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CORRECTIONS

December 1946. No. 7. Page 16.

Fig. 2. Delete the words "PBF Beam forming plates."

Please read the last six lines of the first paragraph on page 18—Valve Type PE04/15A as Plate Modulated R.F. Power Amplifier as follows:—

DC Cathode Current	55	—	mA
Total Effective Grid Circuit Resistance	1	—	Megohm
Plate Dissipation	9	7.5	watts
Driving Power (Approx.)	—	64	milliwatts
Power Output (Approx.)	—	8	watts

PHILIPS TECHNICAL REVIEW

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Messrs. Gordon and Gotch Ltd., Barrack St., Sydney, N.S.W.

A Modern A.F. Power Amplifier System

1. Introduction.

While it is probably correct to say that the fundamentals involved in the design of power amplifiers and loudspeaker systems have altered very little during the past ten years or so, modern designs for power amplifiers incorporate refinements and facilities, developed as a result of experience, which render a modern power amplifier capable of a performance and universality of application which are amazing.

Perhaps the most important of the improvements introduced during the past few years are the use of negative feedback circuits, beam and high slope pentode valves, voltage or current stabilising circuits, tone control circuits and perhaps, last but not least, a system of wiring a number of loudspeakers which minimises the problems of impedance matching and at the same time reduces the danger of shock from the circuits external to the amplifier.

2. Typical Modern Power Amplifier

An appreciation of the practical improvements which have taken place in power amplifier design are best illustrated with the aid of a typical amplifier and for the purposes of this paper an amplifier available to the general public has been adopted [1].

The performance figures for a typical power amplifier of this type are given hereunder:—

Power Output and Distortion

Measured at 1,000 c.p.s. with bass and treble controls set to give a flat frequency response curve.

Output	Distortion
1 watt	1%
10 watts	1%
25 watts	1%
50 watts	1.7%
60 watts	4.3%
70 watts	7.6%
75 watts	15%

[1]) Amplifier Philips Type 952

Some of the distortion at low outputs was inherent in the beat frequency oscillator used for making the measurements. A measurement made at 100 c.p.s. gave 50 watts for 4.3% distortion and at 5,000 c.p.s. the amplifier gave 50 watts for 1.3% distortion.

Sensitivity.

Measured at 1,000 c.p.s. with all controls at maximum:—

Microphone 1 ...... 250 microvolts input gives 50 watts output.

Microphone 2 ...... 250 microvolts input gives 50 watts output.

Pickup ...... 0.15 volts input gives 50 watts output.

These sensitivities correspond to a gain of about 90 dB on pickup and 156 dB on microphone.

Frequency Response.

Response curves are shown in figs. 1 and 2. The high frequency response is deliberately attenuated as quickly as possible after 7 Kc/s, as higher frequencies do not improve intelligibility, but make distortion sound extremely unpleasant if a good speaker is used.

Hum and Noise.

Figures from the microphone channel vary considerably with the input valve used, but average figures with all tone controls giving maximum response are:—

All gain controls at zero, output = 0.1 volt = 0.05 milliwatt = 60 dB down from 50 watts.

Pickup control at maximum, output = 0.1 volt = 0.05 milliwatt = 60 dB down from 50 watts.

One microphone control at max. — with short circuited input — output = 2.5. volts = 31 milliwatts = 32 dB down from 50 watts.

One microphone control at max. — with open circuit input — output = 3.2 volts = 50 milliwatts = 30 dB down from 50 watts.

Much better hum and noise figures can of course be obtained with the tone controls turned down.

Power Consumption.

Varies with output as follows:—

Output	Power Consumption
0 watts	115 watts
50 watts	200 watts
75 watts	225 watts
maximum	240 watts

Input Arrangements.

Pickup terminals are provided at the back of the amplifier and jacks for two independent microphones are on the front panel.

Output Arrangements.

A plug type switch, which is on the rear of the unit adjusts the output impedance to either 200, 125, 75 or 30 ohms. A monitoring jack is provided on the front panel for a pair of headphones. Interconnection terminals are also provided at the back of the amplifier for feeding additional amplifiers if required.

Controls.

Independent gain controls are provided for both microphones and for the pickup. In addition, separate bass and treble controls are fitted. A circuit diagram of this amplifier is given in Fig. 3.

3. Loudspeaker System.

In order to obtain the maximum undistorted output which the amplifier is capable of delivering, the load driven by the amplifier should be matched to the impedance indicated by the output impedance, adjusting plug switch in accordance with common practice. The highest output impedance is 200 ohms and this value has been selected for reasons explained in the following.

When an amplifier is in operation the maximum voltage which can develop across the output terminals for a given power output is determined by the output impedance of the amplifier and, provided that an adequate degree of negative feedback is used in the amplifier, this voltage will not be materially increased by an increase in the impedance of the load to which the amplifier is connected. The following table gives the maximum voltage at the output terminals of an amplifier matched to deliver 50 watts into loads of various impedances, calculated from the well known expression, Watts = E^2/R.

Impedance	Maximum Voltage
100 ohms	77
200 ohms	100
500 ohms	158
1,000 ohms	223
5,000 ohms	500
10,000 ohms	770

Voltages in excess of 100 volts should be regarded as dangerous to human life and should only be permitted if the wiring carrying the voltages is very carefully insulated and installed. It is a fact that many loudspeaker installations are of a temporary nature and quite often the wiring to the loudspeakers is most unsuitable for carrying high voltages. Furthermore, many radio mechanics are accustomed to regard the voltages delivered to loudspeakers as harmless and would not hesitate to connect a loudspeaker to the wiring while the amplifier is switched on.

By limiting the output impedance of this amplifier to 200 ohms the designers have limited the maximum voltage across the output terminals to the comparatively safe value of 100 volts and thereby protected users of the amplifier from the risk of fatal accident through carelessness.

This limitation of output voltage has another very convenient consequence. The maximum power which can be delivered to any loudspeaker connected to the output terminals is limited by the impedance of the speaker transformer. This not only reduces the risk of damaging a loudspeaker by overloading it, but enables the maximum volume which can be produced by any loudspeaker to be limited by using a transformer of suitable impedance. For example, if a volume of sound corresponding to 2 watts is required from a loudspeaker in a particular location and 4 watts in another, the two speakers may be wired in parallel to the output terminals of the amplifier and if one of the speakers has an impedance of 5,000 ohms and the other an impedance of 2,500 ohms, their power will be limited as desired. Loudspeakers can therefore be rated according to power output by means of the impedance of their transformers.

Suitable impedances for various power ratings of loudspeakers are given in the following table:—

Power	*Impedance*
0.25 watt	40,000 ohms
0.5 watt	20,000 ohms
1.0 watt	10,000 ohms
2.0 watts	5,000 ohms
5.0 watts	2,000 ohms
10.0 watts	1,000 ohms

4. Impedance Matching and Frequency Response.

Communication engineers generally regard it as axiomatic that a transmission line must be matched to its load if frequency selection by the line is to be avoided and at first it may appear that the system of wiring loudspeakers described in the foregoing section would adversely affect the frequency response characteristic of the whole system, but this is not so in normal installations.

It is only necessary to match the impedance of a transmission line to avoid reflections if the length of the line is comparable with one quarter of the wavelength corresponding to the highest frequency to be considered. In this case the highest frequency is 7,000 c/s and the corresponding quarter wavelength is approximately 27 miles so the effects of reflections may be disregarded for normal installations.

When audio frequency currents are transmitted over short lines the higher frequencies suffer from attenuation more than the lower frequencies mainly as a consequence of the total capacitance of the cable. The circuit arrangement resembles a resistance capacitance filter in which the resistance is the parallel impedance of the amplifier and the load while the capacitance is that of the cable. The resistance is likely to be less than 100 ohms and with this value for a 3 dB drop at 7,000 c/s, the capacitance of the wiring would have to be approximately .25 μF and such a value is improbable in a normal amplifier installation.

When only a few high impedance speakers are connected to the amplifier the output transformer will be mismatched. However here again no difficulties arise. Negative feedback in the amplifier keeps the gain constant and minimises distortion in the amplifier due to mismatch. So far as frequency distortion due to the transformers is concerned, it should be noted that the output transformer is coupled to a load higher than the correct matching value while the loudspeakers are connected to an input load lower than the correct value.

Frequency distortion in a transformer due to mismatch of the secondary impedance when the primary is loaded only occurs when the output load resistance is too small for correct matching. In such a case the leakage inductance of the transformer leads to attenuation of the higher frequencies. In the case under consideration the output load impedance is too large, and not too small, so no difficulties arise.

With loudspeakers the position is the reverse. If the input load impedance is too large the speaker will be insufficiently damped and attenuation of the lower frequencies may occur, but with this system the input load impedance is too small and not too large so again the arrangement is satisfactory.

The only loss due to the mismatch is that the maximum undistorted output of the amplifier will be reduced, but if the impedance of the speakers is selected to reduce the power handled by the individual speakers, this is not a disadvantage. The voltage of the output is approximately constant regardless of the load. On the other hand if the total impedance of the loudspeakers connected to the amplifier becomes less than the output impedance of the amplifier, distortion will be increased and the amplifier will be unable to deliver its rated power to the speakers. The arrangement will then be one which exceeds the power capacity of the amplifier and it will be necessary to reduce the output impedance of the amplifier in order to match the load. This will reduce the maximum voltage across the output terminals and the power to all speakers will be reduced in the same proportion.

5. Individual Volume Control of Loudspeakers.

Very few loudspeaker installations will require the full power which the amplifier is capable of delivering and this enables a very simple method of individually adjusting the volume of sound from the speakers to be used. Each speaker may be fed from a simple potentiometer connected across the output line and having a resistance equal to about twice the impedance of the speaker it is intended to control. The potentiometers may be used to control the volume from individual loudspeakers without noticeably affecting the volume from the others.

Such a system is very convenient for a house or building having many small rooms. A single radio receiver together with microphones and a pickup if desired, may be used to feed the amplifier which in turn drives a loudspeaker in each of the rooms. The impedance of the speakers is selected according to the size and noise level of the rooms and individual volume control potentiometers may be fitted.

6. Audio Frequency Negative Feedback and Tone Controls.

Negative feedback for the amplifier is derived from a separate secondary winding on the output transformer T3 (Fig. 3) of the amplifier and applied to the cathode of the valve V1D. This is a circuit arrangement much favoured in equipment designed by Philips in preference to feedback from the anode of the output valve. Not only does this feedback reduce distortion due to non-linearity of the valve characteristics but it also reduces distortion due to non-linearity or frequency selection of the output transformer. Furthermore, as clearly explained in a recent article in another journal [2]) feedback from the secondary of the output transformer reduces hum from the power supply while feedback from the anode of the output valve can actually increase the hum. (It will be seen from the circuit diagram that no smoothing chokes are used in this amplifier. See under sub-heading 11). On the other hand, the design must be carefully carried out as the phase shifts in the transformer must be taken into account if instability is to be avoided. With care use can be made of this phase shift to give bass boost to the amplifier.

Included in the feedback circuit is a network of resistances and capacitances including the treble tone control potentiometer R10A. Feedback at very high frequencies is maintained for all adjustments of the tone control by means of the capacitors C7A and C2C. Resistor R6B is so proportioned with respect to capacitor C2C that the feedback is reduced at the very low frequencies. The feedback at the medium higher frequencies can be attenuated by the tone control potentiometer R10A and capacitor C1H. When the arm is moved to the top of the potentiometer, capacitor C1H bypasses resistor R6C and increases the feedback at the higher frequencies thus attenuating the treble response of the amplifier. On the other hand, when the potentiometer arm is moved towards earth, this capacitor C1H bypasses the higher frequency feedback potentials to earth, reduces the feedback at these frequencies and so elevates the treble response of the amplifier.

A curve showing the frequency characteristics of the feedback circuits is given in Fig. 4 for a condition when the treble and bass tone controls are set for maximum response and the attenuation of the feedback at about 30 and 5,000 c/s is clearly shown. This curve should be compared with the corresponding response curves of Figs. 1 and 2 and the impedance curve of Fig. 10.

When designing an amplifier such as this the designer is faced with the choice of placing tone controls either in the feedback path or outside that portion of the amplifier straddled by the feedback. If they are outside the feedback path, the total gain of the amplifier with feedback functioning must be sufficient to give adequate gain to the frequencies attenuated by the tone control, and adjustment of the tone controls will cause a noticeable change in the volume of sound. The effect of an increase in gain at certain frequencies is obtained by reducing the gain at others. If located in the feedback path, the tone control circuits vary the gain of the relative frequencies themselves. The effect of the tone control on the apparent volume is reduced and also the number of stages necessary in the amplifier is reduced because the gain of the amplifier is at a minimum for all frequencies when the tone controls are adjusted for a flat frequency response.

7. Bass Tone Control.

In this typical amplifier, bass control is effected by varying the size of the screen grid bypass capacitor by means of the switch S1A. In effect this is equivalent to a form of feedback at the lower frequencies applied through the screen of this valve. The screen voltage is permitted to change in synchronism with the lower frequencies applied to the control grid of the valve but in opposite phase and this reduces the effective slope of the valve at these frequencies.

8. Output and Driver Stages.

The output stages of this amplifier use two 807 beam power valves (V4A and V4B) driven by a 6V6 valve (V3A) per medium of an interstage transformer T2A. The output valves operate in class AB_2.

In addition to acting as a driver valve the 6V6 valve V3A provides negative feedback for d.c. and so minimises changes in the d.c. potential applied to the screen of the output stages.[3]) This action, which largely contributes to the overall performance of the amplifier is explained in more detail in section 11.

[2]) "Wireless World," May 1946.

[3]) Devised by Messrs. G. Smith, W. Storm and E. Watkinson.

9. Microphone Input Valves.

The microphone input valves are of the 6J7 type connected as triodes. As the input voltage derived from a microphone is very small it has been possible to bias these valves by means of a very large grid leak. When a valve is left with its grid insulated the grid accumulates a negative charge and the potential of the grid can then be controlled by means of the grid leak. If the resistance of the grid leak is sufficiently large the control grid is biased to a value a little less than that produced by the charge accumulated on the isolated grid.

10. Volume Control and Fading Circuits.

The microphones are fed directly to the grids of the microphone input valves and their respective volume controls are located in the outputs of these valves. This permits a very high input impedance to be maintained at the microphone terminals so that crystal microphones may be used if desired.

The pick-up terminals feed the pickup volume control directly. The outputs of the three volume controls are connected to the control grid of the valve V1C via isolating resistances so that any volume control may be adjusted without affecting materially the adjustment of the others.

11. Power Supply Circuits.

Perhaps the most interesting feature of this amplifier from a technical point of view is the power supply and voltage stabilising circuits. Two rectifiers are used, one supplying the anodes of the output stages and the other the screens of the output stages and also the anodes and screens of the driving and voltage amplifying stages. The two power supplies are interconnected in such a manner that the driving valve controls the bias of the output stages in such a manner as to compensate for changes in the screen potentials. No smoothing chokes are used as the overall design is such that these are unnecessary and power which would otherwise be dissipated in chokes is saved.

A simplified form of the voltage stabilisation circuits is shown in Figure 5 and it will be seen from this figure that the driver stage power supply is linked to the power supply for the anodes of the 807 valves by a direct current connection from its control grid to the junction of two resistors R3 and R4 which connect the positive terminal of the 500 volt supply to the negative terminal of the 300 volt supply. The earth circuit of the 300 volt supply is made via the resistors R2 and R1, the voltage across the latter being used to bias the output valves. The bias applied to the 807 valves therefore depends upon the current flowing through the 6V6 driver valve and this current in turn depends upon the voltage of the main 500 volt supply because of the d.c. connection to its control grid. If the voltage of the main supply falls the potential applied to the grid of the driver valve will move in a negative direction thus decreasing the current through this valve and so decreasing the bias applied to the output 807 valves. If the voltage of the 500 volt supply increases the opposite action takes place and the bias to the 807 valves is increased.

The regulation of the 500 volt supply is not perfect and when the output valves commence to function as class B amplifiers, and their consumption of d.c. anode current increases, the effective voltage of the 500 volt supply will fall. In the absence of any compensation network, the output power of the stages would also be decreased. Due to the network the bias voltage also changes and so operating conditions are maintained near to those for maximum output.

Similarly the network also adjusts the screen voltage of the 807 valves to assist in compensating for a fall in anode voltage. The effective screen voltage is the voltage of the 300 volt supply less the voltage drop in the resistors R1 and R2. This voltage drop is partially determined by the current through the driver valve and preliminary stages and partly by the screen current itself. When the voltage of the 500 volt supply decreases the current through the driver 6V6 also decreases thus decreasing the voltage drop in the resistors R1 and R2 and thereby increasing the screen voltage which is 300 volts minus the voltage drop.

The curve in Figure 6 shows the relationships between the bias applied to the 6V6 bias voltage and cathode current and the output voltage of the amplifier. Figure 7 shows a similar relationship between the anode voltage and current of the 807 valves and the voltage output.

Figures 8 and 9 show the relationships for 807 screen current and bias and also the low voltage supply current and voltage (to ground) with respect to output voltage. The extent of the compensation caused by the circuit can be gathered from these figures.

12. Output Impedance.

The output impedance of an amplifier with feedback is largely determined by the magnitude of the feedback and when the frequency response of an amplifier is controlled by means of negative feedback the output impedance of

the amplifier varies with frequency. The shape of this curve will depend on the adjustment of the tone controls of the amplifier and is illustrated in Fig. 10.
—*E.G.B.*

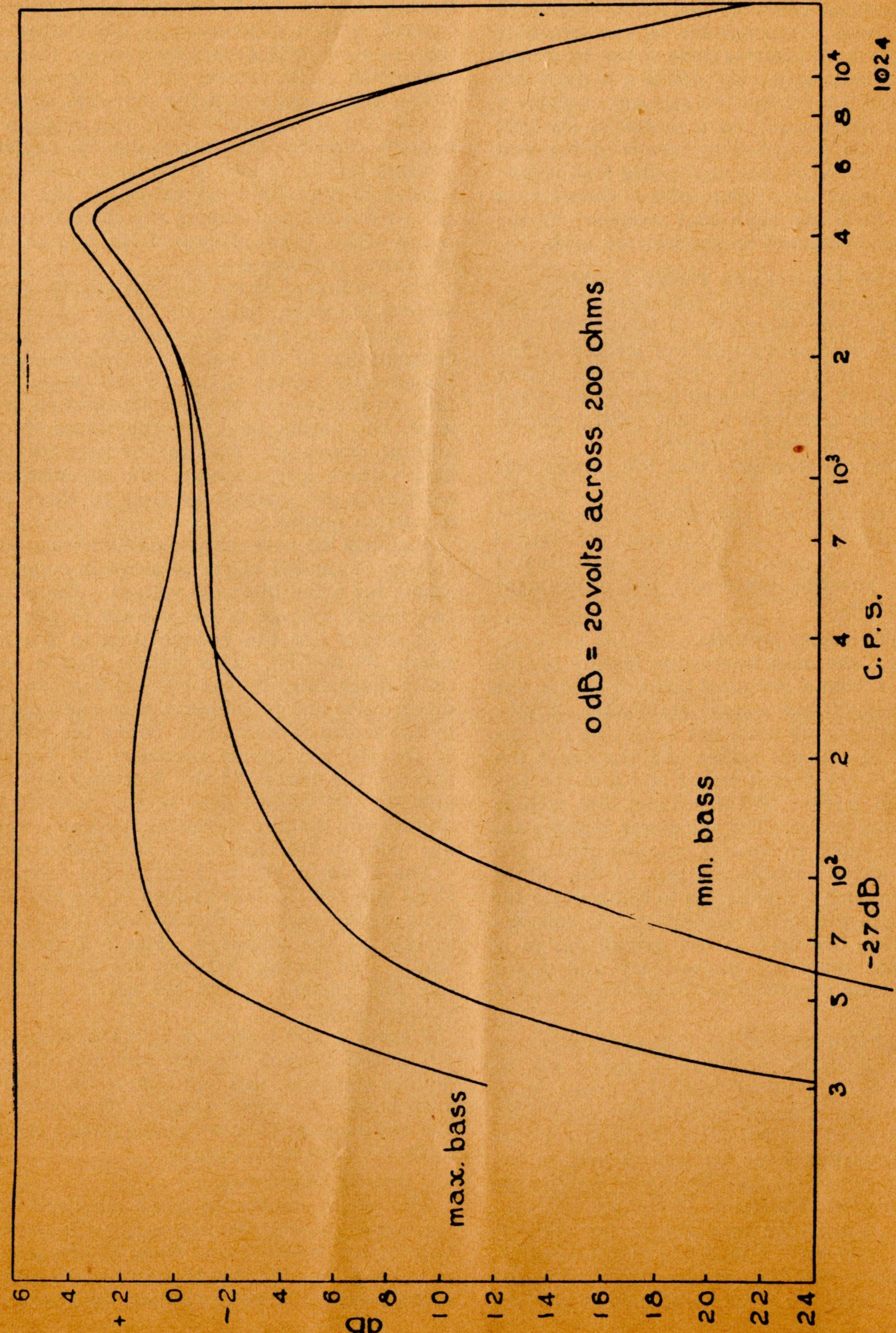

Fig. 1. Microphone response

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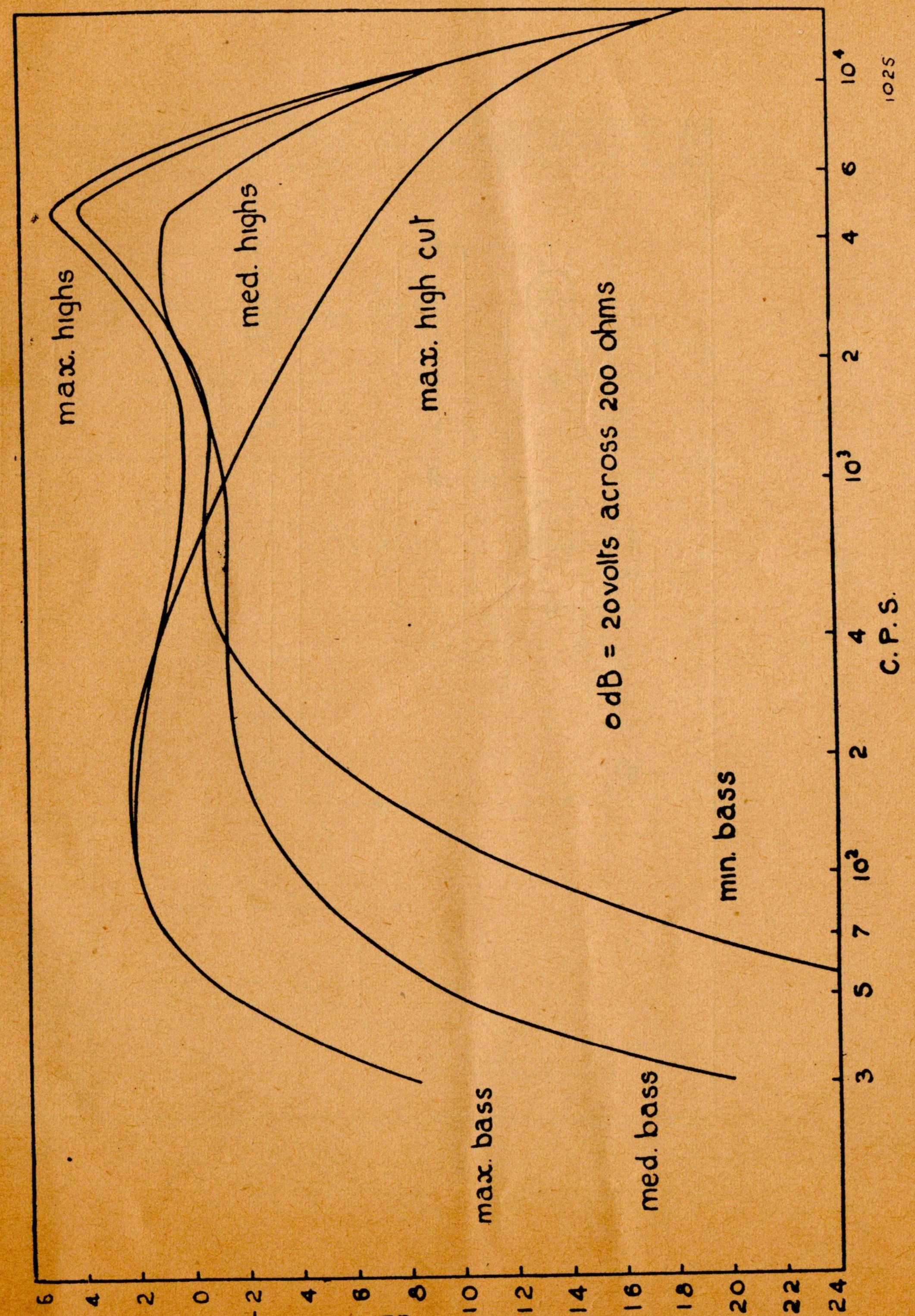

Fig. 2. Pickup response

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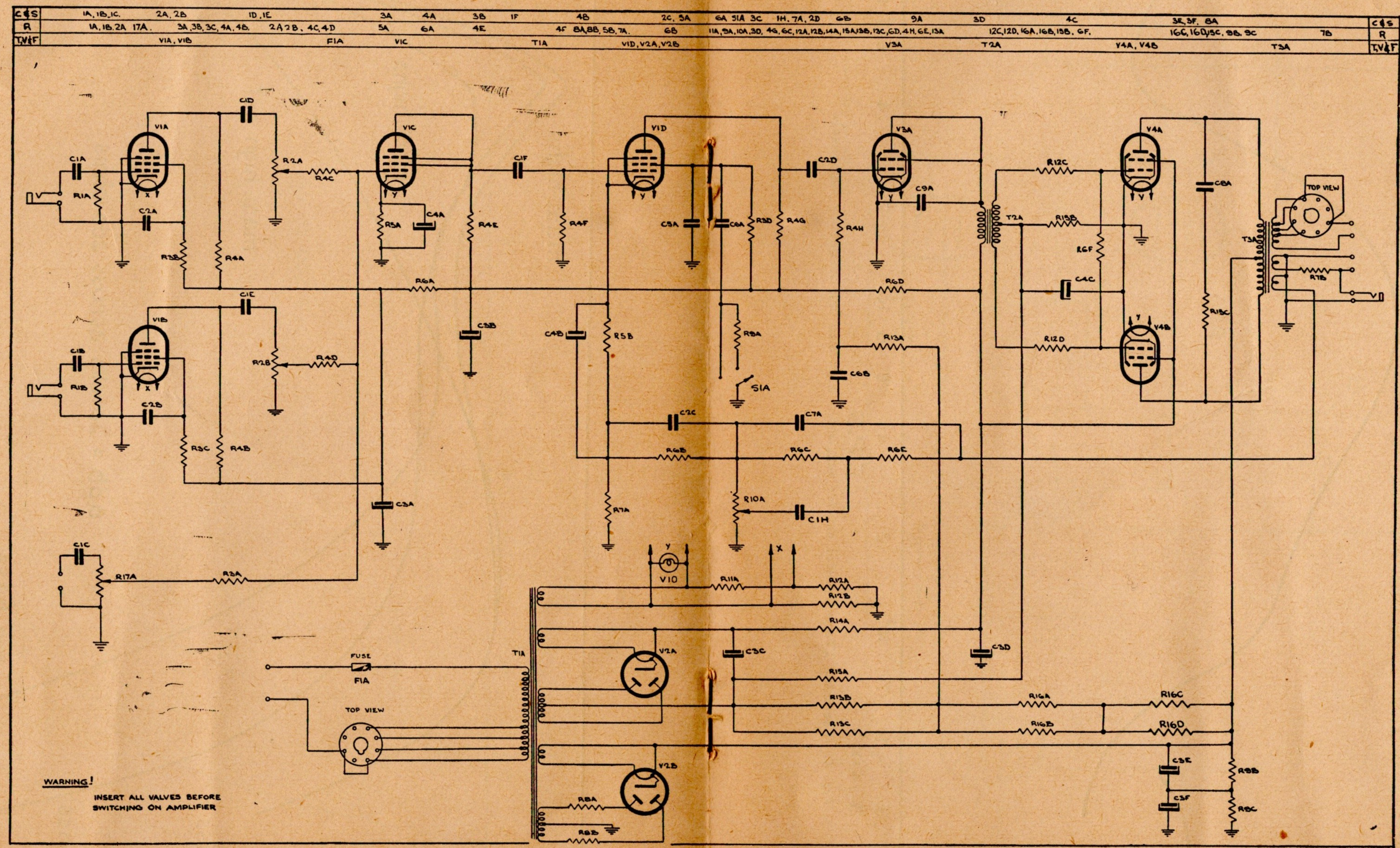

Fig. 3. Circuit Diagram of 952 Amplifier.

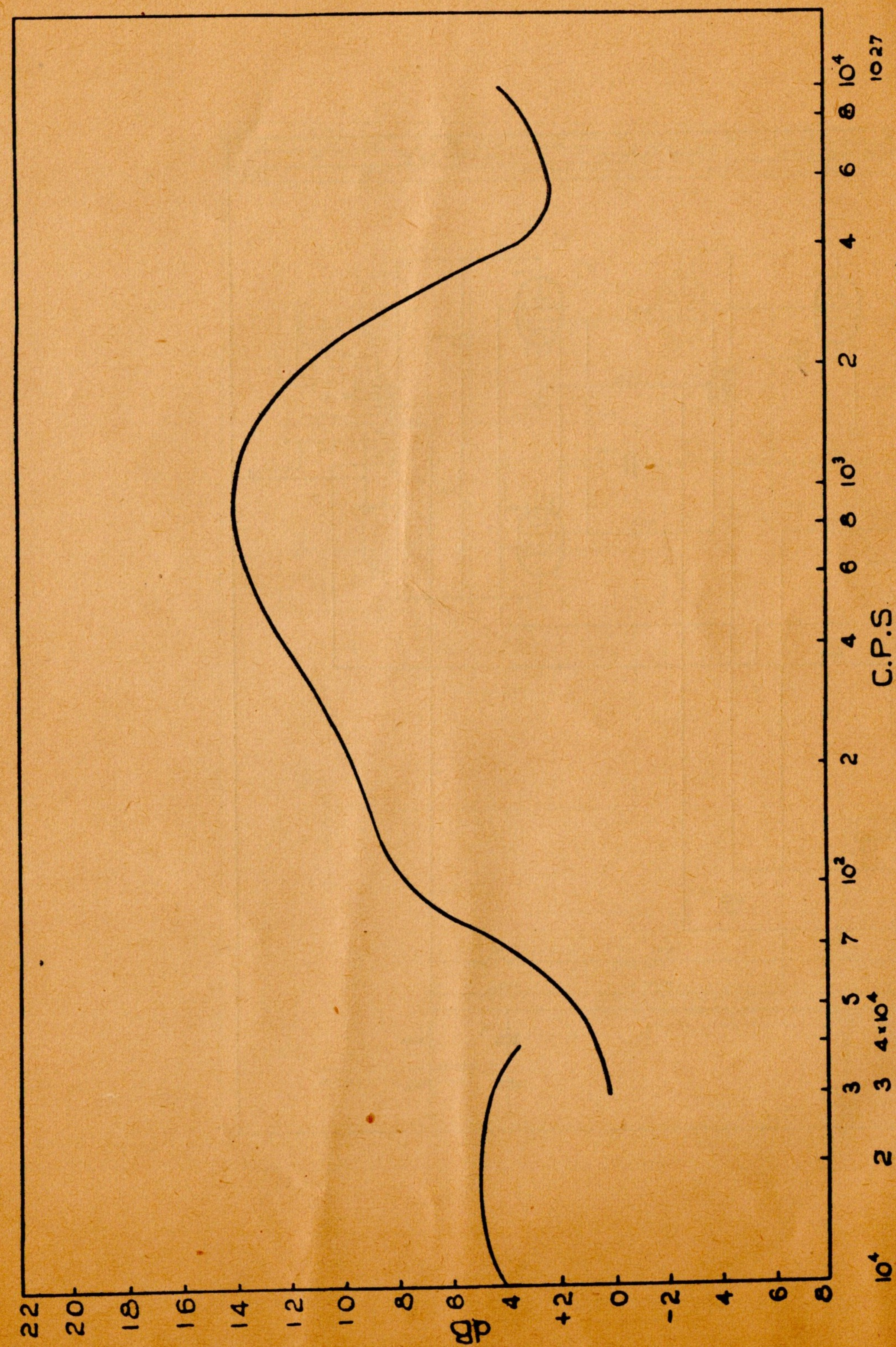

Fig. 4. Feedback (Tone control set for maximum high and low frequency response).

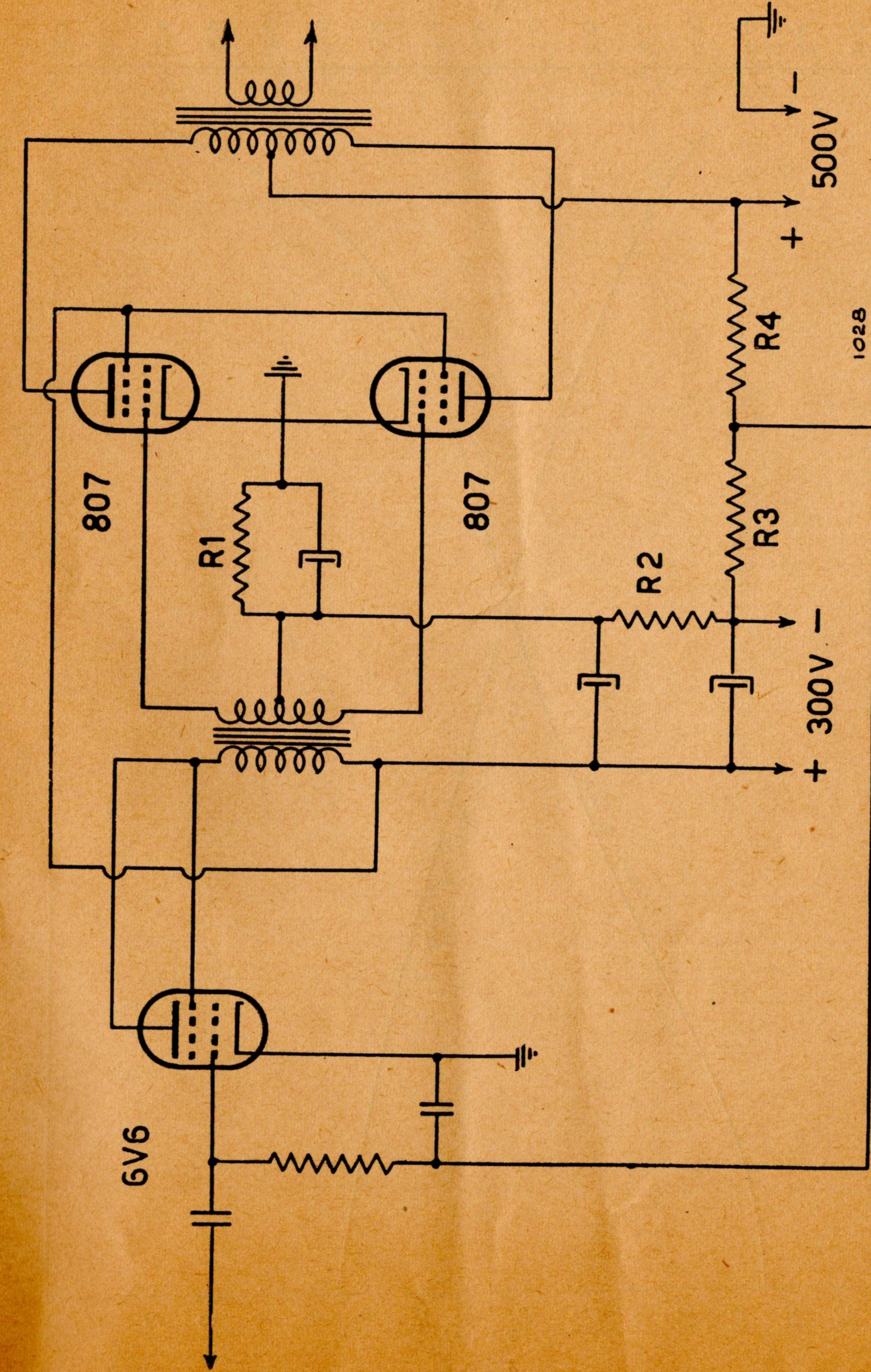

Fig. 5. Voltage stabilisation circuit.

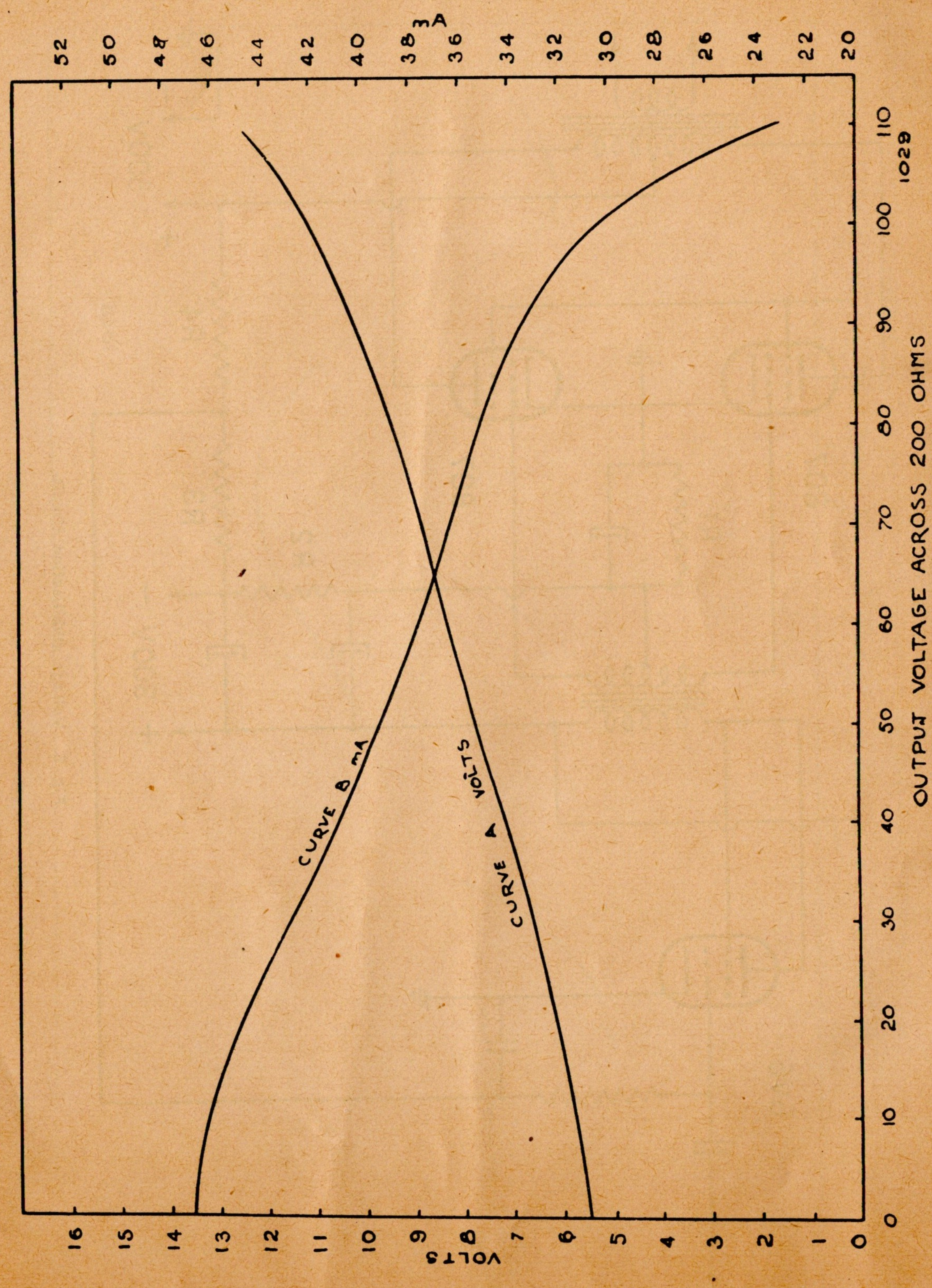

Fig. 6. Curve A, 6V6 Bias voltage. Curve B, 6V6 Cathode current.

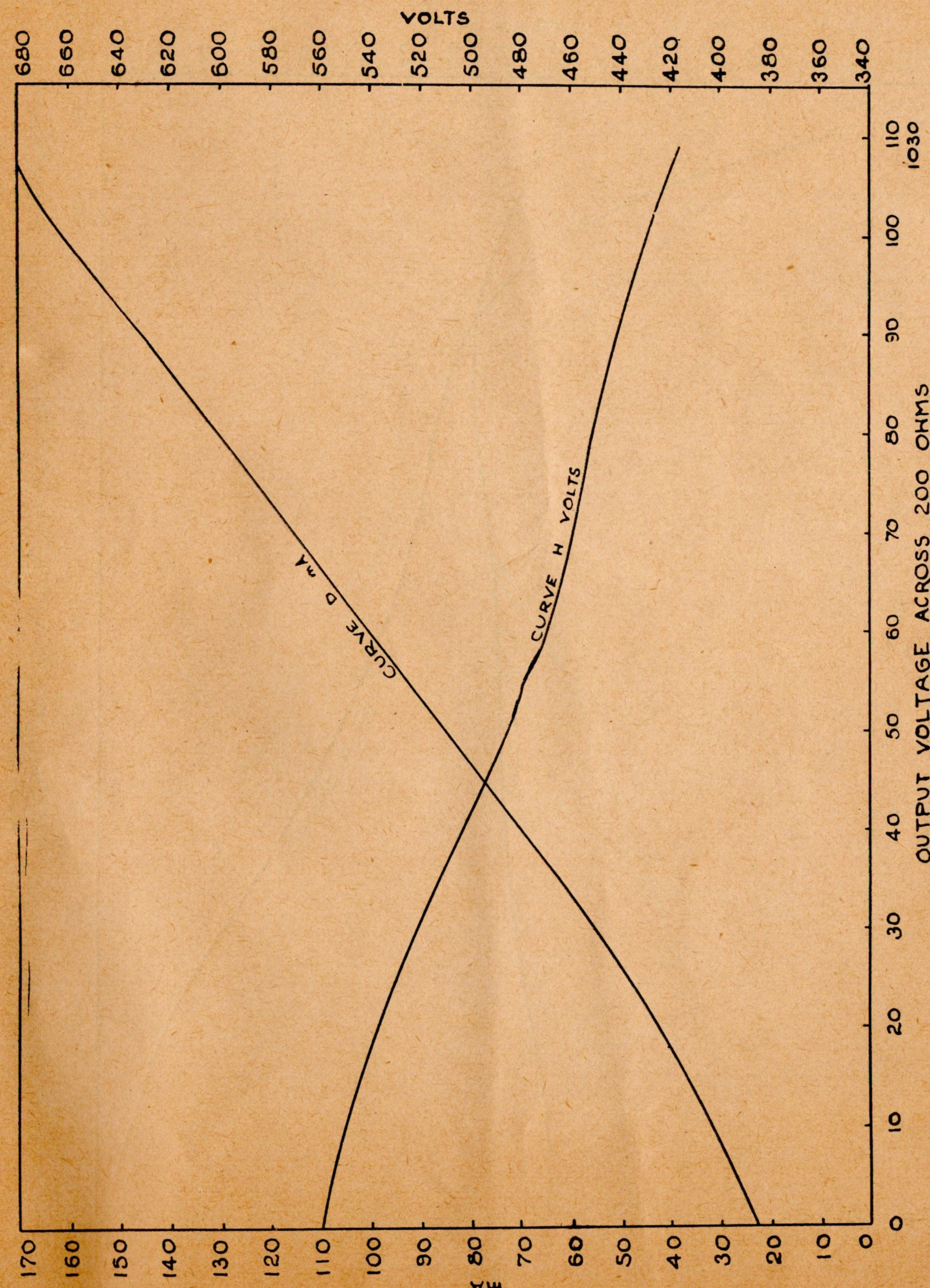

Fig. 7. Curve D, 807 Plate current. Curve H, 807 Plate voltage.

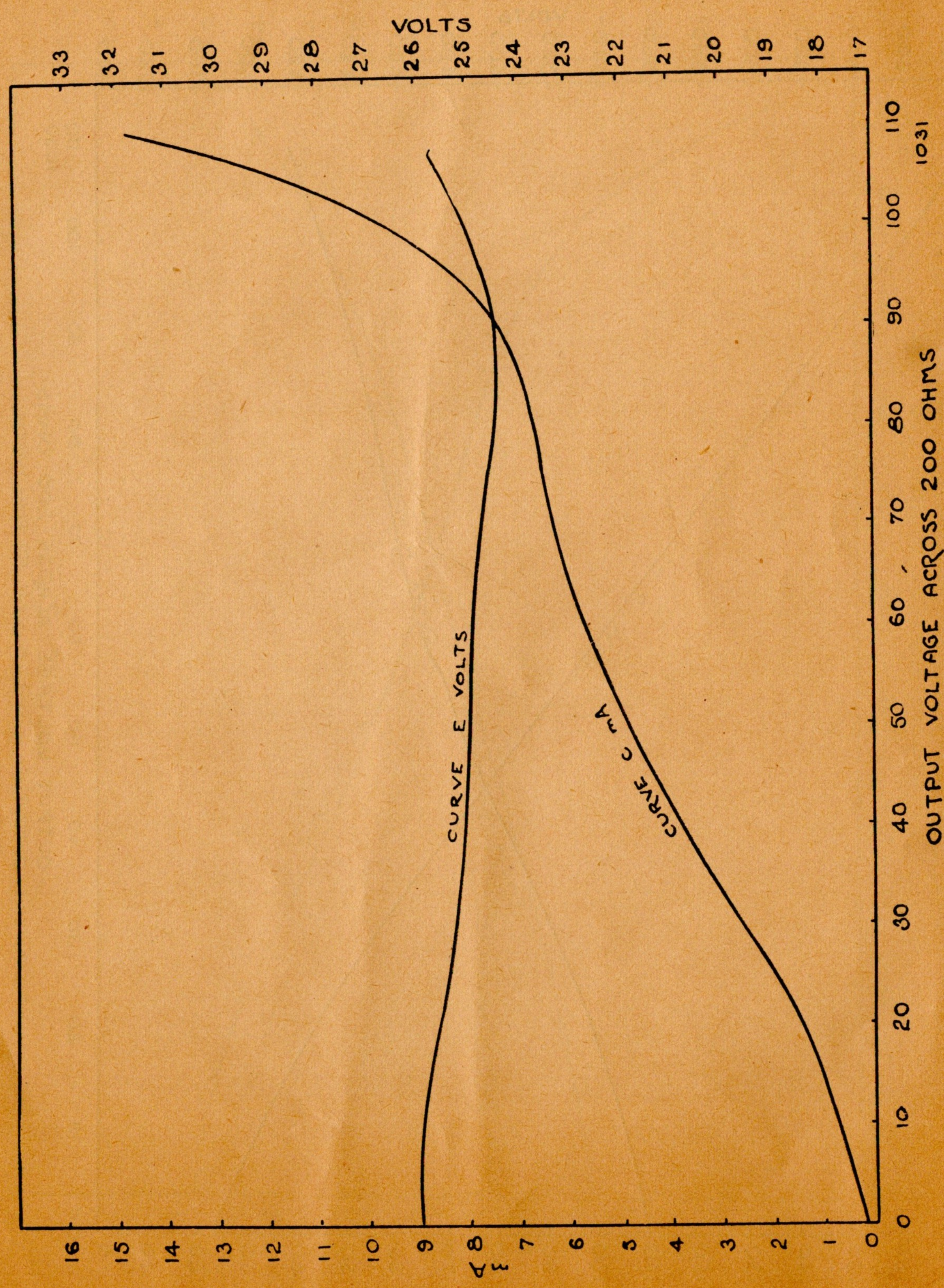

Fig. 8. Curve C, 807 Screen current. Curve E, 807 Bias voltage.

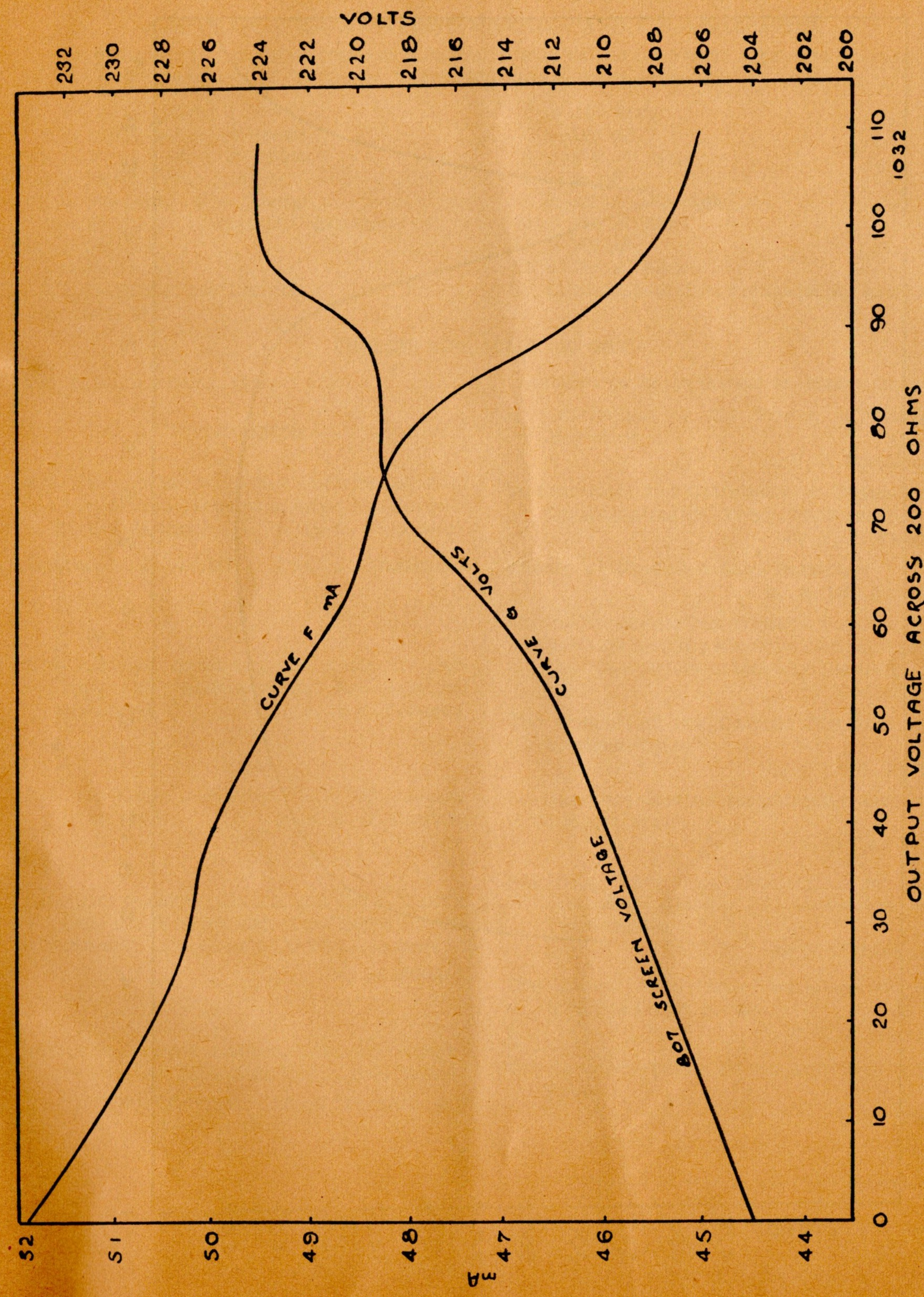

Fig. 9. Curve F, Current from low voltage supply. Curve G, Voltage of low voltage supply.

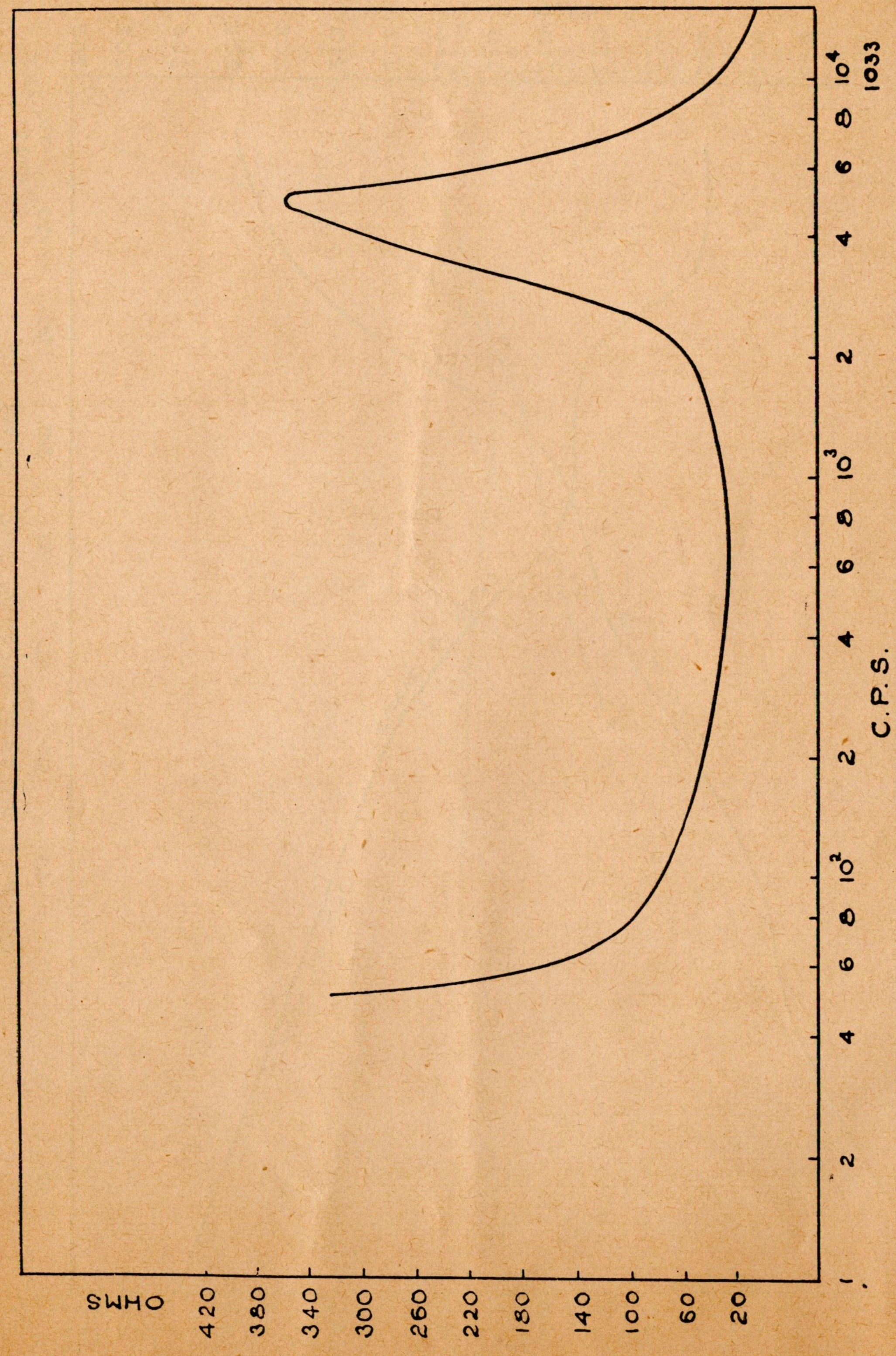

Fig. 10. Output Impedance.

A VERSATILE TRANSMITTING PENTODE AND ITS APPLICATION

In response to numerous requests a list of circuit values for Figure 1 printed on page 15 of the December issue of Technical Communication is given hereunder:

R1 = 50,000 Ohms 1 Watt
2 = 10,000 Ohms 10 Watts
3 = 25,000 Ohms 20 Watts
4 = 50,000 Ohms 1 Watt
5 = 500 Ohms Wire wound
6 = 50 Ohms 1 Watt Non-inductive
C1 = 250 pF
2 = 50 pF
3 = 0—30 pF Air trimmer
4 = 250 pF
5 = .005 Mica
6 = 100 pF
7 = .005 μF Mica
8 = 50 pF
9 = .01 μF, 600 Volts
10 = .005 μF Mica
11 = 100 pF
12 = .005 μF Mica
L1, L2 and L3—Adjust for frequency employed.

PHILIPS RESEARCH REPORTS

Vol. 1, No. 3. April, 1946.

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Articles to be published in future issues.

A contribution to the Theory of Acoustic Radiation
by C. J. Bouwkamp.

Measurement and Calculation of Unsharpness Combinations in X-ray Photography
by H. A. Klasens.

Theory of Grounded Grid Amplifiers
by A. van der Ziel.

On the Excitation Temperature, the Gas Temperature and the Electron Temperature in the High Pressure Mercury Discharge
by W. Elenbaas.

The Control of the Current Distribution in Electron Tubes
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