IMPROVEMENTS IN GLIDE PATH TRANSMITTERS

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Technical Development Report No 91

CIVIL AERONAUTICS ADMINISTRATION

TECHNICAL DEVELOPMENT

INDIANAPOLIS, INDIANA

April 1949

TABLE OF CONTENTS

Manuscript received, July 1948

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SUMMARY

The glide path transmitter which is part of the CAA instrument landing system operates in the frequency region of 335 Mc. The original design of this transmitter was dictated by military specifications and is identified as the AN/CRN-2. This transmitter is currently employed by the CAA in the instrument landing systems installed throughout the United States. The transmitter employs Type 8025 tubes in the tripler and power-amplifier stages. The unsatisfactory results with these tubes has lead to a redesign of the transmitter and a change to Type 2C39 tubes. Further development at the Experimental Station has resulted in extending the tube life expectancy of the 2C39 tubes to 6000 hours This report discusses some of the modifications made at the Experimental Station. A graphical analysis of the operation of the amplifier is presented

INTRODUCTION

The ground equipment for the CAA instrument landing system utilizes three major components, viz., the marker beacons operating at 75 Mc, the localizer operating in the 110 Mc region, and the glide path transmitter operating in the 335 Mc region This report is concerned with the operation of the glide path transmitter, with special reference to the operation of the driver and power-amplifier stages of this transmitter

The glide path transmitter in current use is a transmitter developed originally for the U S Air Forces In the driver and power-amplifier stages, Type 8025 tubes are employed and experience in the field with this type tube has been unsatisfactory. The tubes have exhibited short life and require frequent replacement This condition was recognized during the war years and prompted the Electronic Subdivision of the Air Materiel Command to initiate development work on improved circuits A redesigned driver and power-amplifier stage using Type 2C39 tubes was secured through this development and one of the models was acquired by the CAA Experimental Station The test at Wright-Patterson Air Force Base revealed that while the redesigned equipment showed improved performance, the tube life was still not satisfactory. Tests at the Experimental Station confirmed these results, and further development work was undertaken Upon the completion of this development work, a set of tubes was operated in the transmitter on a life test This life test was continued for 6000 hours and periodic checks were made during the run. The original set of tubes endured the entire period and only negligible changes in the output could be detected

This performance represents an outstanding improvement since the life expectancy of the Type 8025 tube in the AN/CRN-2 transmitter is approximately 400 hours, and with the Type 2C39 tubes in the original modified version of this transmitter the average tube life was even less than 400 hours

THEORY OF OPERATION

The choice of the Type 2C39 tube, the characteristics of which are given in Appendix I, leads logically to the use of the grounded-grid type of circuit since the construction of the tube is ideally suited for proper layout for a grounded-grid amplifier [1, 2]

Before discussing this particular application in the glide path transmitter, a brief discussion of the grounded-grid circuit will be presented and the essential differences between the grounded-grid amplifier and the more conventional type of Class C amplifier will be noted.

As the name implies, the grounded-grid amplifier operates with the grid at rf ground potential The driver voltage is applied between cathode and grid, and the output appears across plate and grid Some of the important differences in the operation of the conventional amplifier and the grounded-grid amplifier

[1] E E. Spitzer, "Grounded Grid Power Amplifiers," ELECTRONICS, April 1946

[2] C E Strong, "The Inverted Amplifier," ELECTRONICS, July 1940

may be examined by referring to the simplified circuits shown in Figs. 1 and 2.

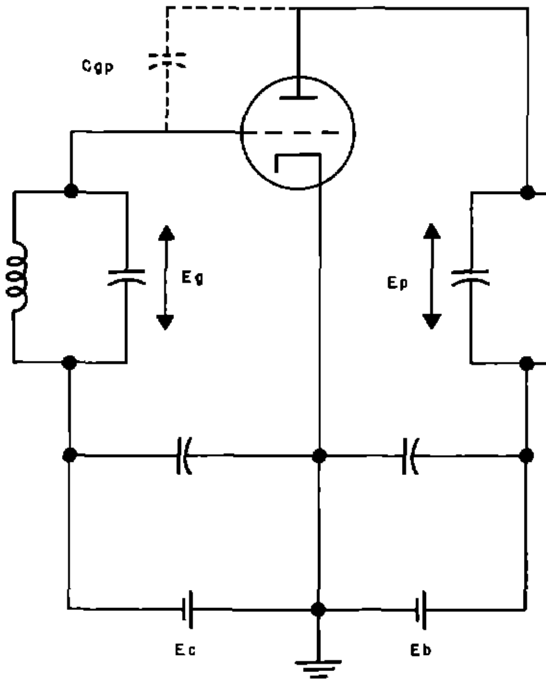

Fig. 1 Circuit of Conventional Class C Amplifier

A consideration of the effects of the inter-electrode tube capacitances reveals an essential difference between the feed-back paths in the two circuits. In the conventional amplifier, the capacitance between grid and plate provides a coupling between input and output circuits. Furthermore, if the load is inductive, this coupling introduces positive feed-back. The presence of this capacitance has plagued designers of triode amplifiers ever since triodes have been used. If stable operation, that is, freedom from regeneration and oscillation is to be accomplished, this capacity must be reduced to a minimum, and in most cases after this capacity is reduced to a minimum, the residual capacity must be neutralized. Many circuit arrangements have been devised for this purpose.

In the grounded-grid amplifier an effect analagous to that produced by the grid-plate capacitance of the conventional amplifier can be represented by the capacitance between plate and cathode as illustrated in Fig. 2. However, the capacitance in the grounded-grid circuit can be reduced by proper construction to an extremely low value since the control grid provides an effective shield between the plate and cathode elements It is for this reason that tubes designed for grounded-grid operation employ a physical arrangement such that the plate and cathode connections are brought out at opposite ends of the tube and the grid connection is located between these elements. Fig 3 illustrates this construction in the Type 2C39 tube

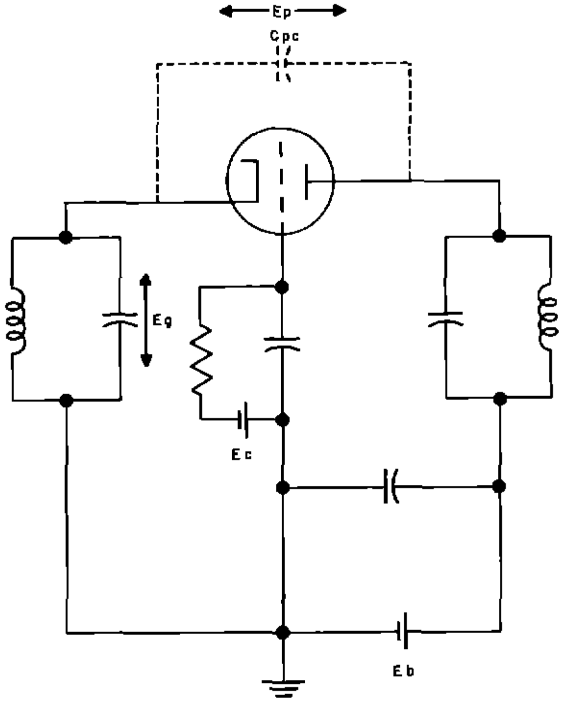

Fig. 2 Circuit of Grounded-Grid Class C Amplifier

Another essential difference between the conventional and grounded-grid Class C amplifier involves the driver power requirements. In the conventional amplifier the driver voltage is isolated from the output circuit. In the grounded-grid amplifier the driver voltage is in series with the amplifier voltage supplying the load. These two voltages are 180 degrees out of phase with respect to the cathode. This is shown in the simplified diagrams, Fig. 4. It is, therefore, apparent that the rf voltage between cathode and plate is the difference between the driver voltage and the grid-plate voltage. The total power output includes a component contributed by

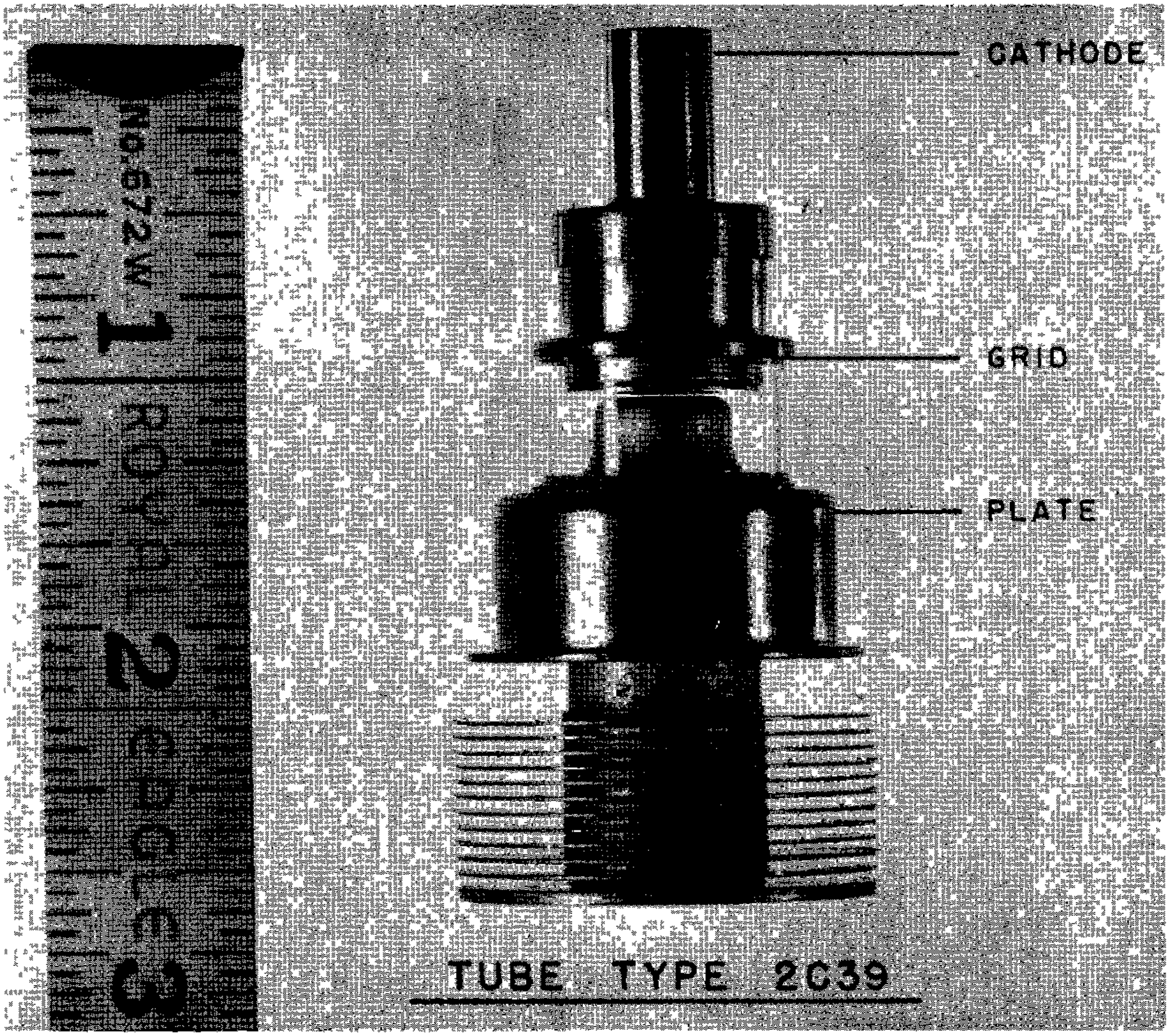

Fig. 3 Tube Type 2C39

the driver voltage and this component is equal to the product of the driver voltage and the fundamental frequency component of the power-amplifier plate current In the case of the Type 2C39 tube, since this is a high-mu triode, the rf grid voltage of the power amplifier is small compared to the plate-voltage swing and contributes a negligible amount of power to the total output power, and may be neglected However, when calculating the driver power requirements, that part of the driver power which supplies the load may be an appreciable part of the total driver power and must be taken into consideration. In the grounded-grid amplifier the total driver power may be divided into three components, viz., the power dissipated at the grid, the power dissipated in the external grid circuit, and the power contributed to the amplifier power output.

THE AN/CRN-2 TRANSMITTER

The driver and the power-amplifier stages of the AN/CRN-2 transmitter, prior to any modifications, are shown in simplified schematic form in Fig 5. After modification and before the life test was commenced, the circuits were changed to that shown in Fig 6.

The heater voltage was reduced from 6 3 to 5.2 volts. This reduction in heater voltage was made after an examination of the effect of this reduction on the characteristics and emission of the tube was shown to be negligible. The purpose of reducing the heater

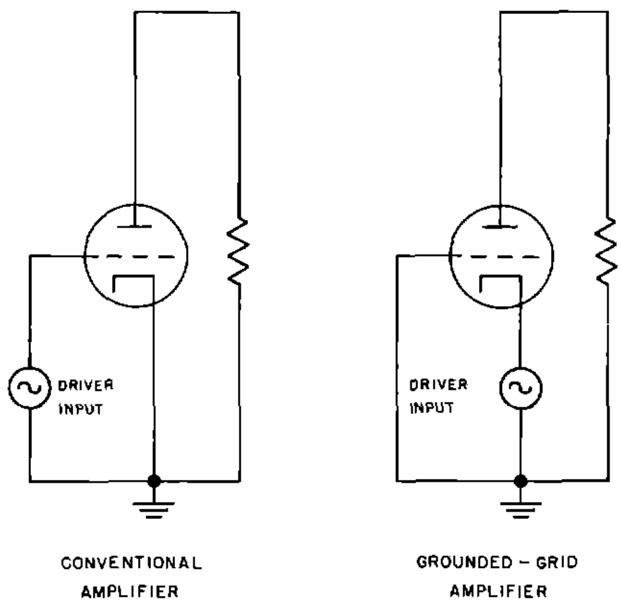

Fig. 4 Simplified Schematic Diagrams of Conventional And Grounded-Grid Amplifiers

voltage was to reduce the heat generated in the vicinity of the control grid. In the 2C39 tube the grid cathode spacing is very small, and an inspection of several of the tubes in the amplifier which had previously failed, showed evidence that tube deterioration had started at the grid, possibly due to grid emission which in turn may have been caused by overheating

The grid condensers which are used to secure the grid at rf ground potential were carefully adjusted to remove any residual inductive reactances In the design of this particular amplifier it was found that approximately 200 mmf capacity neutralized the amplifier. The grid condenser for the tripler-driver stage was also reduced from 550 mmf to 200 mmf.

The capacity of the blower, which directs an air blast on the tubes, was increased and the duct arrangement was changed in order to direct the air blast more effectively. Individual ducts were arranged to provide air cooling to the cathode stems of each of the four 2C39

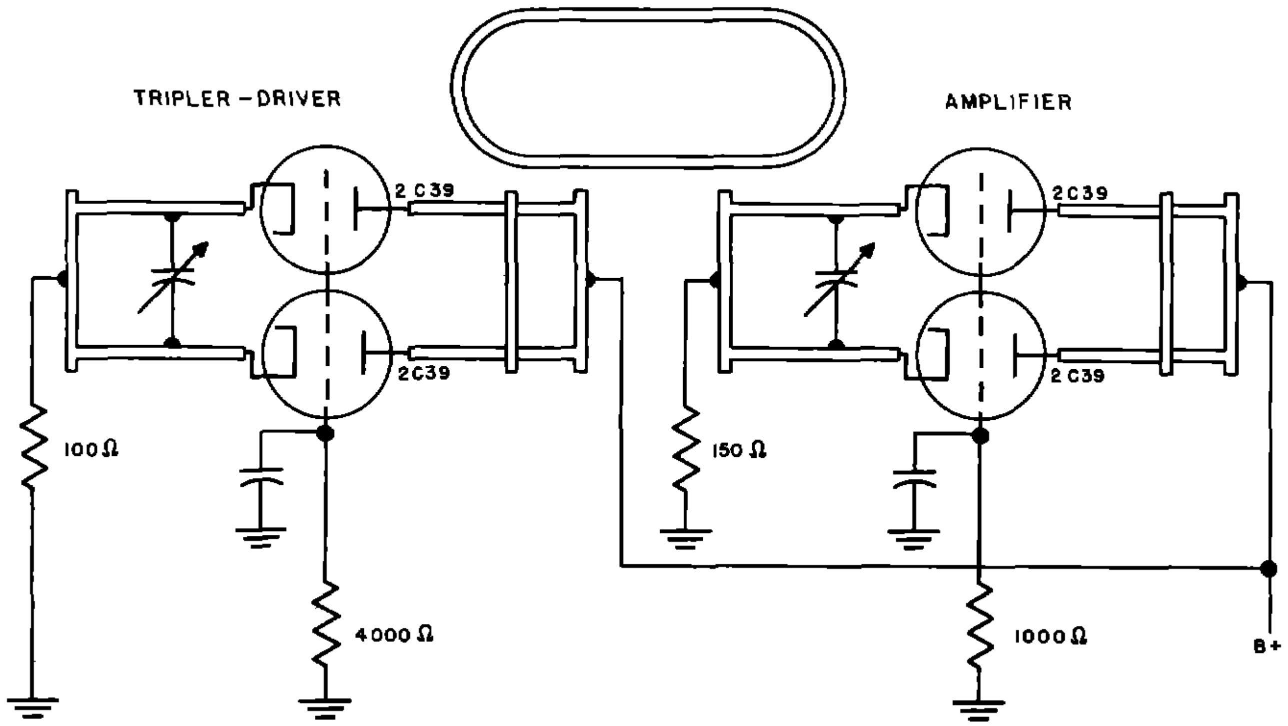

Fig. 5 Simplified Schematic Driver and Power-Amplifier Stages before Modification

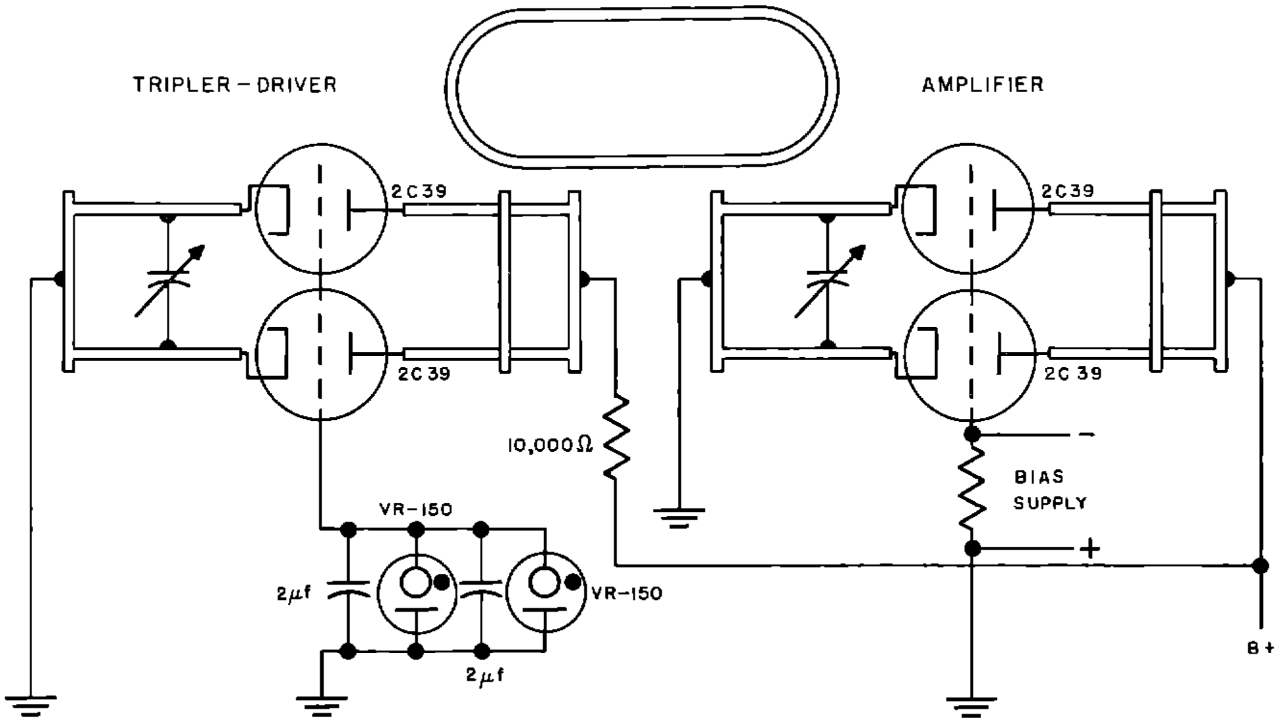

Fig 6 Simplified Schematic Driver and Power-Amplifier Stages after Modification

tubes The air circulation was increased by the addition of an exhaust fan These modifications are shown in Figs 7, 8, and 9

It was found that the grid dissipation played such an important part in determining tube life that it was deemed advisable to furnish the operator some method for determining the grid dissipation. This was accomplished by maintaining a fixed bias and calibrating the grid current meter so that it could be red-lined to indicate the maximum permissible grid dissipation. This has been found to be very valuable in keeping the operator informed as to the maximum allowable dissipation.

Since any life test is a time-consuming process, the merits of these changes were not individually evaluated. The net result was greatly improved tube life, but the contribution of the various changes to this result was not separately determined.

The life test was conducted with power-amplifier tubes manufactured by Matchlett Laboratories, Inc Eimac tubes were used in the tripler-driver stage Both types of tubes operated for 6000 hours without failure.

In the glide path transmitter the tubes in the power-amplifier stage are subjected to more strenuous operating conditions than the tubes in the driver stage. Therefore, it seems appropriate to make a detailed analysis of the operation of the power-amplifier tubes as they were operated during the life test. The method employed followed that outlined by Mouromtseff and Kozanowski.[3]

[3] I. E. Mouromtseff and H N Kozanowski, "Analysis of the Operation of Vacuum Tubes as Class C Amplifiers", Proceedings, Institute of Radio Engineers, Volume 23, No 7, July 1935

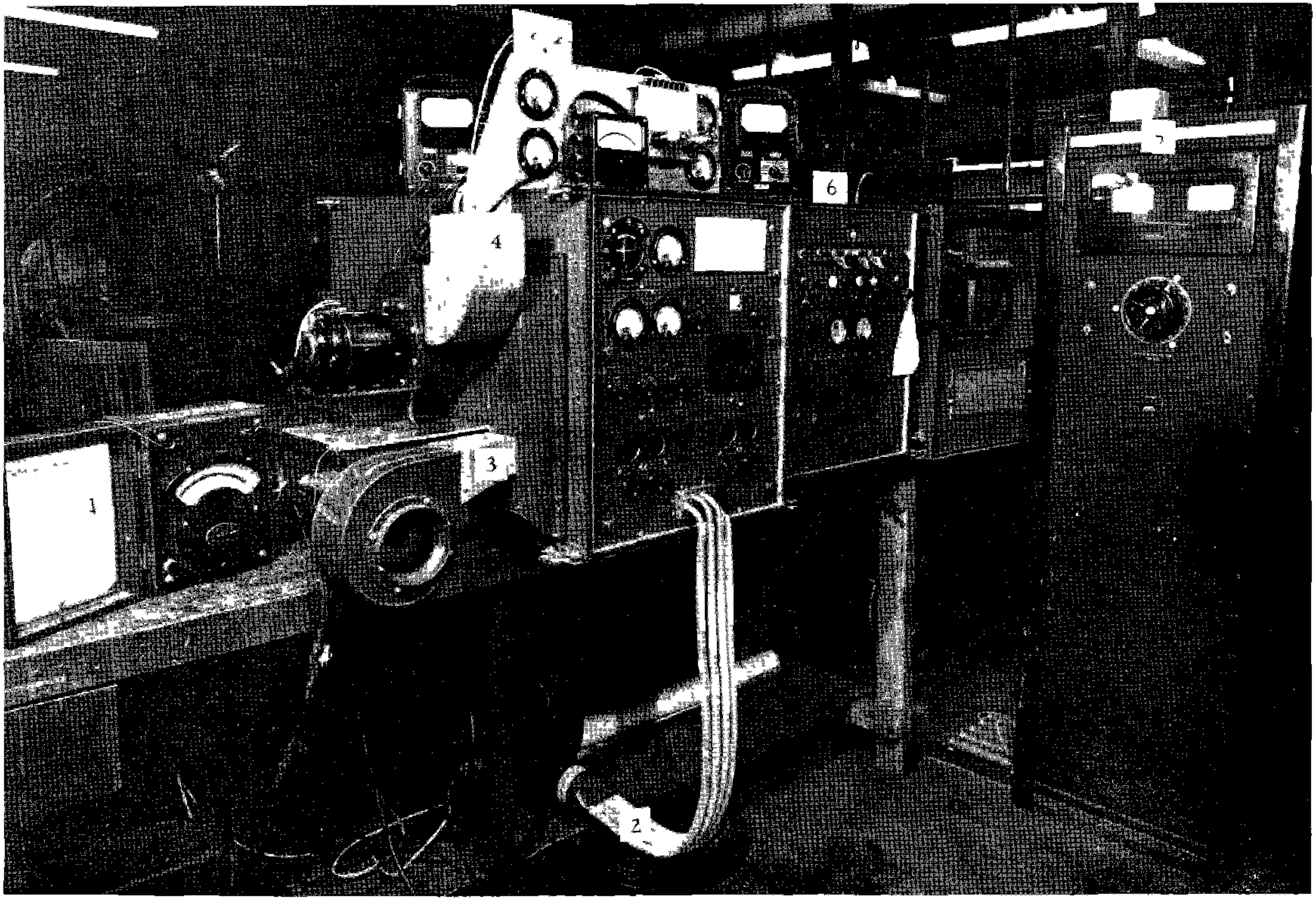

Fig. 7 Test Set-Up for Glide Path Transmitter AN/CRN-2 using 2C39 Tubes

(1) Weston AC-DC Voltmeter (0-1500 scale)
(2) Blower for 4 - 2C39 tube stems
(3) Blower for Final 2C39 Amplifier
(4) Exhaust Blower
(5) Plate Power Supply (0-4000 volts)
(6) Bias Power Supply (0-500 volts)

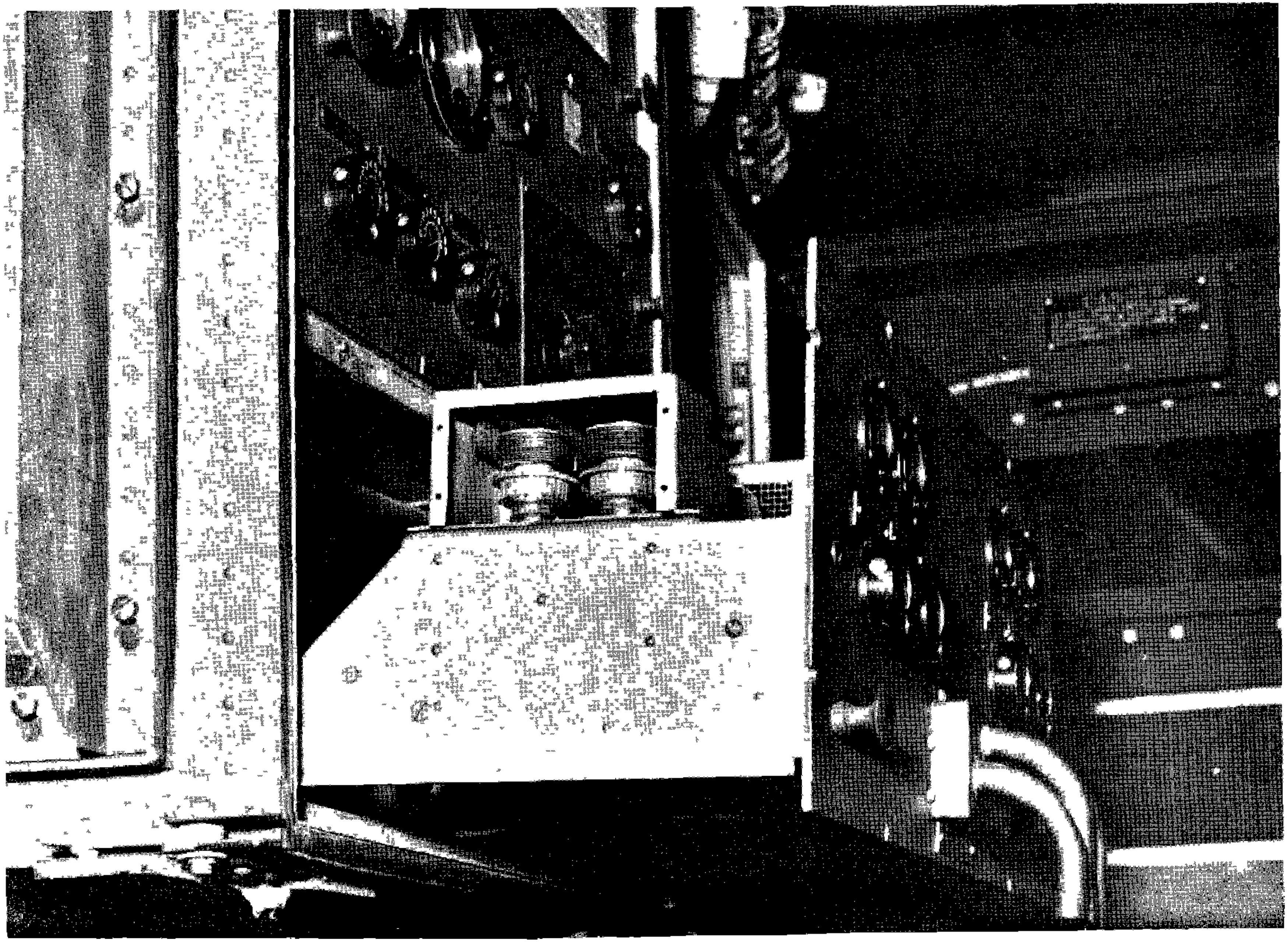

Fig. 8 End View of Amplifier Chassis Showing Tubes in Final Stage

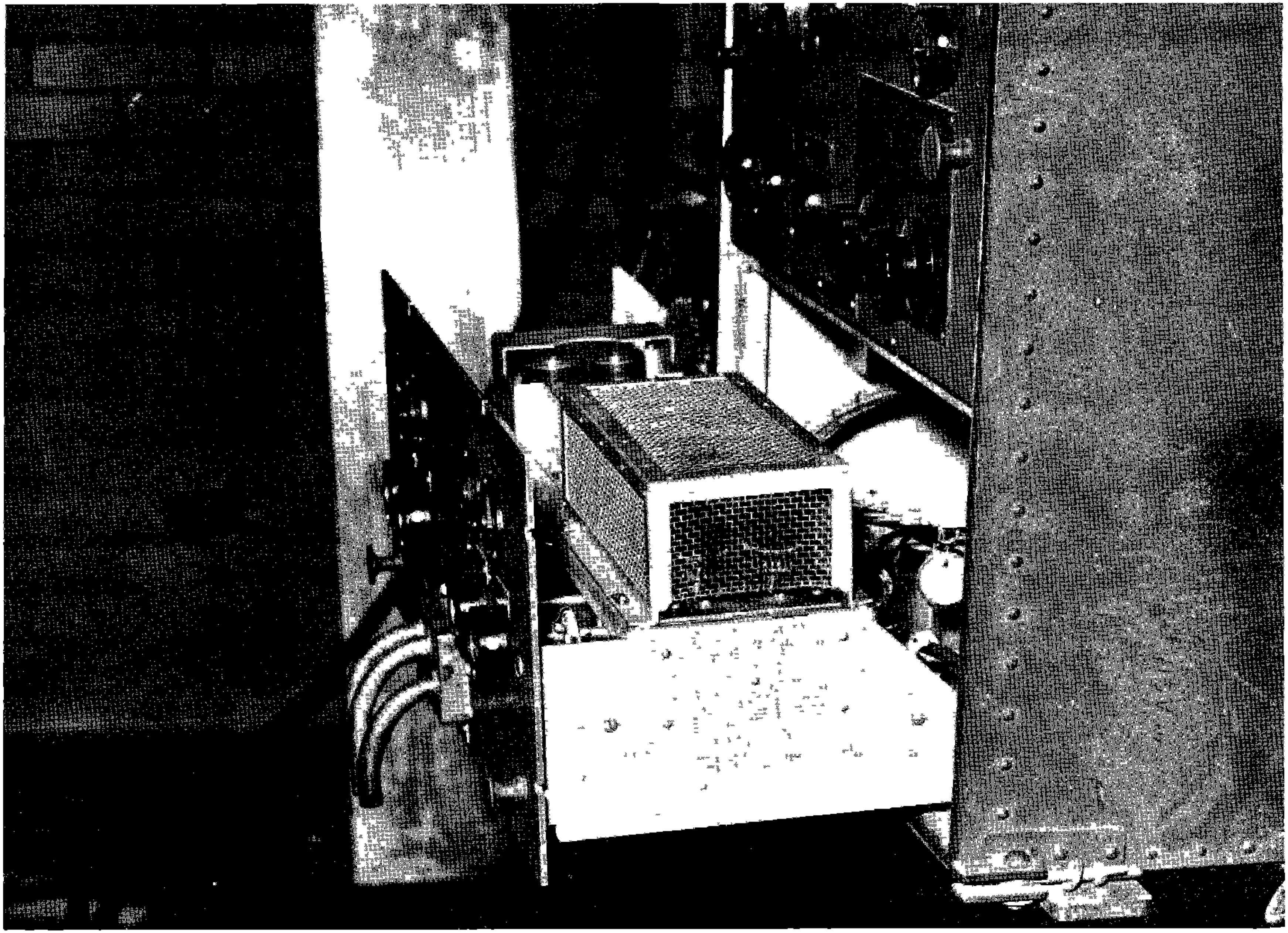

Fig 9 End View of Amplifier Chassis Showing Driver Stage

In the following discussion the symbols are as follows

E_b = the direct plate voltage

I_b = the direct plate current

E_p = the maximum value of plate-voltage swing (voltage between plate and cathode)

E_g = the maximum value of rf grid-voltage swing

E_c = grid bias voltage

i_p = instantaneous value of plate current

i_g = instantaneous value of grid current

I_1 = maximum value of fundamental component of plate current

I_c = direct grid current

W_o = power delivered to output circuit

W'_o = power delivered by output tubes

W_f = power delivered by the driver to the output circuit

W_g = power dissipated on grids of the output tubes

W_1 = power dissipated in external grid circuit

W_d = total driver power

W_{in} = direct power supplied to output tube plates

The method is a graphical one and requires the use of constant plate-current and constant grid-current curves. These curves are shown in Figs. 10 and 11. It was noted that the curves published by the various manufacturers of Type 2C39 tubes differed widely, and some of the tubes of the same manufacturer also differed sufficiently to make it necessary to prepare the charts from the tubes actually used in the transmitter

In addition to the constant current curves the following data necessary for the computation were measured while the transmitter was in operation.

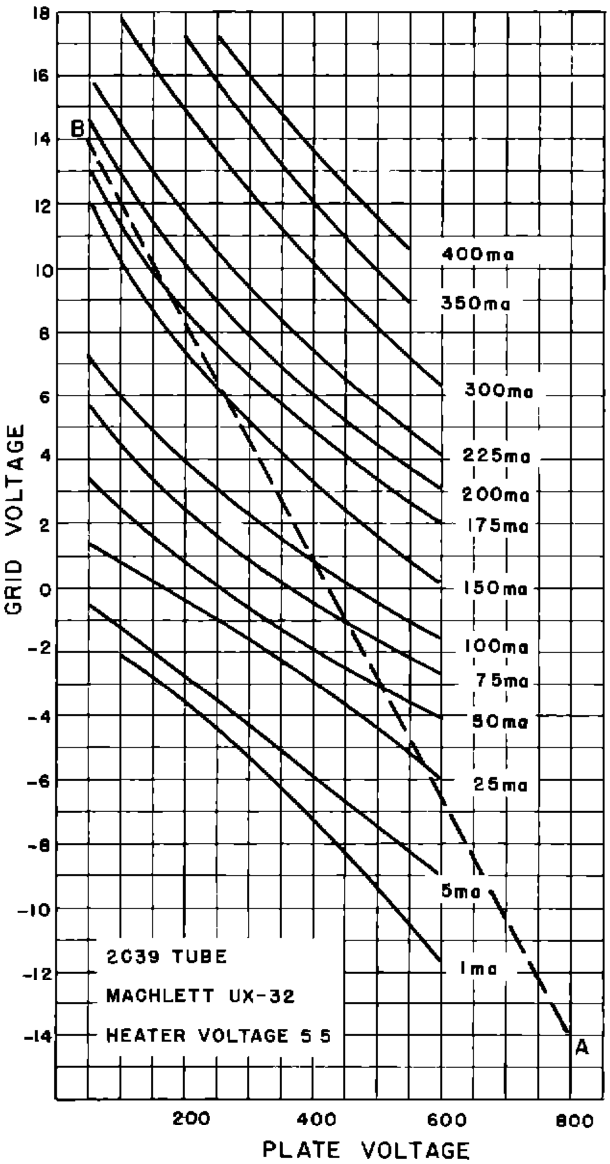

Fig. 10 Constant Plate-Current Curves

Plate current (2 tubes) - 112 ma

Grid current (2 tubes) - 65 ma

Direct plate voltage - 800 volts

Grid bias voltage - minus 14 volts

Next, values of plate-voltage and grid-voltage swing were assumed. Values which are compatible to proper operation of a Class C amplifier were selected and these values were used in the graphical solution to determine the average direct plate and grid currents. By a trial and error process a set of values for grid and plate-voltage swing can be found which fit the measured values of plate and grid current. In this particular case the values of plate-voltage and grid-voltage swing which fit the direct current values as measured are, 750 and 28 volts, respectively.

The results of the graphical anaylsis yield the following values for plate and grid currents

i_b = 58.7 ma (117.4 ma for two tubes)
I_1 = 96.2 ma (192.4 ma for two tubes)
I_c = 28.0 ma (56.0 ma for two tubes)
I_{g1} = 50.3 ma (100.6 ma for two tubes)

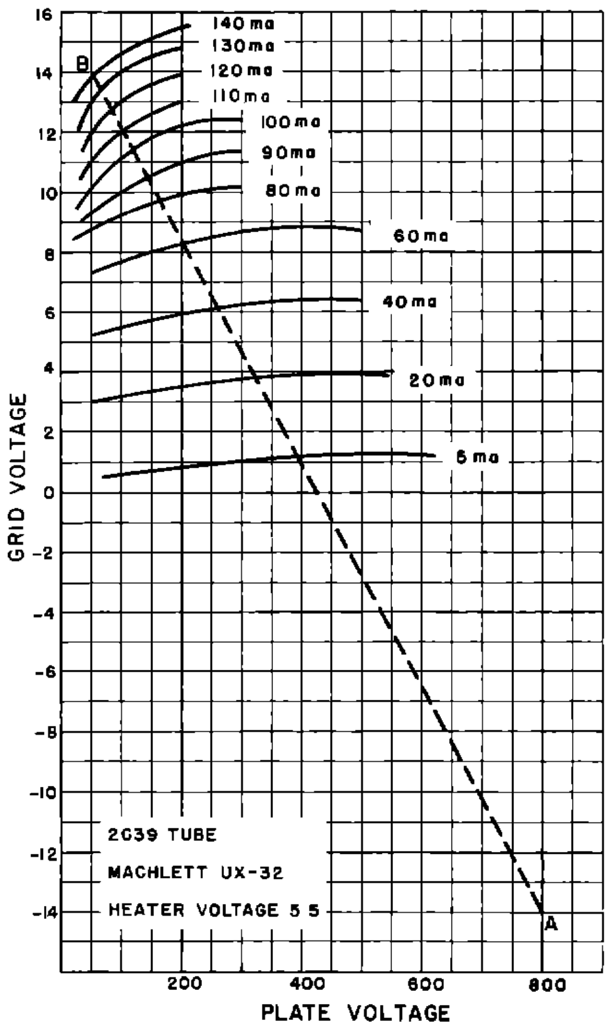

Fig. 11 Constant Grid-Current Curves

Assuming the phase relations shown in Fig. 12, we obtain

$$W_o = \left(E_p + E_g\right) I_1 = 74.8 \text{ watts}$$

$$W'_o = E_p I_1 = 72\ 2 \text{ watts}$$

$$W_f = E_g I_1 = 2\ 69 \text{ watts}$$

$$W_d = E_g \left(I_1 + I_{1g}\right) = 4.10 \text{ watts}$$

$$W_g = E_g I_{g1} = 1.41 \text{ watts}$$

The losses in the external grid circuit are

$$W_1 = E_c \times I_g = 0.84 \text{ watts}$$

The total driver power is

$$W_d = W_g + W_f + W_1$$

$$= 1.41 + 2.69 + 0.84 = 4.94 \text{ watts}$$

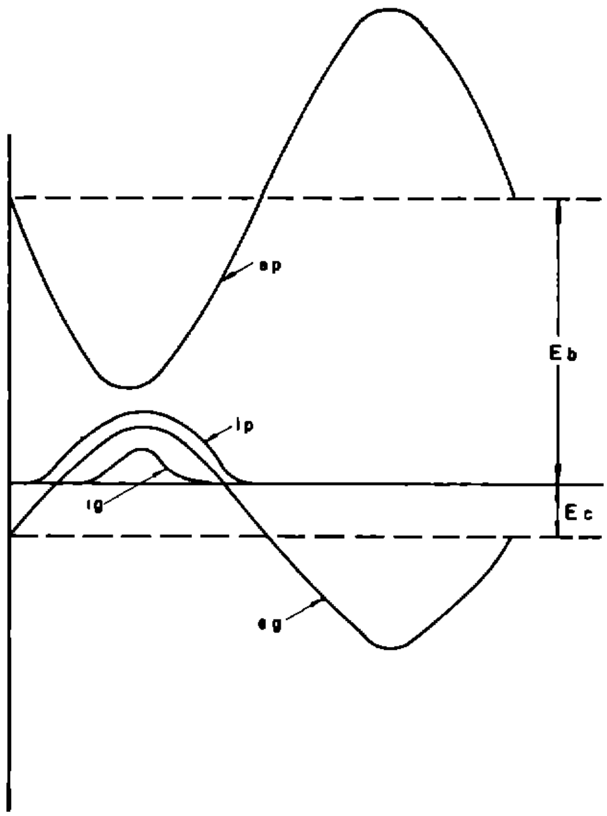

Fig. 12 Phase Relations for Voltages and Currents in Class C Amplifier

$$\text{Power gain} = \frac{74.8}{4.94} = 15.1$$

$$\text{Efficiency} = \frac{W_o}{W_{in}} = \frac{74.8}{100.0} = 74.8 \text{ per cent}$$

The calculated value of the power delivered to the load circuit exceeds the actual power delivered to the load by approximately 25 per cent. This difference between calculated and measured values may be expected since the method used in the analysis will yield a value of power output, which the power-amplifier tube together with the driver tube, delivers to the output circuit, and, this includes the losses in the output circuit as well as the power delivered to the load. Considering the frequency at which the transmitter operates, the output circuit losses do not appear to be excessive.

The inverse condition is observed in the driver circuit. The calculated driver power is approximately 20 per cent less than the measured power delivered by the driver. Here again it will be remembered that the driver stage must furnish the calculated power input required for the power-amplifier stage plus the losses in the circuits associated with the driver stage.

The efficiency calculated above is also affected by these external circuit losses. Based on the power delivered to the load, the efficiency is approximately 50 per cent.

RECOMMENDATIONS

As a result of the experimental work described in this report, the following recommendations, relating to modifications of the AN/CRN-2 transmitter, are made

1. Modify the transmitter to use Type 2C39 Tube in the tripler-driver and power-amplifier stages.
2. Provide a meter for measuring the filament voltage on the 2C39 Tubes and set the voltage to 5.2 volts.
3. Provide a bias supply in the form of a constant voltage source.
4. Provide a regulated plate voltage supply
5. Make adjustable the coupling between the driver stage and the power-amplifier stage.
6. Index the grid current meters in the driver and power-amplifier stages with a red line in order to indicate the maximum allowable grid current which can be tolerated before exceeding the manufacturer's recommended dissipation.
7. Design the condensers used for providing the rf ground for the 2C39 grids to have minimum inductive reactance and to have a capacity of approximately 200 mmf in order to provide optimum stability Hold these condensers to close tolerances.
8. Provide greater blower capacity and ventilation than are provided in the present AN/CRN-2 transmitter. The air blast should be directed toward each of the cathode stems of the 2C39 tubes in addition to the plates.

APPENDIX I

2C39 General Characteristics

Number of Electrodes 3

1. Electrical

Filament voltage	6.3 volts
Filament current	1.1 amp.
Filament power	6.93 watts
Cathode - indirectly heated	
Cathode - oxide coating	
Cathode - area	0.5 cm^2
Cathode - temperature	1050-1250°F
Cathode - color, blood red to medium cherry red	
Cathode - peak emission	0.5 amp.
Cathode - pulse emission	6.0 amp. min.
Cathode - pulse emission life	500 hrs.

2. Average Characteristics

Amplification factor	85
Grid-plate transconductance, S_n, at I_b = 75 ma	17,000 micromhos

3. Direct Interelectrode Capacities

Capacity - grid to plate	1 95 mmf
Capacity - grid to cathode	6 50 mmf
Capacity - plate to cathode	0.035 mmf

4. Maximum frequency for full power 500 Mc

5. Mechanical

Type of cooling

(a) Convection	13 watts plate dissipation
(b) Forced air	100 watts plate dissipation
(c) Maximum seal temperature	175° C
(d) Mounting position	Any
(e) Net weight, approximate	3 5 oz
(f) Grid to cathode spacing	0 005 in. approx
(g) Plate to grid spacing	0.021 in approx.

6 Maximum tube ratings

Plate dissipation	100 watts
Plate voltage	1000 volts
Plate current	75 ma
Cathode current	100 ma
Grid dissipation	3 watts
Grid voltage	-150 volts

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