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THE CONVERSION OF A 6L6 PLATE FAMILY TO NEW SCREEN VOLTAGE CONDITIONS

In order to determine the performance of a tetrode or pentode from its plate characteristics it is necessary to have a suitable plate family for every screen voltage of interest. The well-known Conversion-Factor Chart (see loose-leaf sheet) can be used to convert a tetrode or pentode plate family to new screen-voltage conditions. However, when the Chart is used for this purpose, the useful range of a converted plate family is curtailed for decreases in screen voltage; moreover, the accuracy of the converted family is good only for small changes in screen voltage. When the Chart is used to convert the plate family of the usual tetrode to a new screen-voltage condition, only sections of high plate voltage should be converted, because of errors introduced at low plate voltages by secondary-emission effects.

Although the 6L6 is a tetrode, it may be operated at low plate and control-grid voltages without secondary-emission effects; consequently, the Conversion-Factor Chart may be applied to a 6L6 plate family, provided the range of the converted family is large enough for the purpose and the change in screen voltage is relatively small. This Bulletin describes a method of conversion that produces a plate family whose useful range is not decreased by the conversion. The accuracy of the converted family, even for large changes in screen voltage, is high enough for most applications.

PRINCIPLE OF METHOD

The potential distribution within a tetrode or pentode of given physical structure depends on the voltages applied to the various electrodes. Multiplying all the electrode voltages by the same factor will not change the relative distribution of electrode potentials within the valve. Because the electrode currents in tetrodes and pentodes depend on the potential distribution between cathode and plate, the ratio of the several

electrode currents to each other does not change when all the electrode voltages are multiplied by the same factor, provided space-charge effects change in proportion to the change in voltage. For example, a given family of plate characteristics obtains for a screen voltage (E_{c_2}) of 250 volts; the per cent change in plate current for a change in bias is the same for a screen voltage of 300 volts if the plate-voltage scale and grid-bias parameters are multiplied by $300/250 = 1.2$. The effects of contact potential are not considered in this Bulletin; however, they become serious only for small control-grid bias voltages.

Fig. 2 is the plate family of a 6L6 for a screen voltage of 250 volts. At any plate voltage, the ratio of the plate current (I_b) at a given control-grid bias to the plate current at zero bias does not change when the screen voltage is changed, provided the plate-voltage scale and grid-bias parameters are multiplied by the factor E_{c_2} (new)/250 and operation is confined to regions in which space charge does not control the plate current. In order to convert a given plate family to a new screen-voltage condition, therefore, it is only necessary to have a zero-bias plate characteristic for the screen voltage of interest. A family of such characteristics for the 6L6 is shown in Fig. 1.

EXAMPLE OF CONVERSION

Suppose that the family of plate characteristics shown in Fig. 2, which obtains for a screen voltage of 250 volts, is to be converted for a screen voltage of 300 volts. The zero-bias plate characteristic for $E_{c_2} = 300$ volts, which is shown in Fig. 1, is replotted, as at top in Fig. 3.
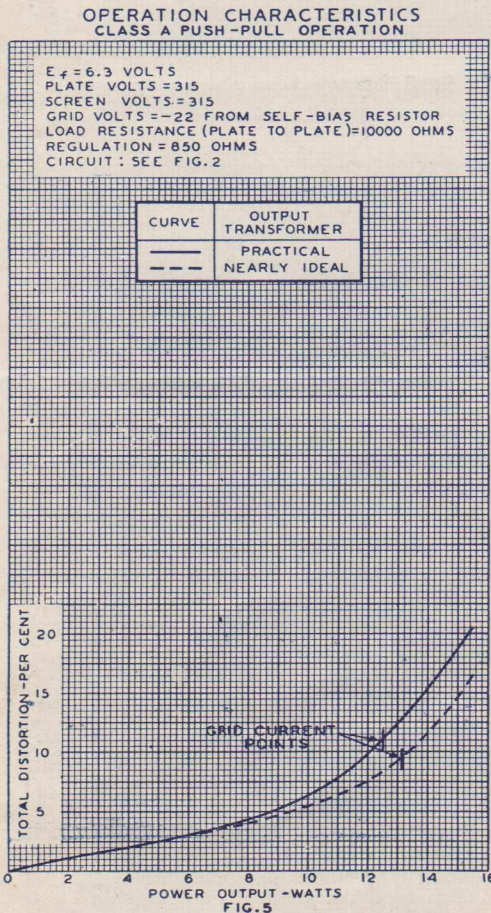
Since all bias values shown in Fig. 2 must be multiplied by $300/250 = 1.2$, corresponding plate characteristics for the new family obtain for bias values that are 20 per cent higher than those shown in Fig. 2. Consider the conversion of the -10-volt characteristic of Fig. 2. At a plate voltage (E_b) of 250 volts in Fig. 2, $AB/AC = 100/187 = 0.535$. On the new characteristic in Fig. 3, which corresponds to a bias of -12 volts, A^1B^1/A^1C^1 must also equal 0.535 at $E_b = 300$ volts. Therefore, $A^1B^1 = 0.535 \times A^1C^1$. From the given zero-bias characteristic of Fig. 3, $A^1C^1 = 244$ at $E_b = 300$ volts; hence, $A^1B^1 = 131$ milliamperes. At $E_b = 200$ volts in Fig. 2, $DE/DF = 98/183 = 0.535$. Therefore, at $E_b = 200 \times 1.2 = 240$ volts in Fig. 3, $D^1E^1 = 0.535 \times 238 = 127$ milliamperes. This process is repeated for a number of plate voltages and a smooth curve is drawn through the points on the new characteristic.

The factor 0.535 can be used for the -10-volt characteristic at plate voltages greater than that at which the knee on the zero-bias characteristic of Fig. 2 occurs; for plate voltages in the immediate region of the knee, a new factor should be determined for each point. The plate characteristics of Fig 2 should not be converted to the left of the dashed line of Fig. 2 because of space-charge effects. This limitation is not a serious one, however, because the region over which the valve usually operates can be converted with sufficient accuracy for most applications. The converted plate characteristic of Fig. 3 for $E_{c_1} = $ -30 volts was obtained in a similar manner to that for $E_{c_1} = $ -12 volts. The curves of figure 3 were checked under dynamic conditions by means of a cathode-ray tube. The dotted portions show regions where measured results departed from calculated results. Because the usual load line does not pass through regions in which plate current is affected by space charge, the calculated and measured curves yield nearly the same dynamic characteristics.
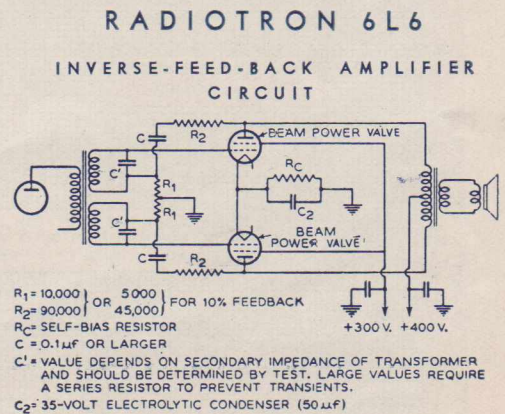
DETERMINATION OF APPROXIMATE OPERATING CONDITIONS

The curves of Fig. 2 are useful in estimating approximate operating conditions for various plate and screen voltages, control-grid biases, and load resistances. For single valve operation, a load line should intersect the zero-bias plate characteristic in the vicinity of the knee; the plate current at which this intersection occurs should be approximately twice the d-c plate current. The load line should also pass through the no-signal plate-current point.

For example, a power supply is capable of furnishing 250 volts at approximately 40 milliamperes. What screen voltage, load, and bias are required for optimum output? The load should intersect a zero-bias characteristic near its knee at a plate current of approximately 75 milliamperes. From Fig. 1, this intersection occurs at a screen voltage of 150 volts and at a plate voltage of 40 volts, as shown. Therefore, the load resistance should be $(250-40)/(0.075-0.04) = 6000$ ohms. The power output is approximately $\frac{1}{2}(250-40)(0.075-0.04) = 3.6$ watts. The bias is easily determined by experiment or by converting the plate family to the new screen-voltage condition, from which low-order distortion components may be calculated. Some slight corrections will be necessary to account for rectification and for the assumed approximations. For push-pull Class A operation, the plate-to-plate load is twice that of a single valve; the power output is approximately twice that obtained from a single valve; the bias and the screen voltage are the same as those of a single valve.
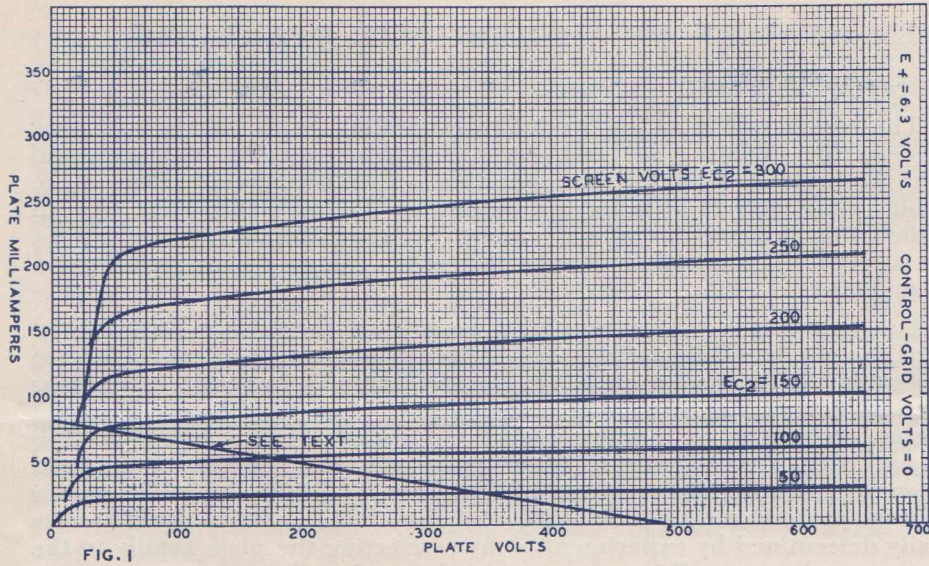
OPERATION CHARACTERISTICS
CLASS A PUSH-PULL OPERATION

RADIOTRON 6F6
(REFER PAGE 6)

$E_f = 6.3$ VOLTS
PLATE VOLTS = 315
SCREEN VOLTS = 315
GRID VOLTS = -22 FROM SELF-BIAS RESISTOR
LOAD RESISTANCE (PLATE TO PLATE) = 10000 OHMS
REGULATION = 850 OHMS
CIRCUIT : SEE FIG. 2

CURVE	OUTPUT TRANSFORMER
———	PRACTICAL
- - -	NEARLY IDEAL

GRID CURRENT POINTS

TOTAL DISTORTION - PER CENT
POWER OUTPUT - WATTS
FIG. 5

RADIOTRON 6L6

INVERSE-FEED-BACK AMPLIFIER CIRCUIT

$R_1 = 10,000$ OR 5000 FOR 10% FEEDBACK
$R_2 = 90,000$ OR 45,000
R_C = SELF-BIAS RESISTOR
$C = 0.1\mu F$ OR LARGER
C' = VALUE DEPENDS ON SECONDARY IMPEDANCE OF TRANSFORMER AND SHOULD BE DETERMINED BY TEST. LARGE VALUES REQUIRE A SERIES RESISTOR TO PREVENT TRANSIENTS.
C_2 = 35-VOLT ELECTROLYTIC CONDENSER $(50\mu F)$

+300 V. +400 V.

RADIOTRON 6L6 CHARACTERISTICS

AVERAGE PLATE CHARACTERISTICS
WITH EC2 AS VARIABLE

Ef = 6.3 VOLTS   CONTROL-GRID VOLTS EC1 = 0

FIG. 1

AVERAGE PLATE CHARACTERISTICS
WITH EC1 AS VARIABLE

Ef = 6.3 VOLTS   SCREEN VOLTS (EC2) = 250

NOTE:- DO NOT CONVERT
CURVES TO THE LEFT
OF THIS BOUNDARY

FIG. 2

PLATE CHARACTERISTICS OBTAINED
BY CONVERSION

Ef = 6.3 VOLTS   SCREEN VOLTS (EC2) = 300

—— CALCULATED
---- MEASURED

LOAD PER TUBE FOR EFFECTIVE PLATE-TO-PLATE
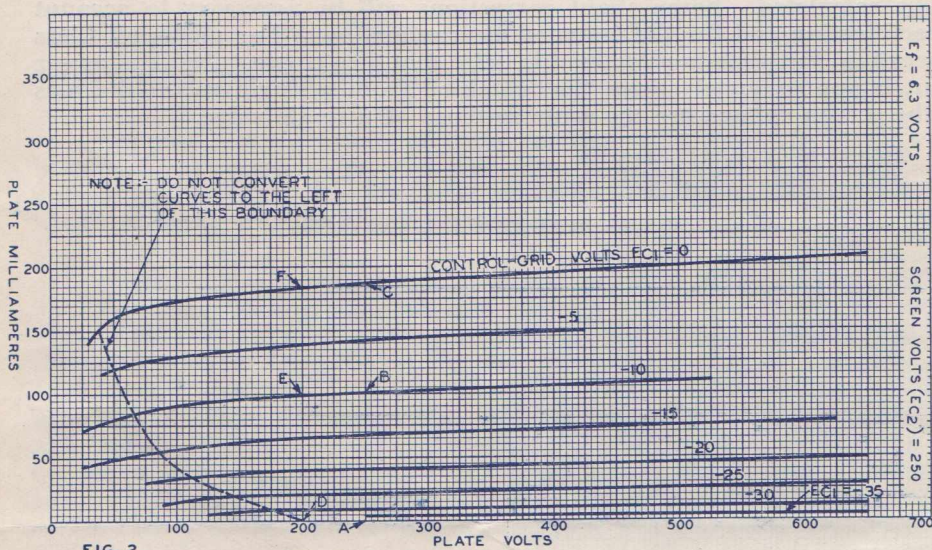LOAD OF 6600 OHMS WITH Eb = 400 VOLTS, EC2 = 300
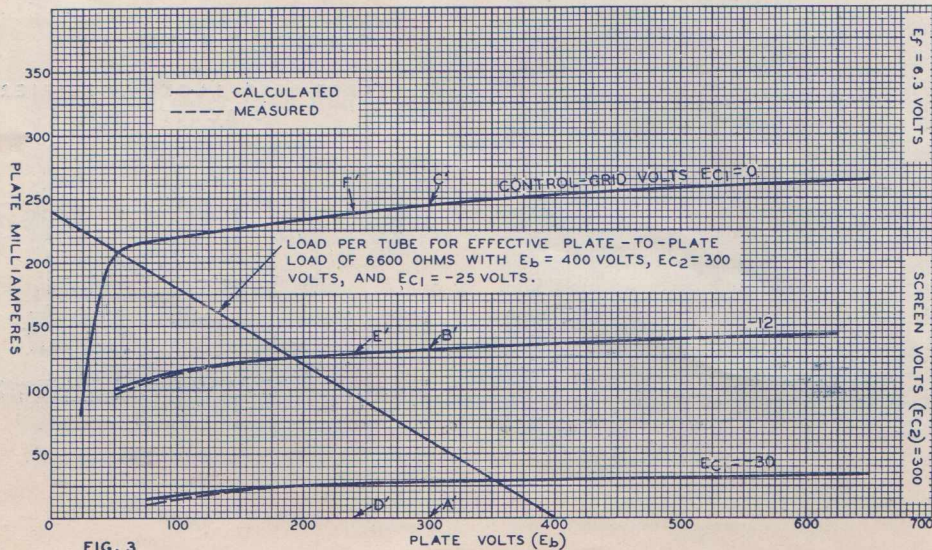VOLTS, AND EC1 = -25 VOLTS.

FIG. 3

RADIOTRON 6F6
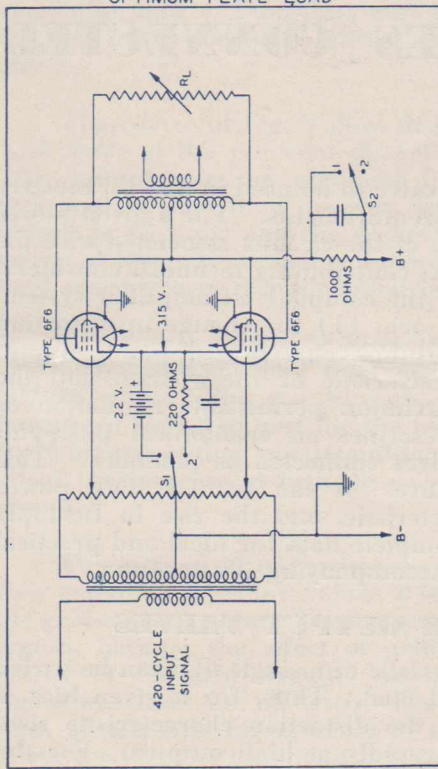
CIRCUIT USED FOR DETERMINATION OF OPTIMUM PLATE LOAD

CIRCUIT USED FOR DETERMINATION OF PRACTICAL OPERATING CONDITIONS
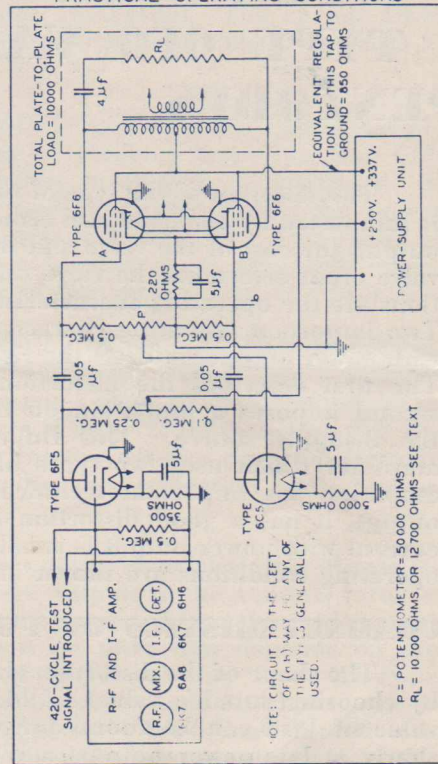
FIG 1

FIG. 2

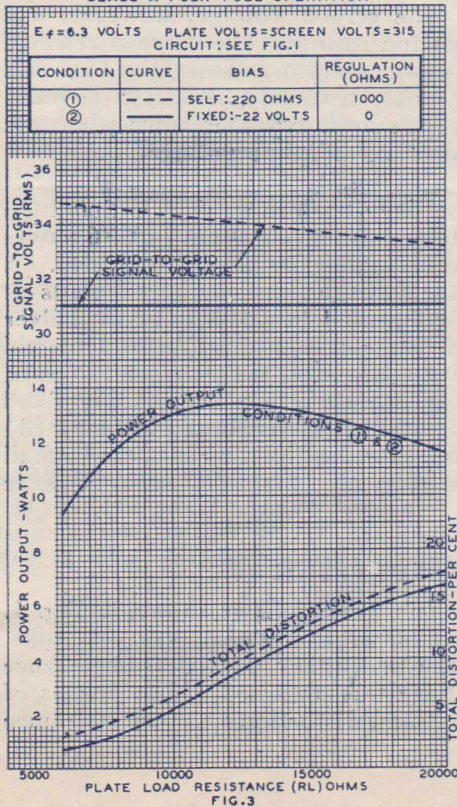### OPERATION CHARACTERISTICS
CLASS A PUSH-PULL OPERATION

E_f = 6.3 VOLTS   PLATE VOLTS = SCREEN VOLTS = 315
CIRCUIT: SEE FIG.1

CONDITION	CURVE	BIAS	REGULATION (OHMS)
①	– – –	SELF: 220 OHMS	1000
②	———	FIXED: –22 VOLTS	0

FIG.3

OPERATION CHARACTERISTICS
CLASS A PUSH-PULL OPERATION

E_f = 6.3 VOLTS   PLATE VOLTS = SCREEN VOLTS = 315
LOAD RESISTANCE (PLATE TO PLATE) = 10000 OHMS
CIRCUIT: SEE FIG.1

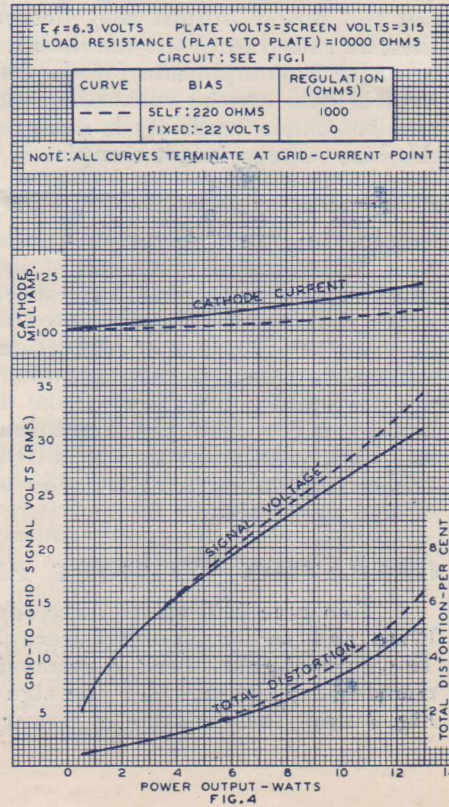| CURVE	BIAS	REGULATION (OHMS)
– – –	SELF: 220 OHMS	1000
———	FIXED: –22 VOLTS	0

NOTE: ALL CURVES TERMINATE AT GRID-CURRENT POINT

FIG.4

NEW OPERATING CONDITION FOR TWO TYPE 6F6 VALVES CONNECTED AS PENTODES

The selection of the type of output valve to be used in a radio receiver is influenced by technical and economic requirements. For a given power output, the cost of the valve and the cost of the circuits associated with the valve often determine the valve selection; contributing technical considerations are the operating characteristics of the complete a-f amplifier system. Two important operating characteristics are: (1) the change in distortion with power output, and (2) the rise in B-supply current with power output. The first describes the distortion characteristic of the system, and the second imposes a limitation on the maximum permissible regulation of the B-supply source. This Bulletin describes an economical push-pull amplifier which uses two types 6F6 valves connected as pentodes. This amplifier has important technical features: it can furnish high power output, it has a good distortion characteristic, and the rise in B-supply current with power output is small. Complete data for ideal and practical operating conditions are shown in the accompanying illustrations.

CHARACTERISTICS OF POWER OUTPUT VALVES

The shape of the distortion characteristic of a single 6F6 can be varied by choosing suitable values of bias and load. Thus, for a given bias, a value of load can be found for which the distortion characteristic rises slowly at low power outputs and very rapidly at high outputs. For the same bias, a more slowly rising distortion characteristic can be obtained with another value of load. As the bias is increased, it is necessary to increase the load resistance in order to reduce distortion. The efficiency of the valve as an amplifier is increased because of the increase in bias, but the power output may decrease. The screen voltage, however, can then be raised until the maximum dissipation rating of the valve is reached in order to compensate for the loss in power output. Thus, the bias and load of 6F6 can be varied in order to satisfy a variety of design requirements. Such flexibility is not possible with some types of valves, because the bias voltage is not completely independent of plate voltage.

The results of a number of preliminary tests have shown that high output at nominal distortion can be obtained from two types of 6F6 valves with 315 volts on plate and screen and -22 volts on the control grid. A single 6F6 operated with these electrode voltages can deliver 5 watts at 7 per cent. total distortion; two valves connected in push-pull can deliver 13 watts at 5.5 per cent. distortion. In either case, negligible control-grid current is drawn at these outputs. In this Bulletin, the characteristics of the push-pull connection will be discussed for three conditions: (1) fixed bias, zero power-supply regulation, and small grid-circuit impedance; (2) self bias, regulation due to a 1000-ohm power-supply circuit, and small grid-circuit impedance; and (3) operation in a commercial radio receiver of average design.

OPERATION WITHOUT PRE-AMPLIFIER

Two type 6F6 valves were connected in push-pull, as shown in Fig. 1. Plate and screen voltages were 315 volts, and the bias was -22 volts. The control-grids were connected to the secondary of a low-impedance transformer, from which the signal voltage was obtained. The curves of Fig. 3 show the variation of power output and distortion vs. load resistance

(R$_L$) for low operating conditions: (1) fixed bias and zero power-supply regulation and (2) self-bias and 1000-ohm regulation. The change from the first to the second condition was accomplished by means of switches S$_1$ and S$_2$.

The curves of Fig. 3 show that, with full signal applied, approximately 13.5 watts at 8.5 per cent distortion can be obtained from two type 6F6 This output may be obtained from either condition of operation, as indicated in Fig. 3. However, with a load of 10,000 ohms, the power output is 13 watts and the distortion is only 5.5 per cent. This value of valves at the grid-current point with a plate-to-plate load of 12,000 ohms. load resistance is recommended because of the lower value of distortion.

The curves of Fig. 4 show the variation of cathode current, grid-to-grid signal voltage, and total distortion vs. power output for a load of 10,000 ohms. The rise in cathode current (plate plus screen current) from zero to full output for the two valves is only 22 milliamperes for the fixed bias condition and 10 milliamperes for the self-bias condition; nearly all of the increase in cathode current is due to rectification in the screen circuit.

The curves of distortion vs. power output show that the distortion rises smoothly from low values at low power outputs to the nominal value at the grid-current point. These curves are not extended into the grid-current region, because the effect of grid current on distortion depends on the nature of the grid circuit. As indicated in Figs. 1 and 2, a 420-cycle signal was used for all tests. The distortion characteristics shown, therefore, obtain only for a signal of this frequency. Additional distortion is introduced by the output transformer at lower frequencies, because of the characteristics of the iron core.

OPERATION IN A TYPICAL RECEIVER

In order to determine the characteristics of the amplifier under practical operating conditions, two type 6F6 valves were connected in the output stage of a commercial radio receiver of average design. The output stage was fed by a two-valve resistance-coupled phase inverter, which was preceded by a diode type of second detector. The output valves were self-biased and the regulation was that due to an 850-ohm power supply. These characteristics are representative of average receiver design.

The results of the preliminary tests indicate that a plate-to-plate load of 10,000 ohms is desirable. In order that the valves actually work into this load, the parallel combination of the reflected load and the transformer primary impedance should equal 10,000 ohms. This condition was satisfied by placing a 12,700-ohm resistor across the primary of the receiver's output transformer; the power delivered to this resistor is the power supplied to the equivalent load, and not the total power furnished by the valve. A second test was conducted in this receiver with an almost ideal output transformer; the required reflected load resistance was 10,700 ohms. The performance curves of the receiver with the practical output transformer and with the nearly ideal output transformer are shown in Fig. 5. The schematic circuit of a portion of the receiver is shown in Fig. 2.

It is not necessary to use the phase-inverter circuit of Fig. 2 in order to duplicate the results shown in this Bulletin. The output valves may be fed by a single-valve transformer-coupled amplifier, or by a push-pull resistance-coupled amplifier. In either case, the results which are comparable to those shown in this Bulletin can be obtained.

The phase inverter was adjusted by applying to the 6F5 a signal of such magnitude that grid current started to flow in valve A. The signal input to the 6C5 was then adjusted by means of the potentiometer (P) until grid current started to flow in valve B. After this adjustment was made, power output, distortion, and total cathode current were measured for both the practical transformer and the nearly ideal transformer. The tests were carried beyond the grid-current point in order to determine the practical distortion characteristic of the system.

Fig. 5 shows that, in a typical receiver, the distortion increases smoothly from low values at low outputs to reasonable values at high outputs. Under the conditions shown in Fig. 2, over 15 watts can be obtained from the system without any discontinuities in the distortion characteristic. These curves also show that the use of a practical output transformer does not reduce the maximum power output and that the total distortion at high outputs is reasonable. The total cathode current is not shown, because the rise was only 4 milliamperes at the 15.5-watt level.

A receiver designed for a maximum output of 15 watts will usually be operated at some lower output level. The distortion characteristics shown in Fig. 5 indicate that low distortion can be expected at these lower outputs and that reproduction will not break up at high outputs. These conclusions were verified by listening tests.

If the output at 5 per cent distortion is arbitrarily defined as a good operating level for this receiver, then the overload characteristic may be defined as the distortion characteristic between the output at 5 per cent distortion and maximum output, regardless of the output at which grid current flows. For this receiver, the output at 5 per cent distortion is approximately 9 watts; the overload characteristic, therefore, extends to 15 watts.

The features of the 6F6 output system described in this Bulletin are: high output (15 watts) at reasonable distortion, low distortion at low outputs, a smooth distortion characteristic, and negligible rise in d-c plate current with signal. The operating conditions for a push-pull amplifier are tabulated below for convenience.

Heater Voltage	6.3 Volts
Plate Voltage	315 Volts
Screen Voltage	315 Volts
Control-Grid Voltage	-22 Volts
Zero-Signal Plate Current (two valves)	84 Milliamperes
Zero-Signal Screen Current (two valves)	16 Milliamperes
Plate-to-Plate Load	10,000 Ohms
Self-Bias Resistor	220 Ohms

These measurements were made with a constant resistive load and may only be applied to the effective load of a loudspeaker if an impedance-correcting network is employed so as to reflect a constant impedance in the plate circuit.

The values given apply to Radiotrons 2A5 and 42 equally with type 6F6.