Operating Features of the Audion

Explanation of its action as an amplifier, as a detector of high-frequency oscillations and as a "valve." By E. H. Armstrong

ALTHOUGH the audion has been in use for several years as an amplifier and a detector of high-frequency oscillations, the explanations advanced to account for its action do not appear to be satisfactory. With the idea of pointing out some features of operation which heretofore do not seem to have been appreciated, the following explanation and oscillograms are given.

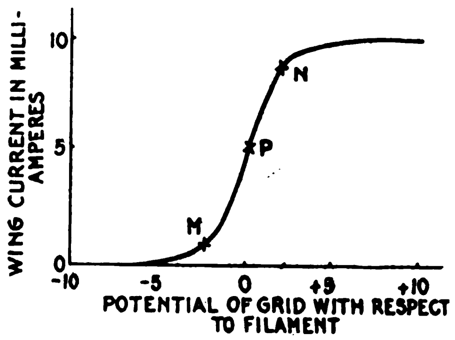

FIG. 1—VARIATION OF WING CURRENT WITH GRID POTENTIAL

The audion is essentially an electron relay; that is, the exhaustion is carried to such a point that the amount of gas present is exceedingly small, and the current between the hot and cold electrodes is entirely thermionic, the absence of gas making impossible the presence of positive ions. The operating characteristic of such a relay is as shown in Fig. 1. This characteristic was obtained in the manner indicated in Fig. 2.

The potential of the grid with respect to the filament was varied in steps between — 10 and + 10 volts, by means of the potentiometer *P*, corresponding readings of grid voltage and wing current being taken in order to plot the curve of Fig. 1. The characteristic shows that, starting with the grid and filament at zero potential difference, a negative charge imparted to the grid produces a decrease in the wing current and a positive charge imparted to the grid produces an increase in the wing current. This is the fundamental action of the audion when used either as an amplifier or a detector. The reason for this action will appear upon examination of the behavior of an audion of the type shown in Fig. 3.

The wings of the audion were placed symmetrically with respect to the filament, but only one grid was employed. It was found that, under similar conditions of filament temperature and voltage of the battery B_2, a considerably smaller current was obtained between the filament and plate on the side in which the grid was inserted. In both measurements the grid was left entirely free of any connection with the rest of the apparatus. Obviously the grid obstructed the flow of the thermionic current. Investigation showed that this was due to the charge accumulating on the grid when exposed to bombardment by the electrons passing from the filament to the wing. The electrons pass readily enough into the grid but cannot easily escape from it, and as a consequence of this negative electricity piles up on the grid. The potential assumed by the grid when exposed to this bombardment may be several volts negative with respect to the negative terminal of the filament, it may be the same as the negative terminal, or it may be positive with respect to the negative terminal, but it will always be negative with respect to the potential of the field in the plane of the grid which would exist if the grid were removed from the bulb. The negative charge on the grid, therefore, impedes the flow of electrons from filament to plate, causing the decrease in the wing current. The placing of a positive charge on the grid from an external source tends to neutralize the negative charge on the grid, thereby permitting an increase in the wing current. The addition of a negative charge to the grid increases the deflection of the electrons and produces a further decrease in the wing current.

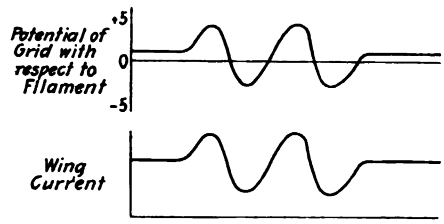

FIG. 4—TIME VARIATION OF GRID POTENTIAL AND WING CURRENT

An alternating emf impressed between the grid and the filament causes variations in the wing current in the manner indicated in Fig. 4, the positive alternation producing an increase and the negative alternation a decrease in the wing current. This is the action in-

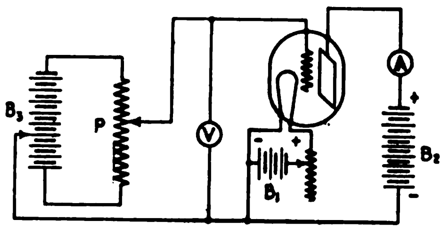

FIG. 2—CONNECTIONS FOR OBSERVING WING CURRENT AND GRID POTENTIAL

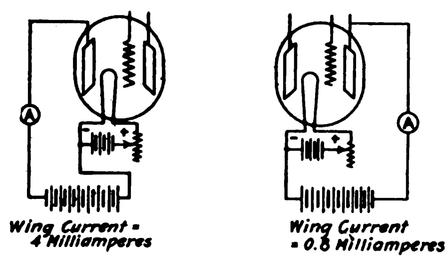

FIG. 3—CONNECTIONS GIVING TWO VALUES OF WING CURRENT

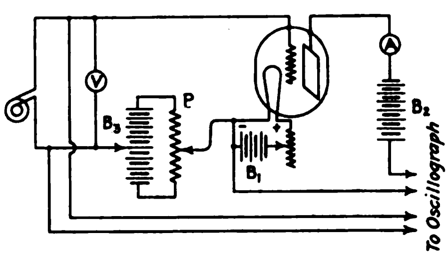

FIG. 5—CONNECTIONS TO OSCILLOGRAPH

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volved in the audion when it is used as an amplifier.

To substantiate the above and other actions, the writer, working in conjunction with Prof. J. H. Morecroft, of Columbia University, has secured oscillograms which substantiate the idea just presented. Fig. 5

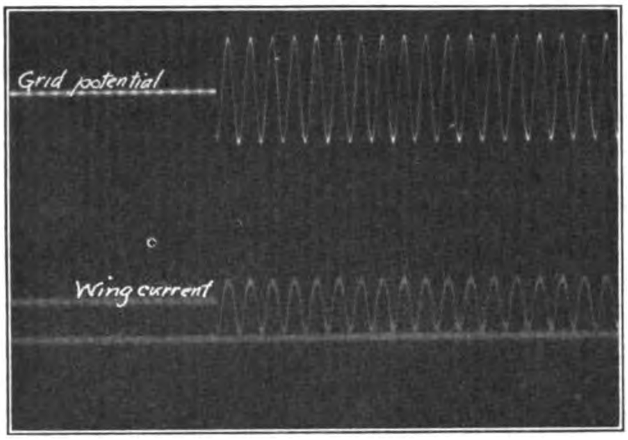


FIG. 6—ACTION OF AUDION AS AN AMPLIFIER

shows the arrangements with which the test was carried out.

The potentiometer P was used to adjust the grid to a potential corresponding to point P at the center of the operating part of the curve shown in Fig. 1. The audion is capable of handling the greatest amount of energy as an amplifier when the grid potential is adjusted to this point.

Fig. 6 shows the oscillogram of the action as an amplifier. The result bears out the explanation already given.

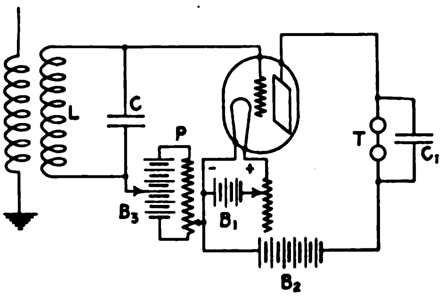
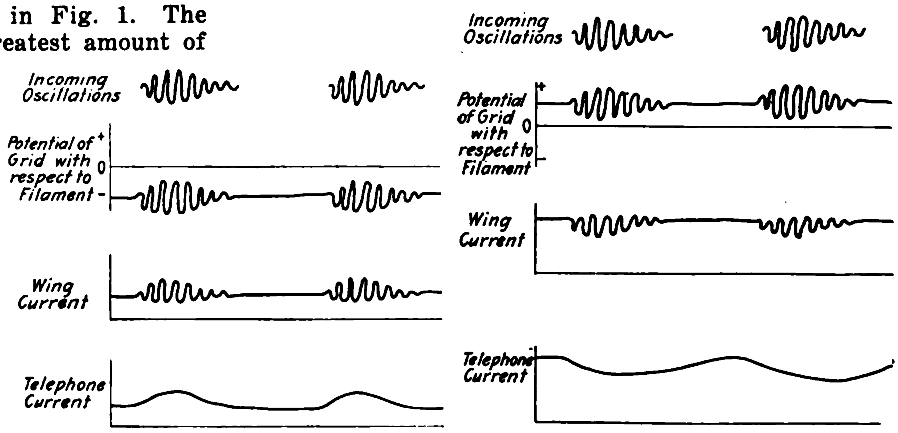


FIG. 7—USE OF AUDION AS AN OSCILLATION DETECTOR



FIGS. 8 AND 9—ACTION OF AUDION AS AN OSCILLATION DETECTOR

The action of the audion as a detector of high-frequency oscillations is quite different from its action as an amplifier. Since the incoming oscillations are of too high a frequency to affect directly the telephone receiver, the audion must be so connected and adjusted that the cumulative effect of a group of oscillations in the grid circuit is translated into a single low-frequency pulse or variation in the telephone current. This may be done in two ways, one depending on the non-linear form of the operating characteristic of the audion and the other depending on the so-called "valve" action between hot and cold electrodes at low pressures.

Fig. 7 shows the connection used for operating in the first-named manner. The potentiometer P is employed for the purpose of adjusting the potential of the grid to point M on the characteristic curve of Fig. 1. The action is much the same as in one of Professor Fleming's methods of using his valve. A group of high-frequency oscillations impressed on the grid causes corresponding high-frequency variations in the continuous current in the wing circuit, but owing to the fixing of the grid potential at the lower bend in the curve by adjustment of the potentiometer in the grid circuit, the amplitude of the positive part of the high-frequency current in the wing circuit exceeds the amplitude of the negative part. As the positive half-waves are greater than the negative half-waves, more electricity flows in one direction than the other, and the condenser C, through which the high-frequency current in the wing circuit flows, becomes charged, the side connected to the battery B_2 having the positive charge. This charge accumulates in C_1 in a relatively short time, approximately that of the duration of a wave train. C_1 then discharges through the telephones T, the rate of this discharge being determined by the constants of the telephones and the condenser. It is probable that this discharge is aperiodic or nearly so. In any case the main part of the discharge through the telephones is in the same direction as the current due to the battery B_2 and constitutes an increase in the current in the telephones. As this action is repeated for each group of oscillations, a series of wave trains causes what might be regarded (in its action on the telephones) as an alternating current in the telephones superposed on the continuous current and having a fundamental frequency equal to the number of wave trains per second. The action is shown diagrammatically in Fig. 8.

If the potential of the grid is adjusted to the upper bend in the curve of Fig. 1, as at point N, the fundamental action will be the same, but the effect of high-frequency oscillations in the grid circuit on the wing current will be reversed. The amplitude of the negative part of the high-frequency oscillations in the wing circuit will exceed the amplitude of the positive part and the condenser C_1 will become charged, but in the opposite sense, the side connected to the battery B_2 becoming negative. The discharge of the condenser through the telephones will therefore be in the opposite direction to the flow of the continuous current of the wing circuit

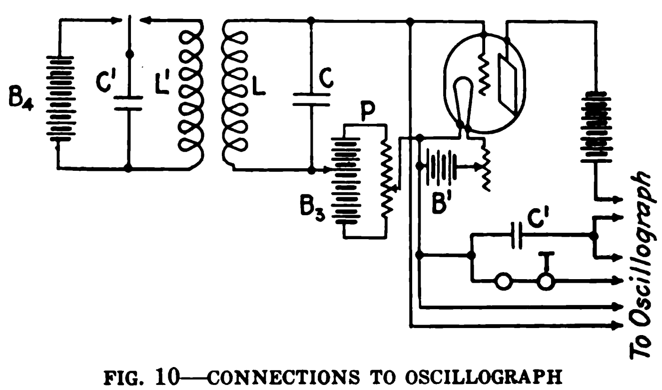


FIG. 10—CONNECTIONS TO OSCILLOGRAPH

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and will constitute a decrease in the telephone current. Diagrammatically the action is as indicated in Fig. 9.

Oscillograms bearing on these actions were obtained in the manner indicated in Fig. 10. Oscillations were set up by the discharge of the condenser C' through the

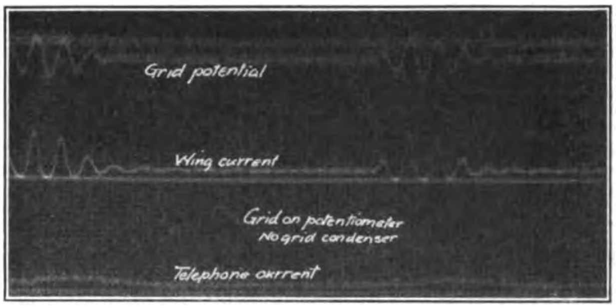

FIG. 11—OSCILLOGRAM OF ACTION AS A DETECTOR

inductance L', which was coupled with the inductance L of the tuned grid circuit. To permit the use of an ordinary General Electric oscillograph, an oscillation frequency of about fifty cycles per second and a group frequency of two or three cycles were employed. The action of the audion is the same regardless of frequency, provided that the circuit constants are suitably modified to fit the frequency employed. In this case the oscillation frequency of the circuit $C'L'$ was fifty cycles and the circuit LC was accordingly tuned to the same frequency. The capacity of C_1 was selected to correspond to the low frequency employed. Figs. 11 and 12 show oscillograms taken as indicated in Fig. 10, with the grid potential adjusted respectively to the lower and upper bends of the operating characteristic.

It will be observed that the telephone current reaches in Fig. 11 its maximum value, and in Fig. 12 its minimum value, when the oscillating current has almost died away. This effect would be shown more plainly with a higher oscillation frequency, but even at the frequency used it is quite evident.

To make use of the "valve" action between hot and cold electrodes for the detection of high-frequency oscillations a connection as shown in Fig. 13 is used.

In this case a condenser C_2 is inserted somewhere in the circuit between the grid and filament to prevent the flow of a continuous current between them, and the grid is therefore left free to assume a potential determined by its position with respect to the filament and wing. Usually this will be somewhere near the center

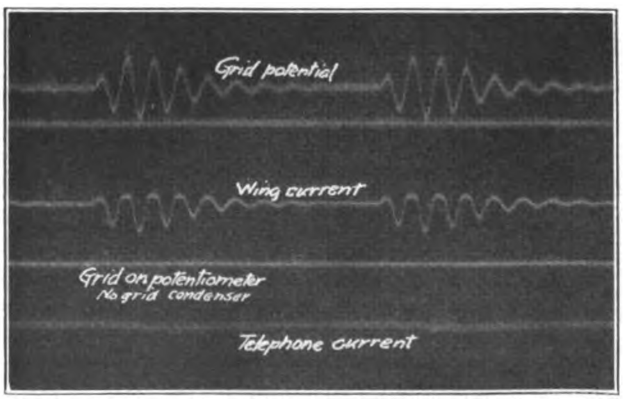

FIG. 12—OSCILLOGRAM OF ACTION AS A DETECTOR

of the operating part of the curve of Fig. 1; that is, near point P. Now the action for incoming oscillations, as far as the closed oscillating circuit, filament, grid and condenser C_2 are concerned, is identical with the rectifying action of the Fleming valve. An incoming wave train sets up oscillations in the closed circuit LC which are rectified by the "valve" action of the filament and grid, and the rectified current is used to charge the condenser C_2. Electrons pass readily enough

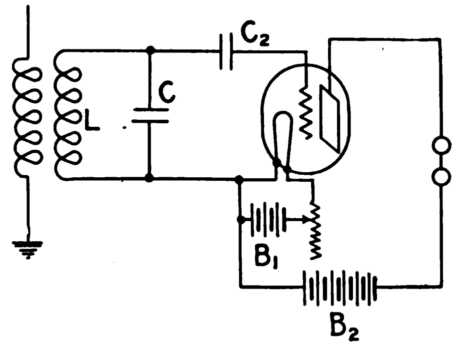

FIG. 13—USE OF AUDION AS A "VALVE"

into the grid but cannot easily escape therefrom, and a negative charge is built up on the side of the condenser connected to the grid. The negative charge thus imparted to the grid cuts down the flow of electrons from the filament to the wing, producing a decrease in the wing and telephone currents. At the end of a wave

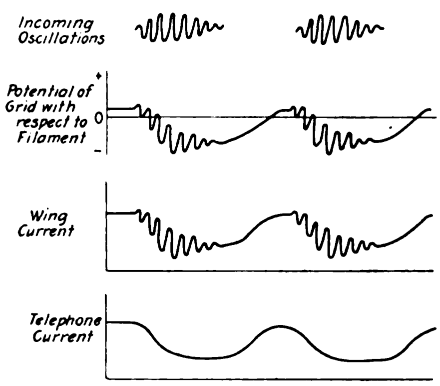

FIG. 14—ACTION OF AUDION AS A "VALVE"

train the charge in C_2 gradually leaks off and the wing current returns to its normal value. The charge and discharge of this condenser take place in the manner indicated in Fig. 14.

One group of oscillations produces a single low-frequency variation (decrease) in the telephone current

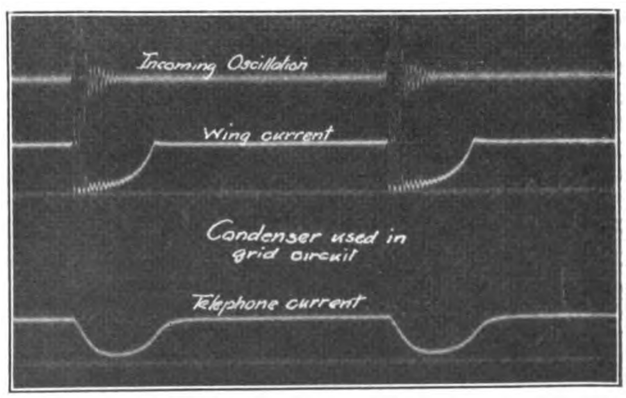

FIG. 15—OSCILLOGRAM OF ACTION AS A "VALVE"

and a series of wave trains produces a corresponding series of low-frequency variations in the telephone current. In Fig. 15 is shown an oscillogram of the behavior of the audion when the "valve" action is employed for the detection of oscillations.

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With the means at hand it was impossible to ascertain the variations of the grid potential, as the leak introduced by connecting the oscillograph to the grid would destroy the cumulative action in the grid condenser. The grid potential, however, varies in exactly the same manner as the wing current. It will be seen that the fundamental detecting action is that of a valve, the high-frequency oscillations being rectified between the filament and grid, thereby causing a charge to accumulate on the grid and in the grid condenser. The charged grid then exerts a relay or trigger action on the wing current so that the audion is at once a rectifier and an amplifier. A somewhat similar combination of rectifying and amplifying actions occurs in the arrangement shown in Fig. 7. The action of the audion is being further studied by Prof. Morecroft and the writer in the research laboratory in electro-mechanics, Columbia University, and the results of these investigations will soon be published.

High-Potential Voltmeter Based on Corona Pressures

Striving by experiment to determine the relation between the corona current and the increase in air pressure which occurs if direct-current corona takes place in an inclosed space, members of the physics department of the University of Illinois, Urbana, have hopes of being able to construct a high-potential voltmeter based on this pressure phenomenon. Professor Jacob Kunz, in describing some of the experiments before the American Physical Society, stated that the tests covered potentials ranging from 3000 volts to 15,000 volts and that manometer deflections as great as 25 cm had been observed. Professor Kunz emphasized the fact that the pressure noted was not due to heating of the air, for the liquid used in the manometer responded instantly upon the application of potential. Curves plotted between potential and pressure from data obtained thus far approximate very nearly to straight lines.

The Electron Theory and Metallic Selenium Crystals

Since the usual free-electron hypothesis does not offer an explanation of (1) the increase of light sensitiveness with pressure, proportional to the conductivity of metallic selenium crystals in the dark, (2) why the change of conductivity by pressure or electrical fields is limited to the region of the crystal under stress, and (3) why the increase of light sensitiveness is limited to the region under pressure and is practically unlimited as to what region of the crystal is illuminated, Prof. F. C. Brown, Iowa State University, Iowa City, has proposed a modified form of the electron theory to satisfy all the fundamental experiments thus far recorded. This new view supposes that a large portion of the conducting electrons in the crystal are ordinarily fixed in the crystal structure in varying degrees of stability. When an electric field is established across the crystal a certain average number of these fixed electrons is rendered unstable or free. The divergence from the usually accepted notion is the conception that these electrons remain free only for a relatively short interval of time. Thus in these crystals the current increases with voltage more rapidly than is required by Ohm's law.

The effect of the increase of pressure is to lessen the degree of the stability, so that the mean interval before the recombination of the electrons is increased. "Obviously," says Professor Brown, "this seems to explain satisfactorily the increased light sensitiveness with increased pressure, and also the exact proportionality observed. It also explains the limitation of this increase to the region of the crystal under pressure. The transmitted light action observed by Prof. L. P. Sieg and myself is probably a mechanical disturbance propagated in the crystal, and enters into this theory only as the disturbance keeps electrons out of their fixed positions. If it were not for this rapid recombination of the electrons, the change of conductivity by pressure or electrical forces should be noticeable throughout a given crystal structure."

In closing his remarks, which were made before the American Physical Society at Chicago, Professor Brown suggested that a study of the conductivity changes very near the region of applied pressures might give some information as to the rate of combination of the electrons.

Valuation in Houston, Tex.

Messrs. James E. Allison & Company, of St. Louis, Mo., have submitted a report on the rate case of the Houston (Tex.) Lighting & Power Company 1905. They represented the company and reported on the capital now invested in the property and entitled to a return. In the letter of transmittal they say that they were aware that the report was to be submitted to the consideration of the Mayor and commission of the city of Houston in connection with a contemplated regulation of rates. A report on the property has been made by Messrs. Lyndon & Elrod, representing the Mayor of Houston.

In stating that valuation for rate making is comparatively new, the report says that the Wisconsin commission "is the one which is in great part responsible for the adoption of theoretical depreciation, and it is a very curious commentary on the theory of its members put forth in the early part of their work that while in nearly all of their cases they figure out the depreciated value, yet when they come actually to assign the amount of capital entitled to returns, the effect of depreciation cannot always be traced clearly in their announced result. The commission, while it has not yet admitted the error of applying this theory, has generally so raised the figures of its valuations as not to bring the results very seriously in question. There seems to have been what may be called an instinctive recognition of a just amount which has often been assigned in the commission's reports without making it very clear just how it was arrived at.

"Nowithstanding that by such methods of arriving at practical justice the Wisconsin commission has preserved itself from bringing about an impossible state of affairs in that State, yet its doctrine, which it does not always follow, has gone forth and has been adopted in many other places without that careful analysis which should have been given it. The consequence is that while Wisconsin has in some quarters gained a reputation for fair treatment of its utilities and may have so far escaped complete stagnation in utility enterprises, other localities which have followed the doctrines of Wisconsin without following its practice are already beginning to feel the effect of a theory of regulation under which private capital will not enter the public service."

An appendix to the report includes papers on the subject of depreciation by Mr. James E. Allison, Prof. Allyn A. Young, Cornell University; Prof. J. Lawrence Laughlin, University of Chicago; Prof. W. F. Gephart, Washington University, and Prof. Lewis H. Haney, University of Texas.

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