NOTE ON THE INPUT IMPEDANCE OF VACUUM TUBES AT RADIO FREQUENCY*

By

JULIUS WEINBERGER

(RESEARCH ENGINEER, RADIO CORPORATION OF AMERICA, NEW YORK)

In the various papers which have been published on the behavior of vacuum tubes with three internal elements, one frequently finds the statement that the input impedance (the impedance of the grid-to-filament path) of the tube is infinite when the grid is maintained at a negative potential with respect to the negative end of the filament. That is, it is assumed that since the d.c. characteristic of grid potential against grid current shows that no current will flow between grid and filament when the grid is negative (in a high vacuum tube), the behavior with alternating, or radio frequency voltages, will be the same. While at audio frequencies this path may act as practically an infinite impedance, I have found that at radio frequencies conditions are quite different.

In tubes, as they are now built, there exists considerable capacitive coupling between the grid-to-filament path and the plate-to-filament path; this coupling is sufficiently strong at radio frequencies to cause the apparent input impedance of the tube to be a function of the character of its output circuit. For example, I have noted that if there is a resistance in the output circuit (as when the tube is used in a resistance coupled amplifier), the input impedance will depend on the value of the output resistance. If the output circuit consists of an inductance, the input impedance will act as a negative resistance, which will reduce the resistance of the input circuit (for example, the secondary circuit of a receiving set to which the tube may be connected as a detector) or even give rise to oscillations.

OUTPUT CIRCUIT CONTAINING RESISTANCE

In order to investigate the nature of these effects experimentally, the set-up shown in Figure 1 was made. A sustained wave oscillator operating at a wave length of 6,000 meters was

*Received by the Editor, October 9, 1919.

located at a considerable distance from the set-up, and a pair of leads brought out to a single loop of wire, which was in turn, coupled to a second single loop. The coil L (about 9 millihenrys) and condenser C served as a receiving circuit to which the tube was connected. Loosely coupled to L was a circuit containing a coil, variable condenser, crystal detector, and portable galvanometer (the latter having a sensitivity of 0.1 microampere per scale division—one scale division equal to 2 mm.).

FIGURE 1—Experimental Set-Up

In series with the grid of the vacuum tube was placed a battery and potentiometer which served to maintain the grid at a negative potential with respect to the filament. The resistances R in the output circuit of the tube were of the deposited tungsten film type made by the General Electric Company.

In order to study the operation of the tube, the procedure was as follows: The tube was connected to LC , with various resistances in its output circuit, and the deflection of G noted for each case. A negative potential of 0.8 volt was maintained on the grid; the radio frequency voltage across C was always considerably less than this and no grid rectification was therefore possible.

After completion of the observations, the grid lead of the tube was disconnected from C , and the filament extinguished; then various resistances of the tungsten film type were shunted across C and the galvanometer deflections again noted. A curve of these is given in Figure 2. In all cases, the circuit LC was kept tuned to resonance by adjusting C .

The equivalent resistance of the tube and its associated output circuit could therefore be read off from the curve of Figure 2 by finding the resistance corresponding to a given galvanometer deflection.

FIGURE 2

EXPERIMENTAL RESULTS

The results of these experiments are given in Table 1. It will be noted that as the output resistance is varied from zero to 5 megohms the apparent input resistance varies from infinity down to a minimum of 50,000 ohms and then up to 170,000 ohms. That this is sometimes equivalent to a considerable increase in effective resistance of the circuit LC is evident from the fact that a resistance of 2 megohms in the output circuit of the tube had the effect of apparently quadrupling the resistance of LC .

TABLE 1

Tube: Western Electric Company's Type D.

Plate Battery: 56 Volt; Filament Current: 1 ampere.

Grid Potential: 0.8 Volt Negative.

Wave Length: 6,000 Meters.

$L = 9.7$ millihenrys.

$C = 0.001$ microfarad.

Resistance in Plate Circuit of Tube, ohms	Galvanometer Deflections Scale Divisions	Effective Input Resistance (Indicated by Galvanometer Deflection) ohms
0	14.8	Infinite
45,000	2.4	130,000
100,000	1.0	60,000
850,000	0.8	50,000
1,450,000	1.0	60,000
5,000,000	3.0	170,000

It is possible to explain the above results on the basis of the following theory:

For radio frequency, at least, a tube with resistance in its output circuit has an effective input resistance which is equal to the total plate circuit resistance divided by the voltage amplification given by the tube for the particular output resistance in question.

By "total plate circuit resistance" is meant the sum of the internal resistance of the tube and the output resistance; by "voltage amplification for a particular output resistance" is meant the ratio of the voltage obtainable across the output resistance to that impressed on the input terminals of the tube. The latter is measureable on a modified Miller bridge, as shown in Figure 3. The theory of the regular Miller bridge for measuring the amplification factor of a vacuum tube has been published.¹ This modification permits the measurement of the ratio of the voltage across the output resistance R to that impressed across the grid and filament. The operation of the apparatus of Figure 3 will be obvious from the diagram.

FIGURE 3—Modified Miller Bridge for Measurement of Voltage Amplification

In order to test this theory it was necessary to determine the total plate circuit resistance with various output resistances. This was done as follows: With a plate battery of 54 volts and the usual negative grid potential of 0.8 volt, a number of tungsten film resistances were successively inserted in the plate circuit. With each resistance the variation in plate current was observed on a sensitive d.c. galvanometer when the plate battery potential was increased and decreased slightly from the value of 54 volts (a variation of one or two volts was made).

¹John M. Miller, PROCEEDINGS OF THE INSTITUTE OF RADIO ENGINEERS, volume 6, page 141, 1918.

The variation in battery potential divided by the corresponding changes in current gave the total plate circuit resistance. The values are tabulated in the second column of Table 2. In the third column are given the values of effective input resistance, corresponding to the output resistances of the first column, which have been taken from Table 1. In the fourth column are given the ratios of columns 2 and 3. These ratios correspond approximately to the voltage amplification values for the resistances of column 1, which are given in the last column.

TABLE 2

Resistance Inserted in Plate Circuit ohms	Total Plate Circuit Resistance (Measured) ohms	Effective Input Resistance (From Table 1) ohms	Ratio of Total Plate Circuit Resistance to Effective Input Resistance	Voltage Amplifi- cation for Resistance of Column 1 (Meas- ured)
0		∞	0	0
45,000	220,000	130,000	1.7	1.8
100,000	325,000	60,000	5.4	5.2
850,000	1,050,000	50,000	21.0	23.5
1,450,000	1,860,000	60,000	31.0	28.9
5,000,000	5,450,000	170,000	31.2	31.0

GENERAL NOTES

The tube used for the above tests was a Western Electric Company's Type D. Similar behavior, at the wave length used, was observed with a Western Electric Company's Type J, and a General Electric Company's Type G tube.

Lack of time prevented the carrying out of extended experiments with inductive and capacitive output circuits and at other wave lengths. However, it was noted that an inductance in the output circuit of about 15 millihenrys caused a *diminution* of resistance of the circuit LC to about one-fourth its value. That is, the effective input impedance of the tube was that of a negative resistance. On the other hand, shunting a resistance in the plate circuit by a condenser of 0.001 microfarad, caused the effective input impedance (which previously had been a low

resistance) apparently to become an infinite resistance. That is, a capacitive output circuit produces neither a positive nor negative resistance effect at the input terminals.

Research Department of the
Radio Corporation of America,
November 24, 1918.

SUMMARY: It is shown experimentally that the input impedance of a three-element vacuum tube at radio frequency is not infinite, as heretofore supposed, but that because of the capacitive coupling between input and output circuits within the tube itself, the input impedance greatly depends on the character of the output circuit. Experiments with resistance in the output circuit are given and a theory is advanced to explain the results observed. The general effect of inductive and capacitive output circuits is mentioned.