External-Anode Vacuum Tube

Results of Investigations Carried On with a New Type of Three-Electrode Vacuum Tube in Which Electrolytic Conduction Through Glass Performs an Important Function

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COMMERCIAL types of electron-tube amplifiers, detectors and oscillators in their present forms, although remarkable for adaptability and efficiency, have been developed along more or less well-defined paths and have deviated very little in principle from the original forms. However, a vacuum tube has been developed by the writer which not only differs radically in construction from those available heretofore but depends for its operation on what is believed to be a new phenomenon, namely, electrolytic conduction in a hot dielectric.

Aside from the simplicity, compactness and ruggedness of the tubes, they are especially interesting because their characteristic curves contain a right-angle bend which makes the tubes unusually sensitive detectors. By proper proportioning of the tube components this bend can be made to occur at zero-control potential. Operation without a polarizing potential on the control is a considerable advantage, because, although it is a comparatively simple matter to polarize the control by shunting the series condenser with a resistance of several megohms, these resistances, as made at present of loose particles, introduce considerable noise into the receiving circuit owing to their variable resistance. One form of the tubes is made to operate at an anode potential of 4 volts, which should be attractive wherever it is desirable to minimize the battery expense, reduce the weight or secure compactness. The exceptional oscillating properties of the tubes make them particularly adapted to use as regenerative or oscillating detectors. The construction and assembly of the tubes is so simple that manufacture on a quantity basis is considerably more feasible than with many other types now available.

A filament, a control electrode and an anode are employed as in other three-electrode vacuum tubes, but these elements are disposed differently, as shown in Fig. 1. The filament is shaped like a hairpin, and surrounding it is the control electrode, which consists of a helical coil of drawn-tungsten wire. These two elements are the only ones inside the tube, the anode being a silver coating applied directly to the outside of the vacuum tube on that portion surrounding the filament and control electrode.

The vacuum tube proper is very small, being hardly more than 3/8 in. (9.5 mm.) in diameter where the electronic action takes place and only 5/8 in. (15.9 mm.) at the base, where more space is required for assembling and sealing the tube after it is evacuated. With the outer glass shell in place, which is provided for protection against drafts and mechanical injury, the tube measures only 7/8 in. (22 mm.) by 3 3/8 in. (85.7 mm.), compared with 1 3/8 in. (34.9 mm.) by 4 in. (10 cm.) for one form of vacuum tube which was very popular in the Signal Corps during the war.

Although very light in construction, this new tube is entirely unaffected by vibrations and uninjured by jars so that it is unnecessary to mount it on cushions as is done with some kinds of tubes. The alignment of the filament and control with respect to each other and the anode is not at all critical; it is only necessary that the filament be placed as near the center of the control as possible, and that the filament be somewhere near the center of the tube in order that the temperature of the glass shall be uniform.

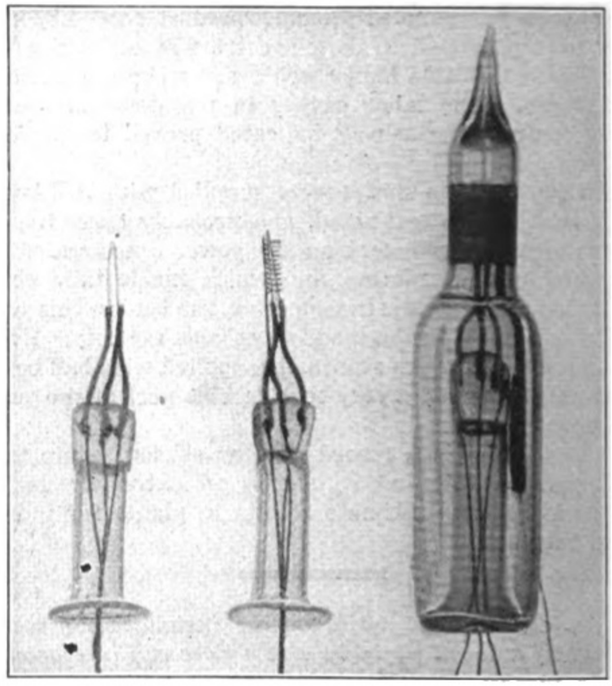


FIG. 1—FILAMENT OR CATHODE, CONTROL HELIX SURROUNDING FILAMENT, AND SILVER DEPOSIT ON OUTSIDE OF TUBE SERVING AS ANODE

At first it was expected that commercial variations in the glass thickness would materially affect operation, but such is not the case, for when made under ordinary conditions the tubes may be interchanged in any circuit without the necessity of readjustments.

In operation the tube is connected like any other three-electrode vacuum tube, except that the control electrode does not have to be polarized when the tube is acting as a detector. Since this tube is exhausted to the highest obtainable vacuum, the filament, when heated by its battery, is the source of a pure electronic emission which forms the connecting link for the battery between the filament and the anode electrode, the resistance of this connecting link varying with the potential of the control.

The point of immediate interest is the passage of current through the glass. Up to the present time glass has been looked upon as a fair insulator, at least, although it has been known that at or near the melting point it becomes a good conductor. This property of becoming strongly conductive when heated to a semi-fluid state is probably shared by all other so-called dielectrics; but it is obvious that it would be absolutely impossible to operate a vacuum tube at such a temperature since glass begins to soften at approximately 425 deg. C. and does not attain red heat until heated to about 600 deg. C. However, when glass is in contact with certain elements, it becomes a good conductor at far lower temperatures than these. The conduction through it when in this condition is purely electrolytic, and all the phenomena accompanying conduction through a liquid electrolyte, such as decomposition, polarization, etc., are present in hot glass.

Before making these tubes conductivity tests of glass in contact with various elements were made by pre-

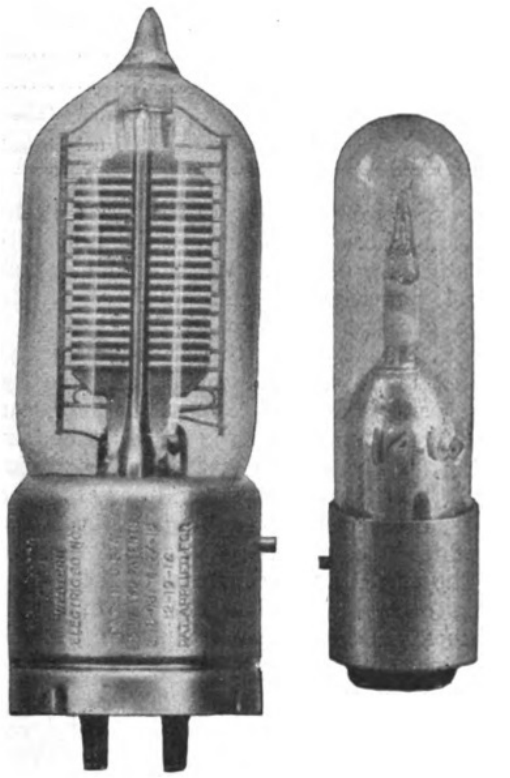


FIG. 2—RELATIVE SIZES OF ARMY VACUUM TUBE AND RECENT DEVELOPMENT

paring short lengths of glass tubing with a band of the metal surrounding the outer circumference near the middle of the tube and a second band of the same metal inside the tube immediately under the outer band, this tube being heated to the required temperature in an electric oven. It was found that when using electrodes of such elements as copper, tin, iron, nickel, platinum, etc., an apparent polarization took place which very greatly increased the resistance of the combination. This is without doubt due to an electrolytic action at the anode surface which renders it almost non-conductive. If the source of potential be short-circuited while the glass is in this condition, the energy held on the electrode surfaces will be returned through the circuit. All of these phenomena, although, of course, perfectly commonplace in a liquid conductor, have, it is believed, up to the present been unknown in a solid.

With silver electrodes polarization is almost entirely absent; so much so that glass with one electrode of silver and one of nickel will at the proper temperature become a fair conductor when the silver is the anode terminal of the applied emf., but will have a very high resistance with silver as the cathode. Current-temperature curves for two glass samples, one with both electrodes of silver and the other having two platinum electrodes, are shown in Fig. 6, the applied potential in each case being 20 volts.

It might be supposed that the electrolytic disassociation of the glass walls would make it impracticable to operate a tube in this manner. However, this was

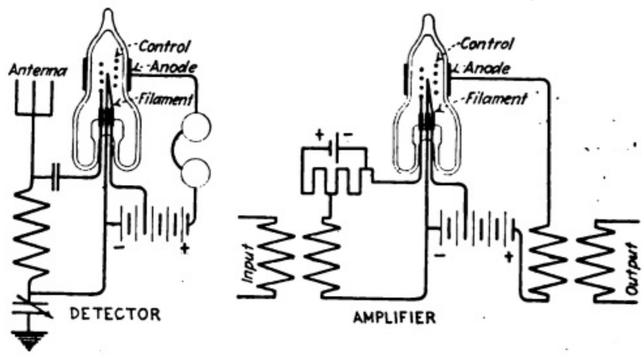
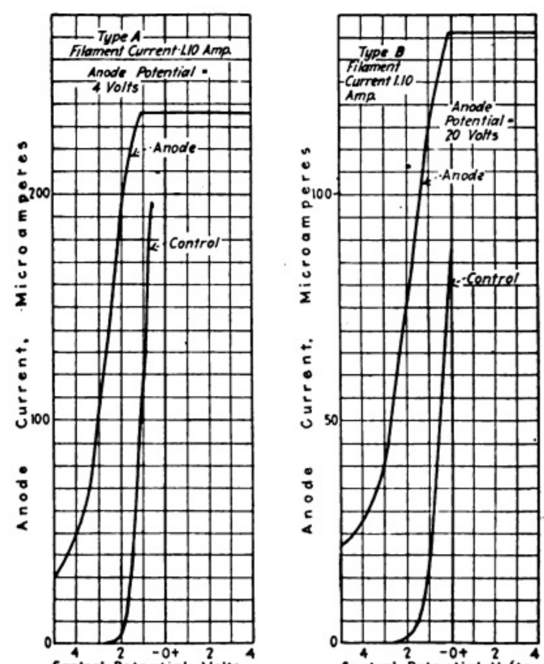


FIG. 3—METHOD OF CONNECTING THE NEW TUBES WHEN USED AS DETECTORS AND AMPLIFIERS

found not to be the case; for it is entirely feasible to so distribute the current density and magnitude that disassociation will take place at a very low rate and the glass life will be one of the smallest factors in the tube life.

Several types of tubes operating by the conductive properties of heated glass have been designed, the glass being heated to the required degree by the filament and maintained at its proper temperature by inclosing the tube within an outer shell of glass. This is



FIGS. 4 AND 5—CHARACTERISTICS OF TYPES A AND B TUBES

provided with vents at its lower end in order that the temperature shall not exceed the proper value.

The evacuation of a tube of this type is extremely simple, for, owing to the very small metallic areas exposed (only several square millimeters instead of as many square centimeters) and their close proximity, it is possible to scavenge the tube of gas by simply lighting the filament and applying a low potential between one leg of the filament and the external anode. The aging potential applied is usually twice the normal operating value. With the first application of this potential there is an emission of gas from the glass tube which is drawn off by the pump, but after a few minutes this ceases and there is apparently no further emission from this source during the life of the tube. During the process of glass disassociation there is a continuous liberation of metallic sodium from the heated portions of the tube, which deposits in the form of a bright silvery coating in the cooler portions of the glass. The presence of this active element within the tube partly accounts for the cleaning up of any occluded gases which may be caused by melting of the constricted portion that connects the tube with the pump when the tube is sealed. With these tubes the presence of gas is very noticeable after sealing, but after a few minutes of normal operation it is to all indications no longer present.

The characteristics of these tubes show one peculiar feature, namely, the flattening of the anode current-control potential curve at or near zero-control potential. The cause of this is readily explained as follows: In this tube there are in effect two resistances—that from filament to inner wall of the tube R_s and that of the glass walls R_g. The latter is nearly a fixed value, determined largely by glass temperature and somewhat by current passing through it, but R_s depends entirely upon the charge residing on the control. It is obvious therefore that as the control is made more positive this resistance is decreased until a point is reached where it is inappreciable compared to R_g. In this condition R_s is the controlling factor in current flow between filament and anode.

The characteristics of the four types of tubes now being made are shown by the accompanying curves. Under normal conditions of filament current and anode potential, for example, the right-angle bend in the anode-current curve of a type A tube occurs at —1 control volts and with 236 microamperes flowing in the anode circuit. With a type B tube the right-angle bend occurs at zero control volts and 172 microamperes. Types C and D, on the other hand, have the bend occur at positive control potentials (1 volt to 2 volts) and with 290 and 304 microamperes flowing respectively.

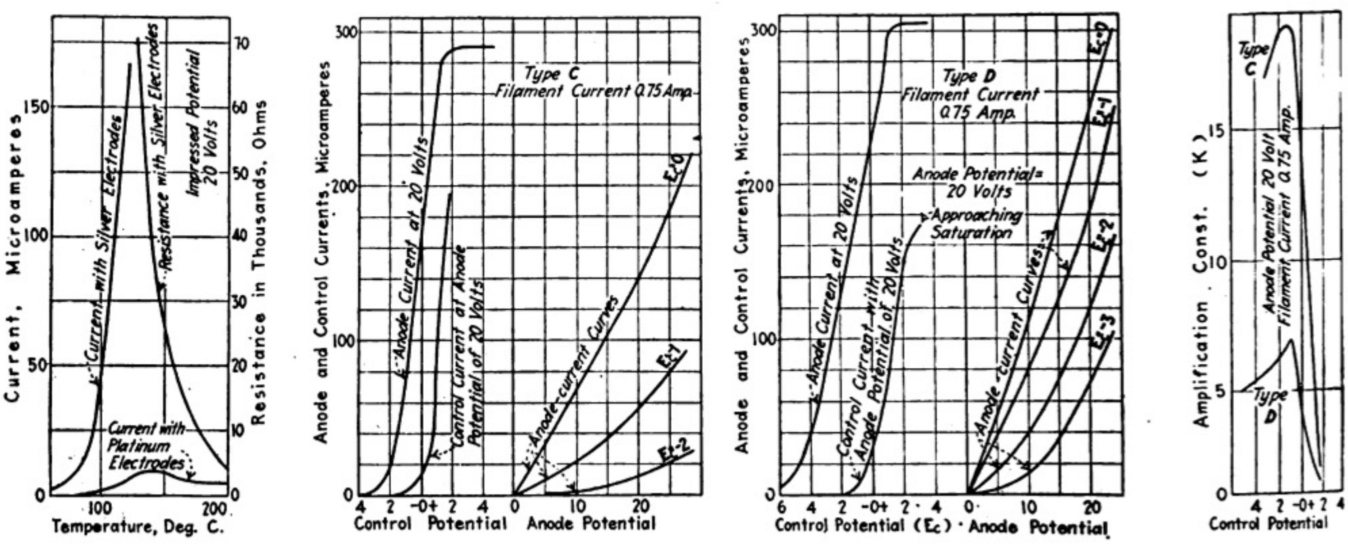
Used as detectors or oscillators, these tubes operate best when a condenser is in series with the control element, although they will operate on the lower portion of their characteristic curves with the control charged negatively. However, the latter method of operation is not so satisfactory as the first.

Decreasing the anode potential causes the bends to occur as usual at more positive control potentials and with less anode current. Because of these right-angle bends it is preferable to operate the tubes at the control potential where they occur if the best detecting characteristics are desired. When used as amplifiers, the control potential is maintained at that value giving the greatest increases or decreases of anode current with variations of the control potential. In this connection it may be noted that the type C tube is particularly adapted to amplification because of the steep current curve, which is still further improved by lowering the anode voltage. The characteristics of the type D tube are particularly interesting because they show the enormous effect produced by the control element, which has only 70 per cent of the turns in type C. The amplification constants of these two tubes at varying control potentials are shown in Fig. 9, type C amplifying more than nineteen times under best conditions. These constants were calculated by the method described by Leslie Miller in the *Proceedings* of the Radio Institute.

The characteristics of these tubes have been checked by Dr. Chaffee of the Cruft Laboratory, Harvard University, and the author wishes to express his appreciation of his most valuable coöperation.

NORMAL OPERATING CONDITIONS OF THE VARIOUS TUBES

Type of Tube	Filament Current (Amp.)	Anode Potential (Volts)	Acting as Detector	Acting as Amplifier
A	1.1	4	Condenser in series with control	....
B	1.1	20	Condenser in series with control....	....
C	0.75	20	Condenser in series with control....	Control polarized—1 volt
D	0.75	20	Condenser in series with control....	Control polarized—1 volt



FIGS. 6, 7, 8 AND 9—CHARACTERISTICS OF GLASS AS A CONDUCTOR, AND PERFORMANCE OF TYPES C AND D VACUUM TUBES AS DETECTORS AND AMPLIFIERS