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DEVELOPMENT OF A VERSATILE LINEAR GRIDDED-TUBE/CAVITY UHF POWER AMPLIFIER

EIMAC

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SEMI-ANNUAL REPORT

FOR

DEVELOPMENT OF A VERSATILE LINEAR GRIDDED-TUBE/CAVITY UHF POWER AMPLIFIER

This Report Covers the Period
October 1, 1973 to April 1, 1974

TR 74-1

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CONTRACT N00123-74-C-0309

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ABSTRACT

Five (5) EIMAC type 8938 or modifications thereof were fabricated and tested over the frequency range 225 to 400 MHz. Tube modifications included (a) application of a special high temperature "Pyrogrid" grid coating, (b) application of high conductivity materials to critical parts of the tube configuration in order to reduce RF losses and provide improved thermal management, (c) the application of a coated particle cathode emitter material.

Two (2) different tunable cavities were fabricated during this period. The first, a narrow band cavity, was built in order to evaluate comparative performance of tubes (8938) and the modifications applied to those tubes. The other tunable cavity is a double-tuned iris coupled configuration and is the prototype wide band cavity for this program.

1.0 PURPOSE

The purpose of this project is to develop and demonstrate the performance of a Versatile Linear Gridded-Tube/Cavity UHF Amplifier with a minimum instantaneous bandwidth of 11.0 MHz and an average power output of 1.25KW ± 1.0 dB over the 225 to 400 MHz frequency band.

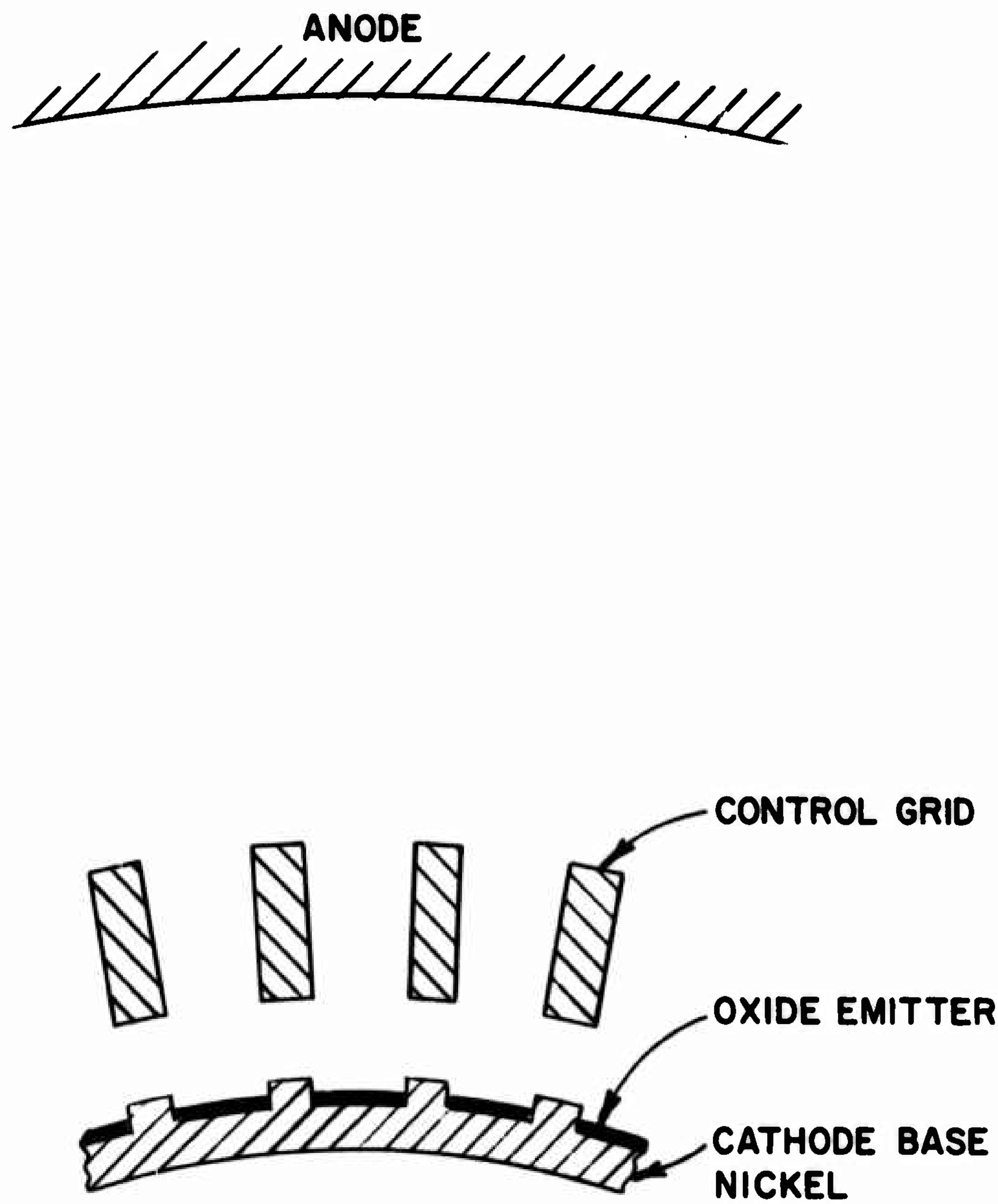
The amplifier design is based on the measured performance of the EIMAC type 8938, a unique focused beam triode having high gain and a non-intercepting control grid. Modifications of the 8938 will be pursued in order to optimize amplifier performance.

2.0 GENERAL FACTUAL DATA

2.1 The EIMAC 8938 Focused Beam Triode (Segmented Cathode)

The EIMAC 8938 is a coaxial based triode electron tube for zero-bias or low-bias operation at high plate voltages. The tube has low ratio of grid-to-plate current even at high positive grid voltages. This is accomplished by use of a segmented-emitter cathode, which, in conjunction with a deep vane control grid, forms ribbon-shaped electron beams that pass between the control grid vanes with very little interception.* This triode design has high gain and high efficiency with very low feedback capacitance from anode to cathode in cathode-driven

*See Figure 1



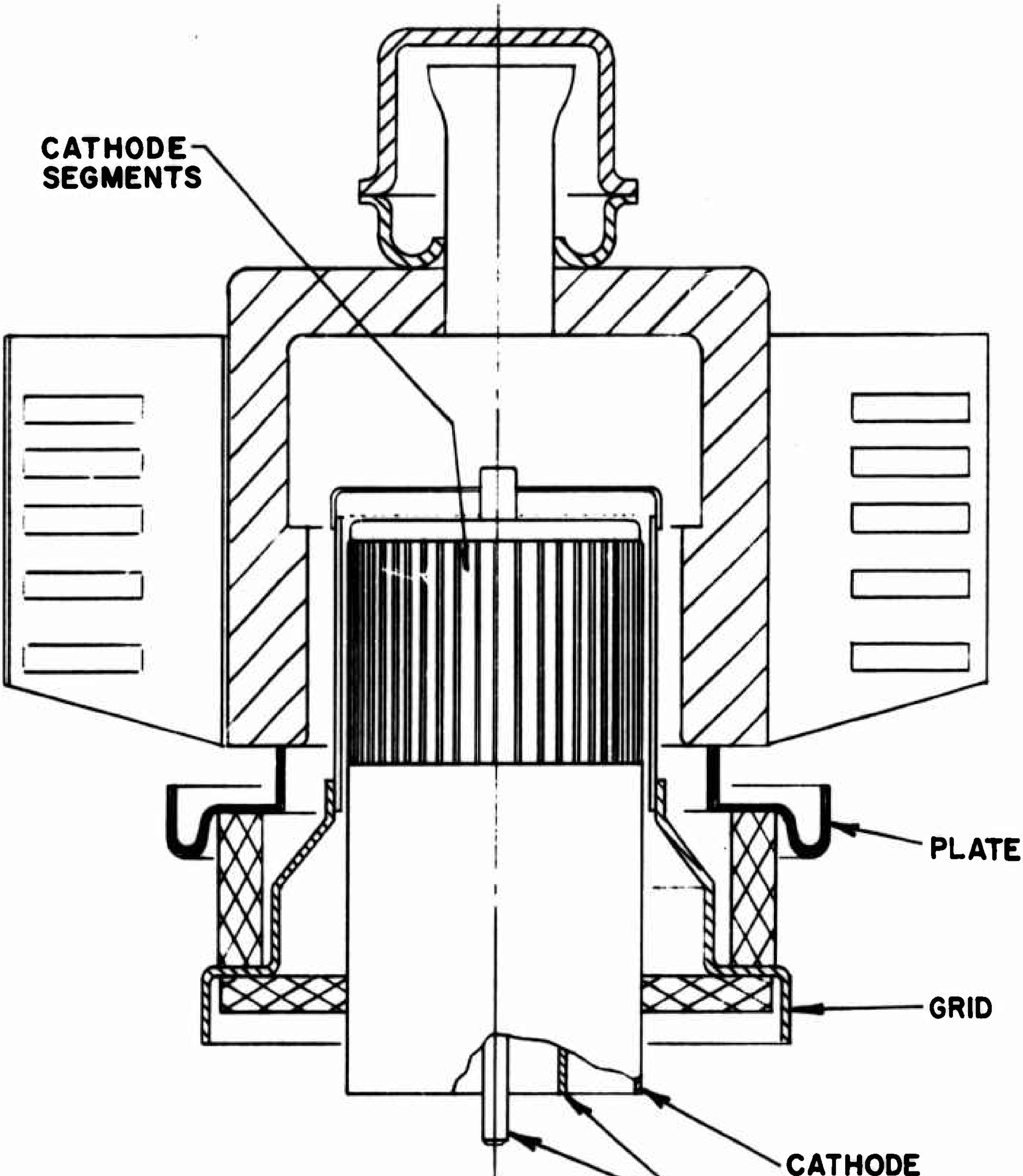
TRANSVERSE SECTION OF 8938 TRIODE
SHOWING SEGMENTED CATHODE

FIG. 1

(grounded-grid) amplifiers. The grid-to-plate amplification factor is great enough to eliminate the requirement for bias voltage in an amplifier so that only one power supply (the plate supply) is required; yet the grid current at peak positive grid-to-cathode voltage can be made to be very low. Thus the grid dissipation power will be low and high power output can be obtained.

The electrical characteristics of this triode are obtained by the unique construction of the cathode and control grid and by the geometrical relationship between the control grid and cathode. The cathode is a metal cylinder with shallow, longitudinal grooves cut into the outer surface and equally spaced around the periphery. These grooves are partially filled with the thermionic electron emitter "oxide cathode mix". The grid is a cylindrical array of metal bars approximately rectangular in section with the narrow side facing the non-emitting metal surface ("land") which lies between the emitting grooves. The segmented cathode and aligned bar grid provides excellent electron beam focusing and minimizes grid current interception. The 8938* has been laboratory tested in radio frequency amplifiers up to 900 MHz. Gains as high as 11 to 14 decibels have been attained using grounded-grid circuitry. The high-mu feature of the tube accounts for the high gain. The tube can be used with zero bias up to a plate potential of 3000 volts. If bias is

*See Figure 2



SECTION OF 8938 TRIODE

FIG. 2

desired to reduce the idling plate current, it is usually quite low - six to thirty volts. Also, the focusing action of the cathode and grid structures reduce the grid interception current to 10 or 15% of the plate current. Therefore, very little radio frequency drive power is necessary to overcome the bias. In addition, since the peak drive voltage is low, the radio frequency charging current is low. Both features are necessary to attain high gain and to minimize circuit heating and thermal drift.

An examination of the constant current plate characteristics* as compared to a typical set of tetrode curves will show a remarkable similarity. The constant current lines are almost horizontal indicating very high plate resistance typical of a tetrode. In the UHF region, the grounded-grid 8938 provides roughly the same gain as a tetrode with far less circuit complexity and fewer power supplies.

2.2 The Coated-Particle-Cathode (CPC)

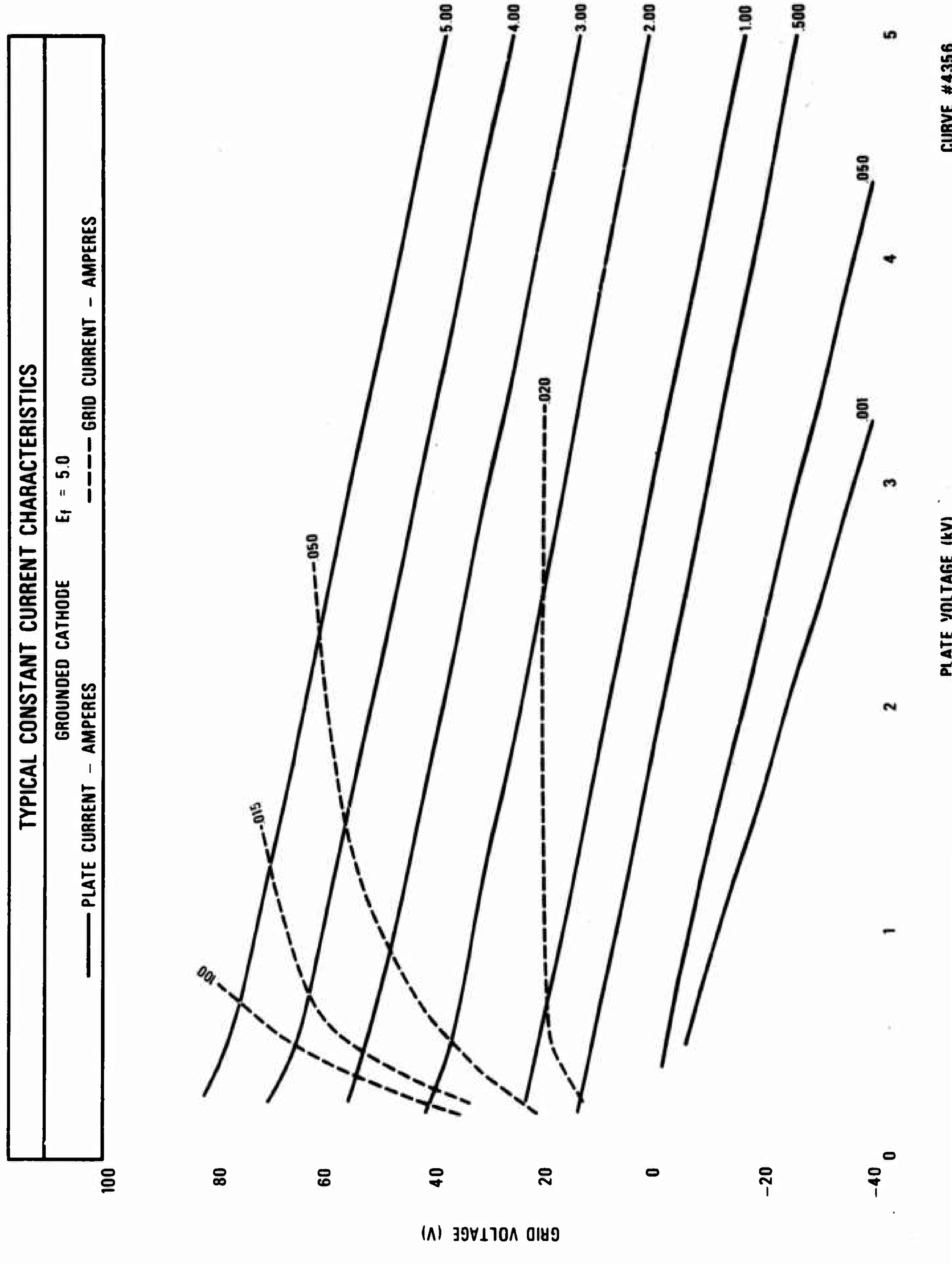
The Coated-Particle-Cathode (CPC) was originated by Maurer and Pleass** of Bell Laboratories. It utilizes a thin coating of nickel covering each particle of an oxide cathode. The nickel coating constitutes one to three percent of the total weight and is applied to the finely-divided carbonate powder prior to application to the cathode base material.

*See Figure 3

** D.W. Maurer & C.M. Pleass, Bell System Tech., J., Dec. 1967, pp 2375-2404.

FIG. 3

8938



TYPICAL CONSTANT CURRENT CHARACTERISTICS
GROUNDED CATHODE
E_f = 5.0
PLATE CURRENT – AMPERES
GRID CURRENT – AMPERES
5.00
4.00
3.00
2.00
1.00
.500
.050
.001
.020
.050
.015
.100
100
80
60
40
20
0
–20
–40
GRID VOLTAGE (V)
0
1
2
3
4
5
PLATE VOLTAGE (kV)

The nickel film inhibits crystal growth and sintering of the oxide particles, enhances electrolytic activation of the oxide, and improves conductivity, according to Maurer and Pleass.

The peak emission capability of the CPC is comparable to the standard oxide cathode; i.e., better than 15 amperes per square centimeter at 825 degrees centigrade true temperature.

In the CPC, a cathode material is available which combines high average current capability, high peak emission, and a low barium sublimation rate, and which is readily applied with conventional oxide-cathode techniques.

The CPC cathode material has been incorporated in the X2135H version of the 8938. Performance data are presented in Section 3.

3.0 DETAILED FACTUAL DATA

3.1 Thermal Management of Triode Amplifier Tubes

3.1.1 RF Conductivity of Electrodes

An anlysis of the conductivity of the electrode supports of the type 8938 triode was made. This analysis takes into account the effect of frequency on the skin resistance of metals and coatings used.

The grid support of the type 8938 triode is made of nickel and the sealing ring and the plate contact flange are made of Kovar alloy. Nickel has a moderate resistance and has an initial permeability (μ_i) of 100 to 200. Kovar has a high specific resistance and a high initial permeability, greater than 1000 at room temperature. However, the Kovar parts are external and are normally silver plated and brazed to the ceramic insulators with copper-silver eutectic alloy which is highly conductive but which, because it is thin, does not increase the thermal conductivity of the Kovar. The calculated skin resistance of the grid support of the 8938 was 0.017 ohms. When the load current and the displacement currents flow through this resistance, the dissipation in the support will be about 7 watts. This additional power which must be removed by conduction to the external contact flange and thence to the cooling air reduces the grid dissipation capability of the tube. The resistance of the surface of the grid support which faces the cathode gives rise to extra power consumption and negative feedback in the input circuit.

3.1.2 X2135J Triodes with High Conductivity Electrodes.

Three tubes (type X2135J) were made with copper-clad seals, plate contact flanges, and grid supports. The thickness of the copper was 0.002 inches, each surface.

The rf resistance of the grid support was thereby reduced from 0.017 ohms (8938) to less than 0.004 ohms, each side. Also, the thermal conductivity of the support and the sealing rings and the plate contact flange was increased by an order of magnitude. These two effects, decrease in rf resistance and an increase in thermal conductivity, will permit operation at 5 to 10 watts greater grid description and improve power gain and efficiency of the tube.

These tubes were tested in a 900 MHz amplifier cavity in order to accentuate differences in rf loss caused by the change in tube materials. The results are compared to results from an 8938 in the table below. All tubes were operated at the same plate input power and loading.

3.2 Performance of an 8938 and X2135J at 900 MHz - TABLE I.

Type	Serial No.	Pout Watts	Pdrive Watts	Gain db
8938		378	30	11.0
X2135J	B4C-78	434	20	13.4
	B4C-79	440	21	13.2
	B4C	440	26	12.3

3.3 X2135P Triode with "Pyrogrid"* Grid Coating

The X2135P which incorporates a "Pyrogrid" grid coating has passed the specification tests for the 8938. Performance

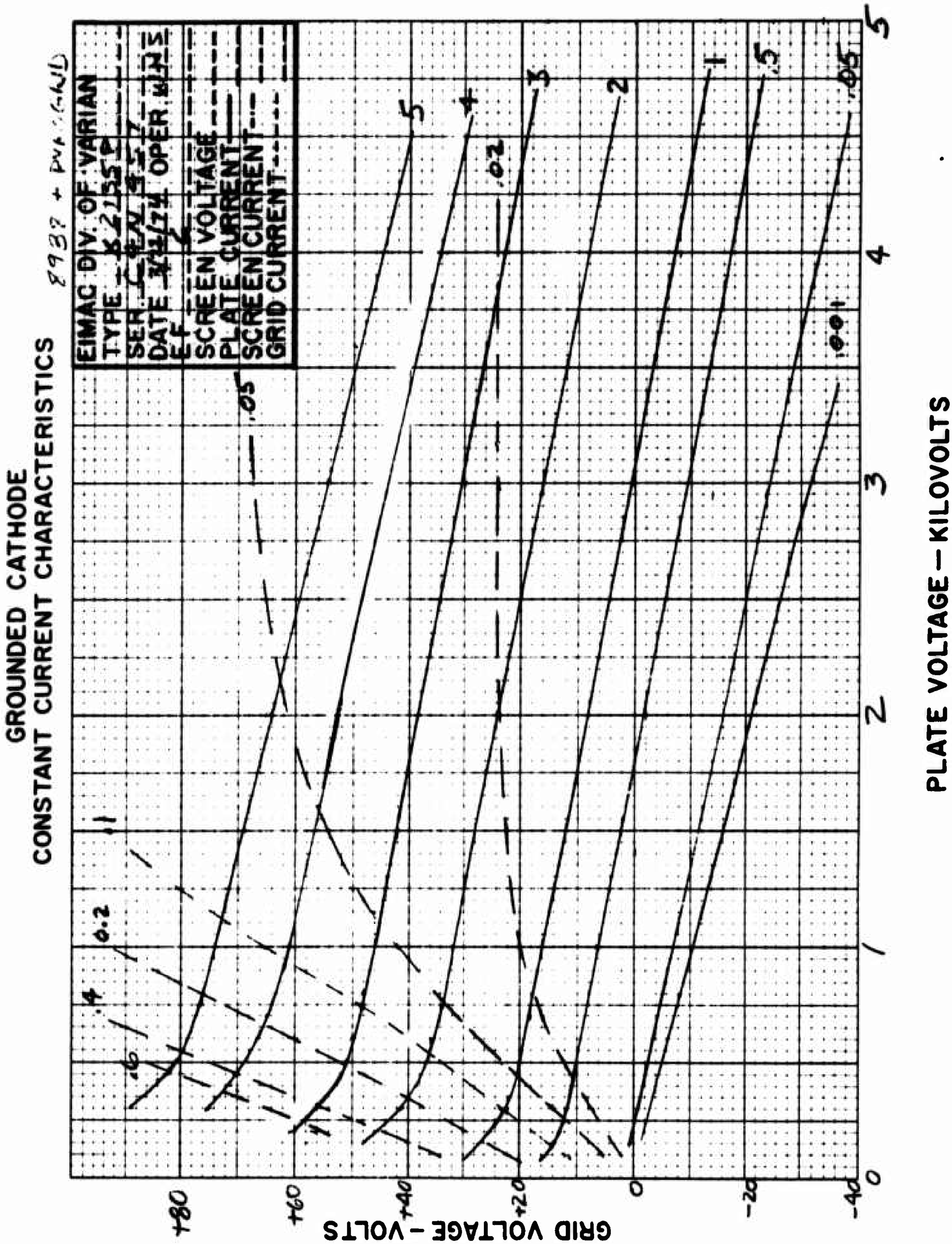
*Carbon-titanium grid coatings "Pyrogrid", were developed in mid 1967 at EIMAC which compared favorably with gold under normal operation and in addition permitted operation substantially over normal ratings without excessive grid emission or cathode poisoning. The coatings are applied by plating from a glow discharge with controlled mixtures of hydrocarbons, inert gasses and metal vapors. The general process is described in U.S. Patent 3,604,970 issued to EIMAC 14 September, 1971.

data are provided in Table II, page 16.

Figure 4 shows a set of constant grid and plate current curves for the X2135P. These characteristic curves are very similar to the 8938 characteristics except that the grid current is higher at high positive grid voltages. The reason is that the "Pyrogrid" coating has a much lower secondary electron emission current ratio; i.e., ratio of secondaries to primaries. This ratio is always less than one, therefore the grid current will always be positive in sign. The result should be an improvement in stability of operation and less tendency to oscillate.

Figure 5 is a photograph of a "Pyrogrid" coated grid such as that used in the X2135P.

FIG. 4



GROUNDED CATHODE
CONSTANT CURRENT CHARACTERISTICS
EIMAC DIV. OF VARIAN
TYPE
SER.
DATE
OPER
SCREEN VOLTAGE
PLATE CURRENT
SCREEN CURRENT
GRID CURRENT
PLATE VOLTAGE — KILOVOLTS
GRID VOLTAGE - VOLTS
+80
+60
+40
+20
0
-20
-40
1
2
3
4
5

FIGURE 5

A "Pyrogrid" coated grid such as that used in the X2135P.

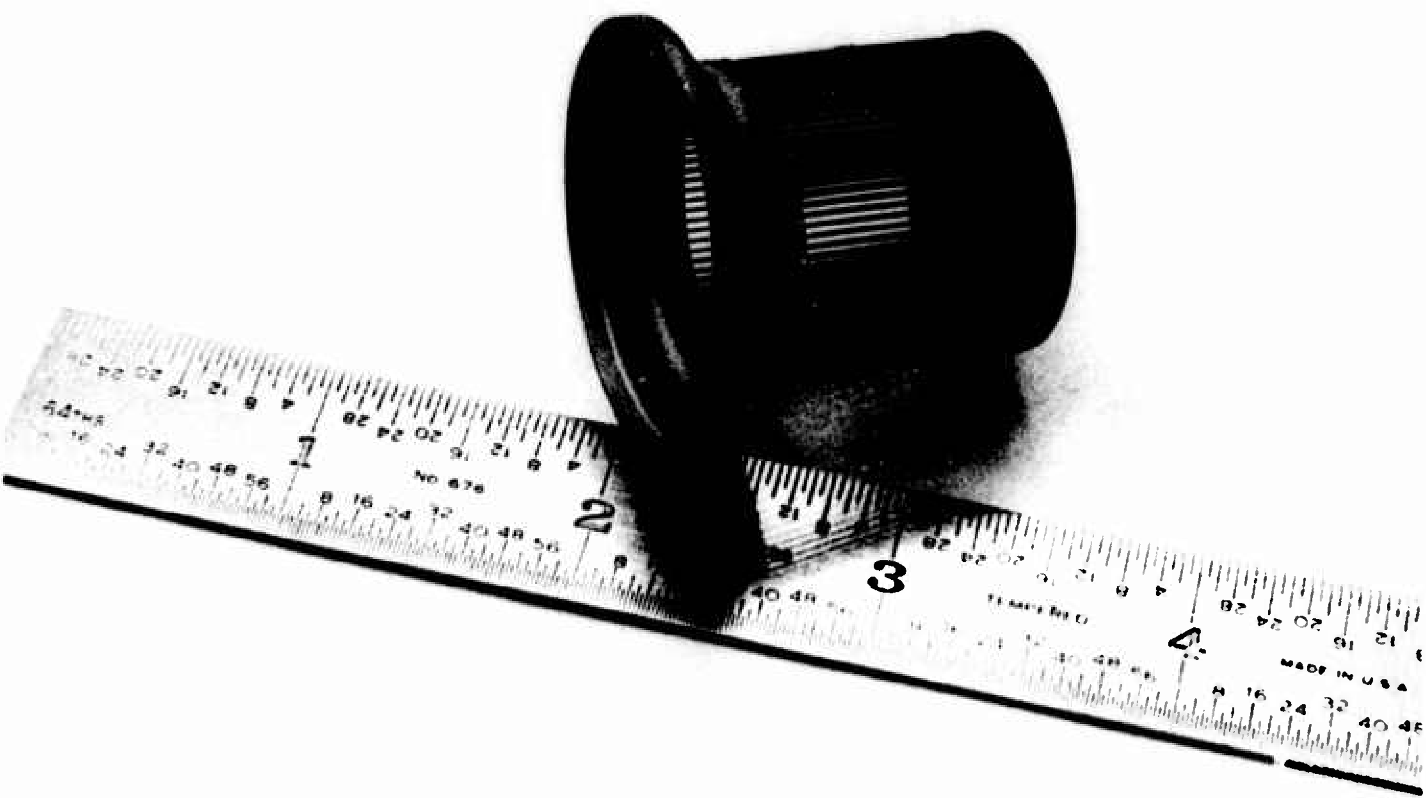
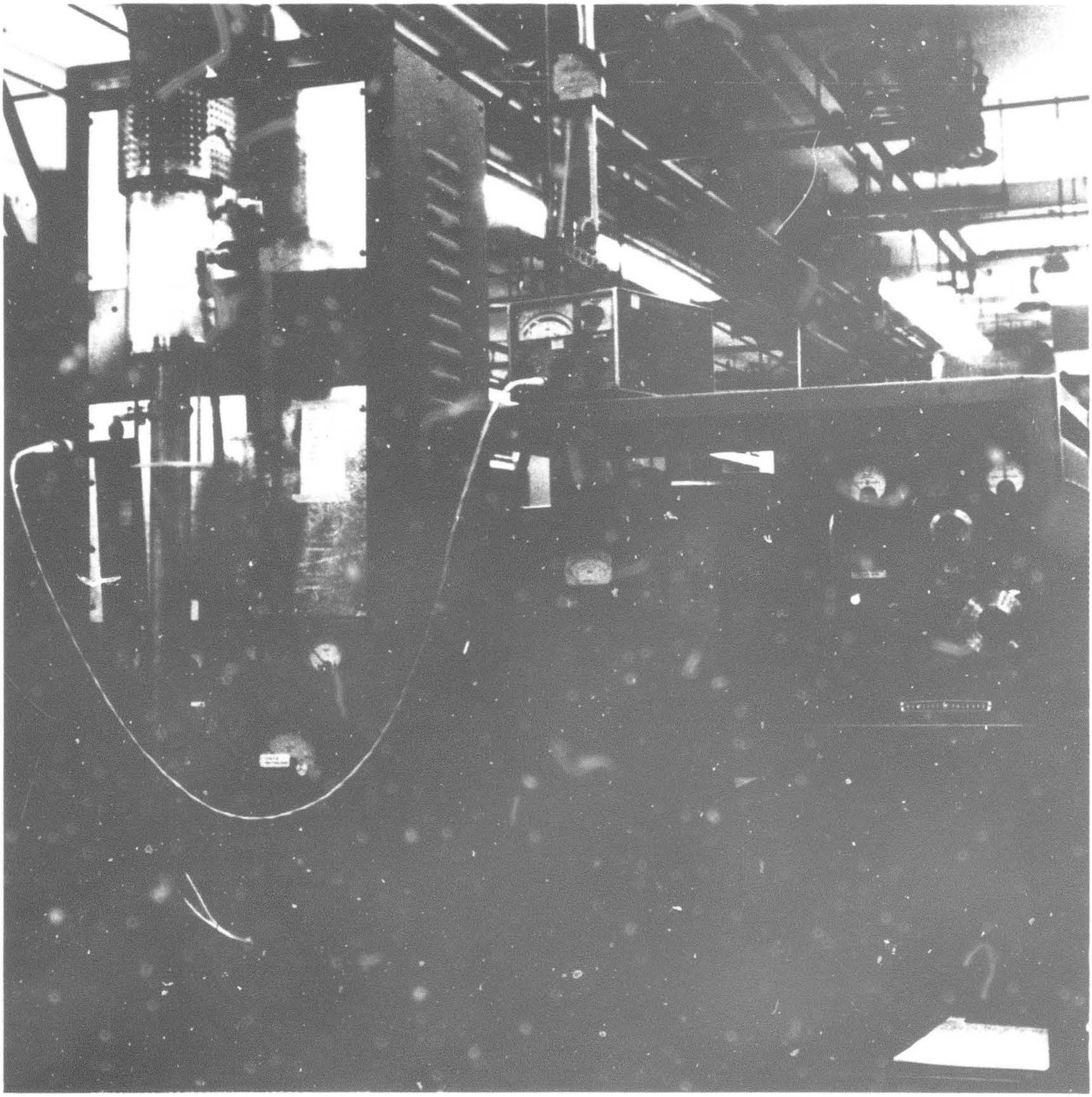


FIG. 5

FIGURE 6

TUNABLE CAVITY FOR TUBE EVALUATION

A tunable (cylindrical narrow band) cavity for tube evaluation in the 225 to 400 MHz range was completed. Figure 6 shows the cavity, rack-mounted, with power supplies and control circuitry at the left side of the photograph.



Pg. 15

FIG. 6

3.4 PERFORMANCE DATA FOR NARROW-BAND CAVITY AMPLIFIER (CATHODE DRIVEN)

TABLE II

The operating condition E_b = 1625 volts I_b = 1.4 amps. was chosen to match the calculated operating condition for optimum performance at eleven (11) MHz bandwidth.

E_b = 1625 V I_b = 1.37 to 1.4A Ibo = 300ma

Frequency	Tube	PO	Pdrive	Gain	Eff	Notes
400MHz	8938-SN-D3B-170	1140W	74.4W	11.8db	51.1%	
400MHz	X2135H-SN-M3L-584	1080	69.1	11.94	47.4	Incorporates CPC Cathode
400MHz	X2135J-SN-B4C-78	1115	57	12.9	49	Incorporates Hi conductivity modification
400MHz	X2135J-SN-B4C-79	1115	58.4	12.8	49	"
400MHz	X2135J-SN-B4C-80	1080	63.7	12.3	47.5	"
400MHz	X2135P-SN-C4N-457	1159	73	12.0	52	Incorporates "Pyrogrid" grid coating
300MHz	8938-SN-D3B-170	1310	84.3	11.9	58.4	
300MHz	X2135J-SN-B4C-78	1267	68.6	12.65	55.6	Inc.Hi-conduct: Mod.
300 MHz	X2135J-SN-B4C-79	1258	69.6	12.56	55.2	"
300MHz	X2135P-SN-C4N-457	1285	90.2	11.55	57.3	"Pyrogrid"
225MHz	8938-SN-D3B-170	1150	82.5	11.45	61.5	(I_b = 1.15A)
225MHz	X2135P-SN-C4N-457	1280	76	12 25	62.5	(I_b = 1.26A) "Pyrogrid"

FIGURE 7

Figure 7 is a photograph showing the prototype, tunable, broadband cavity (on the table at the center of the photograph. The cavity has a double-tuned output circuit with iris coupling between the cavities. Cold tests have been performed on this cavity. The initial data are presented in Figure 8 (Loaded Q vs. distance).

FIG. 7

FIGURE 8

Figure 8 shows a sketch of the doubled-tuned prototype cavity and a curve of the coupling cavity loaded Q as a function of a capacitive loading parameter.

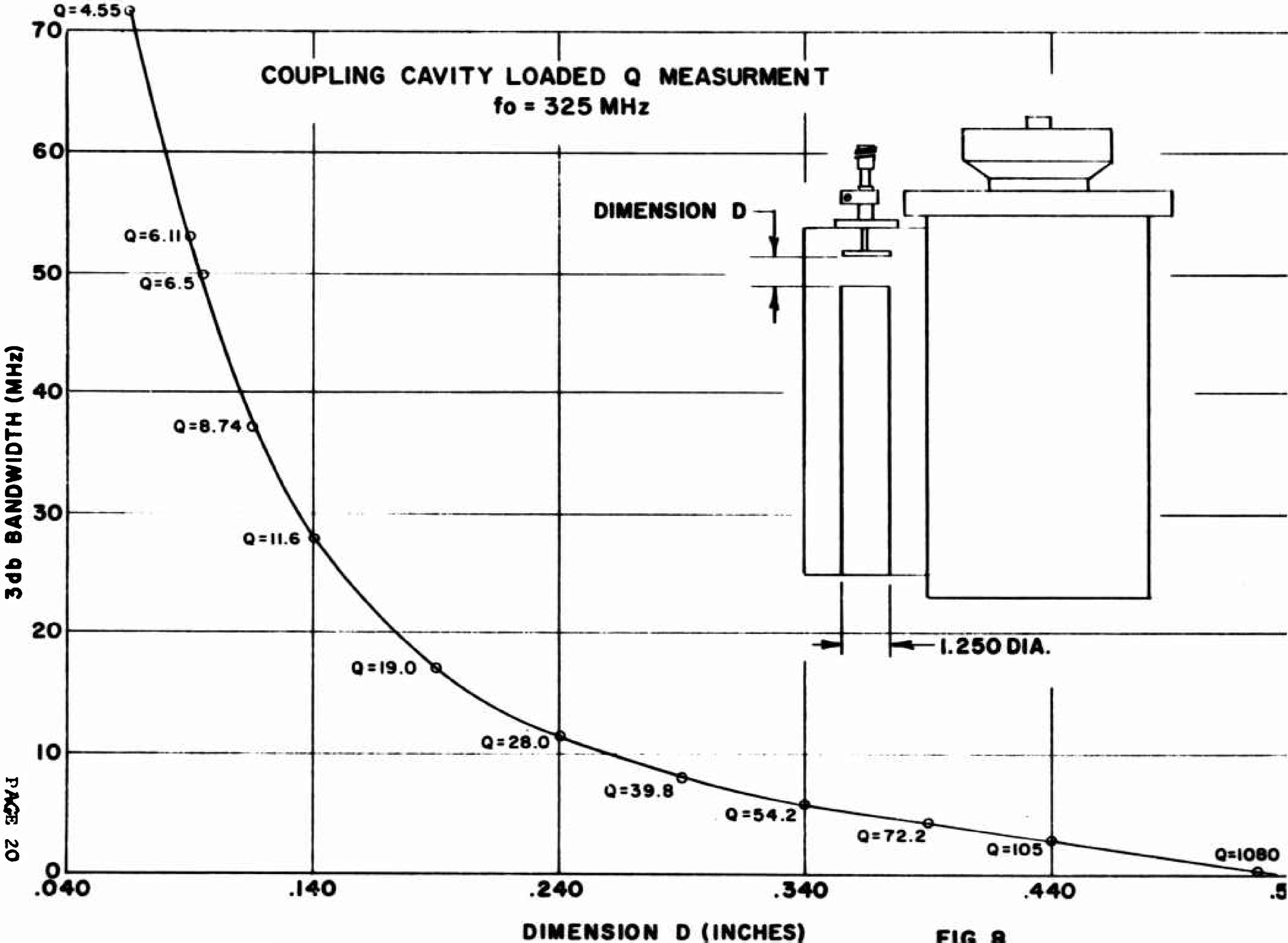

COUPLING CAVITY LOADED Q MEASURMENT
fo = 325 MHz
DIMENSION D
1.250 DIA.
3db BANDWIDTH (MHz)
70
60
50
40
30
20
10
0
.040
.140
.240
.340
.440
.5
DIMENSION D (INCHES)
Q=4.55
Q=6.11
Q=6.5
Q=8.74
Q=11.6
Q=19.0
Q=28.0
Q=39.8
Q=54.2
Q=72.2
Q=105
Q=1080

FIG 8

4.0 CONCLUSIONS

The comparative data presented in Table II, taken in the narrow band cavity amplifier, indicate that the type 8938 triode and the modified versions of it give approximately equivalent performance over the 225 to 400 MHz frequency range.

The narrow-band results at 225 and 300 MHz are satisfactory. Further optimization is required at the 400 MHz end of the tuning range.

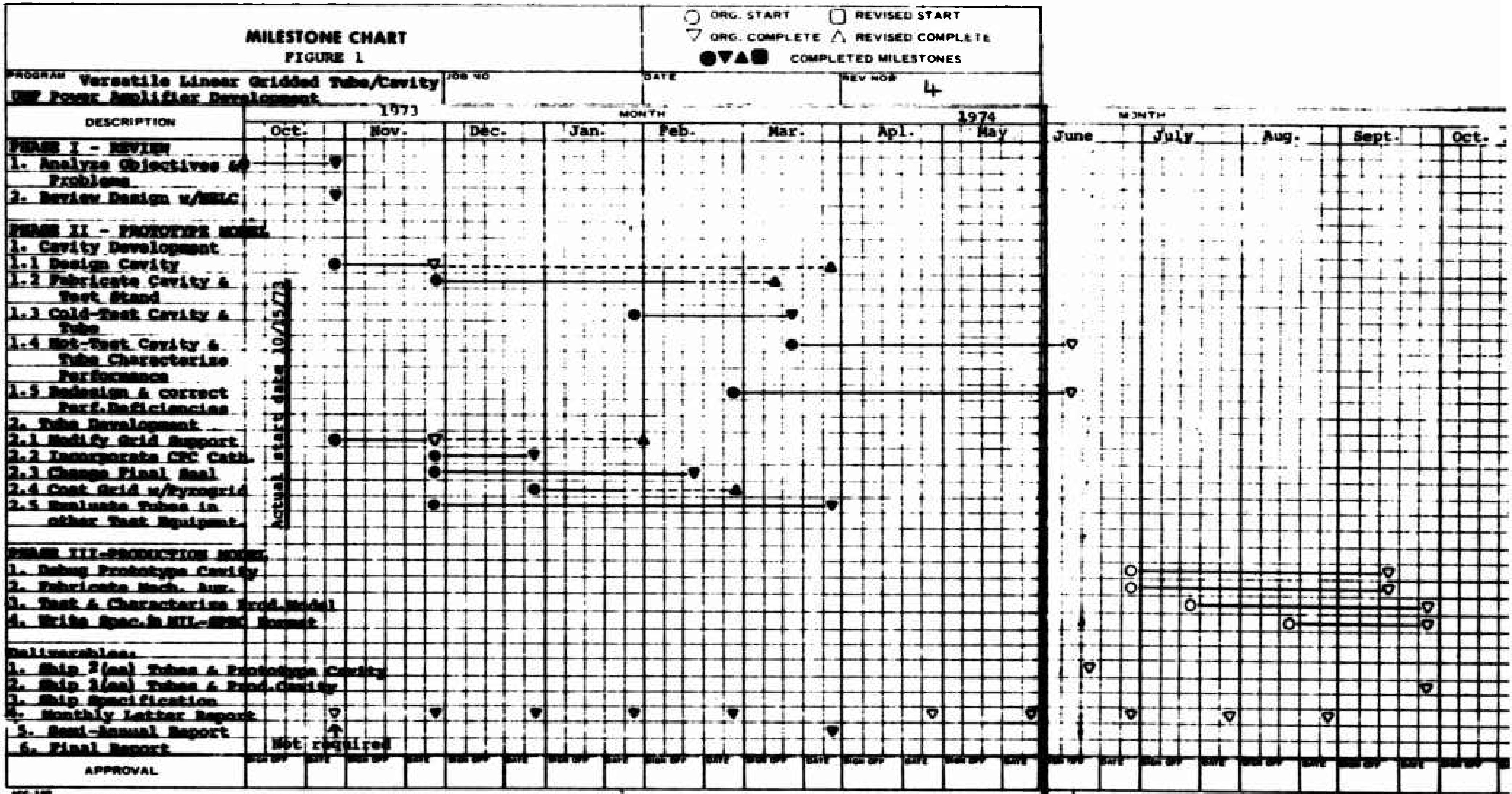
The circuit efficiency of the double-tuned cavity is expected to be lower than that of the narrow-band cavity. Thus the initial performance of the broadband cavity amplifier will probably be somewhat poorer than was achieved in the narrow-band amplifier.

5.0 PROJECT PERFORMANCE & MILESTONE CHART

The expenditures to 3/22/74 were $39,285. Manhours expended were 1,131., The Project Milestone Chart is provided in Figure 9.

6.0 PLANS FOR THE NEXT INTERVAL

Further effort will be devoted toward optimizing the design of the prototype cavity. Broadband amplifier performance measurements will be initiated.



*Revision #1 November 28, 1973

Revision #2 December 31, 1973

Revision #3 January 31, 1974

Revision #4 February 28, 1974

Revision #5 ____________

FIG. 9