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DEPARTMENT OF COMMERCE
BUREAU OF STANDARDS
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Letter
Circular
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Methods of Measuring Properties of Electron Tubes.

In papers dealing with the operation of electrical circuits which use electron tubes, as well as in the design of radio equipment using electron tubes, certain properties of the tube appear to be of much importance. This pamphlet describes apparatus used at the Bureau of Standards for measuring three of these properties by means of an alternating current bridge. The properties are:

(1) Internal input resistance
(2) Internal output resistance
(3) Amplification factor

There are other important factors which are not covered by this letter circular. Some of the more important of these are, inter-electrode capacities, mutual conductance, and detection factor.

The direct current characteristic curves are of importance, but since the method of obtaining them is described in many books on radio measurements (such as Bureau of Standards Circular No.74) a complete description is not included in this letter circular. The characteristic curves that are usually of interest are the grid voltage-grid current, grid voltage-plate current, and plate voltage-plate current curves. To obtain these the tube is connected in a network which includes the variable voltages desired and indicating instruments for measuring the changes of current and voltage in the different circuits. Data may then be taken by varying each voltage over the desired range.

The methods of measurement used have been described by several writers * on the subject and this paper is intended to

* J.M.Miller, Proc.I.R.E., June 1918.
H.J.van der Bijl, "The Thermionic Vacuum Tube," Chap. VII.
J.H.Morecroft, "Principles of Radio Communication," Chap. VI

give convenient circuit arrangements that may be used for the rapid determination of the various properties with the values of the circuit constants that have been found most convenient.

This bridge is an alternating-current bridge which by simple switching arrangements may be used to measure internal input resistance, internal output resistance, and amplification factor under any condition of grid voltage, plate voltage and filament current. The principle involved in each of these measurements can be seen by reference to Fig.1. In each case the contact on the slide wire is varied until there is no sound in the telephone receivers. When this condition is satisfied the value of the factor desired is given by the relation indicated.

The complete circuit arrangement is given in Fig.2, in which

1 and 2 are SPDT switches,
3 is a SPST switch
4, 5, 6, 7 and 8 are terminals to which auxiliary apparatus is connected as indicated,
9 - filament ammeter,
10 - grid voltmeter,
11 - standard receiving tube socket,
12 - terminals for connecting non-standard tubes,
13 - slide wire,
14 - Two-stage audio-frequency amplifier,
G - ground terminal
R - standard resistance box, variable from 0-100,000 ohms,
R_1 - filament rheostat
R_2 - grid voltage divider
R_3 - rheostat 0-10,000 ohms
R_4 - rheostat 0-1000 ohms
S - reversing switch by means of which the grid may be made either positive or negative with respect to the negative side of the filament, as indicated by the + and - signs on the switch.

(1) Measurement of internal input resistance (r_g)

Switches 1. Closed at a
2. Closed at c
3. Open

When the switches are as indicated the circuit may be reduced to the simplified diagram Fig. 1a.

The tube to be measured is placed in the socket 11 or connected to the terminals G, F-, F+, P shown at 13 in Fig. 2. A filament battery is connected to the terminals at 4 and the current indicated by the ammeter (9), adjusted by the rheostat R_1 to the desired value. Between the two of the three terminals at 8 marked "Plate Bat." is connected a battery which must have the exact plate voltage desired as no means is provided for varying this voltage except by the addition of series cells. A voltage divider can not be used because of the extra resistance inserted in the plate circuit. A battery giving the voltage desired for the grid is connected to terminals 5. All the batteries must be placed near the apparatus and connected with as short leads as possible so as to minimize induction from any a.c.sources. The audio-frequency generator used may be either an alternating-current machine or an electron tube generating set. It is desirable that it be capable of being varied over the audible range although this is not necessary. Best settings may be obtained with frequencies of 800 to 1500 cycles per second.

A high-resistance direct-current voltmeter having a resistance of 100,000 ohms or more is connected to the terminals at 8 marked "Plate VM." This voltmeter should be disconnected from the circuit when the bridge is being adjusted. The telephone receivers used for indicating a null point are connected to the second stage of the amplifier unless there is too much noise due to induction to make an accurate setting, in which case measurements may be made with less accuracy using only one stage of amplification. The grid voltage, indicated by the voltmeter (10), is adjusted by the voltage divider R_2 to the desired operating point, R is set at 100,000 ohms and the slide wire adjusted for a minimum sound in the phones. Further adjustments are made by changing the position of the slider of R_4 until the best minimum is obtained, then readjusting the slide wire, repeating this operation until almost a complete silence is obtained for the minimum. It will be noticed that R_4 is a resistance across the input leads, with a variable midpoint at which the ground is connected. It is possible to compensate for capacity-to-ground effects almost entirely by changing the position of the ground in R_4. When there is complete silence in the phones T then

$$r_g = \frac{r_1}{r_2} R$$

If it is desired to measure the alternating current voltage applied to the tube during a measurement a low-voltage a.c. voltmeter (for example a high resistance thermoelement and microammeter calibrated in volts) may be connected across the input terminals (7, Fig.2). It is evident that the alternating current grid voltage is equal to the voltage drop across r_1 (see Fig.1a) when silence is obtained in the phones T. Then the impressed voltage

$$e_g = \frac{r_1 \quad E}{r_1 + r_2 + R_3}$$

where E is the voltage impressed on the bridge and measured by the voltmeter connected across the input terminals.

If the input resistance of the tube is high (over 10^6 ohms) difficulty will be experienced in making accurate settings and the accuracy of the bridge decreases.

(3) Measurement of internal output resistance (r_p)

Switches 1. Closed at b
2. Closed at c
3. Open

When the switches are as indicated the circuit arrangement reduces to that of Fig. 1 (b).

Resistance R is set at about 10,000 ohms and the point C on the slide wire adjusted until a minimum is obtained. R_4 is adjusted along with the slide wire until complete silence is obtained in the telephone receivers. If the ratio $\frac{r_1}{r_2}$ is too large or too small for accuracy then R is changed to bring the setting near the middle of the slide wire. Readings are taken with two or more values of R and the results averaged.

With silence in the phones

$$r_p = \frac{r_1}{r_2} R$$

This measurement includes the resistance of the plate battery which for new cells can be neglected in comparison with the resistance of the tube.

(3) Measurement of the amplification factor (μ)

Switches 1. Open
2. Closed at d
3. Closed

This arrangement of switches reduces the circuit to that of Fig. 1 (c).

The slide wire and R_4 are adjusted for minimum sound as described above and when silence is obtained

$$\mu = \frac{r_2}{r_1}$$

General

In all the preceding measurements, and especially in the measurement of r_g, care should be taken to keep the alternating current input as low as possible consistent with accurate setting of the slide wire.

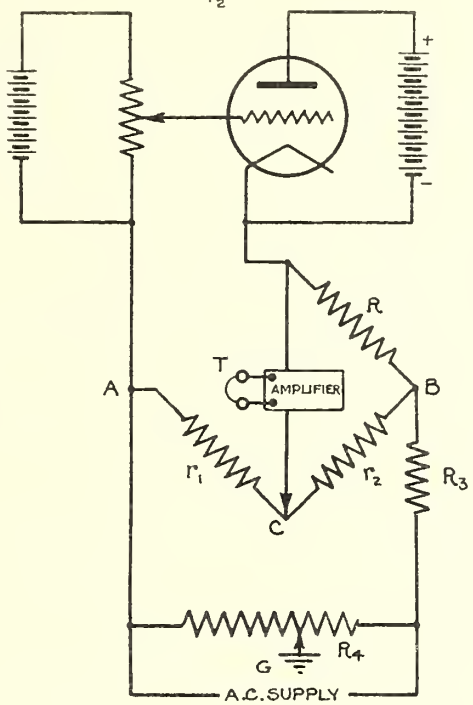
When adjusting for minimum sound the setting of R_4 affects the amount of sound at the minimum and also, to some extent, the position of the setting on the slide wire, so R_4 must be adjusted carefully to obtain a minimum as close to silence as possible. This is best done by moving the slider of R_4 back and forth over the minimum point and at the same time turning the slide wire (13) slowly in one direction until the nearest to complete silence is obtained when R_4 passes its minimum point R_4 is left at this point and the final adjustment made on the slide wire.

Tubes should be left burning for two to five minutes before making measurements to allow them to come to a condition of stability.

Department of Commerce,
Washington, D.C.

FIG.1.(a) INTERNAL INPUT RESISTANCE (r_g)
WHEN THERE IS SILENCE IN THE PHONES T

$$r_g = \frac{r_1}{r_2} R$$



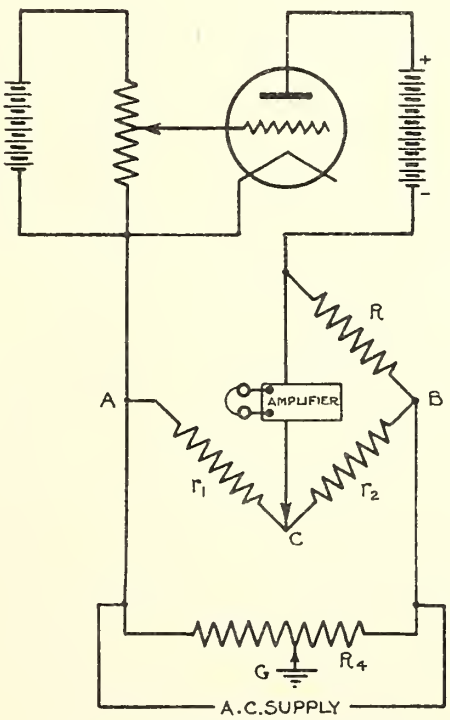


FIG.1.(b) INTERNAL OUTPUT RESISTANCE (r_g)
WHEN THERE IS SILENCE IN THE PHONES T

$$r_p = \frac{r_1}{r_2} R$$

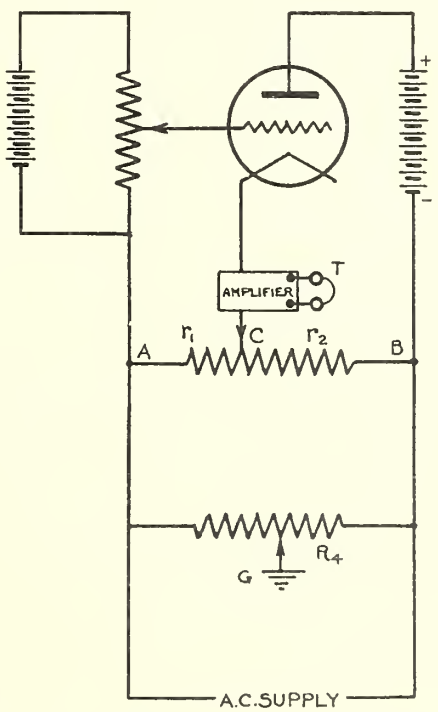


FIG.1.(c) AMPLIFICATION FACTOR (μ)
WHEN THERE IS SILENCE IN THE PHONES, T

$$\mu = \frac{r_2}{r_1}$$

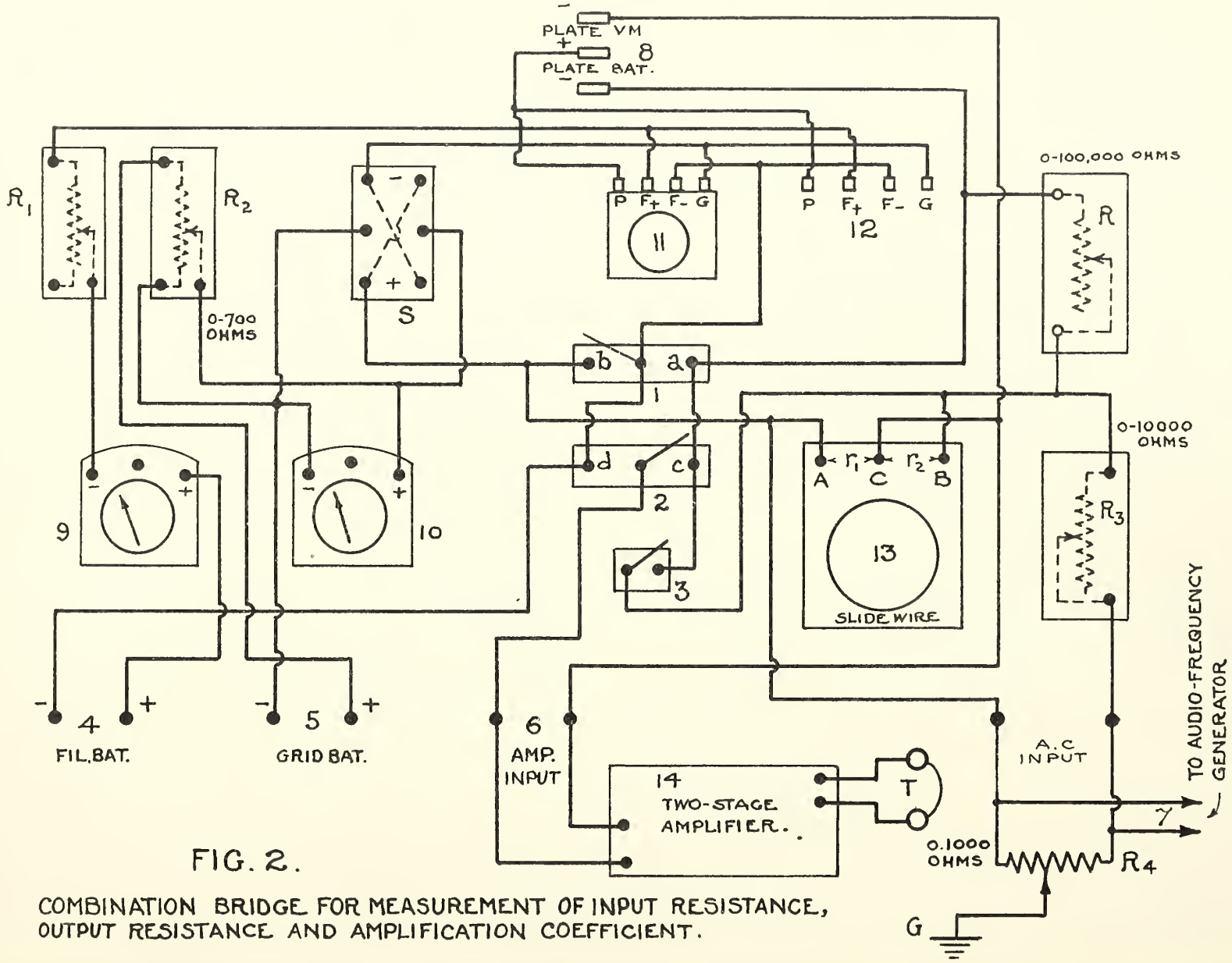


FIG. 2.

COMBINATION BRIDGE FOR MEASUREMENT OF INPUT RESISTANCE, OUTPUT RESISTANCE AND AMPLIFICATION COEFFICIENT.