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

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APPLICATION NOTE
ON
DESIGN OF AUDIO SYSTEMS EMPLOYING
TYPE 2A3 POWER AMPLIFIER TRIODES

The introduction of the 2A3 made possible the design of audio-frequency output systems of unusual power-handling ability and exceptional tone quality. The unique design features incorporated in the 2A3 make possible very high power output at relatively low plate voltages. Used in a suitable audio-frequency power amplifier, two 2A3's in Class A push-pull are capable of delivering 15 watts of audio power to the output transformer with a total harmonic distortion of less than 2.5 per cent.

Two of the more important design features of the 2A3 are its multifilamentary cathode and its extremely high mutual conductance. The multifilamentary cathode consists of a large number of coated filaments arranged in series-parallel combination to provide a very large effective cathode area.

GRAPHICAL SOLUTION FOR THE SELECTION OF 2A3 OPERATING CONDITIONS

In determining the performance obtainable from two 2A3's in Class A push-pull and in selecting output transformer constants, a graphical method of solution can be used. For a general consideration of the method for determining the performance of push-pull audio amplifiers by graphical means, see the paper entitled "Graphical Determination of Performance of Push-Pull Audio Amplifiers" by B. J. Thompson of our Research and Development Laboratory. This paper appeared in Proceedings of the Institute of Radio Engineers for April, 1933.

CLASS A OPERATING CONSIDERATIONS FOR THE 2A3

Class A General Operation

The usual operating point of grid-bias voltage for a Class A amplifier lies approximately midway between zero bias and a bias sufficient to cause plate-current cut-off. If a single tube is used in Class A operation, the operating bias voltage must be such that the d-c plate current does not change appreciably when full-signal voltages are applied to the grid. Only under such conditions can an output having low distortion be obtained.

Strictly speaking, no type of output tube has absolutely linear characteristics. Consequently, a small amount of rectification of the signal voltage usually occurs. The non-linearity of characteristics is therefore responsible for the distortion produced by the tube.

When two tubes are operated in a Class A push-pull circuit, the non-linear sections of their characteristics are made to complement each other to give a substantially linear overall characteristic. This method produces an output free from second harmonic distortion. For this reason, it is possible to use a higher bias voltage for push-pull operation than is usually employed for single-tube operation. An increased bias voltage lowers the internal dissipation of the tube and permits the use of higher plate voltages. Higher plate voltages, in turn, make possible higher power output.

In order to obtain the higher power output of which the 2A3 is capable, two of these tubes are operated in push-pull under bias-voltage conditions which cause considerable rectification in each tube. Additional plate current, then, is drawn because of rectification, but this increased plate current is useful in securing higher power outputs. Under normal recommended operating conditions in a push-pull amplifier, where a plate-supply voltage of very good regulation and a fixed-bias supply voltage are used, the plate current is not cut off during any fraction of the cycle. Consequently, even though the recommended operating conditions specify over-bias grid voltage, this system may be operated as a strictly Class A amplifier.

2A3's should not be operated with more than 300 volts on the plate. The grid-bias voltage should be -62 volts when operated from an a-c filament supply and -60 volts when operated from a d-c supply. The corresponding static plate current for an average 2A3 is 40 milliamperes. This voltage and current rating for no signal input should not be exceeded for best results.

Fixed-Bias Operation of the 2A3 with Over-Bias Voltage

Figure 2 shows a circuit arrangement for the 2A3 in which the bias voltage is obtained from a small triode used as a rectifier. This triode must be a type whose cathode comes to an operating temperature quickly in order that bias will be available to prevent abnormal plate current in the 2A3's. Either a type 26 or 01-A is suitable for use as the bias rectifier.

With the circuit of Figure 1, changes in the d-c plate current of the 2A3 produce some change in bias. With the circuit of Figure 2, the bias voltage is substantially independent of the plate current of the 2A3's.

The ideal case of fixed-bias operation with a fixed plate-voltage supply gives results as shown by the curves marked (I) in Figure 3. The curves (II) show the performance with fixed bias but with a plate-supply source having an equivalent internal resistance of 562 ohms. This represents the condition for the circuit of Figure 2 when a 5Z3 with suitable transformer is used. The performance with an 83 type is intermediate between the values of curves I and II of Figure 3.

The plate circuits of the 2A3's should be fused in the center-tap lead of the output transformer. This is especially important when fixed bias is used. Should the bias-voltage rectifier tube be removed or damaged, the bias on the 2A3's becomes zero. In that event, unless a fuse is provided for protection, excessive plate current can flow and damage the receiver. A suitable fuse is one similar to the small glass-enclosed type often used to fuse the power-supply line in radio sets and rated at 150 milliamperes.

Self-Bias Operation of the 2A3 with Over-Bias Voltage

When 2A3's are operated in a push-pull circuit and are self-biased, a rise in d-c plate current with increasing signal voltages increases the voltage drop across the self-biasing resistor and raises the bias on the tubes. Thus, the operating point on the plate family of the characteristic curves is shifted downward. This shift tends to increase distortion and to lower the power output. Under these conditions, operation intermediate to Class A and Class B is usually obtained at full output since the plate current is cut off for an appreciable fraction of the operating cycle.

When self-biasing circuits are used for the 2A3, it is necessary, therefore, to employ a higher value of plate-load resistance than is used with a fixed or semi-fixed bias arrangement. The purpose of this high resistance is to lessen plate-current swings, limit distortion, and prevent plate-current cut-off at negative signal swings.

Performance of a 2A3 amplifier for self-bias operation (self-bias resistance of 780 ohms) and an assumed internal resistance of the plate-voltage supply of 562 ohms is shown as Curve IV in Figure 3. A comparison with Curve I, which represents the ideal case of fixed supply voltages, shows the necessity of using a high plate load, as previously stated, in order to obtain high power output and low distortion. Increasing the internal resistance of the plate-voltage supply to the somewhat higher values often used commercially will not materially change results from the values of Curve IV.

The circuit diagram in Figure 3 shows the equivalent voltage-supply circuit for the plate and grid-voltage supply. The plate and bias voltages on the power tube at zero-input signal are 300 and -60 volts, respectively. (For a-c filament supply, grid-bias voltage is -62 volts.)

Curves I to IV show the performance of the amplifier for four combinations of the internal resistance values of the plate-voltage and grid-voltage supply. The plate- and grid-supply voltages are adjusted to the values given above. These curves show that it is desirable to use a bias arrangement which will not give bias-voltage fluctuations when the d-c plate current changes. Semi-fixed and fixed-bias arrangements allow higher power output levels to be maintained with a high degree of fidelity.

Semi-Fixed-Bias Operation of the 2A3 with Over-Bias Voltage

Figure 1 shows a circuit arrangement employing semi-fixed bias for the 2A3. The bias voltage is obtained across the speaker-field resistance. Since the plate current for all of the tubes in the set flows through this resistance, the bias voltage is less affected by the d-c plate-current changes in the 2A3's than it is in a self-biasing circuit.

The circuit constants shown in Figure 1 are those for a typical receiver. Since the speaker-field resistance determines the 2A3 bias, it follows that the choice of resistance depends on the total plate-current drain of all the tubes in the set. The performance with this circuit is represented by Curve III.

Balancing of 2A3 Circuits

It may be advisable to provide some means for balancing the plate currents of the 2A3 tubes, as this has the effect of balancing out hum voltages present in the plate-supply voltage.

Two methods of accomplishing this are shown in the circuit diagrams. In Figure 1, a small potentiometer (R_8) is connected between the center taps of the filament windings to permit an adjustment of bias voltage. In Figure 2, the secondary of the input transformer consists of two separate windings. One lead is attached to the center of the potentiometer (R_7) and the other to the slider or arm of the same potentiometer. Adjustment of the potentiometer varies the bias slightly on one of the 2A3's.

Small amounts of hum due to various causes can often be eliminated by adjustment of the potentiometer. Adjustment of the potentiometer for minimum hum usually gives equal plate currents. The potentiometer is adjusted by listening for minimum hum upon installation of the 2A3's in the set. It should not require readjustment until one of the 2A3's is changed.

Power Transformer

Both the circuits of Figure 1 and Figure 2 are designed for use with typical commercial power transformers. There are no special features involved in the design of the power transformer. Any make of transformer having the appropriate voltage windings, correct rating, and good regulation may be used.

Pre-Amplifier Stage

A type 56 tube is used in the pre-amplifier stage, since this tube gives excellent power sensitivity. The 56 also is an economical type.

A plate-supply voltage of 200 volts for the 56 is adequate to give the output signal required to swing the 2A3's. This is the voltage available for plate supply to the other tubes in the set under conditions given in Figure 2. The 56, with 200-volt plate supply, is operated with a bias of -11 volts. The plate current is 3.6 milliamperes.

Input Transformer

The same input transformer, specifications for which are shown on an attached page, is used for both the semi-fixed and fixed-bias arrangements. Commercial-size audio-transformer laminations are used.

The ratio of the input transformer is 1.4 to 1 from the full primary winding to one-half of the secondary winding. The peak voltage which will be induced in the secondary winding is 2 x 90 or 180 volts at the point at which the 56 begins to draw grid current.

In determining the constants for the input transformer, cost, size, response characteristics, and signal requirements must be considered. In order to obtain a low-cost small-size transformer with primary inductance high enough to give good frequency characteristics, a step-down ratio is used. A step-up ratio would require a larger transformer design in order to provide space for the additional secondary turns. However, under the circuit conditions shown, the step-down ratio can give a signal input to the 2A3's sufficiently large to obtain their full output.

TRANSFORMER SPECIFICATIONS

Power Transformer S-79A*

Core

Material	-	Transformer Steel	Allegheny Steel Co. or equivalent
Punching	-	EI - 13A	
Stack	-	1-3/4"	
Weight	-	4.9 lbs.	

Primary

Resistance - 2.4 ohms

Secondary

Resistance at 25°C - 2 x 106 ohms
Induced voltage - 2 x 375 volts RMS
Induced voltage from center tap to tap for bias rectifier - approx. 57 v RMS.

Total weights of copper - 1.0 lb.

INPUT TRANSFORMER S-77*

Core:	Material	-	Audio B	Allegheny Steel Co. or equivalent
	Punching	-	EI - 75	
	Stack	-	3/4"	
	Joint	-	Butt	
	Weight	-	0.6 lb.	

Primary:
Turns - 5000
Location - Between two halves of secondary winding
Turns per layer-240
Layers - 21
Insulation between layers - 0.001" paper
Wire - #40 enamelled
Resistance at 25°C - - - 2000 ohms

Secondary:
Turns - - - - Two windings of 3600 turns each
Location - - - One-half over, one-half under primary
Turns per layer - 240
Layers - - - - 2 x 15
Insulation between layers - 0.001" paper
Wire - - - - #40 enamelled

Total weights of copper - 0.14 lb.

*Our design identification number.

OUTPUT TRANSFORMER S-84*

Core: Material - Audio C Allegheny Steel Co. or equivalent
Punching - EI-11
Stack - - 7/8"
Joint - - Lap
Weight- - 1.0 lb.

Primary: Wire - - - - #32 enamelled
Turns - - - - 1400 tapped at 700
Location - - - Next to core
Turns per layer- 105
Layers - - - 14
Insulation between layers - 0.0015" paper
Resistance at 25° C - - - 98 ohms

Secondary: Turns - - - - 32
Location - - - Wound over insulated primary
Wire - - - - #15 enamelled
Turns per layer 16
Layers - - - 2
Insulation between layers - 0.005" paper
Secondary load - Voice coil of electro-dynamic speaker having an impedance at 60 cycles of 1.06 ohms
Resistance at 25°C - 0.053 ohms
Output - - - 13.3 watts into a 1.06-ohm load at 60 cycles

Total weight of copper = 0.24 lb.

CHOKE S-26*

Core: Material - Dynamo Steel - Allegheny Steel Co. or equivalent
Punchings - EI - 12
Stack - - 1-1/4"
Air gap - 0.004" x 2
Weight - - 1.88 lbs.

Winding: Turns - - - - 1780
Turns per layer - 81
Layers - - - - 22
Insulation between layers - 0.003" paper
Resistance at 25°C - - - approx. 60 ohms
Weight of copper - - - 0.47 lb.
Inductance - - - - - approx. 10 henries (conditions as in Fig.2)

OUTPUT TRANSFORMER S-105*

Core: Material - Audio C Allegheny Steel Co. or equivalent
Stack - 0.875"
Joint - Lap
Weight - 1.0 lb.

*Our design identification number.

Primary:

Turns - - - - - - 2000 tapped at 1000
Location - - - - - Next to core
Wire - - - - - - #33 enamelled
Turns per layer - - 118
Layers - - - - - - 17
Insulation between layers - 0.0015" paper
Resistance at 25°C - 172 ohms total
Inductance - - - 19.5 henries (at full signal)

Secondary:

Location - Wound over primary
Turns = 2000 divided by the square root of $[5400/(R_L+r_s)]$
where,
R_L = external load resistance on secondary terminals
r_s = resistance of secondary winding or approx. 6% of R_L.

*Our design identification number.

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TYPICAL POWER-AMPLIFIER CIRCUITS WITH SEMI-FIXED AND FIXED BIAS

CIRCUIT WITH SEMI-FIXED BIAS

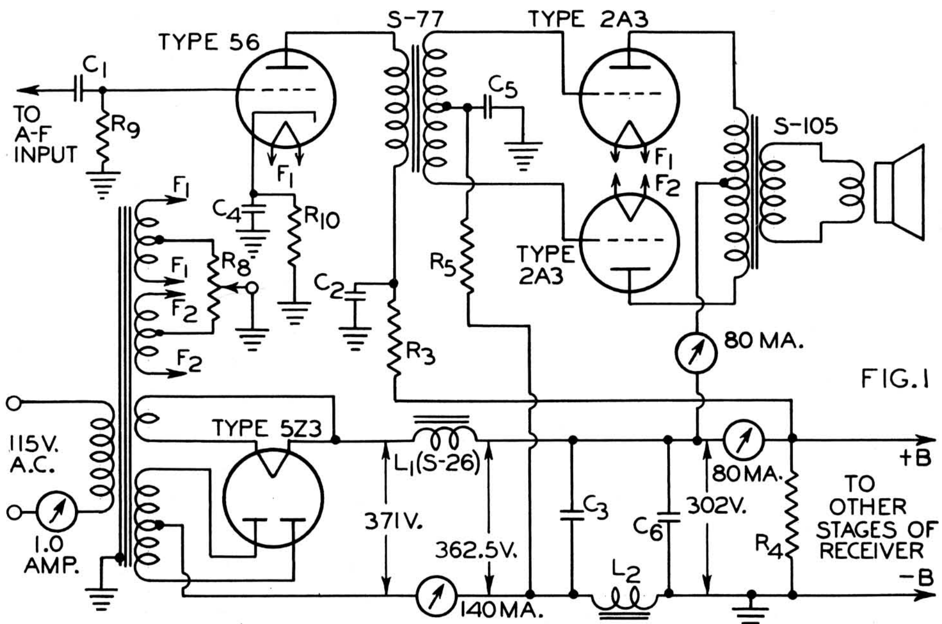

FIG. 1

CIRCUIT WITH FIXED BIAS

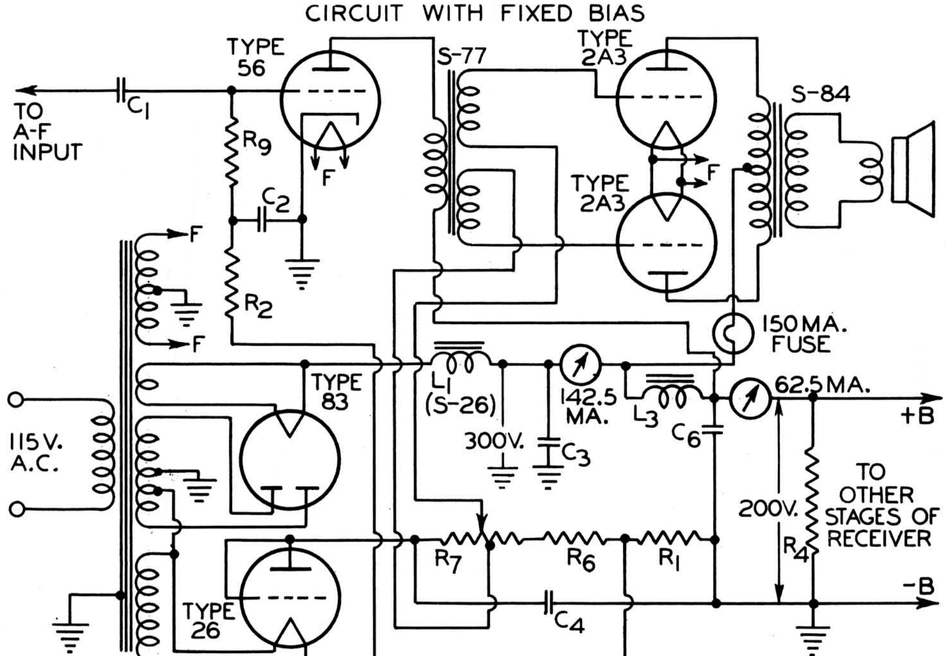

FIG. 2

APPROXIMATE VALUES

C_1 = BLOCKING CONDENSER-0.01 μf
C_2 = BY-PASS CONDENSER-0.25 μf
C_3 = FILTER CONDENSER-10 μf
C_4 = BY-PASS CONDENSER-5 μf
C_5 = BY-PASS CONDENSER-0.05 μf
C_6 = FILTER CONDENSER-5 μf
L_1 = FILTER CHOKE-10 HENRIES AT MAX.MA., 60 OHMS
L_2 = SPEAKER FIELD-430 OHMS
L_3 = SPEAKER FIELD-1600 OHMS
R_1 = 5000 OHMS
R_2 = 200000 OHMS
R_3 = 10000 OHMS
R_4 = BLEEDER
R_5 = 50000 OHMS
R_6 = 22000 OHMS
R_7 = CENTER-TAPPED POTENTIOMETER-2500 OHMS
R_8 = POTENTIOMETER-100 OHMS
R_9 = 0.5 TO 1.0 MEGOHM
R_{10} = 2700 OHMS

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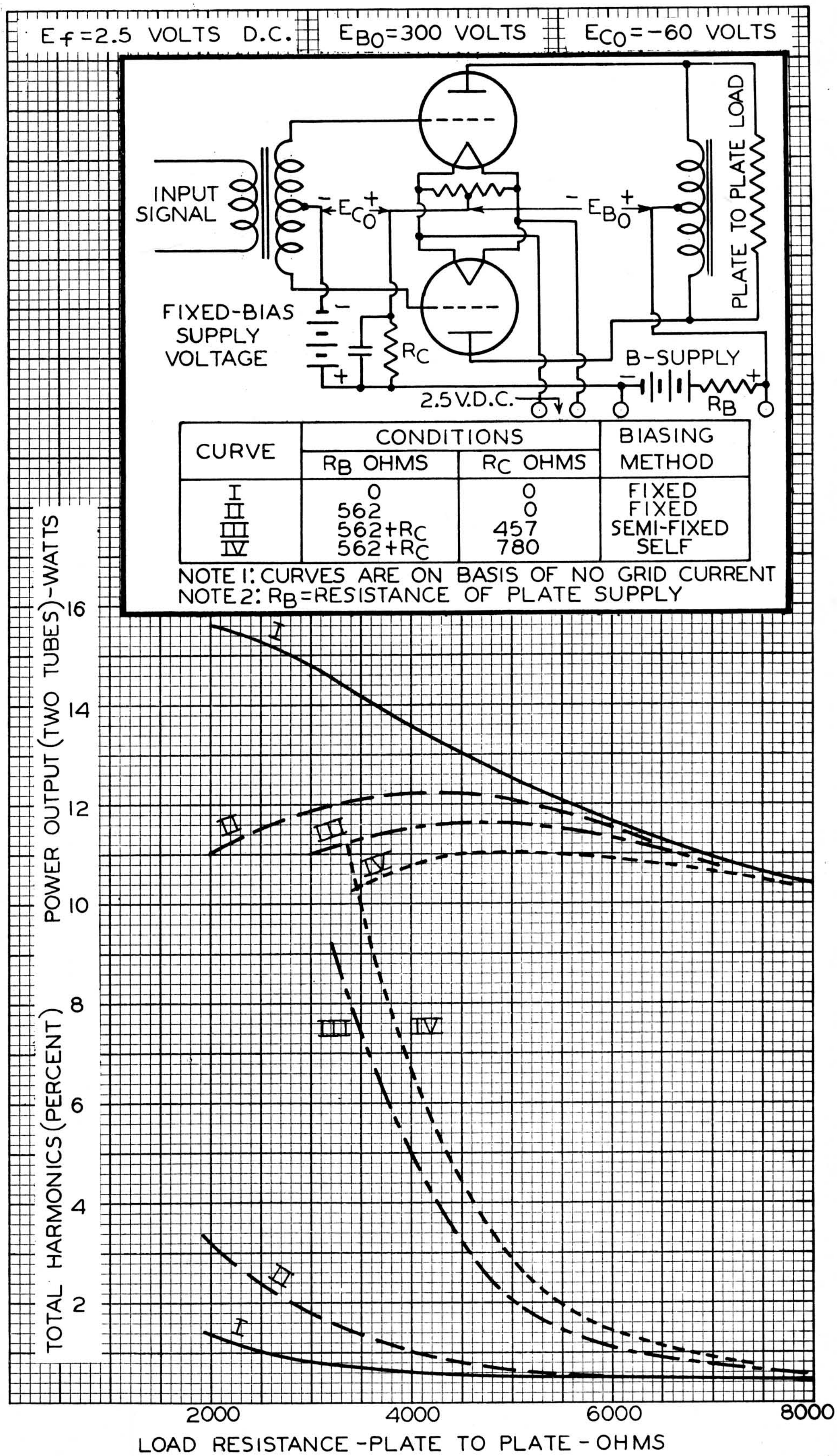
OPERATION CHARACTERISTICS



CURVE	CONDITIONS		BIASING METHOD
	R_B OHMS	R_C OHMS	
I	0	0	FIXED
II	562	0	FIXED
III	562+R_C	457	SEMI-FIXED
IV	562+R_C	780	SELF

DEC. 19, 1933 FIG. 3 92S-5436