relative to a vertical plane when the vessel was 30 yards (28 m.) from cable.

Very little difference was noted in the received signal strength when the coil was submerged below the surface or placed above the surface of water. This gives very valuable information with reference to the future design of coils and their location.

The use of the loud speaker was found to be impractical for this system as the minute energy received at a distance from the cable will not actuate the diafram of a loud speaker, and only when the vessel was within forty yards (37 m.) of the cable was it operative.

The present cable has high resistance, and the use of a larger internal conductor is preferable for efficient operation. At present, the power used costs ten cents per hour, while by use of a larger internal conductor this will be reduced to five cents per hour. This result may be accomplished by an increase of 20 percent over the cost of present cable in the purchase of a new type cable. Should the old type cable be used for future installations, which require 20 miles (32 km.) or more of cable, a special 500 volt machine would have to be designed, while

with the adaption of the larger cable the present Navy Standard motor generator units can be used.

The impedance of the return path thru salt water and earth is theoretically many thousand times less than the impedance of the return path thru the armor, and therefore, the major part of the current will return thru the water, thereby creating a resultant magnetic field. It is thought that the effect of the 500-cycle

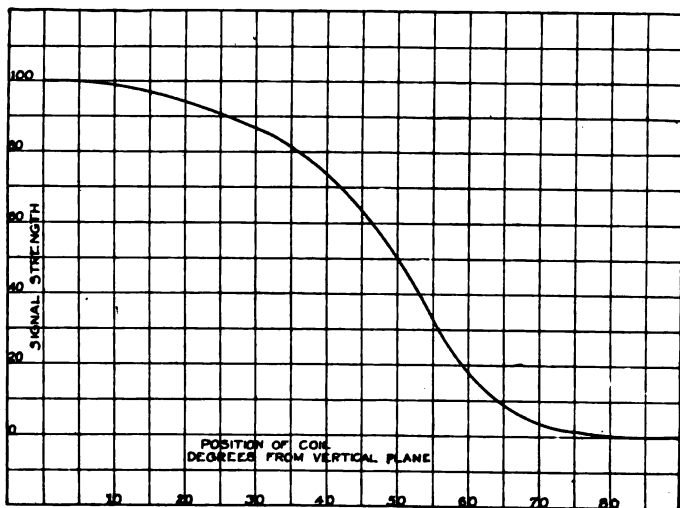


FIGURE 12

current thru the cable has a special concentrating effect on the return current path thru water, whereby it tends to bring this return path close to the cable. This assertion is based on the fact that no stray current return paths were noted, which would have been the case if direct current had been used to energize the cable.

The present connection at the end of the cable between internal conductor and the armor is apparently satisfactory, but it is believed that the resistance of the return path thru earth, water, and armor may be greatly reduced by using a special type of grounding box, a tentative design of which is shown in Figure 13. This box will offer more surface to water and earth, thereby reducing resistance at that part of the circuit, and also it will protect the exposed internal conductor from corrosion.

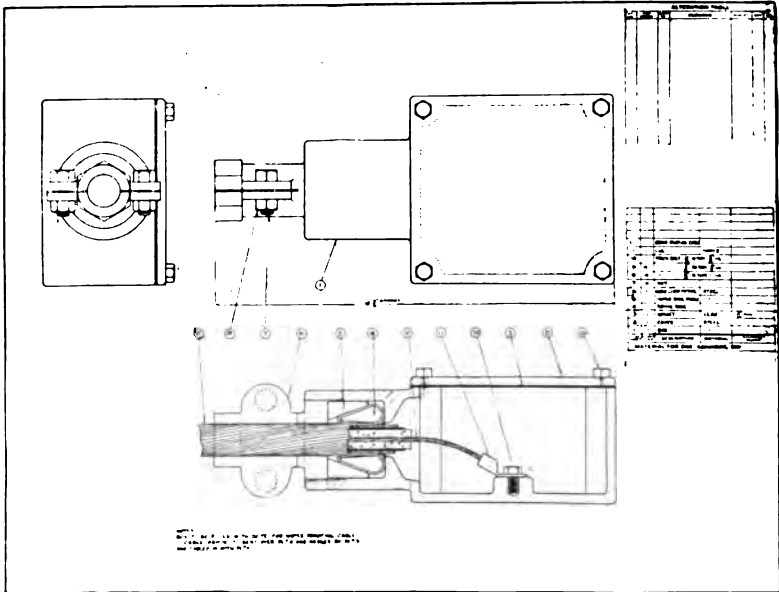


FIGURE 13

THE NEW YORK DEMONSTRATIONS

When the greater part of the preliminary experimental work was completed at New York, arrangements were made whereby the destroyer "Semmes" was assigned for duty in connection with the public demonstration of this system. The object of this demonstration was to bring to the attention of the commercial world the possibilities of this system as an important aid to navigation, especially for the navigation of harbors during foggy or stormy weather.

On October 6th to 9th, inclusive, 1920, demonstrations were given to representatives of various radio companies, shipping interests, pilots' associations, governmental bureaus, naval attachés and others interested in this system. During these demonstrations the various representatives were given an opportunity to inspect the apparatus and personally to pilot the vessel by means of this system.

On each day of the demonstration, during the return trip to the city, a representative of either the Pilots' Association or a steamship company volunteered to pilot the "Semmes" thru Ambrose Channel. In order that the person volunteering

for this duty could better demonstrate the workings of this system, the bridge was blanked with strips of canvas so that it was impossible for the person to note in which direction the ship was being steered. Four persons volunteered for this work, all being able to follow the cable, and at no time were they more than one hundred yards (92 m.) from the cable. On Saturday, October 9, 1920, Captain Battle, of the Cunard Liner "Virgilia," volunteered to pilot the "Semmes" back to port, and gave an excellent demonstration of the possibilities of the system. Captain Battle was a total stranger to the system, but after a little coaching piloted the "Semmes" with such accuracy that he kept the vessel at a distance of 50 yards (46 m.) from the cable, and on the correct side of the channel. This was accomplished by striving to keep the "Semmes" in such a position as to obtain a certain signal strength from the port coil, which operation was entirely practicable.

Captain's Battle's work shows the feasibility of the use of one cable, altho certain persons present, who were technical men, thought that two cables would be better, one cable to be energized with 500-cycle current, and the other with 1,000-cycle current, one cable to be used for outgoing traffic and the other for incoming traffic. One hundred and fifty persons were present at these demonstrations, and approximately ninety percent. were in favor of the single cable. All present were convinced of the practical possibilities of the Audio Piloting Cable, and had nothing but praise for the system.

Among the persons present, interested in the system, from a technical standpoint, were Messrs. E. F. W. Alexanderson, H. Buckley, G. H. Clark, H. L. Curtiss, F. Lowenstein, and G. H. Lewis. The writer had many interesting discussions on the technical and practical details of the system, with the above-mentioned persons, from which much valuable data was obtained.

Special effort was made by the writer to obtain the ideas of numerous seafaring men, on the practical possibilities of the system. The majority of the persons interviewed said that the cable should be laid beyond the light vessel, to a distance of at least five miles, at which place vessels could make good use of the cable, and thereby pick up the light vessel, the sight of which would serve the psychological purpose of giving the navigator more faith in the system and also a point to set a new course from.

The proposed method to be followed, in using the cable, is to pick up the cable at sea and follow it to the light vessel, from which point, by means of a stop watch, speed chart, and the

cable, it will be possible when making standard speeds to know when the ship is approaching the turns in the channel, and thus be doubly assured of safely navigating the ship into the anchorage near the Narrows.

FUTURE WORK

The problem presented to date has been apparently met with the aural receiving equipment, but there is a demand for some kind of a visual device which will indicate directly the location of the cable. Work is now being undertaken by the New York Navy Yard to design such a device.

There are many improvements to be made in the design and installation of the coils, amplifiers, condensers, and switching devices which comprise the aural receiving equipment. Work on this equipment is being done by the New York Navy Yard, in order that Naval vessels can be supplied with this equipment.

It is proposed to build a power unit similar to Figure 14, which will eliminate the use of the "Omnigraph" transmitter and the relay. This unit will consist of a 4-horse-power 220-volt 2 or 3-phase induction motor, a 2-kilowatt 250-volt 500-cycle generator, an exciter for supplying direct current for generator fields, and a commutator for sending characteristic

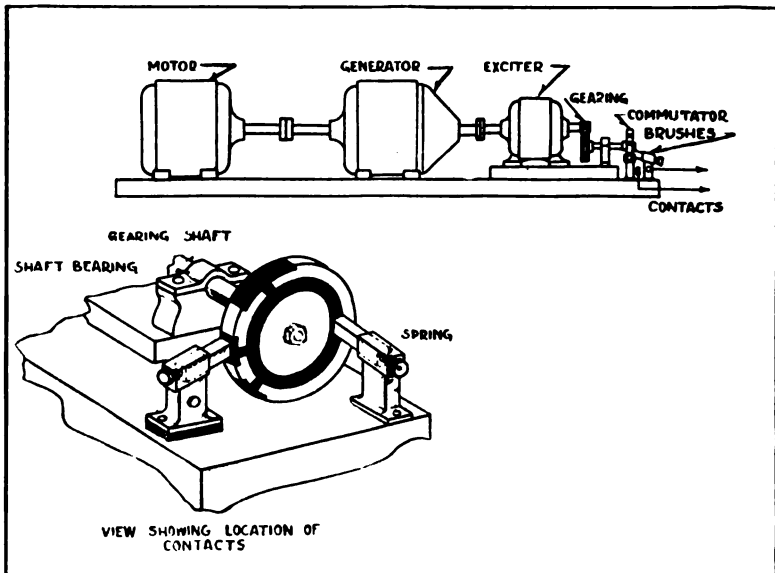


FIGURE 14

signals into the cable. The generator or exciter field rheostats can be used in place of a series regulating device in the cable circuit, by the use of which rheostats the current flow into the cable can be efficiently varied within desired limits.

The cable for the New York Harbor will most likely be laid to a point at least one mile (1.6 km.) beyond the light vessel, from which point it will divide and be laid in a north-easterly and southerly direction, for a distance of approximately five miles (8 km.) Such a combination of cables could take care of transatlantic and northern bound traffic. The northeasterly cable could be an additional safeguard to keep vessels from running aground on Long Island.

It is understood, upon completion of the New York experiments, that the Bureau of Lighthouses, Department of Commerce, will take over the work of installing and maintaining cables in the important harbors of this country.

Arrangements are also being made at the International Communication Conference, now in session at Washington, whereby this aid to navigation will be internationalized and adopted by all countries having seaports.

CONCLUSIONS

The aural system in its present state is a success from a navigational standpoint. Seafaring men are entirely in favor of immediately applying the system for navigating vessels thru harbors, during inclement weather.

The installation of cable in harbors costs comparatively little in comparison with other navigational aids. Thus, the total cost of the proposed New York Harbor installation will not exceed \$50,000, which is about equal to the cost of certain individual beacons and buoys now used in and about the New York Harbor.

When vessels of the Cunard, White Star, and other steamship lines are detained outside of the harbors, because of inclement weather, the hourly maintenance cost per vessel is from \$500 to \$4,000. Figuring the cost of receiving equipment for the Audio Piloting Cable system at approximately \$1,000 per vessel, it can be seen that the equipment will pay for itself within a period of a few hours. It is also thought that the insurance companies will give lower rates to vessels fitted out with this equipment, which will be an additional benefit to the ship owner.

The advantages of the system are numerous and open the

way to greater safety at sea, especially when this system is used in connection with the present chain of United States Naval Radio Compass Stations. Vessels, when approaching the coast, can obtain radio compass bearings and from these bearings steer a course for the mouth of the harbor, at which place they will pick up the cable and follow a course over the cable to the anchorage inside of the harbor.

There are numerous other applications of the induction principle which will further simplify navigation, but as it is not intended to cover these in this paper, no description of them will be given.

In concluding, the writer desires to mention the names of the following persons who were responsible for the successful conclusion of the experimental work on this new system: Commander S. C. Hooper, U. S. N.; Commander R. F. McConnell, U. S. N.; Lieutenant-Commander E. H. Loftin, U. S. N.; Lieutenant H. W. Kitchin, U. S. N.; Ensign R. G. Sidnell, U. S. N. R. F., and Expert Radio Aid Harrison J. Lang.

SUMMARY: A summary of the historical development of audio frequency induction methods of piloting ships carrying coil receivers along current-carrying cables making the desired course is given.

A number of experiments carried out at New London and in New York Harbor are described in detail. The design and mode of use of the cable and the receiving apparatus are fully discussed; and the practical applications of the various systems of audio frequency piloting are given.

DISCUSSION

Greenleaf W. Pickard (by letter): In reading Mr. Crossley's interesting paper I am impressed by the striking audibility curve of Figure 9, with its approach to a null point when the steel vessel carrying the pick-up coils is directly over the cable. As the author points out, this sharp change in sound is very helpful, and I am wondering how this desirable feature could be retained, in the event that our Shipping Board's non-magnetic cement ships ever became popular.

Despite the near-century of history given by Mr. Crossley, I cannot help feeling that the art of induction piloting is yet in its infancy. We are all familiar with the desirability of a sharp null point in radio direction finding, and it would seem possible to do the same thing for an induction system. For example, if instead of a single cable with earth return, a pair of parallel insulated cables are laid, spaced apart say twenty meters (60 feet), and joined at their far ends, then a single pick-up coil, mounted amidships in a vertical fore-and-aft plane, would be unaffected when the vessel was directly over the center of the cable system, but would begin to receive with the slightest deviation to either port or starboard of this line, and the reception curve in a vertical plane normal to the direction of the cables would resemble Figure 9, but with an absolute null point at the center. A further advantage of this arrangement would be that the cable system is now insulated, and the station ammeter and a ground detector would furnish instant information of any mishap to the cable.

Over a suitable network of submerged cables, traversed by currents of controlled intensity and phase relation, any imaginable magnetic field might be made to hover, so molded as to produce any desired effect upon a coil system carried by a vessel. Clearly, we are at the very inception of a new art.

I am inclined to question the statement that "the effect of the 500-cycle current thru the cable has a special concentrating effect upon the return current path thru water, whereby it tends to bring this return path close to the cable." If this were so, it would be equivalent to putting one conductor of the circuit in a tube constituting the return conductor, and this, since the time of André Marie Ampère (who, by the way, deserves inclusion in Mr. Crossley's general history), has been recognized as a combination without external magnetic field.

Robert H. Marriott (by letter): Located, as I am, across the United States from New York, the notice of the reading of Mr. Crossley's paper did not reach me until the day of the meeting. This accounts for a brief discussion by telegram which readers may desire to have explained in some detail.

It appears that we are at the point where we have the science without the art or the theory without the practice, or the demonstrations without the service. Service is what the public needs and what the engineer and scientist want to deliver.

Many things have been said and repeated in scientific dignified terms. A little variation, such as less dignity in expression, may help to bring out what is best.

To make this anticipated art what we believe it should and can be, will require perseverance, energy, and then more perseverance. We should profit by our experience in the development of radio to prevent lost motion, friction and procrastination.

The "cable theory" family has grown up, the "demonstration" family has grown up, but the "service" children apparently have never survived beyond the "lustly yelling period." Expert diagnosticians would probably attribute the pre-natal or early demises to lack of vitality, malnutrition or unsuitable environment. Young physicians freshly equipped with a large quantity of second-hand information might offer more interesting theories.

It looks as if Congress would have to furnish nearly all the food by appropriations. Depending on steamship companies for any appreciable nourishment may result in arrested development, cripples or more deaths.

A policy which makes the success or failure dependent on only one factor, namely, sufficient appropriation by Congress, should result in success, while a policy depending on a number of factors such as several steamship companies' appropriations plus congressional appropriations may result in failure and loss of successive appropriations.

Since the United States is now a maritime nation and the efficiency of its merchant marine depends, in part, on how easily and quickly the vessels enter and leave the ports of the United States, it is quite proper for Congress to see to it that their entrances and exits are made easy.

Ample current in the cable would make it easy for the steamship companies to do their part. Sixty cycle power of sufficiently high voltage, from commercial mains, would reduce first cost and operating costs. Duplicate low resistance cables would

increase reliability and serve for a wide range of developments and refinements for commercial and military purposes.

Dealing with the first thought,—short-sighted instrument manufacturers and others may be against making it simple and inexpensive for the steamships to receive the pilot signals, because the more complicated and expensive the receivers are, the more manufacturers or service companies could charge the steamship companies or Government in profits on single units or for maintenance.

However, experienced manufacturers and service companies know that handicapping an art in its infancy results in an unprofitable, uncertain demand or no demand, while a healthy established art is a certain market for improvements.

Steamship managements and steamships are complex and there are numerous managements and numerous ships. Installing anything new on the ships means that accounts must be shifted, orders must be shifted, habits must be shifted, prejudice must be shifted, and materials must be shifted. Those accounts, orders, habits, prejudices, and materials have inertia and there are lots of those inertias, and they are not all alike. Lots of inertia means that a big force must be applied to get service or that the new thing must be designed to cause minimum shift in accounts, orders, habits, prejudices, and materials. Plenty of current in the cable seems to be the key to the situation.

A big force such as a compelling law is probably not a possibility at this time. Therefore, the practical thing to do, seems to be to minimize the difficulties attached to installing, operating, and maintaining receivers on vessels. Simple receivers can be used if there is enough current in the cable.

Using weak audio frequencies in the cable means that amplifiers will be required on ship board. The first cost of amplifiers alone may cause some of the various human elements in a steamship management to hesitate, postpone, dicker, or cancel the project. Also various individuals connected with the management usually make private inquiries of radio operators, inspectors, engineers, and their amateur friends and relatives. From these various sources they can get stories to the effect that amplifiers howl, the bulbs burn out, the batteries run down, the transformer circuits break open, the apparatus must be kept dry, a great deal of skill is required to locate the coils and apparatus properly and to operate them, lighting circuits and sparking generators and electrolysis and striking metal of the ship's machinery and vibration make noises in the amplifier, two amplifiers

will not work alike, and one amplifier will not work twice alike. Also they can get more or less contradictory stories to the effect that amplifiers are wonderful things which anybody can operate. One class of salesmen may try to sell amplifiers to the steamship companies, which he claims will give no trouble, while another class of salesmen may try to sell them a service on the basis that a service company is necessary to instal the entire receiving system properly, instruct the users, and maintain the system. Another class of salesmen may try to sell them a service which also includes operation by their radio operators. As a result, the steamship management may be more or less divided in opinion and have a general idea that an inexpensive system might not be in working order when needed and a more expensive service might run them ashore instead of in the channel. The net result would probably be for most of the steamship companies to wait for some other company to try it first. Such waiting means delay if not failure because fogs do not occur relatively often. For example, at a given port, fogs which could not be traversed may not exist more than a total of one hundred hours per year or a little over one per cent. of the time. This may mean that a given vessel would have only one chance in a hundred of having an opportunity to use its apparatus in that port. And if only a few vessels were equipped there might be a long time between convincing demonstrations or a general discouragement as to the "worthwhileness" of the device, while with hundreds of vessels equipped, the cable price should be quickly saved to the nation. Such valuable services would keep up an enthusiastic interest and service.

The equipment of numerous vessels seems to be necessary to render sufficient service to create a permanent practice and public service. It appears that the surest and most effective procedure for such a port as New York, is to install a cable supplied with sufficient current to be receivable on shipboard with a simple durable coil and a pair of telephone receivers and a duplicate auxiliary cable for use in case the first cable is damaged. In a port like New York the cable would probably be damaged by anchors until a large number of ships were equipped with receivers so they would have no excuse for anchoring. These simple receivers would be so inexpensive and durable as to remove hesitation on the part of the steamship companies.

As the development of this art is for the public service, the Government could also quite properly expedite the equipping

and reduce the ratio of expense to service by such expedients as follows:

(a) Giving steamship companies the data for construction of receiving coils. •

(b) Advising steamship companies where coils and telephones can be purchased.

(c) Loaning sets of coils and telephones to each steamship company.

(d) Loaning coils and telephones to the masters, mates, and pilots to be used between pilot ship and dock.

(e) By operating the cable at certain hours on heavy sailing days for practice.

(f) By notifying the vessels as to when these practice signals are to be sent and requesting reports on how they were received.

A year of such procedure could result in more than a majority of the United States vessels being equipped and a number of instances of saving in time and money.

This latter situation should make a law possible if necessary, which law would compel all United States vessels to be equipped.

The co-operating with the steamship companies in this respect and the removal of the need to anchor should automatically stop the fouling of the cable.

With the art once established, the steamship companies would want improvements such as visual indicators, automatic devices, and special services and apparatus from service companies and manufacturers. Military branches would have at their disposal means for developing useful devices and for the guiding of the government craft in war and peace times.

Five years from now, New York harbor can have forgotten it was ever without pilot cable service or it can be expecting such a service some day.

RAPID DETERMINATION OF DISTRIBUTED CAPACITY OF COILS*

BY

RALPH R. BATCHER

(WESTERN ELECTRIC COMPANY, NEW YORK)

The common method of measuring the distributed capacity of a coil is to determine by means of a standard condenser connected across its terminals the amounts of capacitance necessary to place it in resonance with a number of known wave lengths. By plotting a curve between the values of wave length squared and the shunted condenser capacitance, a straight line is produced which, if extended, cuts the base line (or the capacity axis) at a point corresponding to the distributed capacity of the coil.

By means of an alignment or nomographic chart, after the plan of the one reproduced herewith, the necessity of making a curve and much of the procedure in taking the measurements are eliminated.

Figure 1 represents a typical set up for such measurements. The condenser C is first adjusted to a value about two-thirds or three-fourths (depending upon limits of scale C_1 on chart) of its maximum value and the wavemeter is then adjusted until it is resonance with the circuit LC . This value of capacitance is

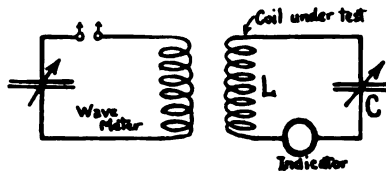


FIGURE 1

called C_1 . Then the wavemeter is adjusted to a wave length just one-half of the first value and C is then varied until it is in tune with the new wave length. Designate this last capacitance by C_2 .

* Received by the Editor, August 30, 1920.

Then, referring to the chart, a straight edge is so placed across the scales that it will cut the C_1 and C_2 scales at the values obtained during the test. Where this line crosses, the C_D scale will determine the distributed capacity.

The accompanying chart is made as follows: Three perpendicular lines are constructed, such as C_D , C_1 , and C_2 , so that the distance between C_D and C_1 is three times the distance between C_1 and C_2 . The scales are laid off so that one unit of capacitance is equal to one unit of distance on the C_D scale, one-twelfth unit of distance on the C_1 scale, and four-ninths unit of distance on the C_2 scale. This arrangement of scales represents only one of a number of possible arrangements that will function in the same manner.

For more accurate results, the distributed capacity can be found starting with other wave lengths as a basis, and the resulting values averaged.

SUMMARY: A measuring method and chart for the rapid determination of the distributed capacity of a coil are given and explained.

MODULATION IN RADIO TELEPHONY*

BY

R. A. HEISING

(WESTERN ELECTRIC COMPANY, NEW YORK, N. Y.)

1. The radio telephone, as an improvement on the radio telegraph, depended upon the development of three things: (a) a source of sustained radio frequency currents, (b) a voice-operated means for controlling the amplitude of the radio frequency oscillations, and (c) an amplitude indicating detector. The first and third of these requirements were first met. Sustained wave generators of various forms and rectifying detectors were brought out about fifteen years ago, but a satisfactory modulator was not secured until later. The actual realization of the radio telephone was so dependent upon the modulator that the development of the latter may be considered the most important step in the production of the radio telephone.

The early experimenters in radio telephony made use of the ordinary telephone microphone as a modulator. Its inability to handle large powers, or to work in parallel was quickly observed. Building large microphones did not solve the problem and attention was diverted in other directions. To accomplish the desired results, many complicated mechanical and electrical contrivances were devised, but they did not prove satisfactory. Technically workable radio telephone systems comprising these crude modulators and sustained wave generators had been devised when there came into the field a new instrument which was destined to revolutionize completely the major part of the art.

2. THE AUDION

With the invention of the audion or 3-element thermionic amplifier by de Forest, the art of radio communication received its most valuable contribution since its conception. The audion has properties such that all three requirements for practical radio telephony were solved at once. Being essentially an amplifier, it can generate oscillations as can all amplifiers. It

*Received by the Editor, November 1, 1920. Presented before THE INSTITUTE OF RADIO ENGINEERS, New York, December 1, 1920.

can modulate oscillations because it acts as a variable resistance in its amplifier action. It can detect oscillations because of the shape of its characteristic curve, and it can amplify weak signals to any degree of loudness. It is, because of its multitudinous uses, the most universal element in the radio field.

As a modulator, the audion may be used for any type of generator: mechanical, arc, or audion generator, but the manner in which it is used varies somewhat in the different cases. The various forms in which it can be used in connection with the audion generator are considerably greater in number than the forms in which it can be used in connection with the others. In this paper there will be described only those forms which are efficiently applicable to medium and small power sets and in which the generator is of the audion class.

3. THE MODULATED WAVE

Before going into the discussion of modulation systems, it may be desirable to say a word or two about the modulated wave. By a modulated wave or a modulated current is meant a sustained wave or radio frequency current the amplitude of which varies in accordance with the desired signal to be sent. An example is shown in Figure 1. The current is represented by the equation

$$i = A \sin \omega t (1 + K \sin \psi t) \quad (1)$$

where the average sustained amplitude is A when no signal is being sent. As soon as a signal wave, such as the simple sine wave indicated in the figure, is to be transmitted, the amplitude of the radio frequency wave varies accordingly as shown. It is indicated as varying between the limits of zero and $2A$ in the

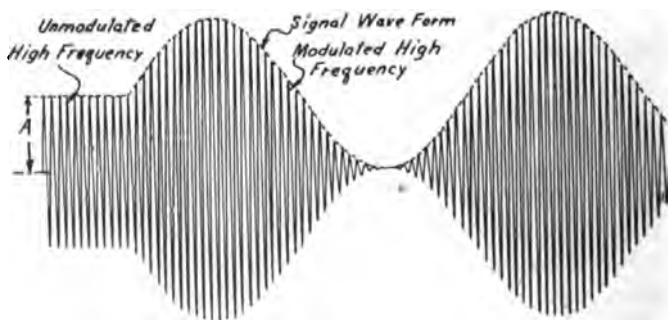


FIGURE 1—Completely Modulated Antenna Current ($K=1$)

diagram. This wave is a completely modulated wave. Stated mathematically, we would say that in equation (1) the constant K is unity. In case the signal wave is of such an amplitude as not to reduce the radio frequency amplitude to zero at any time, we have an incompletely modulated wave as shown in Figure 2. In this case, K is less than unity. Such a condition is very undesirable. It wastes power. A received signal is dependent upon the variation in the transmitted wave amplitude rather than upon the antenna current reading. The wave in Figure 1

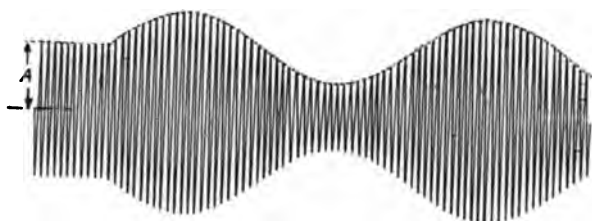


FIGURE 2—Modulated Antenna Current ($K = \frac{1}{2}$)

will give four times the received signal energy of that in Figure 2 altho the antenna currents will give approximately equal ammeter readings. As much power is required for the second signal as for the first, so that the efficiency of the second is only one-fourth that of the first. We should, therefore, always use radio systems which will give complete modulation.

In actual telephonic conversations, the wave is never completely modulated at all times. A speech signal consists of several frequencies of different amplitudes. It is expected that the louder notes will completely modulate the wave while the weaker ones will not. This allows the possibility of the amplitude variation being reproduced at the receiving end. It is usually best so to construct the apparatus that the loudest notes will tend to overmodulate the wave. They are then distorted a small amount but the distortion is not objectionable. The increased volume of the weaker notes more than makes up for the distortion of the stronger ones, if the latter do not consist of more than ten or twenty per cent of the signal.

A high frequency current such as expressed in equation 1 and shown in Figure 1 represents radio frequency power in the antenna which varies with time as shown in Figure 3. The expression for high frequency power

$$i^2 R = RA^2 \sin^2 \omega t (1 + K \sin \psi t)^2 \quad (2)$$

when integrated over the radio frequency cycle gives

$$p = \frac{RA^2}{2} (1 + K \sin \psi t)^2 \\ = \frac{RA^2}{2} \left(1 + 2K \sin \psi t + \frac{K^2}{2} - \frac{K^2}{2} \cos 2\psi t \right) \quad (3)$$

This gives the power as consisting of $\frac{RA^2}{2}$ when not signalling ($K=0$) and having single and double frequency components when a signal is sent. If K is unity, the effective radio frequency power rises to a peak value equal to 4 times the non-signalling value and has an average value of $3/2$ the non-signalling value.

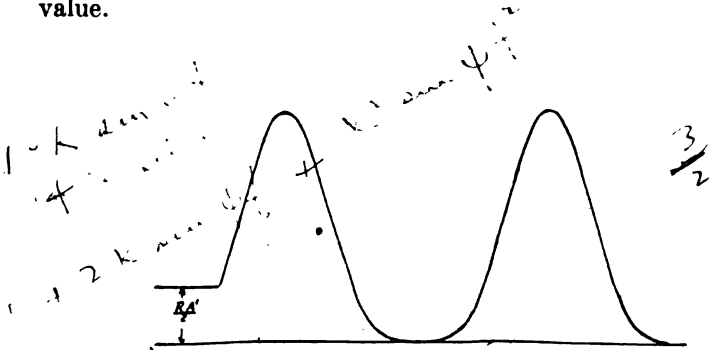


FIGURE 3—Effective Power of Radio Frequency Current in Antenna

Integrating (3) over a signal frequency cycle gives

$$P = \frac{3(A^2 R)}{2} \quad (4)$$

as the radio frequency modulated power delivered to the antenna. That is, the power content of a completely modulated wave is $3/2$ the power content of an unmodulated wave of the same average current. It is to be noted from this that, since the antenna ammeter reads effective value of current, the reading will rise by the factor $\sqrt{1.5}$ when a wave is modulated.

The modulated current in equation 1 can be resolved into a carrier wave and two side frequencies. The power contained in the components is:

Wave		Amplitude	Power
Carrier	ω	A	$\frac{A^2 R}{2}$
Upper side frequency	$\omega + \psi$	$\frac{A}{2}$	$\frac{A^2 R}{8}$
Lower side frequency	$\omega - \psi$	$\frac{A}{2}$	$\frac{A^2 R}{8}$

(5)

This indicates that $\frac{1}{3}$ of the radio frequency power is in the two side frequencies and $\frac{2}{3}$ in the carrier. In systems where the side frequencies only are transmitted and the carrier is not, but is put in at the receiving station, we will require only $\frac{1}{3}$ the radio frequency power to produce the same signal as can be produced by the side frequencies with the carrier frequency. This greater efficiency is often only apparent in tube sets, as many inefficiencies enter into the construction of such a system which neutralize much of the advantage to be gained. This type of radio signal is not, however, common, while the one indicated in the diagram and in equation 1 and containing the carrier is, and only such systems as produce the latter type of wave will be discussed.

4. SYSTEMS OF MODULATION

Systems of modulation may be classified in any number of ways. One classification divides them up into systems of:

1. Absorption.
2. Detuning control.
3. Amplification control.
4. Non-linear or assymmetric conductance.
5. Generation control.
6. Frequency conversion.

This will fairly broadly cover the field. There are, however, many systems which do not fall exactly under any one of these classes but which may be combinations of two or more. The radio art is growing so rapidly that this classification may have to be extended at any time.

5. VAN DER BIJL SYSTEM

One of the earliest radio systems we used is known as the van der Bijl system (United States Patent Number 1,350,752). It is the system which we employed in our experiments at Arlington in 1915 when we transmitted speech successfully from Arlington to Paris, San Francisco, and Honolulu. The system

has been described briefly in the paper by Messrs. Craft and Colpitts in the "Proceedings of the American Institute of Electrical Engineers" of March, 1919. The circuit used at Arlington is shown in Figure 4. In Figure 5 is shown the modulator circuit together with a diagram which illustrates the principle of operation. This system is based upon the fact that the audion's characteristic curve is a parabola. It is classified under the head of modulation by amplification control.

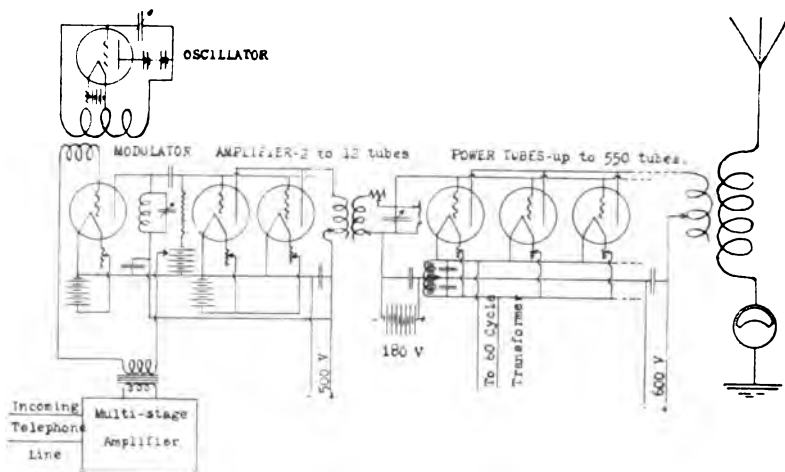


FIGURE 4—Experimental Circuit at Arlington, 1915

The equation of the tube as given by van der Bijl is

$$i = A(E_b + \mu E_c + K)^2 \quad (6)$$

The slope of the curve is given by the equation

$$\frac{di}{dE_c} = 2A\mu(E_b + \mu E_c + K) \quad (7)$$

and is a straight line function of the potential on the grid. A characteristic curve and a curve indicating this variation in slope are shown in Figure 6. These equations hold only as long as E_b is positive, E_c is negative, and $E_b + \mu E_c + K$ is positive. In this system use is made only of that part of the curve for which these equations hold.

If a small radio frequency voltage is impressed upon the grid, the amplitude of the radio frequency current in the plate circuit

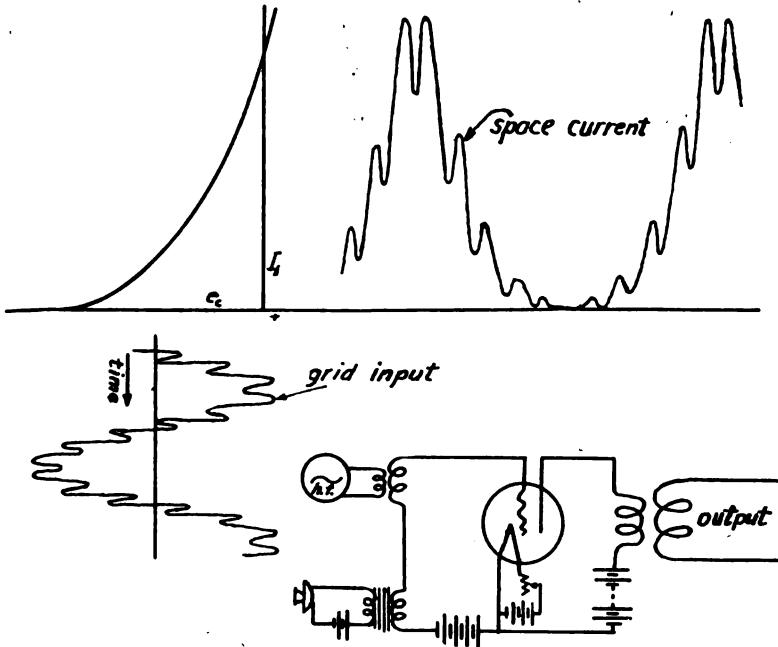


FIGURE 5—van der Bijl Modulation System

depends on what part of the characteristic curve the voltage happens to operate upon. If it operates where the slope is large the alternating plate current will also be large. If it operates near the bottom of the curve where the slope is small, there will be scarcely any alternating plate current. By sliding the small alternating voltage up and down the curve, a current with a continuously varying amplitude may be obtained, the magnitude of which is proportional to the curve slope at the point of operation. Thus by using the signal voltage to slide the small radio frequency voltage up and down the curve, it is possible to produce in the plate circuit an alternating current, the amplitude of which varies according to the signal voltage.

This is illustrated in Figure 5 by impressing upon the grid the voltage wave indicated with the time axis running downward. The amplitude of the radio frequency voltage is smaller than that of the signal voltage and the amplitudes of both are so chosen that only that part of the curve referred to before is operated upon. The resulting space current is then of the form indicated by the curve, the time axis of which runs to the right. Inspection will show that the amplitude of the radio frequency

current is not the same at all times but that it varies in accordance with the signal. On taking out the radio frequency current by means of a tuned circuit it will be found that the envelope of the peaks of the wave is of the form of the desired signal, or in other words that the radio frequency current is modulated in accordance with the signal to be transmitted. The small amount of modulated radio frequency current secured is then amplified until of sufficient power to be put into the antenna.

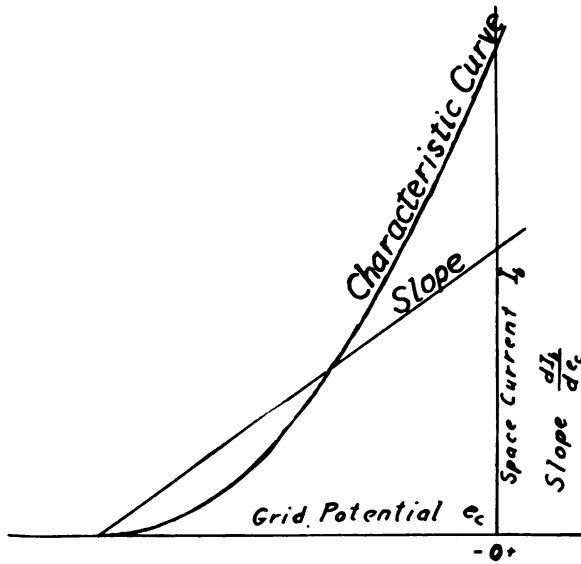


FIGURE 6—Characteristic Curve and Curve Slope of Audion

The efficiency of this system is determined by the last amplifier as is that of all systems in which a small amount of power is modulated and then amplified. By efficiency is meant plate efficiency only: modulated radio frequency power into the antenna circuit divided by plate power supplied. Filament power is not considered. The last stage of the amplifier takes most of the power and will be the only one considered in the simple discussion to follow. The power taken by the last stage is always $E_b I_b$ in a proper amplifier,¹ and the maximum power which it can deliver to the antenna is $\epsilon E_b I_b$. ϵ is the maximum steady power plate circuit efficiency of the amplifier and runs from 25 to 90 percent, depending upon the type of amplifier.

¹See Appendix for a definition of a "proper amplifier."

The power delivered to the antenna is given by equation 3 as

$$p = \frac{RA^2}{2} (1 + K \sin \psi t)^2 \quad (8)$$

The maximum value that this has at any instant is (for $K=1$) $2RA^2$ and this peak value must be supplied by the amplifier tubes. Therefore

$$2RA^2 = \epsilon E_b I_b \text{ or } RA^2 = \frac{\epsilon}{2} E_b I_b \quad (9)$$

Substituting in (8) and integrating over a cycle we get

$$p_{av} = \frac{3}{8} \epsilon E_b I_b \quad (10)$$

or the efficiency of an amplifier delivering modulated current is only $\frac{3}{8}$ the plate circuit efficiency of the amplifier itself under maximum power conditions. The efficiency is lowered further if we consider the power consumed by the oscillator, modulator, and any previous amplifier stages.

The low efficiency of amplifier systems in comparison with some of those systems to be described later is caused by the requirement that full plate current be supplied even when no signal is being sent. Under this condition, the plate efficiency is about $\frac{1}{4}$ the maximum possible and a lowering of the system's over-all transmitting efficiency results. Sometimes it is suggested that this inefficiency be overcome by applying such a negative voltage to the tubes that the space current is reduced to a small amount under the non-signaling condition.² The over-all efficiency is thus raised almost to that of the other systems, but a big distortion occurs. Only half the modulated input wave then operates upon the grid and the alternating space current has an amplitude approaching the square of the input instead of a direct proportionality. This distortion is much greater than that produced by the curvature of the tube's characteristic curve and may be great enough to be objectionable. True amplification of the original small amount of modulated power is thus not secured. The choice between quality and efficiency in amplifier systems is a question to be decided according to requirements.

In the set used at Arlington in 1915, a small tube operating on a plate potential of 120 volts generated a sustained wave of constant amplitude. The incoming telephone line was provided with an amplifier in order that the signal impressed on the modulator would be of sufficient amplitude to carry the radio frequency sustained wave over the entire range of the modulator's

2. ²See Appendix for a definition of an "improper amplifier."

characteristic curve. The modulated radio frequency current resulting was taken out by means of a tuned circuit and impressed upon two stages of amplifiers, the last one of which delivered power to the antenna. The first amplifier consisted of from 2 to 12 audions in parallel depending upon the wave length and the number of power tubes used. The power amplifier consisted of from 300 to 550 audions. Tuned circuits were used to take the radio frequency wave out of the first amplifier and impress it upon the grids of the power tubes. The amplifiers in this circuit differed in no way except size from those which would be constructed to amplify any single frequency. A few resistances were used in the various tuned circuits in the amplifier for the purpose of stabilizing it against oscillations.

The filaments of the power tubes, and for a time of the first amplifier, were lighted by alternating current. In order to reduce the disturbing effect upon the modulated current by the alternating potential along the filament, a choke coil in which a middle tap was provided was connected across the leads. This tap was used as a common point for both the grid and plate circuits. This worked successfully and no disturbing effects due to the alternating filament potential were noticed at the receiving stations.

Photographs of some of these pieces of apparatus are given in Figures 7 to 10. Figure 7 shows the modulator and the amplifiers. The modulator tube with its circuit was in a box by itself. The amplifier tubes were partly in the box containing the circuits and partly in an additional box. All of these boxes were lined with sheet iron which was grounded, so as to reduce electrostatic disturbances and magnetic feed-back from the antenna or antenna circuit. The power tube racks are shown in Figures 8, 9, and 10. These racks were built to hold 50 audions each. Some of the audions were mounted and some were not. Some of the racks were installed and put into operation before a base had been designed for the tube.

It may be interesting to know that we had some bad quality trouble on account of the low resistance of the antenna. When working at 6,000 meters, the antenna inductance was about 1 millihenry and the total antenna circuit resistance was slightly under 2 ohms. These gave a sharpness to the antenna circuit tuning which reduced markedly the amplitude of the side frequencies. The sharpness was such that with loose coupling to the antenna, the quality was changed enough to make voices almost unrecognizable. It was therefore necessary to couple

more closely than would be done to get the maximum power which could otherwise be secured.

The operation of the set as a whole was satisfactory. Completely modulated power was easily obtained and was of very good quality.

A slight modification of this radio system is given in Figure 11 (Patent Number 1,199,180). It consists of a modulator tube having 2 grids instead of one and having the oscillator supply

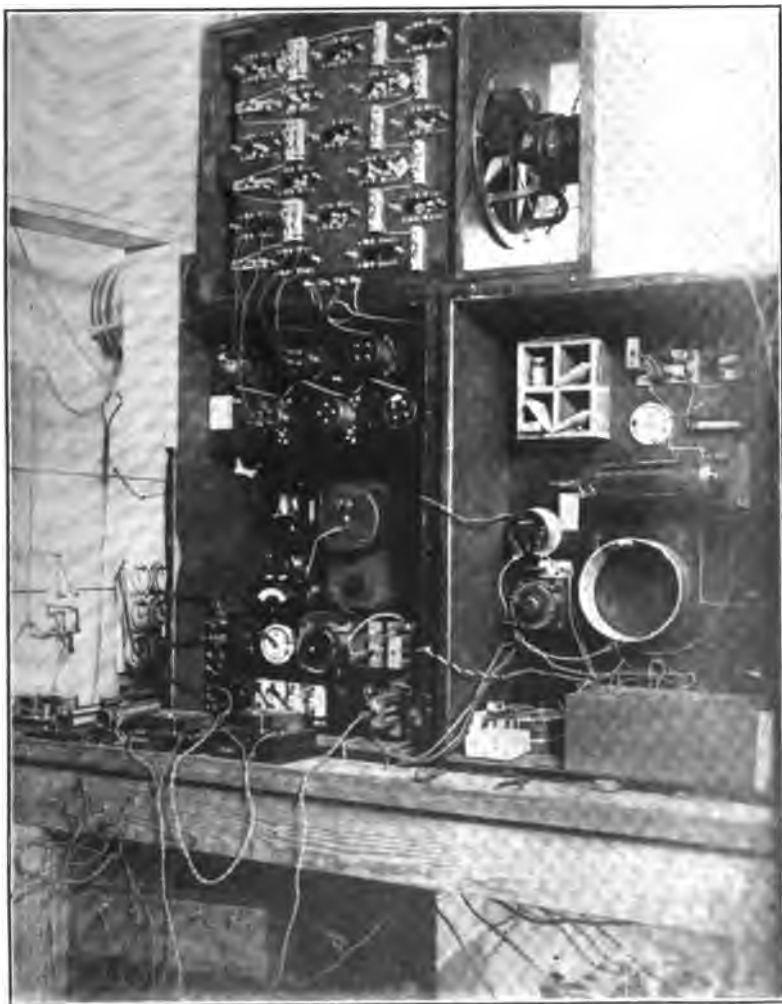


FIGURE 7—Modulator and First Amplifier in Arlington Experimental Set, 1915

a sustained wave to one grid while the signal frequency was impressed upon the other. The action of the two grids with their separate emf's is approximately the same as that of a single grid with the two emf's superimposed. Beyond the slightly different modulator construction, the system does not differ materially from that of valve set B1].

6. COLPITTS' SYSTEM

Under the head of systems for the control of generation may be placed the radio transmission system devised by Dr.



FIGURE 8—Power Tube Racks, First Group

E. H. Colpitts and shown in his Patent, Reissue number 14,380. The diagram is given in Figure 12. The principle in this case is that the grid of the tube, being a control member, can control the amplitude of the generated oscillations according to a signal impressed upon it. A modification, in which the circuit arrangement is different but which retains the principle, was made by Logwood (Patent number 1,218, 195) and is shown in Figure 13.



FIGURE 9—Power Tube Racks, Second Group

This type of radio system has not proved entirely satisfactory. Its greatest objection is that it does not readily give complete modulation. A control curve for a circuit of this type is shown in Figure 14. This curve gives antenna current as a function of the control potential applied to the grid. As long as the signal is small no trouble is encountered. If the signal potential works between the points *X* and *Y* on the curve, a modulated current such as curve *I* in Figure 15 is produced. If, however, the signal is a trifle stronger and goes to the left of *X*, a break

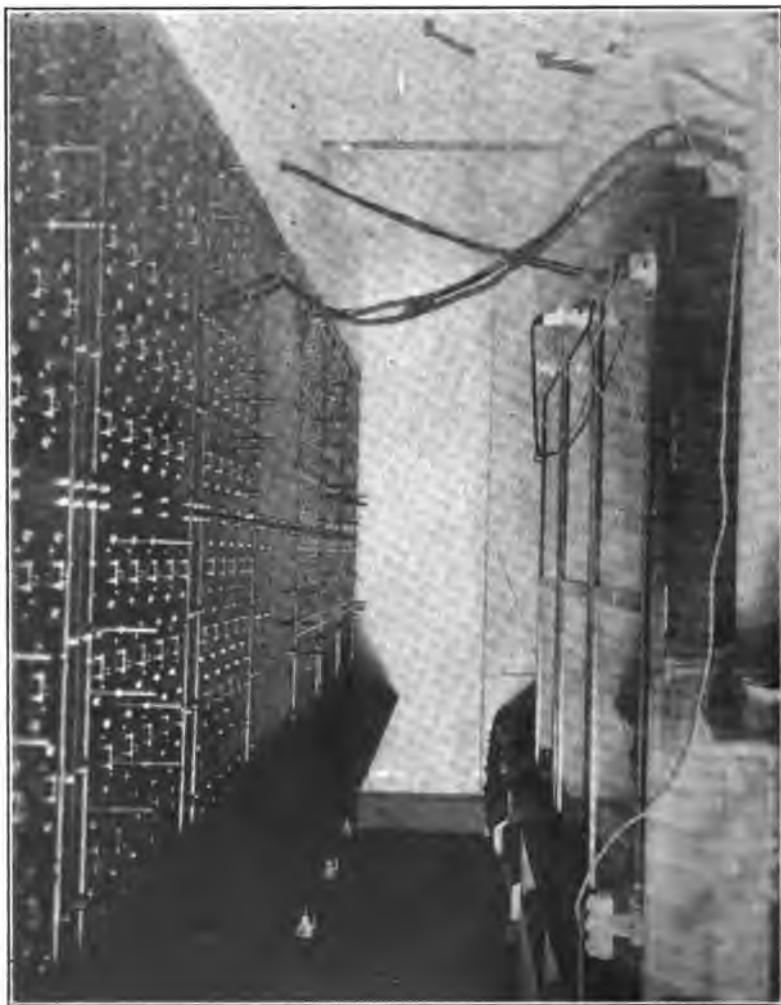


FIGURE 10—Power Tube Racks, Third Group

occurs. Oscillations cease abruptly at that point and do not begin again on the return movement until the point *B* is reached, when they start as suddenly. There is, therefore, a region between the dotted lines erected at *A* and *B* in which oscillations occur only so long as the controlling signal stays upon the upper control curve and does not pass to the left of the point *A*.

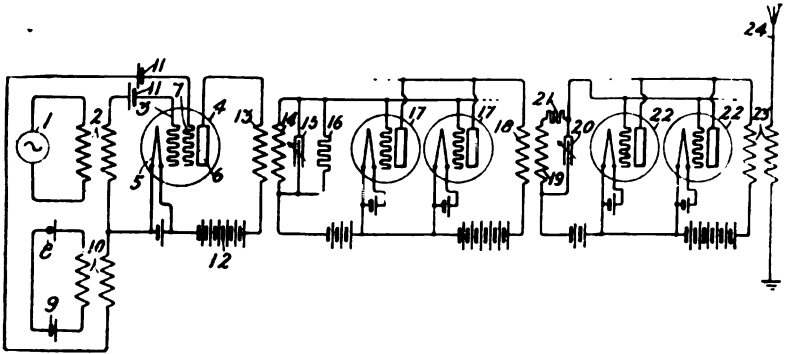


FIGURE 11—Double Grid Modulation System

Curve II in Figure 15 represents a wave produced by a signal which is too strong. It will be observed in this case that a sudden break occurs in the radio frequency amplitude at a certain point and that oscillations do not begin again until the signal potential has moved back to a different value than it had when the oscillations stopped.

This breaking up of the signal by a large amplitude in the signal

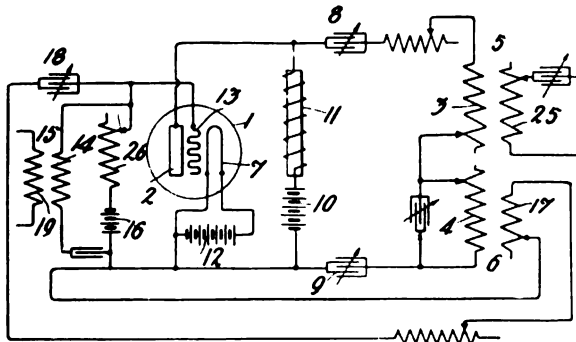


FIGURE 12—Colpitts' Radio System

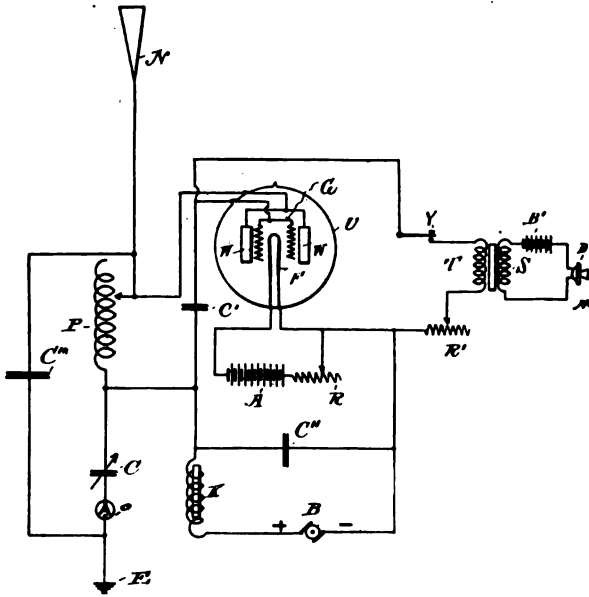


FIGURE 13—Logwood's System

waves, produces a very bad quality. If the signal is not large, the quality is good, but the modulation is incomplete and the system is very inefficient. If an oscillator is adjusted under ordinary conditions which give maximum power and very good efficiency, the percentage of modulation secured is of the order of 20 to 30 percent. It is possible to adjust oscillators so that

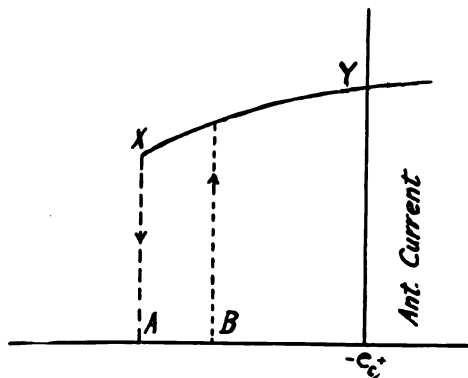


FIGURE 14—Controlled Oscillator Control Curve

the control curve is not discontinuous as indicated but of such a shape as to give complete modulation. However, such an adjustment is hard to secure and does not give good efficiency nor much power. A very careful adjustment must be remade each time the wave length is changed or each time the set is attached to a new antenna.

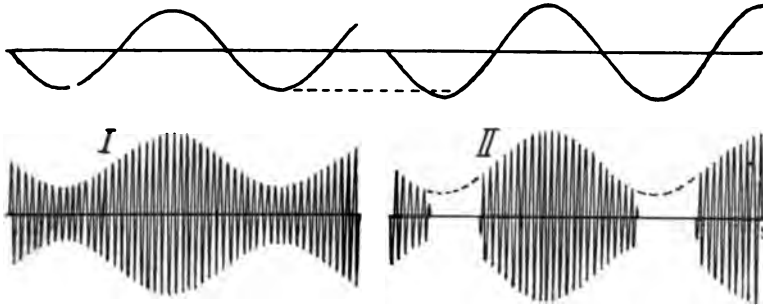


FIGURE 15—Effect of a Strong Signal on a Controlled Oscillator

A system operating on the control of generation principle appears at first as most nearly ideal. Such a system could be either the Colpitts' system just described or one of many systems where another tube is connected to the plate or grid to control the amplitude of the oscillations. In any case, it is necessary that the circuit be constructed to accomplish in its operation one of the following:

1. Vary the current taken by the oscillator, the voltage and efficiency remaining approximately constant.
2. Vary the voltage across the oscillator, the current and efficiency remaining approximately constant.
3. Vary the efficiency of the oscillator, the power supplied remaining approximately constant.
4. Vary both power and efficiency.

That is, the tube circuit must be so constructed that the power or efficiency is varied, or both.

Of these, the first two are ideal, but are not attained in practice. Most come under the third. The fourth cannot be discussed unless a large number of possible combinations are assumed, but the third can be quickly pointed out as inefficient in comparison to others.

The high frequency power in a simple modulated wave as given in equation 3 is

$$p = P (1 + \sin \Psi t)^2 \quad (11)$$

The largest value occurring at any instant is $4P$ and the smallest zero. The oscillator must be capable of delivering $4P$ power to the antenna circuit with the constant plate supply $E_b I_b$ and can do so at the efficiency ϵ which is the maximum plate circuit efficiency the oscillator can have. $4P$ is therefore equal to $\epsilon E_b I_b$

and

$$p = \frac{E_b I_b}{4} \epsilon (1 + \sin \psi t)^2 \quad (12)$$

The efficiency must evidently be varied while talking according to the expression $(1 + \sin \psi t)^2/4$ to give the proper modulated current. Integrating the equation for power over a cycle gives

$$p_{eff} = \frac{3}{8} \epsilon E_b I_b \quad (13)$$

This, it will be observed, is the same as for systems which modulate and then amplify as previously described (equation (10)), and is only half as efficient as some systems to be described later.

If the modulation is not accomplished by varying the efficiency, it might be accomplished by one of the first two classes, in which case the ideal condition is obtained. No audion radio circuit could be more efficient. However, the efficiency of oscillators varies with voltage and with current to a considerable extent and with the controlling circuit attached to the grid or plate, it is almost sure to vary. The result is that systems behaving ideally have not yet been produced. The best controlled oscillator circuits, tho equal in efficiency to those to be described later, have the disadvantages of complexity or distortion or both.

7. MODULATION BY ASSYMETRIC CONDUCTANCE

A system which should be classed under the head of modulation by assymetric or non-linear conductance, is given in Figure 16. Radio frequency and signal frequency voltages are impressed upon a rectifier and a radio frequency tuned circuit in series. The radio frequency and signal frequency sources produce a wave as indicated in Figure 17. The signal in this case, as in all cases, is chosen as a simple sine wave of one frequency. The amplitudes of the signal wave and radio frequency wave are approximately equal tho not necessarily so. When this combination is impressed upon the rectifier, the unilateral conductance of the rectifier passes only the current flowing in one direc-

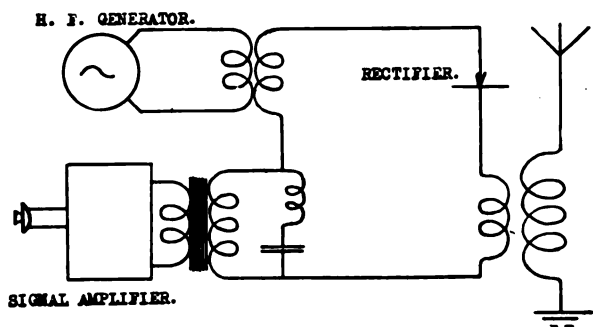


FIGURE 16—Assymmetric Conducting Modulation Circuit

tion as shown in Figure 18. This rectifying action causes a modulated current to be produced. Inspection of Figure 18 will show that the current represented contains a modulated radio frequency component. The audio frequency component readily passes thru the radio frequency transformer in series with the rectifier while the radio frequency component transfers power to the antenna or tuned circuit. The radio frequency component contains numerous harmonics besides the modulated wave, which will cause the flattening of certain peaks. The tuned antenna or radio frequency circuit screen out most of these harmonics while conducting the modulated wave, and the flattened waves are corrected.

In the construction of a circuit of this type, it is necessary

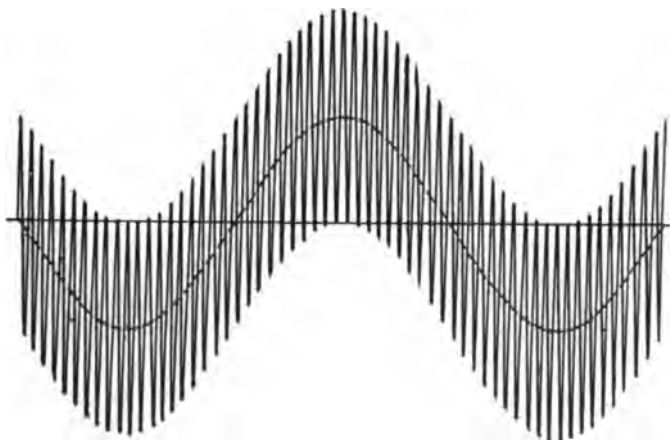


FIGURE 17—Input Wave to Assymmetric Modulator

that the signal frequency amplifiers have low impedance for the radio frequency current and that the radio frequency generator have low impedance for the signal frequency currents. An air core transformer usually accomplishes the latter sufficiently, while, as shown in the diagram, a resonant circuit is placed across the signal frequency amplifier to accomplish the former.



FIGURE 18—Rectified Current from Wave of Figure 17

The system as described considers the rectifier as strictly unilateral. That is not necessarily so. The conductance curve should be other than a straight line (preferably a parabola) in which case it will work satisfactorily. In a system as shown, the signal frequency source must supply practically the same amount of power as does the radio frequency source. This, of course, is not delivered to the antenna in any way and the efficiency of the system is between 25 and 50 percent. If only a small amount of power is modulated and then that is amplified into the antenna, the efficiency will be practically that of the last amplifier— $\frac{3}{8} \epsilon$ (from equation (10)) the same as for all modulator-amplifier systems.

8. MODULATING AMPLIFIER SYSTEM

Another system which falls under the head of modulation by amplification control is illustrated in Figure 19. This system has many characteristics in common with the van der Bijl system as well as with the rectifier system just mentioned. The circuit used is practically the same as for the van der Bijl system. An oscillator supplies a constant alternating potential to the grid of an amplifier while superimposed upon it is the signaling potential from the transmitter. The combination of the signal and radio frequency waves has approximately the same form as that applied to the rectifier system and shown in Figure 17.

The radio frequency is then variably repeated, or in other words, variably amplified in accordance with the audio signaling wave. The modulating amplifier system is an improvement upon the van der Bijl system in that the radio frequency voltage impressed upon the grid is equal to or greater in amplitude than the signaling voltage instead of being very much smaller, and also in the fact that it is possible to produce sufficient power to deliver directly to the antenna.

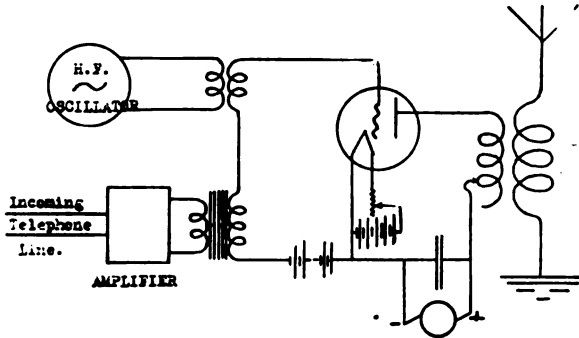


FIGURE 19—Modulating Amplifier Circuit

This system makes use of the unilateral amplifier characteristic of the audion. If we impress upon the grid of the modulating tube a constant negative potential plus the signalling and radio frequency wave of Figure 17, there will be produced in the plate circuit of the tube a current of practically the same wave form as the current thru the rectifier indicated in Figure 18. The constant negative potential applied to the grid is such that the space current is zero when no signal or radio frequency emf. is applied. Upon the application of the two voltages, the characteristic curve is operated upon to the extent that unidirectional pulses of space current flow, the magnitudes of which depend upon how much of the characteristic curve is operated upon. The antenna is tuned to take out the modulated radio frequency component and by-pass the harmonics and signal frequencies the same as in the rectifier system. The quality produced by this system is dependent upon the shape of the characteristic curve of the tube, and would work better if the tube had a straight line characteristic, or one of reversed curvature from that of the actual curve.

Some actual curves for a system of this kind are given in Figure 20. A radio frequency voltage of approximately 325 volts peak value was impressed upon the grids of the modulating amplifier tubes. The continuous potential applied to the grid was varied slowly while leaving the radio frequency voltage

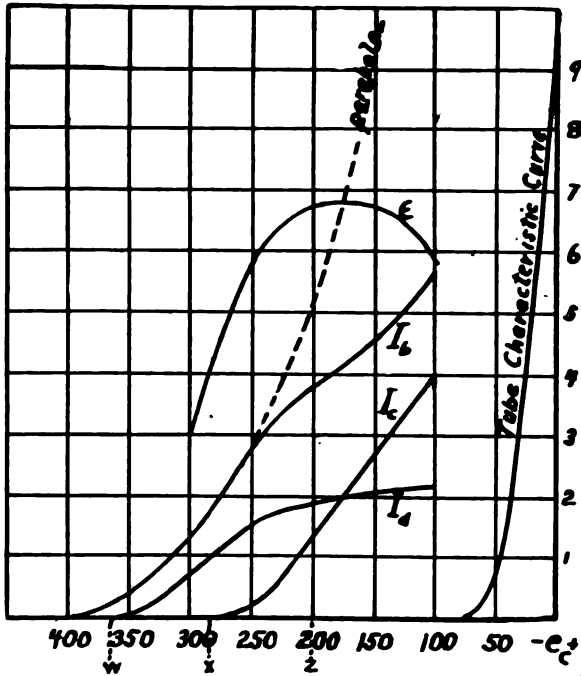


FIGURE 20—Operational and Control Curves of Modulating Amplifier

constant, giving the space, grid, and antenna current curves indicated. There is also shown the characteristic curve of the tubes themselves, and an efficiency curve for the plate circuit. These curves show that a signal voltage with a peak value of 80 volts will work over the entire desirable range on the curves and give a completely modulated radio frequency current.

The condition of operation is to apply a continuous negative potential of 280 volts to the grid, in which case there will be flowing antenna and space currents indicated by the letter X in Figure 20, and then impress at the same time a signal wave

of 80 volts peak value. The point about which the radio frequency voltage varies is moved up and down these curves by the signalling voltage, going from 200 to 360 and giving in the antenna a modulated wave. Under the conditions mentioned, the antenna current will vary about a value of 1 ampere, rising to 1.9 and decreasing to zero. A completely modulated, tho slightly distorted antenna current is thus secured.

In a discussion of the theory and efficiency of this system, it is difficult to express the behavior mathematically due to the shape of these curves. An inspection shows that over the range of operation referred to (*W* to *Z*), the curves do not vary widely from straight lines. If we assume theoretical straight line curves for the control, space current, and efficiency curves, we can write equations which will express simply the behavior of the circuit. Theoretical curves of this kind are shown in Figure 21. The actual curves are shown dotted. The deviation of the actual from the theoretical curves is not great in the case of the control and space current curves, tho it is a little greater in the case of the efficiency curves. Time curves of antenna currents due to the theoretical and actual control curves are given in Figure 22. These show that the deviation of the actual curve from the theoretical is so slight as to affect by but a small percentage any computations we may make. Comparison of actual and theoretical space current curves shows a like result. For the purpose of pointing out the efficiency and power in this system, the hypothetical straight line curves of Figure 21 will be used.

Suppose we represent the space current when signaling by the equation

$$i = I_b (1 + \sin \psi t) \quad (14)$$

where I_b is the average current flowing thru the tube. $\sin \psi t$ represents the signal wave. This assumes that the signal emf. upon the grid is such as to give complete modulation. As the plate voltage is constant the power to the modulating amplifier is

$$P_o = E_b I_b (1 + \sin \psi t) \quad (15)$$

The average power supplied to the amplifier will be the integral of this curve over a cycle and is given by

$$P = E_b I_b \quad (16)$$

The form of the curve for the radio frequency power to the antenna was given in Figure 3 and shown to consist of a single and double frequency components of signal wave frequency. The radio frequency power to the antenna in this case will be

the product of efficiency of the amplifier and the power supplied to it. The efficiency from an inspection of the theoretical curve assumed in Figure 21 is observed to be expressed by the equation:

$$eff = \frac{\epsilon}{2}(1 + \sin \psi t) \quad (17)$$

where ϵ is the plate circuit efficiency at the point so marked

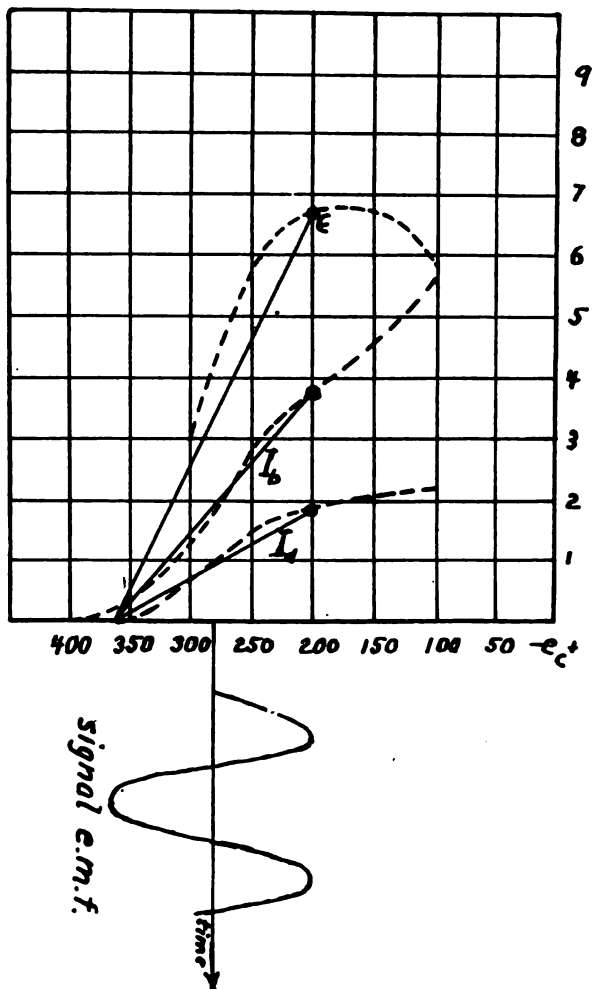


FIGURE 21—Theoretical Operational and Control Curves for Modulating Amplifier—Whole Lines. Actual Curves are Dotted

in the figure. By multiplying this by equation (15), we get the expression for radio frequency power in the antenna:

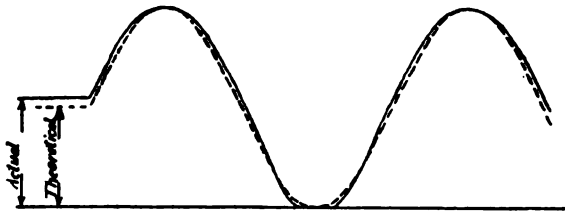


FIGURE 22—Antenna Current Amplitude Curves from Theoretical and Actual Control Curves.

$$P_h = \epsilon \frac{E_b I_b}{2} (1 + \sin \Psi t)^2 \quad (18)$$

which will be observed to be identical in form with that given previously. This equation for power when integrated over a complete cycle gives

$$P_e = \frac{3}{4} \epsilon E_b I_b \quad (19)$$

The steady power supplied at all times is equal to $E_b I_b$ and the coefficient $\frac{3}{4} \epsilon$ gives the efficiency of the system as a generator and modulator combined. ϵ , which is the maximum efficiency of the plate circuit of the amplifier, can have values as high as 80 or 90 percent. It is common to have values over 60 percent. The efficiency of the modulating amplifier is therefore from 45 to 60 percent while modulating, that is, 45 to 60 percent of the direct current power supplied to the modulating amplifier is delivered to the antenna circuit in the form of modulated radio frequency current. This efficiency is as good as is secured with any other vacuum tube system.

This system of modulation was used in some experimental radio sets built for the United States Navy in 1916 and 1917. They were described generally as the multiplex set in the paper of Messrs. Craft and Colpitts mentioned previously. A schematic diagram of the transmitter arrangement is given in Figure 23. In this multiplex set, the intermediate frequency is modulated by the signaling frequency. This intermediate frequency is above the range occurring in the human voice, being in the sets constructed 25,000 to 45,000 cycles. A carrier wave of

238 meters (1,260,000 cycles) is then modulated by the signally modulated intermediate frequency and radiated. Modulation of the intermediate frequency by the signal, and of the radio frequency by the intermediate frequency is accomplished by this system.

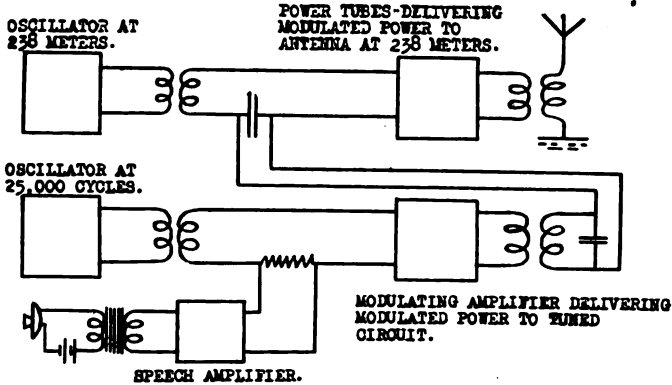


FIGURE 23—Schematic Diagram of Multiplex Modulating Arrangement

9. CONSTANT POTENTIAL AND CONSTANT CURRENT SYSTEMS

Two of the most efficient and satisfactory types of tube systems in use are the "constant potential" and "constant current" systems. In Figure 24 is shown the constant potential system (Patent number 1,137,315). It consists of a signal amplifier tube in series with a radio frequency amplifier tube. The signal amplifier tube, or modulator tube if it is wished to call it such, varies the power supply to the radio frequency amplifier tube according to a signal impressed upon the grid.

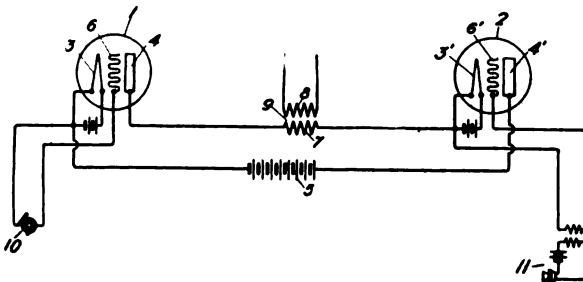


FIGURE 24—Constant Potential Modulating System

The latter tube, having a constant radio frequency voltage supplied to its grid, then converts this modulated power into radio frequency power, delivering a modulated radio frequency current directly to the antenna.

A more general schematic diagram for the constant potential system is given in Figure 25. An amplifier tube is connected in series with a frequency changer to which it delivers amplified power. The frequency changer to be used in this kind of a

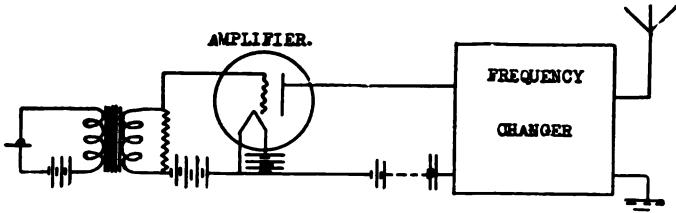


FIGURE 25—Constant Potential System

circuit is one which adds a frequency and not one which multiplies. Such a frequency changer sometimes used in power work consists of a rotor rotating inside a stator. The stator may have supplied to it polyphase power at a frequency f_2 , and if the rotating field which it produces rotates oppositely to the direction of the rotor motion, the power delivered from the rotor is of a frequency equal to the sum of the supplied frequency f_2 and the natural frequency of rotation f_1 , or it is f_1+f_2 . If the polyphase power supplied to the stator rotates the field in the same direction as the rotor moves, that is with a frequency of $-f_2$, the resulting power will have a frequency of f_1-f_2 . If direct current (zero frequency) is supplied, the resulting frequency will be $f_1+0=f_1$. If we supply to the stator a direct current and a polyphase current $+f_2$ we will have added to these frequencies the natural frequency of the frequency changer giving f_1 and f_1+f_2 . Now it happens that a single phase current can be considered as the sum of two frequencies, that is, we may represent a sine wave by the equation

$$I \cos \omega t = \frac{I}{2} (\varepsilon^{+j\omega t} + \varepsilon^{-j\omega t}) \quad (20)$$

This equation indicates that we may consider a simple sine wave as being the sum of two independent alternating currents equal in amplitude, equal in their numerical values of frequency, but

one a positive and the other a negative frequency. A single phase applied to a stator will produce an alternating field inside of it, which alternating field can be considered as produced by two polyphase currents which rotate their fields in opposite directions. If we apply to the stator direct current and single phase current we will get out of the rotor the same frequencies as tho we applied a direct current and positive and negative frequencies, that is, we will get f_1 , f_1+f_2 , and f_1-f_2 . This behavior of the frequency changer provides a manner of producing modulated radio frequency current without the actual modulating of the radio frequency current by a modulator.

For radio purposes, we may use a frequency changer the natural frequency of which is the carrier wave desired, such as $f_1 = 25,000$ cycles. From an amplifier there is supplied a multitude of single phase frequencies f_2 , f_3 , and so on, in the speech signal and each single phase may be said to consist of $+f_2$, $-f_2$, or $+f_3$, $-f_3$, and so on. When these single phase currents, together with the direct current or zero frequency are supplied to the frequency changer, we have delivered to the antenna frequencies of 25,000 cycles plus all of those supplied, or

- 25,000
- 25,000 + f_2
- 25,000 - f_2
- 25,000 + f_3
- 25,000 - f_3
-

The combination of these frequencies, it will be observed, constitutes a radio frequency current modulated by the signal frequencies f_2 , f_3 and so on.

It is not necessary to go to a mechanical generator or frequency changer to accomplish this result, as it can be secured electrically by using an audion generator. In Figure 25 is shown an amplifier delivering power to an audion frequency changer. Zero frequency comes from the battery E_b and is the average direct current flowing thru the audions. The amplifier tube under the influence of a signal impressed upon this grid, delivers plus and minus speech frequencies in the form of single phase currents to the frequency changer which latter adds to all of them a carrier frequency f_1 thereby producing in the antenna a modulated radio frequency current, or a combination of currents of the frequencies f_1 , f_1+f_2 , f_1-f_2 , $f_1 \pm$

This describes in general the principle upon which the constant potential as well as the constant current system operates,

but it is desirable for several reasons to go deeper into the circuit's behavior, and analyze its operation. A study of the characteristic, behavior, and operational curves of the amplifier and generator points out many things which are of great value.

Take for instance the circuit as shown in Figure 25 and impress a signal upon the grid of the amplifier. The variation in grid potential varies the current to the two tubes in series by virtue of the variable resistance of the amplifier. The potential of the battery E_b is constant, but the drop across the amplifier and generator varies as the signal operates upon the amplifier grid. In Figure 26, the top horizontal line represents the battery voltage. Under the non-signaling condition, the voltage

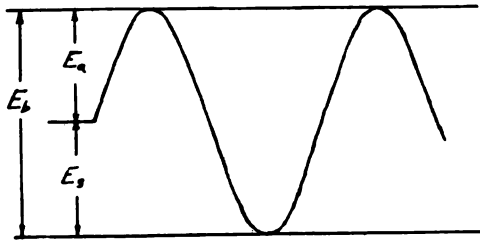


FIGURE 26—Voltage Distribution Between Amplifier and Generator of Constant Potential System

drops across the amplifier, E_a , and the generator, E_g , are equal. As the potential of the amplifier grid varies, the voltage drops across the two tubes change according to the curved line. The voltage drop across the generator thus varies between approximately zero and twice the non-signaling value when a completely modulated wave is being sent. The voltage across the amplifier varies in a similar way, but is maximum when that across the generator is minimum, and vice versa. As the voltages across these elements change, the current does also. As the amplifier grid has its potential changed in a positive direction, the effective resistance of the tube decreases and the current increases. The reverse occurs when the grid potential is varied in the other direction. The variation in potential across the generator causes the power taken by it to vary and also causes it to deliver a variable amplitude radio frequency current to the antenna.

In the constant potential system just described, the source of power E_b supplies a variable current at a constant potential. The converse of this system is one which supplies a constant current at a variable potential. The latter system is described briefly in the paper by Messrs. Craft and Colpitts mentioned before. The circuit diagram is given in Figure 27.

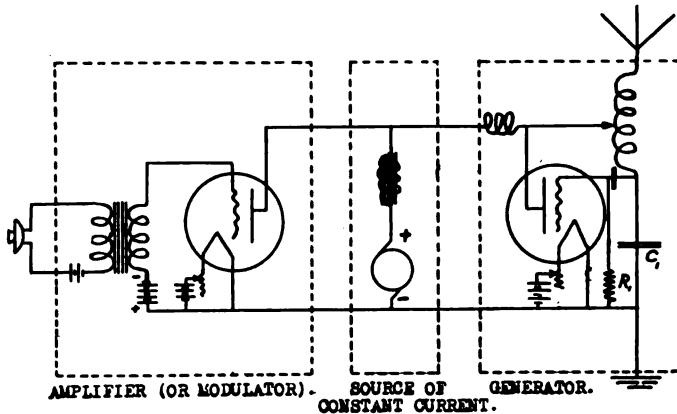


FIGURE 27—Constant Current System Circuit

The generator and amplifier in this case are connected in parallel with a constant current source of supply. This source of supply may be of any form desired, but its simplest and most satisfactory form is that of a constant potential generator or battery and a large choke coil. The constant current supply needs to be constant, or substantially so, in respect to speech frequency variations only. Variations due to change in the generator voltage, change in amplitude of signals, change in antenna resistance, and for very low frequencies such as will not disturb the ear, do not necessarily have to be prevented. It is only variations in current of the order of frequencies occurring in the signal which should be prevented from occurring thru the direct current generator.

The division of the current to the amplifier and oscillator in the constant current system is shown in Figure 28. The total constant space current is I_b , which is the sum of the oscillator current I_o and the amplifier current I_m . When a sine wave signal is transmitted, the currents vary according to the curved line. Distances above the curved line represent amplifier cur-

rent and those below represent oscillator current. Such a variation in the division of the constant current causes the voltage across the tubes to vary. The variation in the current to the amplifier is caused by the signal being impressed upon the grid while that to the oscillator is caused by that part of the constant current taken only by the amplifier being varied. As a result

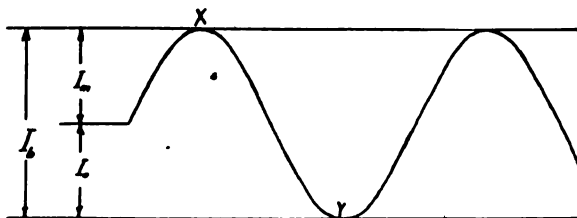


FIGURE 28—Division of Current Between Amplifier and Generator in the Constant Current System

of the presence of the choke coil a variation of amplifier current causes an inverse change in oscillator current, and with it a change in voltage. A curve of oscillator space current as a function of its plate voltage is shown in Figure 29. This curve is a straight line thruout almost its entire length, which means that the voltage of the oscillator must vary in practically the same manner as does the current. If the current to the oscillator

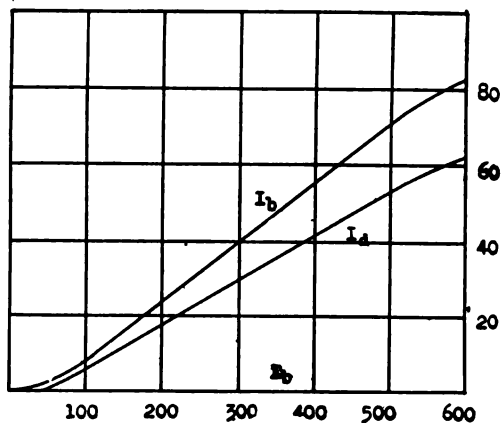


FIGURE 29—Space Current (I_b) and Antenna Current (I_a) of an Oscillator as a Function of Plate Voltage

is caused by the signal impressed upon the amplifier to take the form

$$i = I_o (1 + K \sin \psi t) \quad (21)$$

and shown in Figure 28, the voltage across the oscillator must necessarily be represented by a similar equation for the reasons just mentioned and may be represented by the following which is plotted in Figure 30.

$$e = E_b (1 + K \sin \psi t) \quad (22)$$

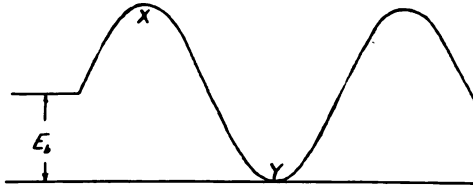


FIGURE 30—Voltage Across Oscillator when Current Varies as in Figure 28

The power supplied to the oscillator is the product of the current and the voltage or

$$\begin{aligned} e i &= E_b I_o (1 + K \sin \psi t)^2 \\ &= E_b I_o \left(1 + 2 K \sin \psi t + \frac{K^2}{2} - \frac{K^2 \cos 2 \psi t}{2} \right) \quad (23) \end{aligned}$$

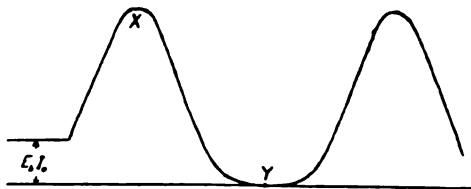


FIGURE 31—Power to Oscillator When Signaling

This equation is plotted in Figure 31. An interesting fact to be observed from this equation and curve is that the power to the oscillator when the modulation is complete ($K = 1$) rises at one point to four times the power taken by it when no signal is being sent and to twice the average value taken by both the oscillator and amplifier. The power at other points drops to zero.

Inspection of the equation shows also that the average power over an audio frequency cycle is 50 percent greater than the power taken when no signal is being sent. It also shows that the power consists of single and double frequency components of the speech frequency exactly as does the power represented by the antenna current shown in Figure 3.

The power taken by the amplifier is somewhat different. The voltage across the oscillator is also the voltage across the amplifier. The current to the amplifier, however is represented by the distance between the top horizontal and curved lines in Figure 28, and is given by the equation.

$$i_m = I_m (1 - K \sin \psi t) \quad (24)$$

The power will be the product of the voltage and current or

$$e i_m = E_b I_m (1 - K^2 \sin^2 \psi t) = E_b I_m \left(1 - \frac{K^2}{2} + \frac{K^2 \cos 2 \psi t}{2} \right) \quad (25)$$

which is plotted in Figure 32 for a value of K equal to unity.

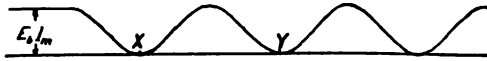


FIGURE 32—Power to Modulator when Signaling

It will be observed here that the power absorbed by the amplifier is a double frequency only of the signaling frequency, that it is a maximum at the time no signal is being sent, and that it has an average value of one-half the maximum when a completely modulating signal is being sent. The power absorbed by the amplifier is zero at the instant that the maximum power is delivered to the oscillator (X in Figures 31 and 32) and is also zero at the time that none is delivered to the oscillator (Y in the same figures). It indicates that there is more heat energy dissipated in the amplifier when not signaling than while signaling. These equations and statements are based upon the assumption that the modulator resistance can be reduced to zero by making the grid positive. Actually, this cannot be accomplished, but it can be reduced sufficiently to give complete modulation and conclusions arrived at by considering this assumption are not far wrong.

The efficiency of the modulating system as such is given by the equation of the power to the oscillator integrated over a cycle divided by the total power from the B battery or

$$\begin{aligned}
 \text{eff} &= \frac{\int_0^{2\pi} \left[E_b I_o \left(1 + 2K \sin \Psi t + \frac{K^2}{2} - \frac{K^2}{2} \cos 2\Psi t \right) \right] dt}{E_b (I_o + I_m)} \\
 &= \frac{E_b I_o \left(1 + \frac{K^2}{2} \right)}{E_b (I_o + I_m)} \quad (26)
 \end{aligned}$$

If K is unity, which is the condition of transmitting a completely modulated wave, the efficiency is $\frac{3}{4}$, that is, *three-quarters of the direct current power from the constant current source goes to the oscillator notwithstanding the fact that the direct current instruments indicate that only one-half does.* Under the conditions of K less than unity, the efficiency of course is reduced, becoming one-half when no signal is being transmitted.

If the plate circuit efficiency of the oscillator is ϵ , the efficiency of the entire radio system (neglecting filament power) is $\frac{3}{4}\epsilon$. The value ϵ can have may be anything up to 80 or 90 percent, the same as previously mentioned for amplifiers. An oscillator running on 300 volts E_b may have an efficiency of 60 percent and one constructed for higher voltages may reach the higher figures mentioned. The efficiency of the entire system may, therefore, reach values of 60 to 70 percent, which is quite high for a radio system.

10. COMPARATIVE EFFICIENCY AND PRACTICABILITY

On comparing the efficiencies of these systems, it will be observed that the constant potential, constant current, and modulating amplifier systems are most efficient and theoretically equal. Amplifier systems all fall below by various amounts down to an efficiency one-half that of the others. Control of generation systems at present known run from an equal value down to very small amounts instead of being better. From the point of view of efficiency, we would choose one of the three most efficient mentioned.

As regards quality or distortion, the constant current and constant potential systems are better than the modulating amplifier. The distortion in the modulating amplifier is produced right in the generator of the radio frequency and is difficult or impossible to eliminate, while in the others, what there is, is produced in the modulator and in many cases can be kept out of the oscillator by suitable circuits. The controlled oscillators known distort also, and the harmonics of the signaling frequency either cannot be eliminated, or if eliminated, it is done with

considerable power loss. Amplifier systems, where a small amount of power is modulated, can have harmonics of the signal frequencies reduced sufficiently by operating on the small amount of power modulated, and then amplifying with a distortionless amplifier. However, an efficient distortionless amplifier of power is hard to construct and adjust and the efficiency of it may fall below 25 percent. These considerations, tho not of great importance now, may be more important in the future when the width of a transmitted band may be limited.

A factor affecting the practicability of these systems is the voltage at which they operate. Some work on lower or higher voltages than others. This comparison is based upon using the same type and number of tubes to get the same power into the antenna. The van der Bijl system, the modulating amplifier system, and the controlled oscillator system require $\sqrt{2}$ times the plate voltage needed for the constant current system. This is because these three systems require all the tubes to deliver a maximum power to the antenna at the normal voltage while the constant current system delivers the same maximum power from one-half the tubes at the instant the modulator and choke coil deliver double oscillator current and double voltage (X in Figures 28 and 31) to the oscillator. The voltage to the first three systems mentioned is constant while to the oscillator in the constant current system, it varies between zero and twice the average.

This may be expressed in a simple manner with a few equations and show what is hard to explain without them. If I is the space current taken by one oscillator tube (or the amplifier tube in a two tube constant current set), at voltage V , the power delivered to the antenna circuit from the one oscillator tube is

$$p = VI\epsilon \quad (27)$$

The peak power when modulating is four times this amount or

$$P = 4VI\epsilon \quad (28)$$

If the same two tubes (oscillator and modulator tubes) are used instead in an amplifier system or a controlled oscillator system running at voltage E , the space current per tube will be

$$i = I \frac{E}{V} \quad (29)$$

as the tubes under maximum power conditions have space currents proportional to the plate voltage (very nearly) whether used as oscillators or power amplifiers. The same maximum

power is to be delivered to the antenna circuit at the same efficiency by *both* tubes instead of one or

$$P = 4 V I \epsilon = 2 i E \epsilon = 2 \frac{I E}{V} E \epsilon \quad (30)$$

giving

$$2 V^2 = E^2 \quad \text{or} \quad E = \sqrt{2} V \quad (31)$$

to give the same modulated power from the same number of similar tubes in an amplifier or controlled oscillator system as is needed for the constant current system.

The constant potential system, of course, requires twice the voltage needed for the constant current system. The use of the lower voltage alone, in many cases, is a most important factor in determining the most desirable system to use.

11. CONCLUSION

The five or six modulation systems discussed in this paper must not be taken as the only ones possible. The possible combinations of tubes, circuits, and microphones which will produce modulated radio frequency currents, seem unlimited. They do however, become more complex, are more difficult to adjust, or are less efficient. In principle, most will fall under the classes described or combinations of them.

No general principle can be stated which covers all radio systems. Some are truly modulation systems while some are systems for producing modulated power. Since the production of modulated power is the ultimate object to be secured in a radio system, all classes have been included in this paper. New methods of generation will undoubtedly be invented in the future and also new methods of modulation giving combinations to be added to those mentioned.

ADDENDUM

In the main part of this paper, many important facts concerning the constant current system are omitted to avoid covering up the main points. The wide use of the system makes it desirable to present many of the omitted facts because they are of value both to a better understanding of the theory, and in designing and building sets.

The oscillator and its operation has been described by the writer in another publication³ but it appears desirable to point

³"The Audion Oscillator," "Journal of the American Institute of Electrical Engineers," April and May, 1920.

out and emphasize certain facts concerning it which are of importance in a radio telephone set. Two of these facts are observable by referring to the curves in Figure 29. These curves represent space and antenna currents of a properly constructed oscillator as a function of plate voltage. They are straight lines except at the extreme ends. Over the most used part of the curves, they are straight lines, which fact insures that if the current to the oscillator is made to take the wave form of a signal, the voltage across the oscillator will also have that wave form, and if the voltage has the signal wave form, the amplitude of the antenna current must have the signal wave form. These two straight line operational curves are thus important characteristics desirable in a set on account of the distortionless modulation obtained.

It is not absolutely necessary that the curves be straight lines to secure a distortionless output, as the latter can be secured if the curves are alike. That is, the space current and antenna current curves must be expressible by the same type of equation tho with different constants. A distortionless modulated current is then secured having the modulation form of the *oscillator current supplied*.

This manner of securing a distortionless output is not as desirable as the arrangement having straight line operational curves. The latter causes the oscillator to behave like a pure resistance to currents sent in by the modulator, while the curved curves cause the oscillator to act as a variable resistance, the value of which is a function of the current. The desirability of an oscillator behaving as a variable resistance depends upon the type of modulator or other source of signal power. It may produce a distortion all of its own and not allow the current to the oscillator to have the wave form of the signal to the modulator.

To secure the desired straight line curves for an oscillator, two requirements must be observed. They are:

1. The tube must operate above temperature saturation for the filament.
2. A grid stopping condenser and leak resistance must be used.

The type of oscillator circuit used is immaterial as all give the same results when properly adjusted.

The curvatures in the operational curves of Figure 29 are from two causes. That at the lower end is on account of the tube impedance rising rapidly at the low voltage, and that at the

upper end (occasionally) is caused by lack of temperature saturation at that voltage.

In separately excited generators, such as shown in Figure 24, the operational curve is not a straight line. The constant radio frequency voltage on the grid does not give space and antenna currents proportional to the plate voltage. To make these curves straight, it is necessary to use the modified circuit shown in Figure 33. The reason this generator has straight line curves like an oscillator is as follows. An oscillator, which has a straight line curve, has a grid voltage proportional to the plate voltage, because the antenna current which produces the grid voltage is proportional to the plate voltage. By making the exciting oscillator have its plate voltage vary the same as that of the generator tube, radio frequency output from the exciting oscillator, which is also the generator tube input, will be proportional to the plate voltage. The input conditions of an oscillator are thus secured for the separately excited tube.

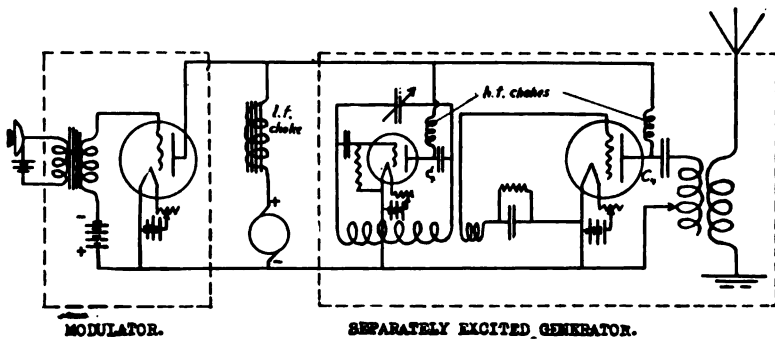


FIGURE 33—System Using Separately Excited Generator with the Exciting Oscillator also Controlled

In the discussion within the paper, the oscillator or generator efficiency ϵ was assumed as constant. As the plate voltage of an oscillator varies, the efficiency varies as shown in Figure 34. Over the larger part of the range of operation the efficiency does not vary greatly, and we are not unjustified in assuming it constant in our discussion. This actual drop in efficiency at the lower values may be explained by referring to Figure 29. It will be observed that the antenna current curve strikes the axis at a value of E_b greater than 0. At this point the efficiency must necessarily be zero. If the curve were entirely straight

and passed thru the origin, the efficiency would be nearly constant thruout the range. As it is, however, the efficiency rises rapidly with voltage from zero at the value of E_b at which oscillations start and approaches a nearly constant value as the plate voltage becomes large.

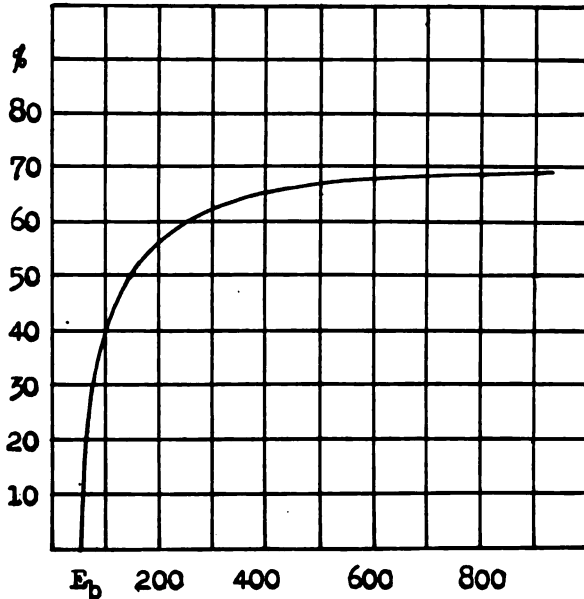


FIGURE 34—Efficiency of an Oscillator or Generator as a Function of Plate Voltage

The point at which we wish the greatest efficiency to occur is the point at which the maximum power is delivered to the antenna, that is, point X in Figure 31. If the efficiency drops a trifle for lower values of plate voltage, we need not concern ourselves greatly because we expect that the antenna current will drop to zero anyway at certain points, and under the conditions in this system at which it does, that is, point Y in Figures 31 and 32, the efficiency may be low, or may even be zero. However, the power delivered to both the oscillator and modulator at that instant is also exceedingly small, if not zero, and the low efficiency causes very little loss. During the rest of the time (between points X and Y), various moderate amounts of power are delivered to the oscillator, and the efficiency is nearly con-

stant thruout most of it. The fact that the efficiency of the oscillator is practically constant thruout that part of the cycle when the largest amounts and the greatest part of the power are delivered to it, justifies us in our assumption of constant efficiency in any but a most exact discussion.

The design of an oscillator for a telephone set demands the proper proportioning of certain elements which may be of small importance for the oscillator only. One element is a condenser necessary to provide a radio frequency path from the plate to the filament and at the same time break that path for direct current. See C_1 in Figure 27 or C_4 in Figure 33. This condenser must also break the path for signal frequency currents so as to force them thru the tube, and therefore cannot be too large. If the condenser is very large, it by-passes some of the signaling current. Power meant for the oscillator is thus wasted. These condensers must be no larger than is necessary to conduct the alternating space current without producing an undesirable phase shift.

Another part of the circuit, the values of which may influence the operation of the set, is the grid leak circuit, that is the sizes of the grid stopping condenser and grid leak resistance. The negative voltage for the grid is caused by the grid current passing thru the grid leak resistance. This usually sets the value of the resistance. A negative charge is maintained by the grid stopping condenser for the grid. As the signal voltage is impressed upon the plate, it is necessary that the negative voltage for the grid vary also, otherwise uneven or intermittant oscillator operation will occur. To avoid this trouble, the stopping condenser should not be so large that it will maintain a charge that can not leak off the grid as fast as the plate voltage falls during a signal. It should not be so small as to introduce a phase shift to the grid, but should be of such a size that with the grid leak resistance it will form a circuit with a time constant much shorter than the period of the highest frequency in the signal. In most radio sets, no trouble is encountered in making these parts of proper size, but if the carrier and signal frequencies are too near the same (such as 15,000 and 2,000 cycles), these elements must be carefully considered.

The most convenient source of constant current for a set is a constant potential battery or generator and a large choke coil. The choke coil should theoretically have infinite inductance, but practically it may be small enough so that its inductive reactance at 800 cycles is 3 or 4 times the resistance of the oscillator or

modulator. Making it larger increases the modulating efficiency, but the maximum possible obtainable is only approached asymptotically. If the choke coil has a reactance three times the resistance of the oscillator at 800 cycles, about 95 percent of the variation in current of that frequency produced by the modulator will pass thru the oscillator and 32 percent will pass thru the choke coil and battery "wattlessly." If the choke coil has a reactance twice that value, 98.6 percent of the current will pass thru the oscillator and 16.5 percent thru the choke coil and battery "wattlessly." Beyond these values, the increase in modulated current is very small compared to the increase in size of the choke coil, and practically is not worth trying to save.

When a direct current generator is used as the *B* circuit supply, its armature inductance is added to that of the choke coil in tending to maintain the current constant.

In the previous discussion of efficiency, no mention was made of an adjustment of the constant current system which increased its efficiency materially. The assumption was made that the non-signaling space current of the modulator equalled that of the oscillator. The non-signaling power efficiency is then $\frac{1}{2}\epsilon$. In practice it has been the custom to make the modulator current one-half that of the oscillator current. The non-signaling efficiency is then $\frac{2}{3}\epsilon$. This adjustment is possible because when a signal is transmitted, the curved characteristic of the modulator causes the average modulator current to rise to an equal value and the condition necessary for proper and complete modulation occurs. The efficiency of the set is thus $\frac{3}{4}\epsilon$ when signaling and $\frac{2}{3}\epsilon$ when not signaling.

In many radio sets it has been the practice to connect a resistance across the high side of the input signal transformer. The purpose of this resistance is twofold. (a) It improves the quality and (b) it stabilizes the amplifier or modulator circuit. It has always been the practice in telephone amplifier work to place a resistance across the input transformer for the maintenance of quality. An open circuited transformer, especially if connected to a capacity load, has a transformation ratio dependent upon the frequency. This distortion is analogous to that produced in a microphone due to the free period of the

diafram. Such distortions, tho giving more volume, reduce the quality, often to a prohibitive degree. Building a microphone for better quality reduces the volume of energy given out materially, while building a transformer for the best quality seldom reduces it more than 50 percent. The practice has therefore been to tolerate the distortion produced in the microphone, but avoid the production of any in the circuit. A transformer designed to be used with a resistance across it can be made to produce no distortion in speech signals.

The modulator circuit, when not using a resistance across the transformer, can be looked upon as consisting of an inductance between filament and grid, with an inductive circuit between filament and plate. These inductances, together with the grid to plate capacity produces a Hartley type oscillator and oscillations may result. The resistance tends to prevent this.

Research Laboratory of The American
Telephone and Telegraph Company, and
the Western Electric Company, Incorporated,
August 23, 1920.

SUMMARY: After considering the general characteristics of a voice-modulated radio frequency current, there is given a systematic classification of the various methods of producing such modulation in transmitters using three-electrode vacuum tubes.

The output, efficiency, stability, completeness of modulation, quality, and other characteristics of each method of modulation are studied.

The apparatus and circuits used in the long distance radiophone tests at Arlington, Virginia, in 1915, are described.

APPENDIX

The question has been asked why an amplifier system has a lower efficiency than the modulating amplifier system when there appears, looking at them broadly, to be no fundamental reason for it. In answer, it should be stated that it is largely a question of quality desired and adjustment made which determine this difference. I shall endeavor to point out the underlying causes and varying modifications which produce the difference.

Before beginning the direct comparison, it appears wise to define two types of amplifiers—the “proper amplifier,” and the “improper amplifier.” By a proper amplifier is meant one which has a constant negative potential of such an amount applied to the grid that the operating point falls upon the static characteristic curve. This is represented in Figure 35 where the negative grid potential e_c establishes the point P_0 as the operating point. The dynamic characteristic curve of the tube

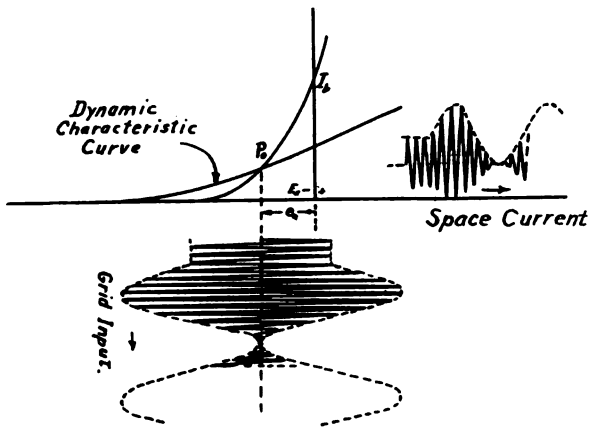


FIGURE 35—Operating Scheme of a Proper Amplifier

and circuit is also represented. The input modulated radio frequency wave to be amplified is represented with the time axis running downward, and the resulting space current is represented with its axis running to the right. Amplifiers for telephone work are constructed upon this principle as they give very little distortion.

By an improper amplifier is meant one which has such a large negative grid potential as to cause the operating point to be

a considerable distance to the left of the bottom of the static characteristic curve. The value of this negative potential may be several times the value at which the static characteristic strikes the X axis. This is represented in Figure 36. A differ-

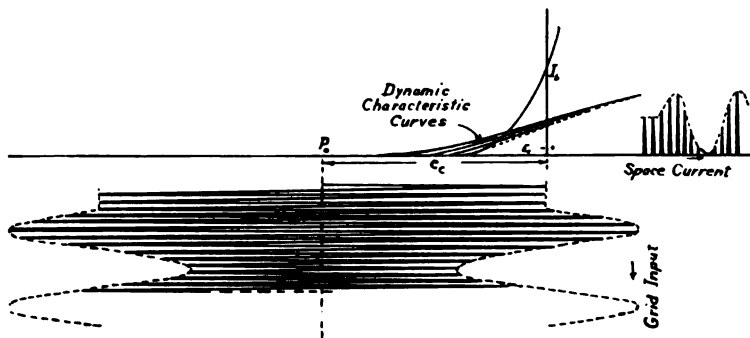


FIGURE 36—Operating Scheme of a High Efficiency Improper Amplifier

ent type of input wave is also used, and a different type of output current is secured. The dynamic characteristic, instead of being a single curve as in the proper amplifier, is a family of curves. Each curve of the family is a function of the amplitude of the input voltage wave as well as of the tube and attached circuit constants. The result is that a varying amplitude wave of the radio telephone class uses a whole family of these dynamic curves. The output of this amplifier is not the same as the input. An enormous distortion of the modulated wave itself is caused, as can be seen by comparing the modulated component of the space current with the input wave. Likewise, a pulsating space current of the modulating frequency occurs which is many times larger than that produced by the curvature of the characteristic curve in the proper amplifier. With this type of amplifier, an incompletely modulated wave is impressed upon the grid, and the action of the amplifier is such as to deliver a completely modulated wave to the antenna. However, a study of the system will show that considerable distortion of the modulating signal is produced. Tho this distortion is greater than in the proper amplifier, it is not any greater than that produced in the modulating amplifier.

In the comparison in the paper of amplifier systems with the modulating amplifier and constant current systems, a proper

amplifier was assumed. One of the causes of the great difference in efficiency can be seen by a reference to Figure 37. It is desired to produce in the antenna modulated radio frequency power represented by curve I which is the power curve for a wave modulated by a single sine signal wave. An assumption is now made, for the purpose of simplifying the comparison, that the proper amplifier can deliver its maximum power with the same plate circuit efficiency as can the modulating amplifier. Such

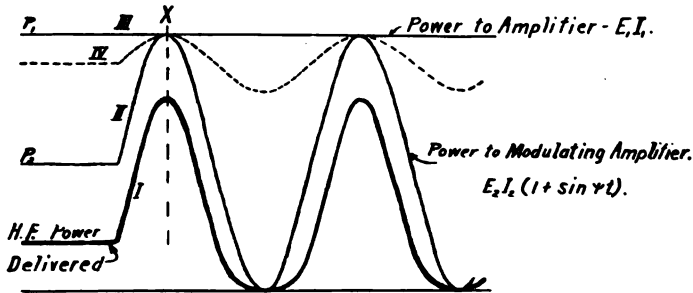


FIGURE 37—Power Curves for the Modulating Amplifier (II) and Proper Amplifier (III and IV)

an assumption is to the advantage of the proper amplifier, and makes the discrepancy between the resulting efficiencies greater than is determined from this comparison. The point at which the efficiencies are assumed equal is marked X in the figure. At that instant both systems can deliver the desired radio frequency power with the same plate input. The plate input needed is indicated as P_1 . If a second assumption is made—that the tube has a straight line characteristic curve—the horizontal line, curve III, is the curve of power taken by the proper amplifier while delivering the desired modulated radio frequency power to the antenna. If this second assumption is not made, the dotted line, curve IV, is the power taken in during the same time. The variation in power in this case is caused by a variation in plate current as a result of the curved characteristic curve of the tube. In the modulating amplifier, the same power P_1 must be taken in at the instant marked X, but since the tube has the signal wave impressed upon its grid, as well as the radio frequency, the space current is varied according to the signal and the power taken is represented by curve II and expressed by equation 15 in the paper. The result is that by

comparing the power represented by curves II and III, that is, by comparing the areas under these curves, the proper amplifier is observed to take twice the power and yet deliver the same amount of power to the antenna. This gives it only one-half the efficiency of the modulating amplifier. If curves II and IV are compared instead, which are the true inputs, the ratio of powers is reduced a trifle from the value of two.

Consideration of the cause of the variation in space current produced by the curved characteristic and its effect upon the efficiency as shown by using curve IV instead of curve III, lead us to an adjustment of the amplifier which brings the efficiency nearer to, and can be made equal to, that of the modulating amplifier. That is, by changing the adjustment, or other factors in the circuit so that the space current of the tube varies with the amplitude of the input radio frequency, the power input curve IV can be made to approach more and more closely to curve II until they coincide. This is accomplished by increasing the negative voltage on the grid until the operating point is moved to the left of the static characteristic curve, and changing the nature of the modulated radio frequency input so as still to give the desired output. When this is done it will be found that we have the conditions mentioned as existing in the improper amplifier, or as represented in Figure 36. In this case curve II stands, not only for the power input to the modulating amplifier, but for the power input to the improper amplifier, and the efficiencies of the two circuits are the same.

A factor to be considered in the comparison of the proper amplifier and the modulating amplifier is the plate circuit efficiency of the tube at maximum power. Plate circuit efficiency must not be confounded with the system efficiencies which are being compared. The system efficiencies being compared are secured by dividing the radio frequency power (modulated), integrated over a signal frequency cycle, by the plate power taken in (either steady or variable), integrated over the same cycle. By plate circuit efficiency is meant steady radio frequency power divided by steady plate power supplied. It is the same as radio frequency power, integrated over a small part of a signal period, divided by plate power taken in, integrated over the same short period. In the comparison first made, it was assumed that the plate circuit efficiencies of the modulating amplifier and proper amplifier were the same at the time X in Figure 37. The plate circuit efficiency of the modulating amplifier at this point may be 80 or even 90 percent, but the corresponding efficiency of

the proper amplifier at that point is around 35 percent with a maximum possible of 50 percent.⁴ This great discrepancy puts the proper amplifier at a still greater disadvantage than the $\frac{1}{2}$ ratio pointed out. To get a high power efficiency in the plate circuit of a tube, the form of the radio frequency wave must be changed from a sine wave, or the method of applying it to the grid must be changed. In order to make the efficiency high, the sides of the input radio frequency wave must be made very steep to make the time during which the resistance of the tube is large but finite, extremely small, or else to cause the tube to have this variation in resistance at a time that the plate potential has dropped to a low value. These requirements demand either a rectangular wave form for the radio frequency input, or such a large negative grid potential that only the peak of the sine wave operates upon the characteristic curve. The latter is the easier to do and is the manner in which the modulating amplifier, as well as the improper amplifier works. The result of using only a small part of the radio frequency wave upon the grid thus causes the tube to operate more as a shock exciter for the tuned circuit than as an amplifier (tho it can be considered as both) and the plate circuit efficiency may rise at the point X to the values mentioned—80 to 90 percent in extreme cases.

The proper amplifier is distinctly not a shock-exciting arrangement and the high efficiencies are never attained. With the attainable values around 35 percent, it is obvious that in Figure 37 the peak power delivered at X cannot be secured with an input of only power P_1 . In fact, the proper amplifier will require approximately $2 P_1$ input at that point to give the desired output and the average power taken in over a modulating cycle will be very close to that same value. The power curve during this cycle will have the form of curve IV, but twice the ordinates or more. In the modulating amplifier, due to the high efficiency at X , curve II represents the true power in, and P_2 (which equals $\frac{1}{2} P_1$) is the average power. Thus the proper amplifier with the combination of low plate circuit efficiency and a nearly constant space current during the modulating cycle gives an overall efficiency about $\frac{1}{4}$ that of the modulating amplifier with its high plate circuit efficiency and varying space current during the modulating cycle.

I might summarize the conclusions arrived at by saying that

⁴ "The Audion Oscillator," "Journal of the American Institute of Electrical Engineers," R. A. Heising, May, 1920.

there are two reasons why a system using the proper amplifier is less efficient than the modulating amplifier system. The first is that the plate current of the proper amplifier is almost constant plate current during the modulating cycle while that of the modulating amplifier varies with the signal. The second is that the maximum plate circuit efficiency of the proper amplifier runs around 35 percent, while in the modulating amplifier it runs around 80 percent. The first reason gives the proper amplifier an over-all efficiency of a trifle over one-half that of the modulating amplifier, and the second reason gives it an over-all efficiency of less than one-half that of the modulating amplifier. The resulting efficiency is therefore around one-fourth that of the modulating amplifier. The efficiency of an amplifier system can be raised to that of the modulating amplifier system if we change the proper amplifier to an improper amplifier and apply an incompletely modulated wave to the grid. The efficiencies and distortions in the two cases will then be the same.

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

ISSUED APRIL 19, 1921—JUNE 14, 1921

By

JOHN B. BRADY

(OURAY BUILDING, WASHINGTON, D. C.)

The object of this section in the PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS is to make available in convenient form for research engineers and others interested, brief information on radio patents which are issued each week by the Patent Office. The rapid development in this art emphasizes the importance of radio research engineers being familiar with patent literature to eliminate, as far as possible, the duplication of effort in research. 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 complete copies of the patents obtained for study. Copies of the patents may be secured at ten cents each by communicating with the Commissioner of Patents, Washington, D. C.

Reissue 15,089—Carl R. Englund, East Orange, New Jersey, original application filed March 11, 1916, patented as number 1,258,548, dated March 5, 1918. Application for reissue filed March 3, 1920, issued April 19, 1921. Assigned to American Telephone and Telegraph Company.

RADIOTELEPHONY. The patent relates to the modulation system wherein the carrier frequency is prevented from reaching the antenna at the transmitter and is renewed from a local source at the receiver for operation with the modulated energy.

*Received by the Editor, June 27, 1921. 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.

Fig. 1.

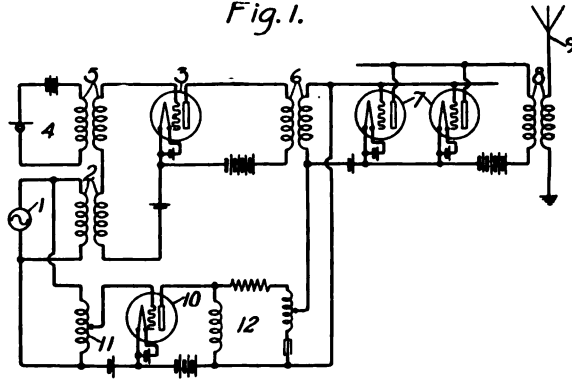
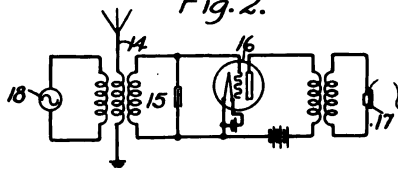


Fig. 2.



REISSUE 15,089—Radiotelephony

1,375,481—Harold D. Arnold, East Orange, New Jersey, filed August 23, 1915, issued April 19, 1921. Assigned to Western Electric Company.

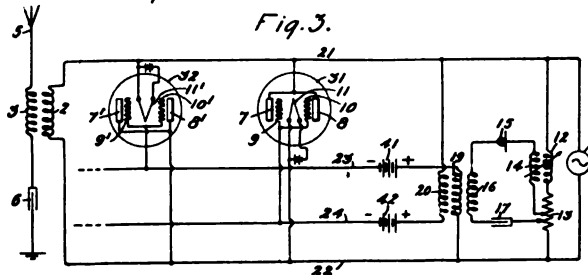
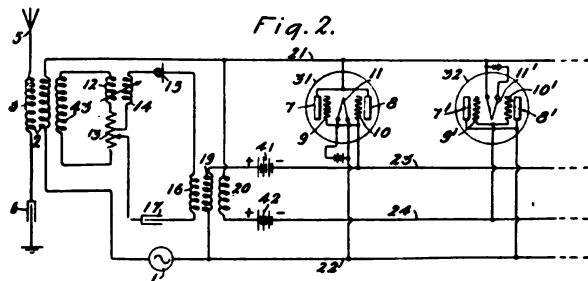
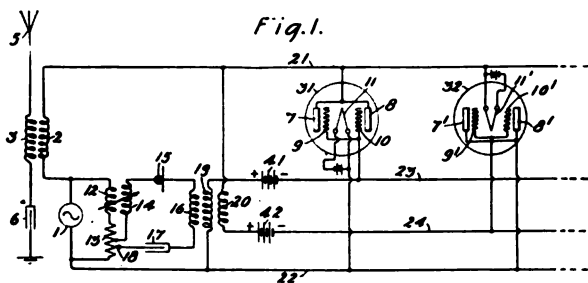
1,375,982—Elihu Thompson, Lynn, Massachusetts, filed November 16, 1916, issued April 26, 1921. Assigned to General Electric Company.

CONDENSER comprising a series of electrodes of greater thickness than the dielectric which separates them, each of the electrodes having rounded edges in such a way that there is a gradual tapering away of the surface of the electrode from the dielectric, thereby avoiding the formation of corona discharges at the edges of the electrodes.

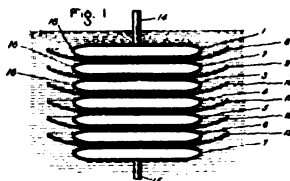
1,375,992—Ernst F. W. Alexanderson, Schenectady, New York, filed April 18, 1919, issued April 26, 1921. Assigned to General Electric Company.

RADIO-RECEIVING SYSTEM comprising an antenna circuit containing currents due to electromagnetic exposure and an electrostatic exposure. The receiving circuit associated with the antenna consists of two aperiodic intermediate circuits, each

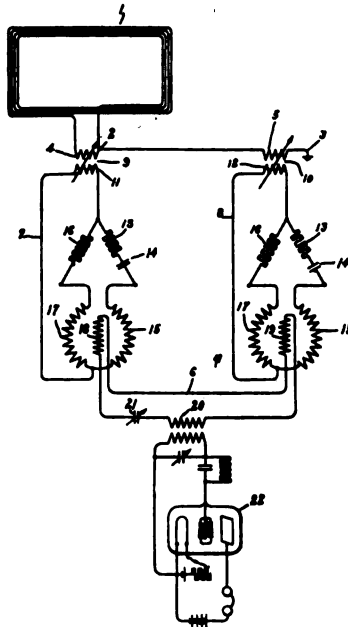
comprising two portions having different phase angle characteristics. The two portions of each intermediate circuit are coupled with the receiver and may be varied to change the phase of the currents impressed on the receiving circuit.



NUMBER 1,375,481—Power-Modulator for Radio Transmission

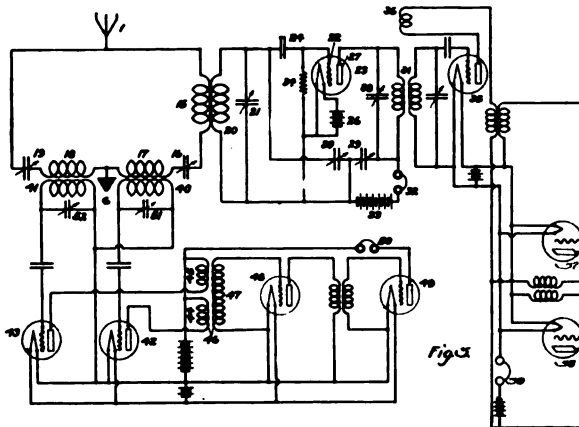


NUMBER 1,375,982—Condenser



NUMBER 1,375,992—Radio-Receiving System

1,376,051—Albert Hoyt Taylor, Grand Forks, North Dakota
 filed April 10, 1919; issued April 26, 1921.



NUMBER 1,376,051—Simultaneous Transmission or Reception
 of Speech and Signals

**SIMULTANEOUS TRANSMISSION OR RECEPTION OF SPEECH
 AND SIGNALS** in which the transmitter emits two widely different

wave lengths with telegraph signals on one of the wave lengths and the telephone conversation intermittently on the two wave lengths. The receiver contains three oscillatory circuits, one of which receives the telegraph signals and the other two of which are arranged to combine the intermittent parts of the telephone conversation.

1,376,592—John Sealy Edward Townsend, Oxford, England, filed April 10, 1918, issued May 3, 1921.

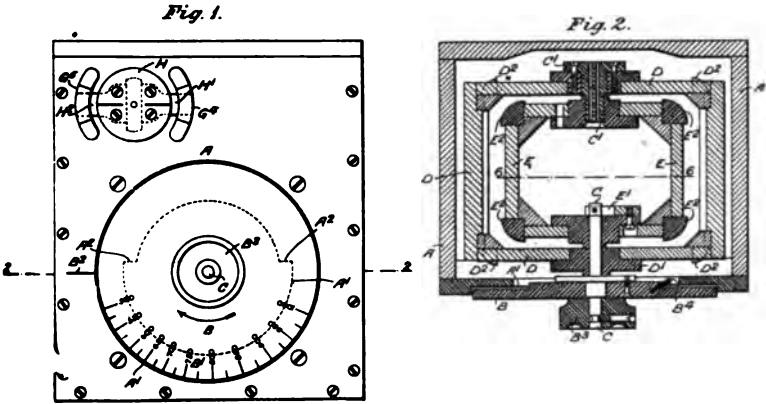
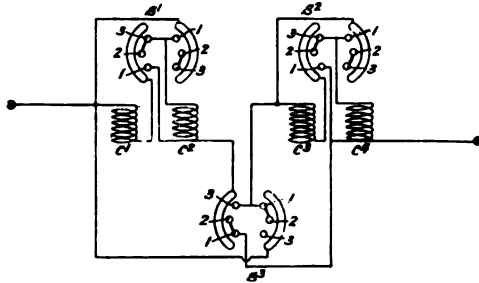


Fig. 1.

Fig. 2.

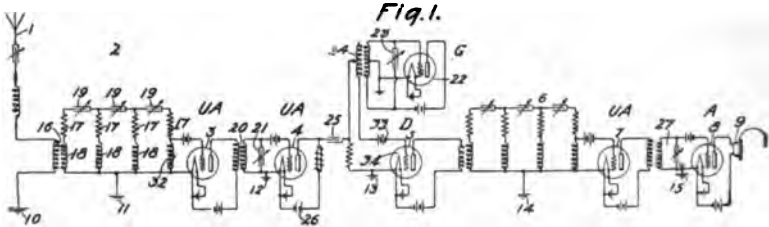


NUMBER 1,376,592—Variometer

1,376,679—Austen M. Curtis, Brooklyn, New York, filed October 10, 1917, issued May 3, 1921. Assigned to Western Electric Company.

RADIO RECEIVING SYSTEM in which the energy of static is converted into a form different from the form of the signaling energy or into a plurality of different forms of energy, only one

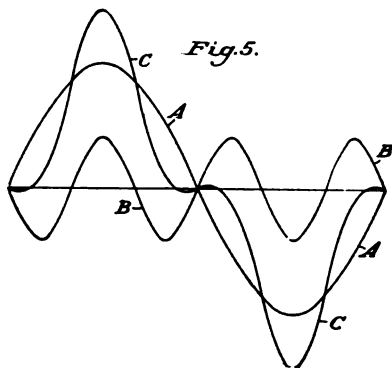
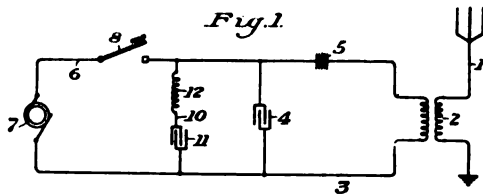
of which corresponds to the signaling energy, the latter having a definite character to which the signaling receiving circuit is selective, so that the effect of the static is reduced in proportion to the conversion of the same into the form or forms to which the signaling receiving circuit is not responsive.



NUMBER 1,376,679—Radio Receiving System

This is accomplished by using between the antenna and the signaling receiving device an intermediate network capable of oscillating at more than one frequency. An irregular electric wave, such as static, on striking the network will have a portion of its energy diverted to the production of the natural oscillations of the network. The more nearly the static approaches a pure impulse, the more nearly will it be completely changed into these natural oscillations. If the frequency of the continuous signaling wave is made to coincide with one of the natural frequencies of the network and a circuit sharply resonant to this frequency is non-reactively, that is, uni-directionally or loosely coupled to the network, the continuous wave and also oscillations of the natural frequency of the network which are caused by the impression of the static upon it, will be produced in the resonant circuit; but the natural frequencies of the network other than the one which is made to coincide with the continuous wave, will be almost completely suppressed. The continuous signaling wave will be reduced in amplitude by losses in the network and in the coupling. The static will be subject to losses which are similar altho different in magnitude, plus a loss caused by the fact that part of its energy has been used in the production of natural oscillations which are not appreciably transmitted to the resonant circuit.

1,377,059—Fulton Cutting, Tuxedo Park, New York, and Bowden Washington, Cambridge, Massachusetts, filed June 26, 1918, issued May 3, 1921.



NUMBER 1,377,059—Production of Electrical
Current Pulses

PRODUCTION OF ELECTRICAL CURRENT PULSES by a modification of the Chaffee system. The transmitter circuit includes an auxiliary circuit 10, 11, and 12 having a frequency of about three times the frequency of the alternator, which absorbs energy at the beginning and end of each wave or alternation of the current supplied by the alternator and restores energy during the middle of the wave, thus producing shortened and peaked waves separated by periods of substantially no activity. The alternator 7 impresses on the system an alternating current which is indicated by curve *A* (Figure 5). The current in the auxiliary circuit is represented by curve *B*. The resultant current represented by *C* is impressed on condenser 4 and is the algebraic sum of the currents *A* and *B*.

1,377,129—Walter Hahnemann, Kiel, Germany, filed January 2, 1915, issued May 3, 1921. Assigned to the firm Signal Gesellschaft m. b. H. of Kiel, Germany.

UNDERWATER WAVE TELEGRAPHY which utilizes a Hertzian oscillator on the hull of a ship having one of the ends of each electrode disposed in a receiver filled with an insulating fluid and with their other ends extending into the water outside.

Fig. 1

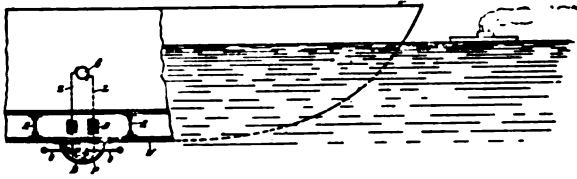


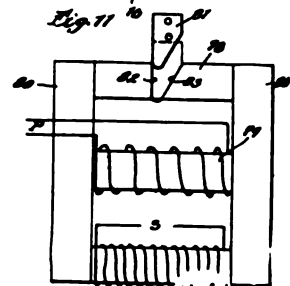
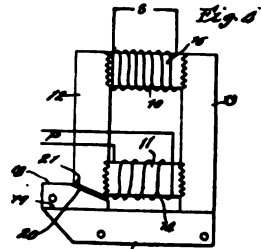
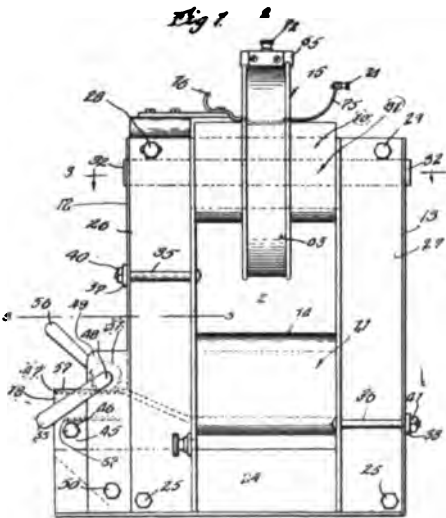
Fig. 2



NUMBER 1,377,129—Underwater Wave Telegraphy

The oscillator is energized by a generator at the transmitter (Figure 1) and a similar oscillator employed at the receiver (Figure 2) connected with an indicating meter. The system utilizes an alternating current having a frequency of at least 3×10^8 per second, that is, such a frequency as to cause the capacity reactance of the transmitting medium at its highest value to be equal to the ohmic resistance of the medium.

1,378,151—Chester H. Thordarson, Chicago, Illinois, filed November 6, 1916, issued May 17, 1921.



NUMBER 1,378,151—Electrical Transformer

ELECTRICAL TRANSFORMER of the closed core type with a movable core element for varying the magnetic flux of the transformer core thereby to vary the input of the transformer and to vary its output correspondingly.

1,378,345—Roy Edwin Hall, Chicago, Illinois, filed May 31, 1919, issued May 17, 1921. Assigned to Hall Research Corporation.

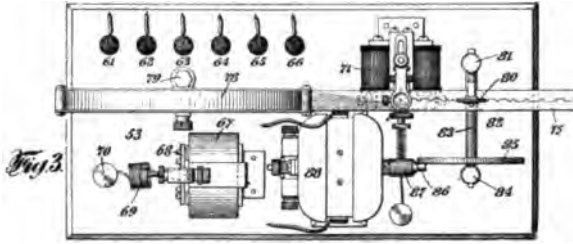


Fig. 4.

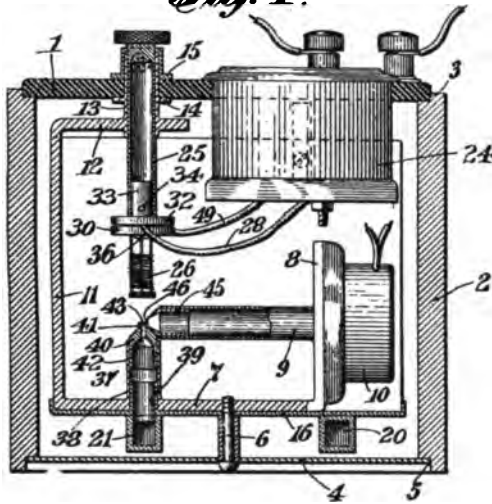
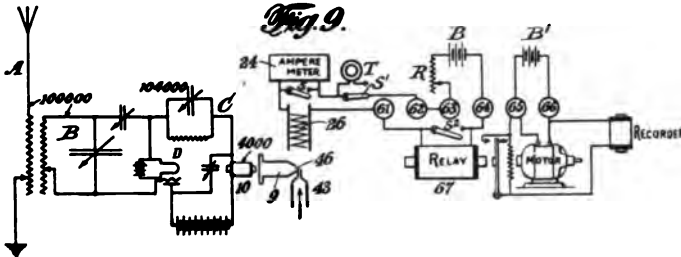


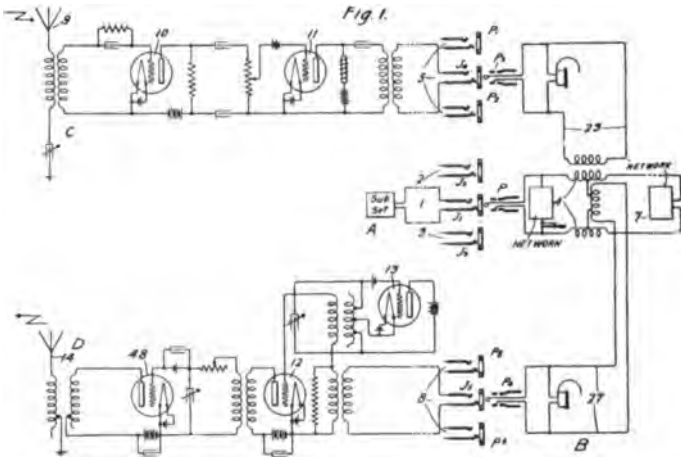
Fig. 9.



NUMBER 1,378,345—Method of and Means For Translating Energy Variations

METHOD OF AND MEANS FOR TRANSLATING ENERGY VARIATIONS whereby a tape record of the incoming radio signal is obtained. A sound sensitive jet of compressed air is varied in accordance with incoming signals and serves to cool an extremely fine wire to vary a condition or quality thereof and actuate a relay in circuit therewith which, in turn, controls the movements of a syphon inker over a progressing tape.

1,378,982—Herbert E. Shreeve, Millburn, New Jersey, filed September 17, 1918, issued May 24, 1921. Assigned to Western Electric Company.

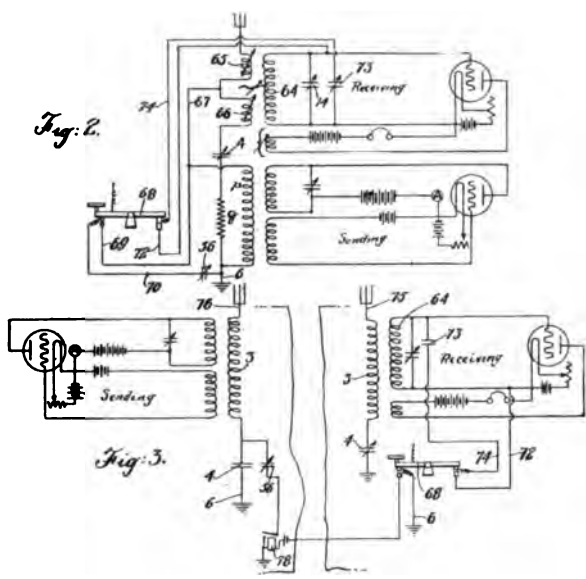


NUMBER 1,378,982—Signaling System

SIGNALING SYSTEM for connecting two telephone subscribers by a combined wire and radio link. A central station operator may connect any subscribers' stations simultaneously to the radio transmitting station or the radio receiving station and thus establish telephone communication by wire and radio.

1,379,144—Paul Ware, New York, N. Y., filed February 8, 1918, issued May 24, 1921. Assigned to Ware Radio, Inc.

CUT-IN SYSTEM OF RADIOTELEGRAPHY which enables the receiving operator to break in on the transmitting operator at any portion of the transmission.



NUMBER 1,379,144—Cut-in System of Radiotelegraphy

1,379,166—Theodore Willard Case, Scipio, New York, filed January 22, 1918, issued May 24, 1921.

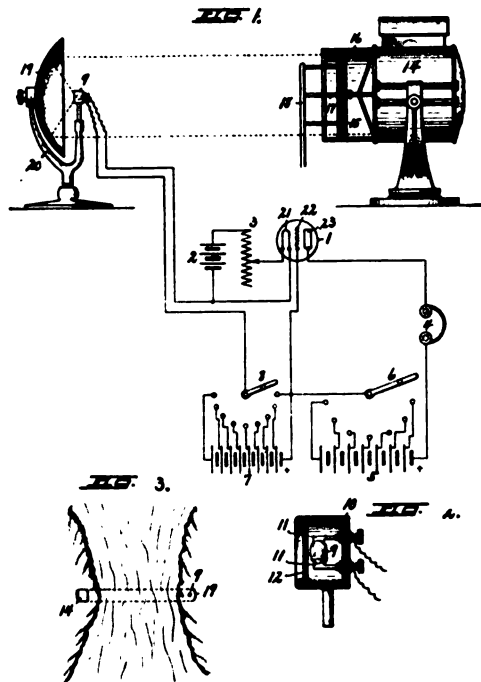
RADIANT ENERGY SIGNALING SYSTEM for transmitting by light rays.

1,379,167—Theodore Willard Case, Scipio, New York, filed February 20, 1918, issued May 24, 1921.

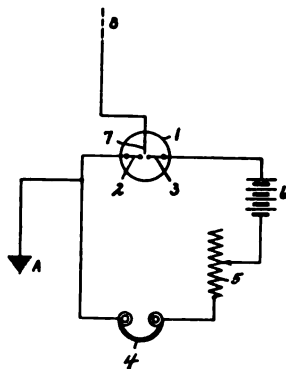
WIRELESS (RADIO) RECEIVER involving a bulb 1 containing a pair of spaced electrodes 2 and 3 connected in a local circuit 4, 5, and 6. The bulb contains a gas of low dielectric constant and is arranged in an antenna-ground circuit with control member 7, whereby the received oscillations vary the conductivity of the gaseous space and thereby effect variations in the frequency of pulsations of the local circuit.

1,379,184—Louis Alan Hazeltine, Hoboken, New Jersey, filed November 1, 1917, issued May 24, 1921. Assigned to Ware Radio, Inc.

SHIELDING RADIO APPARATUS to eliminate the disturbing effects on the tuning caused by movements of the human body, or of other conducting or insulating bodies in the immediate vicinity of the radio apparatus.



NUMBER 1,379,166—Radiant Energy Signaling System



NUMBER 1,379,167—Wireless (Radio) Receiver

1,379,262—Stanton C. Hooper and George H. Clark, Washington, District of Columbia, filed September 16, 1919, issued May 24, 1921.

Fig:4.

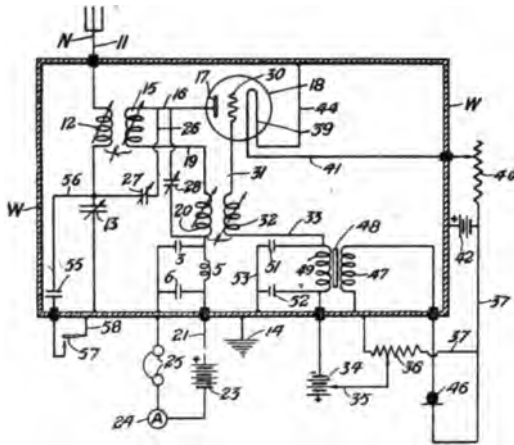


Fig:1.

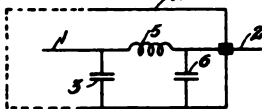


Fig:2.

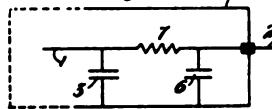
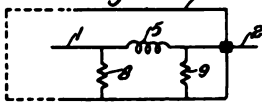


Fig:3.



NUMBER 1,379,184—Shielding Radio Apparatus

RADIO RECEIVING ANTENNA comprising a plurality of antennas located at approximately equal distances apart on a line bearing in the direction of the distant transmitting station. Each antenna includes a tuning capacity and inductance for bringing the antenna to resonance with the incoming wave length. The several antennas are conductively connected at their extremities and the increments of energy received by each integrated in a radio receiving apparatus.

1,379,541—James Erskine-Murray and James Robinson, Biggin Hill, England, filed October 29, 1910, issued May 24, 1921.

ELECTROMAGNETIC WAVE NAVIGATIONAL ARRANGEMENT wherein bearings are determined by noting the interval between the reception of a distinctive signal periodically propagated from the transmitting station in a definite direction and the reception

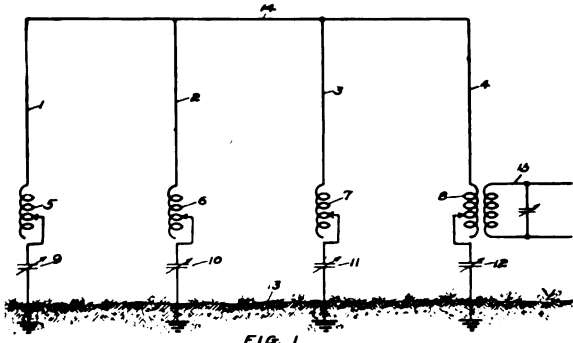


FIG. 1

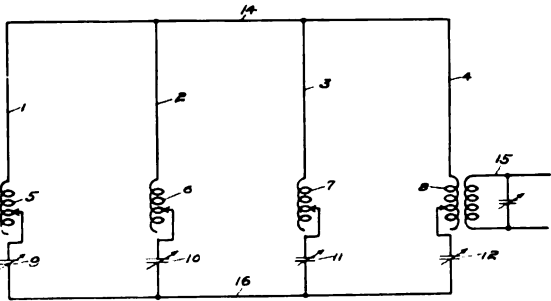


FIG. 2

NUMBER 1,379,262—Radio Receiving Antenna

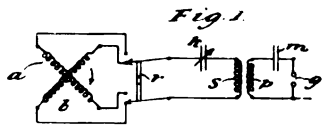


Fig. 1

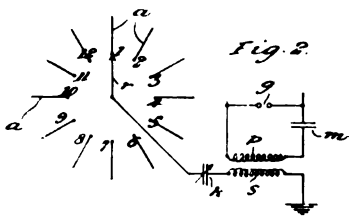


Fig. 2

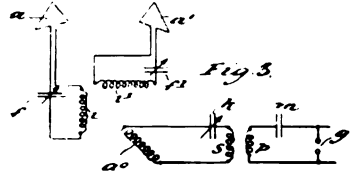
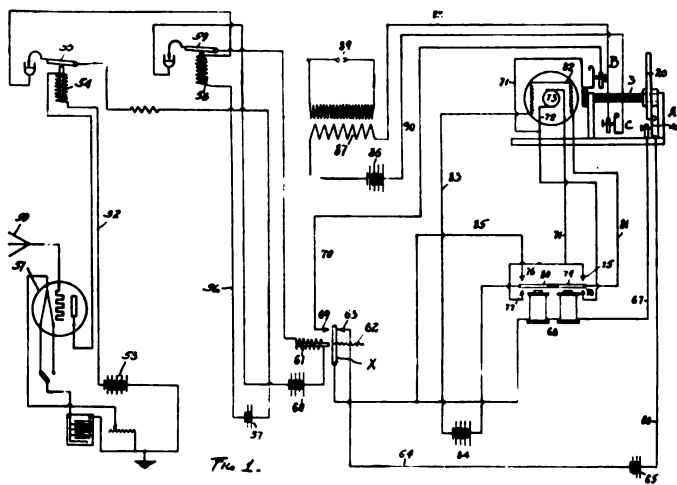


Fig. 3

NUMBER 1,379,541—Electromagnetic Wave Navigational Arrangement

of a pair of successive signals of equal intensity in a series of signals propagated from the transmitting station in pairs of quickly succeeding individual signals at small equal time intervals, the individual signals of each pair varying in relative intensity in a given direction with the position of a movable element which controls the emission of signals at the transmitting station.

1,379,589—Henry H. Hyder, Hollywood, California, filed June 5, 1918, issued May 24, 1921.

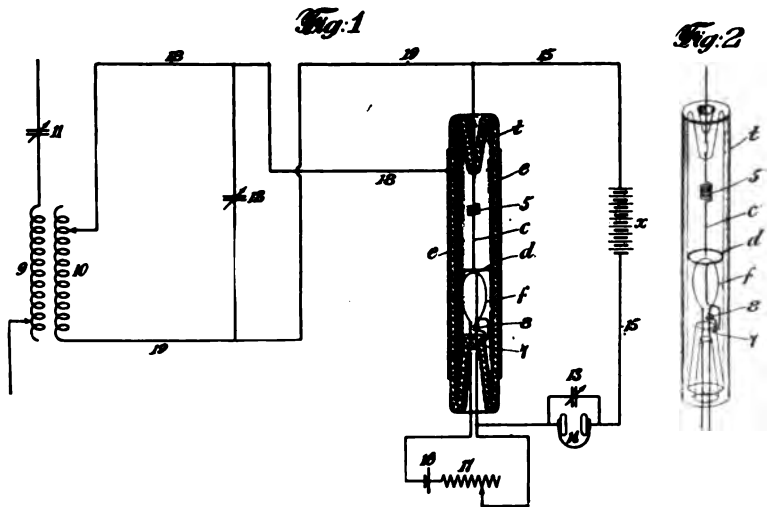


NUMBER 1,379,589—Radio Apparatus

RADIO APPARATUS for mechanically locking an electrical circuit in open position in connection with the exploding of mines. The device may be operated from a distance by a radio operator knowing the necessary intervals of time for closing and opening the circuit controlling the mechanical lock and operating mechanism for closing the working circuit.

1,379,706—Roy Alexander Weagant, Roselle, New Jersey, filed March 10, 1917, issued May 31, 1921. Assigned to Radio Corporation of America.

VACUUM VALVE DETECTOR having an exterior control element. The improvement consists of a guard device *d* in the form of a ring and disposed adjacent to the point where the cath-



NUMBER 1,379,706—Vacuum Valve Detector

ode and anode approach each other and is electrically connected to the cathode. It operates to discharge any charge that occurs or accumulates on the exterior wall of the tube in the vicinity of its location.

1,380,206—Roy Alexander Weagant, Roselle Township, Union County, New Jersey, filed March 10, 1917, issued May 31, 1921. Assigned to Radio Corporation of America.

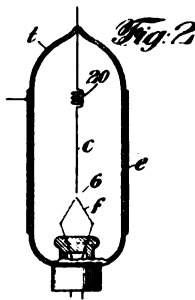
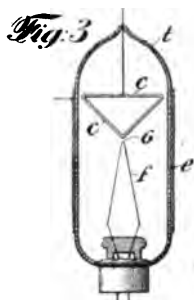
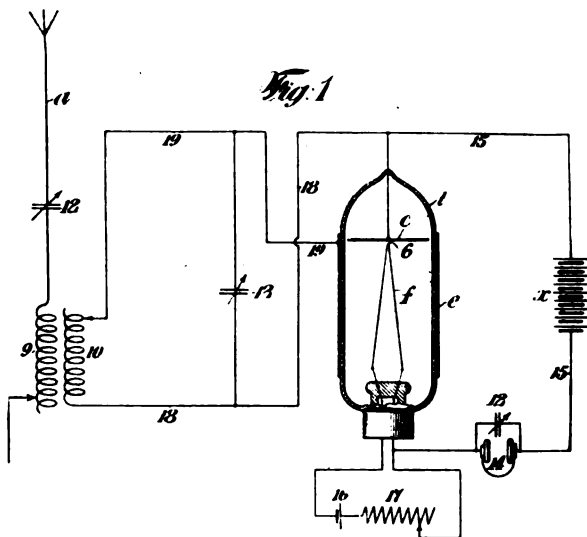
VACUUM VALVE DETECTOR of the external control type. The hot and cold elements are arranged in the tube so that they form points between which the electron flow will be continuous and uninterrupted in the presence of disturbing causes such as static and high potential transmitted impulses.

1,380,663—John Lindgren, Lemont, Illinois, filed May 16, 1918, issued June 7, 1921.

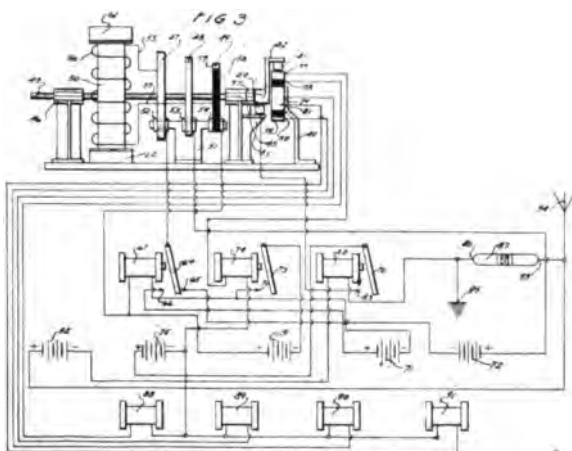
RADIO CONTROL DEVICE for synchronizing the movement of an armature located at a distance receiving station with the movement of a commutator circuit closer located at the transmitter.

1,380,872—Roy E. Thompson, New York, N. Y., filed September 24, 1917, issued June 7, 1921.

RADIO COMMUNICATION TRANSMITTER with an exciting cir-

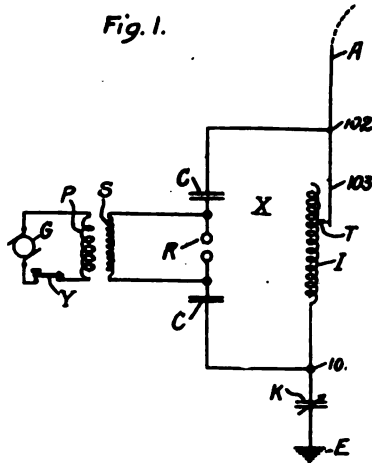


NUMBER 1,380,206—Vacuum Valve Detector



NUMBER 1,380,663—Radio Control Device

Fig. 1.



NUMBER 1,380,872—Radio Communication Transmitter

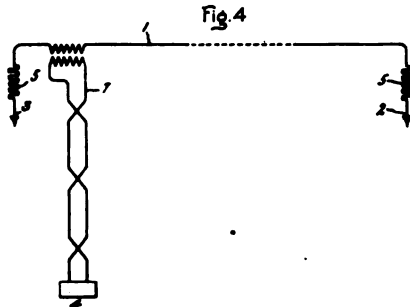
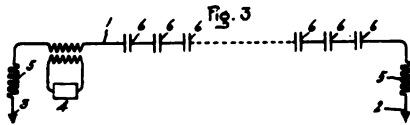
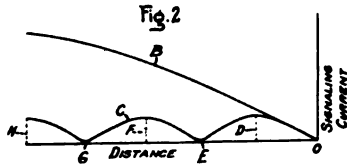
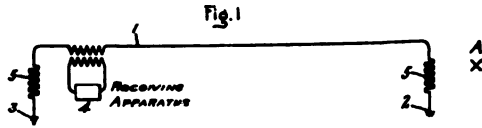
cuit of non-persistent oscillatory character, and a radiating circuit of a persistently oscillating character. A multiple unit spark gap adjustable from a single control is employed in the set.

1,381,089—Harold H. Beverage, Schenectady, New York, filed April 10, 1920, issued June 7, 1921. Assigned to General Electric Company.

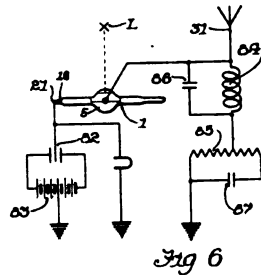
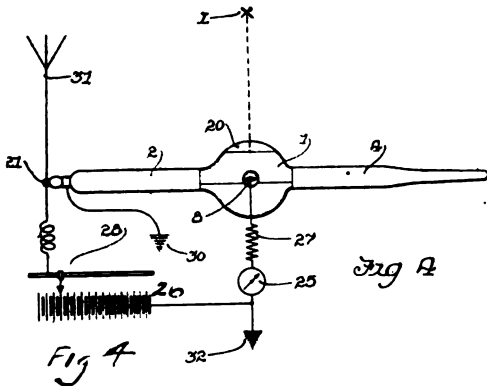
RADIO RECEIVING SYSTEM in which a horizontal receiving antenna is employed. The distributed constants of the antenna are of such values that the waves produced therein will be propagated along its length at substantially the same velocity as that at which the desired signaling waves travel along its length in the ether.

1,381,474—Jakob Kunz, Urbana, Illinois, filed August 24, 1918, issued June 14, 1921. Assigned to Board of Trustees of the University of Illinois.

PHOTO-ELECTRIC CELL, METHOD AND MEANS FOR MAKING THE SAME. The cell may be used as a wave detector and when so employed the cell is excited by the light source *L*, as shown in Figure 4, so that electrons pass from the film electrode to the screen electrode within the cell. The incoming waves entering by way of the antenna 31 are rectified by the cell and give an indication at the indicator 25 then passing to ground at 32.



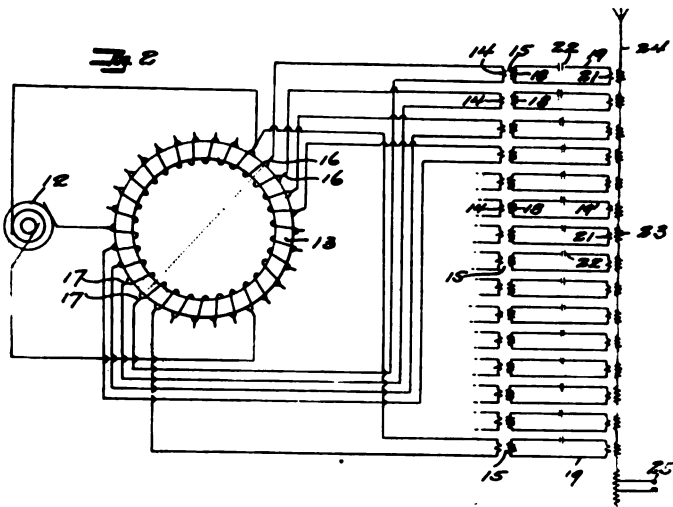
NUMBER 1,381,089—Radio Receiving System



NUMBER 1,381,474—Photo-Electric Cell, Method and Means for Making the Same

The source of current 26 may be omitted. The current operating on the indicator 25 may be amplified by a vacuum tube or other relay device.

1,381,626—Leonard F. Fuller, San Francisco, California, filed January 19, 1918, issued June 14, 1921. Assigned to Federal Telegraph Company.



NUMBER 1,381,626--Process and Apparatus for Producing Radio Frequent Current

PROCESS AND APPARATUS FOR PRODUCING RADIO FREQUENT CURRENT in which the impulses are caused to follow each other in phase by a phase-multiplying transformer. Poly-phase current, preferably three phase, is fed into the phase-multiplying transformer and taps on the phase-multiplying transformer winding are connected to the respective impulse transformers, the taps for each impulse transformer being located at diametrically opposite points. The secondaries of each impulse transformer are included in separate oscillating circuits, each associated with the radiating circuit.

1,381,692—Cesare Bardeloni, Rome, Italy, filed April 12, 1919, issued June 14, 1921.

Fig. 1.

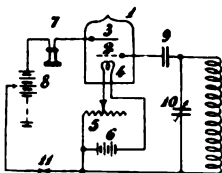


Fig. 2.

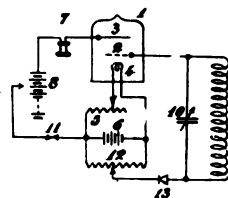


Fig. 3.

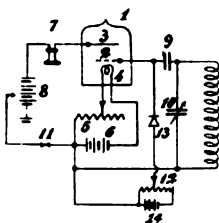


Fig. 4.

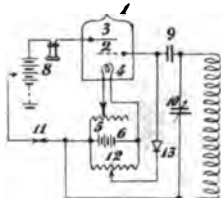


Fig. 5.

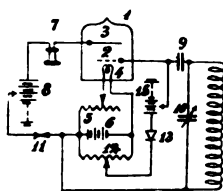
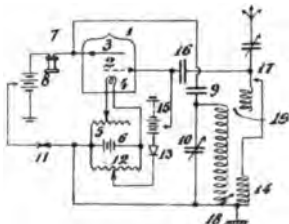


Fig. 6.

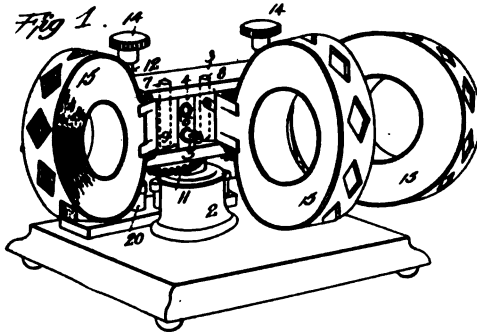


NUMBER 1,381,692--Device for Receiving Radio Telegraphic and Radio Telephonic Signals

DEVICE FOR RECEIVING RADIO TELEGRAPHIC AND RADIO TELEPHONIC SIGNALS, comprising a circuit including an oscillating vacuum tube with the addition of a rectifying device inserted across the filament and grid thru a potentiometer. The action of the rectifying contact, owing to its insertion with respect to the oscillating circuit with which it is connected in parallel and with respect to the electrode 2 of the ionized gas receiver, may be assumed to be a double one: 1st—that of actual amplification of the signals by the increase of positive charges which flow to the electrode 2 during the oscillations set up in the oscillating circuit; 2nd—that of unification of the ionized medium

about the electrode 2, so as to neutralize, by means of negative charges reaching to the electrode thru the contact, the excess of free positive charges due to the direct influence of the electrode 2, which latter thus follows only the charge variations which the aforesaid oscillating circuit impresses thereon.

1,365,170—Robert Fellons Gowen, New York, N. Y., filed August 20, 1919, issued January 11, 1921. Assigned to De Forest Radio Telephone and Telegraph Company.



NUMBER 1,365,170—Inductance Coil Mounting

1,366,627—Ernst F. W. Alexanderson and Samuel P. Nixdorff, Schenectady, New York, filed December 8, 1918, issued January 25, 1921. Assigned to General Electric Company.

HIGH (RADIO) FREQUENCY ALTERNATOR having an exciting field made up of a plurality of semicircular coils embracing the periphery of each half of the machine frame.

1,367,734—Austen M. Curtis, Brooklyn, New York, filed August 16, 1917, issued February 8, 1921. Assigned to Western Electric Company.

CONSTRUCTION OF REACTANCE COILS in which the conductor is wound on a structure composed of two semicylindrical forms. The construction is such that the inductance has no external field.

1,369,601—Ernst F. W. Alexanderson, Schenectady, New York, filed November 4, 1918, issued February 22, 1921. Assigned to General Electric Company.

HIGH (RADIO) FREQUENCY ALTERNATOR having an inductor

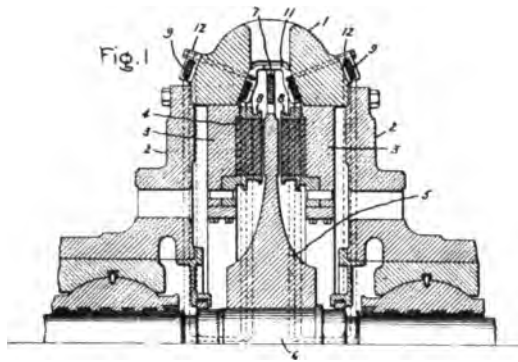
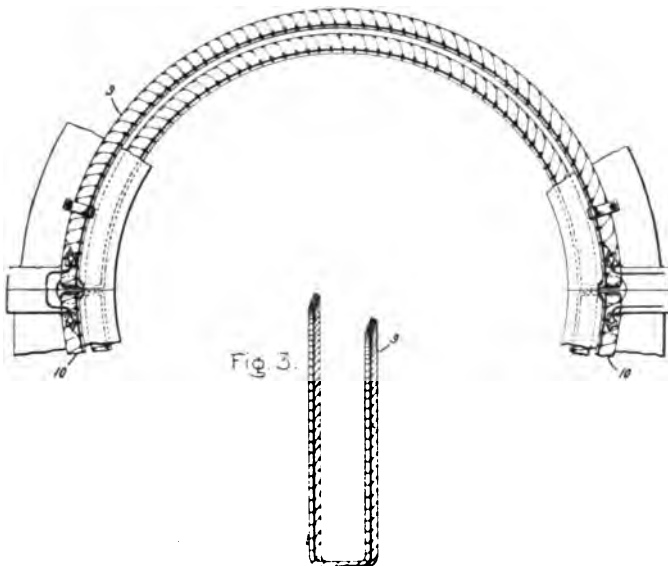
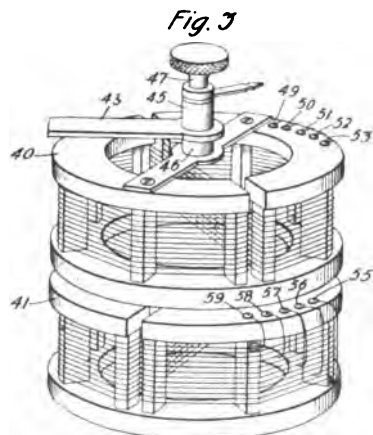


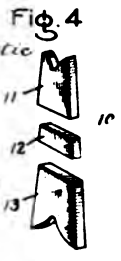
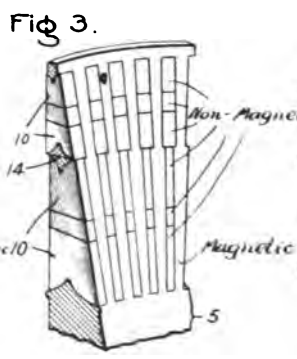
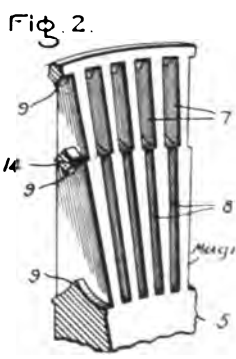
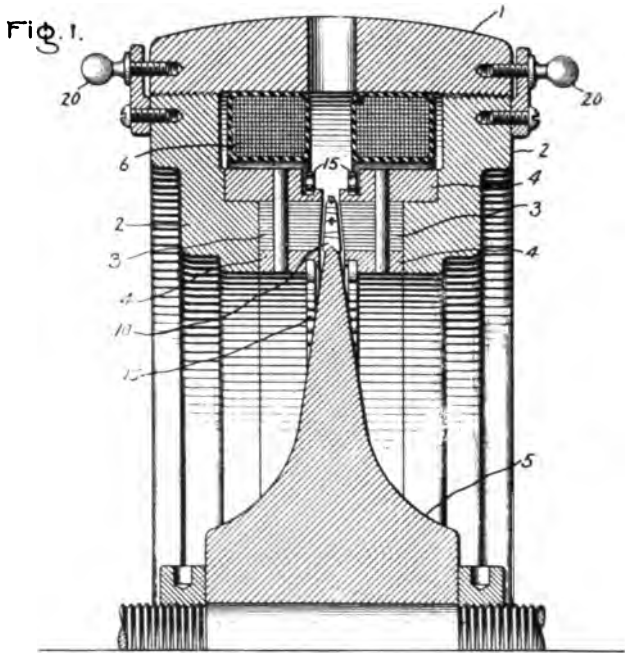
Fig. 2.



NUMBER 1,366,627—High (Radio) Frequency Alternator



NUMBER 1,367,734—Construction of Reactance Coils

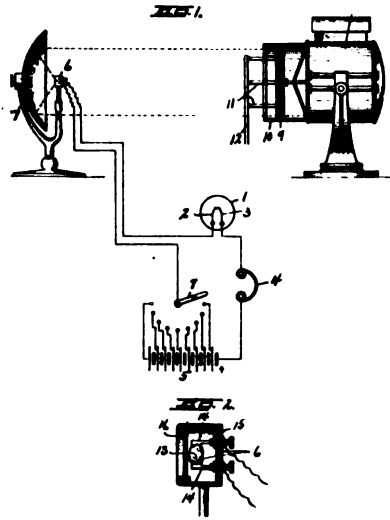


NUMBER 1,369,601 High Radio Frequency Alternator

formed with two circumferential rows of radial slots and non-magnetic filler disposed in the slots.

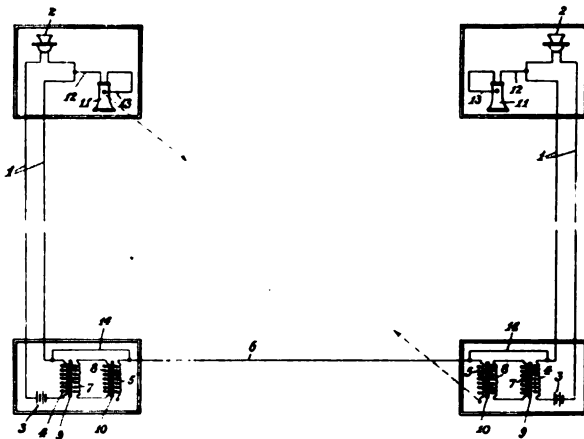
1,369,781 Theodore Willard Case, Scipio, New York, filed February 20, 1918, issued March 1, 1921.

SIGNALING SYSTEM for transmitting by light rays.



NUMBER 1,369,781—Signaling System

1,370,333—William W. Macfarlane, Elkins Park, Pennsylvania,
 filed May 15, 1919, issued March 1, 1921.



NUMBER 1,370,333—System of Communication

SYSTEM OF COMMUNICATION at audio frequency in which the two telephone stations are connected by a single conductor and the other terminals of the respective sets grounded.

FURTHER DISCUSSION ON
"ON THE POULSEN ARC IN COUPLED CIRCUITS"*

BY
P. O. PEDERSEN

P. O. Pedersen (by letter): Mr. L. F. Fuller is of the opinion that I have not used "tuned" fields in my experiments on the Poulsen arc in coupled circuits. Since I myself am responsible for the original discovery of "*The existence, in every particular case, of a certain field intensity, H^0 , giving maximum efficiency and greatest constancy*"¹ and "*The dependence of H^2 on wave length, gas density, supply current, and radio frequency resistance,*"² I really think I would have been altogether too negligent and dull had I not, in every single case, brought the strength of the magnetic field to its most suitable value. And, of course, the field actually was properly chosen in every case.

Some other points in Mr. Fuller's discussion might also warrant comment, but as he agrees with my main conclusion, I do not think there is any necessity for carrying the discussion further.

* PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 9, page 242, 1921.

¹ PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 5, page 309, 1917.

² Italicized in the original.