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A Method of Visualizing Mutual-Conductance Characteristics of Vacuum Tubes

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Abstract

How to visualize characteristics of mutual-conductance vs. grid-voltage of vacuum tubes on the fluoresent screen of a cathode-ray tube and the apparatus which are made under this conception are described.

I. Introduction

Methods to know directly or indirectly the mutual-conductance of vacuum tube have been developed[1] and several instruments[2] which indicate simply by a meter have been accomplished during the past many years. Moreover, the ways to make characteristics of grid-voltage vs. plate-current or plate-current vs. plate-voltage visible are described by M. von Ardenne[3] and others.[4] According to my method which will be explained later, characteristic curve of grid-voltage e_g vs. mutual-conductance G_m can be traced on the fluoresent screen of a cathode-ray tube.

Plate-current is easy to change into potentials which are proportional to i_p by putting a small resistance in the plate circuit. But as mutual-conductance is the ratio of plate-current to grid-voltage it has to be converted into a voltage which is proportional to the ratio. The apparatus made by means of this circuit can be used for testing of tubes in mass-production, the comparison of G_m characteristics of two tubes and determination of the suitable working point of every tube in amplifier or in other miscellaneous circuit design. Moreover, it is very convenient to know G_m in wide range, even when grid-voltage is positive.

II. Action of Fundamental Circuit

The fundamental circuit of this instrument consists of the circuits which are: first, including tube to be tested, second, converting to voltage, third, amplifier and cathode-ray oscillograph as illustrated in Fig. 1. Notations are as follows:

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(1) F. E. Terman; Measurements in Radio Engineering, McGraw-Hill, 1935.

(2) Kazuo Kobayashi; On " MGM-1 " Type G_m Measuring Instrument, Denpa-Nippon, 47, (2, 3), (1950)

(3) Manfred Von Ardenne; Cathode-ray Tubes, Sir Isaac Pitman & Sons, English Edition (1939)

(4) H. M. Wagner; Tube Characteristic Tracer Using Pulse Techniques, Electronics, April (1951).

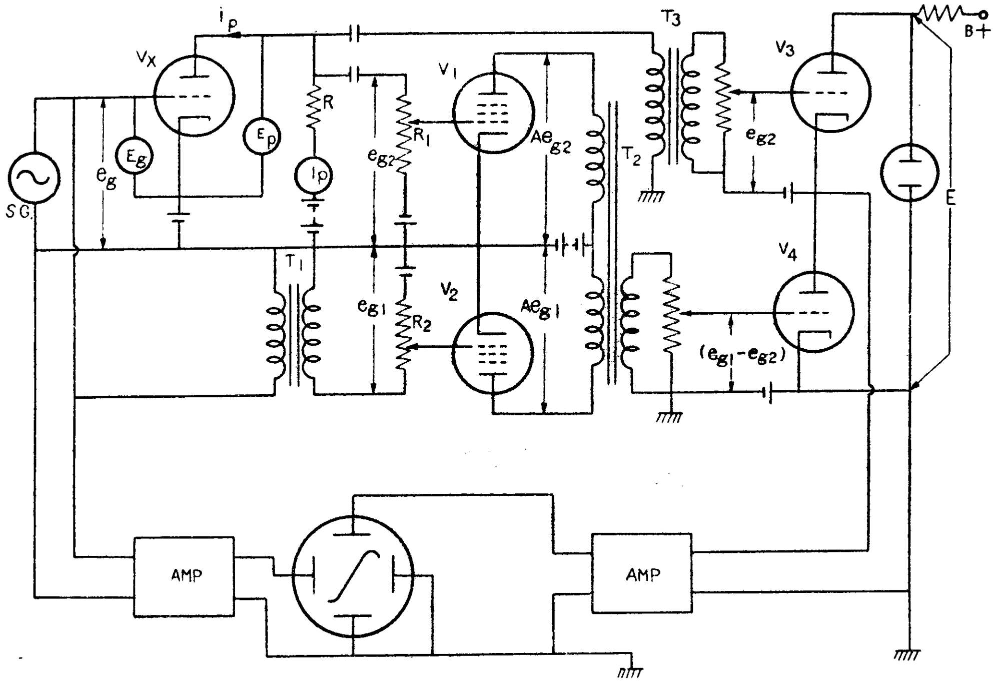


FIG. 1

V_x:	Tube under test
V_1, V_2:	Amplifying tube having constant G_m for varying input signal voltages
V_3, V_4:	Amplifying tube which changes their internal resistance linearly with input signals
V_s:	Constant-voltage glow-tube
R :	A small constant load resistance in plate circuit of V_x
G_m:	Mutual-conductance of V_x
i_p:	a. c. component of plate-current of V_x
e_g:	Input a. c. grid-voltage of V_x
e_{g1} :	Voltage which is proportional to e_g
e_{g2}:	Out-put a. c. voltage which is developed across the load resistance R
A:	Voltage amplification of V_1 and V_2
E:	Constant d. c. potential between V_3 and V_4 which are connected in series
r_3, r_4:	Internal resistance of V_3 and V_4, respectively
e:	Voltage appearing between plate and cathode of V_4

The tube V_x which will act as an amplifying tube has the load resistance R. In this case, R is a pure resistance and much smaller than other loads connected to the anode and also it must be small to avoide large d. c. voltage drop across the resistance. When a voltage e_g applies to the control-grid of V_x from the audio signal generator, over the resistance R an output voltage e_{g2} appears. In general, e_g is bigger than e_{g2} because of small R. Therefore the following equation will be derived.

$$e_{g2} = Ri_p \tag{1}$$

$$G_m = \frac{\partial I_p}{\partial E_g}\ E_p = \text{const.} \doteqdot \frac{i_p}{e_g} = \frac{1}{R}\cdot\frac{e_{g2}}{e_g} \doteqdot \frac{1}{10R}\cdot\frac{e_{g2}}{e_{g1}} \tag{2}$$

where R is constant.

e_{g2} is applied to the control-grid of V_1 by adjusting R_1 to be not over 1 volt. Also e_g becomes e_{g1} passing through the transformer T_1 and their phase difference is just 180°. Then e_{g1} will be stepped down almost one tenth according to R_2 and will be applied to the grid of V_2. V_1 and V_2 are connected in push-pull. Since both e_{g1} and e_{g2} are in phase, output voltage across the transformer T_2 is proportional to the difference between e_{g1} and e_{g2}.

V_1 and V_2 are pentodes having the same characteristics and by choosing the optimum grid-bias voltage, G_m of both tubes may be made constant within about 2 volts for input grid voltages. Therefore output voltages in plate circuit of both tubes will be Ae_{g1} and Ae_{g2}, according to the same amplification A, despite of small variation in grid inputs. Output voltage of T_2 will be $A(e_{g1} - e_{g2})$. V_3 and V_4 are connected in series and are applied constant d. c. voltage E between the plate of V_3 and cathode of V_4. V_3 and V_4 have identical characteristics, too. In this case pentode V_3 and V_4 are used as triode and are set with their grid-bias to the region where internal resistances are changing linearly with grid input voltages. To the control-grid of V_3 is applied the voltage which is proportional to e_{g2} but in opposite phase by V_3. To the V_4 the voltage which is proportional to $e_{g1} - e_{g2}$ is applied. Input voltages of both tubes are in phase. Internal resistance r_3, r_4, of V_3, V_4, respectively, are inversely proportional to their grid input voltages. Then,

$$r_3 = K/e_{g2} \tag{3}$$

$$r_4 = K/(e_{g1} - e_{g2}) \tag{4}$$

where K is the proportional constant of tubes.

The voltage e between anode and cathode of V_4 is then given by the equation,

$$e = \frac{r_4}{r_3 + r_4}\cdot E \tag{5}$$

Substituting (3) and (4) into (5),

$$= \frac{\dfrac{K}{e_{g1} - e_{g2}}}{\dfrac{K}{e_{g1} - e_{g2}} + \dfrac{K}{e_{g2}}}\cdot E = \frac{e_{g2}}{e_{g1}}\cdot E \tag{6}$$

Comparing (2) with (6),

$$e \propto G_m \tag{7}$$

Therefore e is proportional to G_m of V_x by setting every circuit's element and tube constants to optimum conditions.

After amplifying, the voltage e and e_g are applied to vertical and horizontal axis of a cathode-ray tube, respectively. Then G_m characteristics vs. grid-voltage is seen on the fluorescent screen of its tube.

III. Practical Apparatus

The arrangement and connections of these circuits in practice are shown in Fig. 2.

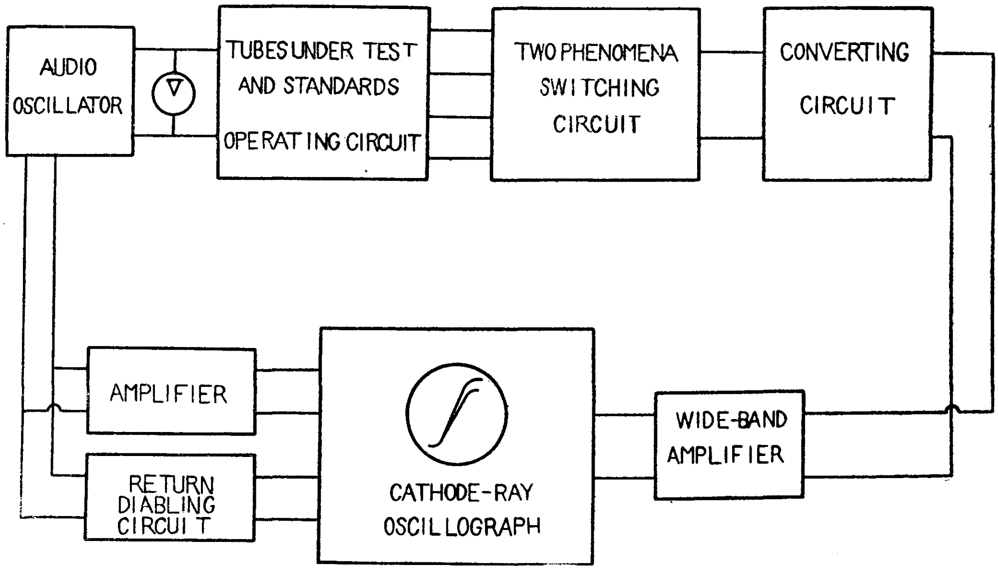


Fig. 2.

An audio oscillator employed for a. c. source of e_g, can generate variable voltages from about 2 to more than 10 volts in good regulation and in pure sinusoidal wave forms, and its frequency can be changed 500 c / s to 5000 c / s. Produced a. c. voltage may be always measured by a voltmeter. The next instrument including V_x to be test has many sockets adapted for various types of tubes which we want to measure, like a tube checker. Moreover, two tubes of same kind ; — one standard and the other to be tested — can be arranged on the board in order to compare their characteristics.

Output voltages of both tubes will be applied to the next circuit which is called " two phenomena switching circuit " to make it possible to see both curves simultaneously on the screen. Using the switching circuit, it is easy to choose tubes of the same characteristic as the standard tube from the coincidence of their curves. This may be used for mass-production at a factory. To determine the working point of tube, voltmeter and ammeter which indicate its plate-current, screen-voltage, plate-voltage and grid-bias voltage are placed in V_x circuit.

The switching circuit[5] consists of multivibrator and two amplifiers which are set almost at unity amplification. Its switching frequency is about 700 c / s. So

(5) K. Izumikawa & S. Oka; Cathode-ray Tubes and Oscillograph, Kyoritsusha, (1942).

it is better to choose second or higher harmonics of its frequency as input grid-voltage e_g in order to stop drifting of the image of the screen.

The next is '' converting circuit ''. This is the vitals in this method and is difficult to adjust all elements to their optimum conditions. Valve-voltmeter and cathode-ray oscillograph should be used for adjustment, that is to check potentials and wave forms in every point of the circuit to satisfy the conditions which have already been mentioned before. Unless V_1, V_2, V_3 and V_4 are operating at suitable point, various errors and distortions will arise.

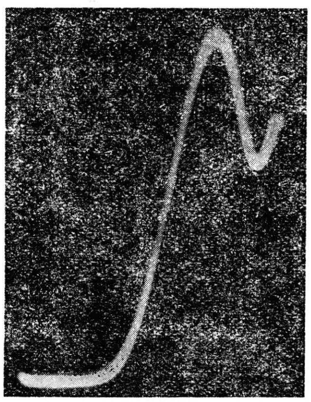
To amplify$_g$ and output voltage e of the converting circuit, wide-band amplifiers are used. By changing the amplification the curve on the screen can illustrated smaller or larger optionally.

Amplified voltage e_g and e are applied to horizontal and vertical deflection plates of the cathode-ray tube, respectively. If there is some phase difference between both voltages, the curve appearing on the screen may display a loop similar to Lissajous figure. Though in the V_x circuit there is a phase shifter, it can not make them coincide perfectly as a single curve.

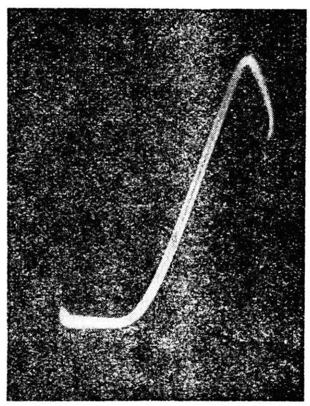
To avoid the disagreement of the characteristic curve, " return diabling circuit " is employed. Negative rectangular pulse is applied between grid and cathode of the cathode-ray tube. Then it makes the returning curve disappear during the interval of $\frac{\pi}{2}$ and $\frac{3\pi}{2}$ in input voltage e_g.

IV. Results in Measurement

Several photos of G_m characteristics which have been taken by this apparatus are shown in Fig. 3.



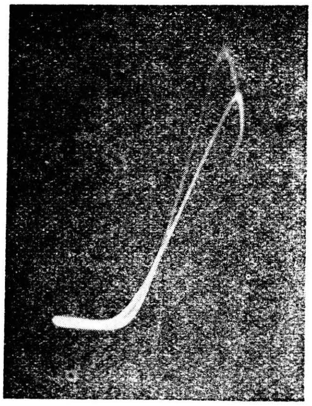
(a) 6C6



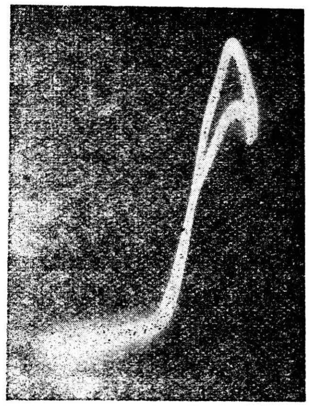
(b) No. 1 No. 2

Fig. 3.

The photos were taken by this instrument, and vertical and horizontal axis are G_m and e_g respectively.



(c) 6C6 No. 1, No. 3



(d) 6K7, 6J7

Where; E_p = d. c. plate voltage, E_{sg} = screen-grid voltage,

E_g = grid-bias voltage, e_g = swing a.c. grid voltage.

Explanation of results are as follows:

Photo (a): V_x; 6C6 (No 1), $E_p = 200$ volts, $E_{sg} = 100$ v,

$E_g = -5$ v, $e_g = 10$ v (crest value).

(b): V_x; 6C6 (No 1) & (No 2)

$E_p = 285$ v, $E_{sg} = 115$ v,

$E_g = -6$ v.

Both have nearly the same characteristics.

(c): V_x ; 6C6 (No 1) & (No 3),

$E_p = 275$ v, $E_{sg} = 120$ v,

$E_g = -6$ v.

No 3 tube was inferior to No 1 which was used as standard.

(d): V_x ; 6K7 & 6J7,

$E_p = 225$ v, $E_{sg} = 80$ v,

$E_g = -4$ v.

It is clearly to be seen in the picture 6K7's G_m is bigger than that of 6J7 under the same conditions.

V. About Errors

In this method an absolute value of G_m will be hardly obtainable because of complicated adjustment. Even though all the adjusting elements of the whole circuits including vacuum tubes were set in optimum states, errors in the final results would be less than 20% of the real values except the vicinity of the center in illustrated G_m curve on the screen. If the exciting signal is made smaller, the resultant image may be nearer the real one.

Also G_m of the same tubes have been measured by the well-known bridge circuit to compare with that taken by the visual method. V_1, V_2, V_3, and V_4 have been selected among a lot of tubes by using the bridge method.

Now, we must pay attention to the following to get more exact characteristics of G_m.

1) Characterics of V_1 , V_2 , and V_3 , V_4 should be the same respectively and those tubes must be working under the same conditions. Concerning V_3 and V_4, input voltages are admitted under 3 volts. Especially care must be taken to select suitable grid-bias voltages for both cases.

2) Coupling transformer T_1, T_2, and T_3 must have high qualities – low resistance, low leakage inductance, low losses and higher satulation. This is in order to avoid amplitude and phase distortions while signals pass through the transformers.

3) Coupling condensers and dividing resistances may be selected with suitable values to avoid much phase difference.

4) e_{g1} must be bigger than e_{g2}.

5) E should be kept always constant. Batteries as the d. c. source may be better, but rectified source using glow-tubes was sufficient to employ for this purpose. Variation of the source voltage will cause drifting of the images.

6) Wave forms of input signals should be pure sinusoidal and after passing through V_x, V_1, V_2, V_3 and V_4 they should be as similar as possible. Amplitude of signal should not exceed over 10 volts (crest value). The smaller signals the more correct the curves will be.

VI. Conclusion

This instrument will not be suitable for measurement of absolute mutual-conductance because of the reasons already mentioned above. But this is to be used for judgement of good or bad tubes and for determination of best operating point, morever it is very convenient to know the outline of tube characteristics in wider region extending over negative and positive grid-voltages. If the tube is inferior to the standard one, by changing grid-bias voltage or plate-voltage it can be used as a good one. Although the results are not very accurate, this can also be employed to know the dynamic·characteristics of tubes by putting their load resistance instead of the smaller R.

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