THE UNIVERSITY OF MICHIGAN
ANN ARBOR, MICHIGAN

QUARTERLY PROGRESS REPORT NO. 15

FOR

RESEARCH AND DEVELOPMENT ON HIGH-POWER CRESTATRONS

FOR THE 100-300 MC FREQUENCY RANGE

This report covers the period January 1, 1964 to April 1, 1964

Electron Physics Laboratory
Department of Electrical Engineering

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Project Engineer

J. E. Rowe
J. E. Rowe, Director
Electron Physics Laboratory

Project 03783

NAVY DEPARTMENT BUREAU OF SHIPS
ELECTRONICS DIVISION
CONTRACT NO. NObsr-81403
PROJECT SERIAL NO. SF0100 201
TASK NO. 9294

April, 1964

ABSTRACT

A series of trajectory plots for a reduced diameter $P_{\mu} = 20$ gun is shown. A reasonably well-behaved beam throughout the gun region is obtained. The electrostatically focused tube using one of the improved $P_{\mu} = 4.46$ guns is seen to yield only fair transmission to the collector at reduced voltages. Some low-level oscillations appear to limit the transmission.

The revised design of the 100-watt Crestatrons has resulted in a tube with sufficient gain and power output. Only very minor modifications in the design have been found to be necessary for the final tubes.

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Scientific and Engineering Personnel		Time Worked in Man Months*
J. Rowe	Professor of Electrical Engineering	.15
J. Boers	Associate Research Engineers	.93
G. Konrad		1.02
W. Rensel	Assistant Research Engineer	.46
R. Maire	Research Assistants	1.05
C. Rhee		1.81
Service Personnel		7.64

* Time Worked is based on 172 hours per month.

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RESEARCH AND DEVELOPMENT ON HIGH-POWER CRESTATRONS

FOR THE 100-300 MC FREQUENCY RANGE

1. Introduction (G. T. Konrad)

Contract NObsr-81403 comprises a research and development program on high-power 100-300 mc Crestatrons. The aim is to construct compact 100-watt Crestatrons employing permanent magnet focusing. Initially the tubes will be tested in a solenoid until they meet electrical specifications, but ultimately the permanent magnet focused tubes employing a depressed potential collector will be ruggedized so as to meet environmental specifications. This work is being conducted by the Bendix Research Laboratories on a subcontract from The University of Michigan.

Theoretical as well as experimental studies on high-perveance hollow-beam electron guns, in addition to electrostatic focusing systems initiated some time ago on this program, are being continued by The University of Michigan. The ultimate goal of these studies is to demonstrate the feasibility of using electrostatically focused, high-power, hollow electron beams in microwave devices. In addition, it is intended to work out a design for an electron gun compatible with a high-power vhf Crestatron.

2. Computer Design of High-Perveance Hollow-Beam Guns (C. K. Rhee)

A series of beam trajectories for the $P_{\mu} = 20$ gun with a smaller mean beam diameter than reported previously was obtained from the digital computer program during the past quarter. Again the strong space-charge forces presented the main difficulty in obtaining a well focused beam, as may be expected from this type of high perveance gun.

The trajectory plots of Fig. 2.1 through Fig. 2.4 show the various stages of modification in the gun geometry that were necessary in order to overcome the effects of the space-charge forces. In Fig. 2.1, for instance, the beam started to diverge even before it passed through the first anode, thus making the focusing action of the lens negligible. Figure 2.2 shows somewhat improved beam trajectories due to the placement of the focusing electrodes and the lens closer to the beam edge. However, these changes caused an appreciable drop in perveance and crossing of electron trajectories. In Fig. 2.3 the first anode was moved toward the beam edge and the lens was changed to a conical shape in an attempt to raise the perveance and to reduce the crossing of the beam trajectories. As may be seen, an improvement resulted. In order to decrease the divergence of the beam in the first anode region further, the cathode was curved, as shown in Fig. 2.4. Also, the lens was formed into a step-shape to reduce crossing of the beam trajectories. The plot in Fig. 2.4 shows satisfactory beam trajectories, although the beam diverges outside of the gun region.

During the coming quarter an axial magnetic field will be applied in the gun region in addition to electrostatic focusing fields. Both $P_\mu = 20$ guns will be programmed for digital computer solution under these conditions. It is hoped that more simple electrode geometries can be realized when the electrostatic focusing fields are reduced in the presence of magnetic focusing forces.

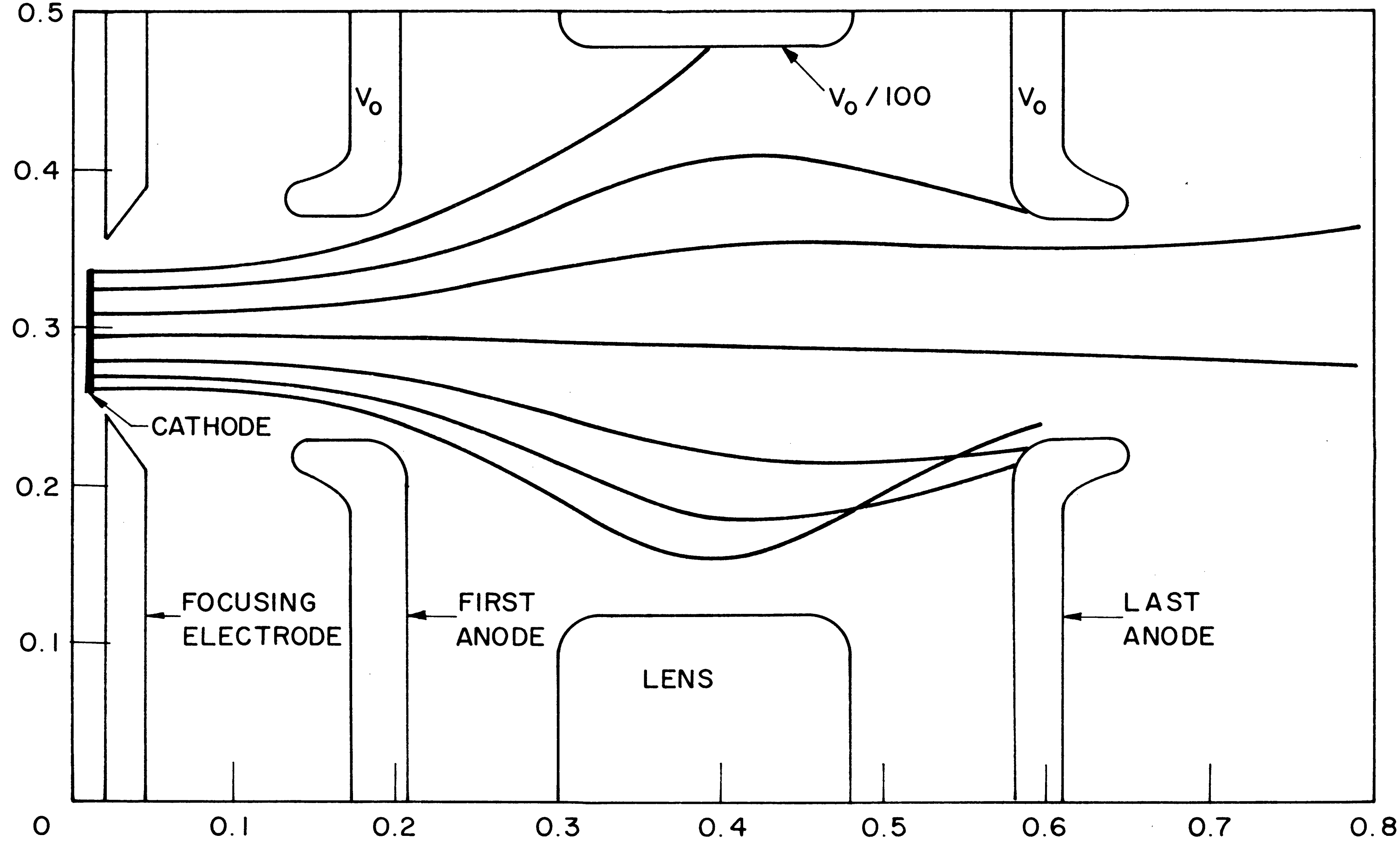

FIG. 2.1 TRAJECTORY PLOT FOR ELECTROSTATICALLY-FOCUSED P_μ = 20 GUN.

(J_o = 6.705 x 10^3 AMP/m^2, P_μ = 17.249)

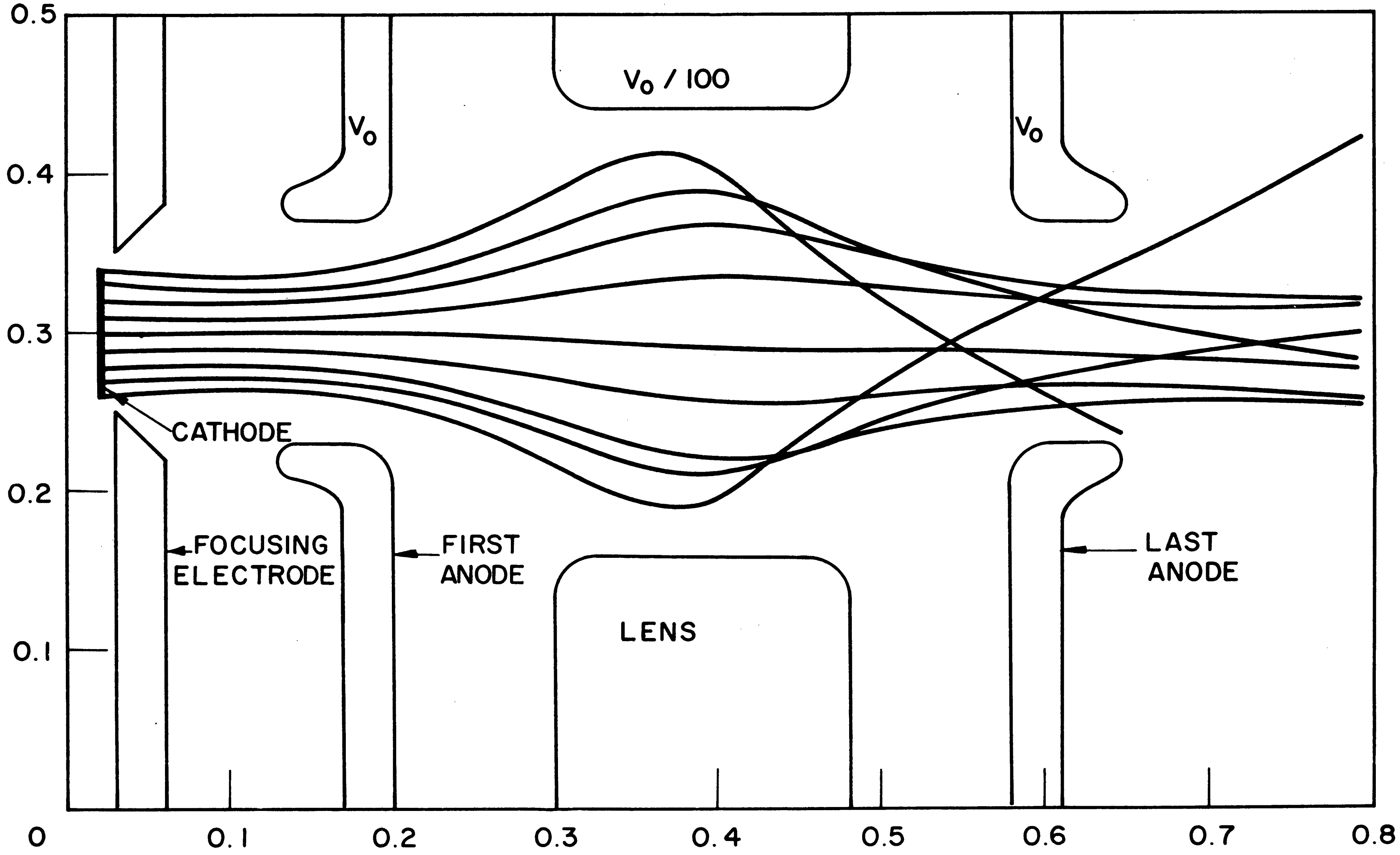

FIG. 2.2 TRAJECTORY PLOT FOR ELECTROSTATICALLY-FOCUSED P_μ = 20 GUN.

($J_o = 4.192 \times 10^3$ AMP/m^2, $P_\mu = 14.0$)

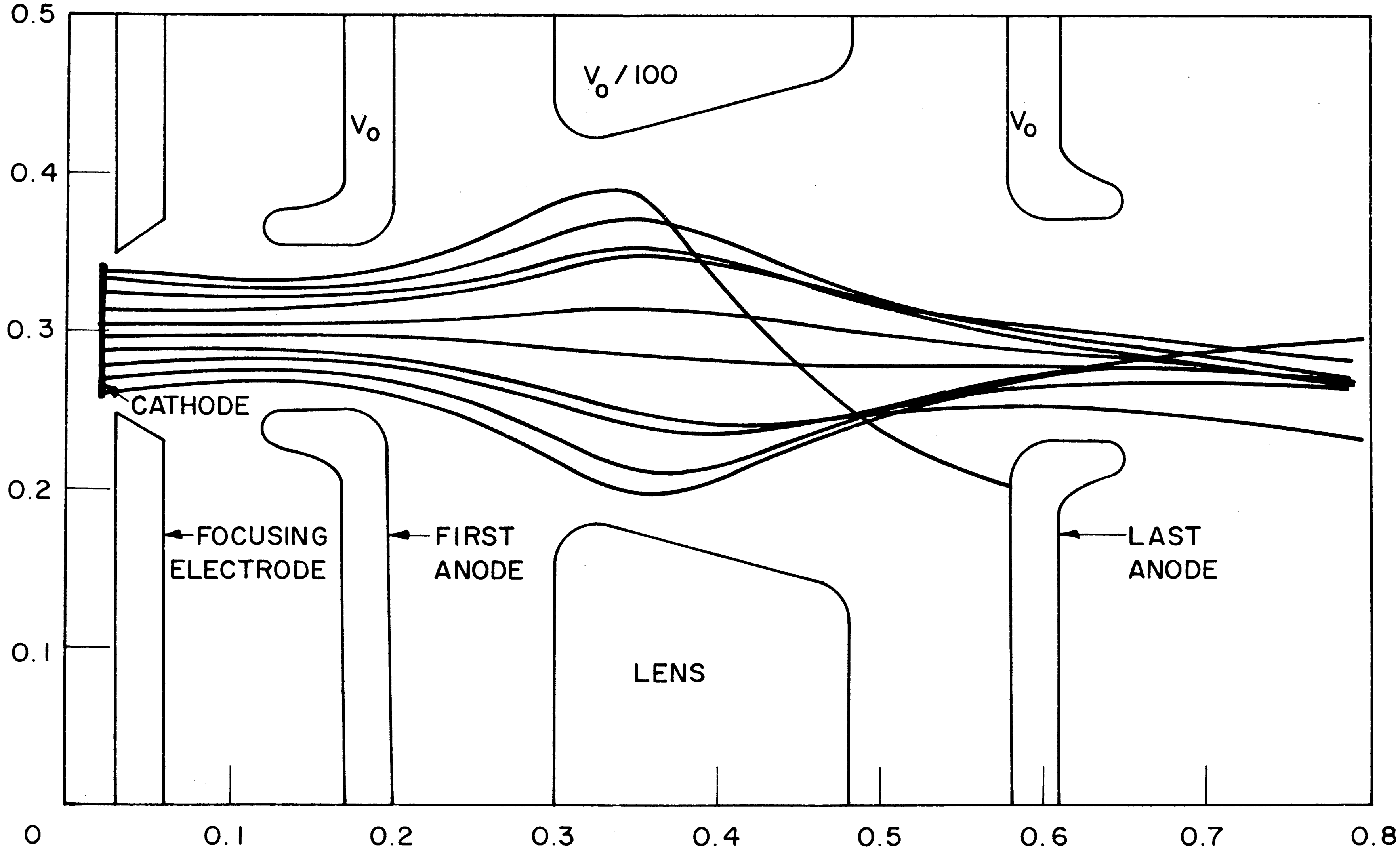

FIG. 2.3 TRAJECTORY PLOT FOR ELECTROSTATICALLY-FOCUSED P_μ = 20 GUN.

($J_o = 4.656 \times 10^3$ AMP/m^2, $P_\mu = 17.7$)

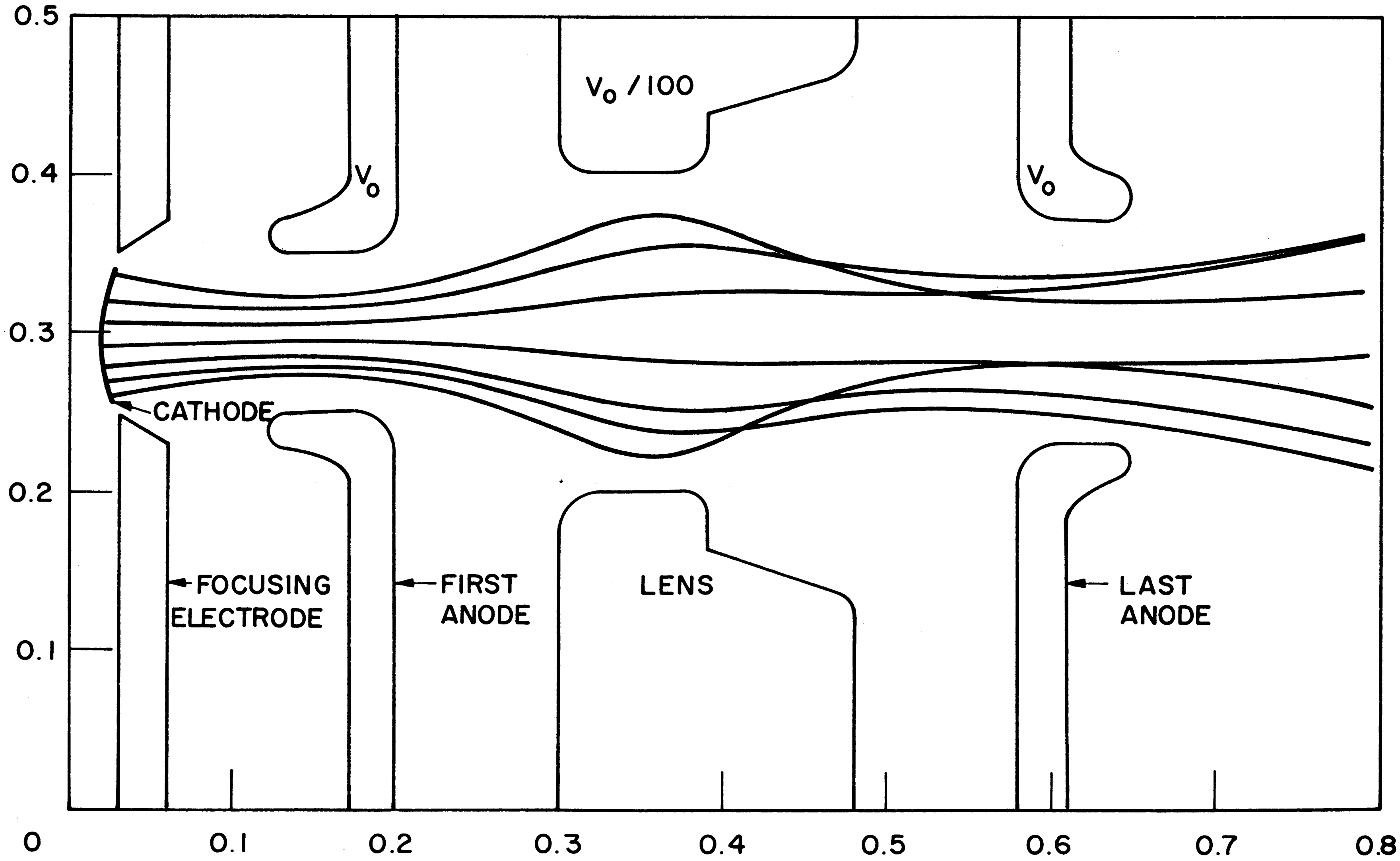

FIG. 2.4 TRAJECTORY PLOT FOR ELECTROSTATICALLY-FOCUSED P_μ = 20 GUN.

(J_o = 7.203 x 10^3 AMP/m^2, P_μ = 19.573)

3. Experiments on the Electrostatically-Focused Hollow-Beam Tube (C. K. Rhee)

The experimental work on the vhf Crestatron was delayed considerably due to intermittent short circuits that occurred inside the tube.

The beam focusing tests were repeated up to a voltage of 1100 volts. As the beam voltage was increased beyond 900 volts, low-level r-f oscillations were observed and the beam transmission began to drop, as shown in Fig. 3.1. It may be seen from this figure that the beam transmission is somewhat improved as compared to the data obtained from the previous tube and reported in the last progress report. This is believed to be due to a more ideal geometry in the entrance to the focusing system. The data obtained on the present tube so far is only tentative. It is expected that the r-f oscillations can be eliminated and that improved transmission can be obtained from 900 volts up to the design voltage of 1500 volts. These tests will be conducted during the coming quarter. In addition the beam transmission will be studied under r-f drive.

4. Work Conducted at the Bendix Research Laboratories*

4.1 Introduction. Previous reports have discussed the theoretical design, have dealt with various tests of component parts and have presented the results of r-f tests on 16 metal-ceramic tubes. Since the last progress report two more tubes were constructed and tested in this series. Table 4.1 lists the more important physical and electrical parameters of these tubes.

In order to optimize the r-f performance it was necessary to revise the tube design. These considerations were presented in the

* This material was submitted by K. C. Earl of the Bendix Research Laboratories.

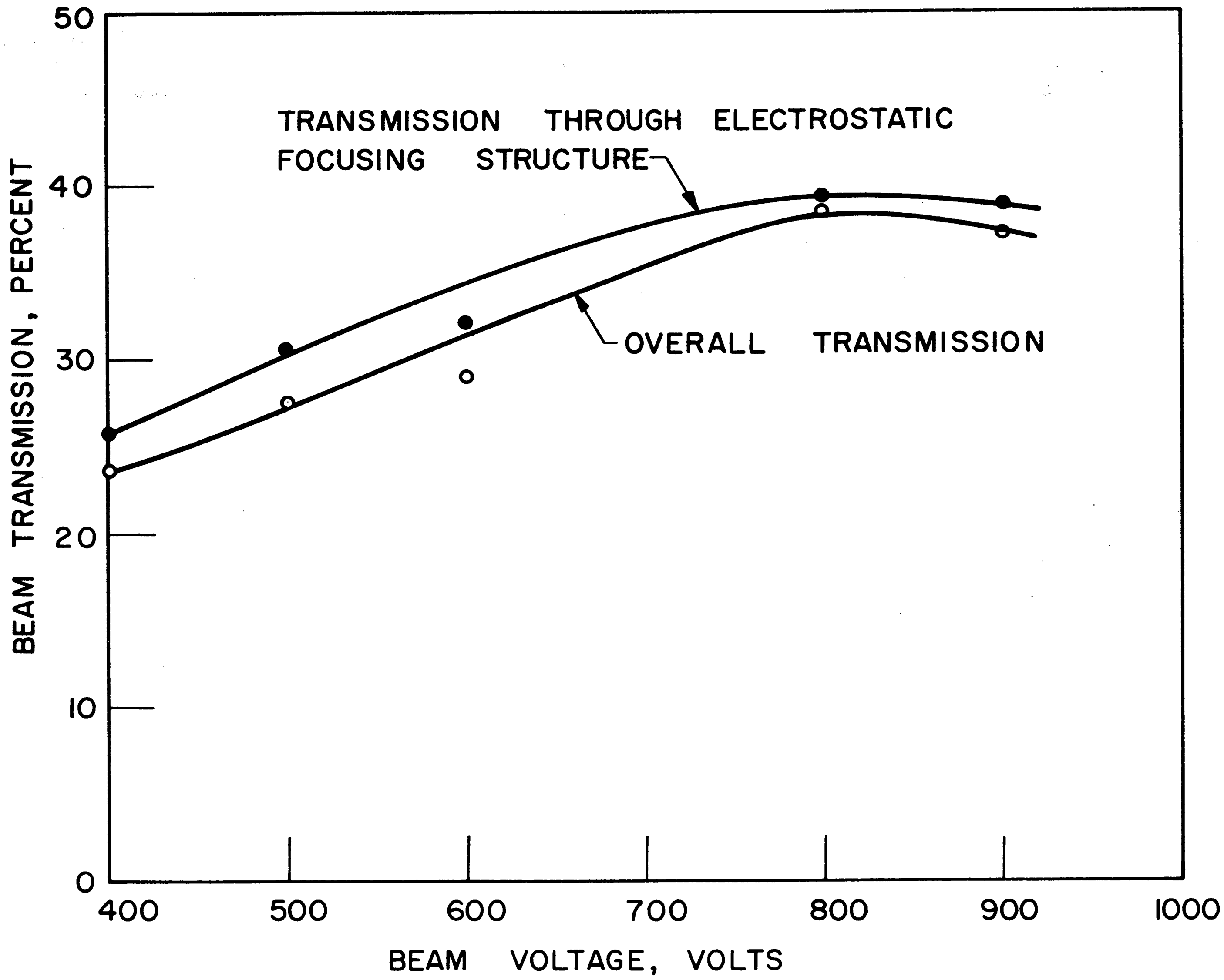

FIG. 3.1 BEAM TRANSMISSION VS. BEAM VOLTAGE.

Table 4.1a

Electrical and Physical Data of Tubes Constructed

Tube No. TW-143-A	Date Completed	Helix Length Inches	TPI Helix	Input Conn. and Length	Output Conn. and Length	Gun Type	Operating Conditions I_o	Operating Conditions V_o	Nominal Gain Obtained	Power Output Obtained	Notes
1	3-1-63	9.6	11.5	Tapered Shield 4"	Tapered Shield 4"	Triode	105	680	15 to 18	15	Glass to kovar r-f feedthrus and stem header. Filter not used so low freqs. appear better than they should.
2		9.6	11.5	Tapered Shield 4"	Tapered Shield 4"	Triode	---	---		---	Tube not completed due to data on No. 1 indicating change of plans.
3	3-20-63	9.6	10	Tapered Shield 4"	Tapered Shield 4"	Triode	143	700	16	15	This tube developed an open inner anode and arc breakdown. Filters not used so low freqs. appear better than they should.
4	4-2-63	5.6	10	Tapered Shield 2"	Tapered Shield 2"	Triode	350	830	16 to 23	40 to 60	Ultimate failure due to leakage in gun.
5	5-8-63	5.6	10	Tapered Shield 2"	Tapered Shield 2"	Triode	---	---	---	---	Heater failure before data could be obtained.
6	5-24-63	5.6	10 Tapered to 20	Tapered Shield 2"	Tapered Shield 2"	Triode	---	---	---	---	Helix connection to r-f feed-through failed during bake out.
7	5-30-63	5.6	10 Tapered to 20	Tapered Shield 2.8"	Tapered Shield 2.8"	Triode	200	490 to 560	12	20	Helix tapered to much r-f performance poor.
8	6-20-63	5.6	10 Tapered to 15	Tapered Shield 2"	Tapered Shield 2"	Triode	280	770	15	30 to 40	Helix tapered too much.
9	6-22-63	5.6	11.5	Tapered Shield 2"	Tapered Shield 2"	Triode	400	1180	10	50 to 100	First tube to give 100 watts.
10	6-26-63	5.6	11.5 Stretched Output Match	Tapered Shield 2"	Tapered Shield 2"	Triode	250	680 to 940	10	30 to 60	Obtained momentary I_k of 600 ma and P_o of 140 watts but sufficient examination of P_o not made. osc. possible.
11	6-28-63	5.6	13	Tapered Shield 2"	Tapered Shield 2"	Triode	---	---	---	---	R-F feedthrough failure during bake out.

Table 4.1b (Contd.)

Tube No. TW-143-A	Date Completed	Helix Length Inches	TPI Helix	Input Conn. and Length	Output Conn. and Length	Gun Type	Operating Conditions I_o	V_o	Nominal Gain Obtained	Power Output Obtained	Notes
12	7-3-63	5.6	13	Tapered Shield 2"	Tapered Shield 2"	Triode	150	580 to 700	10 to 13	15	Poor activation of cathode 150 ma, maximum cathode current.
13	8-8-63	5.6	13	Tapered Shield 2"	Tapered Shield 2"	Triode	200	625 to 840	10	15 to 20	200 ma maximum cathode current.
14	9-19-63	5.6	11.5	Tapered Shield 2"	Coupled Helix 2"	Triode	400	930 to 990	5 to 10	20 to 30	High loss in output coupler degraded performance.
15	10-16-63	7.7	11.5	Tapered Shield 2"	Coupled Helix 2"	3 Anode	600	1140 to 1240	10 to 12	40 to 85	Severe inverse overload and high loss in output coupler degraded performance.
16	10-28-63	6.6	11.5	Coupled Helix 2"	Coupled Helix 2"	3 Anode	400	820 to 910	4 to 6	10	High loss in both input and output couplers degraded performance. Depressed potential collector.
17	12-16-63	7.7	11.5	Tapered Shield 2"	Coupled Helix 2"	3 Anode	75	460 to 540	12	10	Low temperature bake out limited cathode activation severely to 75 ma. low temperature due to leak.
18	1-7-64	6.6	11.5	Coupled Helix 2"	Coupled Helix 2"	3 Anode	400	850	14	40 to 50	Best operation of coupled helix tubes but excessive trouble with oscillations due to matches
Tube No. TW-147-											
1	1-24-64	7	8	Coupled Helix 3"	Coupled Helix 3"	3 Anode Spokes Coated	200	1000 to 1070	5	15 to 30	R-F matches not very good oscillations limited testing to excessively high voltages. Depressed potential collector.
2	2-13-64	7	8	Coupled Helix 3"	Coupled Helix 3"	3 Anode Spoke Coated	250	1300	6	13 to 22	R-F matches changed during bake out same problem as with tube 1. Results to this time not conclusive.
3	3-26-64	9		Tapered Shield 2½"	Tapered Shield 2½"	2 Anode	500	1050 to 1500	15	60 to 167 99 to 149 @ 1450 volts	R-F matches changed some during bake out. Tube much more stable than previous. Power outputs 99 to 149 over 100 to 300 mc at 1450 volts. Optimum voltages caused oscillation due to high gain so gain must be reduced. Most successful tube to date.

last quarterly report. Experimental results on three tubes of the new design will be described below and are also summarized in Table 4.1.

4.2 Test Results on Tubes TW-143-A-17 and 18. Tube No. 17 contained a coupled-helix output matching section and a tapered input matching section. Only a low temperature bakeout was possible because of a leak occurring during bakeout and therefore the tube was tested at only 70 to 75 ma of beam current. Gains of 7 to 10 db were observed with maximum power outputs of 10 watts.

Tube No. 18 contained coupled-helix couplers for both input and output matching sections. Beam currents of 340 ma were achieved. Power outputs of 40 to 50 watts were obtained in the 150 to 300 mc range but with inverse overload characteristics. Efficiencies were in the 15 to 19 percent range. Higher beam currents could not be maintained because of interception and beam breakup caused by the spokes in the three anode gun. Figure 4.1 is a plot of power output vs. power input for tube No. 18 operating at 800 volts and 400 ma.

4.3 Test Results on Tubes TW-147-1, 2 and 3. Three tubes of the new design have been built and tested, tubes 1 and 2 with coupled-helix couplers and tube 3 with tapered matching sections. The coupled-helix couplers exhibited insufficient performance giving marginal VSWR and excessive loss. In these tubes, the tendency to oscillate was strong and maximum beam currents achieved were 200 ma for tube 1 and 250 ma for tube 2. Figure 4.2 is a plot of the double-ended VSWR and insertion loss of tube 1 and Fig. 4.3 gives this information on tube 2. Figures 4.4 and 4.5 show power output vs. power input for tubes 1 and 2, respectively.

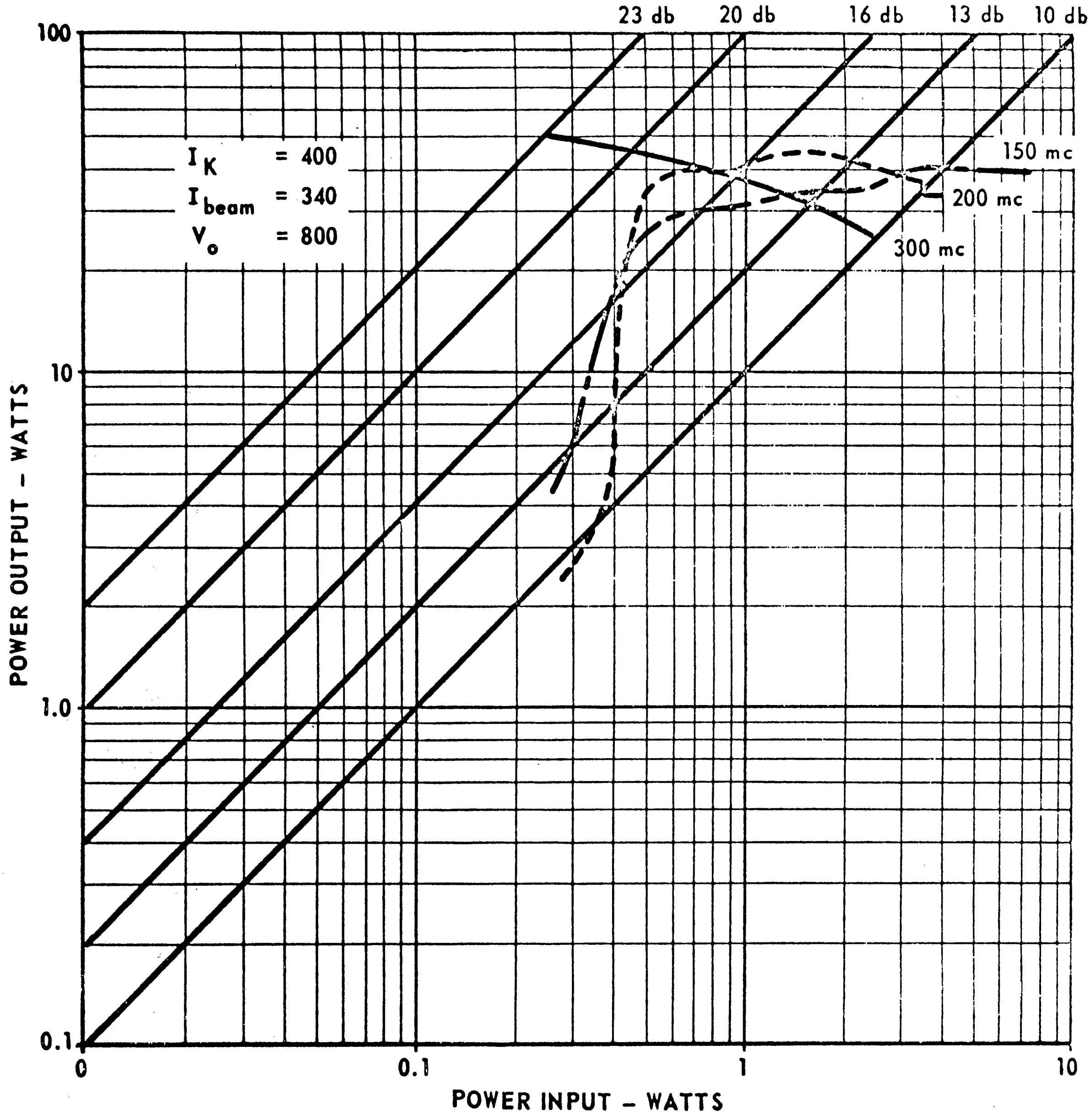

FIG. 4.1 POWER OUTPUT VS. POWER INPUT FOR TW-143-A-18.

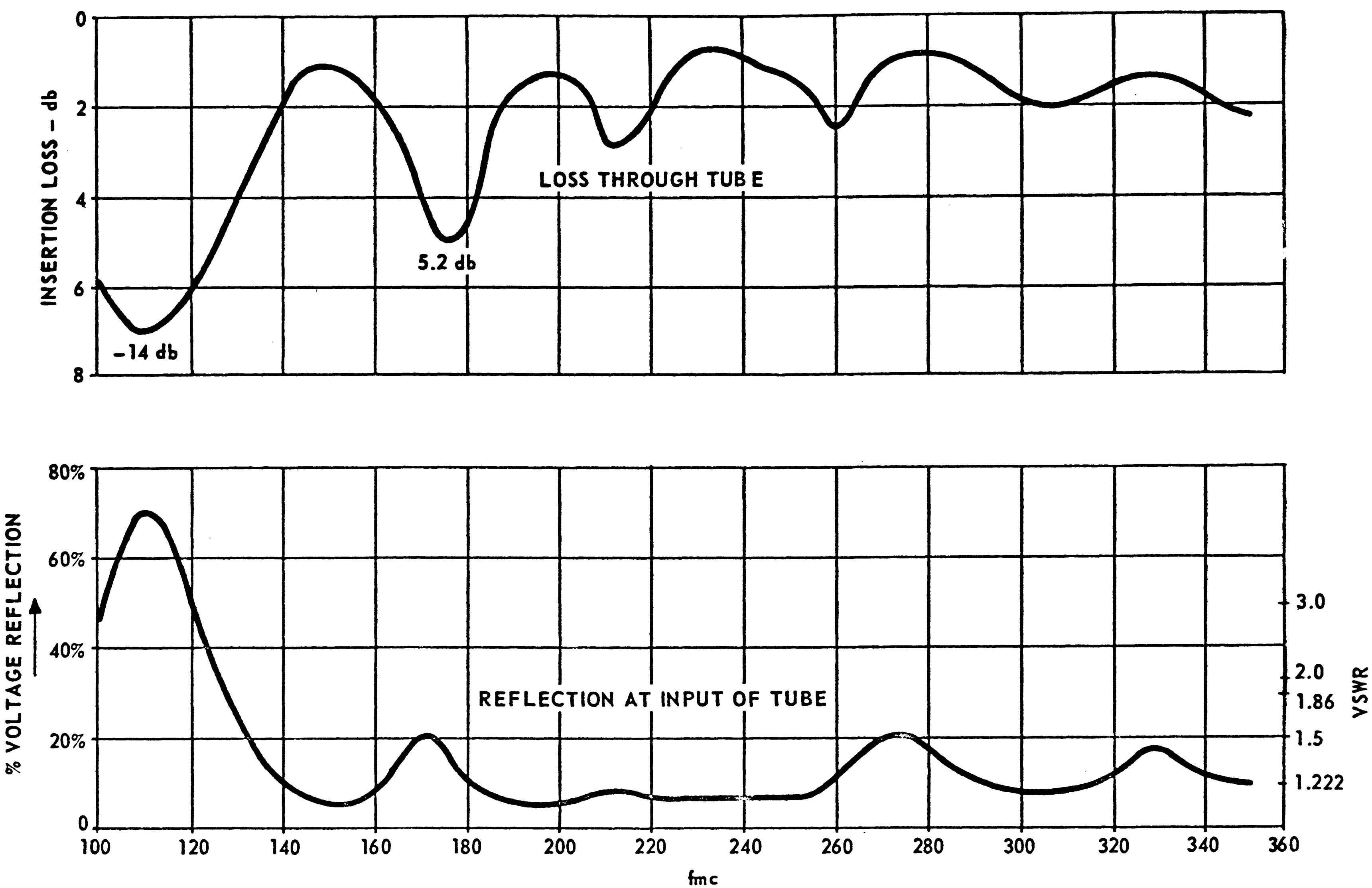

FIG. 4.2 VSWR AND INSERTION LOSS VS. FREQUENCY FOR TW-147-1.

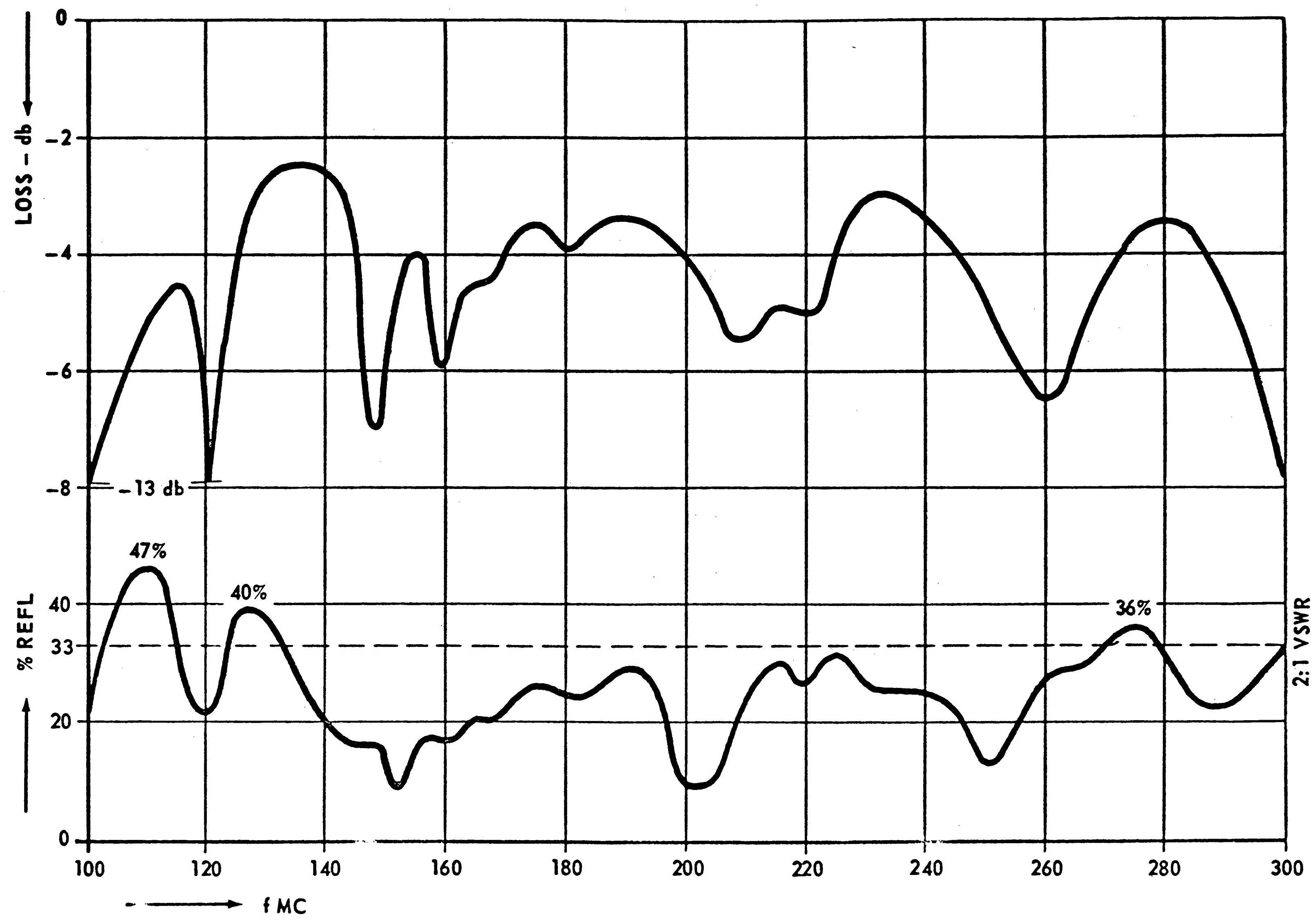

FIG. 4.3 VSWR AND INSERTION LOSS VS. FREQUENCY FOR TW-147-2.

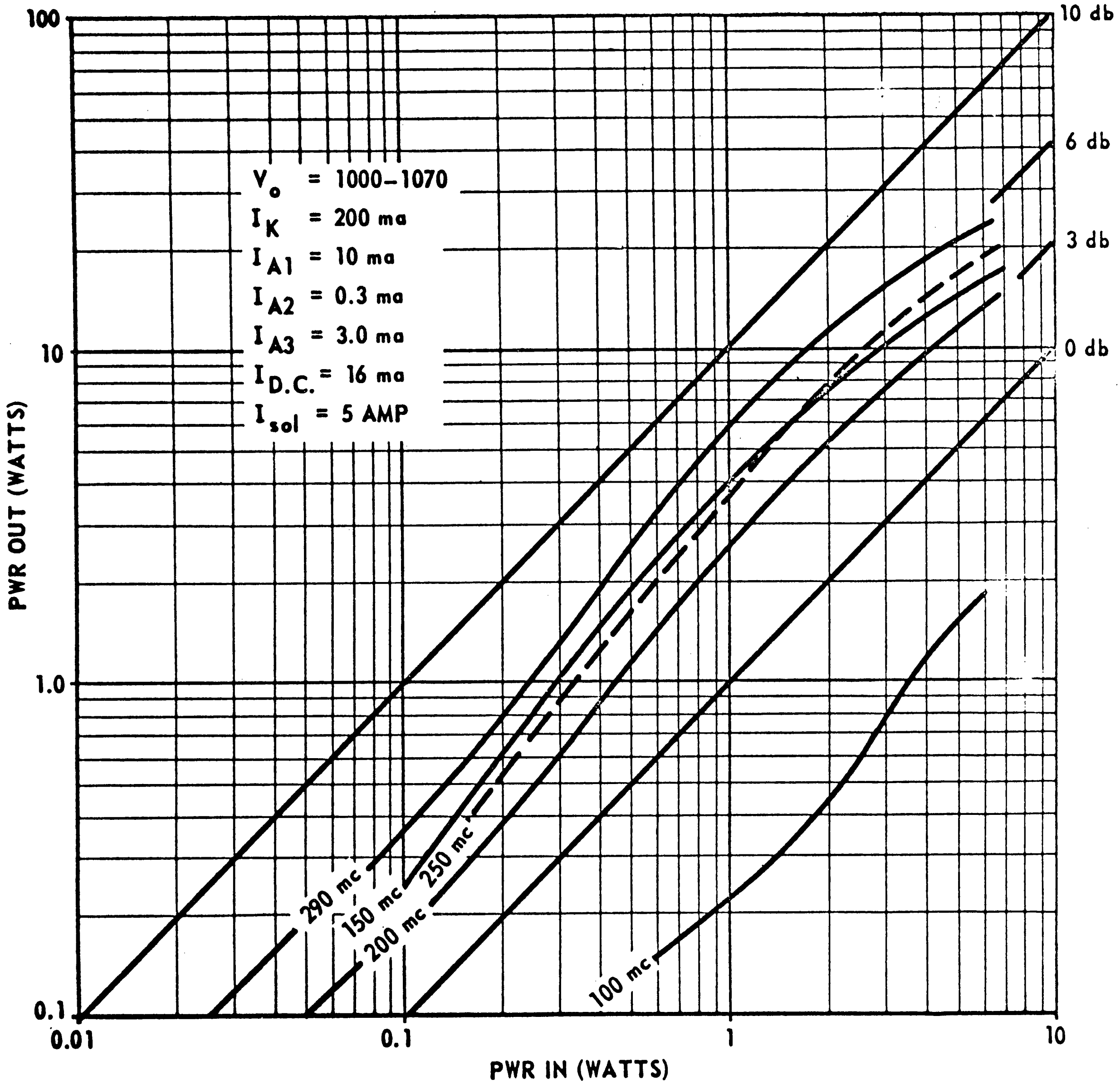

FIG. 4.4 POWER OUTPUT VS. POWER INPUT FOR TW-147-1.

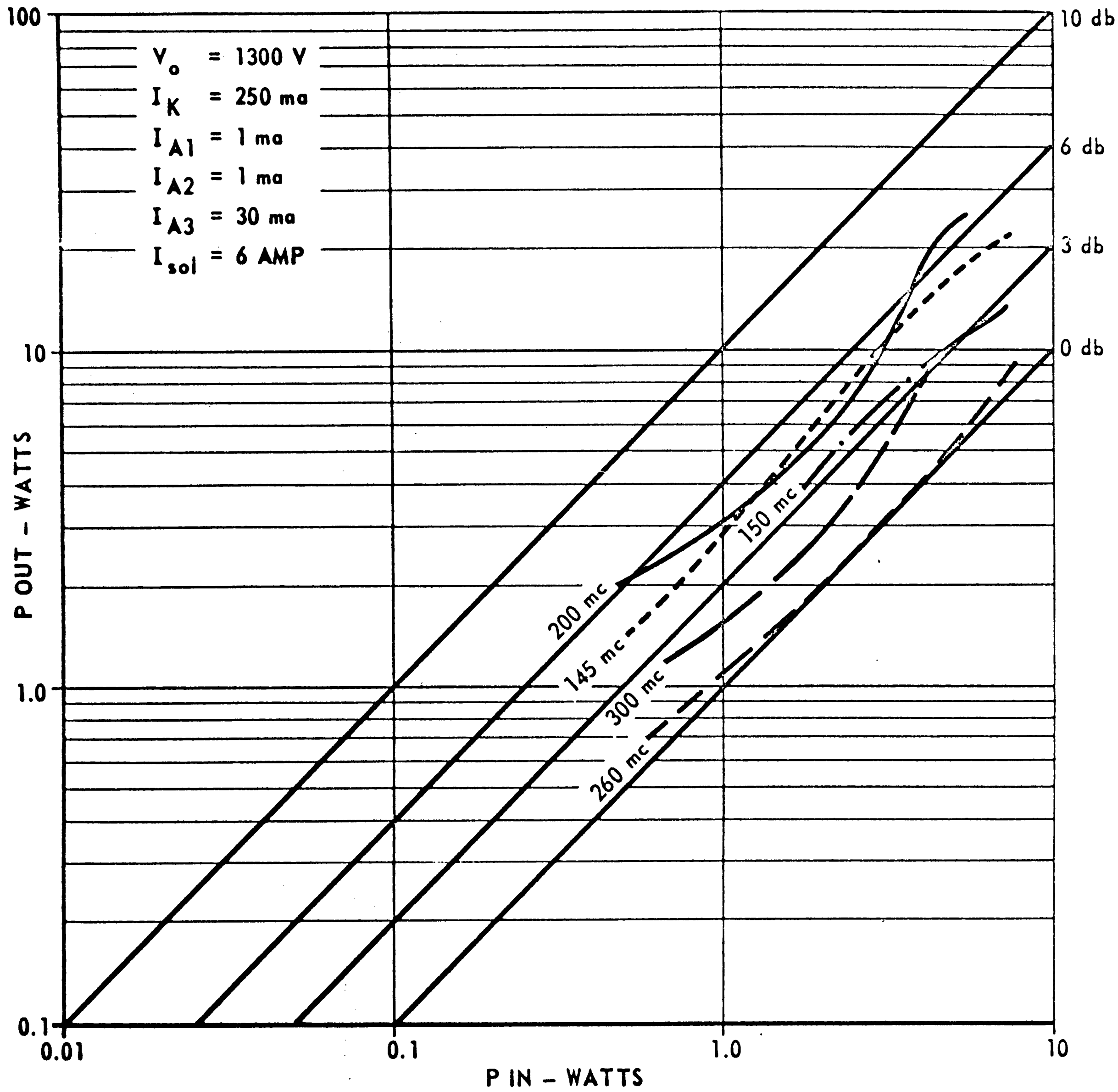

FIG. 4.5 POWER OUTPUT VS. POWER INPUT FOR TW-147-2.

Tube TW-147-3 was constructed using tapered matching sections and was the first tube to utilize the new two anode spokeless electron gun. This tube was much more stable than the first two and the tube was operated at 500 ma of beam current at voltages above and below the optimum voltage. Gain was higher than expected on this 9-inch helix and the tube did oscillate at voltages between 1100 and 1400. Small-signal gains of 20 to 24 db were recorded at full beam currents and 1100 volts. Figure 4.6 plots the maximum power output vs. frequency, with beam voltage as a parameter. Figure 4.6 also shows the saturated gain associated with the power output. Figure 4.7 is a plot of synchronous voltage vs. frequency obtained experimentally by adjusting the voltage for maximum small-signal gain with very low, (10 ma), of beam current. Figure 4.8 is a plot of power and gain at 250 ma of beam current, with the voltage adjusted for maximum small-signal gain.

It can be seen from the test data that a minimum of 99 watts of r-f power output was obtained at 100, 150, 200, 250 and 290 mc. R-f data was not taken at 300 mc because sufficient r-f drive power was not available. This power output was obtained at beam currents of 500 ma and a voltage of 1450 volts. This voltage was higher than optimum, in order to suppress oscillations and therefore the power output vs. power input had inverse saturation overload characteristics. At 1100 volts, which was below optimum voltage, almost 100 watts was obtained throughout the frequency range except at 100 mc. At this lower voltage the power output vs. power input curves exhibit the normal saturation overload characteristics. Adjustment of parameters to fully meet the requirements will be made and incorporated in future tubes. All of the measurements give the output power at

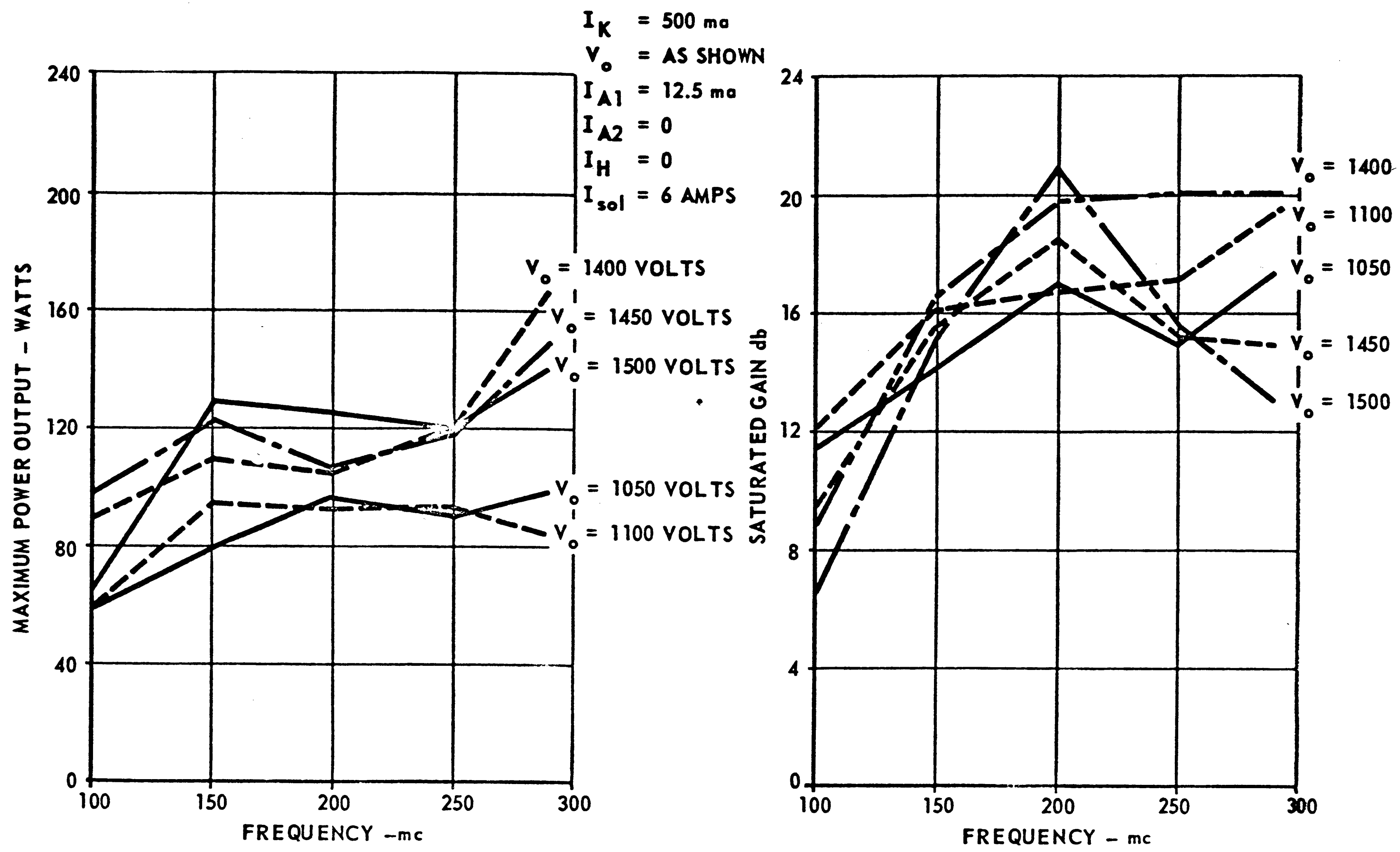

FIG. 4.6 MAXIMUM POWER OUTPUT AND SATURATED GAIN VS. FREQUENCY FOR TW-147-3.

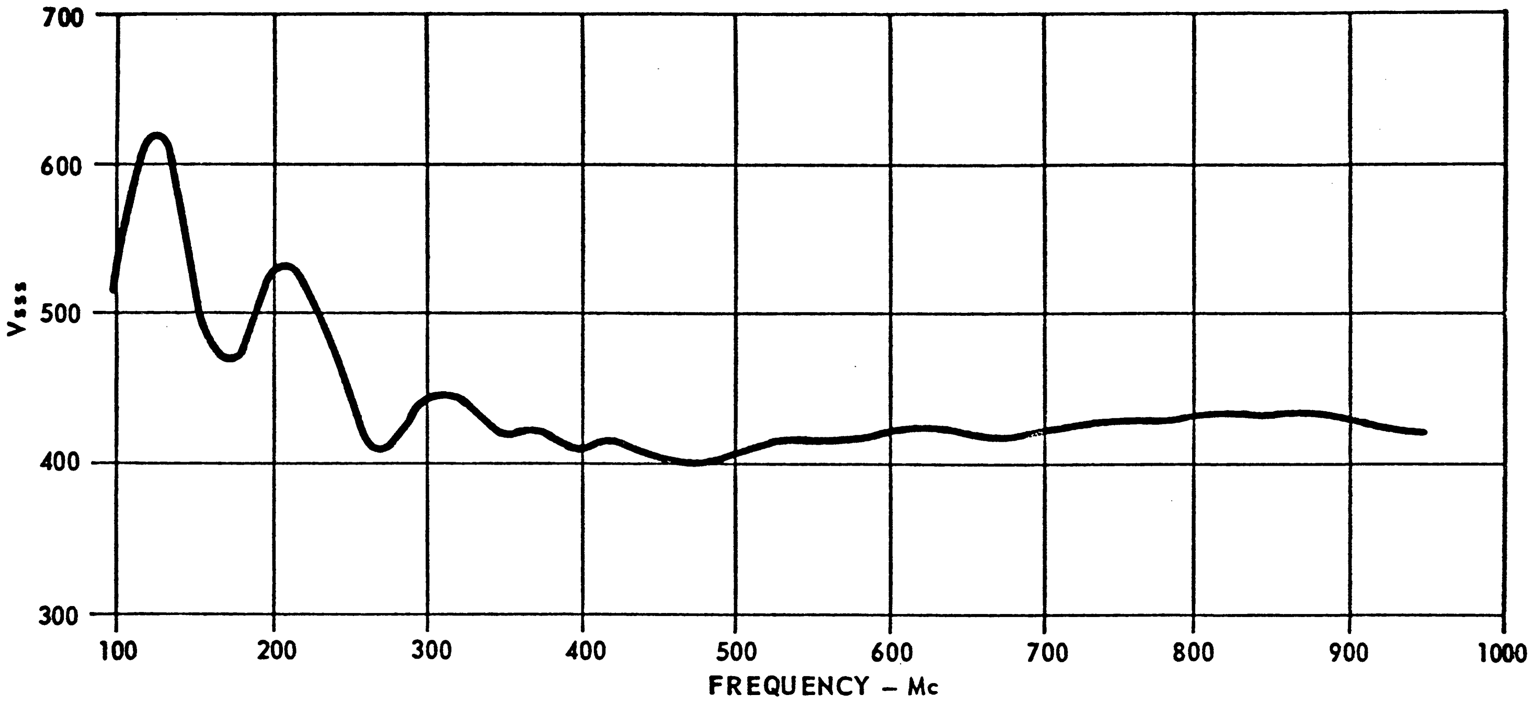

FIG. 4.7 SMALL SIGNAL SYNCHRONOUS VOLTAGE AT LOW BEAM CURRENT FOR TW-147-3.

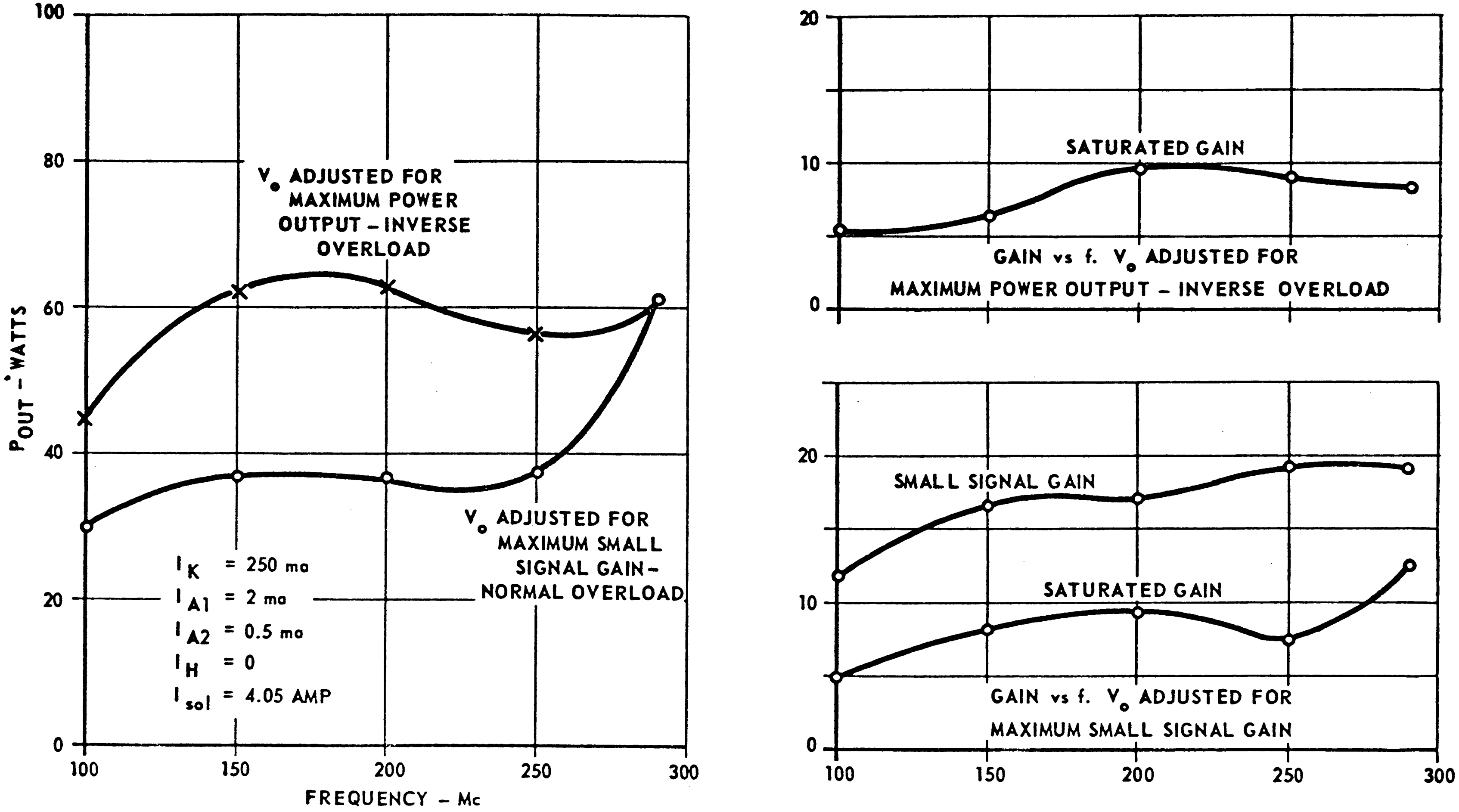

FIG. 4.8 POWER OUTPUT AND GAIN VS. FREQUENCY AT MEDIUM BEAM CURRENT FOR TW-147-3.

the r-f output terminal of the tube and filters are used in the r-f line to the output power meter so that all harmonics are attenuated and do not add to the indicated power output.

5. Summary and Future Work (G. T. Konrad)

The $P_{\mu} = 20$ gun design with a reduced beam diameter has now been completed. This is the gun that may ultimately be useful in a 1-kw tube. During the coming quarter it is intended to study the focusing action of an axial magnetic field in the small as well as the larger diameter $P_{\mu} = 20$ guns by means of the digital computer. The latter gun is presently under construction and will be checked in the beam analyzer.

The data obtained on the electrostatically focused tube to date is tentative. Some small-level oscillations disturbed the beam focusing efficiency. At voltages up to 800 volts higher beam transmission was observed than on any previous electrostatically focused tube on this program. This work will be continued during the coming quarter for higher voltages and under conditions of r-f drive.

Very encouraging results were obtained from the most recent 100-watt Crestatron. Power levels and gain well within the design requirements were observed. These results warrant the initiation of the next phase in the development of these tubes, namely environmental ruggedization and a change to permanent magnet focusing methods. The initial work on this phase is already under way and will continue during the next quarter.

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