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UNIVERSITY OF MICHIGAN
ENGINEERING RESEARCH INSTITUTE

ELECTRONIC DEFENSE GROUP TECHNICAL MEMORANDUM NO. 23

SUBJECT: Analysis of the Grounded Grid Power Amplifier

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I. INTRODUCTION

In the UHF and VHF ranges, the conventional grounded cathode power amplifier (see Figure 1) is limited in its applications. Some of the problems which arise as frequency is increased are as follows:

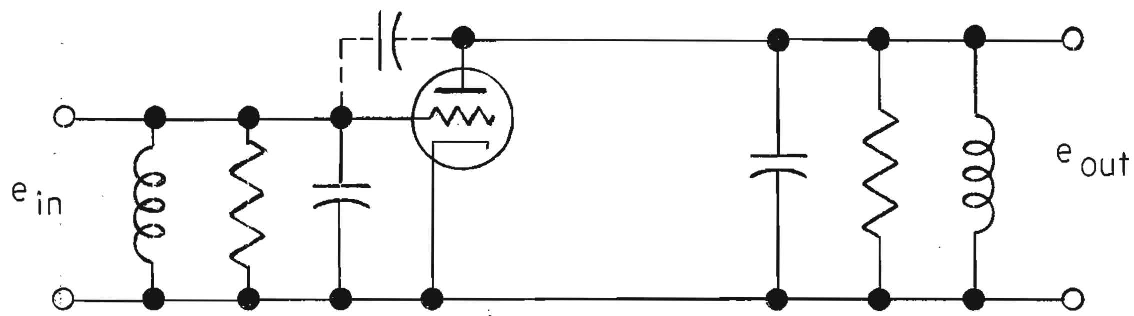
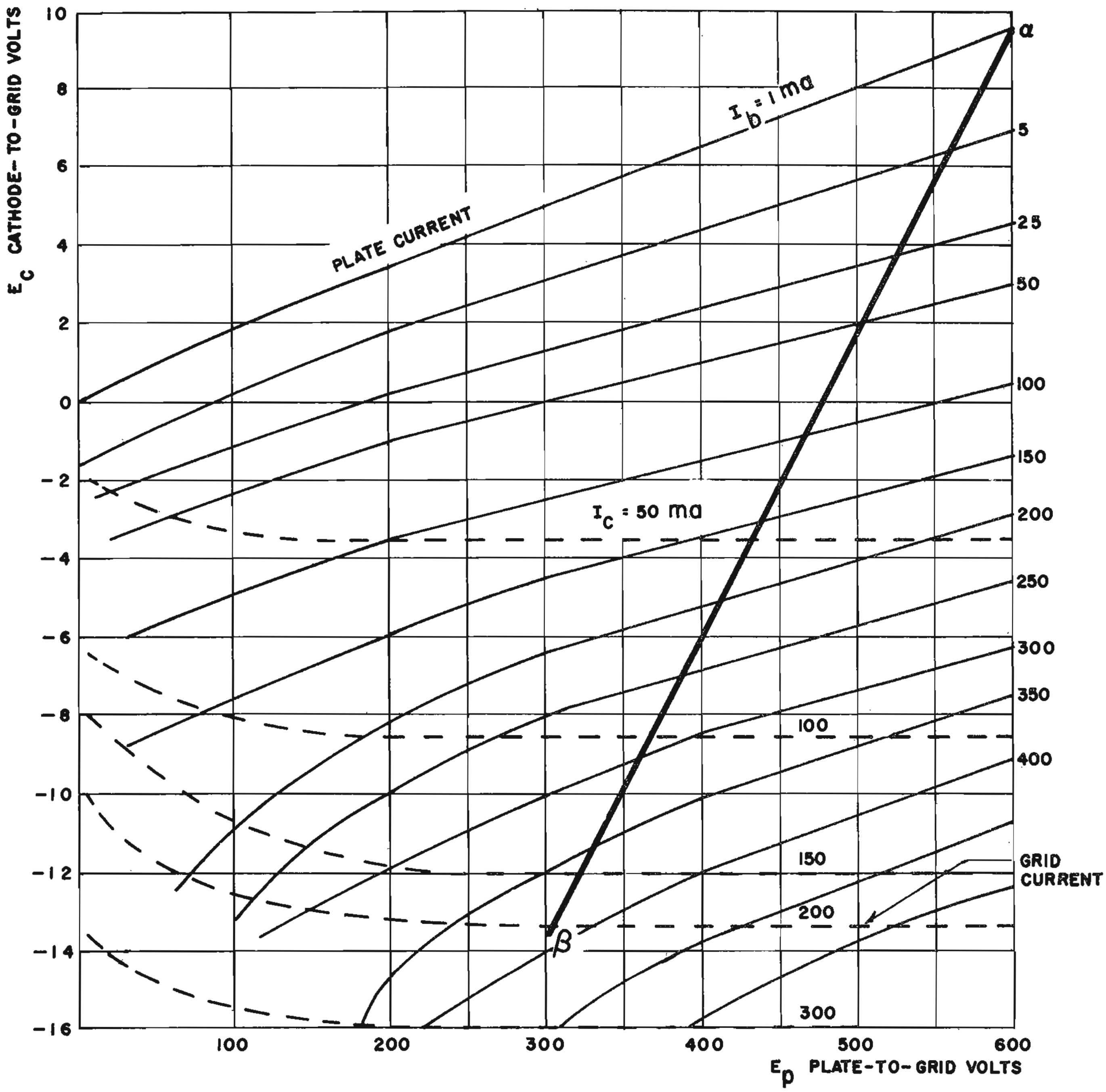


FIG. I
RF CIRCUIT OF GROUNDED CATHODE POWER AMPLIFIER

a. The grid to plate capacitance (output to input) causes a degenerative feedback which drastically reduces the gain of the amplifier, and neutralization becomes electrically critically and physically awkward.

b. If a tetrode or pentode is used to correct the problem of output-to-input capacitive coupling, transient time then becomes the limiting factor.

c. Cathode lead inductance reduces the input impedance excessively.



2C39-A CONSTANT-CURRENT CHARACTERISTICS AS GROUNDED-GRID POWER AMPLIFIER

FIG. 3

2.3 Program, Calculator, and Experimental Results

Graphical analyses of this type generally become quite long and tedious. An example of a simple method of performing this analysis is given here. R. I. Sarbacher describes a simple calculator (given at the end of this report) for this purpose.[1] An example of the analysis procedure of a grounded grid power amplifier using the calculator on the 2C39A follows:

Step 1. Plot the characteristic curves for the 2C39-A as described in Section 1 (Plotted in Figure 3).

Step 2. Assume E_c, E_{bb}, e_c and e_p, and draw the load line as described in Section 2.

For the 2C39-A example, set:

E_{bb} = 600 v.	e_c = 23	(See Figure 4A)
E_c = +9.5 v.	e_p = 300	

This example load line is drawn on the characteristic curves (Figure 3) between points α and β. In this case the one ma constant-current curve is considered cutoff. This is Class B operation.

Step 3. Set point G of the calculator on point α of the load line. Rotate the calculator until curve A of the calculator goes through point β of the load line. Read off the values of grid and plate current at the intersections of the load line and curves A, B, C, D, E and F, and tabulate these values on Figure 4B. (Note that the load line does not necessarily have to be drawn on the characteristic curves but rather the transparent ruler enclosed with the calculator may be used.)

The average DC plate current, I_p, is given by:

$$I_p = \frac{A/2 + B + C + D + E + F}{12} \qquad (1)$$

[1] R. I. Sarbacher, "Graphical Determination of PA Performance," Electronics, December 1942.

PROGRAM SHEET NO. 1 FOR CLASS B, AND C GROUNDED GRID POWER AMPLIFIER ANALYSIS

GIVEN — OPERATION Class B — TUBE TYPE 2C39-A

E_{bb} 600 $\qquad e_c$ 23

E_c +9.5 $\qquad e_p$ 300

FIND

I_p 0.107 $\qquad I_g$ 0.043 $\qquad I_c$ 0.150

i_p 0.178 $\qquad i_c$ 0.254

RF Power Out $= \frac{e_p i_p}{2} =$ 26.7 watts

Power Input to Plate $= E_{bb} \times I_p =$ 64 watts

Efficiency $= \frac{\text{Power Out} \times 100}{\text{Power Input to Plate}} =$ 42 %

Plate Dissipation = Power Input to Plate - RF Power Out 37.3 watts

RF Power Input to Grid $= \frac{e_c i_c}{2} =$ 2.92 watts

Power Gain $= \frac{\text{RF Power Out}}{\text{RF Power In}} =$ 9.2

Plate Circuit Impedance $= \frac{e_p}{i_p} =$ 1680 ohms

Input Impedance $= \frac{e_c}{i_c} =$ 90.5 ohms

E_{bb} = DC Plate to Grid Voltage

e_p = Peak RF Plate to Grid Voltage

I_p = DC Plate Current

i_p = Peak RF Fundamental Plate Current

E_c = DC Cathode to Grid Voltage (Bias)

e_c = Peak RF Cathode to Grid Voltage

I_c = DC Cathode Current

i_c = Peak RF Fundamental Cathode Current

I_g = DC Grid Current

i_g = Peak RF Fundamental Grid Current

Figure 4A

PROGRAM SHEET NO. 2 FOR CLASS B AND C GROUNDED GRID POWER AMPLIFIER ANALYSIS

PLATE CURRENT		+	GRID CURRENT		=	CATHODE CURRENT	
A	0.38		A'	0.20		A"	0.58
A/2	0.19		A'/2	0.10		A"/2	0.29
B	0.37		B'	0.175		B"	0.545
C	0.33		C'	0.130		C"	0.46
D	0.24		D'	0.08		D"	0.32
E	0.12		E'	0.03		E"	0.15
F	0.03		F'			F"	0.03
S	1.28	+	S'	0.515	=	S"	1.795

$$I_p = \frac{S}{12} = 0.107$$

$$I_g = \frac{S'}{12} = 0.043$$

$$I_c = \frac{S''}{12} = 0.150$$

Figure 4B

The fundamental RF plate current, i_p, is:

$$i_p = 1/12\left[A + 1.932B + 1.732C + 1.414D + E + 0.518F\right]$$

The fundamental RF grid current is:

$$i_g = 1/12\left[A' + 1.932B' + 1.732C' + 1.414D' + E' + 0.518F'\right]$$

The fundamental RF cathode current is:

$$i_c = i_g + i_p$$

These quantities should be recorded on Figure 4A.

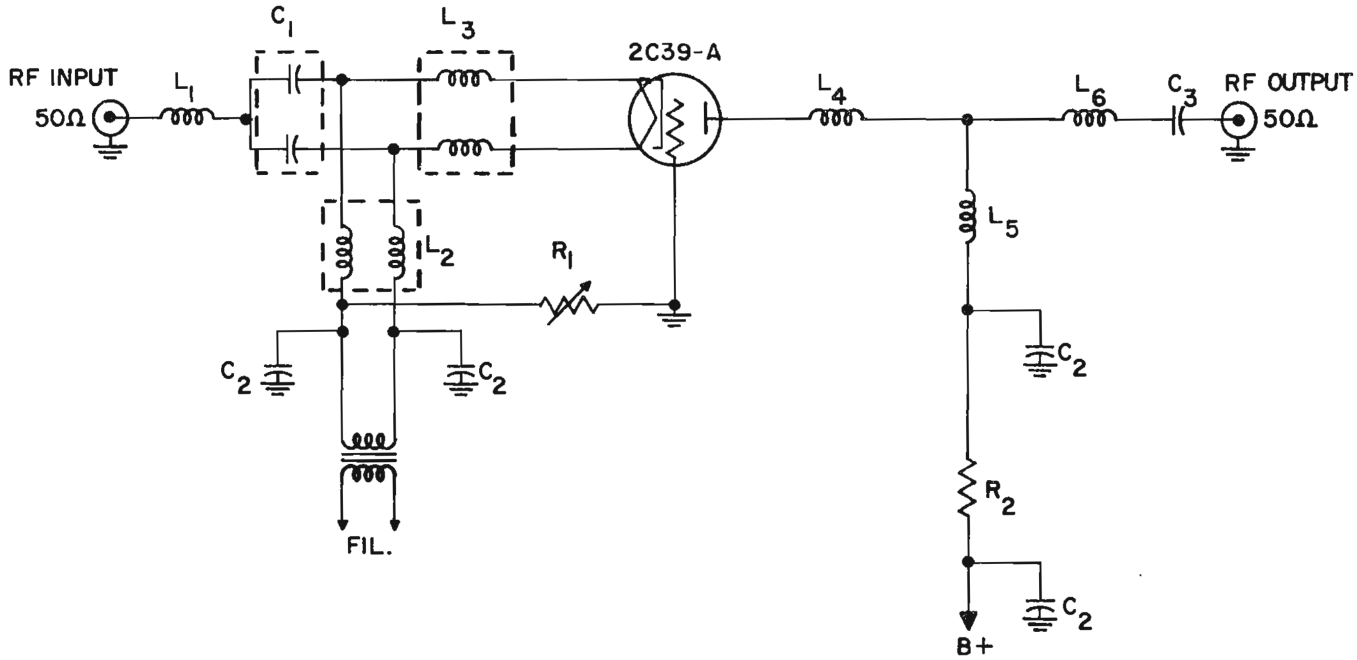
Step 4. Other quantities such as RF power out, power input to plate, etc., are easily found at this point (See Figure 4B).

The example case given here was built and tested. The complete circuit diagram is given in Figure 5. Tchebycheff two pole minimum transmission loss matching networks were used as the RF input and output circuits.[1] The experimental results came remarkably close to the predicted results considering the fact that the normal RF plate circuit efficiency in most high frequency amplifiers is only about 80%. Compare the predicted results in Figure 4B with the experimental results given in Figure 6.

2.4 How to Choose the Best "Q" Point

The analysis of class B and C power amplifiers at best leave a great deal to be desired. Since the basic parameters (E_c, E_p, e_c and e_p) must be assumed, such important factors as gain, power out, and efficiency are not known until the analysis is completed. The question "How do I choose the basic parameters (or "Q" point) to meet my specification?" immediately arises. There is no direct answer to this question except that of using a trial and error process. Some engineering judgement is required at this point. The grounded-grid power amplifier should generally be operated as a

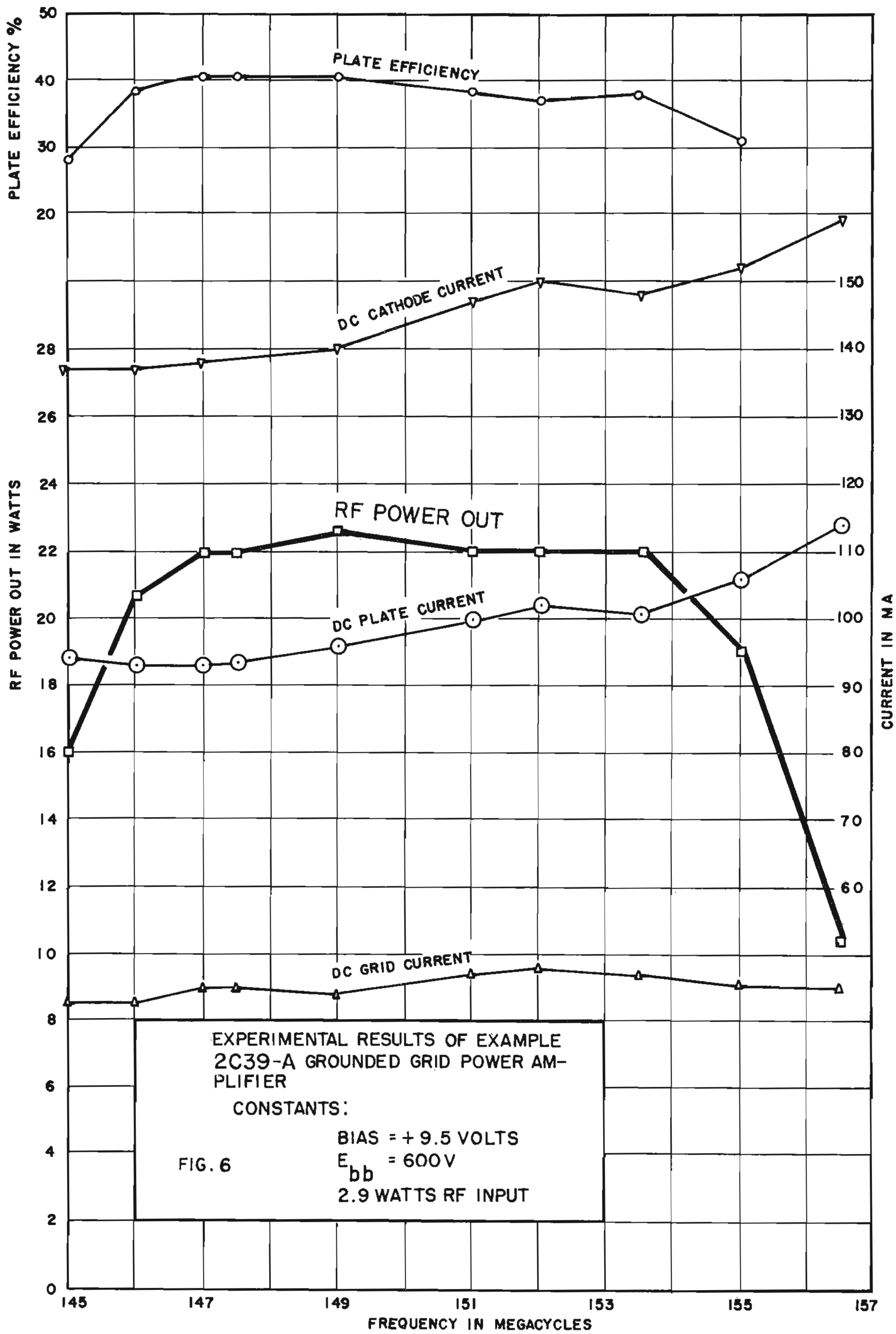
[1] J. L. Dautremont, Jr. and P. H. Rogers, "A Minimum Transmission Loss Tschebycheff Two-Pole Matching Network," Electronic Defense Group Technical Memorandum No. 17, University of Michigan, April 1955.



R_1	100 Ω POT.	L_1	0.0217 μh	
R_2	100 Ω	L_2	0.0882 μh	bifilar
C_1	27.8 μμf	L_3	0.0238 μh	"
C_2	1000 μμf	L_4	0.116 μh	
C_3	1.68 μμf	L_5	0.0241 μh	
		L_6	0.619 μh	

COMPLETE CIRCUIT DIAGRAM OF EXAMPLE 2C39-A GROUNDED GRID POWER AMPLIFIER (10mc PREDICTED OUTPUT BANDWIDTH)

FIG. 5



EXPERIMENTAL RESULTS OF EXAMPLE 2C39-A GROUNDED GRID POWER AMPLIFIER

CONSTANTS:

FIG. 6

BIAS = + 9.5 VOLTS

E_{bb} = 600 V

2.9 WATTS RF INPUT

class B power amplifier; that is, the tube should be biased to cutoff because the RF power gain and plate circuit efficiency can be made high, and the input impedance is small under this condition.[1] If the amplifier is operated far beyond cutoff then the efficiency remains high but the power gain decreases since:

$$\text{power in} = e_c^2 \, i_c$$

and

$$\text{power gain} = \frac{\text{Power out}}{e_c^2 \, i_c}$$

Note that the quantity e_c^2 will surely increase too rapidly for good power gain as the amplifier is operated farther and farther from cutoff. Moreover, if the amplifier is operated as a class "A" amplifier, the efficiency and RF power out will decrease. Hence, operation as a Class B amplifier will generally give the best results as far as plate efficiency, RF power out, input impedance, and power gain are concerned.

Also, to get the most RF power out of the power amplifier at a reasonable efficiency, the amplifier should be driven as hard as possible without exceeding the ratings of the tube used. Usually the limits will be the DC plate current and DC grid current. To find the operating point which will give the most power out with a given E_{bb} and E_c, plot the curve shown in Figure 7. Note that efficiency increases as the "limit" curves are followed to the right.

2.5 How to Find the Fundamental RF Plate Resistance R_o

Since the grounded-grid power amplifier does not approximate a constant current source, it is desirable to know the effective fundamental RF plate resistance, R_o, in order to design an efficient plate network. The usual method of finding the source impedance in a linear network is to measure the voltage across the output with two values of known resistance across the output. This results in the following (see Figure 8

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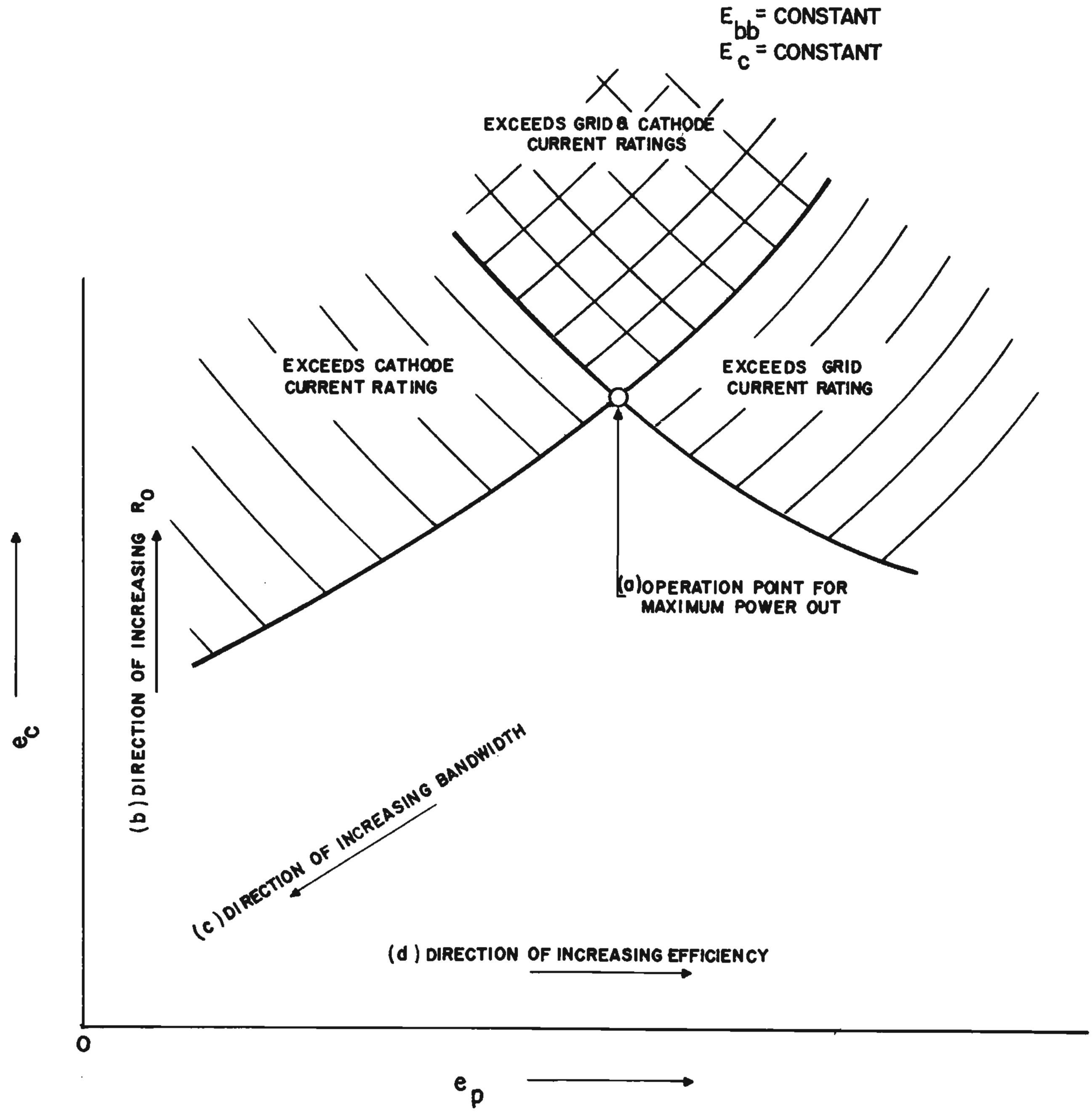
[1] The input impedance is $\frac{e_c}{i_c}$. This is small if e_c is small. A small input impedance decreases the plate to cathode capacitive feedback and makes the input matching problem easier.



LOCATION OF THE OPERATION POINT FOR MAXIMUM POWER OUT

FIG. 7

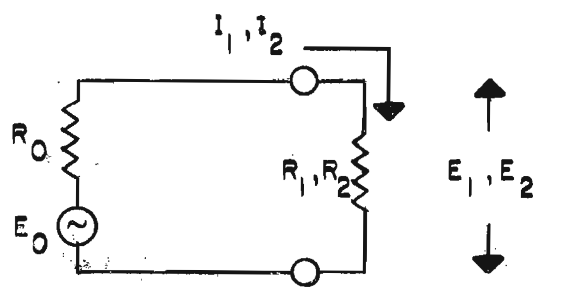
for definitions of parameters):

$$R_o = \frac{E_2 - E_1}{I_1 - I_2} \qquad -(2)$$

To find R_o for a grounded-grid power amplifier, let $(E_2 - E_1)$ and $(I_2 - I_1)$ approach zero, while holding E_{bb}, E_c, and e_c constant. This results in the following formula:

$$R_o = -\frac{ep}{ip} \qquad \begin{aligned} E_{bb} &= \text{constant} \\ E_c &= \text{constant} \\ e_c &= \text{constant} \end{aligned}$$

Hence R_o is simply the negative slope of the e_p vs i_p curve holding E_{bb}, E_c and e_c constant. (Note that e_p and i_p are RF voltages and currents). If three or four points of the e_p vs i_p curve are found, a curve may be drawn through them and the slope is obtained at the desired operating point. The "final" Q point should be known before this is done.[1] Notice on Figure 7 that R_o increases as e_c increases.



EVALUATION OF SOURCE IMPEDANCE
FIG 8

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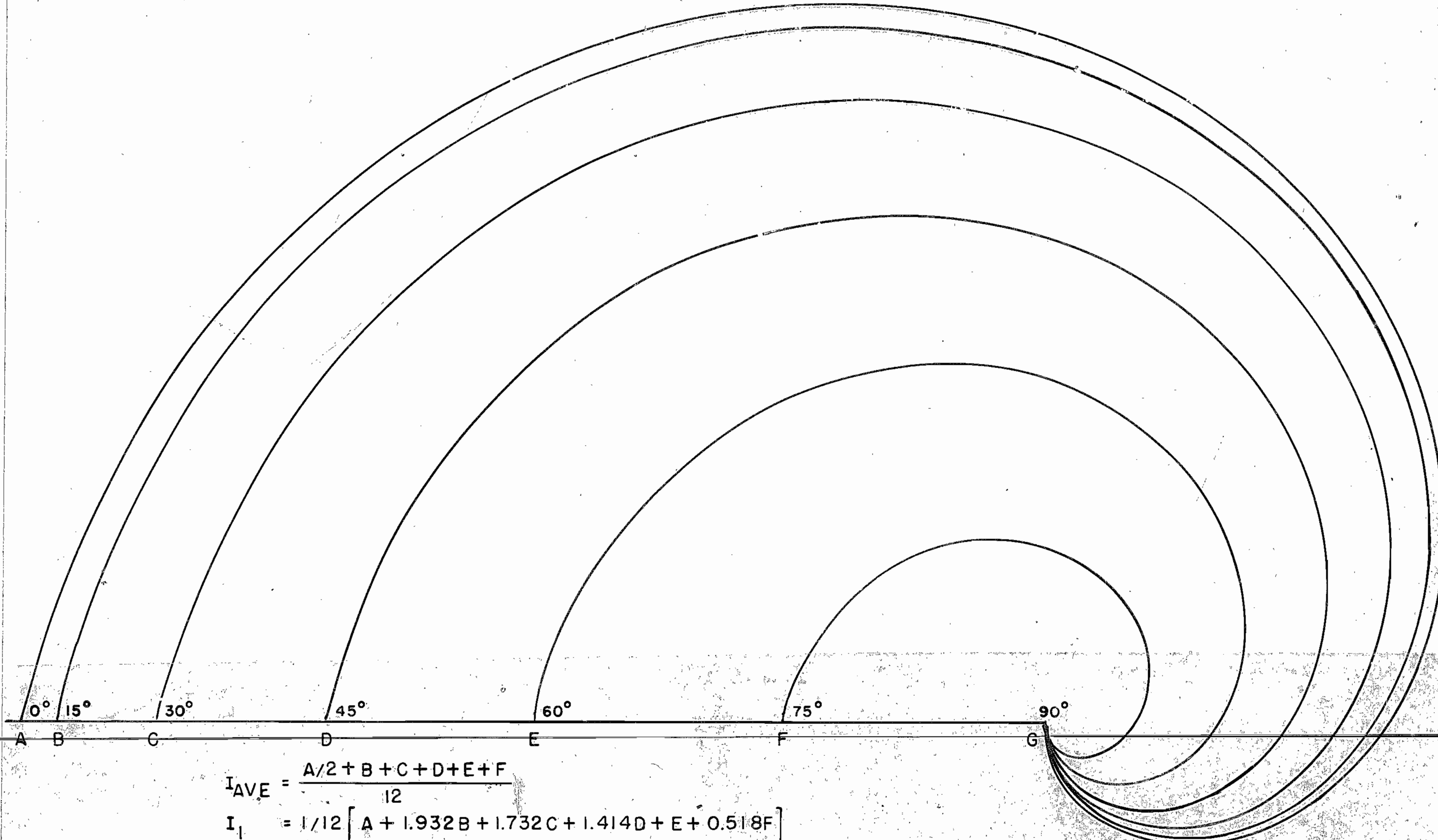
[1] R_o = 4000 for the 2C39-A example case.

2.6 Comments

To get a clear overall understanding of a grounded-grid power amplifier, carefully consider statements (a), (b), (c), and (d) of Figure 7. The only way to prove these statements is to do a complete graphical analysis of a class B grounded-grid power amplifier, plot the curve of Figure 7, and see that the statements are true.

The bandwidth of the amplifier is influenced by the RF plate circuit configuration used, the plate resistance, R_o, and the plate circuit impedance. The direction of increasing bandwidth with a given circuit configuration is shown in Figure 7.



$$I_{AVE} = \frac{A/2 + B + C + D + E + F}{12}$$

$$I_1 = 1/12\left[A + 1.932B + 1.732C + 1.414D + E + 0.518F\right]$$

CLASS B AND C

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