TRIODE VALVES AS ELECTRIC AMPLIFIERS.

AMONG the most exquisite tools that modern wireless telegraphy now proffers to investigators working in the fields of pure science, that known as the amplifier stands out as being of the most obvious promise in various directions. The amplifier offers the means of magnifying varying electro-motive forces and currents, otherwise imperceptible, so that they come within the range of ordinary laboratory measuring and recording instruments. It was developed during the war to a high pitch of excellence, not only for the improvement of wireless telegraph signals, but also for other kinds of signalling and for listening under water and under the ground—that is to say, it has been fully developed for the magnification of the high-frequency currents used in wireless telegraphy and for currents of telephonic frequency. Descriptions of the apparatus have now been published in many places, and the tool as thus developed will in due course take its place in the laboratory. For many purposes, however, an amplifier that will faithfully magnify slow variations of a current or electro-motive force is demanded, and since little has been published about such apparatus, the following notes of methods used in the writer's laboratory during the past few years are now presented.

As the term is usually understood nowadays, an amplifier consists of one or more of the three-electrode thermionic vacuum valves of wireless telegraphy associated with auxiliary transformers or analogous apparatus. This particular kind of valve may for brevity be called a triode valve, or even a triode. It comprises a hot filament for supplying electrons, which serves as cathode, a plate, or cylinder, which serves as anode, and an intervening grid, all contained in a highly evacuated bulb. The bulbs generally used in amplifiers are about the same size as the common incandescent filament lamp, but the filament cathode of the triode is proportioned so as to become white hot when a battery of about 5 volts is joined to its terminals to supply about three-quarters of an ampere of current. A battery of, say, 50 volts, connected with its positive pole to the anode and its negative pole to the cathode, causes a current of order one milliampere to flow when the grid is at the same electric potential as the mid-point of the filament, and of perhaps twice this value when the grid is given a potential one volt higher.

The reason for this influence of the grid may be briefly explained as follows: When, in obedience to the electro-motive force applied between anode and filament, an electron current flows from the filament, the distributed electric charge in the space creates an electric field that tends to repel electrons back to the filament, or, in other words, gives rise to a back electro-motive force acting against the battery. But making the grid positive relative to the filament partially neutralises the field of the space charge, and therefore reduces the back electro-motive force. This influence is greater the closer the mesh of the grid; in some commercial triodes one volt on the grid will cancel ten volts of the back electro-motive force, or, in other words, one volt applied to the grid is worth ten volts applied in the anode circuit. At the same time, the current flowing on to the grid when one volt is applied between grid and filament is, perhaps, only a microampere; the multiplication of current performed by the triode is thus a thousandfold. Moreover, since the energy input to the grid is, in the assumed circumstances, 1×10^{-6} watt, and the consequent additional energy output of the high-voltage battery in the anode circuit 50×10^{-3} watt, the energy ratio is 50,000. Not all this output is available for use, however; we may, in fact, scarcely hope to use half of it.

It is worth while emphasising here a difference between an electro-magnetic transformer and a triode regarded as a transformer. The transformer may be arranged to give in its secondary circuit a voltage many times that applied to the primary, but the current is correspondingly diminished to keep the output of the energy equal to the input (losses being neglected). But in the case of the triode valve the current, as well as the electro-motive force, is multiplied, and the consequently multiplied energy output takes place at the expense of the high-voltage battery.

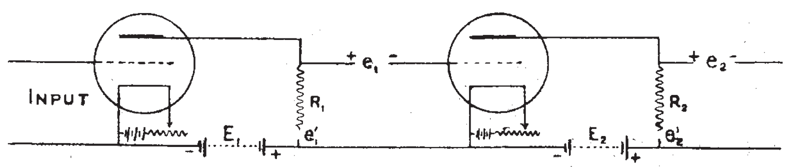

FIG. 1.

The most highly developed type of amplifier is that intended for the magnification of currents alternating more than 100 times per second, and consists of a number of triode valves linked in tandem by means of the mutual inductance of transformers. The earliest instruments were probably constructed by de Forest. Excellent instruments can now be made for any frequency between 100 and 1,000,000. It is stated that Mr. H. J. Round, of the Marconi Co., has used up to twenty-two triodes in tandem, and obtained magnifications of potential difference of about half-a-million-fold. As already stated, amplifiers for rapidly alternating current have been described elsewhere, and are not the subject of this article.

The type of amplifier described in Fig. 1 may be used for magnifying currents that vary slowly. It appears to have been conceived first in the French Military Radio-telegraphic Laboratory in Paris. In this apparatus the linkage between successive triode valves is accomplished by means of resistances and batteries. Considering the anode circuit of the first bulb, we see that it contains a resistance R_1 and a high-voltage battery E_1. Let $E_1=80$ volts, $R_1=30{,}000$ ohms, and the current be 1 milliampere. At present ignore the batteries marked e_1, e_1'; then the fall of potential along R_1 is $30{,}000\times 10^{-3}=30$ volts. Such a potential difference applied between the grid and filament of the second triode would put this tube completely out of action. It is therefore necessary to introduce a neutralising battery of about 30 volts at the point marked e_1, or at the point marked e_1'. In the latter case the battery will, in fact, be a portion of the battery E. Suppose

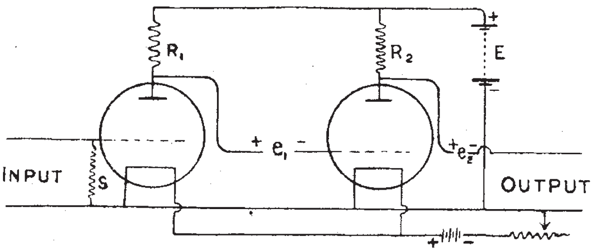

FIG. 2

this to be done, and imagine an electro-motive force e_g to be applied between the input terminals of the amplifier. Then it can be shown that the consequent increase of current in the anode circuit is

$$\frac{ge_g}{R_1+1/h_a},$$

where g is the triode's voltage factor, and h_a its differential conductance. These parameters are frequently of the order

$$g=10 \text{ and } h_a=10^{-4}.$$

The electro-motive force handed on to the second triode from the terminals of R_1 is clearly of magnitude

$$\frac{R_1 ge_g}{R_1+1/h_a}.$$

Using the value of R_1 suggested above, we find that the multiplier of e_g becomes

$$\frac{30\times 10^3\times 10}{40\times 10^3}=7\cdot 5.$$

The amplification approaches the limit 10 (that is, the value of g) the greater we take the value of R_1; but obvious practical reasons limit the magnitude of this resistance.

This type of amplifier, usually spoken of as a resistance cascade amplifier, has been much used by the Americans and the French for amplifying rapidly varying currents, but in that case a condenser is substituted for the battery at e_1; a "grid leak" of order a megohm must then be connected between grid and filament in each triode in order to avoid the accumulation of negative electricity on the now insulated grid. The complete instrument is then usually connected so as to utilise a common battery of 4 or 6 volts for all filaments, and a common battery of about 80 volts for all anodes. Adopting common battery connections, a finished two-stage amplifier is seen in Fig. 2. The grid leak S connected between the first grid and its filament might be about a megohm, and is necessary only when the circuits from which the input to the amplifier comes are such as would otherwise leave the grid insulated. According to the computations given above for one stage, the amplification with this two-stage instrument should be

$$7\cdot 5\times 7\cdot 5=56\text{-fold}.$$

Finally, a mode of connection due to the present writer may be described. It is shown in Fig. 3, arranged to constitute a two-stage amplifier suitable for use with slowly varying currents. The first triode of the pair has resistances Q_1, R_1, S_1, connected so as to constitute with the bulb the four arms of a balanced Wheatstone bridge. The high-voltage battery E_1 is connected across two opposite corners of the bridge. An electrical stimulus applied to the grid causes the balance to be disturbed, and a corresponding potential difference arises between the filament lead and the junction of Q_1 and R_1. This difference of potential is conveyed to the next triode by direct connections. The magnification is the same as that obtained with the arrangement of Fig. 2 when resistances S_1, S_2 are taken of the same value as R_1 in that figure. A grid leak S is used when necessary, for the reason explained before.

In conclusion, it would be well to point out that in deciding upon the resistances and the voltages to be employed in constructing these amplifiers, the characteristics of the triodes should be kept in mind with the view of using them all at such adjustments that the relation between input

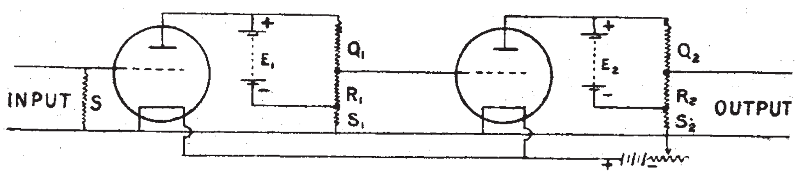

FIG. 3.

and output potential differences is linear, and the magnification therefore free from distortion.

W. H. ECCLES.

INDIAN GEOLOGY.[1]

THE appearance of a manual of Indian geology of so excellent a character as the present work, written by an Indian geologist, is an event of some importance, since it furnishes a fresh and convincing answer to the argument so often

1 "Geology of India for Students. By D. N. Wadia. Pp. xx+398+xx plates. (London: Macmillan and Co. Ltd., 1919. Price 18s. net.