RCA MANUFACTURING COMPANY, INC.
A RADIO CORPORATION OF AMERICA SUBSIDIARY
Harrison, New Jersey

RCA RADIOTRON
DIVISION

APPLICATION NOTE No.54
December 20, 1935.

APPLICATION NOTE ON CLASS AB OPERATION OF TYPE 6F6 TUBES CONNECTED AS PENTODES

The operating conditions for obtaining optimum performance from two type 6F6 tubes when they are connected as pentodes and operated as a Class AB amplifier depend upon permissible distortion, desired power output, limitations of plate and screen dissipation, the efficiencies of available input transformers, and practical values of equivalent resistance in plate and screen circuits. The usual considerations for optimum Class AB operation are based on the assumption that the equivalent series resistance in the plate and screen circuits is nearly zero. Because this assumption is seldom justifiable in practice, it is the purpose of this Note to discuss the effect of plate and screen resistance on the operation of two type 6F6 tubes when they are connected as pentodes and operated as a Class AB amplifier.

Description of Circuit

Fig. 1 is the schematic diagram of the circuit used in these tests. A 6F6, connected as a triode, was used as a driver and was coupled to the output stage by means of a suitable interstage transformer. Power for plate and screen circuits was furnished by a high-voltage battery (E) of nearly zero resistance. The voltage of this battery and the current through the bleeder were adjusted before each test to give the voltages indicated on the diagram. The plate voltage for the driver and the screen voltage for the output tubes were obtained from the same point on the power-supply unit. The driver tube was self-biased throughout the tests; the bias for the output tubes was obtained either from a battery or from a self-biasing resistor, depending upon the nature of the test.

The circuit shown is similar to that used in practice. Resistor R_d may be replaced by a choke whose resistance equals R_d; resistor R_b represents the resistance of the power transformer, rectifier tube, and any choke that may be used in the first filter section. In general, however, the plate voltage of pentode output tubes need not be choke-filtered because of the high plate resistance of these types.

Plate and Screen Regulations

The total resistance in the plate circuit of the 6F6 output tubes consists of: (1) r_p, the plate resistance of the tubes; (2) R_p, the load resistance; (3) R_c, the series resistance common to grid and plate circuits; and (4) R_b, the equivalent series resistance of that section of the power-supply unit common to the plate circuit. The total resistance in the screen circuit consists of: (1) r_d, the screen-cathode resistance of the tubes; (2) R_c, the series resistance common to grid and plate circuits; and (3) R, the equivalent series resistance of the entire power-supply unit. It should be noted that R_c in self-biased circuits is the value of the bias resistor.

If a plate-voltage source of nearly zero resistance is used in place of a regular power-supply system, and if resistance is then introduced in series with this source until it has the same voltage regulation as the regular power-supply system, the resistance added to the source is the equivalent series resistance of the regular power supply. In practice, the equivalent series resistance is determined by measuring the slope of the line joining the voltage outputs at zero and maximum power output. These voltages correspond to minimum and maximum current drain. Referring to Fig. 1, it is noted that plate regulation is determined by measuring the voltage across points 1 and 2 corresponding to zero output and to maximum output; similarly, screen regulation is determined by measuring the voltages across points 3 and 2 for the same conditions.

It is evident that the screen regulation is always greater than the plate regulation in the circuit of Fig. 1. However, for the purpose of this Note, it is convenient to refer to plate regulation as the value of R_b and to screen regulation as the additional resistance R_d. This is also desirable from a practical point of view, since R_d usually represents the resistance of the field coil of a loudspeaker.

Description of Tests

With the circuit of Fig. 1, preliminary tests were conducted in order to determine the optimum input-transformer ratio and the optimum plate-to-plate load for both fixed- and self-bias conditions and for practical values of plate and screen regulation. The results of these tests show that the optimum plate-to-plate load is substantially independent of plate regulation, screen regulation, or the method of obtaining bias; the value of the load depends upon the power output desired, the permissible distortion, and the allowable plate and screen dissipation. The optimum input-transformer ratio was found to be dependent on plate and screen regulation and as to whether the bias is obtained from a battery or from a self-biasing resistor.

After optimum conditions for each test were determined, signal was applied to the input of the driver; the grids of the output tubes were driven positive during a portion of the input-voltage cycle in order to obtain high output. Power output, distortion, plate current, screen current, and control-grid current were then measured. In each test, maximum signal input to the driver was that which just caused driver grid current to flow.

(A) Fixed-Bias Operation

The curves of Fig. 2 show the variation of screen current, plate current, control-grid current, and distortion vs. power output for two operating conditions: (1) zero plate regulation and zero screen regulation; and (2) 1000-ohm plate regulation and 2000-ohm screen regulation. The control-grid bias was fixed throughout this test. As mentioned previously, a different optimum input-transformer ratio was required for each operating condition; these optimum ratios are shown in the figure and in the Summary Table.

Curves for conditions (1) and (2) show that the same power output (approximately 19 watts at 5 per cent distortion) can be obtained from either operating condition if the input-transformer ratio is optimum in each case. The data in Fig. 2 and in the Summary Table also show that driver grid current started to flow with a smaller input signal in (2) than in (1), even though the maximum power output was the same for each test. This is due, of course, to the effect of the screen regulation (R_d) in reducing the driver plate voltage and, hence, the driver bias.

(B) Self-Bias Operation

The results of the self-bias test, shown by curves for conditions (1) and (2), in Fig. 3, indicate that approximately 17 to 19 watts at 5 per cent distortion can be realized if the input-transformer ratio is optimum for each operating condition. The plate and the screen current are independent of plate and screen regulation, although the distortion for a given power output is dependent upon regulation.

Comparing these curves with those of Fig. 2, it is seen that the rise in cathode current was less for self- than for fixed-bias operation and that the effect of regulation was to reduce the optimum power output from 19.4 to 17.1 watts, a decrease of only about 12 per cent. The introduction of regulation in the fixed-bias test did not change the power output.

Harmonic Distortion

A harmonic analysis of the output obtained from the set-up of test (B), was made in order to ascertain the nature of the distortion present for a practical operating condition. The optimum plate-to-plate load was 10,000 ohms, the input transformer ratio was 1.74, the tubes were completely self-biased, and plate and screen regulation were 1000 and 2000 ohms, respectively. The results are shown in Fig. 4. Only second and third harmonics are present at low signal levels, after which fifth, seventh, ninth, and eleventh harmonics appear. At high signal levels, high-order odd harmonics form an appreciable part of the total distortion. The lack of high-order even harmonics is due, of course, to the cancellation of these harmonics in the plate circuit of the push-pull stage. The second harmonic shown is introduced by the driver stage; a smaller driver will increase this distortion for the same power output.

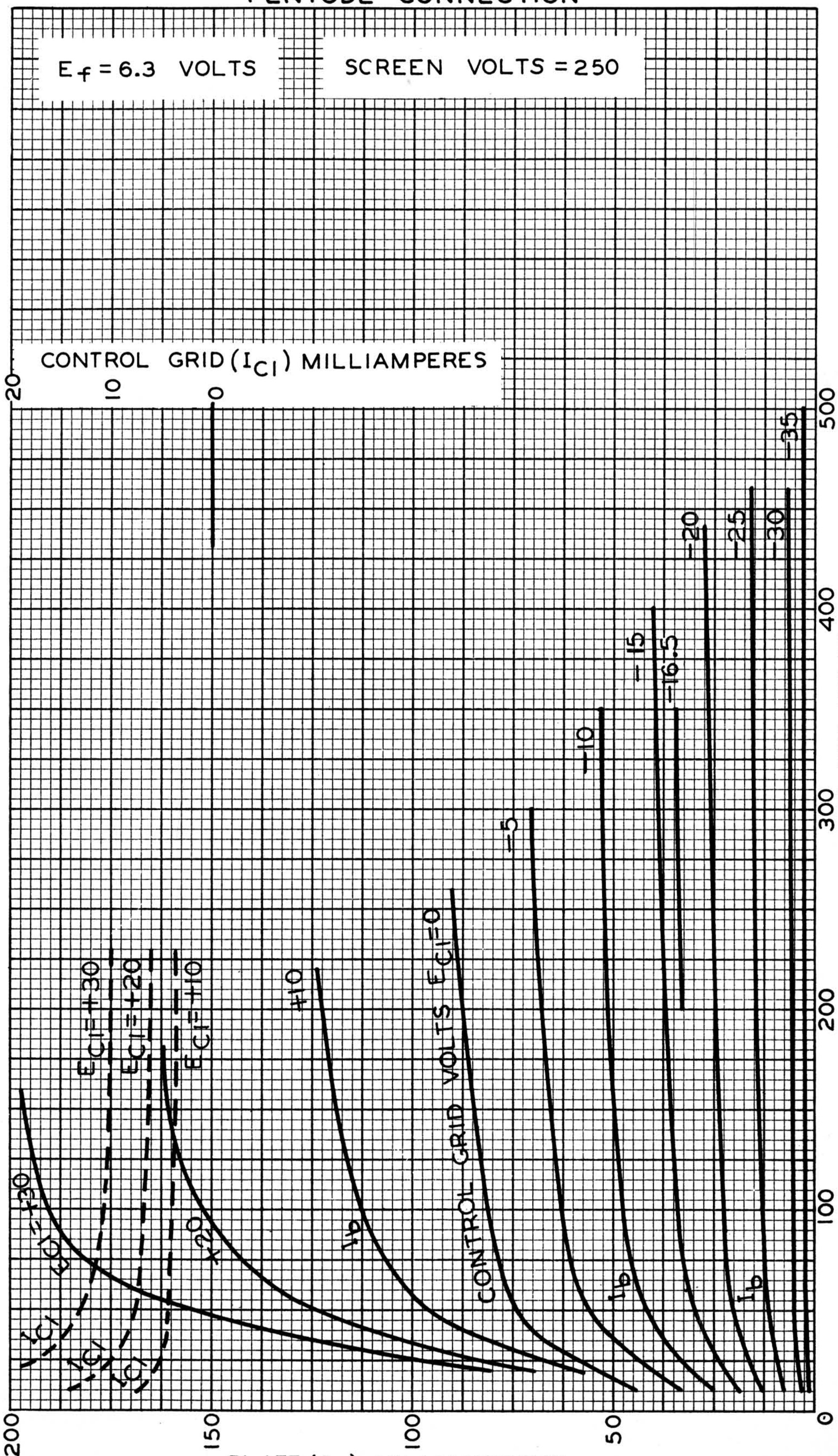
Conclusion

Two 6F6's when connected as pentodes in a push-pull circuit and operated beyond the grid-current point, can provide power outputs up to approximately 19 watts at 5 per cent distortion; the actual output depends upon the regulation of the plate and the screen power supply and the method of obtaining bias. It should also be noted that approximately 8 watts output can be obtained before high-order distortion appears; at this output, the total distortion is approximately 2 per cent.

The efficiency of the input transformer used in these tests is typical of the average transformer and is listed for each test in the Summary Table. It must be remembered, however, that the leakage inductance of this transformer should be small at all times, regardless of its efficiency as a power-transferring device. The ratio of the input transformer was optimum in each test; any serious deviation from the optimum ratios will result in either less power output or increased distortion.

RCA-6F6

AVERAGE PLATE CHARACTERISTICS
PENTODE CONNECTION



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SUMMARY TABLE

CLASS AB OPERATION OF TYPE 6F6 TUBES (PENTODE CONNECTED)

INDEX	DRIVER STAGE[1]				INTERSTAGE TRANSFORMER[2]		OUTPUT STAGE[3]											
	Tube Type	Input-Signal Volts (RMS)	Plate Load Ohms	Max. Power Output Milliwatts	Primary / 1/2 Secondary	Peak Power Efficiency Per Cent	Resistance (R_b) of Plate-Supply Source Ohms	Additional Resistance (R_d) of Screen Supply Ohms	Grid-Supply Resistance (R_c) Ohms	Grid-Input Peak Power Milliwatts	Grid-Input Peak Voltage Volts (per tube)	D-C Grid Current Milliamperes (per tube)	Zero-Signal D-C Plate Current Milliamperes (per tube)	Max.-Signal D-C Plate Current Milliamperes (per tube)	Zero-Signal D-C Screen Current Milliamperes (per tube)	Max.-Signal D-C Screen Current Milliamperes (per tube)	Power Output Watts (2 tubes)	Total Harmonic Distortion Per Cent
Fig.2	6F6#	14.5	58500	290	3.33:1.0	40.3	0	0	0*	117	37.3	0.65	17	41.5	2.5	8.0	18.5	4.9
Fig.2	6F6#	10.1	21800	288	1.54:1.0	73.5	1000	2000	0*	210	47.4	1.2	17	39.5	2.5	8.0	18.5	5.1
Fig.3	6F6#	14.6	51100	365	2.50:1.0	47.7	0	0	340	174	52.3	0.9	27	39.5	4.0	8.5	19.4	5.1
Fig.3	6F6#	10.3	33100	261	1.74:1.0	64.4	1000	2000	340	168	50.5	1.0	27	37.5	4.0	7.5	17.1	5.0

Screen connected to plate. * Fixed bias of -26 volts.

[1] Zero-signal plate voltage, 250 volts; zero-signal plate current, 31 ma.; self-bias resistor, 650 ohms; plate resistance (rp), 2600 ohms.

[2] Primary resistance, 1000 ohms; secondary resistance, 400 ohms each half; equivalent core loss resistance, 100000 ohms.

[3] Zero-signal plate voltage, 375 volts; zero-signal screen voltage, 250 volts; plate-to-plate load, 10000 ohms.

SCHEMATIC DIAGRAM OF TEST CIRCUIT FOR 6F6'S OPERATED AS CLASS AB PENTODES

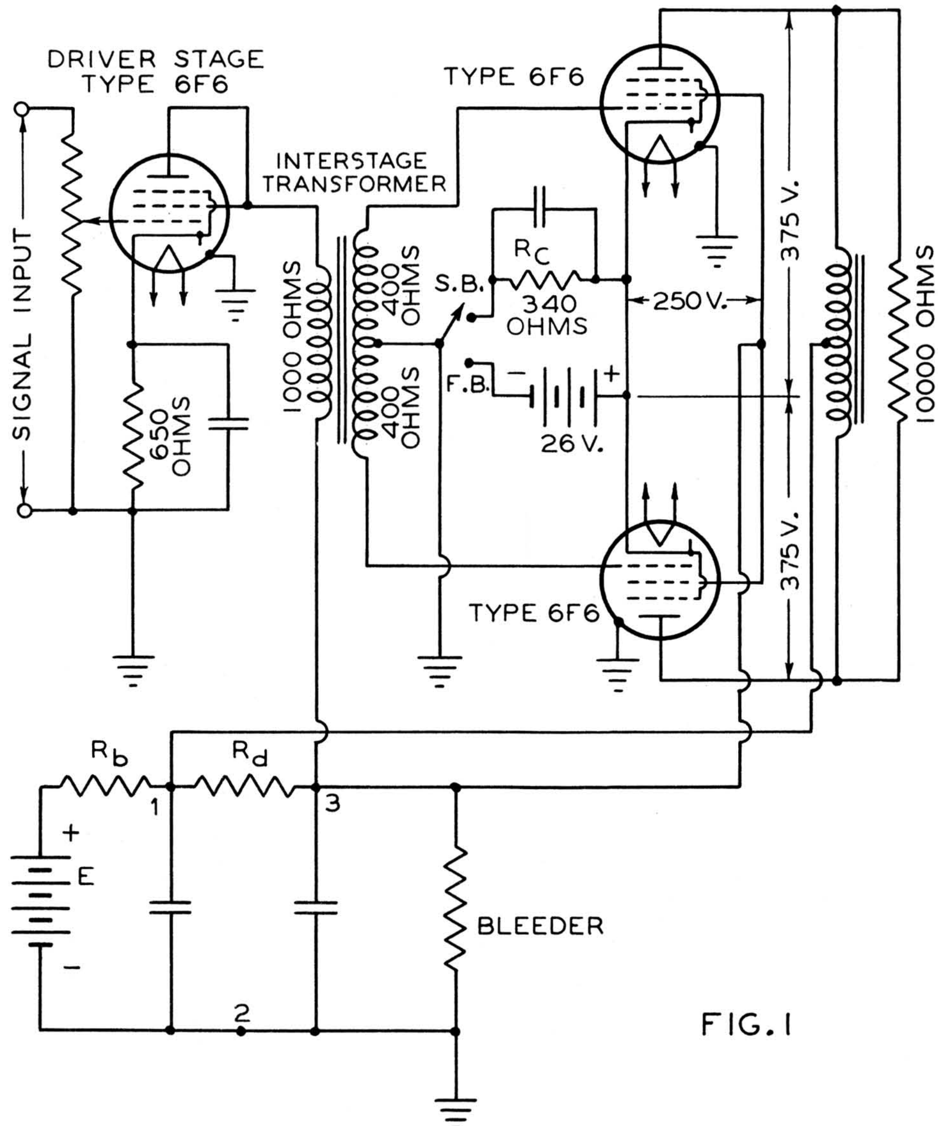

FIG. 1

S.B. = SELF-BIAS CONNECTION

F.B. = FIXED-BIAS CONNECTION

R_b = EQUIVALENT SERIES RESISTANCE OF POWER-SUPPLY IN PLATE CIRCUIT

R_d = ADDITIONAL EQUIVALENT SERIES RESISTANCE OF POWER-SUPPLY IN SCREEN CIRCUIT

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OPERATION CHARACTERISTICS

PENTODE CONNECTION-CLASS AB OPERATION

E_f = 6.3 VOLTS

INPUT STAGE: CLASS A DRIVER-ONE TYPE 6F6 AS TRIODE
PLATE VOLTS = 250
SELF-BIAS RESISTOR = 650 OHMS

OUTPUT STAGE: CLASS AB-TWO TYPE 6F6'S AS PENTODES
ZERO-SIGNAL PLATE VOLTS = 375, FROM SOURCE HAVING RESISTANCE (R_b) SHOWN IN TABLE
ZERO-SIGNAL SCREEN VOLTS = 250, FROM THE ABOVE 375-VOLT PLATE SUPPLY THROUGH RESISTANCE (R_d) SHOWN IN TABLE
ZERO-SIGNAL BIAS VOLTS = -26, FROM GRID-BIAS SUPPLY HAVING ZERO RESISTANCE
OUTPUT LOAD, PLATE TO PLATE = 10000 OHMS

CONDI-TION	CURVE	R_b Ohms	R_d Ohms	DRIVER STAGE: Input-Sig. Volts* (RMS)	DRIVER STAGE: Plate Load Ohms	INTERSTAGE TRANSFORMER: Voltage Ratio Prim.:1/2 Sec.	Peak Power Efficiency %
1	solid	0	0	14.5	58500	3.33:1	40.3
2	dashed	1000	2000	10.1	21800	1.54:1	73.5

* For maximum output

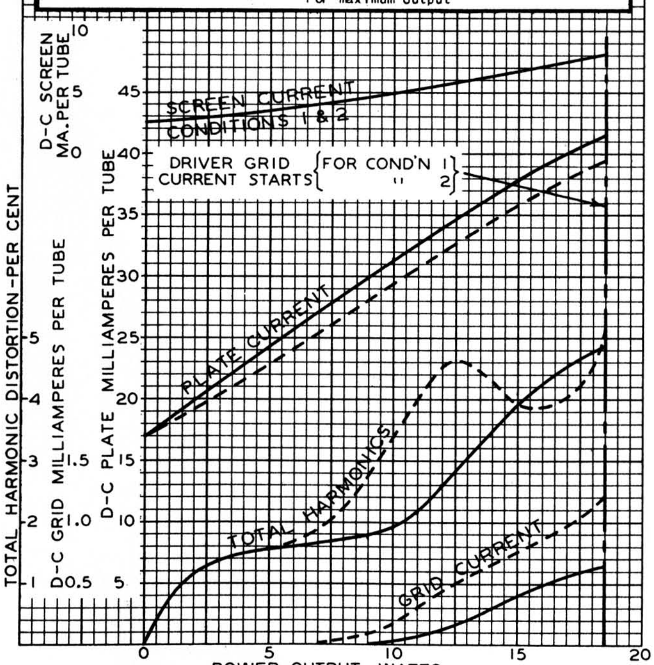

FIG.2

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OPERATION CHARACTERISTICS

PENTODE CONNECTION-CLASS AB OPERATION

E_f = 6.3 VOLTS

INPUT STAGE: CLASS A DRIVER-ONE TYPE 6F6 AS TRIODE
PLATE VOLTS = 250
SELF-BIAS RESISTOR = 650 OHMS

OUTPUT STAGE: CLASS AB-TWO TYPE 6F6'S AS PENTODES
ZERO-SIGNAL PLATE VOLTS = 375 FROM SOURCE HAVING RESISTANCE (R_b) SHOWN IN TABLE
ZERO-SIGNAL SCREEN VOLTS = 250, FROM THE ABOVE 375-VOLT PLATE SUPPLY THROUGH RESISTANCE (R_d) SHOWN IN TABLE
ZERO-SIGNAL BIAS VOLTS = VALUE FROM GRID-BIAS RESISTOR (R_C) OF 340 OHMS
OUTPUT LOAD, PLATE TO PLATE = 10000 OHMS

CONDI-TION	CURVE	R_b Ohms	R_d Ohms	DRIVER STAGE: Input-Sig. Volts* (RMS)	DRIVER STAGE: Plate Load Ohms	INTERSTAGE TRANSFORMER: Voltage Ratio Prim.:1/2 Sec.	Peak Power Efficiency %
1	solid	0	0	14.6	51100	2.50:1	47.7
2	dashed	1000	2000	10.3	33100	1.74:1	64.4

* For maximum output

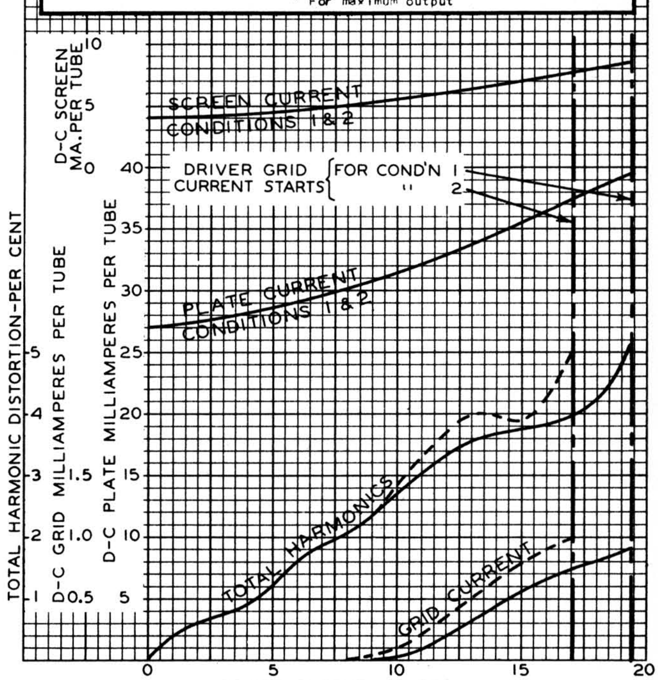

FIG.3

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OPERATION CHARACTERISTICS
PENTODE CONNECTION-CLASS AB OPERATION

E_f = 6.3 VOLTS

INPUT STAGE: CLASS A DRIVER-ONE TYPE 6F6 AS TRIODE
PLATE VOLTS = 250
SELF-BIAS RESISTOR = 650 OHMS

OUTPUT STAGE: CLASS AB-TWO TYPE 6F6'S AS PENTODES
ZERO-SIGNAL PLATE VOLTS = 375, FROM SOURCE HAVING RESISTANCE (R_b) SHOWN IN TABLE
ZERO-SIGNAL SCREEN VOLTS = 250, FROM THE ABOVE 375-VOLT PLATE SUPPLY THROUGH RESISTANCE (R_d) SHOWN IN TABLE
ZERO-SIGNAL BIAS VOLTS = VALUE FROM GRID-BIAS RESISTOR (R_c) OF 340 OHMS
OUTPUT LOAD, PLATE TO PLATE = 10000 OHMS

R_b Ohms	R_d Ohms	DRIVER STAGE		INTERSTAGE TRANSFORMER	
		Input-Signal Volts* (RMS)	Plate Load Ohms	Voltage Ratio Prim.:1/2 Sec.	Peak Power Efficiency - %
1000	2000	10.3	33100	1.74:1	64.4

* For maximum output

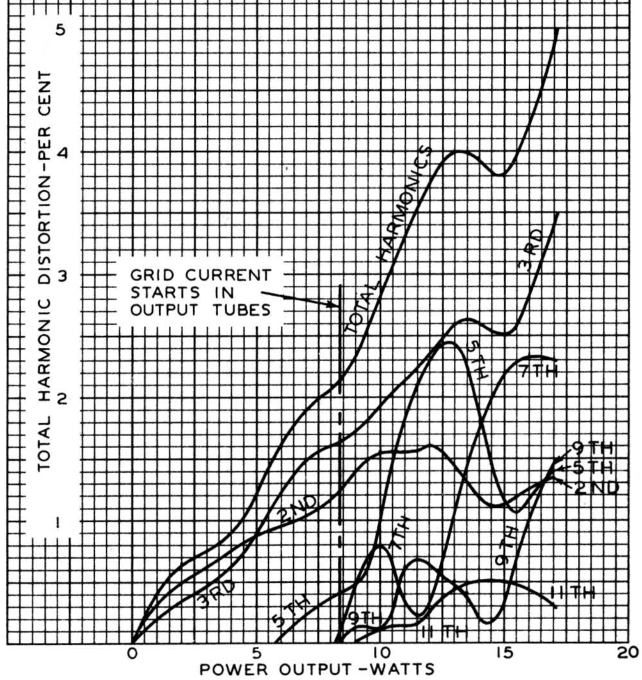

FIG.4