REPRINT OF SECTIONS ON

WIRELESS TELEGRAPHY AND WIRELESS TELEPHONY

FROM

PRACTICAL PHYSICS

BY

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GINN AND COMPANY

BOSTON · NEW YORK · CHICAGO · LONDON
ATLANTA · DALLAS · COLUMBUS · SAN FRANCISCO

Electrical Radiations

485. Proof that the discharge of a Leyden jar is oscillatory. We found in § 408, p. 346, that the sound waves sent out by a sounding tuning fork will set into vibration an adjacent fork, provided the latter has the same natural period as the former. Following is the complete electrical analogy of this experiment.

Let the inner and outer coats of a Leyden jar *A* (see Fig. 455) be connected by a loop of wire *cdef*, the sliding crosspiece *de* being arranged so that the length of the loop may be altered at will. Also let a strip of tin foil be brought over the edge of this jar from the inner coat to within about 1 millimeter of the outer coat at *C*. Let the two coats of an exactly similar jar *B* be connected with the knobs *n* and *n′* by a second similar wire loop of fixed length. Let the two jars be placed side by side with their loops parallel, and let the jar *B* be successively charged and discharged by connecting its coats with a static machine or an induction coil. At each discharge of jar *B* through the knobs *n* and *n′* a spark will appear in the other jar at *C*, provided the crosspiece *de* is so placed that the areas of the two loops are equal. When *de* is slid along so as to make one loop considerably larger or smaller than the other, the spark at *C* will disappear.

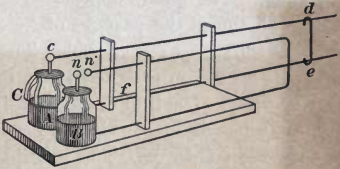


Fig. 455. Sympathetic electrical vibrations

The experiment therefore demonstrates that two electrical circuits, like two tuning forks, can be *tuned* so as to respond to each other sympathetically, and that just as the tuning forks will cease to respond as soon as the period of one is slightly altered, so this *electric resonance* disappears when the exact symmetry of the two circuits is destroyed. Since, obviously, this phenomenon of resonance can occur only between systems which have *natural periods* of vibration, the experiment proves that the discharge of a Leyden jar is a vibratory, that is, an oscillatory, phenomenon. As a matter of fact, when such a spark is viewed in a rapidly revolving mirror, it is actually found to consist of from ten to thirty flashes following each other at equal intervals. Fig. 456 is a photograph of such a spark.

In spite of these oscillations the whole discharge may be made to take place in the incredibly short time of $\frac{1}{1,000,000}$ of a second. This fact, coupled with the extreme brightness of the spark, has made possible the surprising results of so-called *instantaneous electric-spark photography.* The plate opposite page 425 shows the passage of a bullet through a soap bubble. The film was rotated continuously instead of intermittently, as in ordinary moving-picture photography. The illuminating flashes, 5000 per second, were so nearly instantaneous that the outlines are not blurred.

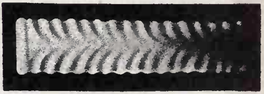


Fig. 456. Oscillations of the electric spark

486. Electric waves. The experiment of § 485 demonstrates not only that the discharge of a Leyden jar is oscillatory but also that these electrical oscillations set up in the surrounding medium disturbances, or waves of some sort, which travel to a neighboring circuit and act upon it precisely as the air waves acted on the second tuning fork in the sound experiment. Whether these are waves in the air, like sound waves, or disturbances in the ether, like light waves, can be determined by measuring their velocity of propagation. The first determination of this velocity was made by Heinrich Hertz (see opposite p. 102) in 1888. He found it to be precisely the same as that of light, that is, 300,000 kilometers per second. *This result shows, therefore, that electrical oscillations set up waves in the ether.* These waves are now known as Hertzian waves.

The length of the waves emitted by the oscillatory spark of instantaneous photography is evidently very great, namely, about $\frac{300,000,000}{10,000,000} = 30$ meters, since the velocity of light is

300,000,000 meters per second, and since there are 10,000,000 oscillations per second; for we have seen in § 382, p. 323, that wave length is equal to velocity divided by the number of oscillations per second. By diminishing the size of the jar and the length of the circuit the length of the waves may be greatly reduced. By causing the electrical discharges to take place between two balls only a fraction of a millimeter in diameter, instead of between the coats of a condenser, electrical waves have been obtained as short as .3 centimeter, — only ten times as long as the longest measured heat waves.

487. Detection of electric waves. In the experiment of § 485 we detected the presence of the electric waves by means of a small spark gap C in a circuit almost identical with that in which the oscillations were set up. The visible spark may be employed for the detection of waves many feet away from the source, but for detecting the feeble waves which come in from a source hundreds or thousands of miles away we must depend upon sounds produced in an extremely sensitive telephone receiver, as explained in the next section.

488. Wireless telegraphy. Commercial wireless telegraphy was realized in 1896 by Marconi (see opposite p. 316), eight years after the discovery of Hertzian waves. The essential elements of a tuned *wave-train*, or "spark," system of wireless telegraphy are as follows:

The key K at the transmitting station (Fig. 457, (1)) is depressed to allow a current from the alternator A to pass through the primary coil P of a transformer T_1, the frequency of the alternations in practice being usually about 500 cycles per second. The high-voltage current induced in the secondary S charges the condenser C_1 until its potential rises high enough to cause a spark discharge to take place across the gap s. This discharge of C_1 is oscillatory (§ 485), and the oscillations thus produced in the condenser circuit containing C_1, s, and L_1 may, in a low-power short-wave transmitting set, have a frequency as high as 1,000,000 per second. An oscillation frequency much lower than this is generally used and is subject to the control of the operator through the sliding contact c, precisely as in the case illustrated in Fig. 455. The oscillations in the condenser circuit induce oscillations in the aërial-wire system, which is tuned to resonance with it through the sliding contact c'.

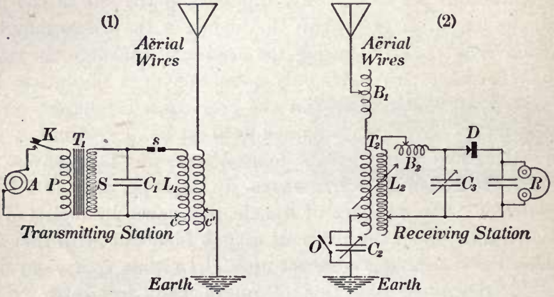


FIG. 457. Transmitting and receiving stations for wireless telegraphy

As long as the key K is kept closed (assuming a 500-cycle alternator to be used), 1000 sparks per second occur at s, and therefore a regular series of 1000 wave trains (Fig. 458) pass off from the aërial every second and move away with the velocity of light. If the oscillations which produce a wave train have a frequency of, say, 500,000 per second, each wave in the wave train has a length of $\frac{300,000,000}{500,000}$, or 600 meters; and if these wave trains are produced at the rate of 1000 per second, they follow each other at regular distances of 300,000 meters, that is, nearly 200 miles.

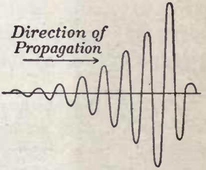
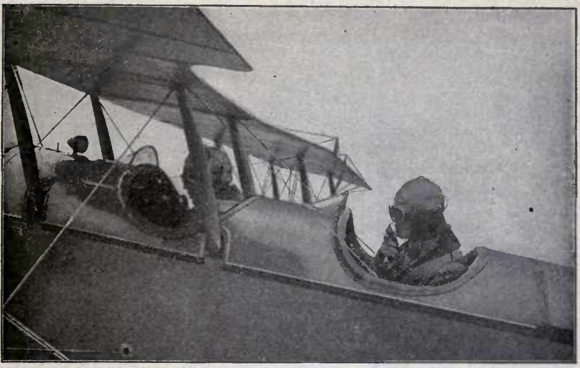


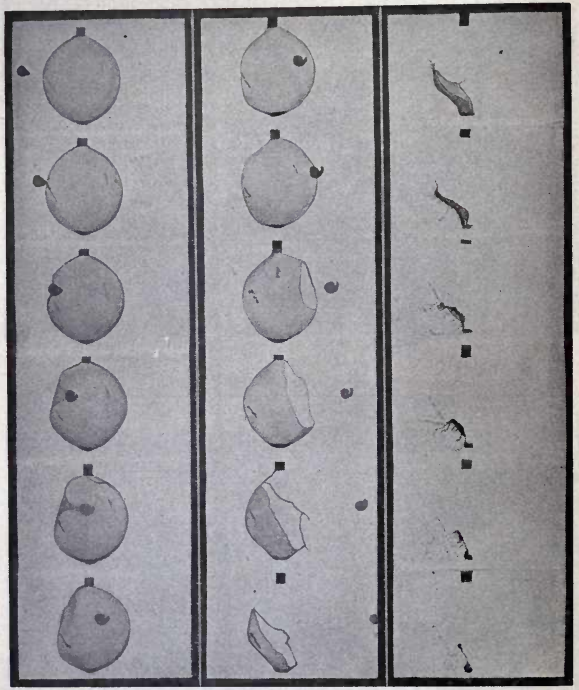
FIG. 458. One wave train from oscillatory discharge

The waves sent out by the aërial system of the transmitting station induce like oscillations in the distant aërial system of the receiving station (Fig. 457, (2)), which is tuned to resonance with it. In case the receiving aërial must be tuned to respond to very long waves, the switch O is closed to cut out the condenser C_2, and the inductance, or loading coil, B_1 is used; whereas, to tune to very short waves, the switch O is opened and the variable



The Wireless Telephone utilized in Aviation

One of the most notable developments of the war was the directing of a squadron of airplanes in intricate maneuvers by wireless telephone either from the ground or by the commander in the leading plane. The upper panel shows the pilot and the observer conversing with special apparatus designed to eliminate plane noises, and the lower panel shows President Wilson talking by wireless to airplanes



Cinematograph Film of a Bullet fired through a Soap Bubble

The flight of the missile may be followed easily. It will be seen that the bubble breaks, not when the bullet enters, but when it emerges. (From "Moving Pictures," by F. A. Talbot. Courtesy of J. B. Lippincott Company) condenser C_2 is brought into use, the loading coil not being utilized.[1] The oscillations in the aërial circuit of the receiving station induce exactly similar ones in the detector circuit, which is tuned to resonance with the receiving aërial by means of L_2, B_2, and C_3. The so-called detector of these oscillations may be simply a crystal of galena D in series with the telephone receivers R. This crystal, like the tungar rectifier of § 374, has the property of transmitting a current in one direction only.[2] Were it not for this property the telephone could not be used as a detector, because its diaphragm cannot vibrate with a frequency of the order of a million; and even if it could, it would produce sound waves far above the limit of hearing. Because of this rectifying property of the crystal the receiver diaphragm is drawn in only once while the oscillations produced by a given wave train last, this effect being due to the rectified pulsating current which passes in one direction through the receivers and then ceases until the oscillations due to the next spark arrive. Since 1000 of the intermittent wave trains strike upon the aërial each second, the operator at the receiving station hears *a continuous musical note of this pitch as long as the key K is depressed.* The working of the key, however, as in ordinary telegraphy, breaks the regular series of wave trains into *groups of wave trains*, so that the short and long notes heard in the receivers (Fig. 459) correspond to the dots and dashes of telegraphy.

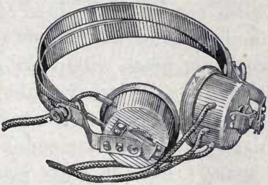


FIG. 459. United States navy standard radio receivers

The receiving circuit, when tuned as shown in Fig. 457, (2), is highly *selective*; that is, it will not pick up waves of other periods. The loading coils B_1 and B_2, as well as the two variable condensers C_2 and C_3, are usually omitted from small amateur receiving sets; but when this is done, the receiving set is less selective and less sensitive. The resistance of the receivers is so high, usually from 1000 to 4000 ohms, that

[1] In the diagram an arrow drawn diagonally across a condenser indicates that, for the sake of tuning, the condenser is made adjustable. Similarly, an arrow across two circuits coupled inductively, like the primary and secondary of the "oscillation transformer" T_2, indicates that the amount of interaction of the two circuits can be varied, as, for example, by sliding one coil a longer or shorter distance inside the other.

[2] Crystal detectors have been largely superseded by the "audion" for both wireless telegraphy and wireless telephony.

they do not interfere with the oscillations of the condenser system across which they are placed. *The receiving station shown in Fig. 457, (2), may also be used for receiving wireless-telephone messages.* The simplified circuit of an audion receiving station is shown opposite page 441.

Although the spark, or wave-train, system of wireless telegraphy is still widely used, the "continuous wave" system is rapidly displacing it. Just as sound waves differing slightly in frequency combine to produce the phenomenon of beats (§ 396), so electrical oscillations differing in frequency give, when combined, a "beat effect." For instance, if electrical oscillations of, say, 30,000 per second and 31,000 per second combine, beats will occur at the rate of 1000 per second, which is a frequency within the limit of hearing. The electrical oscillations mentioned above have a frequency beyond the limit of hearing and hence are said to have *radio* frequency; but the beats being within the range of hearing have an *audio* frequency. Now let us assume that there is at the transmitting station an alternating-current generator which throws into the aërial powerful undamped oscillations of 30,000 per second; and suppose further that at the receiving station there is an oscillation generator which maintains relatively weak oscillations of 31,000 per second in the local receiving aërial. These weak oscillations produced in the receiving aërial by the local generator make no sound in the receiver, being above the limit of hearing; but *whenever, and as long as,* the operator at the transmitting station depresses his key, waves come in at the rate of 30,000 per second, strike against the receiving aërial and develop therein weak oscillations which combine with those already present to make 1000 beats per second. These beat effects are rectified by a crystal or by a vacuum tube and passed through the receiver. The listener, therefore, hears long and short musical sounds just as he does when receiving by the spark system. The beat method of receiving is called the heterodyne system.

489. Modulated continuous waves.* The vibrations constituting articulate speech are exceedingly complex, as may be seen from an inspection of the full-page halftone opposite page 346. Because of this complexity it is impossible to transmit speech by means of discontinuous waves (Fig. 460) such as are employed in the system of spark telegraphy described in the preceding section. The parts of the voice lost because

FIG. 460. A series of wave trains

of the gaps between the wave trains would render the language unintelligible. Theoretically the voice could be transmitted by continuous electromagnetic waves having the frequencies of voice vibrations, but such a method is entirely impracticable on account of the enormous length of aërial needed to produce such long waves and the tremendous amount of power which would be required. Therefore, the only satisfactory method thus far developed is to transmit speech

FIG. 461. Continuous, or carrier, waves of radio frequency

on continuous, or "carrier," waves (Fig. 461) having a frequency (*radio* frequency) above the limit of hearing.

At the sending station the continuous waves (Fig. 461) are "modulated" by the voice at the transmitter; that is, the sound waves of the voice act upon the apparatus in such a way as to alter the otherwise uniform amplitude of the series of continuous waves (Fig. 462). These "modulated" continuous waves on reaching the aërial of the receiving station produce corresponding oscillatory currents in the wires of the

* The pupil should master §§ 374, 375, 376, 485, 486, 487, and 488 before reading the six sections following.

aërial. By means of a crystal or a vacuum tube, the oscillatory currents are rectified into a series of *unidirectional* electrical currents, or pulses, somewhat after the manner indicated

Fig. 462. Modulated radio-frequency waves

in Fig. 463. These variable pulses of radio frequency, on reaching the telephone receivers of the listener, produce diaphragm vibrations of low frequencies (*audio* frequencies), which

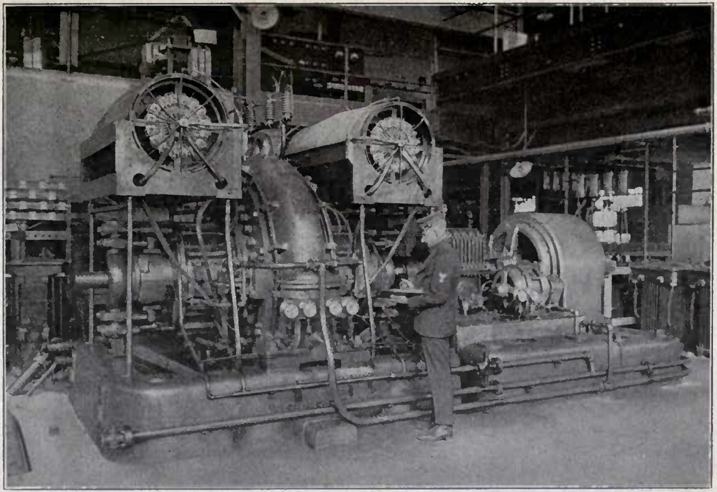
Fig. 463. Rectified oscillations

rarely go outside the limits of 100 and 3000 vibrations per second. They are represented by the irregular line in Fig. 464. The vibrations of the diaphragms of the receivers, therefore,

Fig. 464. Audio-frequency variations

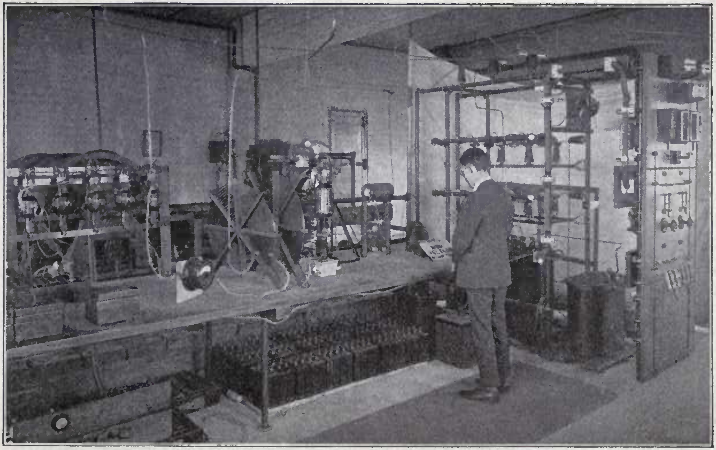
correspond to the vibrations of the voice of the speaker at the distant transmitting station.

490. Method of producing continuous waves. One of the most important of the different means of producing high-power continuous waves is by use of the Alexanderson high-frequency alternator (see on opposite page). This is an alternating-current dynamo made in various powers up to 200 kilowatts (= 268 horse power), the rotor in some of the machines having the very high speed of 20,000 revolutions per minute. For transoceanic telegraphy these machines cause currents of from 600 to 1200 amperes to oscillate in the sending aërial. This powerful sustained oscillation of electrons in an aërial produces continuous electromagnetic waves (Fig. 461).



ALEXANDERSON HIGH-FREQUENCY ALTERNATOR, NEW BRUNSWICK (N. J.) WIRELESS STATION

This picture shows one of the devices now in use for the production of continuous radio-frequency waves. At the top and on each side of the 200-kilowatt generator are the oscillation transformers. At the extreme right is the motor which drives the generator



Courtesy of Radio Corporation of America

INTERIOR OF RADIO BROADCASTING STATION (WGY), GENERAL ELECTRIC COMPANY, SCHENECTADY, N. Y.

At the extreme left is a bank of large vacuum tubes; in the center is a spiral oscillation transformer, to the right of which is a huge power tube. At the extreme right is the control panel, while beneath the table are the condensers. The transmitter is in another room — the Studio Room

491. The vacuum tube. There are several devices by which the voice waves may modulate, or vary the amplitude of, the carrier waves, the most important being the highly exhausted "vacuum tube" (see Fig. 465, the halftone opposite p. 441, and the drawing and legend opposite p. 33).

In attempting to reach an understanding of an "audion" amplifier or other form of vacuum tube, it is well to remember

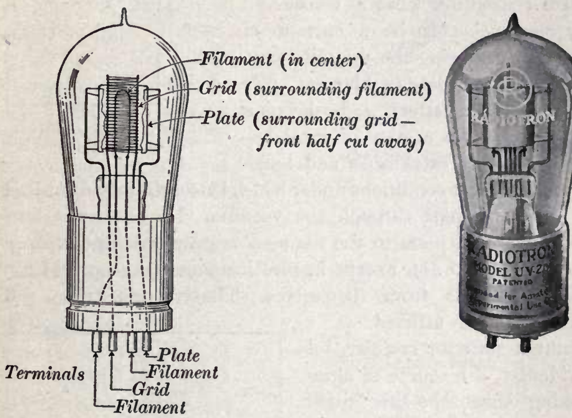


Fig. 465. A popular form of vacuum tube used in radio receiving

that a current of electricity is a stream of negative electrons which, when passing through a vacuum, move with enormous velocity (thousands of miles per second (§ 498)), but when passing along a wire (ordinary conduction) move quite slowly (a few centimeters per second). Now we found in studying the tungar rectifier (§ 374) that these negative electrons escape freely from an incandescent filament under certain conditions. When the battery B (Fig. 466) has its + terminal connected to the plate P of the vacuum tube and its – terminal to the filament *F*, no current can flow across the vacuum *so long as the filament is cold.* When, however, the filament is maintained at incandescence by a battery *A*, the negative electrons escape from it and are drawn in a steady stream across the vacuum by the attraction of the + plate *P*. This flow of – electrons from filament to plate constitutes what is considered by convention to be a current of electricity flowing the opposite way, namely, from plate to filament. We now see how battery *A*, by keeping the filament in a state of incandescence, merely establishes and maintains one of the conditions under which battery *B* may discharge a steady current through the vacuum. No electronic flow from the cold plate to the filament is ever possible, because cold bodies do not, except in rare instances (see pp. 441 ff.) eject electrons from themselves. The vacuum tube can therefore be utilized as a vacuum *valve*, or rectifier, for evidently, if a source of alternating current be substituted for the direct current source (battery *B*), the vacuum valve would transmit current in one direction only, half of each cycle being held in check.

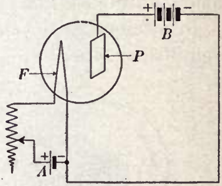


FIG. 466. A two-electrode vacuum valve

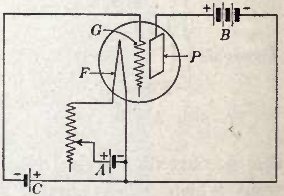
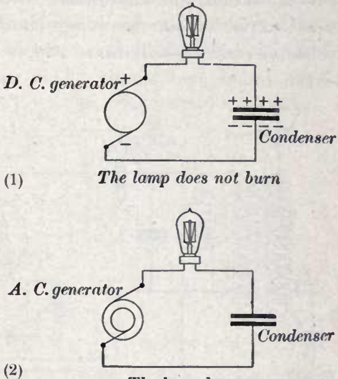


FIG. 467. A three-electrode vacuum tube

If a screen of fine wire *G*, known as a "grid," be introduced between the filament and the plate of Fig. 466 (see Fig. 467) *and the grid be maintained at a sufficiently high – potential* by a battery *C*, the – electrons are repelled back into the incandescent filament and cannot escape from it, and thus the electronic flow is completely checked; that is, *no current flows across the vacuum.* If now the − potential of the grid be varied, say, from zero to the amount required to stop the electronic flow, the current from battery *B* through the vacuum is thereby varied from the possible maximum in Fig. 466 to zero. Variation of the grid potential, therefore, affords us a means of controlling and of varying the flow of current through a vacuum tube. Indeed, it is found that *slight* changes in the grid voltage produce surprisingly *great* changes in the current through the tube; that is, the tube is an *amplifier.*

492. Transfer of energy through a condenser. In Fig. 468, (1), the E.M.F. of the direct-current dynamo causes a rush of electrons out of one side of the condenser while electrons to an equal extent rush into the other side. The sides of the condenser are thus charged + and − and they remain so as long as the dynamo runs. It is evident that under these conditions there is no flow of current and that consequently the lamp does not burn. If, however, an alternating-current dynamo is used (Fig. 468, (2)), the alternating E.M.F. causes an alternating rush of electrons which charges the condenser first one way and then the opposite way. It is clear, then, that with an alternating-current dynamo, lamp, and condenser thus arranged we may have an alternating current through the



(1) *The lamp does not burn*

(2) *The lamp burns*

Fig. 468. Energy transferred through a condenser

lamp which will cause it to light up. Condensers of variable capacity are widely used in the circuits of wireless apparatus as aids in tuning, and they permit passage of electrical energy in the manner explained above.

493. The receiving station. Fig. 469 represents a "regenerative" receiving circuit capable of receiving long or short waves. When the modulated waves (Fig. 462) reach the tuned aërial of the receiving station, they develop therein feeble electrical oscillations which induce oscillations in L_2 of the tuned grid circuit. This varies the potential of the

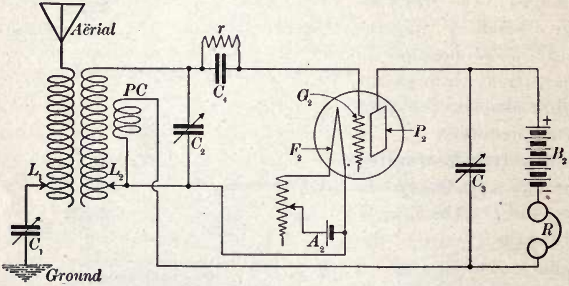


FIG. 469. A regenerative receiving circuit

grid G_2, thus causing corresponding changes in the strength of the electronic current flowing from the incandescent filament F_2 to the plate P_2 and thence back through the plate coil PC. The plate circuit is so tuned with respect to the grid circuit that these current variations in the plate coil react inductively on the coil L_2 connected with the grid circuit to strengthen the original grid-circuit current. This intensifies the variations in potential at the grid, which in turn intensifies the variations in strength of the electronic current from filament to plate, and this still further intensifies the variations in potential at the grid, and so on, up to the limit of the electron supply in the tube. This is the *Armstrong regenerative principle* by which very feeble oscillations produced by the incoming waves may be amplified and then used to intensify the original oscillations. *The energy for regeneration comes from the battery B_2.* When the tube is in use the grid tends to accumulate a negative charge which, as we have seen (§ 491), would tend to block completely the action of the tube. Therefore, a high-resistance grid leak r is shunted around the condenser C_4 to permit the return

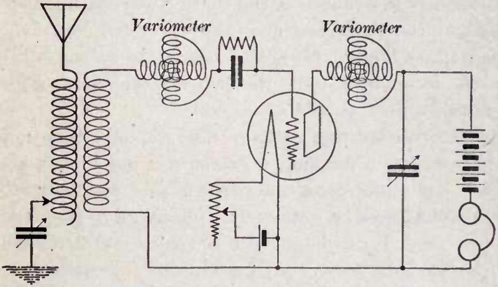


FIG. 470. A two-variometer tuned-plate-circuit for receiving short waves

of such a detrimental accumulation of electrons to the filament F_2 by way of r and L_2. The telephone receivers used in wireless work contain thousands of turns of very fine wire wound upon iron and because of the consequent "choke-coil" effect, or impedance, of these coils for *high-frequency* changes in current strength, the *radio*-frequency variations (Fig. 463) of the plate current pass largely by way of the variable condenser C_3, while the slower *audio*-frequency variations (Fig. 464) of the plate current pass readily through the receivers to actuate the diaphragm.

Fig. 470 shows a two-variometer circuit for the reception of short waves. A variometer is a variable inductance used for tuning and it consists of two coils in series, one of which revolves within the other. If current is passed through the variometer when the inner coil is turned so that its magnetic field combines with that of the other coil to make the greatest resultant magnetic field, the inductance of the variometer is found to have its greatest value and the adjustment is then for the longer waves, or slower oscillations. If the inner coil is now turned through 180°, the resultant magnetic field is at minimum strength; and, because of the small inductance, the variometer is adjusted to the shorter waves. Intermediate positions of the inner coil are used for wave lengths lying between these limits. Complete tuning is accomplished by use of the two variometers, the two variable condensers and the sliding contact on the aërial coil.

494. The transmitting station. The vacuum tube may be used not only as a rectifier, a detector, a modulator, and an amplifier, but under certain conditions as a *generator of oscillations* varying over an extremely wide range of frequency — from less than 1 oscillation per second to 300,000,000 or more per second. Nearly all present-day "broadcasting" is done by use of vacuum-tube generators. For high-power long-distance transmission *banks* of vacuum-tube amplifiers may be used to throw into an aërial an aggregate power of many hundreds of kilowatts. Indeed, at the present time rapid progress is being made in the experimental construction of power tubes *each one of which* is capable of giving an amazing output. The life of a vacuum tube is generally from 1000 to 5000 hours, whereas a high-frequency alternator, such as the Alexanderson, will last for many years.

It is entirely beyond the scope of this book to explain the actual details of a wireless-telephone transmitting station. However, the method used at present in high-power long-distance transmission is indicated in Fig. 471 and may be outlined as follows: Air vibrations produced by the voice make variations in the current of the primary circuit of the telephone transmitter (§ 376). This induces corresponding E.M.F.'s in the secondary circuit, which impresses audio-frequency variations of potential upon the grid of a vacuum-tube modulator. The resulting changes of audio frequency in the current of the plate circuit of the modulator correspondingly affect the output of the high-frequency oscillation generator. This modulated radio-frequency output is

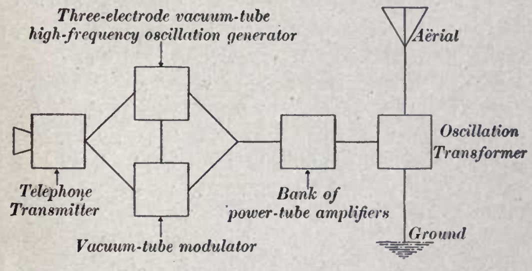


FIG. 471. High-power long-distance wireless-telephone transmitting station

amplified by a bank of three-electrode power tubes and is then delivered to the aërial through an oscillation transformer. In broadcasting stations (see opposite p. 429) a weaker and somewhat simpler arrangement of tubes is used.

NOTE. The following reference books will prove helpful to teachers and to those pupils who desire a more complete understanding of "wireless": (1) BUCHER, Practical Wireless Telegraphy, Wireless Press, 326 Broadway, New York City; (2) GOLDSMITH, Radio Telephony, Wireless Press, 326 Broadway, New York City; (3) HAUSMANN and others, Radio Phone Receiving, Van Nostrand Co., 8 Warren St., New York City; (4) MORECROFT, Principles of Radio Communication, John Wiley and Sons, 432 Fourth Ave., New York City; (5) SCOTT-TAGGART, Thermionic Tubes in Radio Telegraphy and Telephony, Wireless Press, 326 Broadway, New York City; (6) Elementary Principles of Radio Telegraphy and Telephony (Radio Communication Pamphlet 1), 79 pages, illustrated, 10 cents, Superintendent of Documents, Government Printing Office, Washington, D.C., 1922.

Although transoceanic telephonic communication has been successfully and repeatedly accomplished (see opposite p. 441), no regular service for such communication has yet been established.

495. The electromagnetic theory of light. The study of electromagnetic radiations, like those discussed in the preceding paragraphs, has shown not only that they have the speed of light but that they are reflected, refracted, and polarized, — in fact, that they possess all the properties of light waves, the only apparent difference being in their greater wave length. Hence *modern physics regards light as an electromagnetic phenomenon*; that is, light waves are thought to be generated by the oscillations of the electrically charged parts of the atoms. It was as long ago as 1864 that Clerk-Maxwell, (see opposite p. 102), of Cambridge, England, one of the world's most brilliant physicists and mathematicians, showed that it ought to be possible to create ether waves by means of electrical disturbances. But the experimental confirmation of his theory did not come until the time of Hertz's experiments (1888). Maxwell and Hertz together, therefore, share the honor of establishing the modern electromagnetic theory of light.

Cathode and Röntgen Rays

496. The electric spark in partial vacua. Let *a* and *b* (Fig. 472) be the terminals of an induction coil or static machine; *e* and *f*, electrodes sealed into a glass tube 60 or 80 centimeters long; *g*, a rubber tube leading to an air pump by which the tube may be exhausted. Let the coil be started before the exhaustion is begun. A spark will pass between *a* and *b*, since *ab* is a very much shorter path than *ef*. Then let the tube be rapidly exhausted. When the pressure has been reduced to a few centimeters of mercury, the discharge

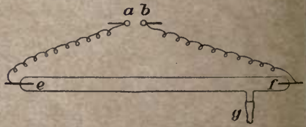


Fig. 472. Discharge in partial vacua