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FINAL ENGINEERING REPORT ON THE DEVELOPMENT OF A LOW-NOISE L-BAND CYCLOTRON-WAVE LINEATOR

Report No. WG-168-FE
Period Covered: October 15, 1961 to June 30, 1962

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Dated: July 31, 1962

FOR

LINCOLN LABORATORIES
LEXINGTON 73, MASSACHUSETTS

UNDER

SUBCONTRACT NO. 260
PRIME CONTRACT NO. AF 19(604)-7400

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I. INTRODUCTION

The object of this project has been to design, develop, and construct a feasibility model of a low-noise L-band cyclotron-wave device (hereafter referred to as a LINEATOR) for isolation and overload protection of a solid-state negative resistance preamplifier for high-power radar. The operating frequency is centered at 1,295 Mc.

A feasibility model complete with solenoid and power supplies, and packaged in a form suitable for complete performance testing on a general-purpose space-tracking and measurements radar constructed by Lincoln Laboratories was delivered. This unit has the capability of withstanding 50 kw of peak incident power and providing greater than 100 db of isolation to the solid-state amplifier during the transmitter pulse. Recovery is automatic and essentially instantaneous. During the receiving period the terminal insertion loss is approximately 0.3 db, with a total effective input noise temperature less than 35°K.

II. BACKGROUND AND LINEATOR DESCRIPTION

The basic principles of cyclotron-wave couplers have been known for more than thirteen years.[1] That such couplers would be capable of very-low-noise behavior was first pointed out by R. Adler,[2] in connection with the invention of the electron beam parametric amplifier (EBPA). The idea of combining fast-wave ("Cuccia") couplers with negative-resistance amplifiers originated with Dr. Adler at least as early as 1959,[3] as an alternative to the quadrupole structure for producing gain. During 1960, as data were being accumulated on the power-handling capabilities of the EBPA, it became clear that very large peak incident powers could be handled by the input coupler of a device designed primarily for low-noise amplification. In early 1961, Zenith became aware of a specific requirement at Lincoln Laboratories for a low-noise protective device to be used on a multi-megawatt radar installation.

Conferences were held among Mr. Carl Blake, and Drs. R. Adler and C. B. Crumly of Zenith, during which specific preliminary designs were explored. At a meeting on May 24, 1961, a tentative S-band design was agreed upon which incorporated a gated beam. A proposal was submitted by Zenith Radio Research Corporation on June 23, 1961, on this requirement. A revised proposal was submitted on July 28, 1961, covering a similar design for an L-band device. This latter

1 C. L. Cuccia, "The electron coupler", RCA Review, vol. 10, pp. 270-303; June, 1949.

2 R Adler, "A new principle of signal amplification," Conference on Electron-Tube Research, Berkeley, Calif., June, 1957. See also: R. Adler, "Parametric amplification of the fast electron wave," Proc. IRE, vol. 46, pp. 1300-1301; June, 1958.

3 Private communication.

proposal resulted in this Subcontract which initiated the development of the LINEATOR.

The LINEATOR is a passive non-reciprocal electron-beam-type device, similar to a circulator, except with linear rather than a circular, configuration. The prototype model was constructed with four ports (See Fig. 1), three of which are for signal-handling purposes, and one is for initial beam noise removal.

In operation, signals fed into port No. 2 are transferred with low loss and little added noise to a negative-resistance type amplifier (maser or varactor diode) connected to port No. 3, and finally flow out of port No. 4 to the receiver.

During radar transmission, the high power incident on port No. 2 automatically collapses the beam, destroying the coupling between ports 2 and 3, thus isolating the amplifier and receiver from the radar pulse. In effect, the LINEATOR functions as a combination T-R switch, power limiter, and circulator, eliminating the need for these components in the radar system. The signal port can then be connected directly to the main duplexer, with a consequent reduction in insertion loss in the signal path.

The inherent phase and amplitude stability of cyclotron-wave devices makes practical the use of LINEATORS in monopulse and array-type radars. The prototype LINEATOR was designed for use on a general-purpose space-tracking and measurements radar, constructed by Lincoln Laboratories, which is intended to incorporate additional monopulse channels.

The following sections of the report will be devoted to the design, development, testing, and evaluation of the prototype LINEATOR.

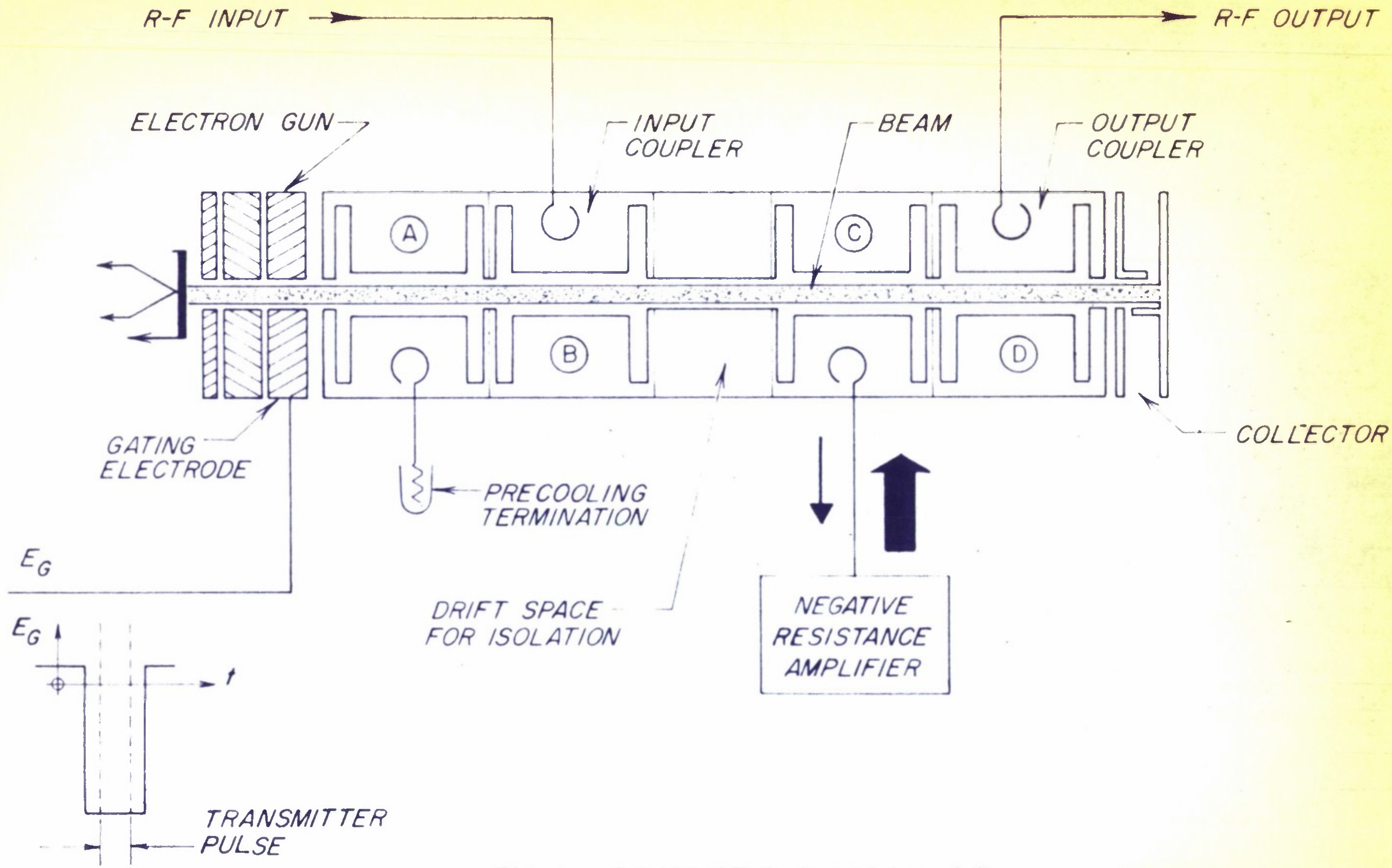


FIG. I SCHEMATIC DIAGRAM OF PROTOTYPE LINEATOR

III. LINEATOR DESIGN AND DEVELOPMENT

a. General:

The approach used to arrive at the initial LINEATOR design was to modify a known design at L-band keeping in mind the following considerations:

1. The highest possible ratio between the unloaded and loaded Q is required in order to reflect the greatest possible fraction of incident power when the electron beam is turned off.
2. Not only is the highest possible value of unloaded Q required, but the lowest practical value of loaded Q is also desirable; thus, the bandwidth should be maximized.
3. The design should not exceed the limits of 200 milliamperes per square centimeter on current density and 2 micropervs on perveance.

Table 1 shows a comparison between a typical 1,300 Mc EBPA design and the initial 1,295 Mc LINEATOR design. Note that the current density of the LINEATOR is comparable to that of a 1,300 Mc EBPA, so that a similar long life is expected. The ratio of the Cuccia coupler plate width to spacing was reduced to give a lower loaded Q with the same current density. The ratio of plate spacing to beam diameter was reduced; this change was possible without the danger of overload because the substantially higher beam current reduces the excursion of the beam for a given beam power. Also, no provision for clearance of "idler" excursions need be made, since no idler is present in the LINEATOR. The theoretical saturation level at the output coupler for the 1,295 Mc LINEATOR design is 3 milliwatts.

With this design, it was calculated that approximately 2% of the incident power during the transmitter pulse (beam off) would be dissipated in the cavity. As will be seen later, the prototype design and characteristics do not differ greatly from the indicated parameters.

TABLE 1

COMPARISON OF EBPA AND LINEATOR DESIGNS

PARAMETER	TYPICAL 1,300 Mc EBPA DESIGN	1,295 Mc INITIAL LINEATOR DESIGN
BEAM VOLTAGE	10 volts	25 volts
BEAM CURRENT	50 microamperes	250 microamperes
CURRENT DENSITY	.095 AMP/cm^2	.100 AMP/cm^2
PERVEANCE	1.58×10^{-6}	2.0×10^{-6}
BEAM RADIUS	.005 in.	.011 in.
PLATE SPACING	.030 in.	.044 in.
PLATE WIDTH	.120 in.	.053 in.
PLATE LENGTH	.600 in.	.880 in.
BEAM LOADING RESISTANCE	4000 ohms	2000 ohms
BANDWIDTH (3 db points)	88 Mc	132 Mc
LOADED Q	14.8	9.5
UNLOADED Q	350	4000
COUPLER LOSS	.35	.02

Besides meeting specific design requirements, it was necessary to arrive at a general design and configuration which would meet the input power requirements, satisfy operating conditions, be adaptable to handling and processing, and which would represent, as closely as possible for a prototype device, the minimum practical size and weight.

The following technical descriptions detail the design and development of the prototype LINEATOR.

b. Cavity Design and Development:

Based on the results of previous cavity design, a brass test cavity, shown in Fig. 2, which had the design Cuccia-plate length, width, and spacing, and had a resonant frequency within the range of interest, was fabricated. Tests revealed that this cavity had a resonant frequency of 1,588 Mc and an unloaded Q of 576. It was realized that in obtaining the correct resonant frequency with the same physical configuration, the cavity would become prohibitively large. Further, it was not a simple matter of scaling from the test cavity, because all of the cavity dimensions could not be changed. (The Cuccia plate, length, and spacing were fixed). In order to establish a cavity design which would not be too long nor too large in diameter, a series of modifications were made on the test cavity to lower its resonant frequency. The first modification was to increase the amount of inductance represented by the cavity-wall extension of the Cuccia plates. Fig. 3 shows this modification. Tests now revealed that the resonant frequency was 1,426 Mc and the unloaded Q was 790. By shorting the Cuccia plates, it was established that the cavity was operating in the correct mode.

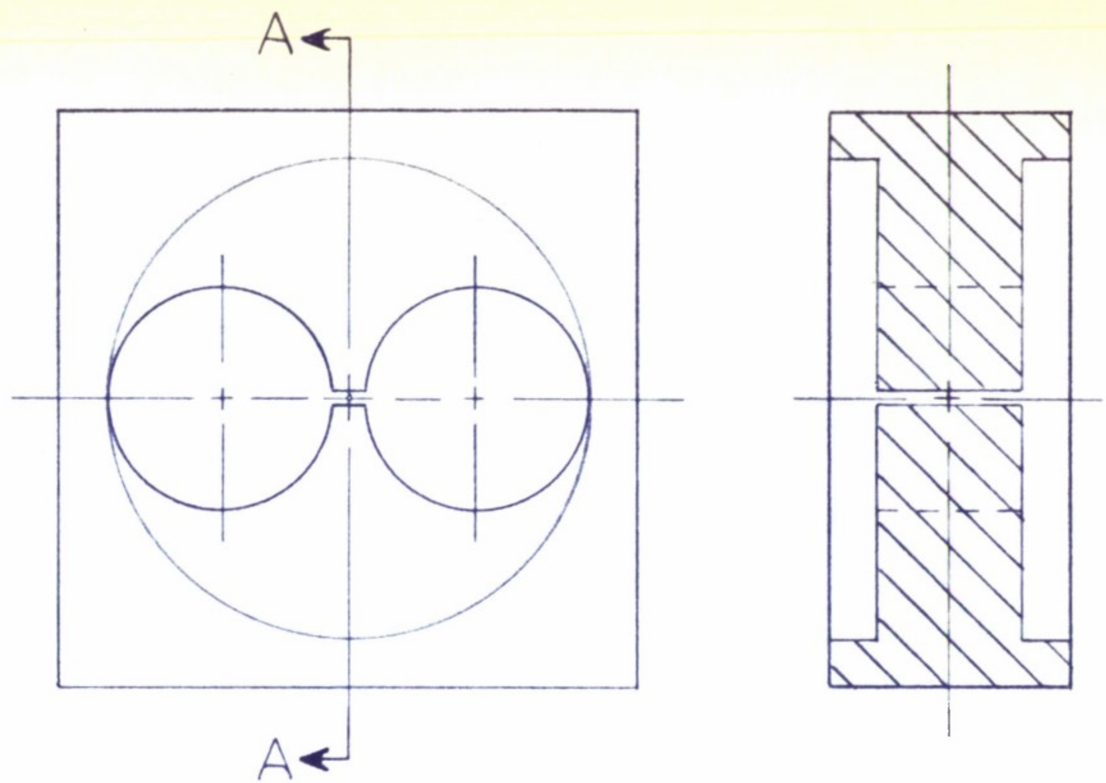


FIG 2 BRASS TEST CAVITY

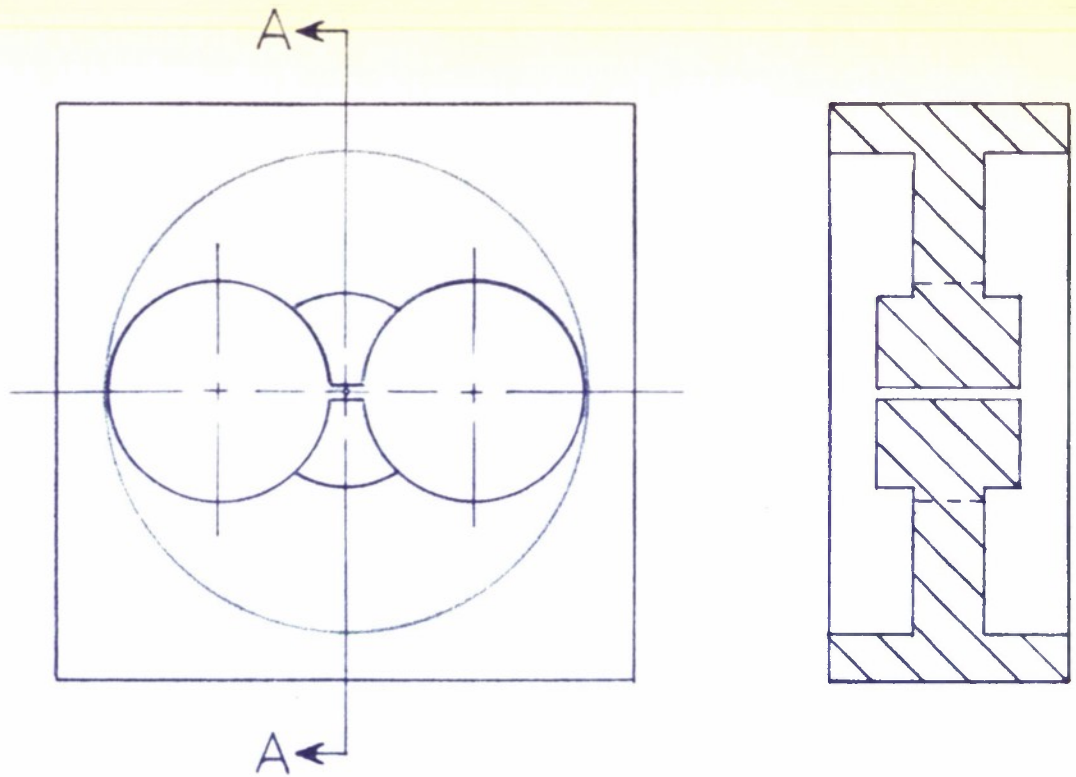


FIG. 3 BRASS TEST CAVITY, MODIFICATION #1

The next modification was, again to lower the resonant frequency by further increasing the inductance. This was accomplished by cutting away part of the remaining webbing of the cavity as shown in Fig. 4. In this form, the cavity had a resonant frequency of 1,017 Mc and an unloaded Q of 1,356.

At this point, it would have been possible to increase the resonant frequency of the cavity by decreasing its longitudinal length. However, this would not solve the problem of end coupling to the cavity nor would it be possible to rotate adjacent cavities with respect to one another to provide added beam-off isolation. Therefore, the cavity design was changed to accommodate these conditions. Fig. 5 shows the first prototype copper cavity (prototype cavity I).

The resonant frequency of this unit after electro-polishing was found to be 1,031 Mc and the unloaded Q was 4,300. The next step was to raise the resonant frequency of this cavity by decreasing its length. However, after a series of cuts had brought the cavity length down to 1.1 inches, the resonant frequency had been raised to only 1,180 Mc. It appeared that the inductance of the Cuccia plate support was still the dominant factor in the resonant frequency of this particular cavity configuration, and that it would be necessary to (1) decrease the amount of undercut (decrease the inductance) in order to raise the resonant frequency (prototype cavity II) or to (2) design the cavity in such a way that the Cuccia plate support was not undercut and to increase the over-all cavity length accordingly in order to raise the resonant frequency (prototype cavity III) Fig. 6 shows the test cuts and results for prototype cavities I, II, and III.

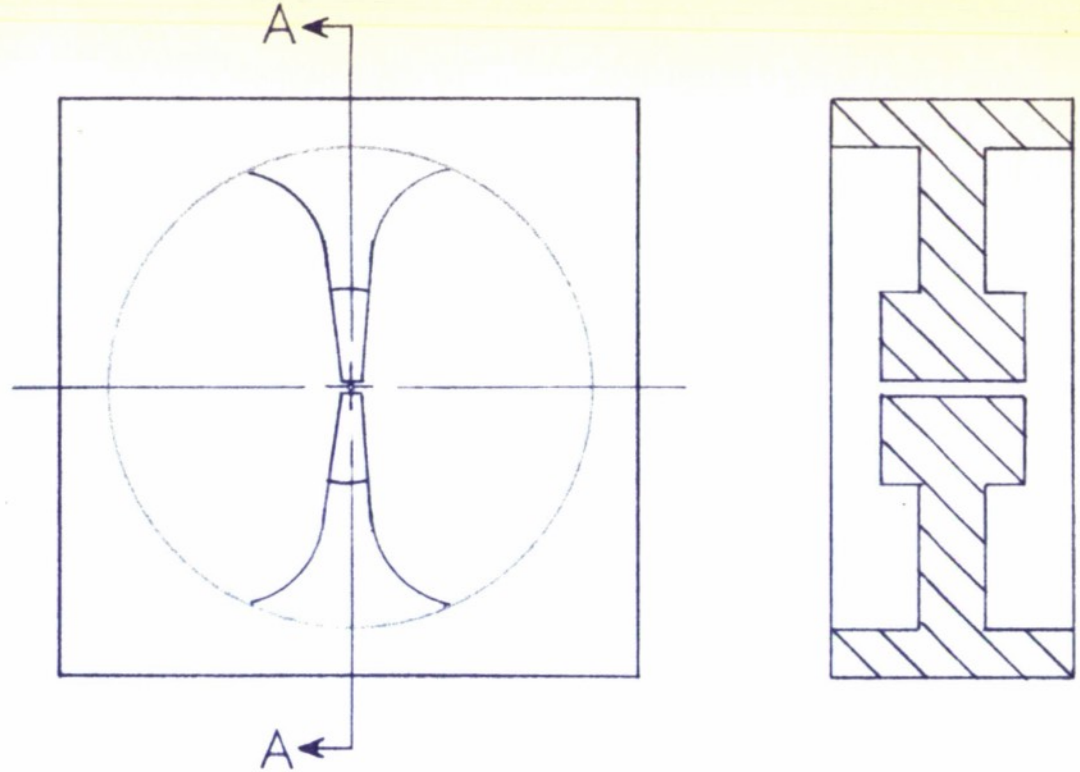


FIG. 4 BRASS TEST CAVITY MODIFICATION #2

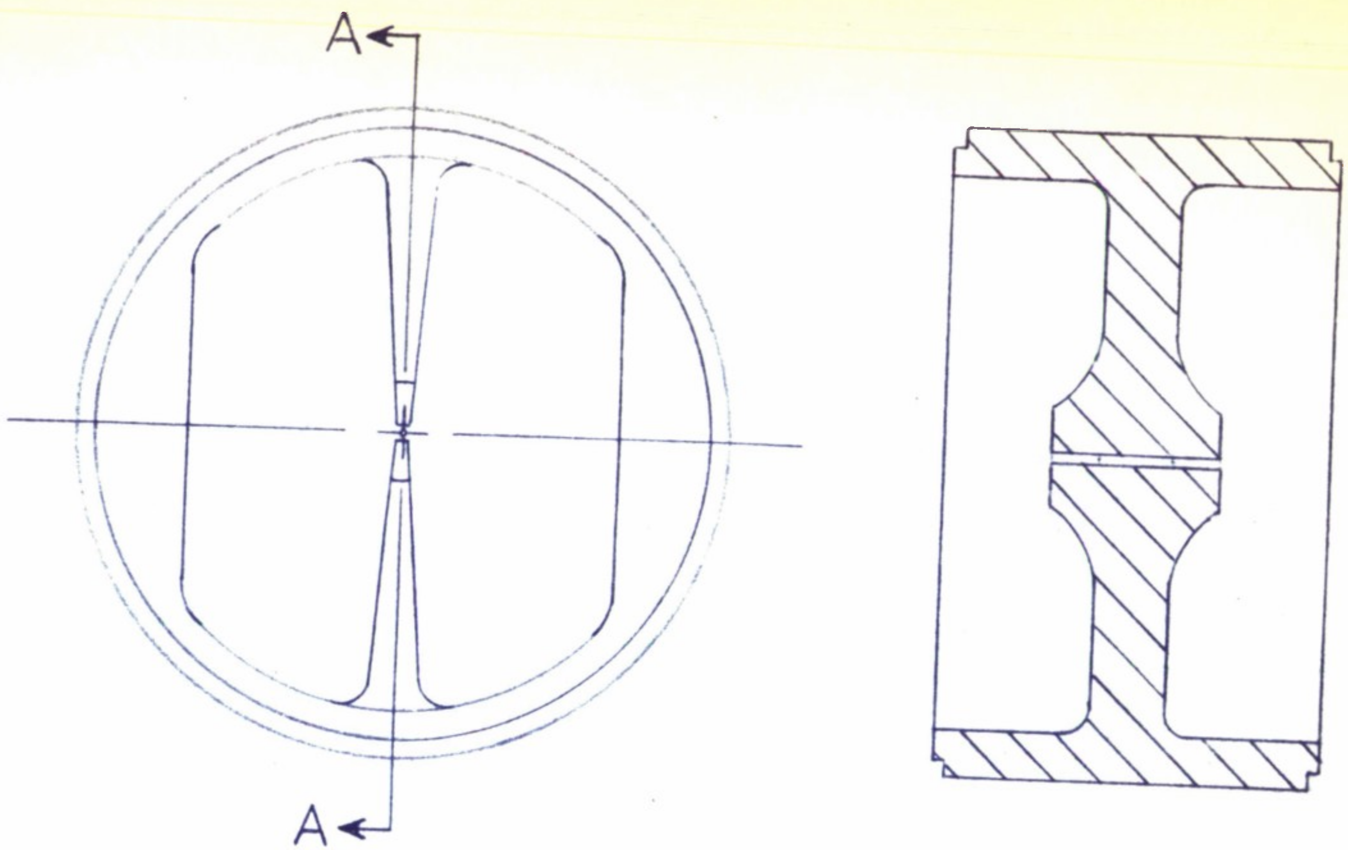


FIG. 5 PROTOTYPE COPPER CAVITY I

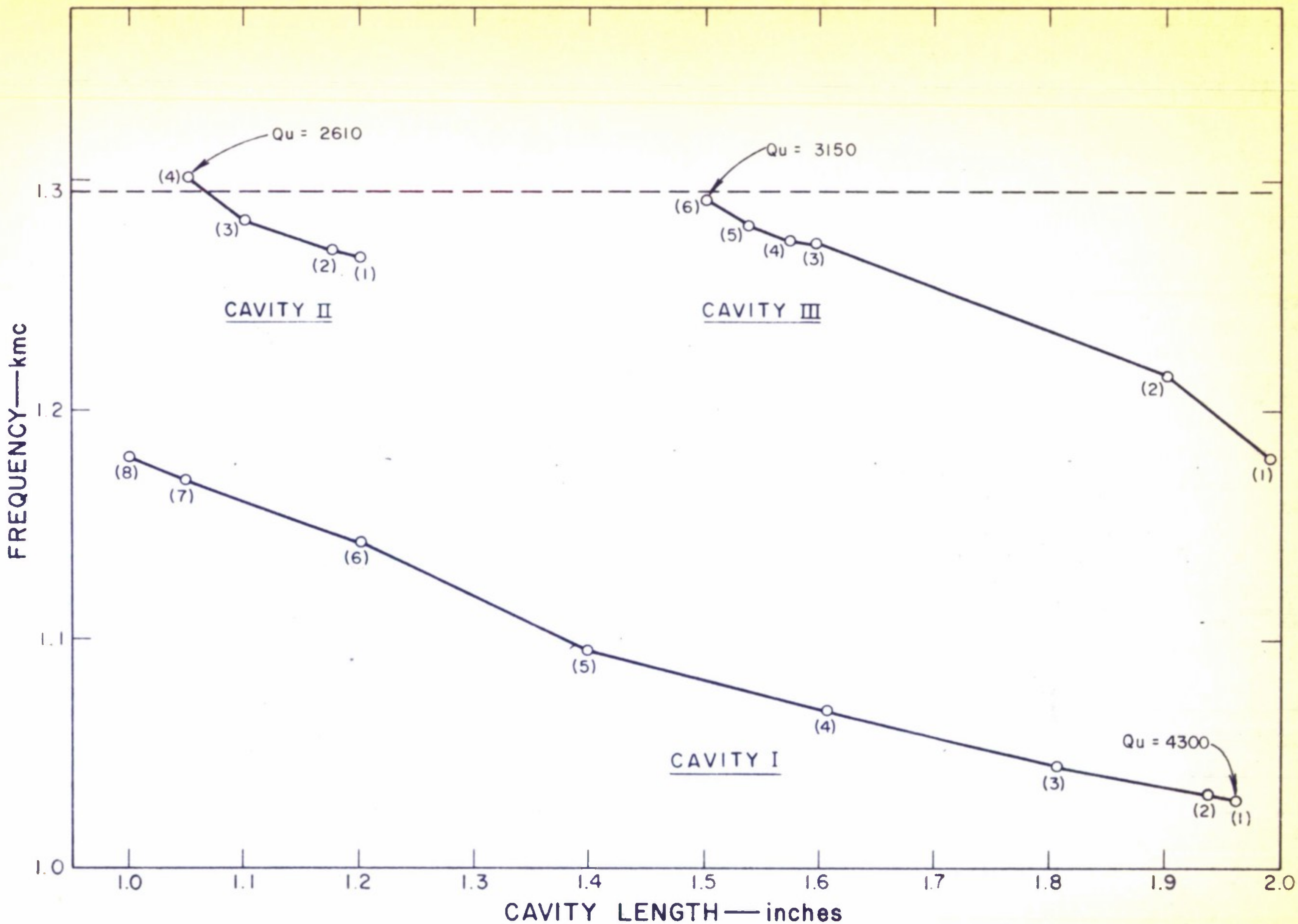


FIG. 6 RESONANT FREQUENCY AS A FUNCTION OF LENGTH FOR PROTOTYPE COPPER CAVITIES

Cavity III was chosen for the prototype LINEATOR because although it is longer than cavity II it is much easier to fabricate, it has a higher unloaded Q, and its configuration lends itself to tighter coupling. Fig. 7 shows cavity III.

c. Coupling Loop Design and Development:

Although the coupling loop design and configuration was dependent upon the final choice of cavity design, consideration of the coupling loop was initiated early in the program.

The first step was the design and fabrication of the brass TM01 shunt resistance calibration cavity shown in Fig. 8 which was later used to facilitate the coupling loop determination. Tests showed that this cavity had a resonant frequency of 1,300 Mc and an unloaded Q of 1,870. On the basis of this, its shunt resistance was calculated and found to be 4.38×10^4 ohms.

Next, a 0.440" x 0.880" x 0.053" sample of balsa wood was placed in the calibration cavity. The unloaded Q of the calibration cavity was again measured. This time it was found to be 1,370. (The shift in resonant frequency caused by the introduction of the sample was less than 2 Mc). Using this and the previous information, the resistance of the sample was calculated and found to be 12×10^4 ohms. The calibrated sample resistance now constituted a means for determining the shunt resistance of the prototype cavity thereby making it possible to calculate the amount of coupling required.

During the testing of the prototype cavities, a preliminary test loop design was established. This initial configuration was based on the requirements that the loop must be self-supporting, free from current discontinuities, and that it would couple to the

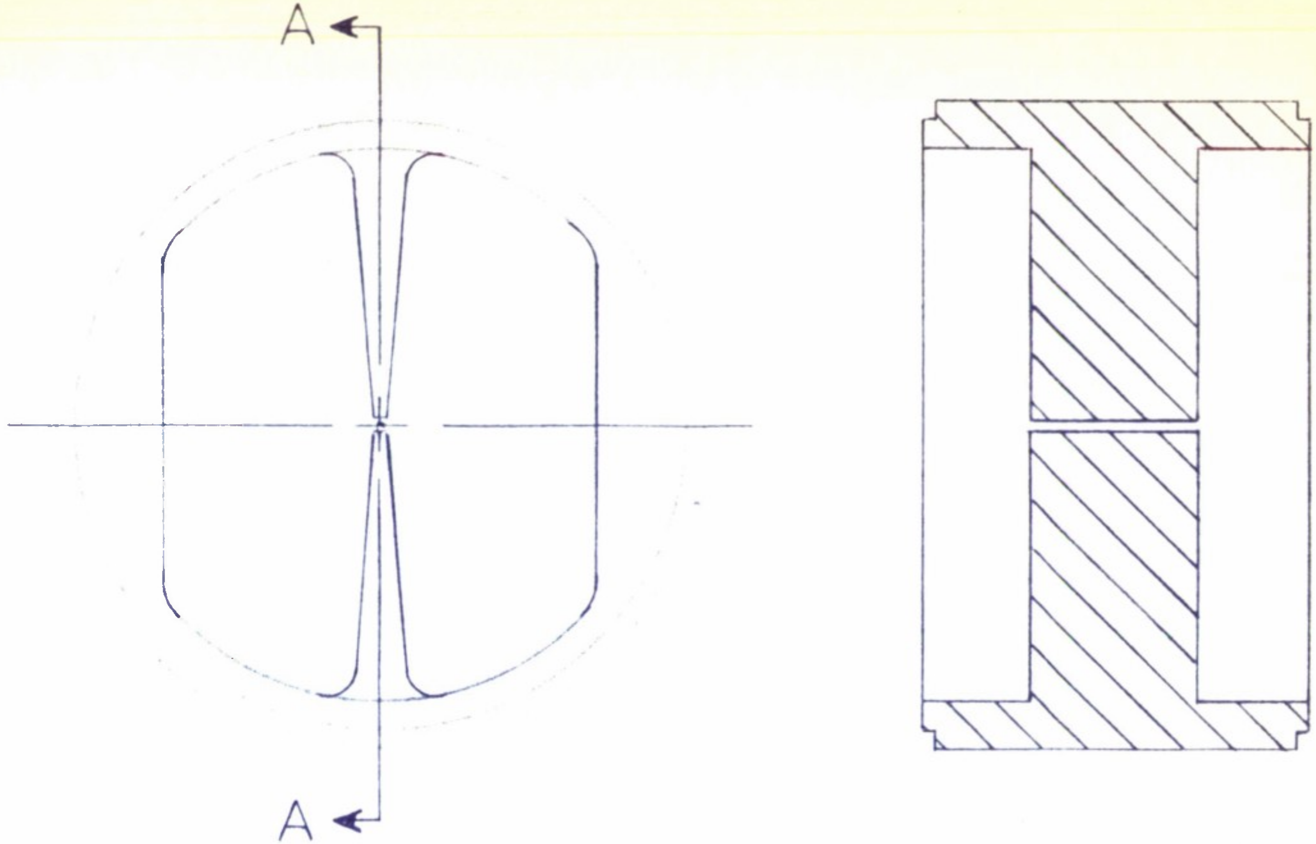


FIG. 7 PROTOTYPE COPPER CAVITY III

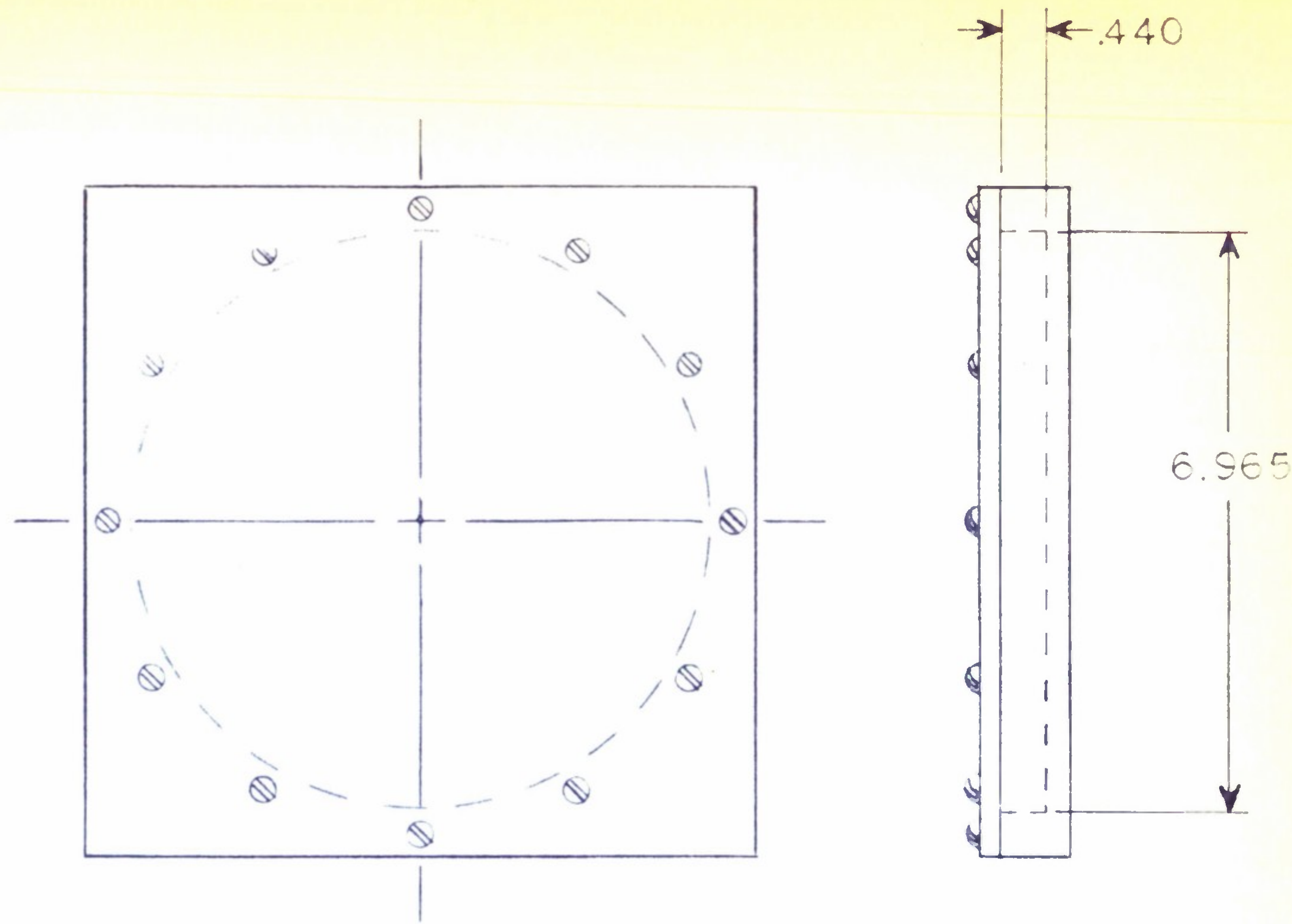


FIG. 8 BRASS SHUNT RESISTANCE CALIBRATION CAVITY
TM 01 MODE

end magnetic fields of the cavity.

After the prototype cavity configuration was fixed, its shunt resistance was determined by introducing a 0.044" x 0.880" x 0.053" sample of balsa wood, (the resistance of this sample was one-tenth that of the original sample or 12×10^3 ohms) between the Cuccia plates and measuring the resulting unloaded Q of the cavity. This turned out to be 143 and was combined with the knowledge of the unloaded Q of the cavity without resistive loading to calculate the shunt resistance of the prototype cavity, referred to the Cuccia plates. This was found to be 250,000 ohms.

Thus, it was possible to determine that for the correct amount of coupling, neglecting line and coaxial window losses, and for the beam-off condition, the input VSWR should be 125 to 1 (this is the ratio of the cavity shunt resistance to the beam-loading resistance).

It will be shown later that the coaxial window loss was found to be 0.1 db. Because the window was designed for a matched input and output, its loss represents a matched attenuator in the line, and the input VSWR with the window in place should be approximately 40 to 1. The coupling loop configuration and position were adjusted experimentally to meet this condition.

During the coupling loop determination, it was found that the resonant frequency of the cavity varied with the amount of coupling for a fixed loop configuration. This is illustrated in Fig. 9. To compensate for this, a tuning screw was introduced at a point of symmetry in the cavity side wall. It was found that as the tuning screw approached the Cuccia plates, the increased capacity lowered the resonant frequency. Using the tuning screw, it was possible to

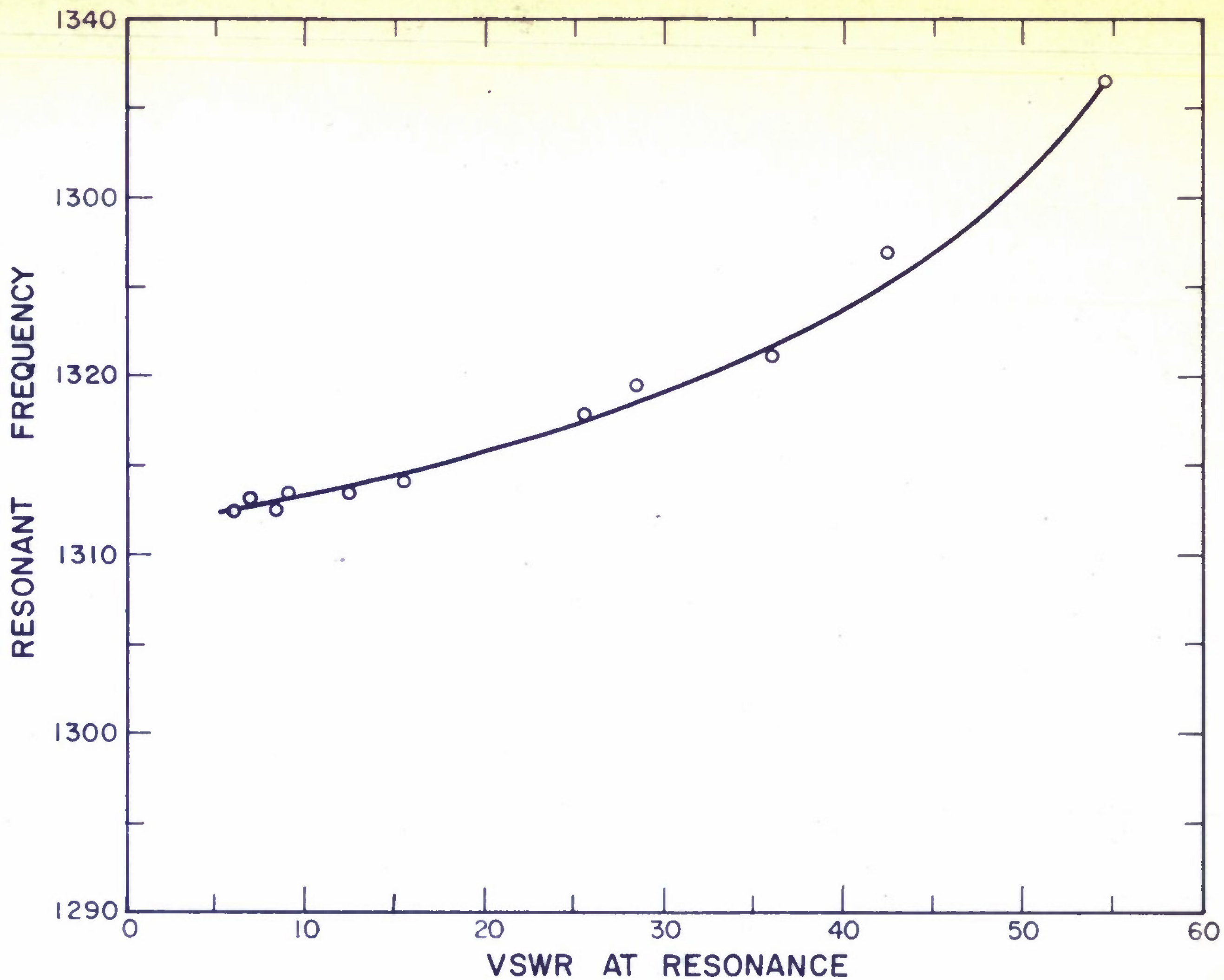


FIG. 9 RESONANT FREQUENCY AS A FUNCTION OF COUPLING FOR CONSTANT LOOP CONFIGURATION

adjust the resonant frequency of the prototype cavity to 1,295 Mc under maximum coupling conditions.

d. Coaxial Seal Design and Development:

The coaxial seal design was based on the requirements of low insertion loss, good matching, high power-handling capability, good mechanical and thermal properties, and low dieletric losses.

Electrically, the windows were designed on the basis of constant-impedance matching methods, excluding the effects of shunt susceptance (which proved to be negligible for the chosen thickness of the window and the frequency of operation).

Several alternative mechanical designs were investigated and are discussed below:

1. A conventional ceramic-to-metal sealing technique using Kovar center and outer conductors. This technique utilizes materials which provide matched thermal expansion of the alumina (AL-300) and metal components during the brazing and processing cycles. The Kovar surfaces are copper plated to a thickness of 0.0005 to 0.001 inch (approximately 5 to 10 times the skin depth at L-band) for good electrical conductivity. The assembly is brazed in a vacuum using the activate-metal (Titanium) metallizing process.

   Although several test seals were produced, this process was abandoned because of non-uniform metallizing, low yield, and difficulties with thermal transfer in the large metal housing of the high-power coaxial-seal transition section.

2. Ceramic-to-metal sealing technique. This technique was

used for the fabrication of the high power coaxial seal for the prototype LINEATOR. It employs a Kovar butt seal for the center conductor and a concentric Kovar ring seal for the outer conductor. (Again the Kovar is copper-plated). The window material is an alumina ceramic (AL-300), supplied by Western Gold and Platinum Company, which has been metallized with a film of pure Tungsten metal by a new process. The bond strength of this type of metallizing is reported to be superior to the conventional "moly-manganese" process. No plating is required and pure copper may be used as a brazing material. The metallizing thickness is negligible thus permitting close-tolerance fits.

It was possible to produce vacuum-tight seals utilizing this technique on a "one-shot" brazing basis, using a hydrogen furnace.

3. Utilization of a commercially available ceramic-metal feed through. This seal utilizes an alumina ceramic, a molybdenum center pin, and a Kovar outer sealing sleeve. By incorporating this device into a coaxial impedance transformation section, it was possible to produce a reasonably good low power window.

The high power seal described in 2 is shown in Fig. 10. Electrical test results on this unit are shown in Fig. 11.

The input to the three remaining cavities of the prototype LINEATOR employed the seal described in 3. Fig. 12 shows this seal and Fig. 13 shows the test results on this unit.

Although the above coaxial seals proved to be satisfactory for the prototype LINEATOR, a major portion of the losses in the LINEATOR

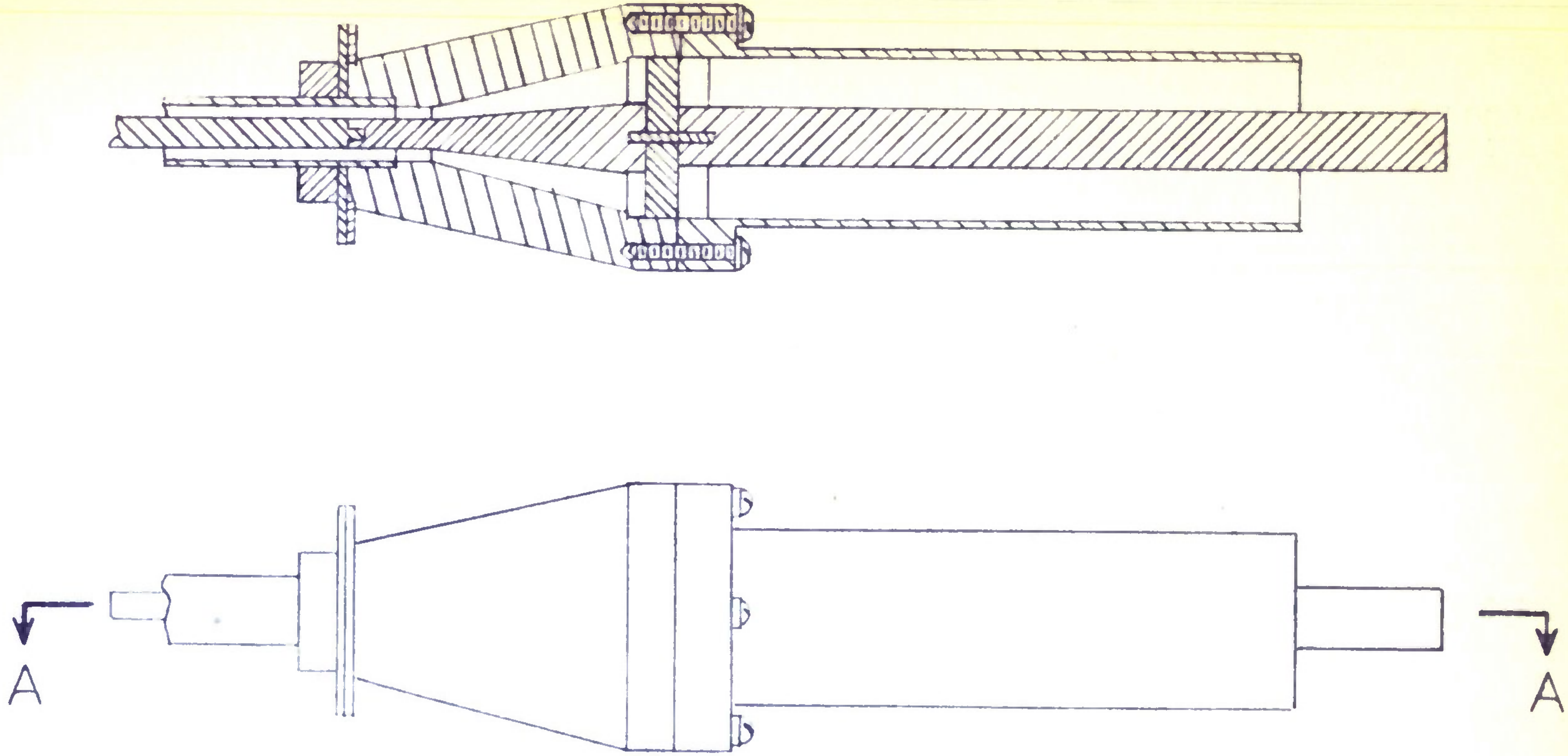


FIG. 10
HIGH POWER WINDOW ASSEMBLY

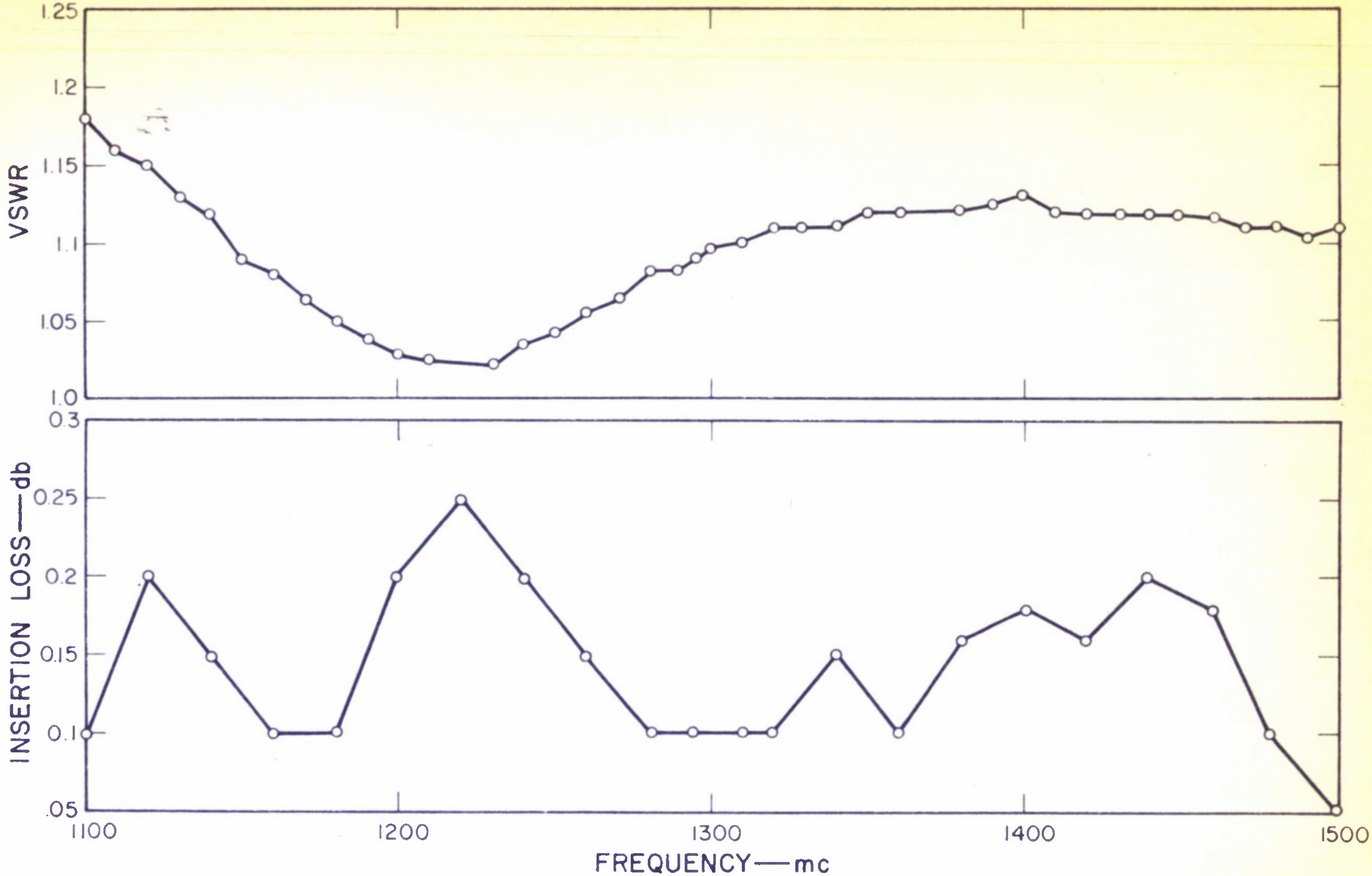


FIG. 11 VSWR, INSERTION LOSS AS A FUNCTION OF FREQUENCY FOR HIGH POWER COAXIAL WINDOW

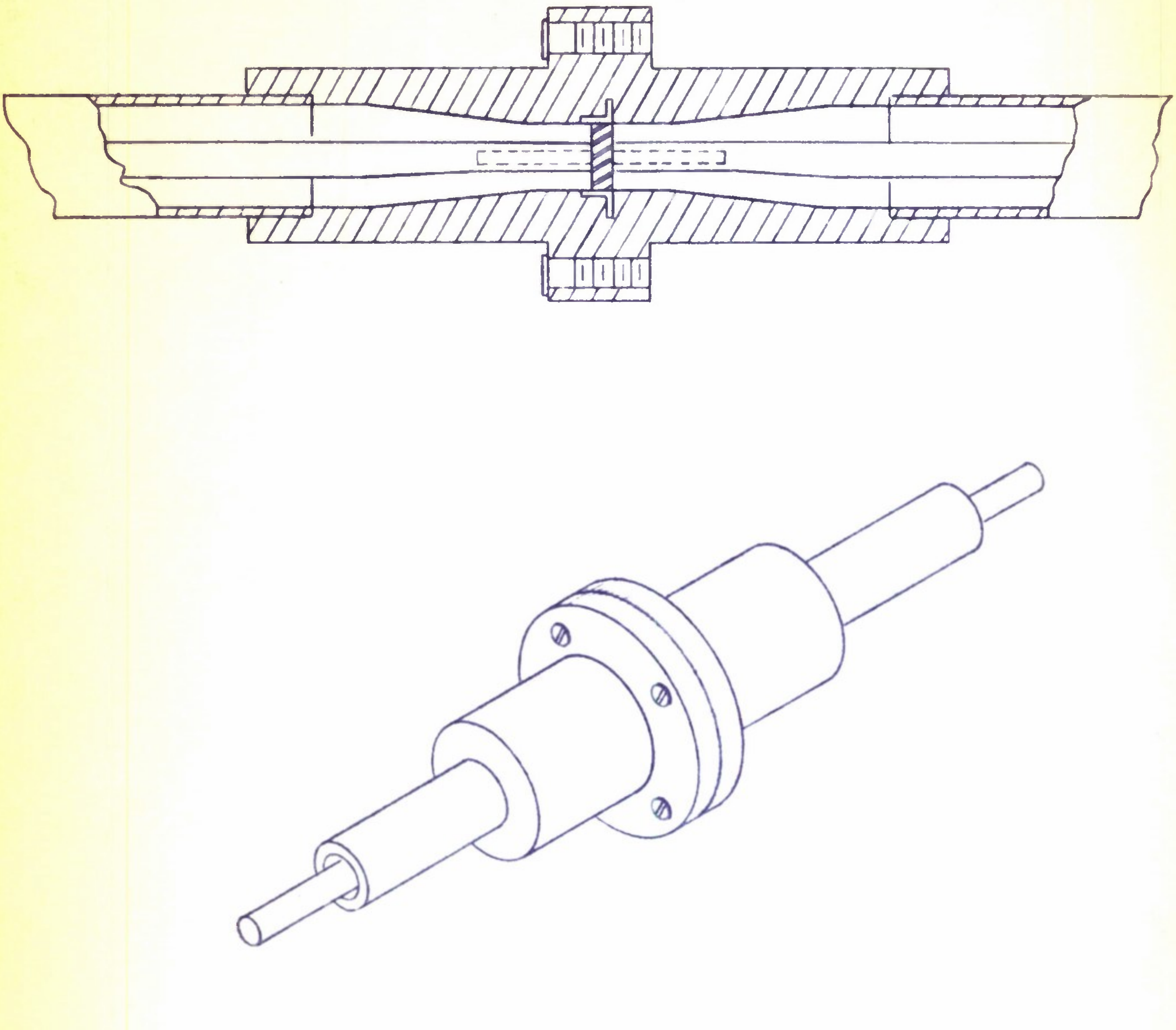


FIG. 12 LOW POWER COAXIAL SEAL ASSEMBLY

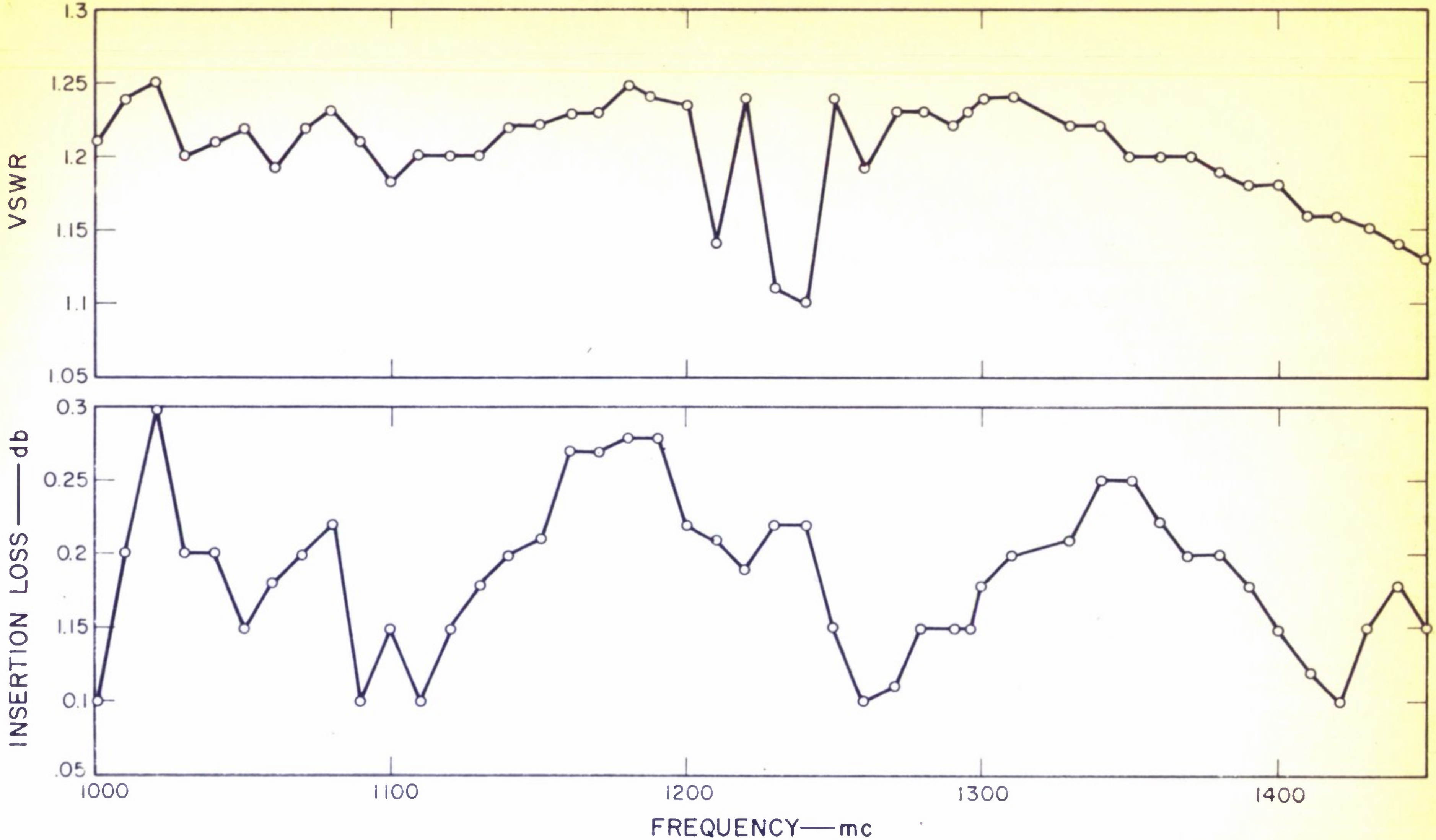


FIG. 13 VSWR, INSERTION LOSS AS A FUNCTION OF FREQUENCY FOR LOW POWER SEAL, INCLUDING CONNECTORS

is contributed by the coaxial seals. Because there is room for further improvement in the basic seal design, it is quite likely these losses can be reduced in future tubes.

Also because of the magnetic properties of Kovar, the windows must be located outside the magnetic field of the solenoid. It is contemplated that future tubes will incorporate a novel low-loss non-magnetic window which is now under development. The non-magnetic seal, which can be located close to the tube body, greatly facilitates the fabrication of the tube, reduces coaxial line length, and increases the mechanical strength and stability of the device.

e. Gun and Collector Design:

The gun design followed established techniques based on the requirements of beam voltage, beam current, current density, perveance, beam radius, frequency, and magnetic fields. The gun employs a conventional oxide-coated cathode, and a provisional five electrode configuration which was chosen in order to provide a maximum of flexibility in operating conditions and to insure a minimum of electron beam excess noise.

The first gun design was incorporated into a standard 1,300 Mc EBPA, which constituted the beam tester. It was found that interception was occurring at the elements following the first anode. Fig. 14 illustrates this condition. Here, the first three anodes (A, A_2, A_3) were tied together and the last two control electrodes (B_1, B_2) were tied together. Then beam current I_o, anode current I_A, and control electrode current I_b were plotted as a function of anode voltage. The plot shows that the beam current is maximum at approximately the design value of V_A, 85 volts, but at the same time

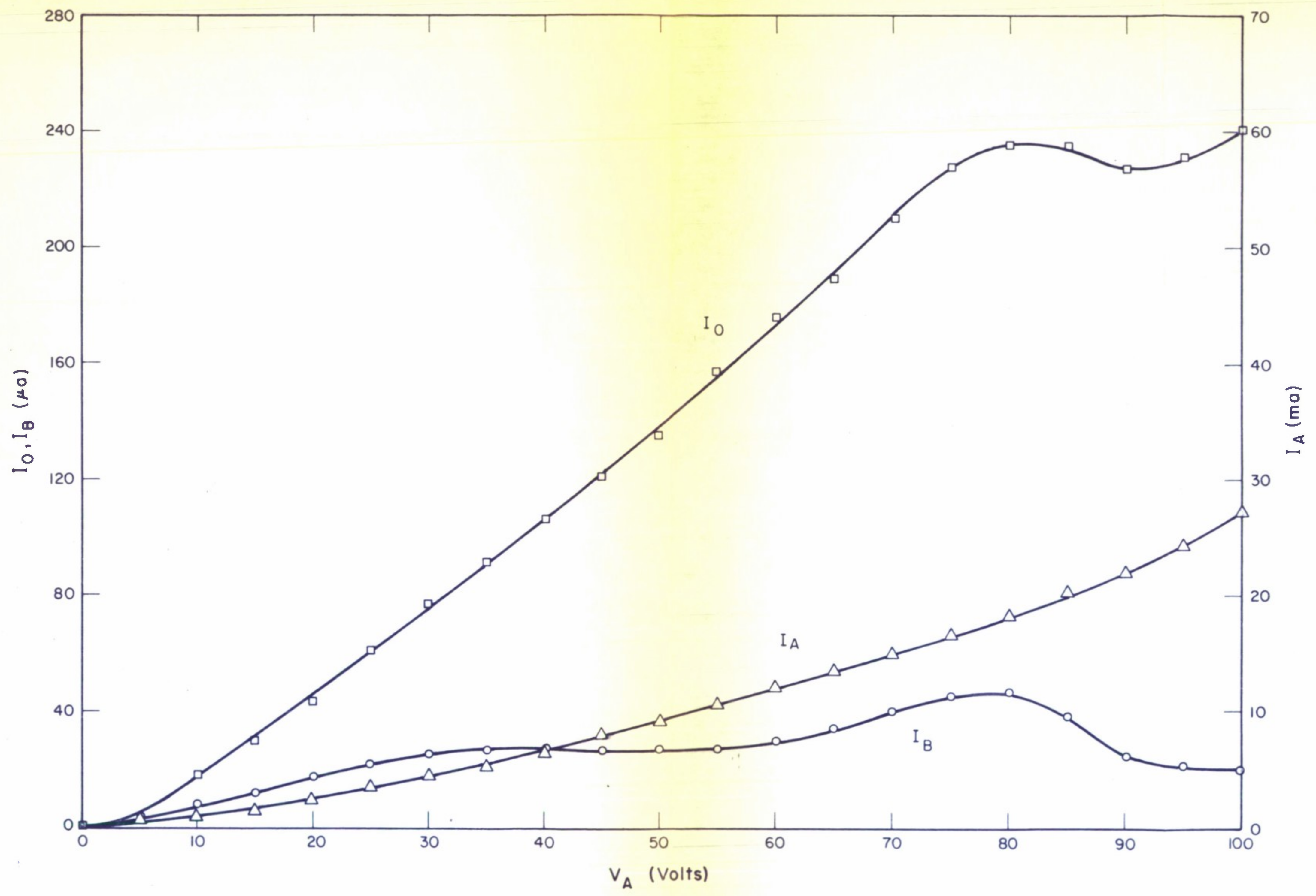


FIG. 14 I_O, I_B AND I_A AS A FUNCTION OF V_B

there occurs a maximum of interception at the same value. As a result of this information, the lens aperture was increased, the focal length of the lens was recalculated along with the new required operating parameters.

Aside from the interception, all the other characteristics of the gun were normal and applicable to the LINEATOR design.

The next step was to incorporate the modified gun design and collector design, along with a prototype cavity, to form a beam-test cavity. This would confirm the new gun design, the beam loading of the Cuccia cavity, the impedance transformation of the coupling loop, and the effectiveness of the collector.

The collector was designed as a crossed-field, two-parallel-plate device. One plate operates at Cuccia potential while the other operates at +200 volts above cathode potential. The length and width of the collector plates were increased over standard L-band EBPA designs to insure maximum electron capture and reduce the possibility of electrons returning through the tube in the reverse direction.

Tests on the cavity beam tester showed that the modified gun design was correct and that the collector was operating as expected.

Details of the performance of the beam-test cavity are given in j of this section.

f. Solenoid Design:

The solenoid design was based on the magnetic field requirements, the length of uniform field, aperture size required by the tube capsule, operating conditions, and input power limitations.

After the prototype cavity design had been fixed, and the general physical structure of the tube established, the following solenoid requirements were determined:

1. Solenoid field strength - 475 gauss, maximum.
2. Solenoid minimum uniform field length - 10.5 inches.
3. Solenoid throat diameter to accommodate tube capsule - 4 inches.
4. Over-all length of solenoid - 12 inches, nominal.
5. Solenoid throat is to be open at both ends and a 4-screw centering adjustment for 3.5 inch diameter tube capsule is to be provided.
6. Solenoid to be air cooled.
7. Ambient temperature range - 20 to 130°F.
8. General requirements - minimum size and best commercial practices.

These requirements were placed out for quote and after the responses were considered, an order was placed with Litton Industries, San Carlos, California to supply the solenoid for the prototype LINEATOR.

The resulting solenoid has the following characteristics:

1. 475 gauss, maximum.
2. Uniform field length, 10.5 inches.
3. Inside diameter, 4 inches.
4. Over-all length (excluding fittings), 15 inches.
5. Centering adjustment screws, 4 each end, 90° apart.
6. Power supply requirements 22.6 v, 8 amps at 40°C.
7. Side mounted barrier type terminals.
8. Air cooled, plenum chamber, 20 CFM for 25°C rise.
9. Steel outer shell with mounting base.

10. Finish - flat black enamel.

Fig. 15 shows a reproduced plot of the solenoid magnetic field.

g. Test Devices:

1. Power-limit test cavity. This device, shown in Fig. 16 and whose characteristics are illustrated by Fig. 17 was designed, fabricated and delivered to Lincoln Laboratories to determine power design factors before the first full prototype LINEATOR was constructed. It consisted of a high power coaxial window, input line, coupling loop, and cavity, and included a Pyrex window for visual inspection of the unit during tests.

Because an O-ring seal was used for the inspection window, the cavity was not sealed off at ZRRC. Instead, a copper tubulation six inches in length was provided so that the cavity could be continuously pumped while under test.

For the first power test at Lincoln Laboratories, the power limit test cavity was evacuated to a pressure of approximately 10^{-5} mm of Hg. Upon the application of 0.15 watts average power, 50 watts peak for a pulse width of 3 microseconds and a PRF of 100, high voltage arcing occurred in the cavity.

The cavity was then put on a high vacuum system and evacuated to 1.5×10^{-7} mm. As the RF power was increased, the pressure started to increase because of outgassing. When the pressure reached 10^{-4} mm, high voltage arcing again occurred. The RF power was decreased and the cavity was again evacuated to 4×10^{-7} mm.

Again the RF power was increased; this time voltage breakdown did not occur and the following data were taken:

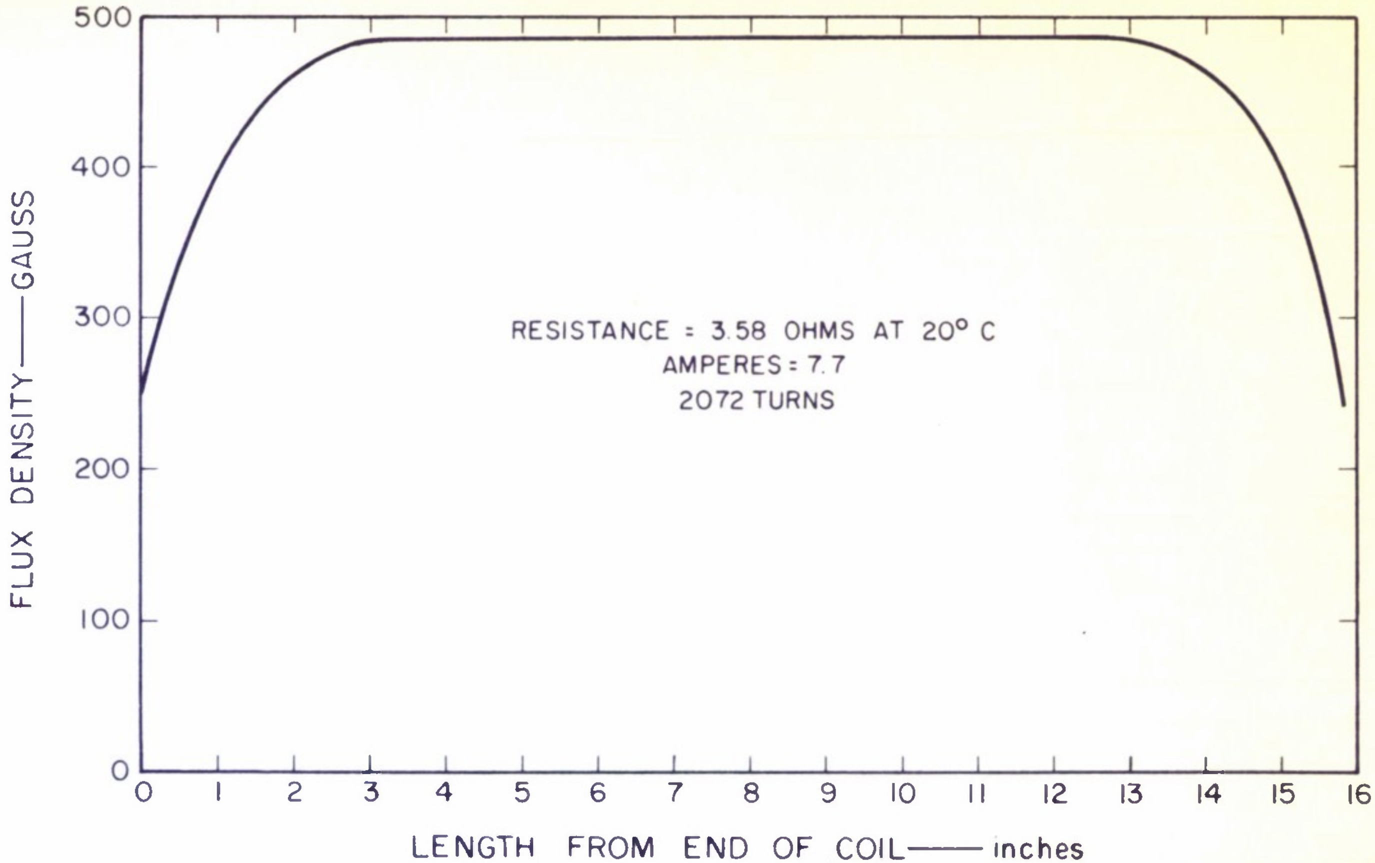


FIG. 15 SOLENOID, MODEL 244

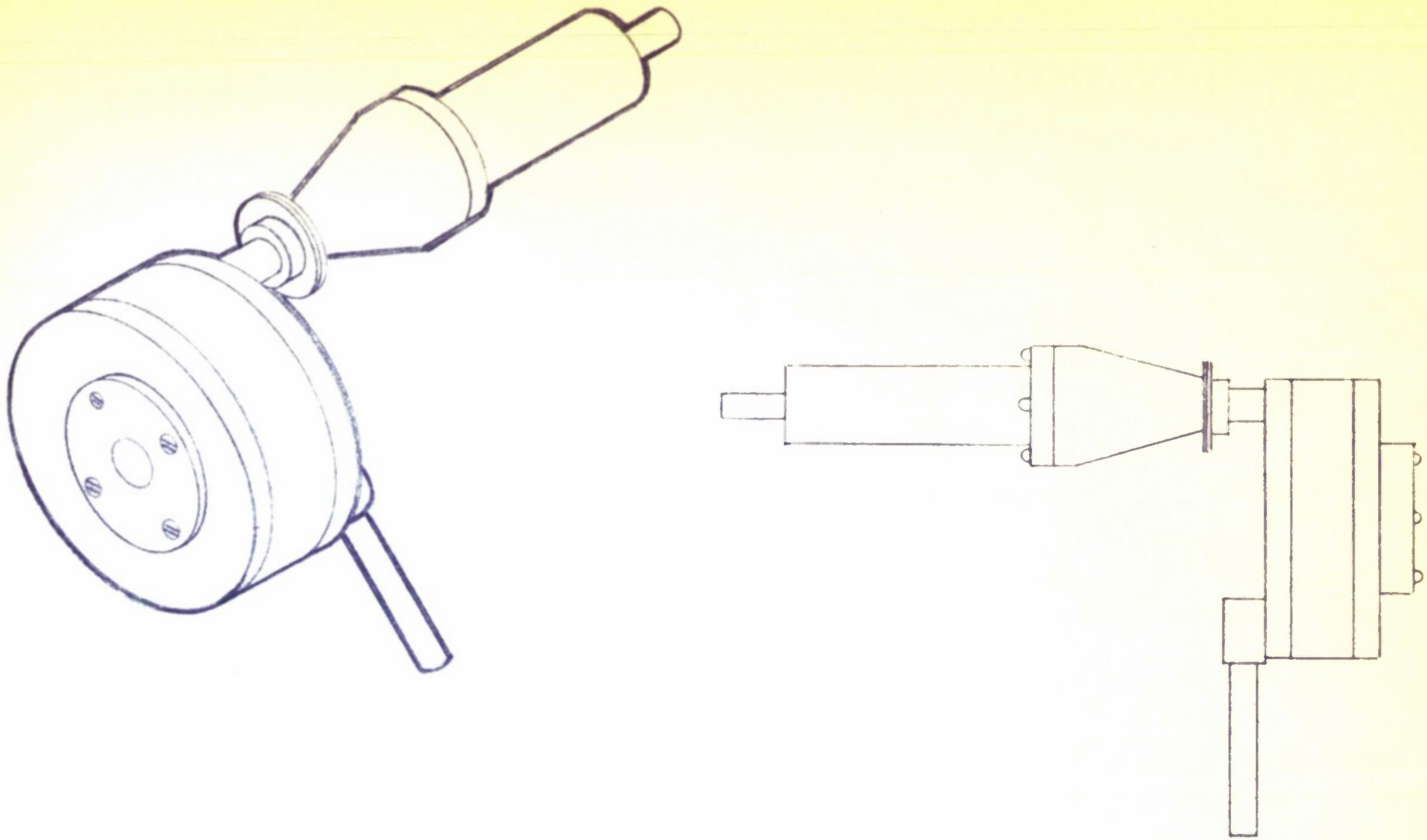


FIG. 16
LINEATOR, POWER LIMIT TEST CAVITY

[illegible]EQ.	MINIMUM POSITION	DETUNED POSITION	Δcm	Δλ	VSWR OR ρ
00	24.87	23.51	1.36	.059	90
10	25.52	24.05	1.47	.0694	89
20	26.17	24.55	1.62	.0659	100
30	26.89	25.03	1.86	.0749	100
40	27.66	25.58	2.13	.068	85
[illegible]	28.49	26.04	2.45	.109	84
60	29.42	26.52	2.90	.122	80
70	30.4	26.98	3.48	.145	70
80	31.57	27.67	3.90	.167	100
40	32.76	27.92	4.84	.212	100
00	34.02	28.39	5.63	.244	90
[illegible]	35.25	28.84	6.41	.250	96
20	36.89	29.28	7.61	.335	90
[illegible]	37.40	29.74	7.66	.340	100
40	38.27	30.15	8.12	.363	<100
[illegible]	38.60	30.57	8.03 ?		<100
60	39.72	31.02	8.70	.392	100
70	40.30	31.58	8.72	.394	100
80	40.89	31.85	8.94	.402	96
90	41.36	32.27	9.09	.420	96
00	41.90	32.68	9.22	.430	100

DETUNED SHORT		
[illegible]EQ.	MIN. POS.	VSWR/ρ

LINEATOR

DEVICE: POWER LIMIT TEST CAVITY PROJ. WG 168

$f_0 = 1302$ mc

$f_1 = 1350$ mc

$f_2 = 1262$ mc

$\Delta f = 88$ mc

$Q_L = \frac{1302}{88} \approx 15$

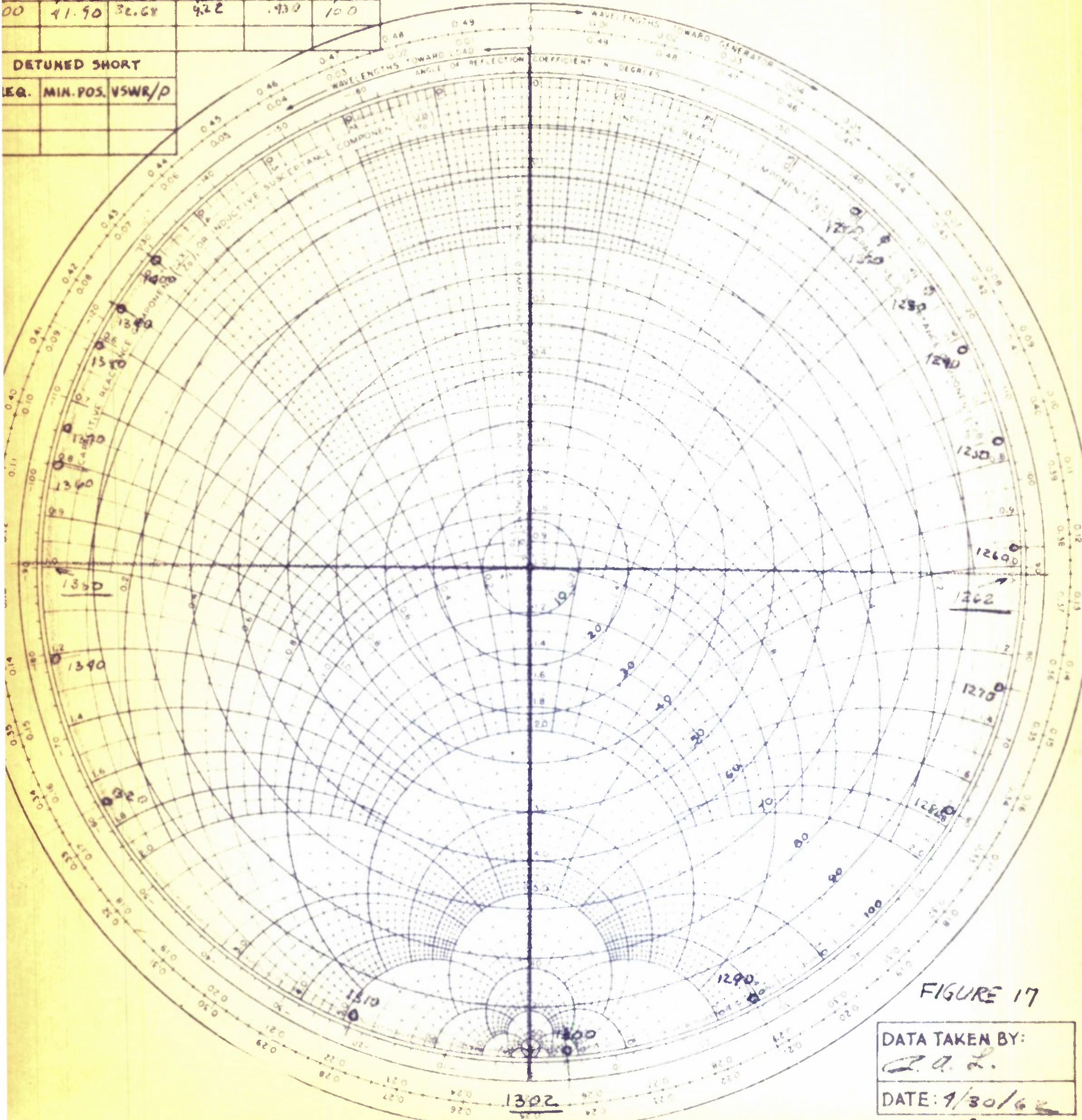


FIGURE 17

DATA TAKEN BY:
C. A. L.
DATE: 4/30/6[illegible]

TABLE II
POWER LIMIT CAVITY TESTS

FREQUENCY (kMc)	AVERAGE POWER (watts)	PEAK POWER (KW)	PRESSURE (mm Hg)
1.311	15.2	15.2	4.0×10^{-7}
1.313	13.6	13.6	"
1.315	14.8	14.8	"
1.319	17.6	17.6	4.0×10^{-7}
1.324	13.6	13.6	"
1.329	14.4	14.4	"
1.333	14.4	14.4	"
1.338	12.8	12.8	"
1.342	12.0	12.0	"
1.347	12.0	12.0	"
1.352	6.4	6.4	"
1.304	13.6	13.6	4.5×10^{-7}
1.284	30.0	30.0	4.0×10^{-7}
1.270	26.0	26.0	"
1.255	19.0	19.0	3.5×10^{-7}

Average power tests were conducted at 1,309 kMc using a 10 microsecond pulse and a PRF of 1600 pps. Under these conditions, the power from the magnetron was 280 watts average at 17.5 kw peak. Again breakdown did not occur.

h. Beam Test Cavity:

The beam test cavity shown in Fig. 18 incorporated an electron gun, prototype cavity, coupling loop, low-power coaxial seal and

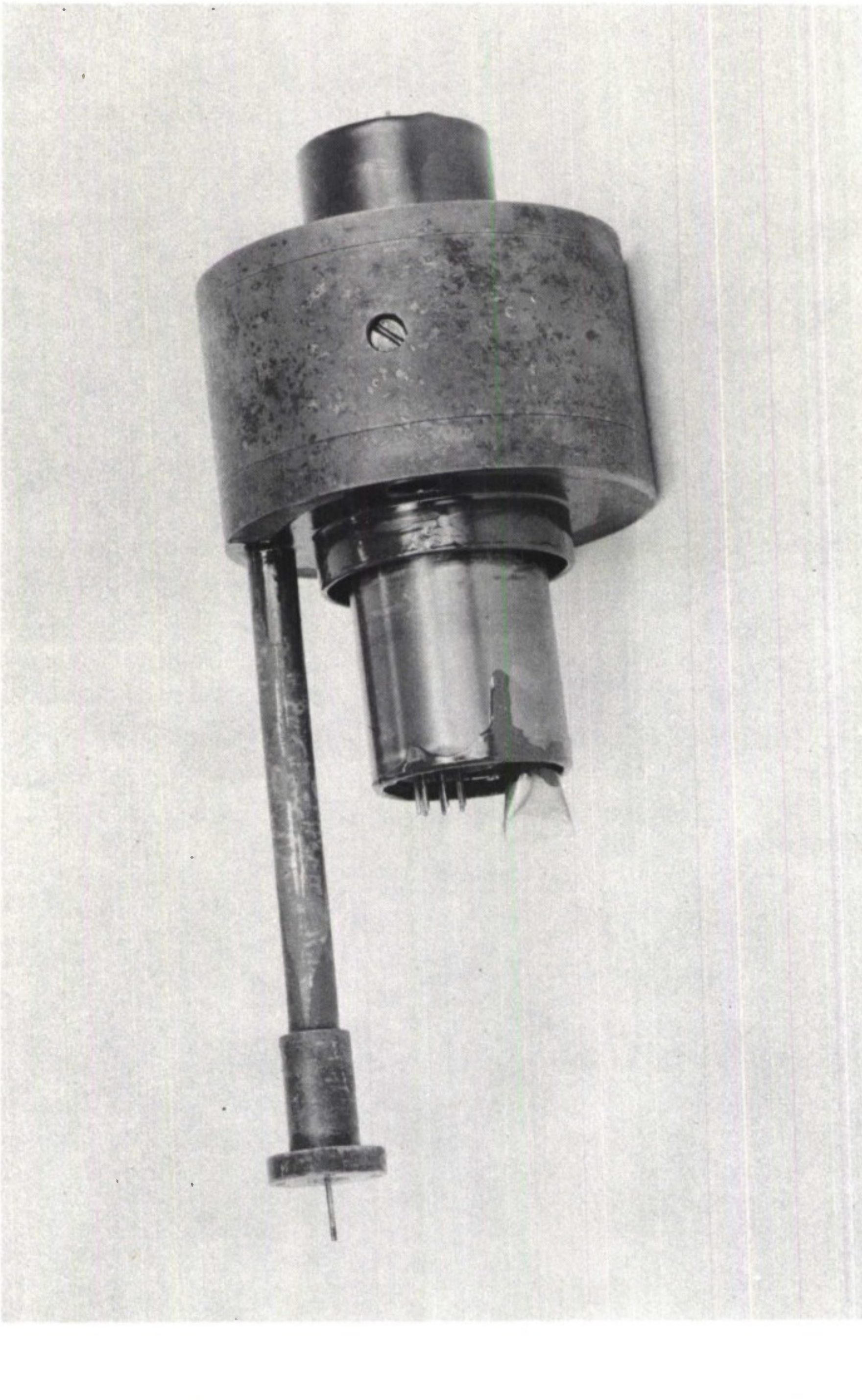


FIG. 18

BEAM TEST CAVITY

input line, and collector. (See Fig. 19). This unit was fabricated and tested in order to confirm the gun design, operating characteristics of the Cuccia cavity and coupling loop with electron-beam loading, and the collector design.

The tests revealed that the gun design and modifications were correct and that the gun was satisfactory for the prototype LINEATOR. The tests further showed that it was possible to match to the electron beam and that the cavity and coupling loop designs were satisfactory for the prototype LINEATOR. Results of a typical test sequence are shown in Fig. 20.

A quantitative measurement was made of the uncancelled noise temperature of the beam. It was found to be between 800 and 1000°K, as expected.

The coupler loss was measured and found to be approximately 0.05 db.

This information positively confirmed the design factors and the final stages of fabrication of the first prototype LINEATOR were initiated.

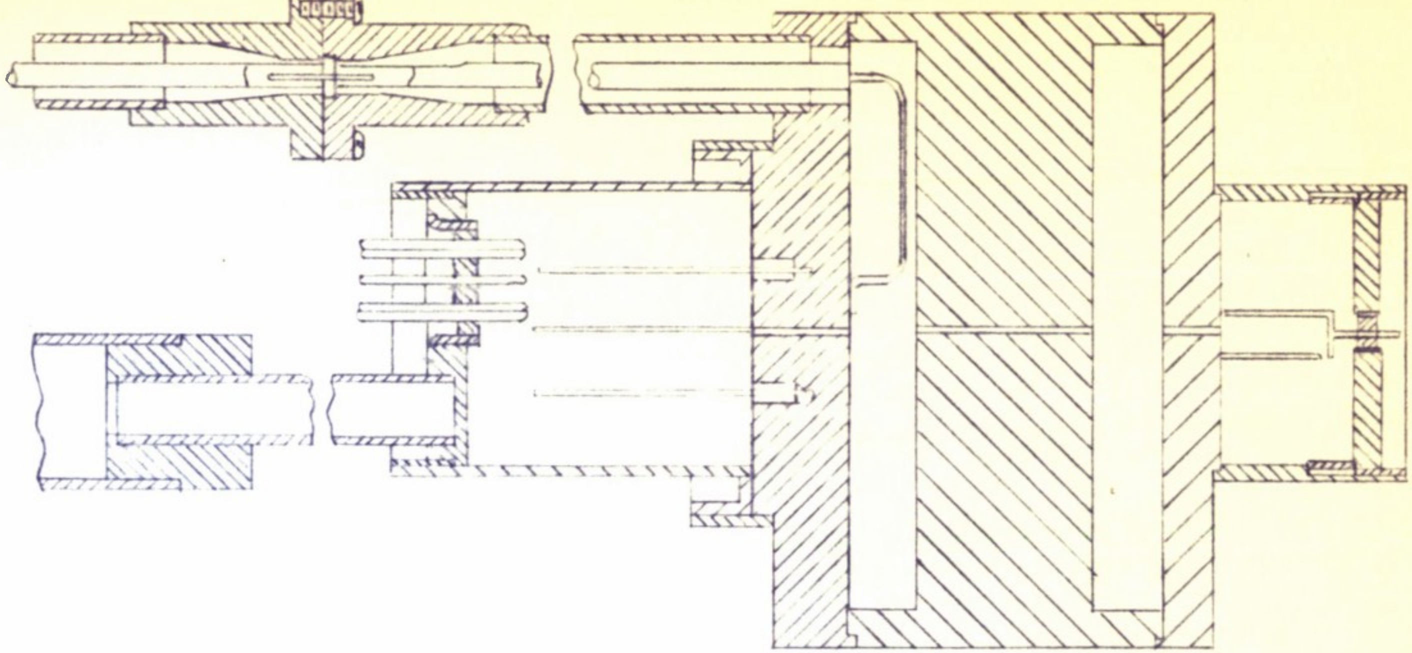
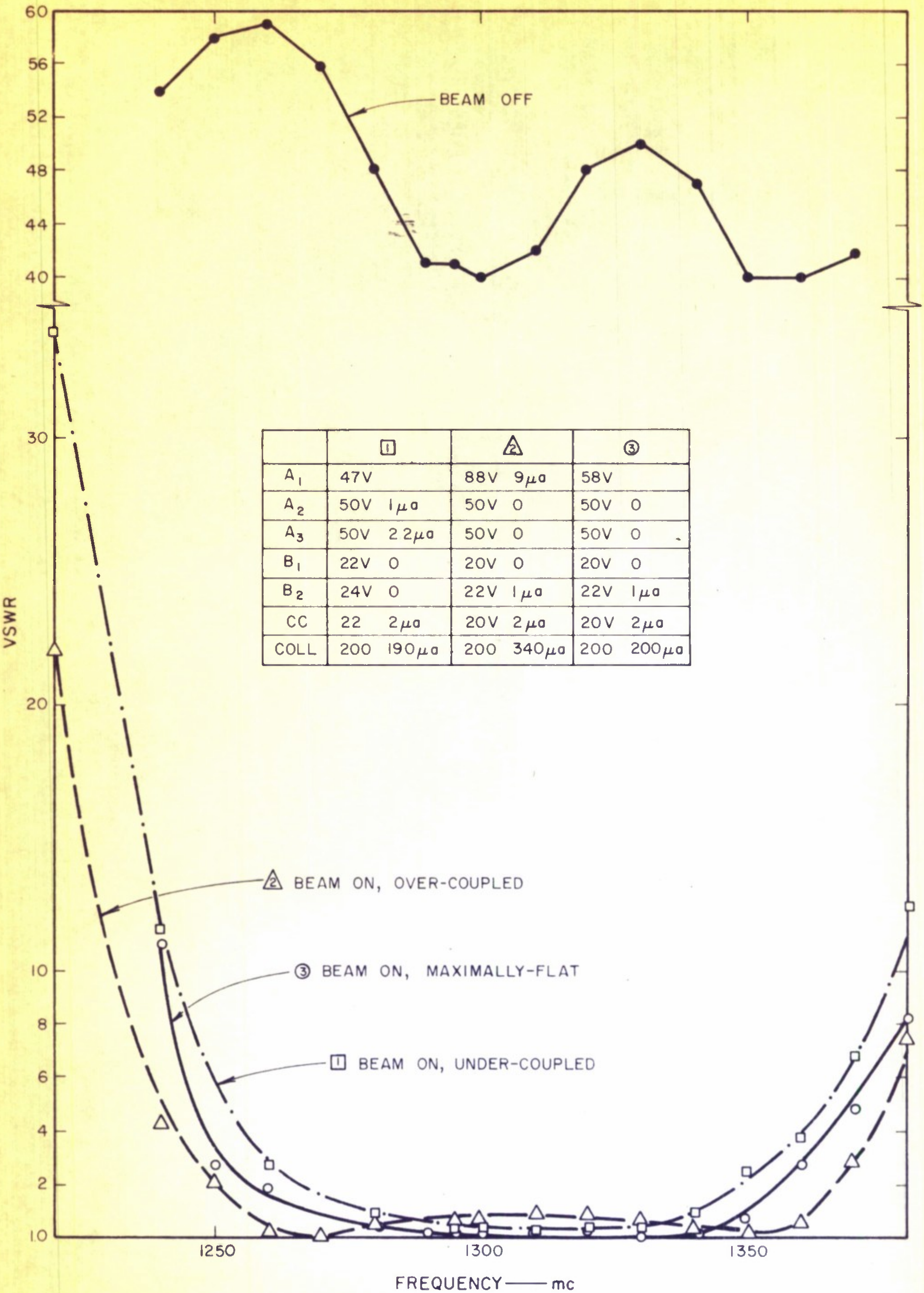


FIG. 19
BEAM TESTER ASSY



	1	2	3
A_1	47V	88V 9μa	58V
A_2	50V 1μa	50V 0	50V 0
A_3	50V 22μa	50V 0	50V 0
B_1	22V 0	20V 0	20V 0
B_2	24V 0	22V 1μa	22V 1μa
CC	22 2μa	20V 2μa	20V 2μa
COLL	200 190μa	200 340μa	200 200μa

FIG. 20 INPUT VSWR AS A FUNCTION OF FREQUENCY FOR LINEATOR BEAM TESTER

IV. COMPLETED LINEATOR

a. First Prototype LINEATOR:

Fig. 21 shows the completed prototype LINEATOR outside of its supporting capsule. Figs. 22 and 23 shows the LINEATOR placed in the solenoid and ready for operation.

In general, the tests on the first prototype four-cavity LINEATOR revealed that the device was operating as expected.

However, the primary tests for the input match and tuning revealed that the center frequency of cavity No. 2, the signal input cavity, was 1,340 Mc, whereas the three other cavities were close to 1,295 Mc. It was found that by externally tuning all input ports, a compromise operating condition could be obtained whereby all of the cavities were operating at the same frequency.

The initial insertion loss and noise measurements at 1,295 Mc were made under this condition. The tests revealed that the insertion loss between cavities No. 2 and No. 3 was 0.75 db and that the excess electron-beam noise temperature with cavity No. 1 terminated at room temperature was approximately 35°K. See Table 3.

After the first series of tests, the LINEATOR was X-rayed in order to discern the relative positions of the coupling loops, the coaxial center conductors, and the window-center conductor connections. The X-ray pictures revealed a discrepancy in the position of coupling loops Nos. 1, 3, and 4. Coupling loop No. 2 was found to be in almost perfect position. This information combined with the prior knowledge of the position of the coupling loops in the power limit cavity and the beam tester made it clear that a more precise positioning of the coupling loops must be maintained and that there

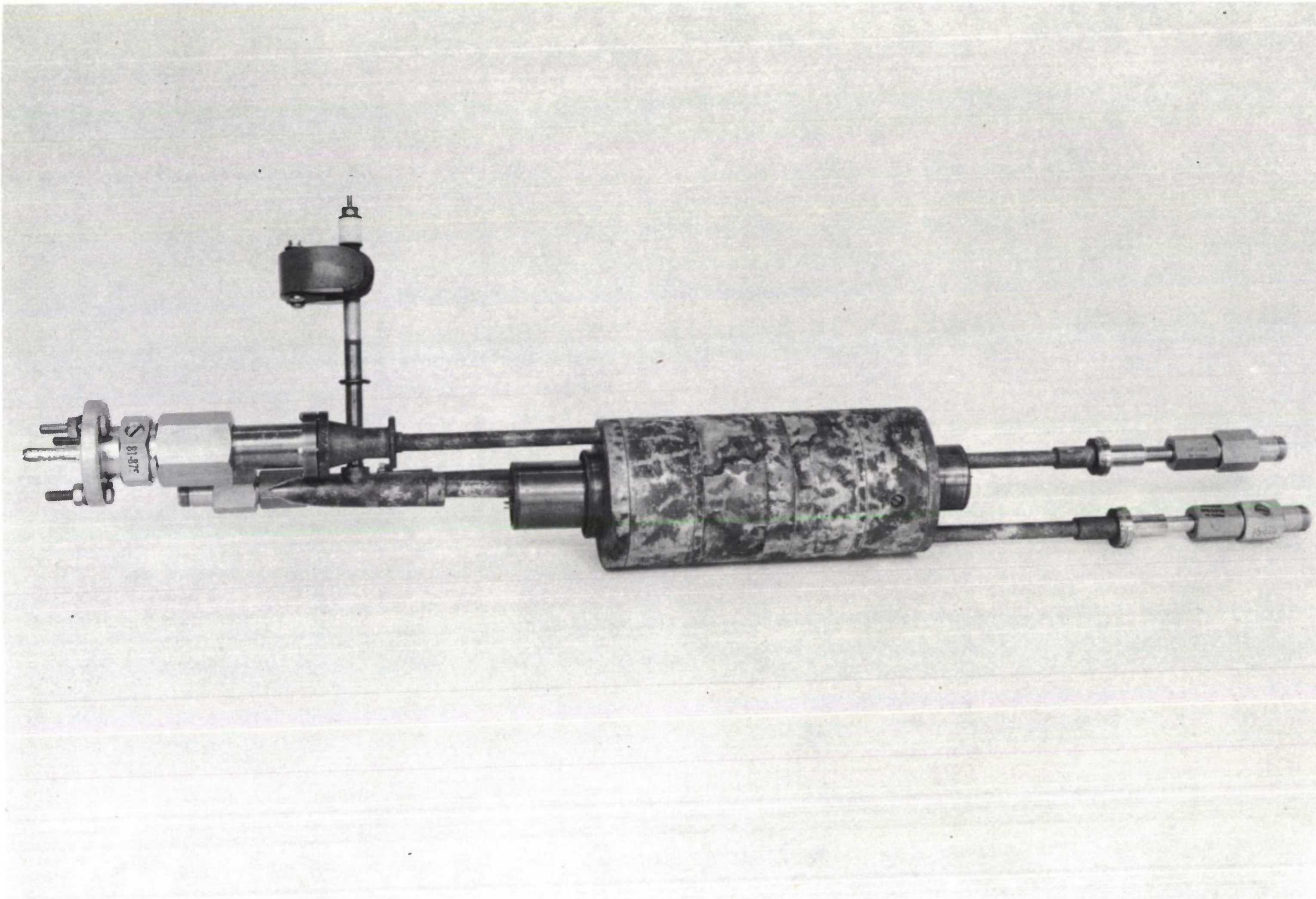


FIG. 21

PROTOTYPE LINEATOR

FIG. 22
PROTOTYPE LINEATOR

FIG. 23
PROTOTYPE LINEATOR

TABLE III

INITIAL INSERTION LOSS AND NOISE MEASUREMENTS
1,295 Mc

INPUT TO:	OUTPUT FROM:	INSERTION LOSS	ELECTRON BEAM EXCESS NOISE TEMPERATURE	COMMENTS
Cavity #2	Cavity #3	0.75 db	$35^{o}K$	#1 Terminated
Cavity #1	Cavity #2	0.72 db	$69^{o}K$	
Cavity #1	Cavity #3	1.2 db	$77^{o}K$	#2 Shorted
Cavity #1	Cavity #4	1.2 db	$98^{o}K$	#2 and #3 Shorted
Cavity #2	Cavity #4	.9 db	$63^{o}K$	#3 Shorted #1 Terminated
Cavity #3	Cavity #4	.65 db	$53^{o}K$	#1 Terminated #2 Open

was a basic source of error which was being compensated for by the mal-positioning of the coupling loops.

Further investigation revealed that there was a 0.020" penetration discrepancy between the cold-test loop and those actually being used in the operating device. This meant that if the production loops were in perfect position, the resonant frequency of the cavity would be higher than that observed under test and alignment conditions. (This was the situation with cavity No. 2).

As a result of this, steps were taken to correct the production coupling loop configuration, to control more closely the loop shape and position, to maintain better center-conductor spacing, and to conduct tests during the stacking of the tube with actual loops, line lengths, and coaxial windows in place.

The second series of tests on the first four-cavity LINEATOR revealed that the external tuning devices were largely responsible for the higher-than-expected insertion losses. It was found possible to tune the input ports by teflon slugs inserted in the input coaxial lines, and again to establish a compromise operating condition. Under this condition, it was found that the insertion loss between cavities No. 2 and 3 averaged 0.29 db for a series of three measurements and that the average excess noise temperature of the electron beam was 42°K.

The expected excess noise temperature of the electron beam was less than 25°K. This level of performance can be achieved when all of the cavities have the same resonant frequency and the operating parameters can be adjusted for minimum noise without seriously compromising the input and output match. See b below.

Table 4 shows the measured insertion losses after tuning by means of the teflon slugs in the input coaxial lines of cavities No. 1, 2, and 3.

TABLE IV

FIRST PROTOTYPE
INSERTION LOSS MEASUREMENTS, 2nd SERIES
1,295 Mc

INPUT TO:	OUTPUT FROM:	INSERTION LOSS	COMMENTS
Cavity #2	Cavity #3	0.29 db	#1 Terminated
Cavity #1	Cavity #2	0.4 db	
Cavity #1	Cavity #3	0.5 db	#2 Shorted
Cavity #1	Cavity #4	1.2 db	#2 & #3 Shorted
Cavity #2	Cavity #4	0.9 db	#3 Shorted
Cavity #3	Cavity #4	0.7 db	#1 Terminated #2 Open

Fig. 24 shows a typical noise measurement test setup.

b. Second Prototype LINEATOR:

The test information on the second prototype four-cavity LINEATOR showed a marked improvement in the performance of the device.

The position of the coupling loops and cavity resonant frequencies were closely controlled so that this unit was operated and tested without the necessity of including external tuning devices.

The first step in investigating the performance of this tube was to observe its general operation, match, and transmission characteristics. The only immediately observable discrepancy in

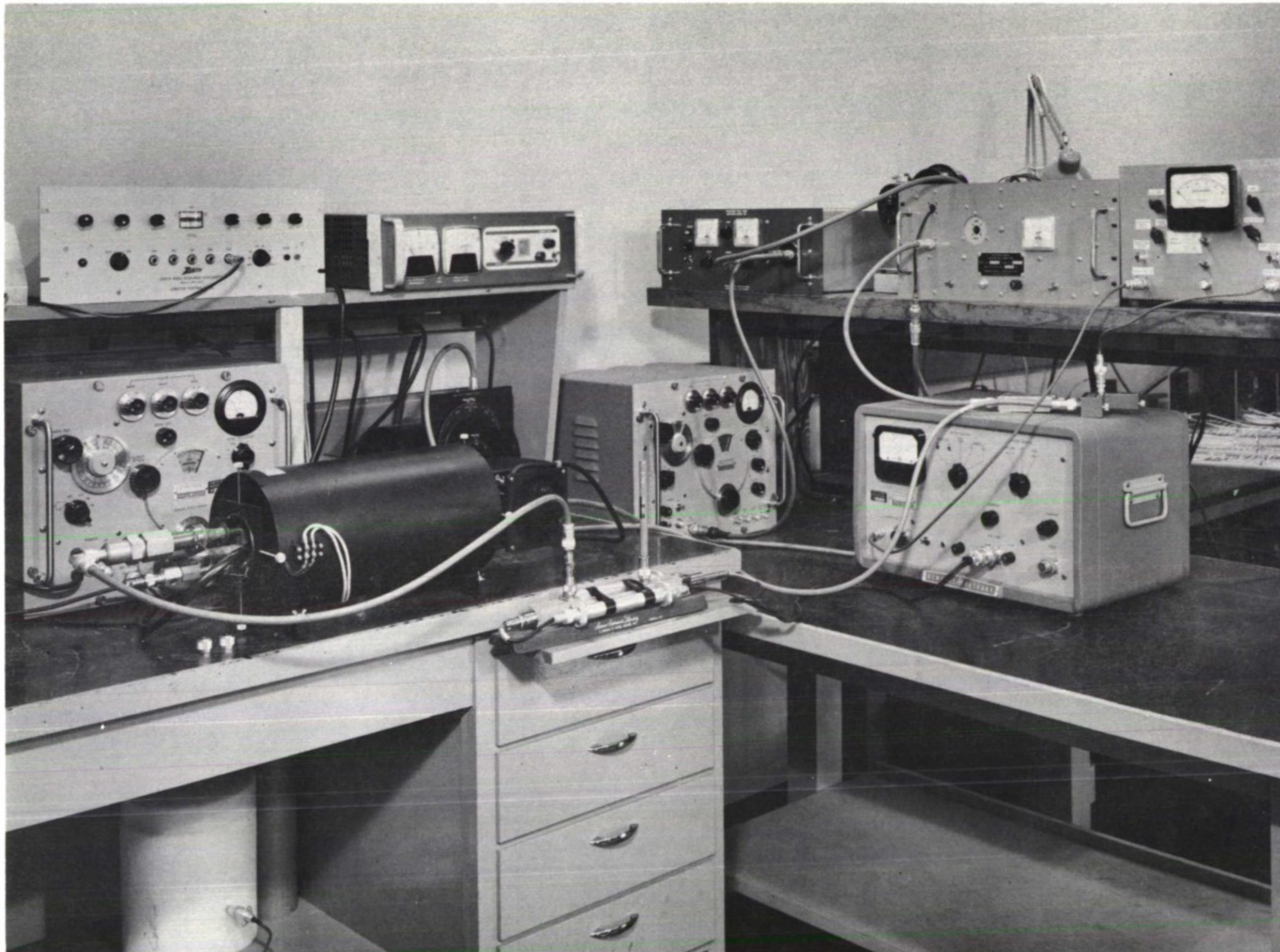


FIG. 24

LINEATOR TEST SET UP

its operation after careful focusing was an existing leakage current between the two control electrodes. This condition was corrected by carefully cleaning the 7-pin tube socket.

The next step was a series of insertion loss and noise measurements. Table 5 shows the final set of data in this series.

TABLE V

SECOND PROTOTYPE LINEATOR
INSERTION LOSS AND NOISE MEASUREMENTS
1,295 Mc

INPUT TO:	OUTPUT FROM:	INSERTION LOSS	ELECTRON BEAM EXCESS NOISE TEMPERATURE	COMMENTS
Cavity #2	Cavity #3	0.3 db	10°K	#1 Terminated
Cavity #1	Cavity #2	0.3 db	10°K	
Cavity #1	Cavity #3	.45 db	17.5°K	#2 Shorted
Cavity #1	Cavity #4	.65 db	45.5°K	#2 and #3 Shorted
Cavity #2	Cavity #4	.6 db	35°K	#1 Terminated #3 Shorted
Cavity #3	Cavity #4	.4 db	21°K	#1 Terminated #2 Shorted

A_1 = 60 volts

A_2 = 65 volts

A_3 = 34 volts

B_1 = 16 volts

B_2 = 16 volts

CC = 22 volts

COIL = 200 volts

I_{A1} = 11.5 ma

I_{A2} = 12 microamperes

I_{A3} = 1 microamperes

I_{B1} = 1 microamperes

I_{B2} = 1 microamperes

I_{cc} = 6 microamperes

I_{coil} = 220 microamperes

Isolation measurements were conducted and test results are shown in Table 6.

TABLE VI

ISOLATION MEASUREMENTS

BEAM OFF

INPUT TO:	OUTPUT FROM:	ISOLATION
Cavity #4	Cavity #3	-104 dbm
Cavity #3	Cavity #4	-102 dbm
Cavity #2	Cavity #1	-108 dbm
Cavity #1	Cavity #2	-108 dbm (limit)
Cavity #1	Cavity #3	-125 dbm

BEAM ON

INPUT TO:	OUTPUT FROM:	ISOLATION	COMMENTS
Cavity #4	Cavity #3	-104 dbm	#1 and #2 Terminated
Cavity #1	Cavity #3	-73 dbm	#2 Terminated

The amount of power required to overload the beam was also investigated. These results are depicted in Fig. 25 which shows the Cuccia and collector current for fixed operating potentials as a function of input power.

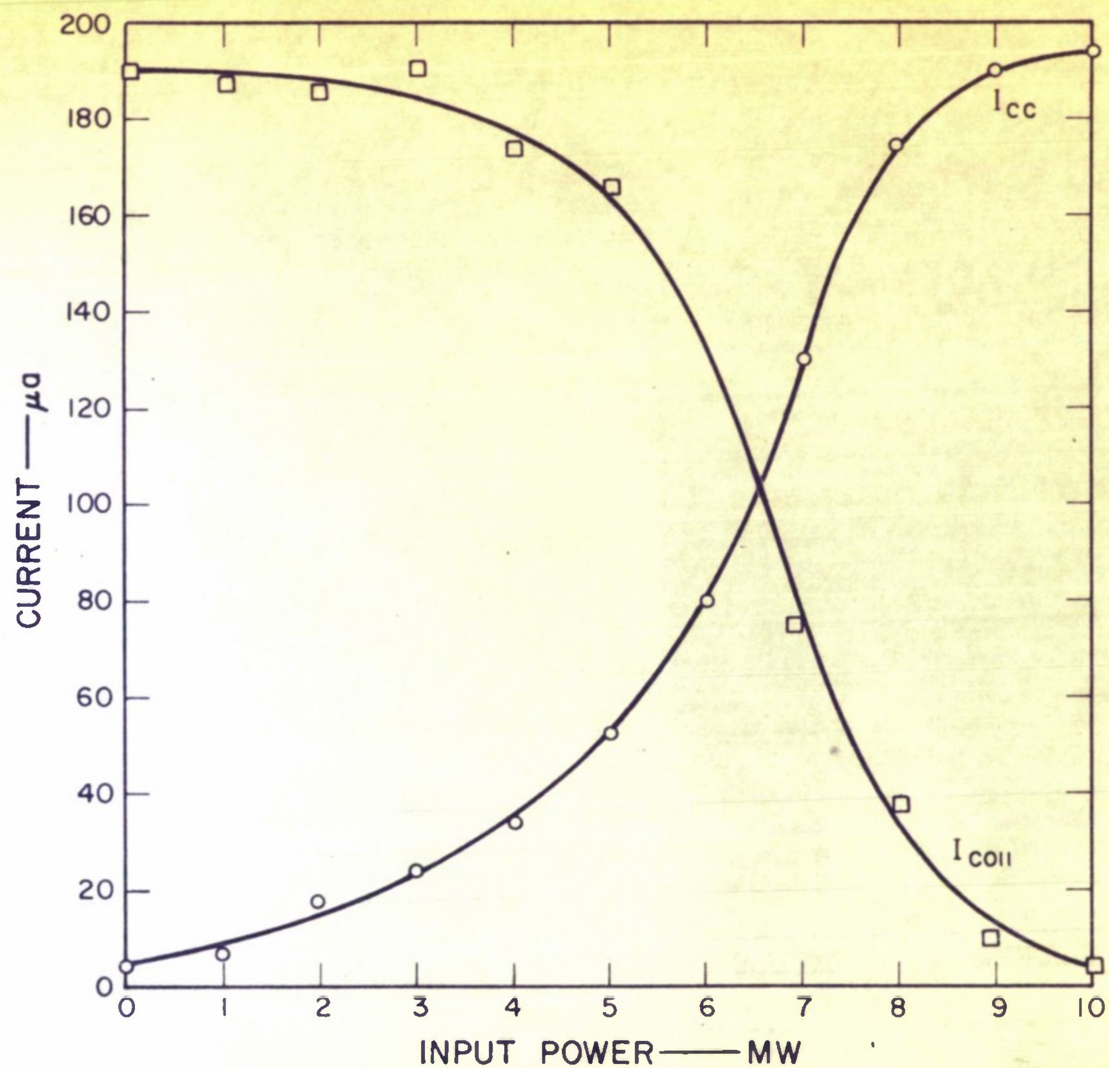


FIG. 25 I_{cc} AND I_{co11} AS A FUNCTION OF INPUT POWER, CAVITY 2

V. CONCLUSIONS

Measured results with the prototype LINEATOR are generally in good agreement with the original predicted characteristics. The following objectives of the program have been met:

1. The feasibility of obtaining low noise with high overload capability in a cyclotron-wave device has been demonstrated.

2. Insertion loss between input and amplifier ports was reduced to 0.3 db, which is somewhat higher than expected. Further work on reduction of coaxial window loss is indicated, and this should lead to substantially better performance.

3. Excess noise due to the electron beam was demonstrated to be of the order of 10 $^{\circ}$K, lower than normally encountered in standard EBPA tubes.

4. Peak-power-handling capability of at least 50 kw is indicated by tests on a cavity structure, although tests on the actual prototype tube have not yet been performed. Average-power capability will be more than adequate with the intended duty cycle.

5. Cold isolation between cavities exceeds 100 db, more than sufficient for the intended application.

6. The prototype LINEATOR has demonstrated that the performance objectives can be met with a unit having reasonable size and weight, with the expectation of long life.

7. The correspondence between design predictions and actual results strongly suggests that no major design difficulties will be encountered in refinement for production of additional units.