ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR

THEORETICAL STUDY, DESIGN, AND CONSTRUCTION OF CW MAGNETRONS FOR FREQUENCY MODULATION

QUARTERLY PROGRESS REPORT NO. 3

Period Covering June 1, 1952, to September 1, 1952
Electron Tube Laboratory
Department of Electrical Engineering

BY

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September 1952

TABLE OF CONTENTS

PERSONNEL

Scientific and Engineering Personnel		Time Worked in Man Months*
W. G. Dow	Professor of Electrical Engineering	Supervisor
J. R. Black	Research Engineer	1.96
J. A. Boyd	Instructors in Electrical Engineering	.09
G. Hok		.23
J. Needle		.27
D. Hoover	Research Assistant	1.51
G. Dombrowski	Research Associates	2.61
W. Peterson		.46
Service Personnel		
V. R. Burris	Machine Shop Foreman	1.24
R. F. Steiner	Assembly Technicians	1.95
J. W. Van Natter		2.28
R. F. Denning	Instrument Makers	.23
T. G. Keith		2.30
D. McCormick		.19
E. Burnais	Laboratory Assistant	.87
P. Woodhead	Technical Illustrator	2.26
M. Gotanda	Stenographer	1.48

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* Time worked is based on 172 hours per month.

MAJOR REPORTS ISSUED TO DATE

Contract No. W-36-039 sc-32245. Subject: Theoretical Study, Design and Construction of C-W Magnetrons for Frequency Modulation.

Technical Report No. 1

H. W. Welch, Jr., "Space-Charge Effects and Frequency Characteristics of C-W Magnetrons Relative to the Problem of Frequency Modulation," November 15, 1948.

Technical Report No. 2

H. W. Welch, Jr., G. R. Brewer, "Operation of Interdigital Magnetrons in the Zero-Order Mode," May 23, 1949.

Technical Report No. 3

H. W. Welch, Jr., J. R. Black, G. R. Brewer, G. Hok, "Final Report," May 27, 1949.

Contract No. W-36-039 sc-35561. Subject: Theoretical Study, Design and Construction of C-W Magnetrons for Frequency Modulation.

Technical Report No. 4

H. W. Welch, Jr., "Effects of Space Charge on Frequency Characteristics of Magnetrons," Proc. IRE, 38, 1434-1449, December 1950.

Technical Report No. 5

H. W. Welch, Jr., S. Ruthberg, H. W. Batten, W. Peterson, "Analysis of Dynamic Characteristics of the Magnetron Space Charge, Preliminary Results," January 1951.

Technical Report No. 6

J. S. Needle, G. Hok, "A New Single-Cavity Resonator for a Multianode Magnetron," January 8, 1951.

Technical Report No. 7

J. R. Black, H. W. Welch, Jr., G. R. Brewer, J. S. Needle, W. Peterson, "Theoretical Study, Design, and Construction of C-W Magnetrons for Frequency Modulation," Final Report, February 1951.

Contract No. DA-36-039 sc-5423. Subject: Theoretical Study, Design and Construction of C-W Magnetrons for Frequency Modulation.

Technical Report No. 8

G. R. Brewer, "The Propagation of Electromagnetic Waves in a Magnetron-Type Space Charge," July 1951.

Technical Report No. 10

G. Hok, "Space-Charge Equilibrium in a Magnetron: A Statistical Approach," July 13, 1951.

Technical Report No. 11

J. S. Needle, "The Insertion Magnetron: A New External-Cavity Magnetron for Low-Power Electronically-Tunable Operation in the 10 to 20-cm Wavelength Range," August 1951.

Technical Report No. 12

H. W. Welch, Jr., "Dynamic Frequency Characteristics of the Magnetron Space Charge; Frequency Pushing and Voltage Tuning," November 1951.

Technical Report No. 13

J. R. Black, J. A. Boyd, G. R. Brewer, G. Hok, J. S. Needle, W. Peterson, S. Ruthberg, R. F. Steiner, H. W. Welch, "Theoretical Study, Design and Construction of C-W Magnetrons for Frequency Modulation," Final Report, January 1952.

Contract No. DA-36-039 sc-15450. Subject: Theoretical Study, Design and Construction of C-W Magnetrons for Frequency Modulation.

Technical Report No. 9

G. R. Brewer, translator. "On the Properties of Tubes in a Constant Magnetic Field," by O. Doehler, J. Brossart and G. Mourier. Annales de Radioélectricité, 1948-1950.

LIST OF ILLUSTRATIONS

ABSTRACT

This report presents the progress made at the University of Michigan Electron Tube Laboratory during the period of April 1, through August 31, 1952.

The progress made on the development of an interdigital voltage-tunable magnetron operating in the S-band region is presented. This tube is being developed for local oscillator use.

A new circuit is described for medium Q, voltage-tunable operation of a coaxial magnetron.

Preliminary results obtained in a study to determine the effect of the cathode line on magnetron operation are given.

Results obtained with a mechanically tunable magnetron designed to operate at the 500 watt level in the S-band region are discussed.

The first pictures obtained from the trajectron operating with a magnetron space-charge present are included. This is an experimental magnetron designed for the study of the space-charge in a smooth-bore d-c magnetron.

THEORETICAL STUDY, DESIGN, AND CONSTRUCTION OF CW MAGNETRONS FOR FREQUENCY MODULATION

QUARTERLY PROGRESS REPORT NO. 3

1. Objectives for the Period (J. R. Black)

The purpose of this report is to summarize the progress in the University of Michigan Electron Tube Laboratory during the period from June 1, 1952, to September 1, 1952, on contract No. DA-36-039 sc-15450.

The general objectives of the program are to increase the knowledge of space-charge effects and frequency characteristics in c-w magnetrons and to apply this knowledge to the development of magnetrons which can be frequency modulated. Since December 1, 1951, the program has emphasized the development of various tube designs into practical, usable forms. Voltage-tunable magnetrons operating in the S-band region have received the major interest.

The program for this period was to develope four different tube structures, three of which are capable of voltage-tunable operation, and one capable of mechanical tuning or narrow band f-m. During this period, however, it became apparent that one of the voltage-tunable structures was far superior to the other two. At this point effort was dropped on the two inferior voltage-tunable structures to allow more energy to be placed on the promising structure.

Only one theoretical investigation was to be supported and was to be done at a reduced rate. This is the experimental investigation of the space-charge distribution in a d-c smooth-bore magnetron.

2. Technical Papers Presented During the Period (J. R. Black)

The following papers were presented at the IRE Tenth Annual Conference on Electron Tubes held in Ottawa, Canada, June 16-18, 1952:

"Initial Space Charge Waves in Magnetrons" by G. Hok

"Recent Progress on Voltage-Tunable Magnetrons" by J. Boyd

"New Types of Magnetron Anodes" by J. Needle and P. Dicker.

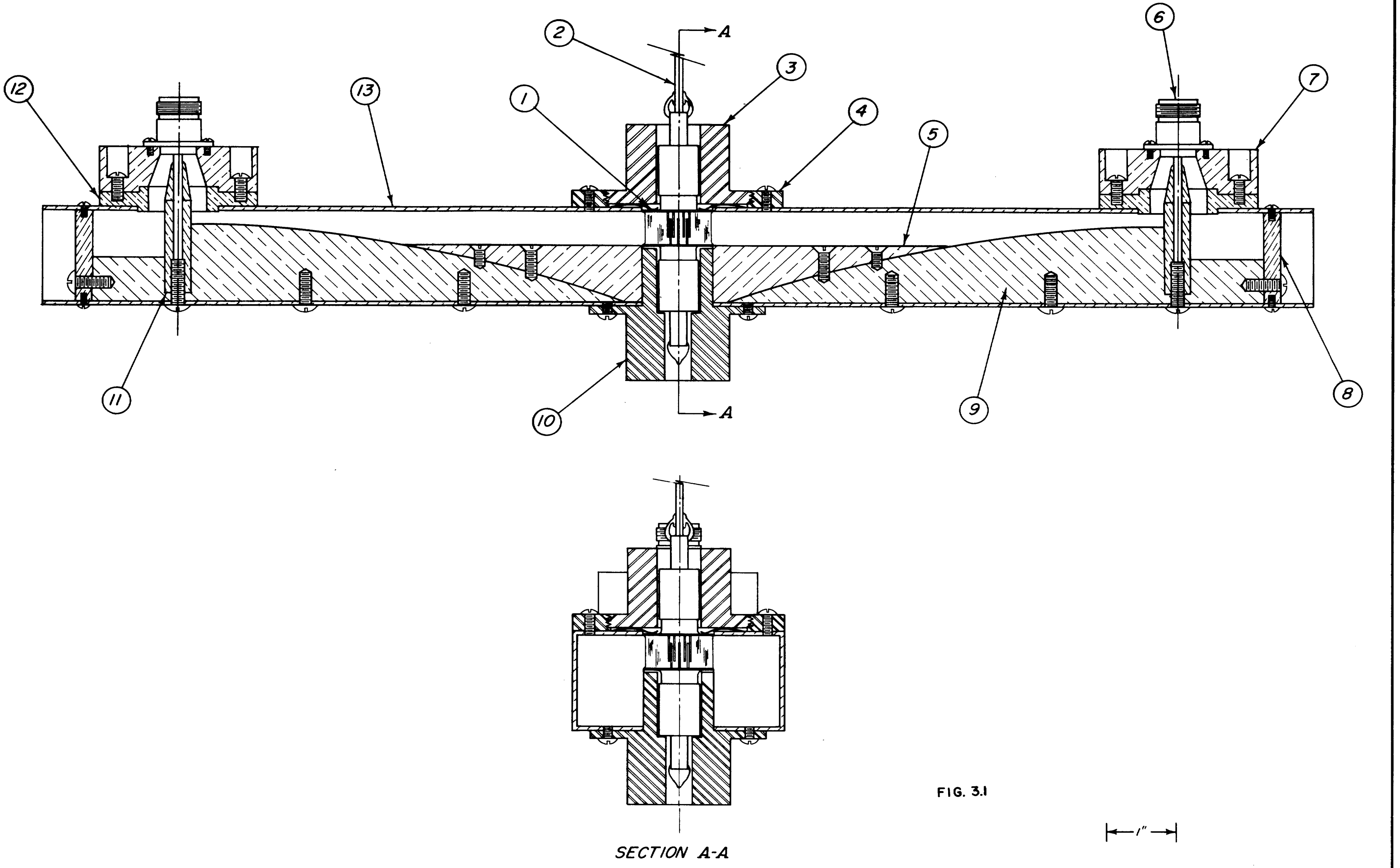
3. Model 11 Low Power External-Cavity Magnetron (J. A. Boyd)

The Model 11 magnetron is a voltage-tunable tube which operates in the frequency range of 2000 to 3000 mc. The tube contains an interdigital anode structure and associated cathode with a vacuum envelope. Fig. (3.1) shows the cavity and the mounting position of the tube within the cavity. Essentially the cavity is a ridge wave guide tapered at each end to 50 ohm coaxial terminals. A number of tubes have been completed and tested during the period covered by this report.

3.1 Model 11 Tube No. 80

This tube uses a thoriated tungsten cathode which has not been carburized, therefore, giving essentially tungsten emission. Measurements of power output and frequency have been made on this tube. The results of this test are presented in Figs. (3.2), (3.3) and (3.4). From these data it is seen that the power output is between 4.5 and 16 mw over a frequency range of 1770 to 2930 mc. Plate current varies from 1 to 4 ma, and the tube tunes at the rate of approximately 1 mc per volt change in the anode voltage. The cathode temperature was critical for operation of the tube to produce a clean signal output.

To determine the character of the output signal, the signal was fed through a crystal and then to an oscilloscope. The oscilloscope was synchronized with the 60 cycle modulating voltage which was used in series



SECTION A-A

FIG. 3.1

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64," DECIMAL ± .005," ANGULAR ± 1/2°

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DESIGNED BY JAB
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CHECKED BY JAB
DATE 3-31-52

TITLE DUAL OUTPUT CAVITY
MOD. 11 MAGNETRON

DWG. NO. C-2059

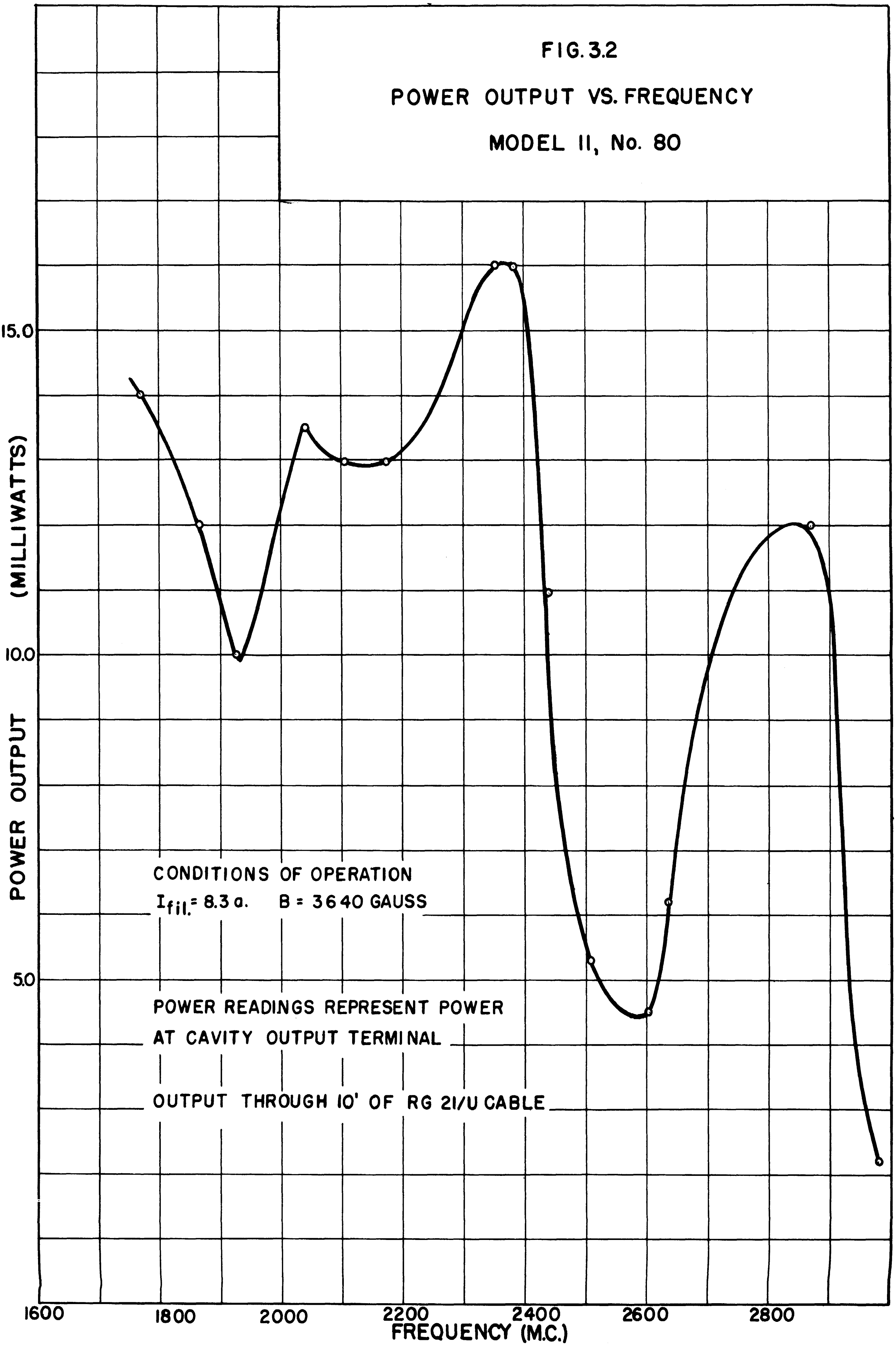


FIG. 3.2

POWER OUTPUT VS. FREQUENCY

MODEL 11, No. 80

CONDITIONS OF OPERATION

$I_{fil.}$ = 8.3 a. B = 3640 GAUSS

POWER READINGS REPRESENT POWER AT CAVITY OUTPUT TERMINAL

OUTPUT THROUGH 10' OF RG 21/U CABLE

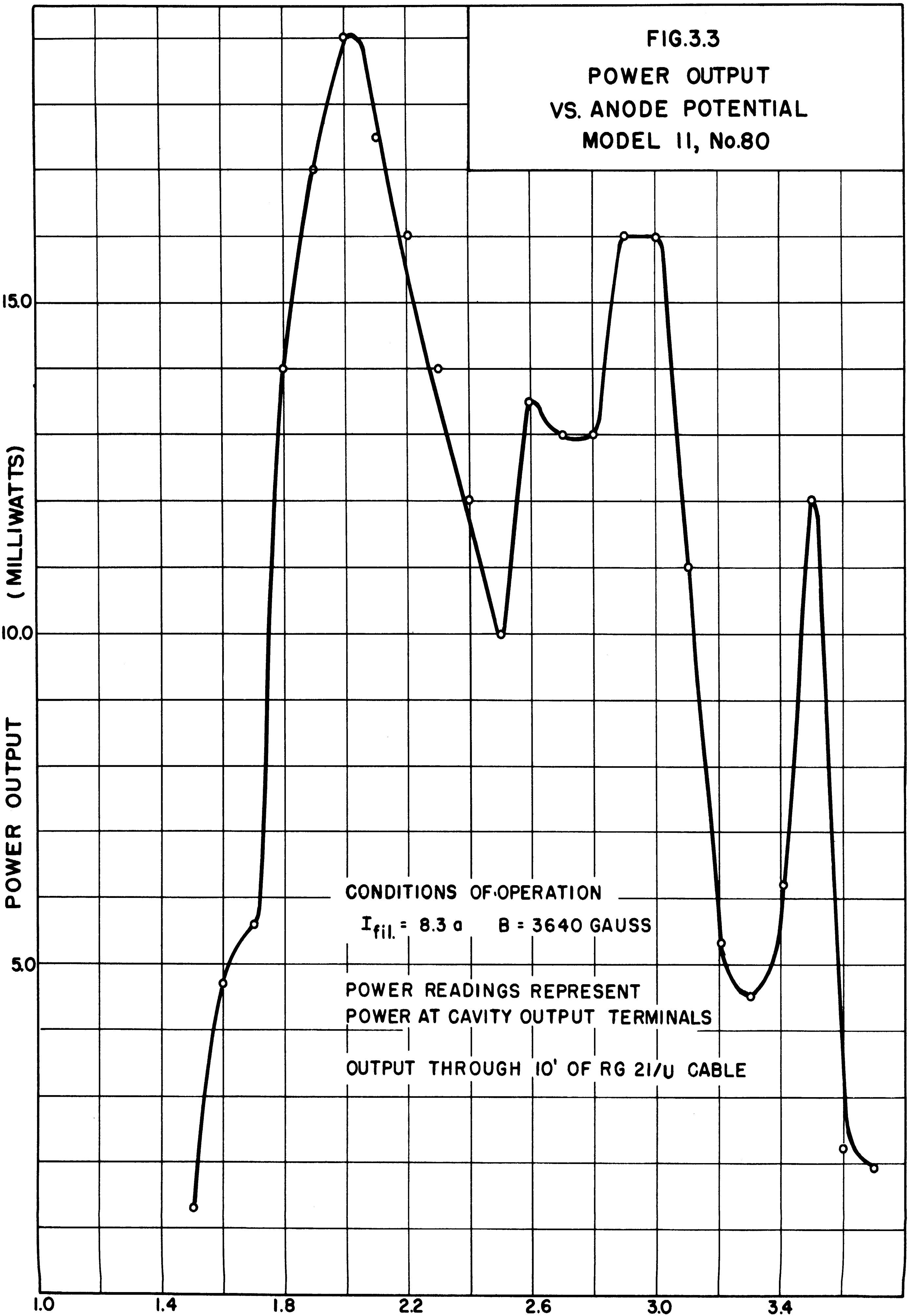


FIG.3.3

POWER OUTPUT
VS. ANODE POTENTIAL
MODEL 11, No.80

CONDITIONS OF OPERATION

$I_{fil.}$ = 8.3 a   B = 3640 GAUSS

POWER READINGS REPRESENT
POWER AT CAVITY OUTPUT TERMINALS

OUTPUT THROUGH 10' OF RG 21/U CABLE

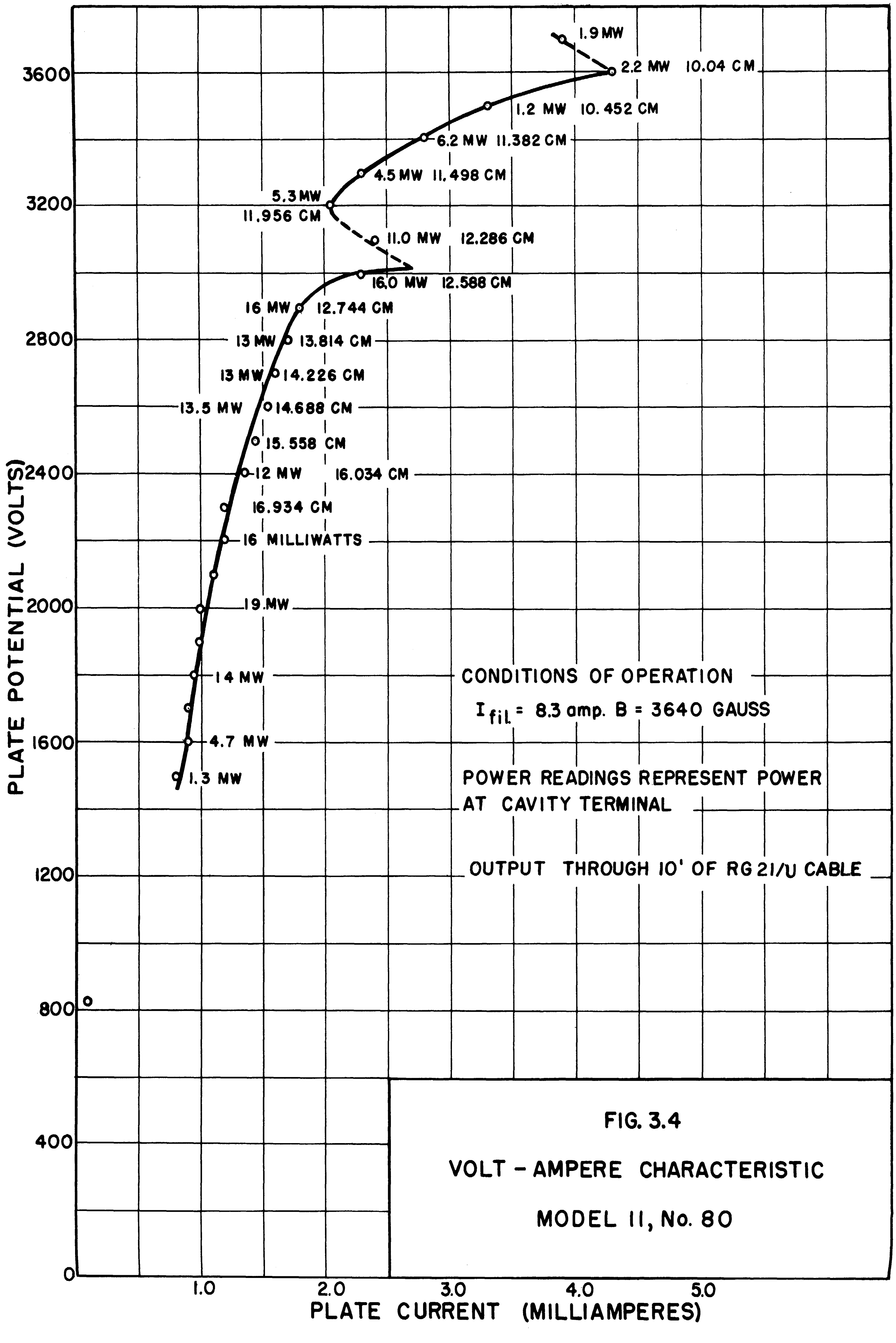


FIG. 3.4

VOLT - AMPERE CHARACTERISTIC

MODEL 11, No. 80

with the dc anode supply voltage. This arrangement made it possible to observe the output as a function of voltage and to determine the effects of changing various parameters. Since the frequency change was linear with voltage it was possible to calibrate the oscilloscope to give output as a function of frequency. When the tube was operated cw the voltage could be varied only over a relatively narrow range without readjustment of the cathode and still maintain a clean signal. This was due to the change in the back heating which caused a corresponding change in the cathode temperature. However, when the anode voltage was varied at a 60 cycle rate it was possible to adjust the cathode temperature so that the tube operated satisfactorily over a sweep range of 1250 volts. Thus once the sweep range has been determined, giving an average back-heating power, it is possible to adjust the cathode input power for optimum clean signal operation of the tube.

Qualitative measurements on the noise content of the magnetron output have been made by comparing it with the output of a reflex klystron. This comparison was made by alternately feeding the two signals into an S-band spectrum analyzer using a second reflex klystron as the local oscillator for the spectrum analyzer. When the magnetron was operated cw the signal as observed on the spectrum analyzer appeared to be unstable, in that there were random shifts in the frequency, and also the signal became alternately noisy and clean. The cathode input power was a critical factor in this operation. When the anode voltage was modulated a very small amount at a 60 cycle rate the signal became steady and all visable noise disappeared. The magnetron output signal under these conditions compared favorably in both magnitude and noise content with a 707 B reflex klystron oscillator.

Qualitative tests indicated a detectable magnetron signal on the spectrum analyzer screen at least 60 db above noise present. For the particular arrangement used, results were similar when the output from a reflex klystron was substituted for the voltage-tuned magnetron.

An attempt was made to modulate the magnetron with a 1 mc modulator, and although these tests are incomplete, preliminary results indicate that the signal is clean but that there is a slight jitter in the frequency. For this test it was necessary to use dc for the cathode filament supply. The cathode consists of a single helix and when an ac filament supply was used it was found that the variation in the magnetic field due to the filament current was sufficient to cause frequency modulation in the output signal.

Fig. (3.5) shows frequency versus anode voltage, curve (a) gives the experimentally determined data, while curve (b) was determined by using the Hartree relation. The diameter of the anode used in this calculation was .250 inches, the inside diameter of the anode is .233 inches. It should be noted that the effective anode diameter in the case of round anode bars must be determined experimentally since this effective diameter will depend upon the anode spacing. This diameter was used since it gave results in agreement with the experimentally determined data. The magnetic field measurements are believed to be correct to within five percent so that the results shown in Fig. (3.5) are believed to justify the assumptions made regarding the effective anode diameter.

3.2 Model 11 Tube No. 81

This tube used a pure tungsten cathode, otherwise it was identical with No. 80. The output signal of this tube as displayed on the oscilloscope screen versus anode voltage, was more stable and had fewer

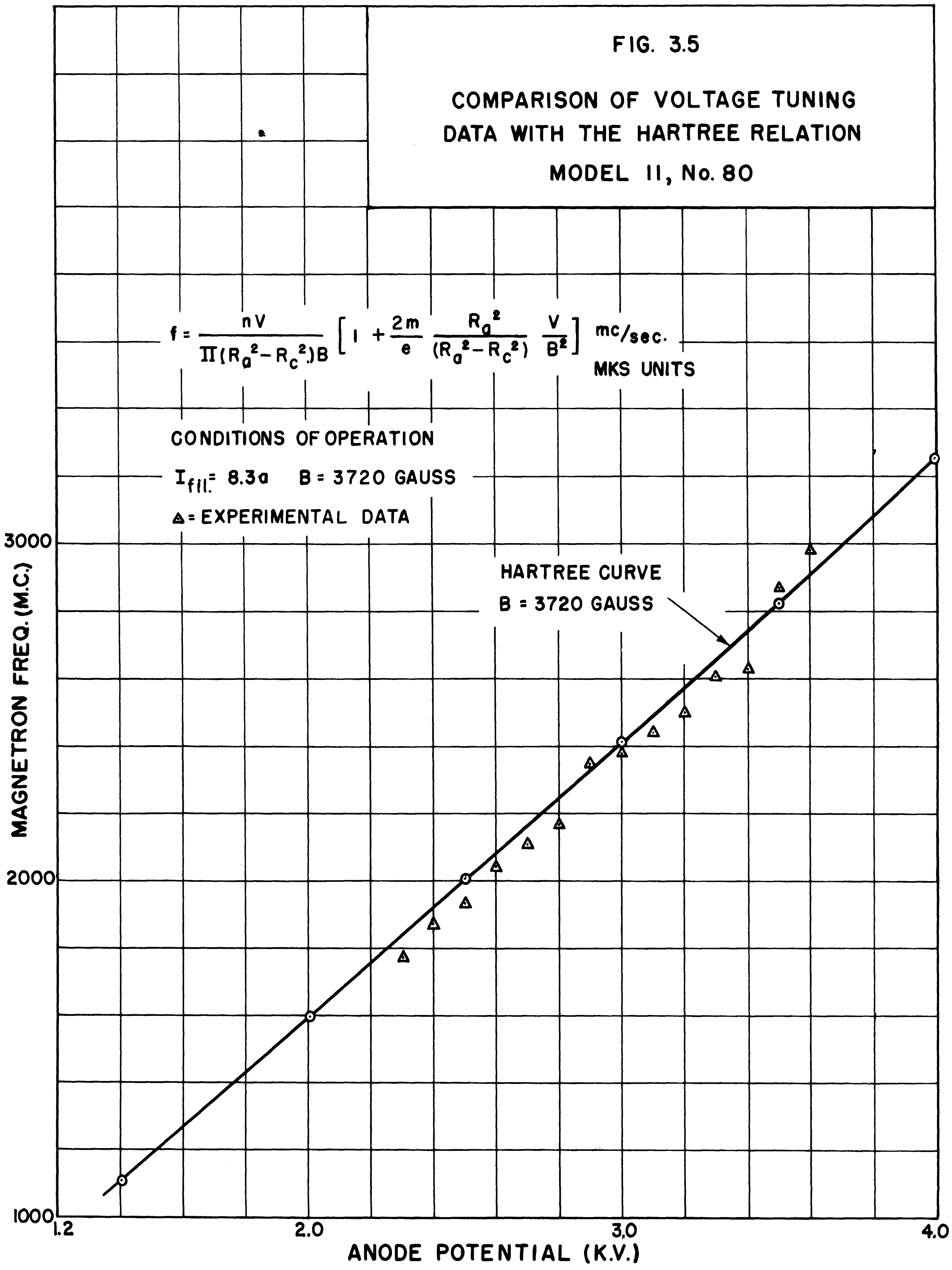


FIG. 3.5

COMPARISON OF VOLTAGE TUNING DATA WITH THE HARTREE RELATION MODEL 11, No. 80

variations in output power than the output of tube No. 80. The cathode temperature was critical, but the operation of the tube was not as sensitive to changes in filament current as was the case for No. 80. More anode current and more power output was obtained from this tube than from No. 80. Fig. (3.6) shows power output versus anode voltage. The anode current varied from 3.4 ma at 2400 volts to 10.4 ma at 3500 volts. Complete frequency measurements were not taken, however, spot checks were made which indicated that the frequency range covered was from 2000 to 3000 mc.

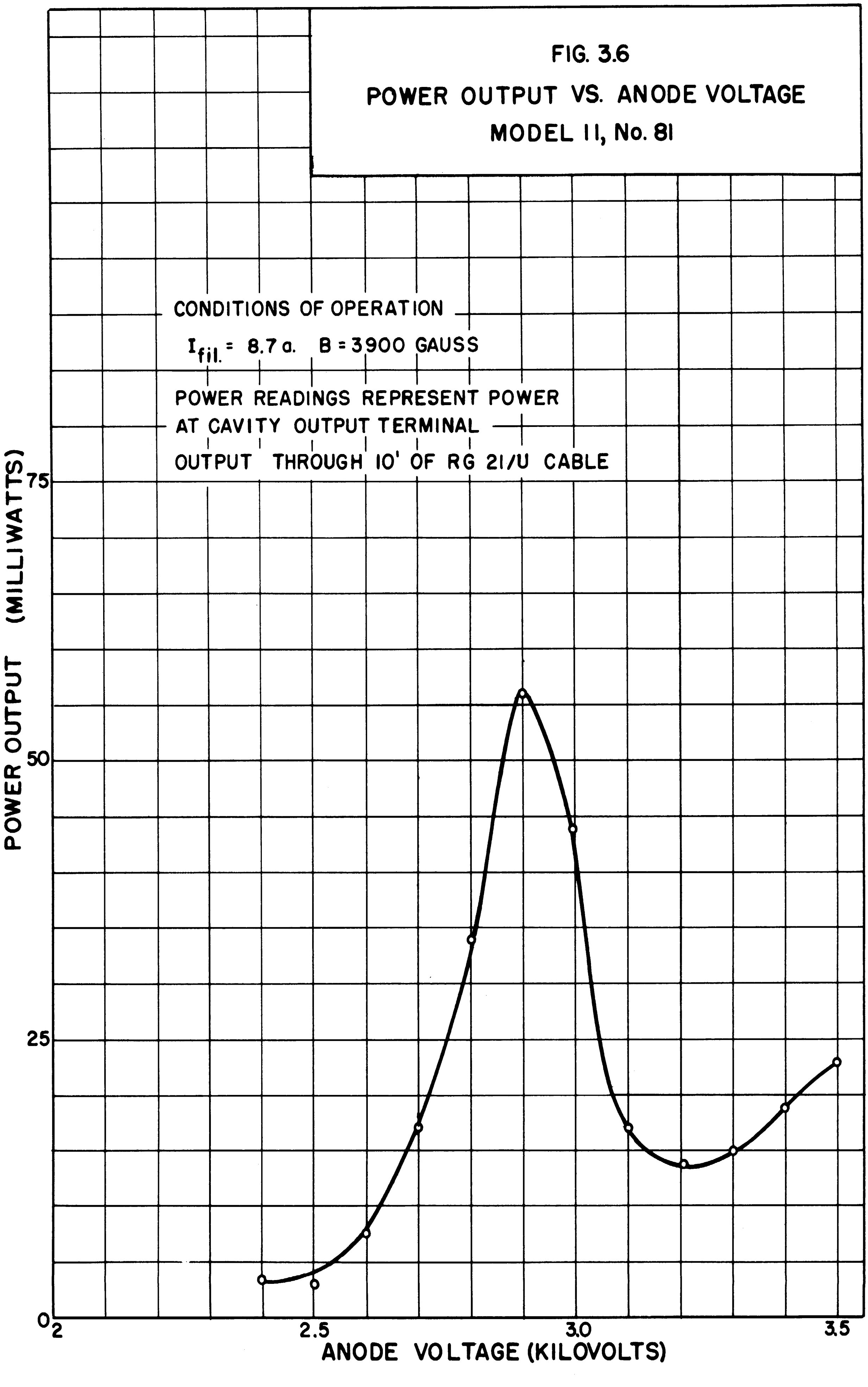
During the construction of the cathode for this tube a small notch was burned in the cathode end hat while spot welding the filament to the end hat. Even though the surfaces were smooth, the uneven surface caused sufficient concentration of field strength at this point to cause the tube to breakdown at approximately 3600 volts. This resulting arc damaged one of the anode bars to the extent that it was not considered feasible to continue testing the tube even though it still can be operated.

3.3 Model 11 Tube No. 82

This tube uses a button cathode as shown in Fig. (3.7). The upper end hat contains an oxide coating which serves as the electron source for the tube, the lower end hat is pure nickel and contains no heater or emitting surface. This lower end hat serves to contain the electrons within the interaction space, it may serve as a repeller or as a collector depending upon the method of operation.

The tube was first tested with an anode voltage consisting of a 600 volt 60 cycle sine wave superimposed upon the dc supply. For this test the lower end hat (or collector) was connected directly to the cathode. A filament current of 1.8 amperes was required to start oscillations, however, once the tube started to oscillate both the cathode and the collector began to heat up. The filament current could be reduced to zero and the

FIG. 3.6
POWER OUTPUT VS. ANODE VOLTAGE
MODEL 11, No. 81



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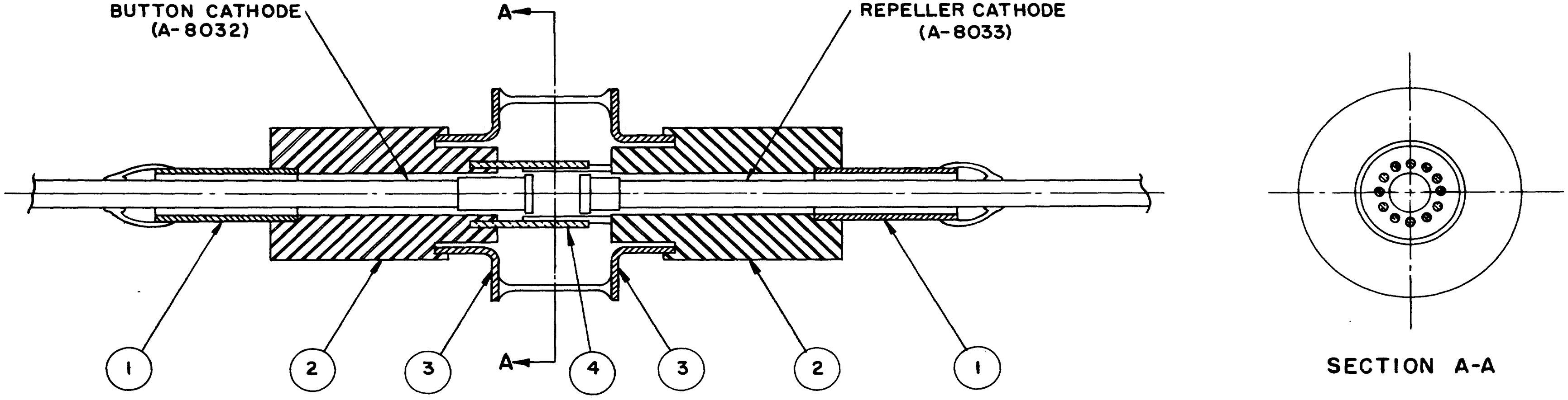

FIG. 3.7

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64." DECIMAL ± .005." ANGULAR ± ½°

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DRAWN BY PLW
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CHECKED BY [illegible]
DATE 8-13-52

PROJECT 2009

TITLE
MODEL II INTERDIGITAL MAGNETRON
WITH BUTTON CATHODE

CLASSIFICATION

DWG. NO. B- 10,011-a

ISSUE
DATE

tube continued to oscillate, in fact both the cathode and the collector were heated to a bright red temperature by the back bombardment. The plate voltage could not be raised above 1500 volts because above this level the cathode temperature became unstable and tended to "run away" causing arc over in the tube. The power output versus anode voltage, as observed on an oscilloscope, was stable and nearly uniform over a wide frequency range. Pulsed tests indicated that the tube voltage-tuned from 2380 mc to 1380 mc with a magnetic field of 2900 gauss and from 1900 mc to 1200 mc with a magnetic field of 3900 gauss. Thus, for similar values of B the frequency range of voltage-tunable operation for this tube is lower than for the tubes with regular cathodes.

The following experiments were performed to determine the nature and cause of the heating of the cathode and collector. First a milliammeter was connected between the collector and cathode, this meter indicated that the collector was being bombarded by electrons. A variable voltage supply was then connected between the collector and cathode, the collector being negative with respect to the cathode. It was necessary to make the collector 100 volts negative with respect to the cathode before the collector current was reduced to zero. The tube was also operated with the collector floating, and under these conditions the collector did not heat up, however, the output did not appear to be as great in this case.

These experiments thus indicate that electrons exsist in the interaction space which have energies sufficient to build up a space charge which is approximately 100 volts negative with respect to the cathode. These are the electrons which gain energy from the r-f field in the sorting process and which are returned to the cathode. In the normal magnetron structure these high energy electrons are collected on their return to the cathode and their energy is dissipated in the form of heat at the cathode, producing back-heating. In this case there is no physical cathode to collect these high energy electrons, thus making possible the formation of a space-charge cloud which is 100 volts negative with respect to the emitter. Once this space-charge cloud has been formed both the collector and the cathode will be bombarded by electrons, producing the heating effects which were observed.

Two new button type cathodes have been designed. One as shown in Fig. (3.8) is similar to the first model described above, in that it has an emitter and a collector. However, both end hat structures are made of molybdenum and are made much heavier than the previous model in order to dissipate the heat due to the back bombardment of the electrons. The second type will employ an emitter identical to that shown in Fig. (3.8) but the collector will consist of the molybdenum type collector in addition to a probe which will extend into the interaction space. This probe arrangement is shown in Fig. (3.9). The probe is smaller in diameter than the original cathode but it is expected that the probe will tend to collect the returning electrons and thus prevent the building up of the space charge due to the high energy electrons which causes back-heating of this emitter surface. These cathodes are nearing completion and will be tested in the near future.

3.4 Models 11 A and 11 B

As indicated in section 3.1, the effective anode diameter was greater than expected. This caused the frequency range covered to be lower than desired. To overcome this difficulty the Model 11 with an anode diameter of .268 inches from center to center of the anode bars was modified by decreasing this diameter to .235 inches. This tube has been designated as Model 11 B and will hereafter be referred to as such.

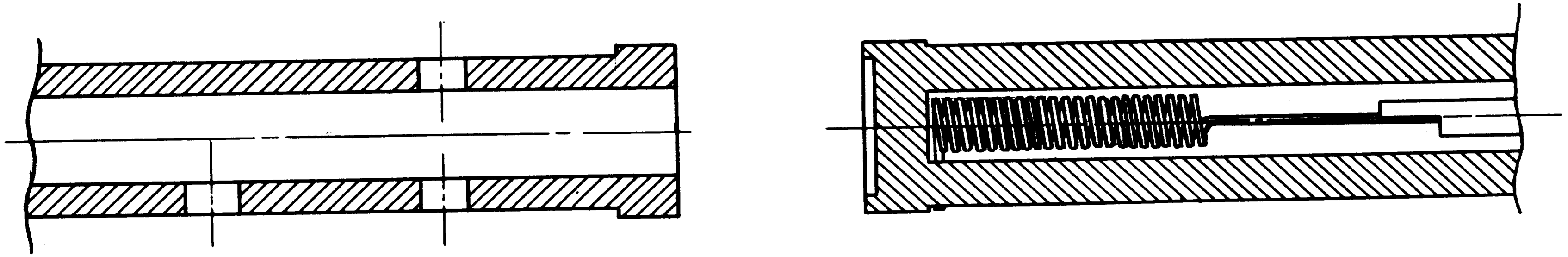

FIG. 3.8

BUTTON CATHODE, SECOND MODEL

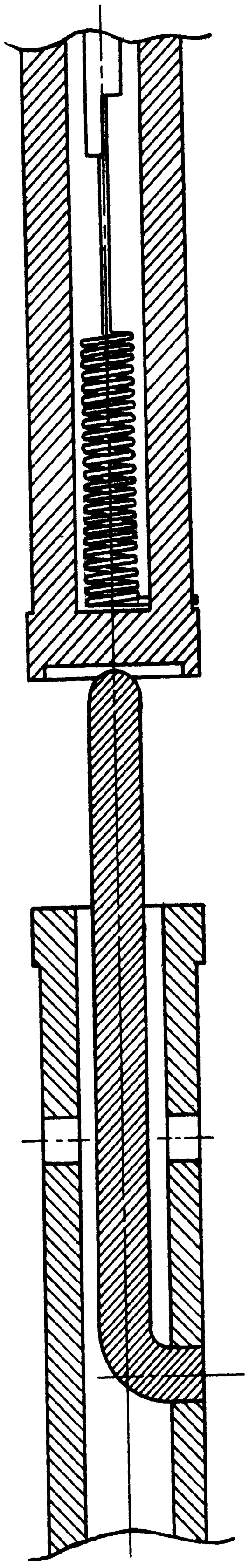

FIG. 3.9

BUTTON CATHODE, THIRD MODEL

This change in the anode radius should increase the frequency of operation until the range of voltage-tuning is more nearly centered about 3000 mc.

Model 11 A is similar to the Model 11, except that it uses square anode bars. The anode bars are arranged such that the inside anode diameter is .235 inches; the same as the anode bar center to center diameter of the Model 11 B. It is hoped that a study of the operation of these tubes may lead to a better understanding of voltage-tunable operation in the magnetron. As an aid in studying the operation of the tubes, a flux plot of the potential distribution in the interaction space of each tube has been made. These plots are shown in Figs. (3.10) and (3.11).

One significant difference in the two flux plots is the variation in the field strength in the region (a) for the two geometries, assuming equal r-f voltages on each. Since a high r-f field is necessary to produce effective bunching within this region the square anodes would seem to have an advantage. However, since the anode to anode capacitance is greater for the square anode structure than for the round anode structure, it will require a greater induced current in the square anode structure to produce the same voltage. Thus the development of a high r-f field and the bunching of the electrons are interdependent phenomena and it is impossible to conclude from the flux plots alone which type of structure is the better. A careful study of the known properties of the two structures such as anode bar-to-bar capacitance and the flux plots in connection with experimental data should provide at least a partial answer to the question.

4. Model 9 Magnetron With a "Ground-Plane" Circuit. (J. Needle)

A new type of circuit structure for operation with the Model 9 insertion magnetron was constructed during this period. This circuit

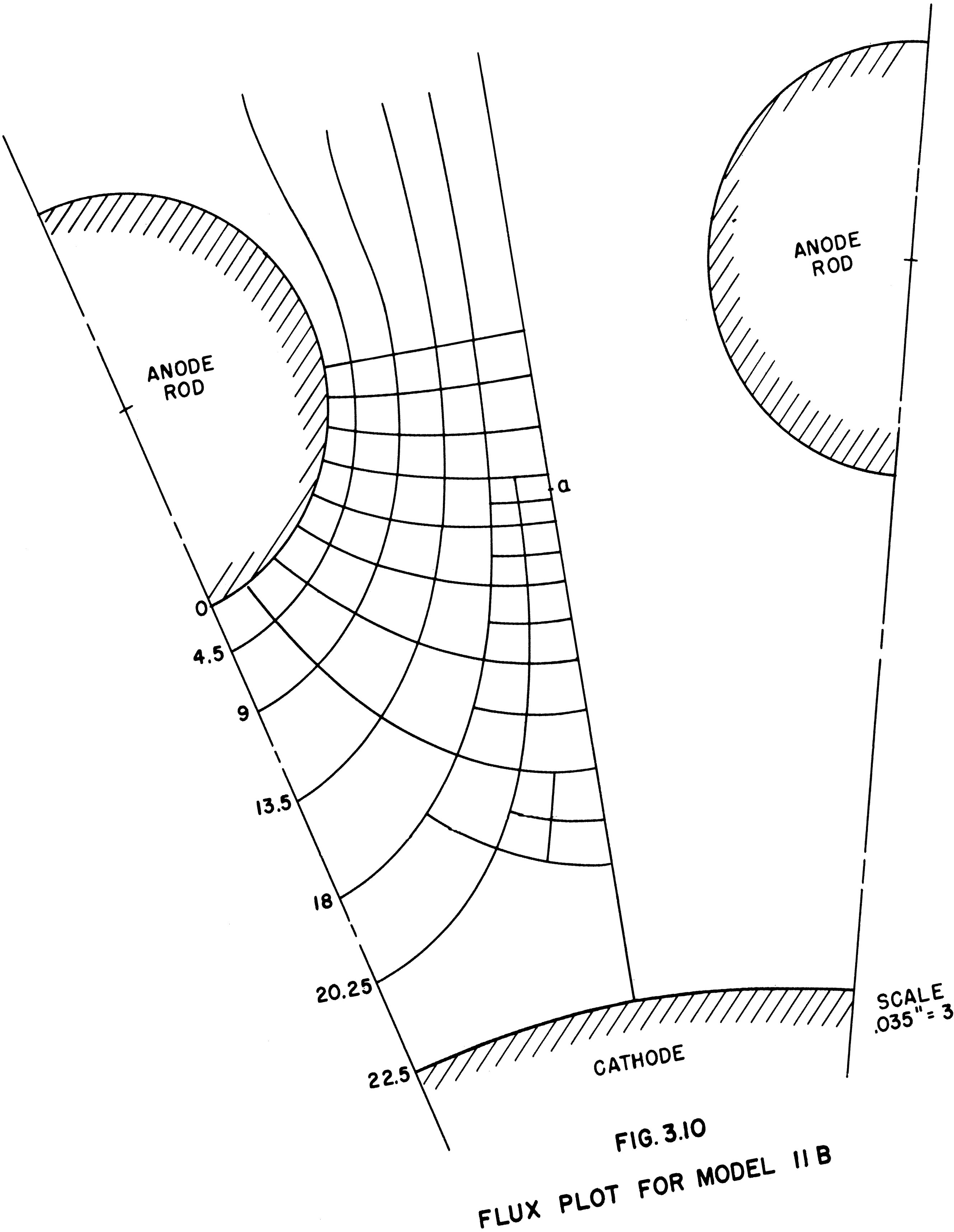

FIG. 3.10

FLUX PLOT FOR MODEL 11 B

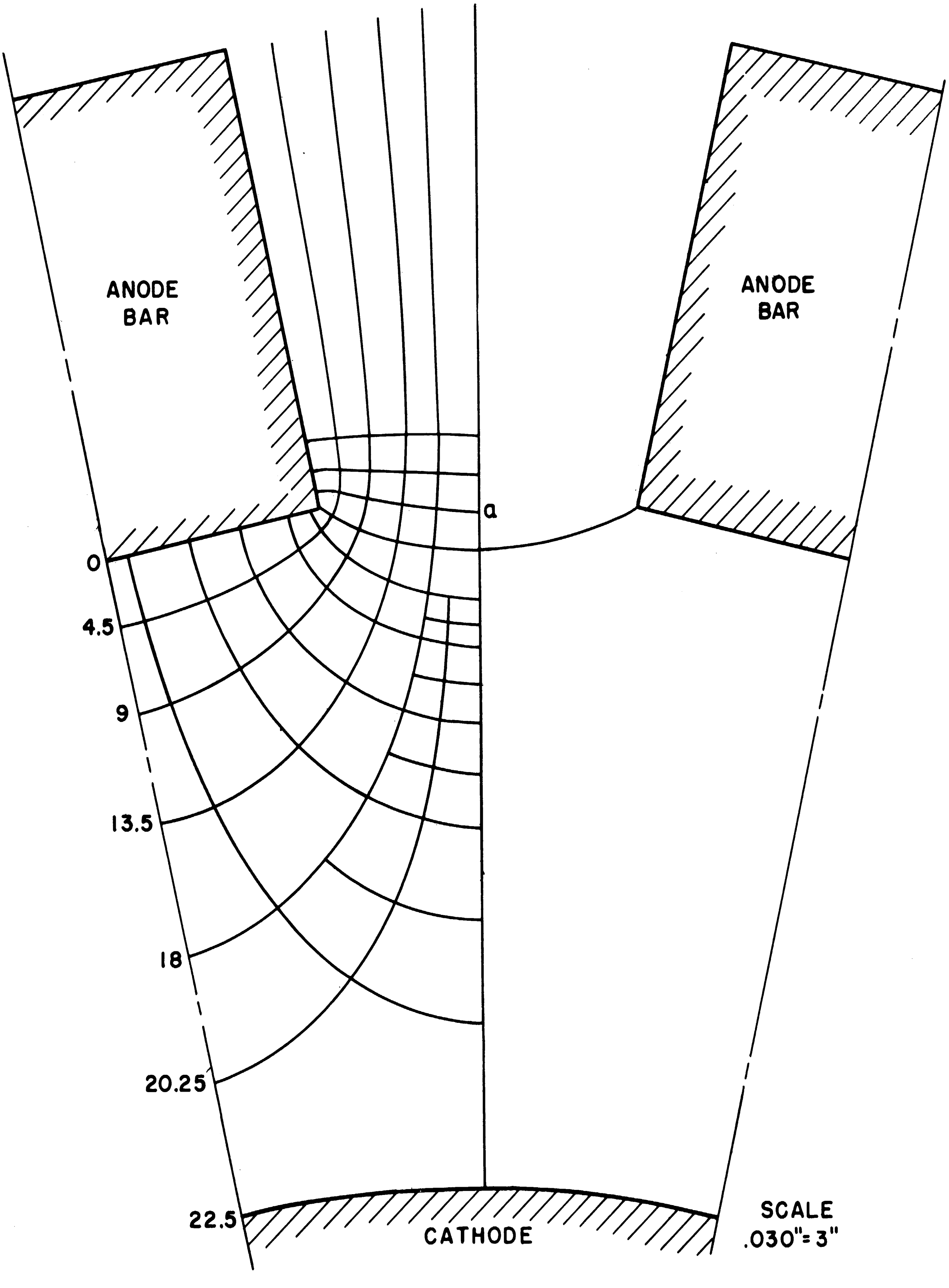

FIG. 3.11

FLUX PLOT FOR MODEL 11A

consists of a section of standard S-band wave guide and a cylindrical rod which is located on the longitudinal axis of the wave guide. Fig. (4.1) shows an assembly drawing of this structure together with the Model 9 insertion magnetron. It should be apparent from this figure that the magnetron will be coupled to a load through this modified or ground-plane coaxial transmission line. The center conductor of the transmission line is attached to the vane anodes of the magnetron and the bar anodes are connected to the wave guide. The characteristic impedance of this ground-plane type of coaxial transmission line can conveniently be made as high as 150 ohms. In addition to providing a larger characteristic impedance than is practical with a concentric cylinder line, higher magnetic fields are more easily attainable with this circuit arrangement.

A limited amount of testing was carried out with this circuit and tube arrangement. The results of these limited tests indicate that higher power output can be attained with this structure than with a coaxial system of practical dimensions, however, the bandwidth of this particular structure is smaller than the low Q coaxial circuits used to date.

5. Cathode Circuit Study (G. Dombrowski)

The anode structures of the insertion magnetron (Model 9) and interdigital magnetron (Model 11) are electrically coupled to the cathode-heater system. This may result in undesirable leakage of r-f power through the heater leads and conversely, the cathode-heater structure may produce undesirable effects on the magnetron interaction itself. One of these effects, conceivably, is that the cathode potential may become unbalanced with respect to the potentials of alternate anode surfaces. Another is the effect of the impedance coupled into the anode circuit. This study

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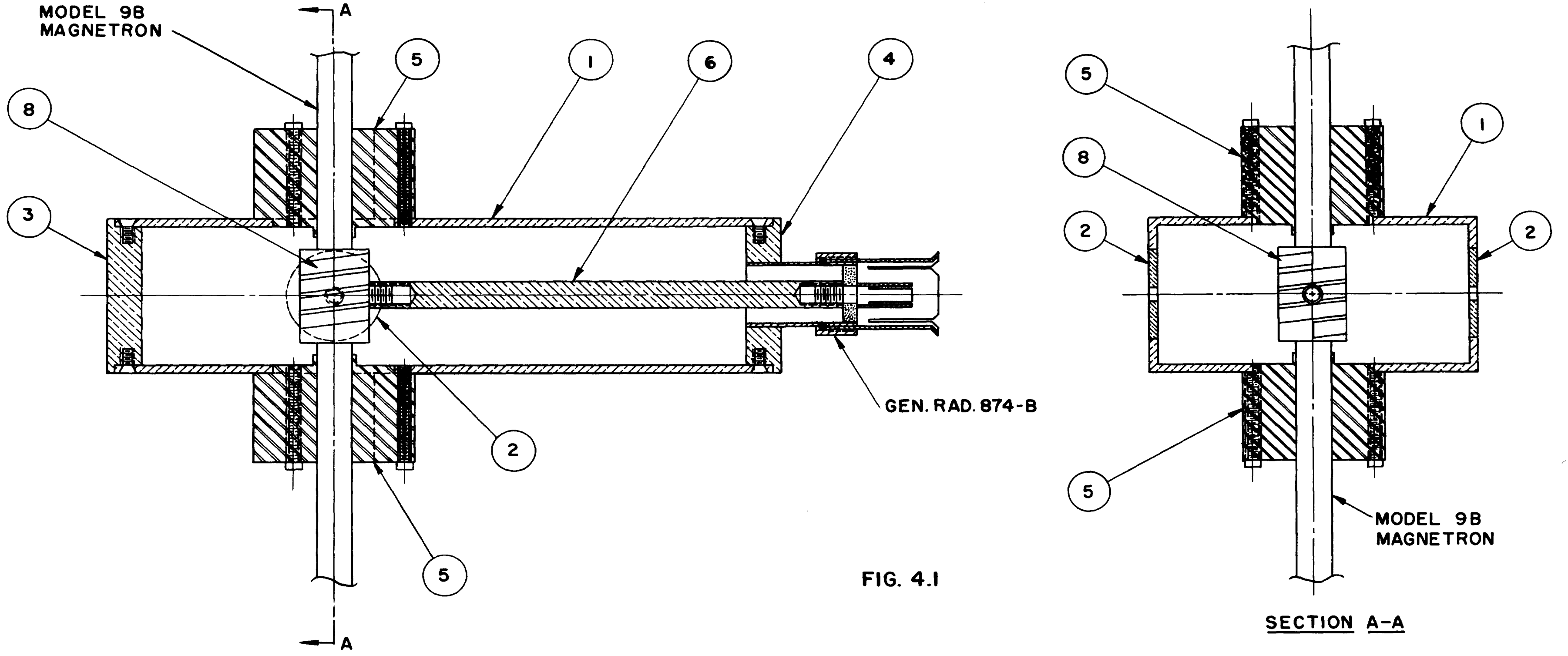

FIG. 4.1

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64," DECIMAL ± .005," ANGULAR ± 1/2°

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DESIGNED BY JN
DRAWN BY PLW
CHECKED BY
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SCALE FULL
DATE 7-31-52

PROJECT 2009

TITLE
GROUND-PLANE COAXIAL OUTPUT SYSTEM

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is to determine the extent of these effects and to obtain a suitable cathode structure from these considerations.

The inherent simplicity of the insertion magnetron structure makes it suitable for cathode circuit tests. A Model 9 B tube (no. 78) was operated in a high-Q mechanically tuned cavity as shown in Fig. (5.1). Initial tests were made with an adjustable by-pass capacitor structure as shown in the figure. The experimental results obtained with this combination of tube, cavity and cathode circuit are shown in Figs. (5.2), (5.3) and (5.4).

Fig. (5.2) shows a range of by-pass phase, d_3/λ, for uniform operation and also a sharply resonant dip in power output with frequency pulling. This is most readily explained by means of a simple equivalent circuit of Fig. (5.5). The cathode line and its by-pass form a resonant circuit which is capacitively coupled to the anode set. When the cathode circuit is far from resonance, the effective cavity capacitance is $C_{\text{vanes-bars}} + C_{\text{vanes-cathode}}$. At parallel resonance between the cathode line and $C_{\text{bars-cathode}}$, the effective cavity capacitance is $C_{\text{vanes-bars}}$ alone. The wavelength is thus decreased by this resonance, which is seen to occur for $d_3/\lambda = 0.70$. When the cathode line is made inductive, a series resonance between $C_{\text{vanes-cathode}}$ and the cathode line occurs, and the anode set is effectively loaded with a short circuit. This occurs for $d_3/\lambda = .66$, (Fig. 5.3) and the r-f output is of course zero. Detuning from this resonance reduces the loading effect of the cathode and more r-f power is delivered to the load. The presentations of Figs. (5.2) and (5.3) are somewhat different: the parallel and series resonances of Fig. (5.3) are too close together to be distinguished from each other in Fig. (5.2), and there is a much sharper dip in mode boundary current

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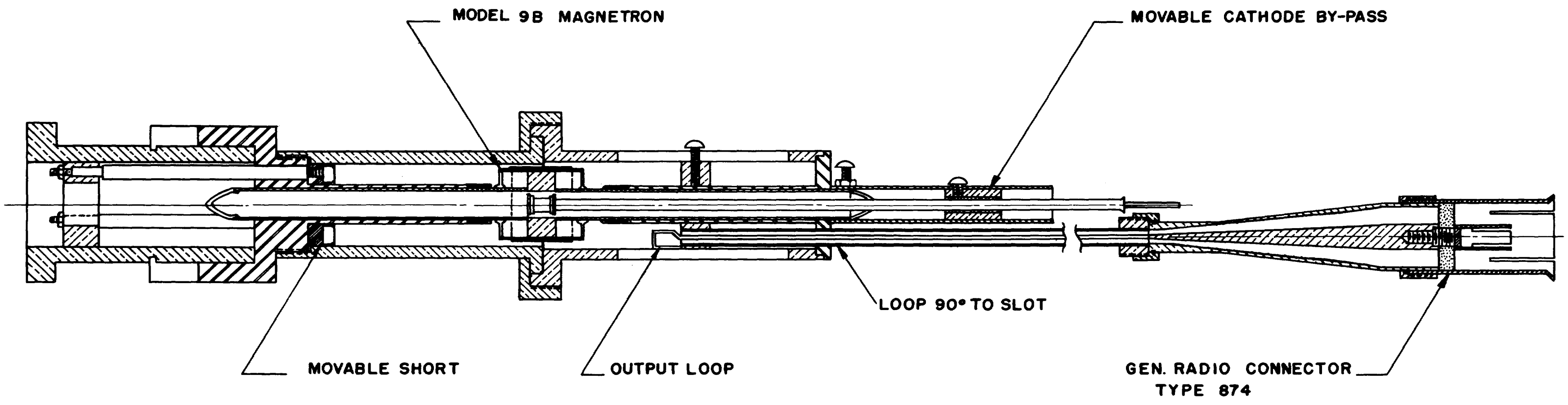

FIG. 5.1

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64," DECIMAL ± .005," ANGULAR ± 1/2°

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PROJECT 2009	TITLE EXPERIMENTAL CO-AXIAL CAVITY FOR MODEL 9B MAGNETRON	
CLASSIFICATION	DWG. NO. B-2074	

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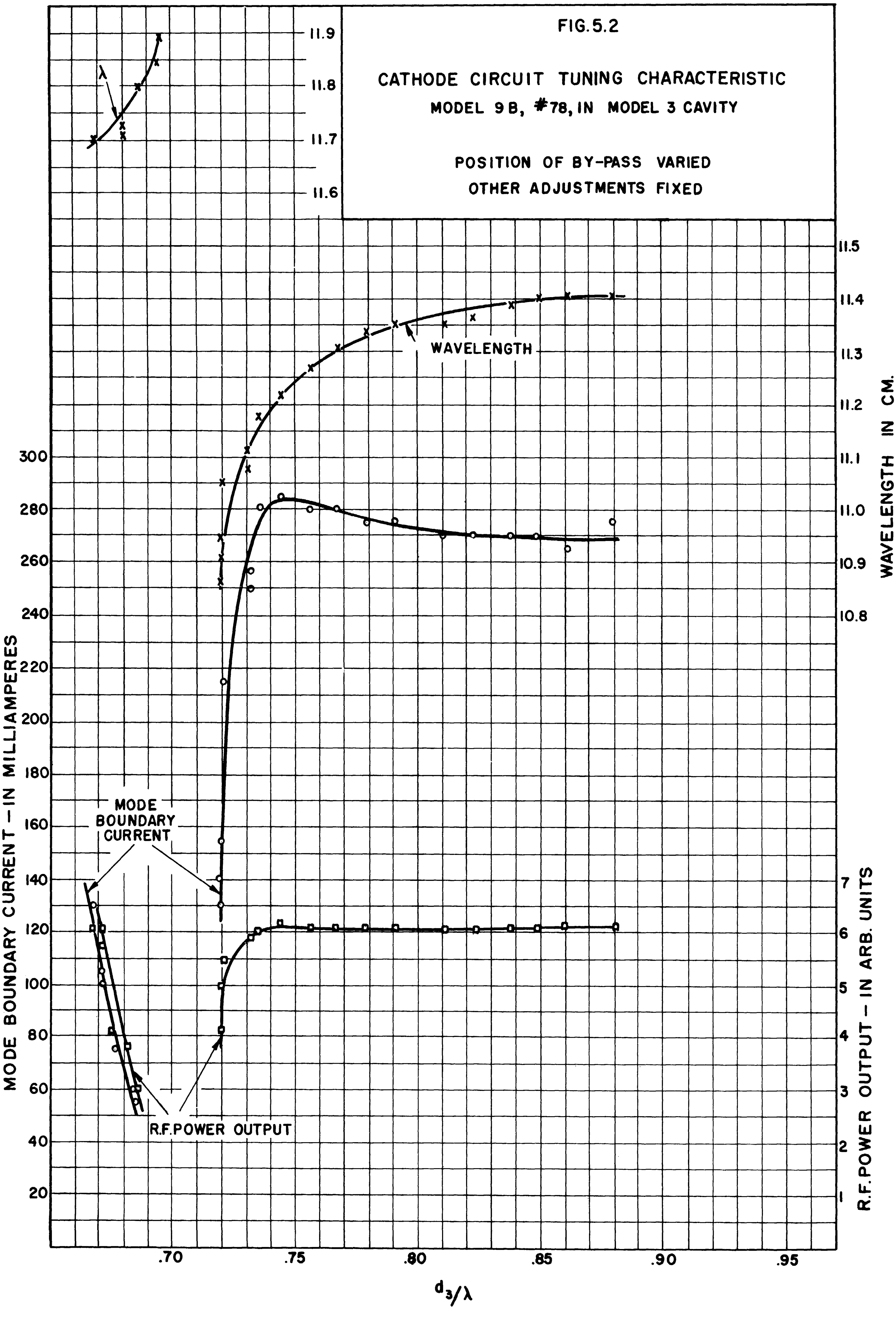

FIG. 5.2

CATHODE CIRCUIT TUNING CHARACTERISTIC
MODEL 9 B, #78, IN MODEL 3 CAVITY

POSITION OF BY-PASS VARIED
OTHER ADJUSTMENTS FIXED

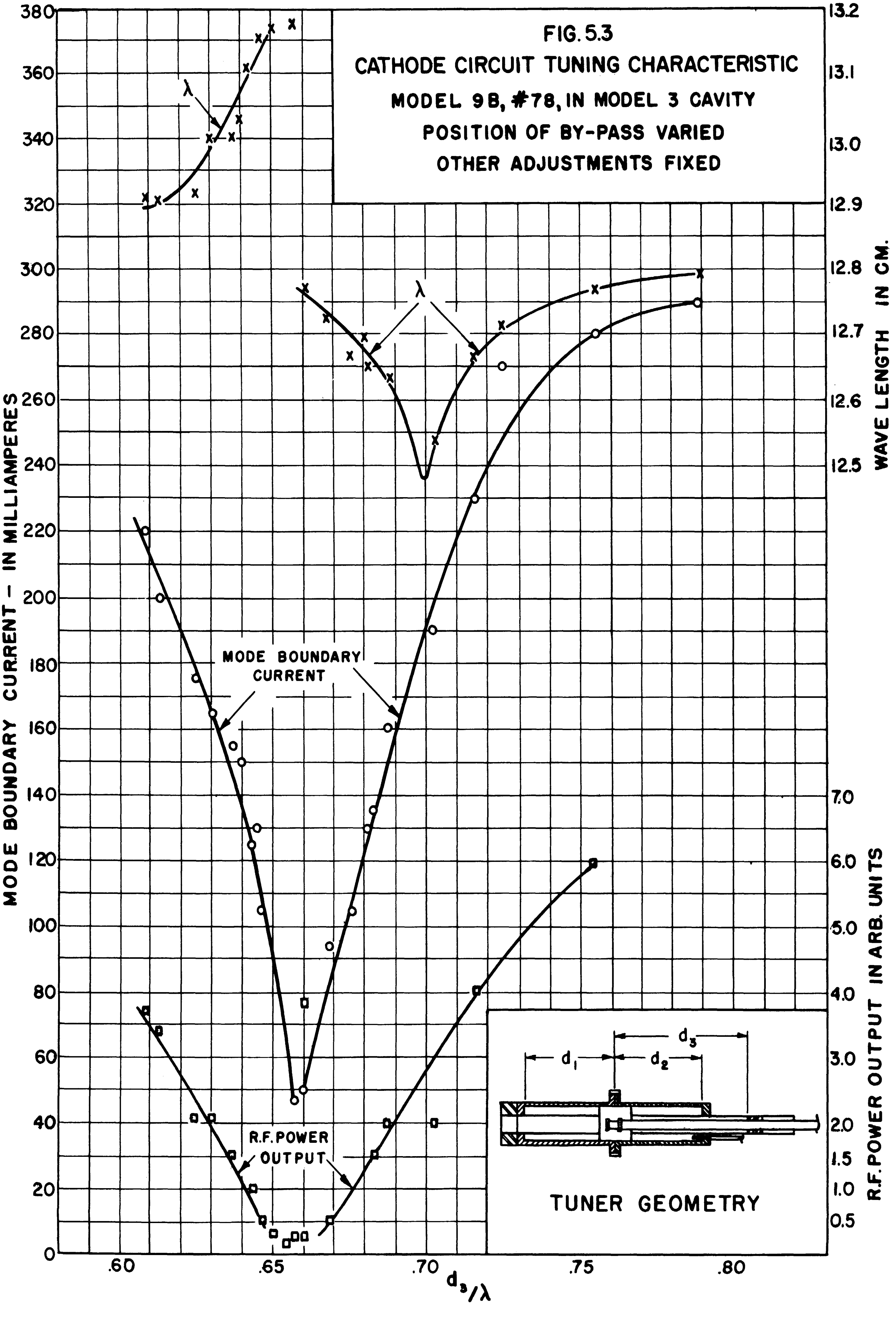

FIG. 5.3

CATHODE CIRCUIT TUNING CHARACTERISTIC

MODEL 9B, #78, IN MODEL 3 CAVITY

POSITION OF BY-PASS VARIED

OTHER ADJUSTMENTS FIXED

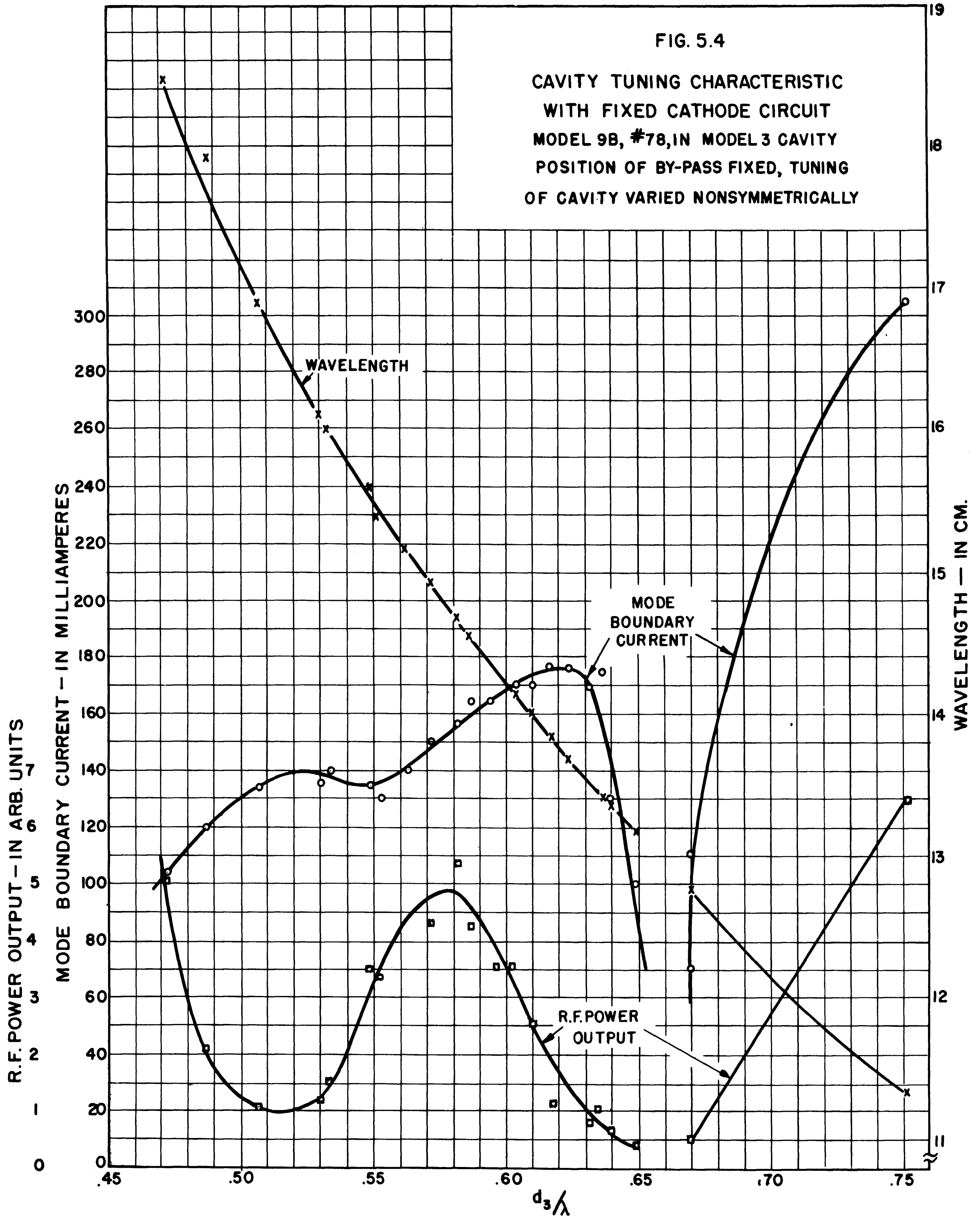

FIG. 5.4

CAVITY TUNING CHARACTERISTIC WITH FIXED CATHODE CIRCUIT MODEL 9B, #78, IN MODEL 3 CAVITY POSITION OF BY-PASS FIXED, TUNING OF CAVITY VARIED NONSYMMETRICALLY

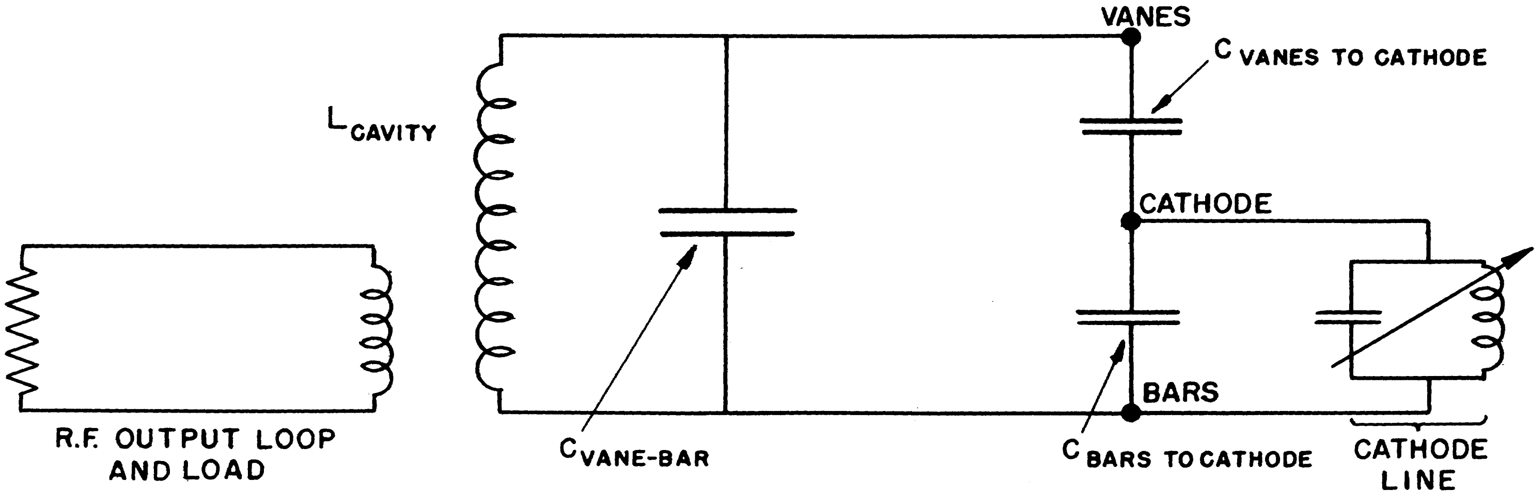

FIG. 5.5

EQUIVALENT CIRCUIT OF MODEL 9B MAGNETRON CATHODE CIRCUIT and r-f output. This may possibly be the result of variations in electrical contacts involved in the cavity and/or cathode circuits.

It may be inferred from these figures that cathode unbalance does not play an important part here, since the entire range of balance is traversed from d_3/λ varying from .80 to .70 (Fig. 5.3) without significant change in the trend caused by impedance effects alone.

Fig. (5.4) shows the performance variation of a tuned cavity with fixed by-pass placement. The cyclic variation of r-f output is attributed to variation in loop and output line coupling. An improved output coupling is being made to overcome this difficulty. The general trend of r-f output and the mode boundary is related to the change in symmetry of the cavity as well as the electrical length of the cathode system. Further data will be required to determine the optimum operation considering the assymetrical tuning mechanism, i.e., tuning by variation of either d_1 or d_2 but not both.

The magnetron became gassy during the course of these measurements and finally became inoperable. The tube is now unusable because of leaks. Another Model 9 B tube of the same cathode design is being constructed.

6. Model 10 Coaxial Voltage-Tunable Magnetron (G. Dombrowski, J. R. Black)

The Model 10 magnetron is a modified version of the Model 9 structure designed to dissipate approximately 500 watts of power. This study was initiated in an effort to obtain a voltage-tunable signal at high power levels. Fig. (6.1) is an assembly drawing of the Model 10.

Quarterly Progress Reports No. 1, April, 1952, and No. 2, June, 1952, discuss tests made on the Model 10 No. 73 tube. As was mentioned, the glass output seal of this tube cracked in an attempt to obtain c-w

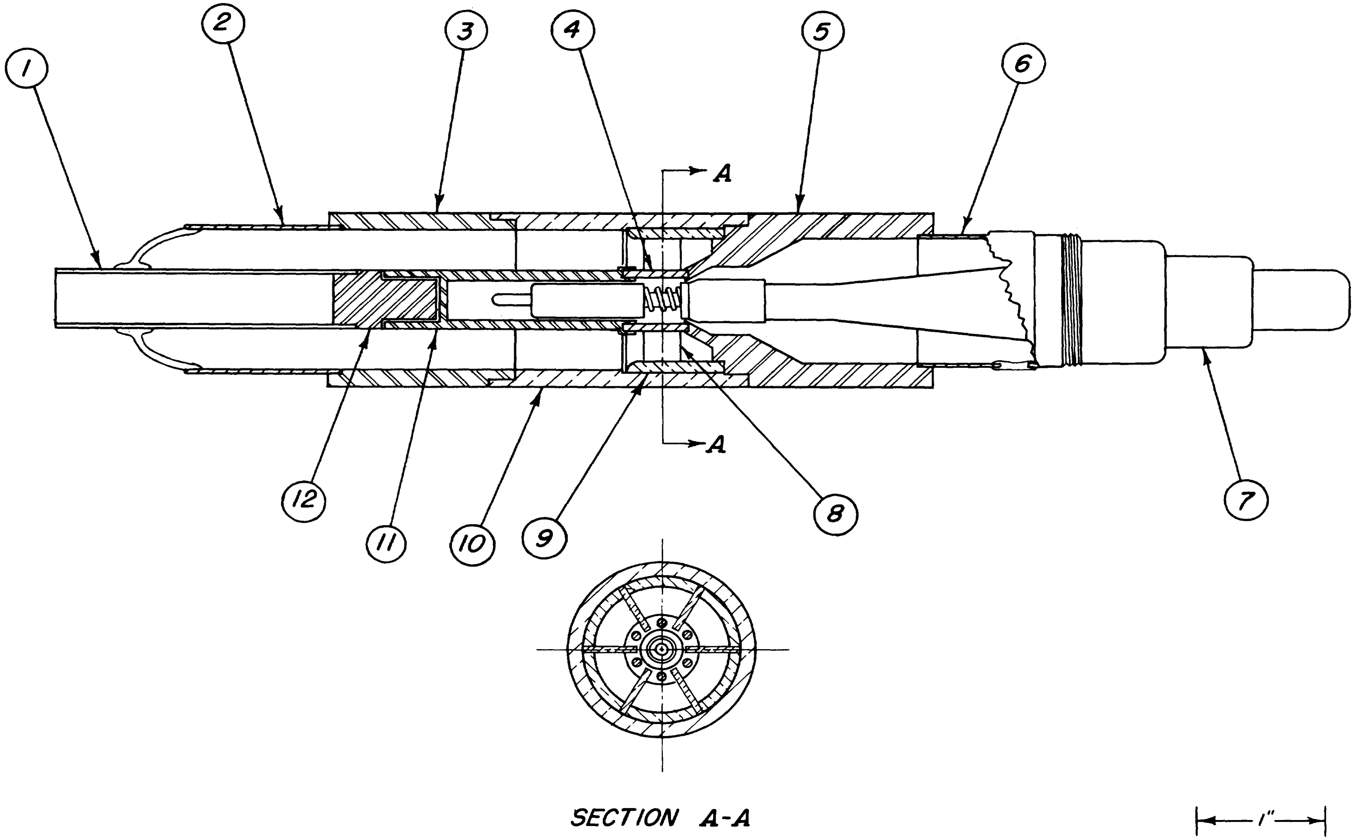

FIG. 6.1

ALL DIMENSIONS UNLESS OTHERWISE SPECIFIED MUST BE HELD TO A TOLERANCE - FRACTIONAL ± 1/64" DECIMAL ± .005" ANGULAR ± 1/2°

ENGINEERING RESEARCH INSTITUTE
UNIVERSITY OF MICHIGAN
ANN ARBOR MICHIGAN

PROJECT 2009

CLASSIFICATION

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SCALE FULL
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DWG. NO. B-10,010

power output measurements. The tube was reprocessed, but was found to be gassy. Construction was then started on a new model of this tube, after it was decided that the old reworked model (No. 73) would be difficult to clean properly. At the time the new structure was ready for assembly, it became apparent that an interdigital structure held greater promise for a high-power voltage-tunable source. All effort on the Model 10 structure was then suspended in favor of an interdigital tube.

7. Model 8 Rectangular-Cavity Magnetron (J. R. Black)

The Model 8 resonant circuit is readily adapted to several different types of magnetrons. It is a full wavelength rectangular resonator capacitively loaded at its two voltage maxima points. Various electrical structures could be placed at either of these voltage points. The interests of this laboratory have been to develope two different versions of this tube. These are:

a. A mechanically tunable c-w magnetron producing 500 watts output power. The tube would contain an interdigital magnetron anode at one voltage maxima and a variable cup-rod capacitor at the other voltage maxima.

b. An f-m, c-w magnetron producing 500 watts of r-f power output. This tube would contain an interdigital magnetron anode at one voltage maxima and a variable reactance anode structure at the other voltage maxima. The reactance section will be either the variable magnetron space-charge type or the spiral beam type.

Initially effort was placed on the mechanically-tunable structure. Quarterly Progress Report No. 1, April, 1952, discussed results obtained from the Model 8 C tube where a mechanically-tunable signal was obtained over a frequency range of 1,500 to 2,500 mc. The tube, however, was plagued with two parasitic resonances and a low mode current boundary.

Model 8 C was completed and tested during this period. Fig. (7.1) shows an assembly drawing of this tube. Molybdenum wire anodes were employed in this model to keep the total anode capacitance low. The anode fingers were made to overlap one another in an effort to redurc r-f coupling to the cathode line. The above two changes in design were made in an attempt to increase the mode current boundary and to shift the parasitic modes out of the tuning range of the tube.

With the cathode removed the Model 8 D cold tested to tune from 1550 to 2600 mc with no parasitic modes present in that range. However, with the tube operating hot two modes were present, neither of them being the desired tunable cavity mode. These modes appeared at 2900 mc and at 1660 mc. The high frequency mode is associated with the two full wavelength mode of the cavity while the low frequency mode is associated with the resonant circuit formed by the cathode line, the cathode chokes and the pole pieces. Apparently a reversal in phase takes place in the circuit between the two anode sections allowing pi mode operation of the anode.

The Model 8 program has been discontinued in order to allow more time to be devoted to the development of voltage-tunable tubes.

It is felt that the method of mechanical tuning employed by the Model 8 structure is a promising technique for accomplishing wide tuning range magnetrons in the frequency range above 5,000 mc and warrants further development at a later date.

8. The Trajectron, An Experimental DC Magnetron (W. Peterson)

The main purpose of this experiment is to attain a more complete understanding of magnetrons by studying the space charge in a smooth-bore dc magnetron.

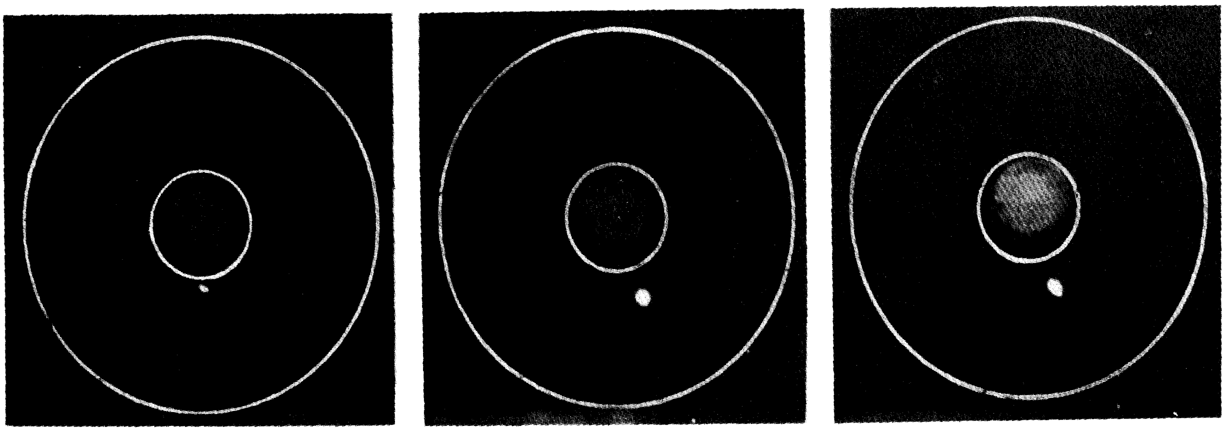
The tube which will be used for this work is a dc smooth-bore magnetron with an electron gun in the same envelope arranged so that a beam of electrons can be sent into the space charge in an axial direction just grazing the cathode. The exit point of the beam will show on a fluorescent screen; thus an electron's position as a function of time after it leaves the cathode may be measured.

During the past quarter the trajectron was operated for the first time with the beam reasonable well aligned and the magnetron diode operating at the same time. Photographs were taken of the fluorescent screen showing the deflected spot. The photographs were taken on Linagraph Ortho film, which is insensitive to red light. A green filter, matched to the spectrum of P-1 phosphor, was also used. The light from the cathode shows on the pictures but it doesn't obscure the beam spot in any case.

Typical full size photographs are shown in Figs. (8.1) and (8.2) for two sets of operating conditions. The beam voltage and the corresponding time which the beam spent in the space charge is shown on each photograph. The light in the center is from the cathode, but light shows only through a hole in the phosphor which has a somewhat smaller diameter than the cathode. The cathode and anode boundaries are shown by circles drawn on the photographs.

The magnetron was cut off in both sets of photographs shown; in Fig. (8.1) the anode voltage was only slightly below cutoff, while in Fig. (8.2) the voltage was about one-fourth cutoff voltage. The beam is observed to enlarge in the cutoff magnetron, especially in the case where the anode voltage is considerably below cutoff. The reason hasn't been established. It may be that the random motion of the electrons in the space charge, which results in magnetron noise, also causes variations in the trajectories of the beam electrons. Also, electron collisions may result in the distribution of the trajectories. A third explanation of the enlarging of the beam spot may lie in the initial distribution of velocities in the beam.

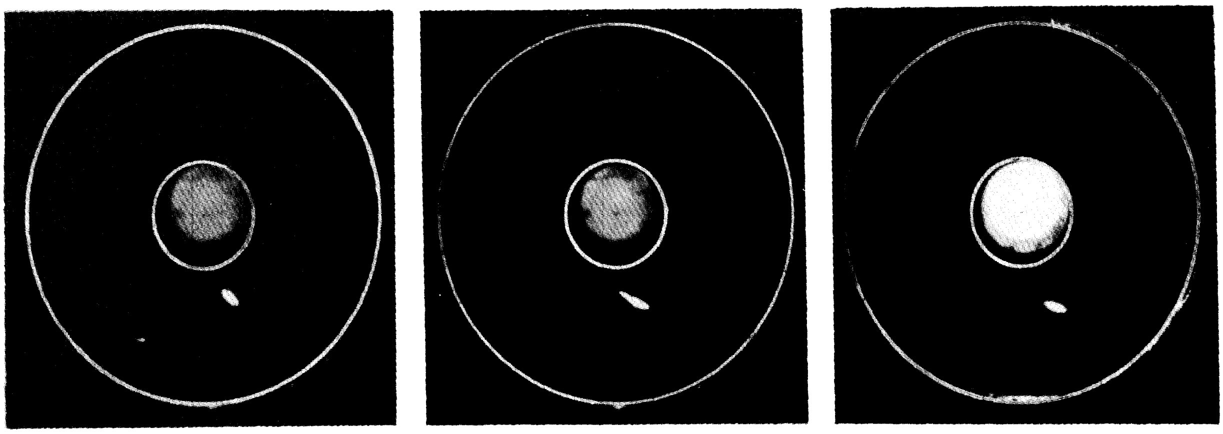
FIG. 8.1



UNDEFLECTED SPOT
($E_{ANODE} = 0$)

$E_{BEAM} = 3500$
($t = 1.5$)

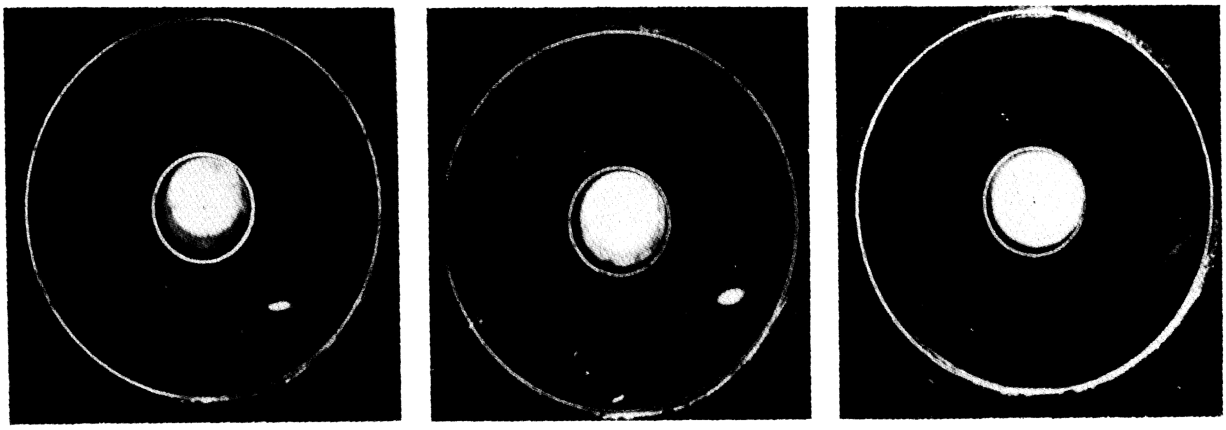
$E_{BEAM} = 3000$
($t = 1.6$)



$E_{BEAM} = 2500$
($t = 1.8$)

$E_{BEAM} = 2000$
($t = 2.0$)

$E_{BEAM} = 1500$
($t = 2.3$)



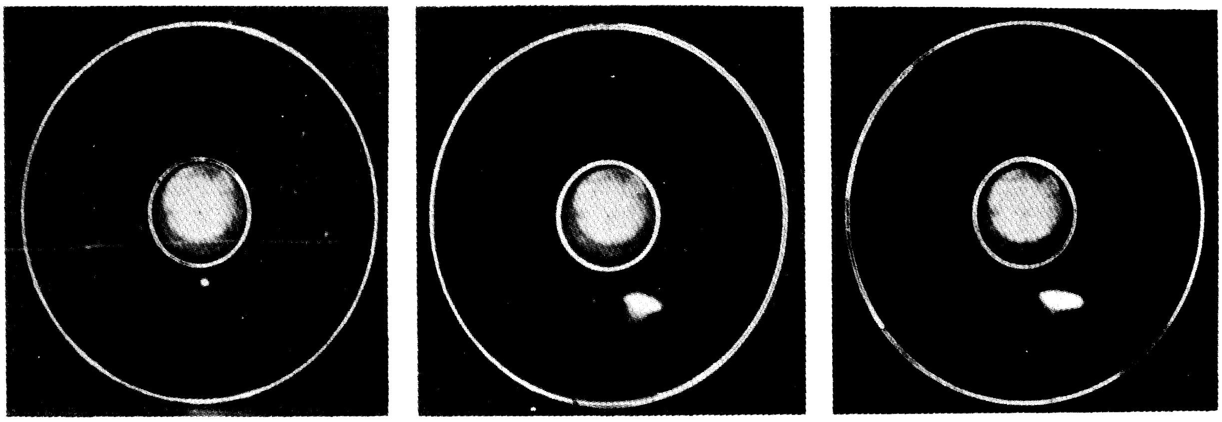
$E_{BEAM} = 1000$
($t = 2.8$)

$E_{BEAM} = 750$
($t = 3.3$)

$E_{BEAM} = 450$
($t = 4.2$)

BEAM SPOT OF THE TRAJECTRON
FULL SIZE PHOTOGRAPHS WITH ANODE AND CATHODE CIRCLES DRAWN IN
($E_{ANODE} = 800$ V., $I_{ANODE} = 100$ MA., $B = 74$ GAUSS,
t = TIME IN MILLIMICROSECONDS)

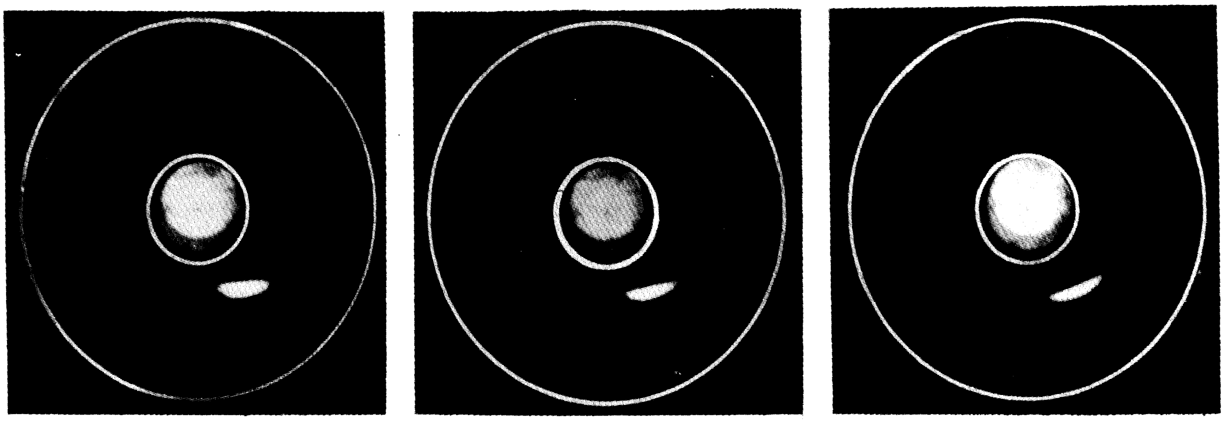
FIG. 8.2



UNDEFLECTED SPOT ($E_{ANODE} = 0$)

$E_{BEAM} = 3400$ ($t = 1.5$)

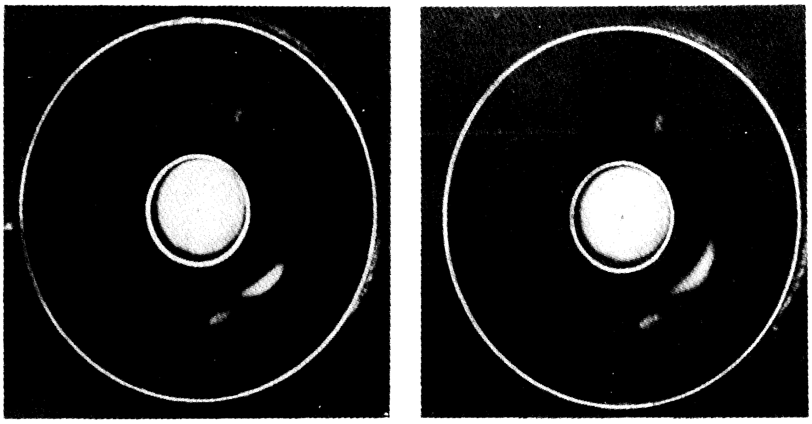
$E_{BEAM} = 3000$ ($t = 1.6$)



$E_{BEAM} = 2400$ ($t = 1.8$)

$E_{BEAM} = 2000$ ($t = 2.1$)

$E_{BEAM} = 1600$ ($t = 2.2$)



$E_{BEAM} = 1300$ ($t = 2.5$)

$E_{BEAM} = 1000$ ($t = 2.8$)

BEAM SPOT OF THE TRAJECTRON
FULL SIZE PHOTOGRAPHS WITH ANODE AND CATHODE CIRCLES DRAWN IN
($E_{ANODE} = 1300V.$, $I_{ANODE} = 10$ MA., $B = 148$ GAUSS,
t = TIME IN MILLIMICROSECONDS)

The photographs showing the undeflected beam indicate that the beam was not aligned as well as possible. Although the spot should be right at the cathode surface it is actually about .090 inches out. To facilliate future alignment of the beam, short pieces of .005 inch wire have been spot welded to the cathode at the entrance point and the exit point of the beam. These will cause small shadows in the spot which will make accurate beam alignment easier.

It is felt that the trajectron is operating quite satisfactorily, and only slight modifications in its design are anticipated. The emphasis will now be on aligning the beam accurately, obtaining data on photographs for a wide range of operating conditions, and on interpreting the data.

9. Conclusion (J. R. Black)

During this period it has become apparent that the interdigital magnetron is inherently a superior structure for voltage-tuning than the coaxial magnetron. This is mainly due to the improved magnetic circuit of the interdigital structure and to the high impedance obtainable across the anode sections. Interdigital magnetrons can be made to operate at higher voltages with the stronger magnetic field, thus a larger temperature limited current may be drawn at the higher voltages, increasing the power input and hence the power output of the magnetron.

Furthermore, the coaxial structure exhibits a vane mode, (similar to that occurring in a vane magnetron) which is not coupled to the load. The vane mode occurs at a relatively low voltage due to the inferior magnetic field. Voltage-tuning has been employed at voltages below that voltage at which the vane mode occurs. As a result, the tubes could not be operated at moderate power levels. While the interdigital structure exhibits a first order mode as well as the zero order mode, the first order mode can be loaded down by the output coupling making this mode useful for voltage-tuning.

As a result of the above conclusions it was decided during this period that all effort envolving the use of coaxial magnetrons for voltage-tuning be terminated.

Tests made with button cathodes in the Model 11 interdigital voltage-tunable magnetron indicate that the tube operates well without a physical cathode present in the interaction space. Such an arrangement is desirable in an interdigital structure to reduce power coupled out by the cathode stem and to reduce the dependence of cathode temperature on the anode voltage.

A new circuit structure for the Model 9 coaxial voltage-tunable magnetron has been devised. This "ground-plane" circuit presents a medium Q, relatively high impedance load to the tube. Higher powers are obtainable over a smaller voltage-tunable bandwidth with this circuit than is obtainable when the standard coaxial circuit is employed.

Progress has been made in the cathode circuit study being preformed on a Model 9 magnetron. The interest here lies in determining the effect the cathode line has on the tube operation and to devise a cathode circuit which will be effective over as wide a frequency range as possible. This information will be applicable to interdigital magnetrons as well as to coaxial magnetrons.

No further results have been obtained from the Model 10 coaxial voltage-tunable magnetron. This project has been dropped.

The Model 8 D rectangular-cavity magnetron was tested during this period with negative results. This project has been dropped for the time being.

The trajectron has been operated for the first time with a magnetron space-charge present. Only slight changes in the design of the present tube are anticipated. Emphasis will now be on the collection of accurate data.

10. Program for the Next Quarter (J. R. Black)

Effort is to be placed solely on the interdigital voltage-tunable tubes and on the completion of the trajectron study.

The program for the voltage-tunable interdigital magnetrons will be as follows:

a. Obtain our final model of the S-band voltage-tunable tube (Model 11) having a power output and a signal-to-noise ratio adequate for local oscillator use.

b. Develope a voltage-tunable tube for local oscillator use in the C-band.

c. Develope a voltage-tunable tube for local oscillator use in the X-band.

d. Develope a high power voltage-tunable tube in the S-band.

In the above list work will commence immediately on (b) and (d). It is planned that work will start on (c) at some future date. (a) is nearing completion.

The use of button cathodes for voltage-tunable magnetrons will continue to receive attention. Also, work will continue on the study of the effect of the cathode line on the operation of voltage-tunable tubes.

An effort will be made to complete the trajectron study within the next half year.

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