PROCEEDINGS

of the

RADIO CLUB *of* AMERICA

Vol. I No. 2 April, 1920

RCA SPECIAL NOTICES

To the Membership:—

For the benefit of those who were unable to attend the Annual Meeting we take pleasure in announcing the results of the election of officers for 1920. The constitution of the club provides for the selection by the Board of two additional Directors to serve for 1920, and we announce their names in the below list. The election results follow:—

Officers	*Directors (Elected)*	
Pres. E. H. Armstrong	P. F. Godley	
Vice-Pres. L. G. Pacent	H. Sadenwater	
Treas. E. V. Amy	T. Johnson, Jr.	
Corr. Sec. T. J. Styles	A. Hebert	By the Board
Rec. Sec. W. S. Lemmon	G. Burghardt	

If you have not received your Proceedings, and you are a member of the Radio Club of America, in good standing, we suggest that you notify the Corresponding Secretary, Mr. T. J. Styles at 1112 South Curtis Ave., Richmond Hill, N. Y., giving him your correct mailing address. Also if you have not yet sent in your war record to the Secretary, kindly do so at once; we are interested in the war-time doings of every R C A member.

The Proceedings "ball" has started rolling,—we are trying to make the Proceedings representative of the Radio Club of America. If you have any items of special interest or constructive suggestions they will be gladly received by your Editorial Committee.

The February number of the Proceedings did not appear, due to delays in obtaining the paper. The first section, however, is printed in this issue, and regular issues will follow about the first of each month.

Editor.

Office of the Editor of Proceedings:

319 West 94th St., New York City
Walter S. Lemmon—Editor
Ernest V. Amy
Austin Lescarboura
Lester Spangenberg

The Vacuum Tube as a Detector and Amplifier

By L. M. Clement

Presented at Meeting of the Radio Club of America, Columbia University, January 16, 1920

The audion or vacuum tube, as it is sometimes called, due in large measure to the rapid development work during the great war and partly to the pre-war development of several of the large companies, is a necessity to all fully-equipped radio telephone and telegraph stations.

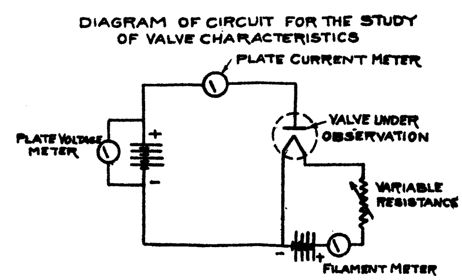
The audion, as we all know, consists of an evacuated glass tube or bulb which contains the filament, the plate, which generally surrounds it, and the control electrode or grid which is generally mounted between the filament and the plate. When this device is associated with the proper apparatus and operated under the proper conditions, it can be made to function as a detector, an amplifier, an oscillator, or a modulator.

In order to be able to design apparatus which will operate under proper conditions, we must first know something about what goes on in the tube under different conditions.

Edison, during some of his experimental work with the incandescent lamp, found that current could be made to flow from a plate inside the bulb to the filament but not in the reverse direction. This phenomenon is called "Edison Effect" and it remained unaccounted for for a number of years but was finally explained by the Electron Theory.

Filament

The filament of the audion, generally in the form of a wire, is heated by the electric current to such a temperature that a large number of electrons attain sufficient velocity to leave the surface of the wire. The filament then is deficient in negative electricity, or, in other words, has a



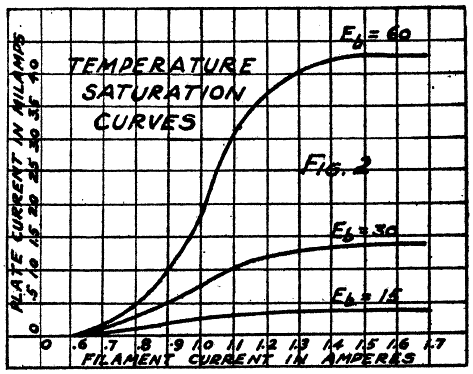
-FIG. 1-

positive charge which attracts the electrons which have left its surface. If no outside forces are active, a state of equilibrium is said to exist when the number of electrons leaving per unit of time is equal to the number falling back on the filament in that time.

Because of its very high melting point, allowing of very high operating temperature, tungsten is a very suitable substance for vacuum tube filaments. Platinum wire filaments which have been coated with certain metallic oxides have been found to emit a copious supply of electrons at comparatively low temperatures. This accounts for the long life of the so-called "coated" type of filament.

Plate

If the filament is placed in an evacuated bulb, it is obvious that the electrons will penetrate the space surrounding the fila-



ment to a greater distance than they will in air, because of the removal of the large gas molecules. Suppose now an electrode in the form of a plate is introduced in the bulb and a potential positive with respect to the filament is applied to it. The negative electrons will flow to the plate. Instead of thinking of a flow of electrons from the filament to the plate, we generally think of a flow of current from the plate to the filament; that is, from the positive to the negatively charged body. If a negative potential were applied to the plate, no electrons would be attracted to the plate, and hence no current would flow because of the lack of these carriers of negative electricity. If an alternating potential were applied to the plate it is obvious that current would only flow through that part of the cycle when the plate was positive with respect to the filament.

The two-element tube, due to its unilateral conductivity, has found some application as a rectifier. The General Electric Company has built some commercial types of rectifiers and some tubes have been built for potentials of 180,000 volts.

Fleming recognized that this device could be used to rectify or detect radio frequency signals. He called the rectifier for this purpose a receiving valve. The device was not very generally used as it was not far superior to the ordinary crystal detectors which required no external battery.

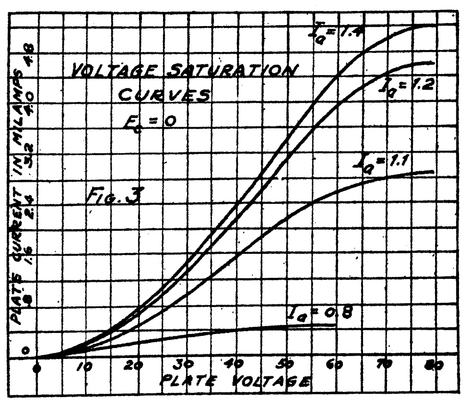
Ionization

In these old valves for receiving work, due to the low voltages employed, a high degree of vacuum was not necessary. In rectifiers similar to the Kenotrons of the General Electric Company, which are designed to operate at high voltage, it is necessary to remove the gas molecules to prevent ionization by collision. Ionization is generally accompanied by a pink or blue glow which fills the tube. The presence of gas in the tube causes irregularity of action at low voltages and excessive ionization or even arcing at high voltages.

In order to overcome these difficulties it is necessary to so evacuate the tube that excessive ionization does not occur at the operating voltage. This is accomplished by special vacuum pumps; and the heating of the elements, and even tubes themselves, to drive off occluded gases.

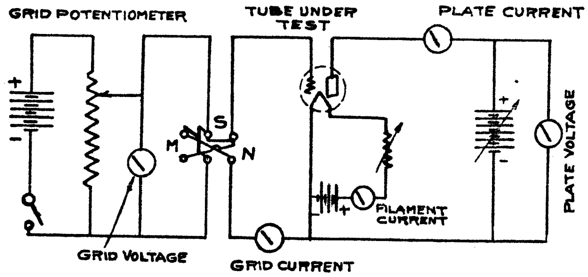
Temperature Saturation

In order to study the action of these valves under different conditions, a circuit shown in Figure 1 is used. The data in Table I shows the effect of filament current (which is a measure of the filament temperature) on the plate current for different plate potentials. These results are shown in the curves of Figure 2. For a constant plate potential, we observe that the plate current increases with filament current until saturation point is reached, after which no rise in the plate current takes place.



On the section of the 60 volt curve, Figure 2, AB, the plate voltage is drawing to the plate all of the electrons emitted, but beyond the saturation point the filament is supplying more electrons than the plate potential can draw to it. This is due to the resultant charge of the cloud of electrons between the filament and the plate which causes the excess of electrons to be returned to the filament This is sometimes spoken of as the space charge effect.

CIRCUIT OF TUBE CHARACTERISTIC CURVE MEASURING SET.



-FIG. 4-

As is to be expected the saturation points for the 30 and 15 volt currents occur at lower filament temperatures. In general, tubes should be operated beyond the temperature saturation points as then a small change in filament current produces practically no change in plate current.

Voltage Saturation

The voltage-current characteristics of the valve were taken at three different filament temperatures. This data is contained in Table II and plotted on curves in Figure 3. As the plate voltage is increased the plate current rises until the saturation point is reached, beyond which an increase of voltage does not produce an increase of current.

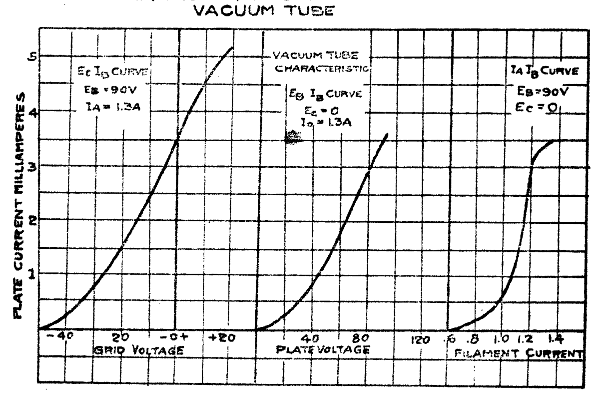
Below the saturation point the filament is emitting more electrons than can be drawn to the plate at the plate voltage applied, due to the space charge effect. Beyond the saturation point all of the electrons emitted by the filament are drawn to the plate. The saturation occurs at lower plate currents when the filament current is less because fewer electrons are available.

The Audion or Vacuum Tube

Dr. DeForest found that the plate current or flow of electrons between the filament and the plate could be controlled by the application of potentials to a third grid-like structure placed between the filament and the plate.

The tubes (or audions as they were called by Dr. DeForest) made several years ago were not pumped very well and consequently contained a large number of gas molecules which made their action more or less unsteady. The high vacuum tubes manufactured by the British, French, General Electric Company and Western

CHARACTERISTIC CURVES OF A VACUUM TUBE

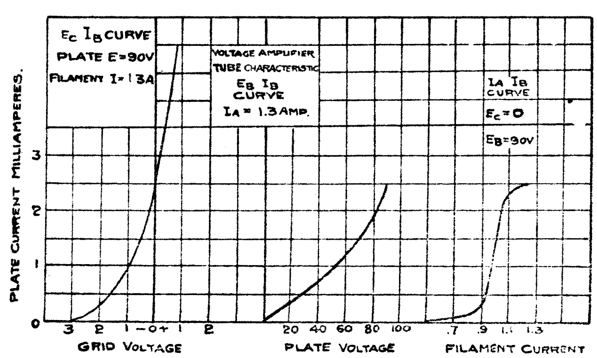


-FIG. 5.-

Electric Company are pumped to a very high degree of vacuum and consequently little trouble from ionization is experienced.

Let us consider what goes on inside of the audion, and its relation to the operation of the device. The electrons, as we know, are small negatively-charged particles which are repelled by a negative charge and are attracted by a positive one. In an audion there is a flow of electrons from the filament through the grid to the plate. If there is no charge on the grid this flow will not be materially affected by its presence. If, however, the grid be negatively charged with respect to the filament, it will tend to neutralize the effect of the plate, which will result in a decrease of plate current. This can be said in another way; namely, the negative charge on the grid is in effect

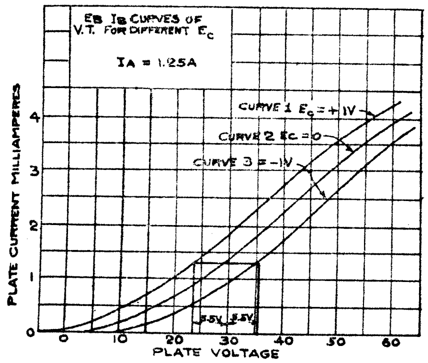
CHARACTERISTIC CURVES OF A VACUUM TUBE



-FIG. 6-

a space charge which is added to the space charge of the tube and causes some of the electrons to fall back on the filament and thus reduce the plate current.

CHARACTERISTIC E_B I_B CURVES OF A VACUUM TUBE TAKEN AT DIFFERENT VALUES OF E_c.



-FIG. 7-

When the grid is negative with respect to filament, no electrons are drawn to it, hence the resistance between filament and grid is infinite and practically no power loss occurs in this portion of the circuit.

A positive charge on the grid tends to neutralize the space charge effect and a greater current will flow in the plate circuit. In this condition, also, electrons will be attracted to the grid and cause current to flow between it and the filament inside the tube. This is equivalent to shunting the input circuit of the audion with a resistance. For this reason it is desirable that the grid be always maintained at a negative potential with respect to filament.

There are some losses which occur even when the grid is maintained at a negative potential but the nature of these can not be discussed in this paper.

TABLE I

Temperature Saturation—

Plate current in Milliamperes

Filament Current Amperes	Plate Voltage 15	Plate Voltage 30	Plate Voltage 60
.6	.006	.007	.008
.7	.051	.076	.098
.8	.136	.320	.510
1.1	.340	1.180	3.200
1.2	.380	1.300	3.800
1.3	.420	1.380	4.00
1.4	.440	1.440	4.30
1.7	.450	1.450	4.350

TABLE II

Voltage Saturation—

Plate Current in Milliamperes

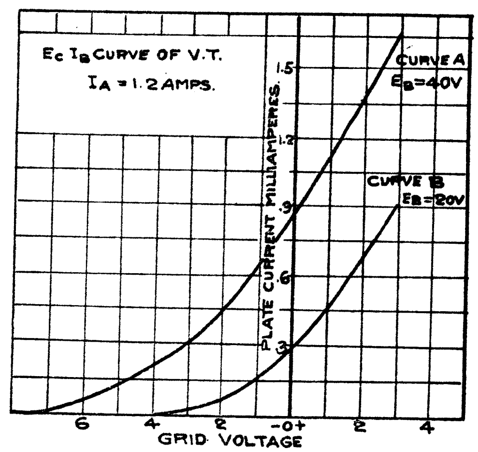
Plate Voltage	Fil. Current .8 Amp.	Fil. Current 1.2 Amp.	Fil. Current 1.4 Amps.
10	.072	.168	.170
15	.137	.360	.400
30	.320	1.310	1.450
60	.460	3.900	4.450
80	.500	4.600	5.700

Characteristic Curves

A good deal can be found out about an audion by a study of its characteristic curves. These curves show the relation between grid voltage and plate current at constant filament current, the relation between plate voltage and plate current at a constant filament current, and the relation between filament current and plate current at a constant plate voltage. In order to be able to get this data easily, the apparatus is arranged as shown in Figure 4. The subscripts a, b and c refer to the filament, plate, and grid circuits of the tube, respectively.

Note—E_a = Filament Volts
E_b = Plate Volts
E_c = Grid Volts
I_a = Filament Current
I_b = Plate Current
I_c = Grid Current

GRID VOLTAGE (E_c) - PLATE CURRENT (I_B) CHARACTERISTIC

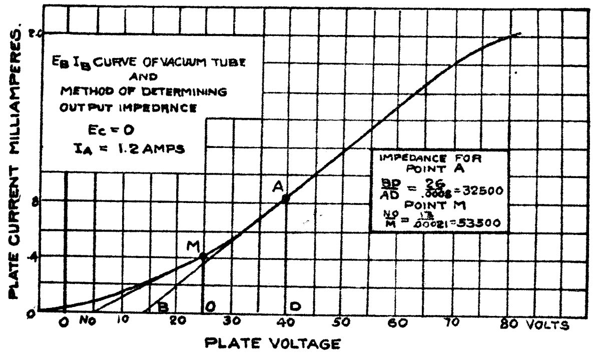


-FIG. 8-

Plate Current Filament

Current Characteristic

With a grid connected to the negative leg of the filament and with a constant



-FIG. 9.-

the same change in plate potential. This ratio is known as the maximum amplification factor of the tube and is generally referred to as the letter K_m.

A very general but practical method of determinging the amplification constant is to divide the plate potential by that value of the grid potential which produces zero plate current.

The amplification factor is dependent upon the geometry of the tube and to some extent upon the conditions under which it is to be operated.

potential applied to the plate, note the different values of plate current for various values of filament current. Such a curve, taken on a coated filament tube, is shown in Figure 5. It should be noted that the curve shows saturation near 1.2 amperes. In all vacuum tube apparatus the tubes should be operated above this saturation point so that small changes in the filament current will not affect the operation of the tube.

Plate Current Plate Voltage Characteristics

The plate current plate voltage characteristics can be obtained in a similar manner by maintaining the filament current constant at the operating value, which should be greater than that necessary for saturation. The E_b and I_b curves for three types of tube are shown in Figures 5, 6, 7, and 9. The voltage saturation is shown clearly by the bending over of the curve in Figure 9.

Grid Voltage Plate Current Characteristics

The variation of plate current with grid voltages at constant plate potential and filament current is called a grid voltage plate current characteristic. Such characteristics for two different kinds of tube are shown in Figure 5, 6, and 8. Figure 7 shows a series of E_b and I_b curves taken at different values of E_c. This shows clearly that the plate current can be varied by changing either the plate potential or grid potential.

The Amplification Constant

From the curve of Figure 7 we find that the plate current for $E_c = 0$ and $E_b = 30$ volts is 1.3 milliamperes. Referring to the curve for $E_c = +1$ volt the plate voltage which would give the same current is 24.5 volts. It is evident from this that a one volt charge on the grid is equivalent to a 5.5 volt change on the plate. By inspection of the curve for $E_c = 1$ volt, we find that the one volt grid change corresponds to a 5.5 volt change in the plate, thus the grid voltage produces an effect 5.5 times as great as that produced by

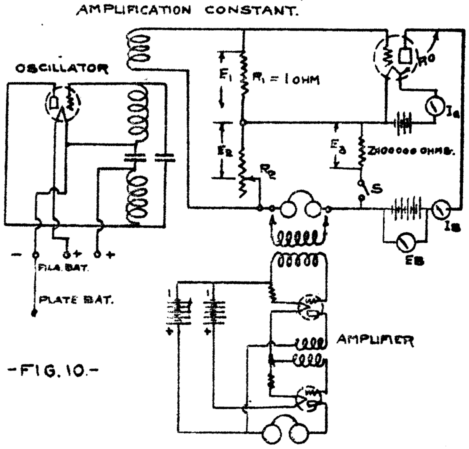
The Output Impedance R_o

Ohm's Law tells us that the current flowing in a circuit is dependent upon its resistance and the applied electromotive force and is expressed as follows:

$I = \frac{E}{R}$, when I = current in amperes
E = E.M.F. in volts
R = resistance in ohms

The current in the plate circuit of a tube does not follow Ohm's Law because it is not only dependent upon plate voltage but on grid voltage as well. It is of importance to know the output impedance of the tube in order to design some of the V.T. circuits correctly. The impedance of the tube for audio frequencies is essentially a pure resistance and its symbol is R_o. The output impedance for a small input voltage for any given set of conditions can be obtained from the E_b I_b characteristic as follows:

BRIDGE METHOD OF MEASURING AMPLIFICATION CONSTANT.



-FIG. 10.-

From the E_b I_b curve of Figure 9, which was taken under the desired conditions of grid voltage and filament current, draw a

(Continued on page 24)

tangent AB to the curve at the point of operating voltage A and draw the line AB. The impedance is given by the quotient of the intercept BD volts divided by the current AD. For the particular tube taken, it is found to be 32,500 ohms.

In order to obtain the impedance of a tube at a grid voltage other than zero, a voltage must be added to or subtracted from the operating voltage equal to the grid potential multiplied by the amplification factor. The impedance can then be obtained from the E_b I_b curve for zero E_c at the effective plate potential determined above.

Dr. Miller of the Bureau of Standards, has devised a simple bridge method of determining both the amplification constant K_o and the output impedance of the tube R_o. The operation of a similar bridge modified by H. J. Van der Bijl of the W. E. Co. is explained as follows:

Fig. 10 is a circuit diagram of the bridge showing the vacuum tube low frequency oscillator and the low frequency amplifier which is used to secure greater accuracy in the reading. It is necessary to carefully shield the bridge, oscillator, etc., by mounting the units in iron boxes, in order to be able to obtain a quiet null point for balance.

The applied alternating voltage from the oscillator should not be greater than a few volts so that the tube will not be overloaded. The resistance R_1 is made 1 ohm so that the voltage across R_2 will be equal numerically to R_2E_1.

The voltage set up in the plate circuit of the tube will be equal to KE. If now R_2 is adjusted until $R_2E_1 = KE$, no current will flow in the telephone receivers and K will be given by the numerical value of R_2. For a measurement of R_o, close the switch S, and vary R_2 until no sound is heard in the telephone receivers.

This means that the voltage across $Z =$ the voltage across R_2 or

$$\frac{KE_1Z}{R_o + Z} = R_2E_1$$

from which, for the case where $Z = 100,000$,

$$R_o = \left\{ \frac{K}{R_2} - 1 \right\} 100,000$$

In order to obtain R_o we must measure the amplification factor under the operating conditions and determine the value of R_2 as above. Knowing these, the value of R_o can be computed by the R_o equation. The question of design of detectors and amplifiers involves the proper choice of circuit and tube constants for the particular form of device in mind.

(The next section of this paper will treat of the Design of Amplifiers and Detectors.)