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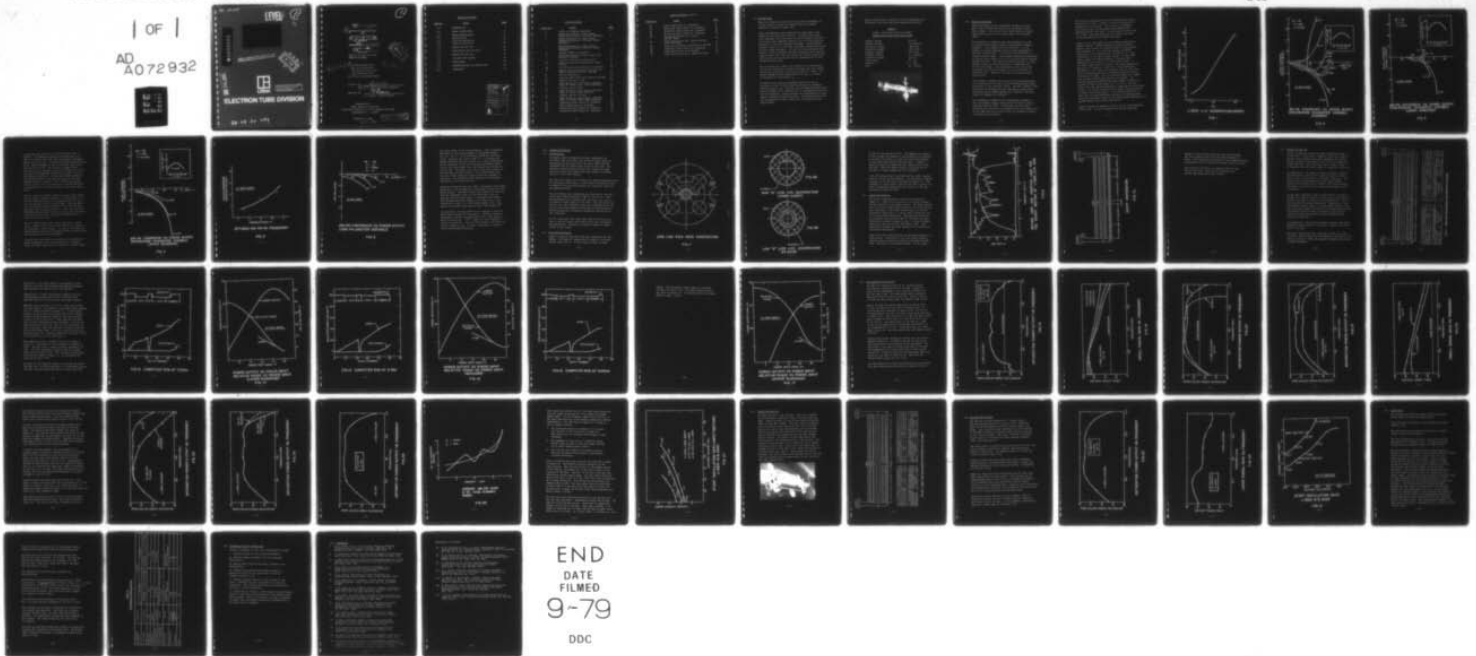
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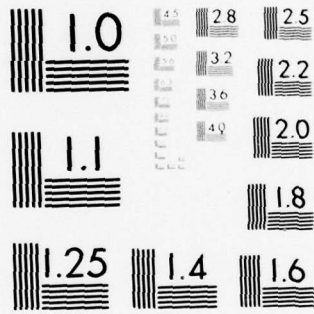
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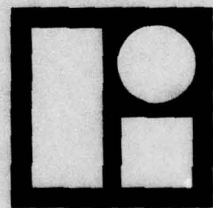


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FEASIBILITY DEMONSTRATION
OF A
HIGH POWER WIDEBAND TWT
WITH LOW AM/PM DISTORTION.

Contract ¹⁵ N00173-77-C-0214 ^{new}

⑨ FINAL REPORT
CLIN 0002

Exhibit A, CDRL Item A003
NRL # 541298

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⑪ 26 Feb 79

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⑫ 59 p.

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February 26, 1979

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1.0 INTRODUCTION

Loss-line stabilized tubes have been under development at Litton Industries under the supervision of the Naval Research Laboratories since 1973.

Early developmental tubes demonstrated high power, wide bandwidth and efficient operation. In-band distributed loss techniques were developed to form attenuator sections to provide lower bandedge stability and to allow efficient operation at the high frequency bandedge. Stabilization problems, however, at the upper bandedge prevented operation at full design perveance. In the last tube preceding this Contract, upper bandedge stability techniques were improved significantly; but, the tube exhibited in-band regenerative oscillations which prevented direct demonstration of this stability improvement.

The two tubes built under this Contract both demonstrated oscillation stability at design perveance and fully demonstrated the potential of loss line stabilized tubes. The design changes and the demonstration of these two tubes as discussed in this report.

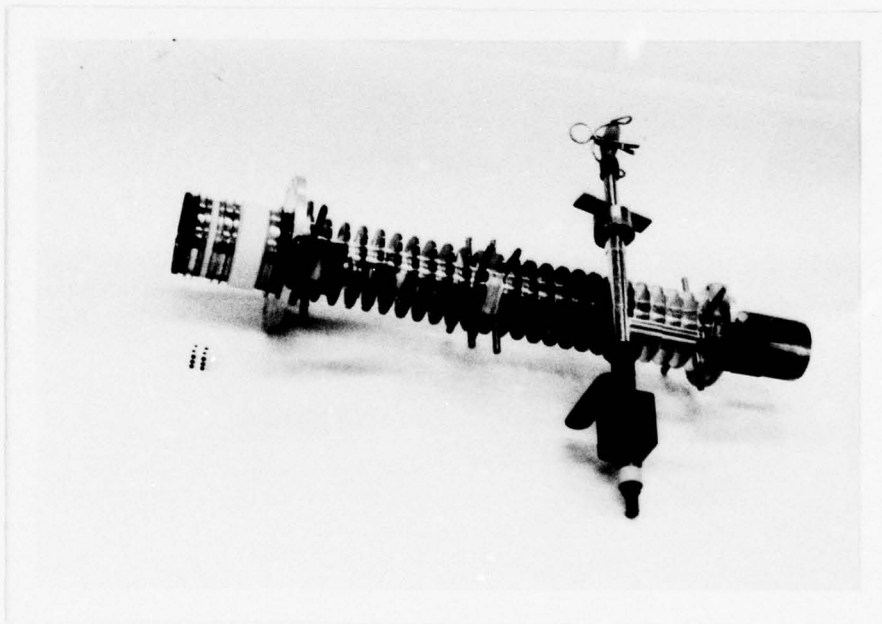
In addition to stability considerations there was an additional effort to study AM-PM conversion in wideband coupled cavity tubes. Calculations are presented which show that low AM-PM can be obtained over a considerable portion of the hot bandwidth. Design changes were implemented in these tubes to minimize AM-PM conversion. Lower AM-PM conversion was demonstrated on these tubes than on comparable loss button tubes.

Table I shows typical electrical and RF parameters for the L-5631 loss line stabilized coupled cavity TWT.

TABLE I

L-5631 - Loss Line Stabilized CCTWT
Typical Electrical And RF Parameters

Cathode voltage	32.0 kV
Cathode current	6.5 amperes
Grid pulse voltage	300 volts
Grid bias voltage	-500 volts
Filament voltage	10.5 volts
Filament current	5 amperes
Collector voltage	10.6 kV
Power output	20 kW
Frequency	7 - 11 GHz
Gain	36 dB min.



2.0 AM-PM CALCULATIONS

AM-PM conversion is the incremental increase of total phase shift through the tube for an incremental drive power change. It is zero in the small signal or linear region and non-zero in the large signal or non-linear region.

The dependence of AM-PM on the tube parameters, b , QC , C and d was investigated using a large signal computer program²¹. This program was written by Dr. J. R. M. Vaughan of Litton Industries and has been published in the IEEE Transactions. It has since been modified to include absolute phase. The program essentially calculates the power, gain, phase, etc. in a cavity by cavity sequence through the tube. The electron beam is modeled by a beam segment having one RF period which is subdivided into 12 disks of charge. The parameters b , QC , C and d are calculated from Pierce's theory and are calculated for reference only. They are not used in the large signal calculations.

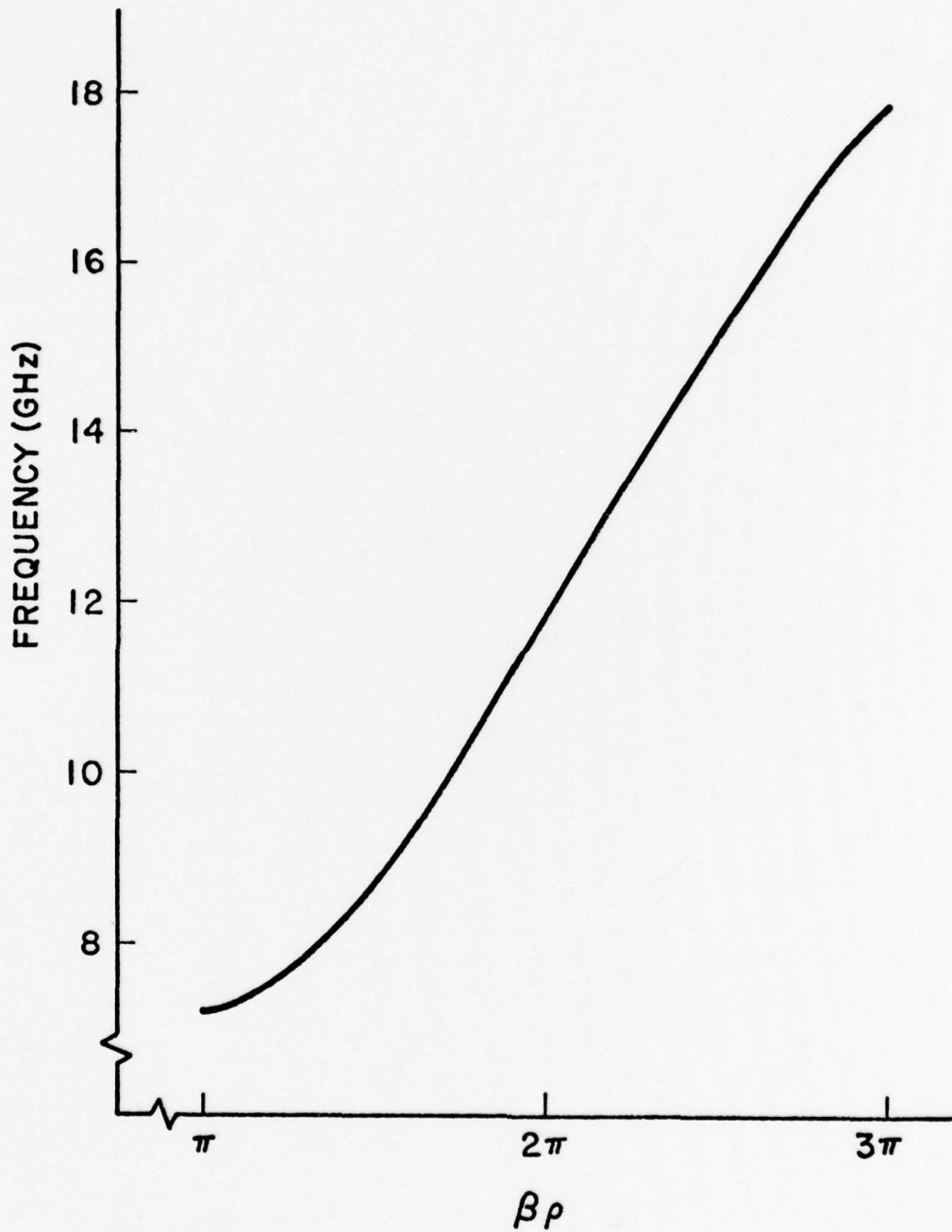
The program in general works quite well in modeling tubes up to saturation, but does not work satisfactorily beyond saturation in the overdrive region. We were, however, most interested in studying the near saturation region where the nonlinearity process begins and, therefore, for this region the program was adequate.

The dependence of AM-PM on the synchronism parameter b was investigated using a long section of circuit with no attenuator and no sever. In practice the tube would oscillate but this fact is unimportant for the calculations. It was important not to allow sever or attenuator effects to influence the results.

The circuit investigated was the broadband type used in the loss line tubes. Figure 1 shows the unloaded ω - β diagram for this circuit. The circuit is coalesced at 12 GHz so that no stop band exists between the passband and the slot mode. The hot band is from 7 GHz to 11 GHz. Cold test data for this circuit was used in the calculations for AM-PM conversion.

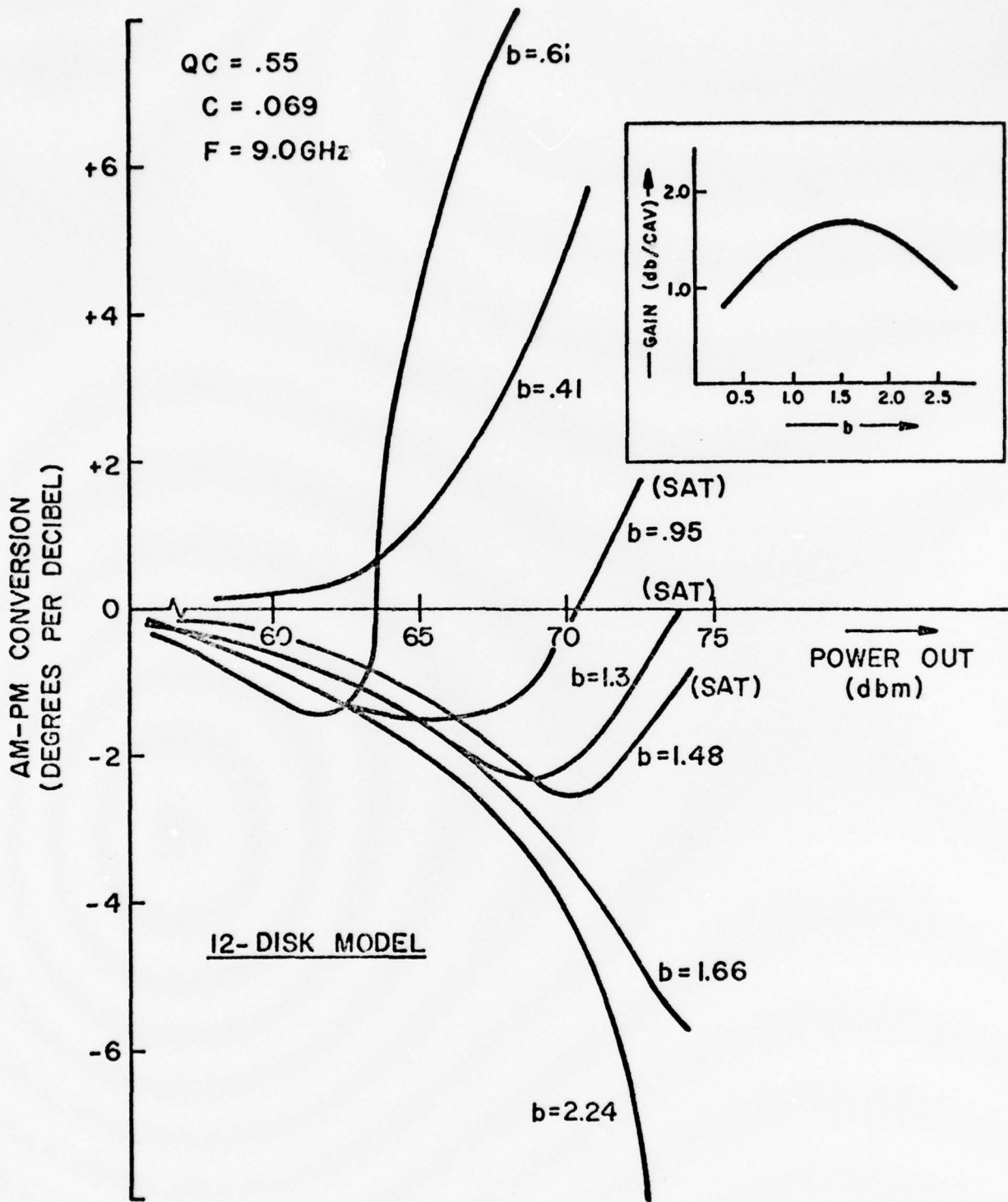
Figure 2 shows the results of the computer analysis at midband (9 GHz). AM-PM conversion is shown plotted against power output for several values of the synchronism parameter b . For low power output the AM-PM conversion is low regardless of the value of b . This corresponds to the small signal region. In the large signal region the AM-PM conversion increases and, depending on the value of b , can be quite large. In the upper right corner of Figure 2 the small signal gain per cavity is shown as a function of the synchronism parameter b . For values of b greater than b_0 , the value of b for maximum gain, both the AM-PM conversion and the efficiency are high. As b is decreased there is a region of b in which the AM-PM conversion is minimum. For midband the maximum AM-PM from small signal to saturation is about $2^\circ/\text{dB}$ in this region ($1 \leq b \leq 1.5$). For low values of b the AM-PM conversion is large and the efficiency is low. The AM-PM conversion also changes sign indicating a shorter tube phase length. It is also interesting to note that for high efficiency operation the maximum AM-PM occurs at saturation while for an undervoltaged condition, the maximum AM-PM occurs before saturation.

Figure 3 shows the computer results for the lower bandedge of the tube. At this frequency the circuit impedance



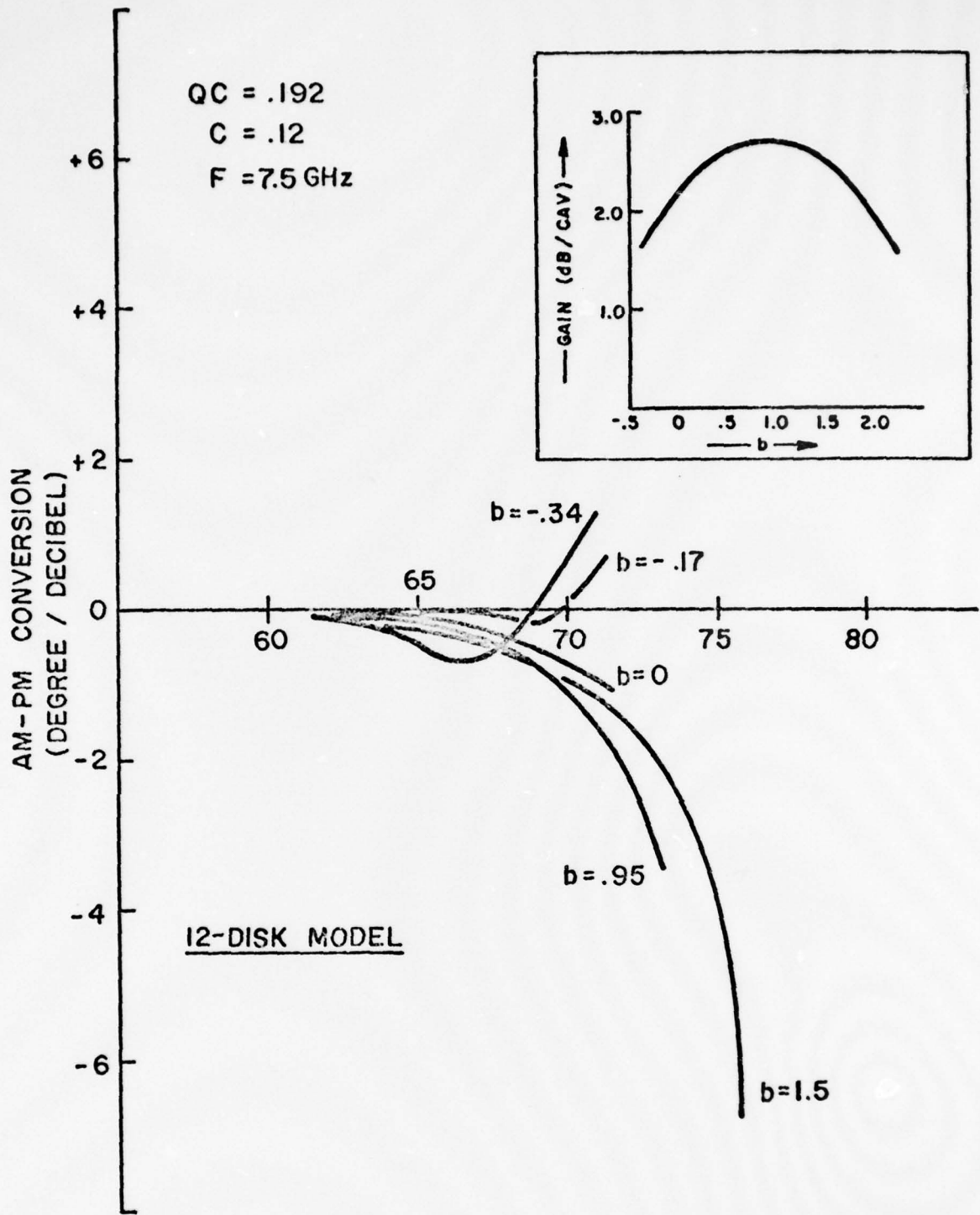
L-5631 ω - β DIAGRAM (UNLOADED)

FIG. 1



AM-PM CONVERSION VS. POWER OUTPUT
 SYNCHRONISM PARAMETER VARIABLE.
 (MIDBAND)

FIG. 2



AM-PM CONVERSION VS. POWER OUTPUT
SYNCHRONISM PARAMETER VARIABLE.
(LOWER BANDEDGE)

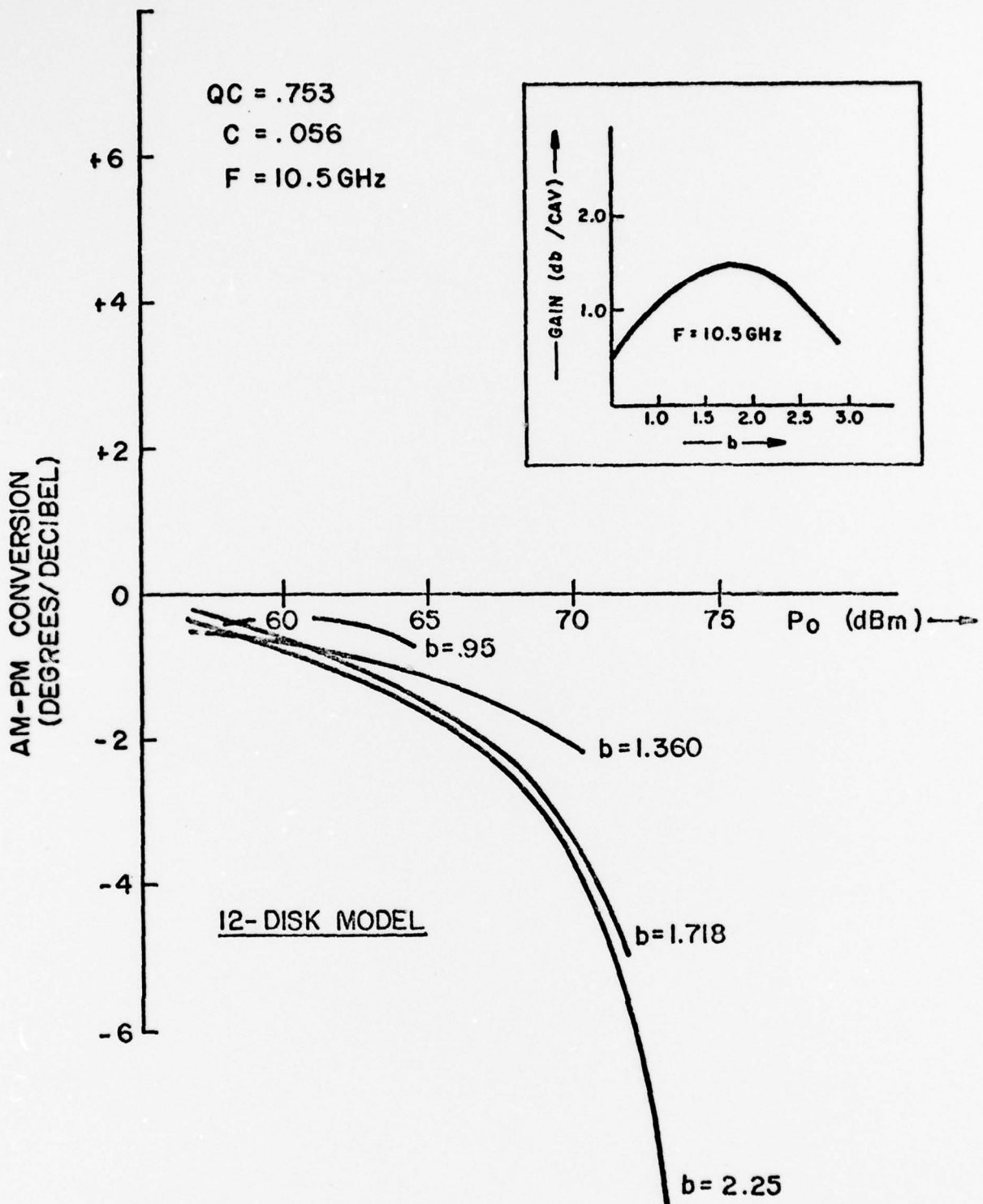
FIG. 3

is high and the value of C is almost double that at midband. The AM-PM conversion is minimum near $b = 0$ and is less than $1^\circ/\text{dB}$ over the drive range from small signal to saturation. The improved AM-PM characteristics at the lower bandedge are due to the high value C and the low value of QC. The circuit is highly under-voltaged at this frequency, but the efficiency is still reasonable although much lower than it could be for an overvoltaged condition. The minimum AM-PM voltage at the lower bandedge is the same voltage for which the minimum occurs at midband. This somewhat unexpected result leads to the conclusion that a minimum AM-PM can be obtained over a large percentage of the total bandwidth.

Figure 4 shows the AM-PM conversion versus power output for the upper frequency bandedge. The impedance is low at this frequency and the corresponding value of C is low and the value of QC is quite high. The best AM-PM at a reasonable efficiency occurs just below the maximum small signal gain at about $b = 1.36$. Better values of AM-PM occur for lower values of b, but the efficiency falls off dramatically. The maximum AM-PM occurs at saturation in this case.

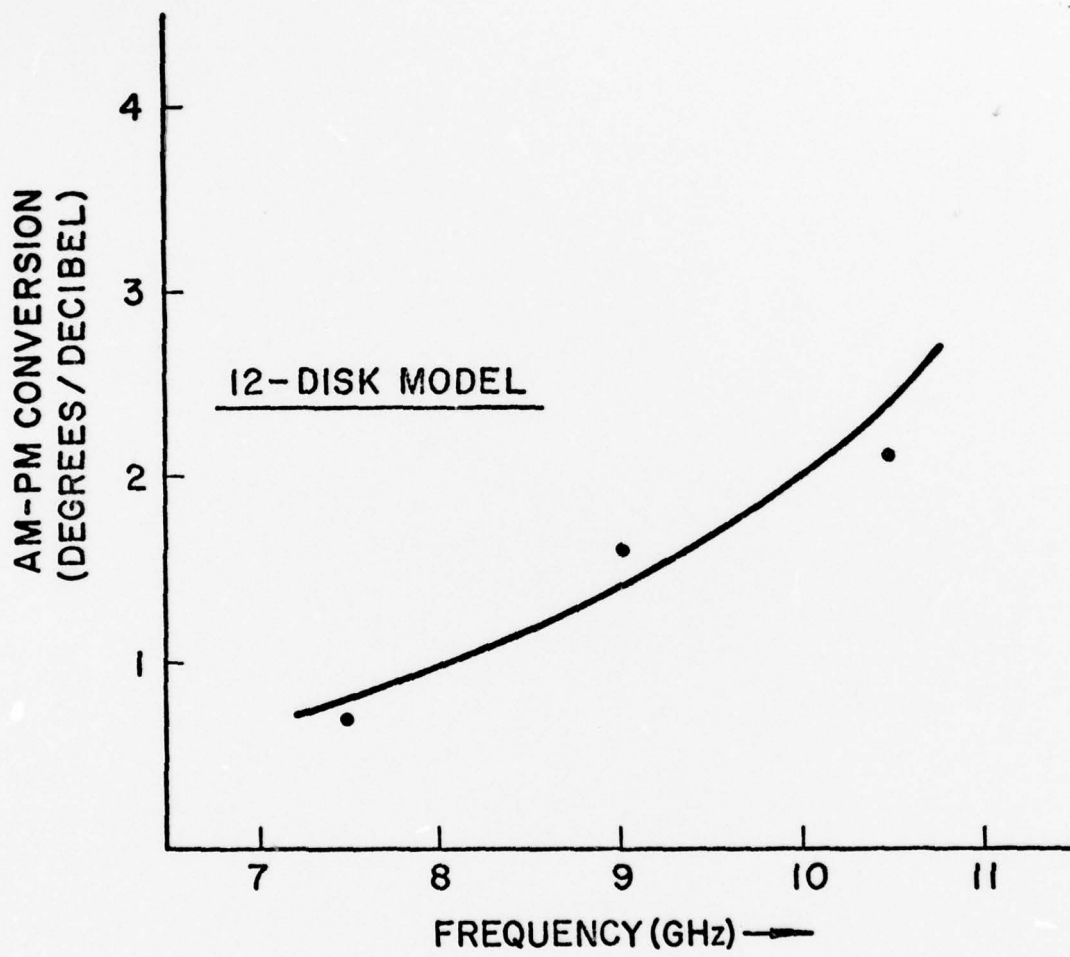
The best AM-PM values occur across the band at about 30 kV. Figure 5 shows the optimum AM-PM as a function of frequency at this voltage. It can be seen that the AM-PM values increase with frequency and the best results are obtained at the lower bandedge.

Computer runs were made to determine the dependence of AM-PM conversion on the loss parameter d. Figure 6 shows the AM-PM conversion as a function of power output



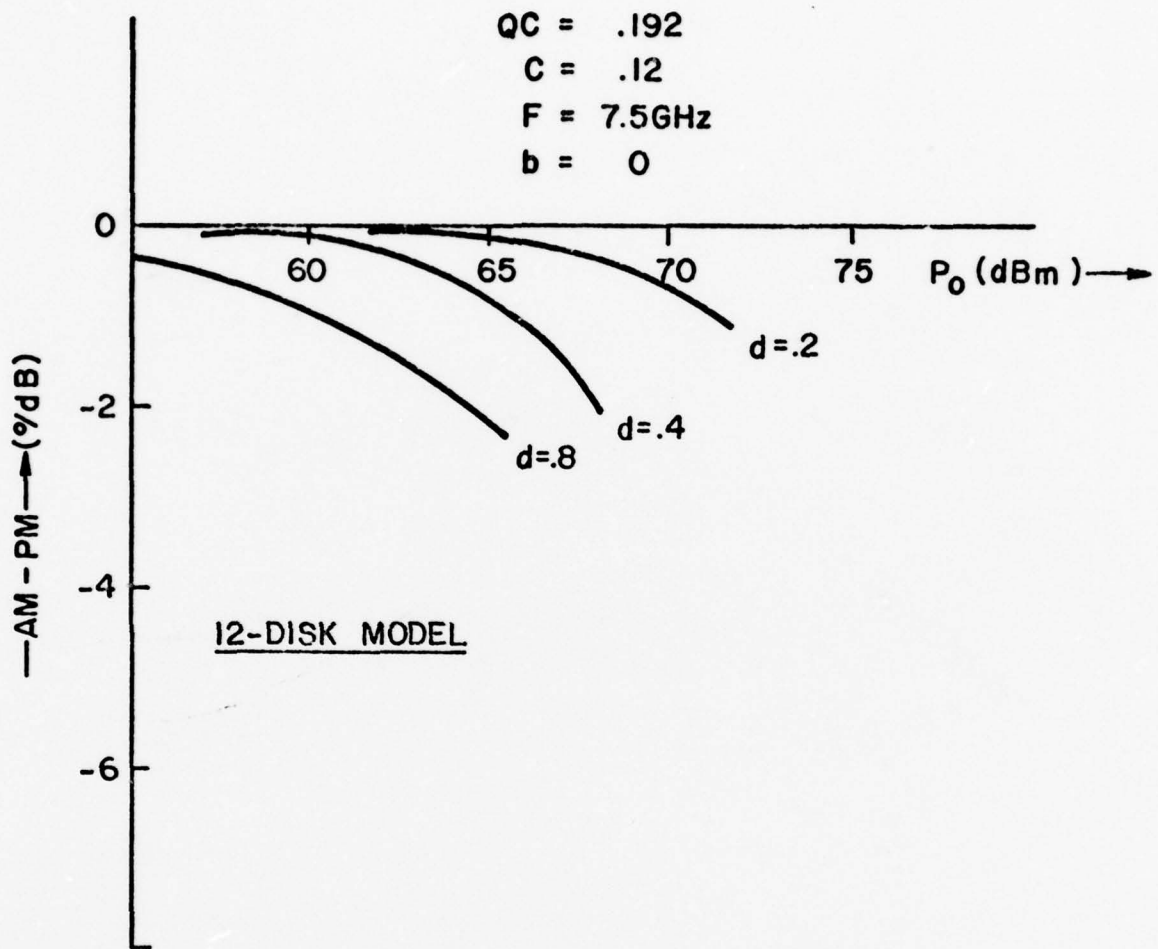
AM-PM CONVERSION VS. POWER OUTPUT
 SYNCHRONISM PARAMETER VARIABLE.
 (UPPER BANDEDGE)

FIG. 4



OPTIMUM AM-PM VS. FREQUENCY

FIG. 5



AM-PM CONVERSION VS. POWER OUTPUT
LOSS PARAMETER VARIABLE

FIG. 6

for three values of the loss parameter. The calculations were made at the lower bandedge at the AM-PM minimum ($b = 0$). For $d = .2$ the calculated AM-PM was less than $1^\circ/\text{dB}$. Doubling the circuit loss ($d = .4$) doubles the AM-PM conversion and also results in a loss of efficiency. Further increase of the loss increases the AM-PM conversion at the same output power and reduces the efficiency of the tube. Therefore, the loss in the power section of the tube must be kept minimum. For a PPM focused tube all pole pieces should be copper plated for minimum resistivity. No distributed loss should be intentionally introduced to the power section.

Additional computer runs were made to determine the optimum positions of the attenuator in the output section for best AM-PM results. The best results were obtained as expected with the attenuator close to the sever and as far as possible from the tube output. In general good results were obtained when the length of the power section was sufficient to yield 15 - 20 dB small signal gain. This agrees with results published by Ober¹¹ and Nishihara¹⁷.

In conclusion, the best AM-PM circuit design is also the best circuit design for efficiency. Impedance should be maximized to obtain a maximum value of C . This insures QC is low since $QC \propto 1/C^2$. Also, the loss parameter d should be minimized. The best AM-PM values occur when the tube is undervoltaged. The best efficiency is obtained for an overvoltaged condition.

3.0 DESIGN MODIFICATION

3.1 Stabilization

The upper cutoff instability problem, manifested by the early loss line tubes, was solved in these tubes by increasing the loss per cavity at upper cutoff and by including loss in nearly every cavity of the tube. The cavities in the bellows and weld seal regions (8 total cavities) cannot be loaded since they cannot be directly exposed to the lossy ceramic.

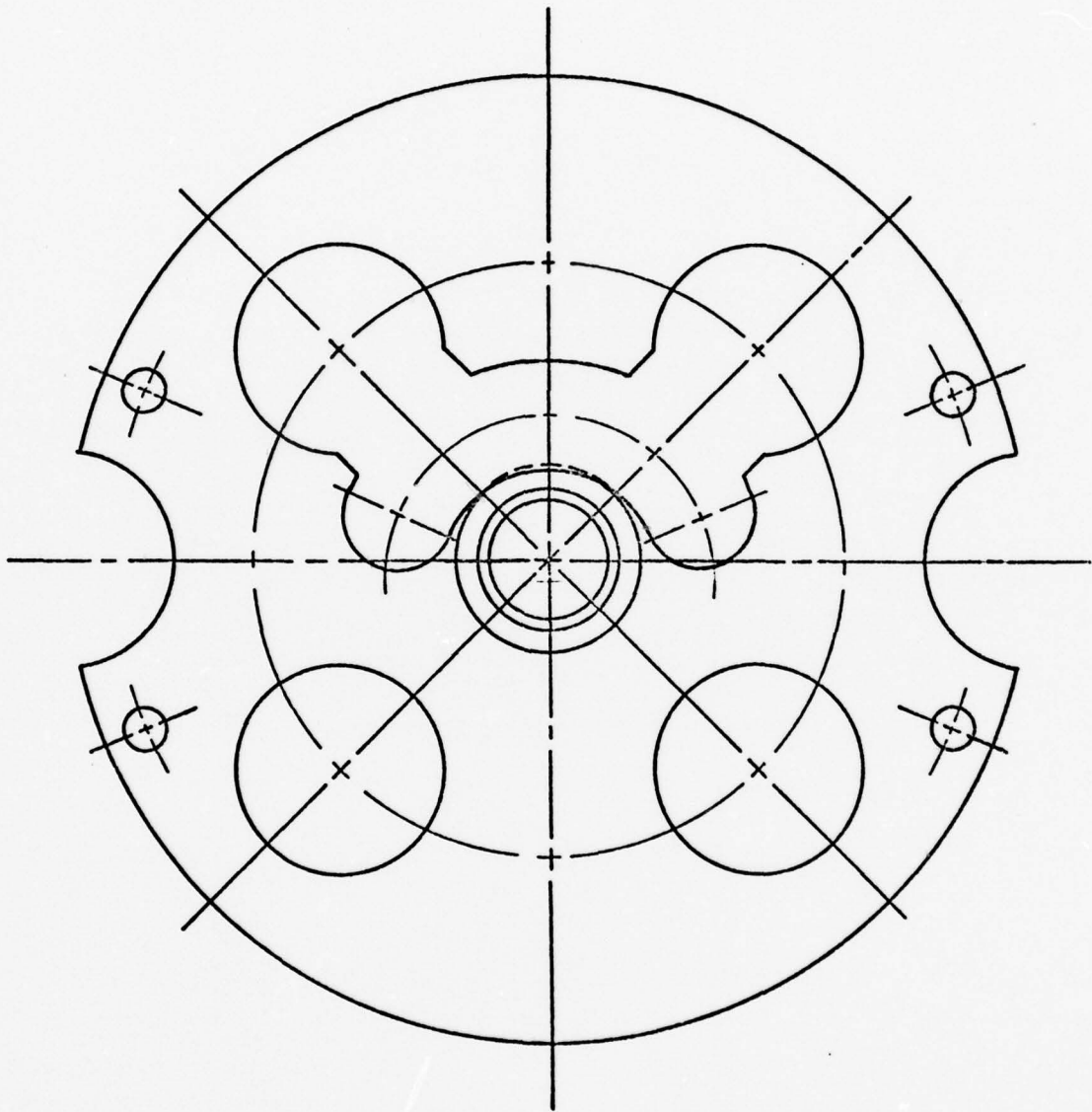
Two loss lines were used to obtain the desired characteristics for the upper cutoff loss. A very high "Q" design was used to suppress the oscillation while not "spilling" loss into the operating band.

The distributed loss attenuation was provided by two additional loss lines oriented at 180° to each other. Since the attenuators are confined near the sever this loss is not added to every cavity in the tube. Two loss lines were used to form the attenuator since the perturbations to the circuit are rather large for this type of loading and an uneven loading will accentuate mismatches around the $\beta p = 3\pi/2$ frequency.

In all, there were four loss lines used to stabilize the tube — two for upper cutoff and two for the distributed loss attenuator. These are oriented as shown in Figure 7 at 90° to each other.

3.2 Loss Rod Fabrication

Figure 8 shows how the loss rods were fabricated for this design. The high "Q" construction is used for the upper cutoff stabilization. A thin stripe of loss is used



LOSS LINE POLE PIECE CONSTRUCTION

FIG. 7

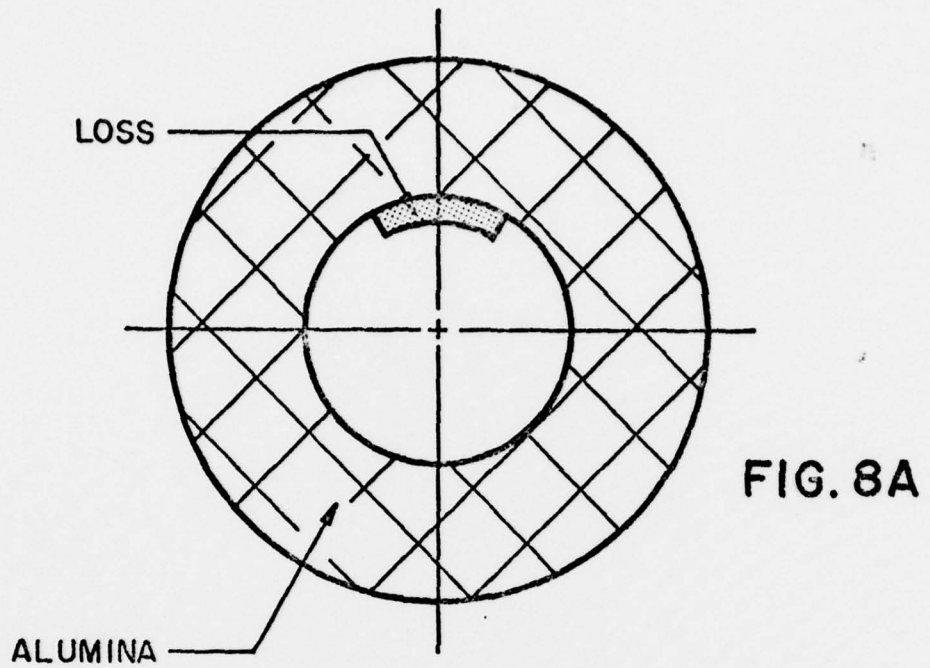


FIG. 8A

HIGH "Q" LOSS LINE CONSTRUCTION
(UPPER CUTOFF)

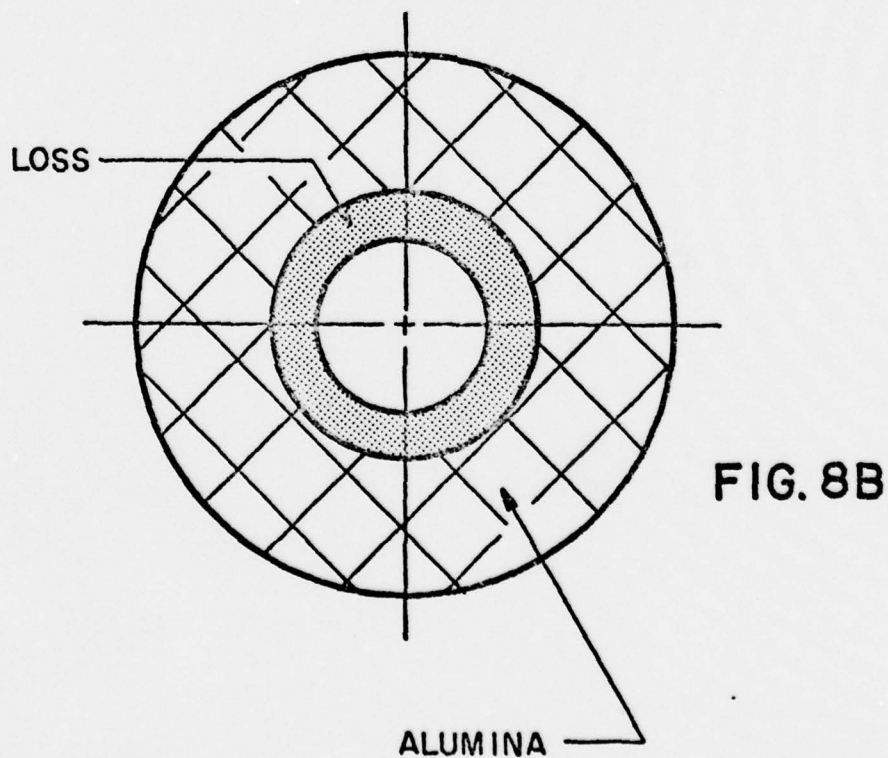


FIG. 8B

LOW "Q" LOSS LINE CONSTRUCTION
(IN-BAND)

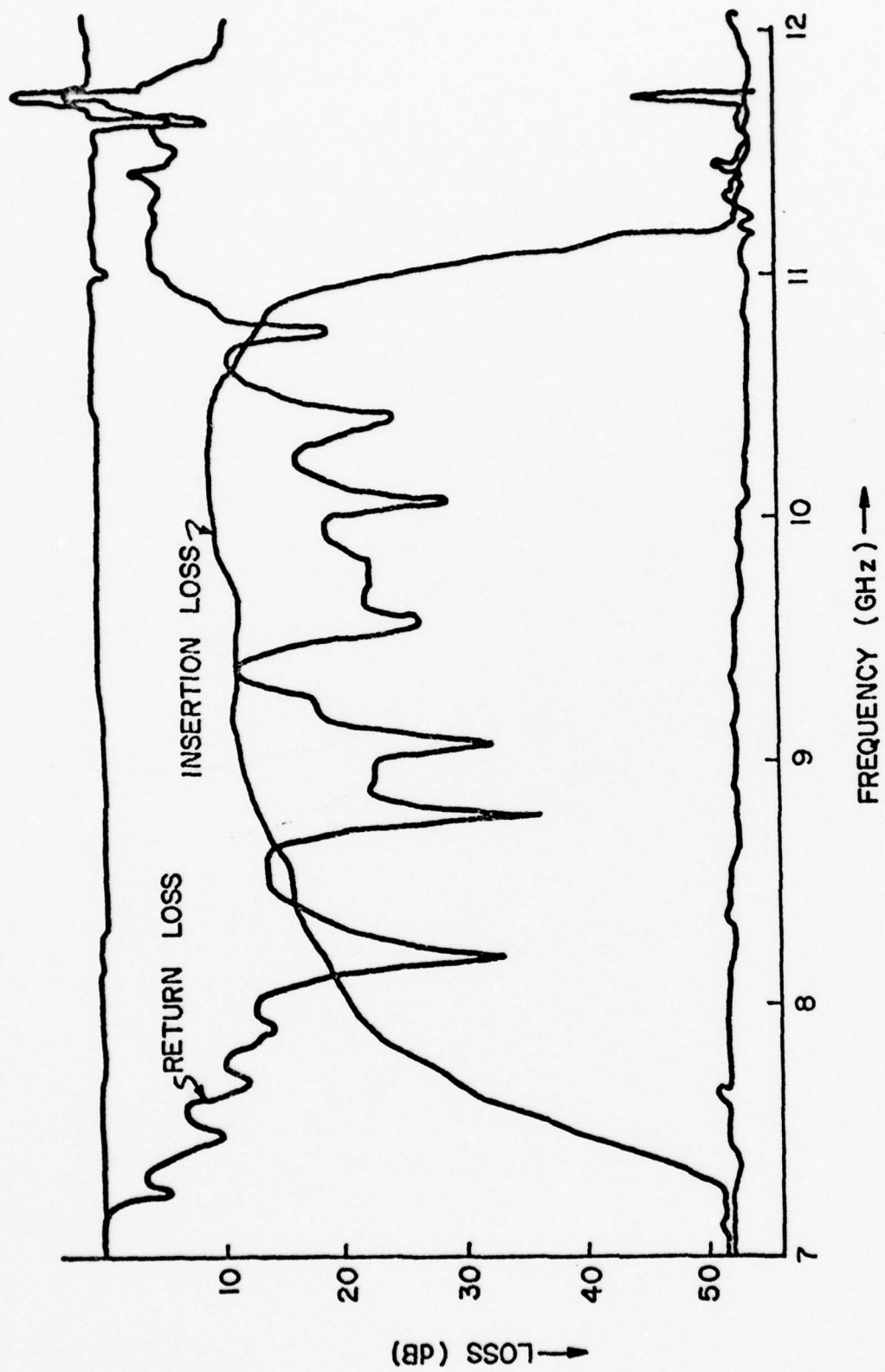
to achieve the desired effect. The angular orientation of the stripe with respect to the coupling iris produces a variable "Q" useful in final cold test determination of the upper band rolloff characteristic. Figure 9 shows the match and insertion loss characteristics for S/N 2001. Note the sharp rolloff at the high end of the band (11 GHz) produced by the "stripers".

A low "Q" construction is achieved with a heavy coating over the entire inside diameter. The electrical response is shown at the low end of the band in Figure 9.1. The resonance is tuned below 7 GHz and the loss "spills" out over the operating band being very heavy at 7 GHz and decreasing across the band.

3.3 Cavity Distribution

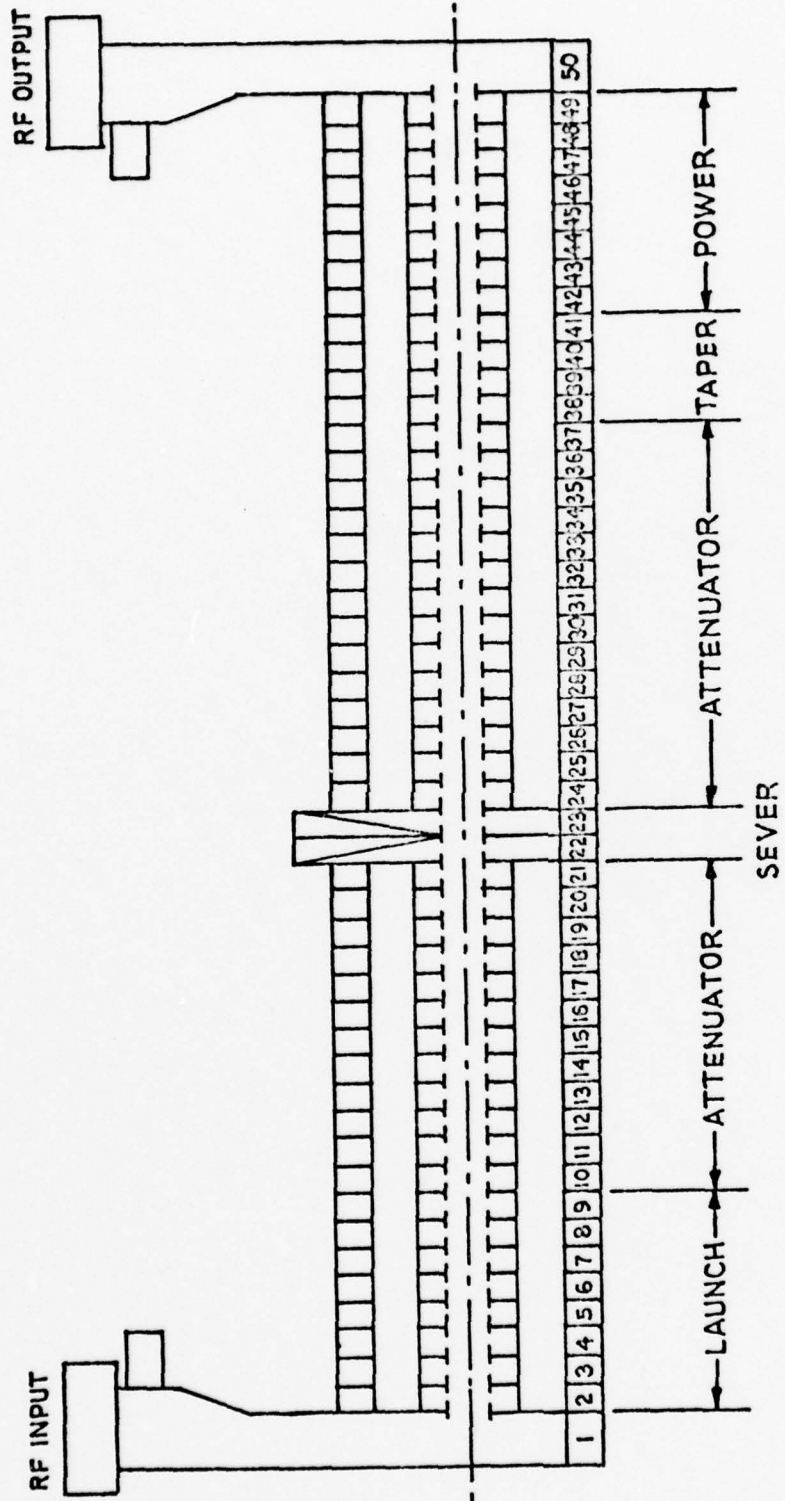
The cavity distribution for both tubes is shown in Figure 10. There are 20 cavities in the input section and 26 cavities in the output section. The input section has an 8 cavity launch subsection and a 12 cavity attenuator subsection. The output section has a 14 cavity attenuator subsection, a 4 cavity taper subsection, and an 8 cavity power subsection. The taper subsection is an attenuator section with high "Q" in-band loss which effectively reduces the gain in the 7 - 8 GHz frequency region but adds very little loss above 9 GHz. This effectively extends the power section to 12 cavities at the higher frequencies.

There are 8 loss rods utilized in this tube design, 4 in each section. Cavities² 21, 24, and 49 are manifold cavities used to convey the fluid to and from the loss rods. The sever is a standard design. In the early



RETURN LOSS AND INSERTION LOSS FOR THE OUTPUT SECTION OF L-5631, S/N 2001.

FIG.9



CAVITY DISTRIBUTION

FIG. 10

models of the loss line tube the loss rods extended the full length of the tube and passed through the sever. The construction utilized in this design provides considerably more RF isolation between circuit sections.

Each section, therefore, is complete with its own set of loss rods. The loss rod assemblies are shorter and mechanically more stable.

4.0 DESIGN FOR S/N 2001

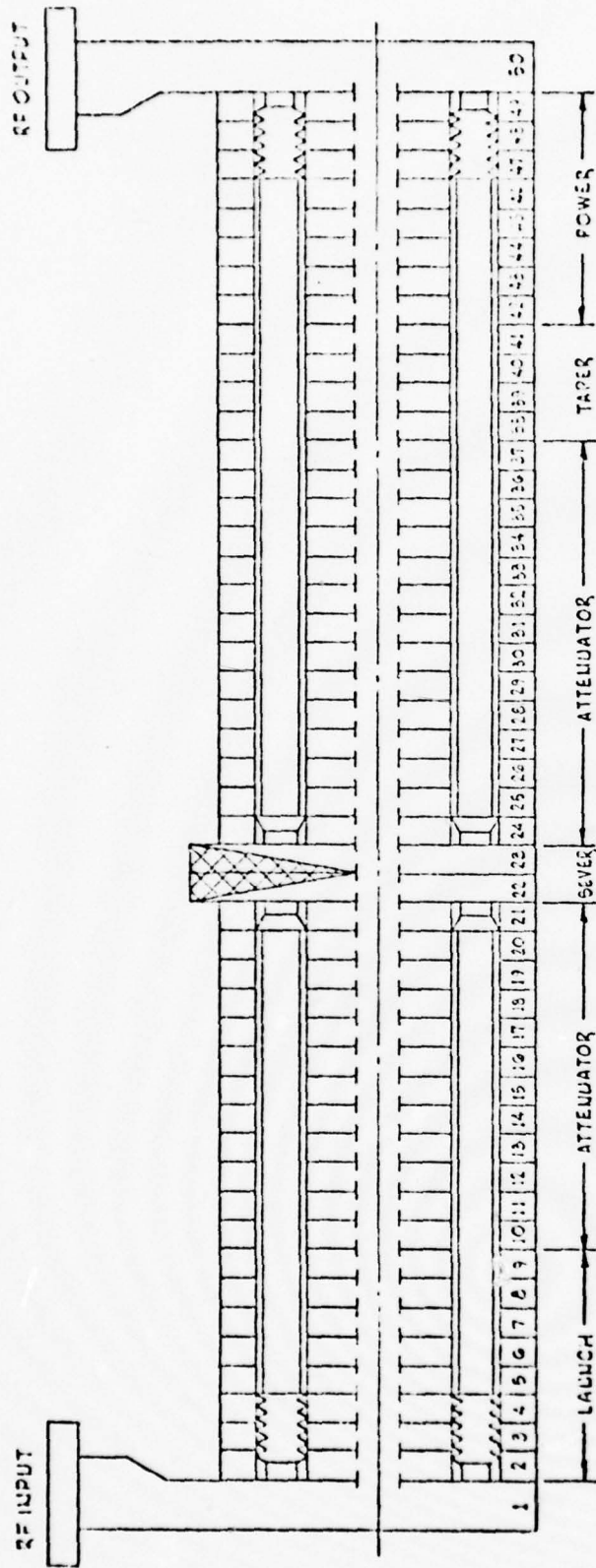
Figure 11 shows the cavity and loss distribution chart for S/N 2001. There were 2 symmetric loss lines, Type A, having .6 dB reference loss and 2 symmetric loss lines, Type B, having 6 dB reference loss in both the input and output sections. This reference loss or type of loss is constant over the total length of a specific loss line.

In subsection 1, the launch section, the Type A sleeves were shorted over the first 3 cavities and have .260 in. wide X .125 in. long slots in the last 5 cavities. The Type B sleeves were shorted over the entire length. Therefore no in-band loss is added in the launch section and there is no loss at all in the bellows region (first 3 cavities).

In the input attenuator region, subsection 2, the Type A sleeves have .260 in. wide X .125 in. long slots for every cavity. The Type B sleeves had continuous slots .125 in. wide oriented for heavy attenuation. Subsections 1 and 2 were brazed together with the corresponding sleeves. The loss rods were inserted and welded to the manifold cavities. The manifold cavities were then brazed to the section. Loss line covers were welded in place completing the section construction.

In subsection 3, the output attenuator section, the sleeve geometries were similar to subsection 2 except that there were 13 cavities.

The taper section used the same type sleeves as in subsections 2 and 3 except that the angular orientation of the slot was varied to lower the resonant frequency and produce a light attenuator.



2 SYMMETRICAL (REF # 682) LOSS LINE A		
SLOT WIDTH	1/CAVITY	1/CAVITY (CENTERED)
.125	.200	.200
SLOT HEIGHT		.125

2 SYMMETRICAL (REF # 682) LOSS LINE B		
SLOT WIDTH	UN-LOADED	HEAVY ATTENUATOR
.125	SHORTED SLEEVES	CONTINUOUS
		.125

2 SYMMETRICAL (REF # 682) LOSS LINE A		
SLOT WIDTH	1/CAV	1/CAVITY (CENTERED)
.125	.200	.200
SLOT HEIGHT		.125

2 SYMMETRICAL (REF # 682) LOSS LINE B		
SLOT WIDTH	UN-LOADED	HEAVY ATTENUATOR
.125	SHORTED SLEEVES	CONTINUOUS
		.125

FIG. 11 LOSS LINE AND SLEEVE DISTRIBUTION S/N 2001

Subsection 5, the power section, was similar to subsection 1 and the same sleeves were used with shorted ends placed at the output end of the section.

Subsections 3, 4 and 5 were brazed together with the corresponding sleeves and with the loss lines and manifold cavities in place formed the output section.

Computer runs were made at 7.5 GHz, 9 GHz and 10.5 GHz for this design. The results of the large signal computer run at 7.5 GHz are shown in Figure 12. In the launch section the gain rate is very high but is then sharply reduced in the attenuator region so that the net gain is about 24 dB at the sever. After the sever the gain rate is still curtailed by the attenuator. Even in the power section the gain rate does not increase until the last 8 cavities. The tube saturates at about 20 kW and 56 dB large signal gain. The drive characteristics are shown in Figure 13. AM-PM at saturation is about $1.3^{\circ}/\text{dB}$ as calculated from the 12 disk model.

The computer results at midband (9 GHz) are shown in Figure 14. The effect of the attenuator is smaller at 9 GHz. The gain rate is almost constant throughout the tube. The tube saturates at about 22 kW and a large signal gain of about 49 dB. The calculated AM-PM characteristics are shown in Figure 15. At saturation the calculations show $1^{\circ}/\text{dB}$.

In Figure 16 the computer results at 10.5 GHz are shown. The gain rate is low and some power is transferred outside the power section indicating that it is not quite long

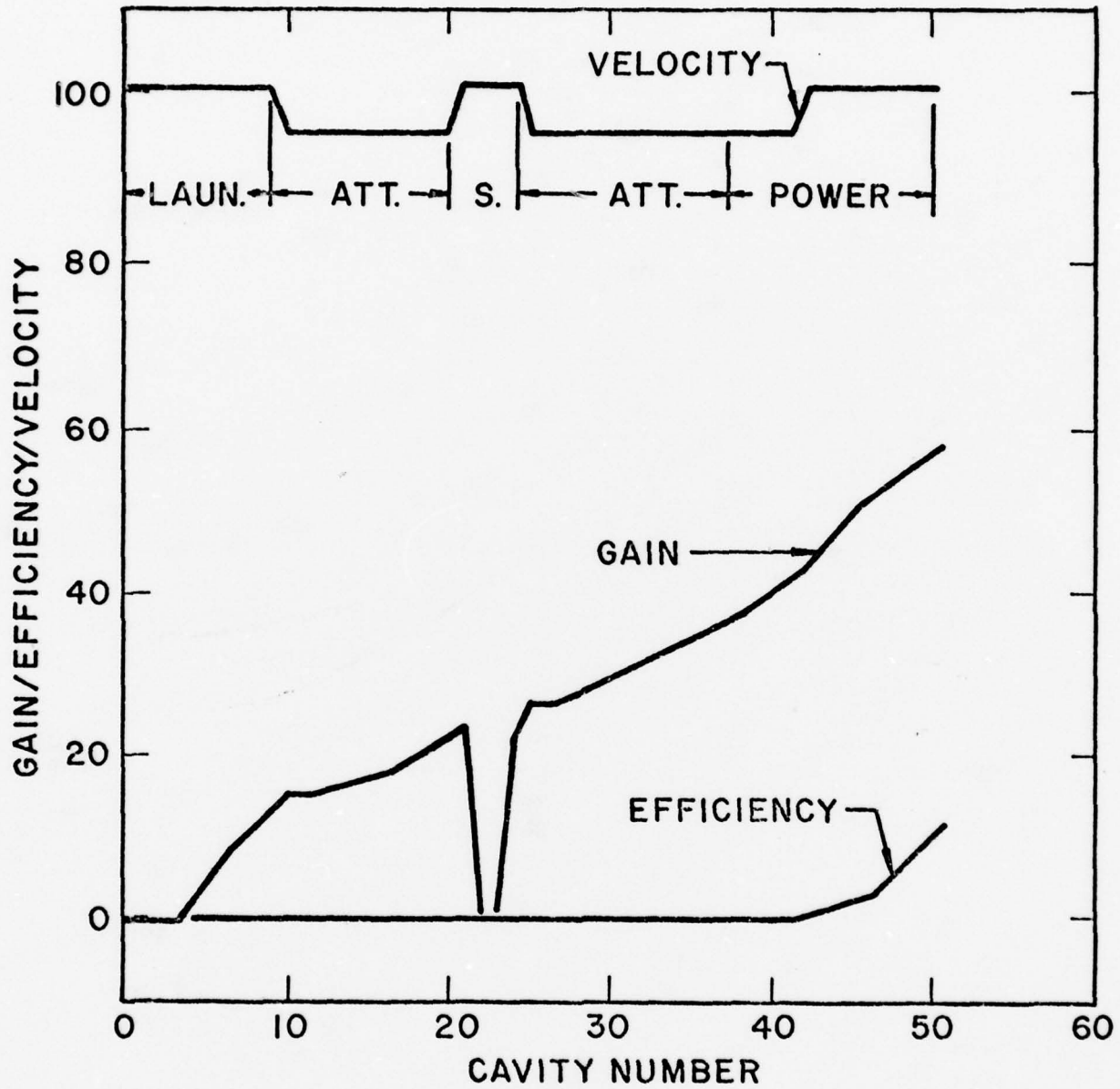
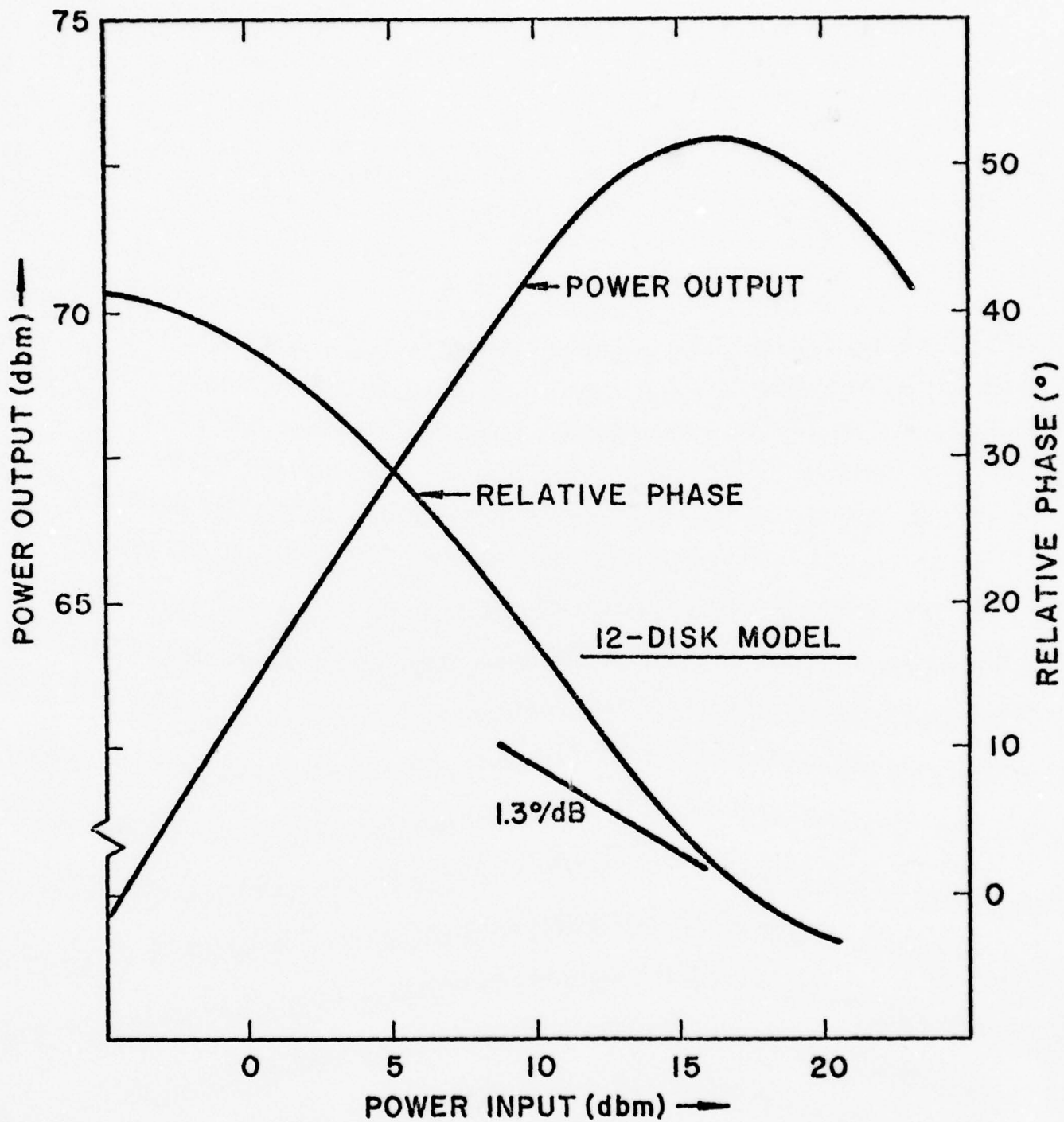


FIG.12 COMPUTER RUN AT 7.5 GHz



POWER OUTPUT VS. POWER INPUT
 RELATIVE PHASE VS. POWER INPUT
 (LOWER BANDEDGE)

FIG. 13

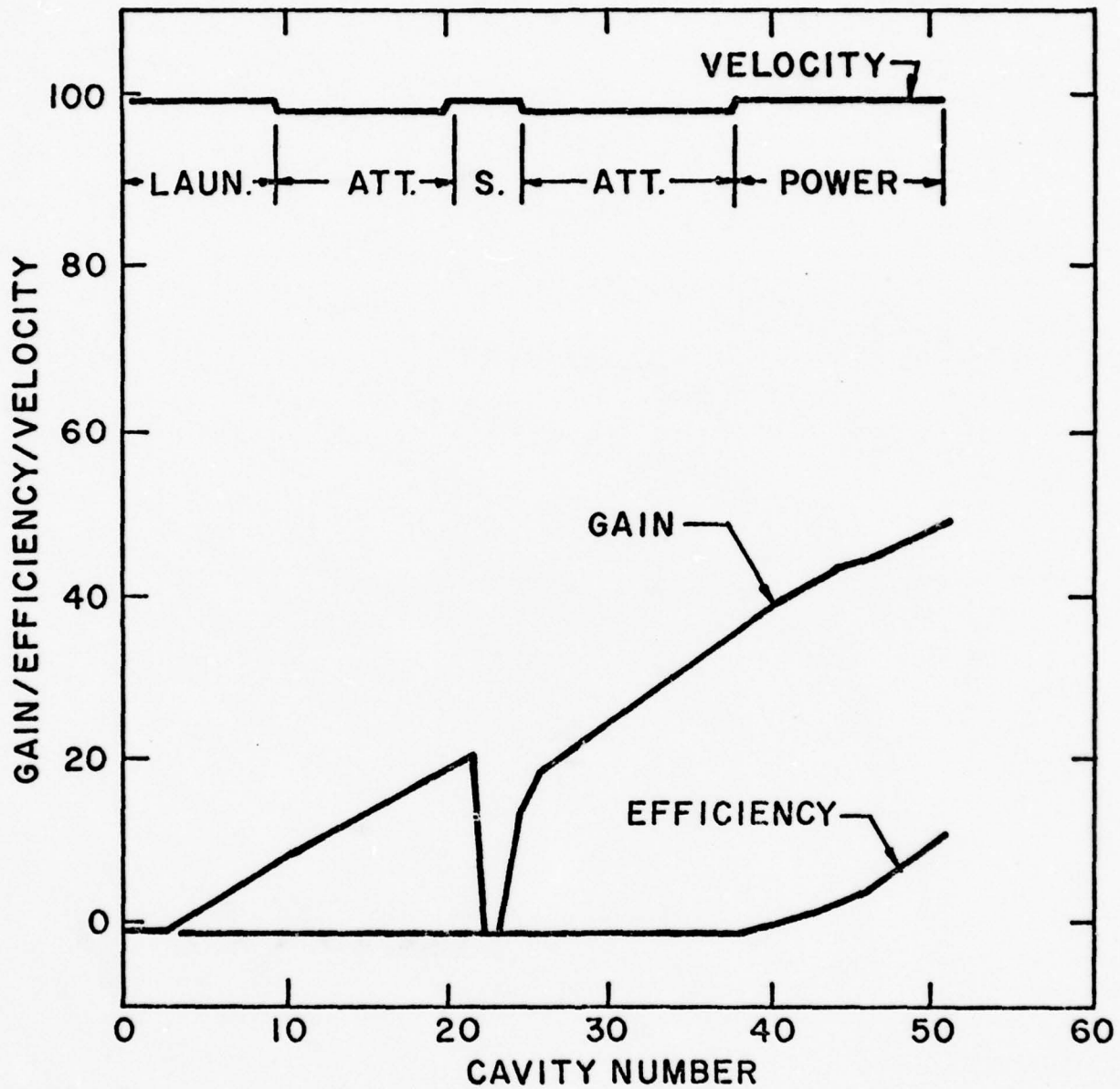
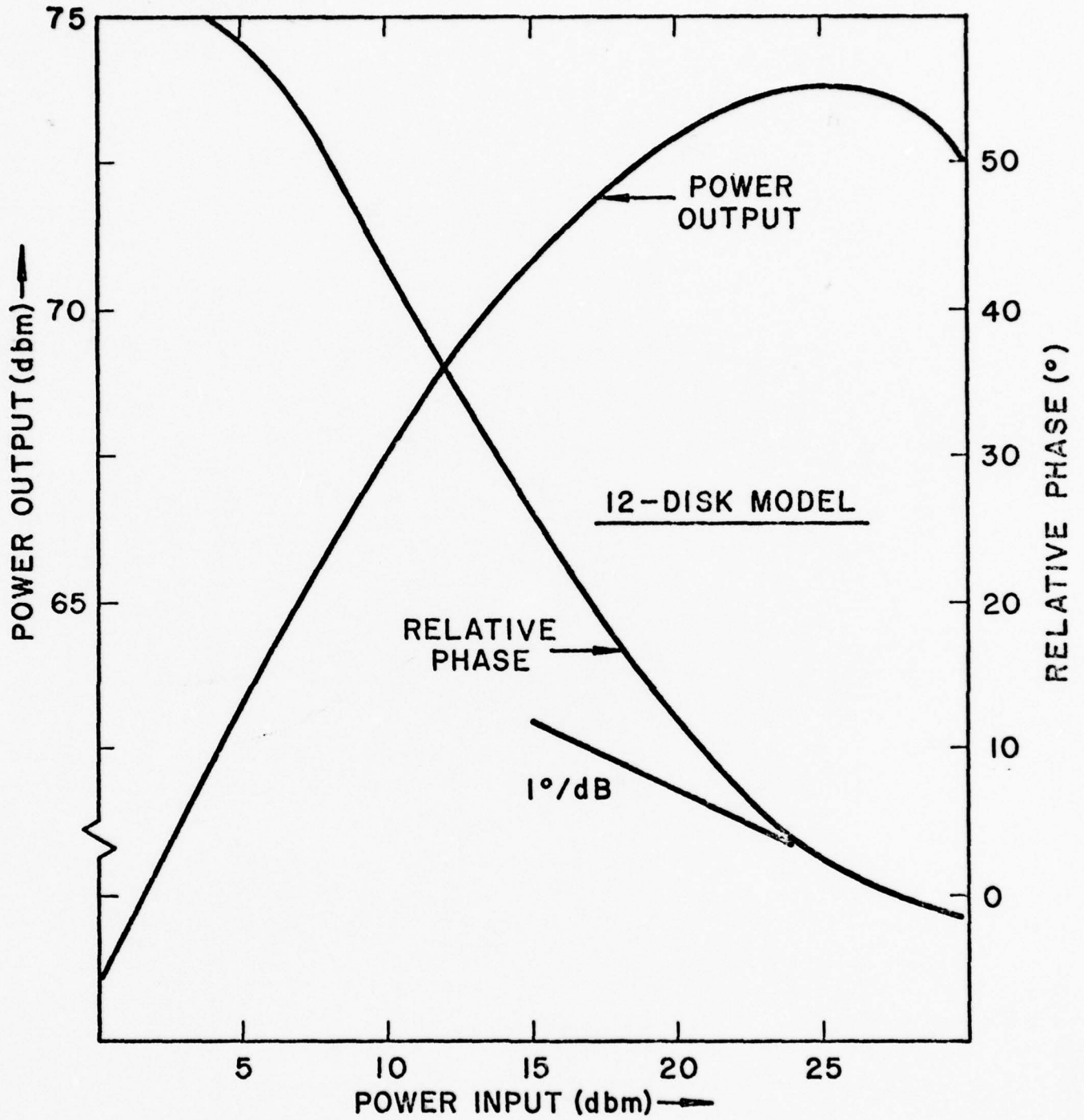


FIG.14 COMPUTER RUN AT 9 GHz



POWER OUTPUT VS. POWER INPUT
 RELATIVE PHASE VS. POWER INPUT
 (MIDBAND)

FIG. 15

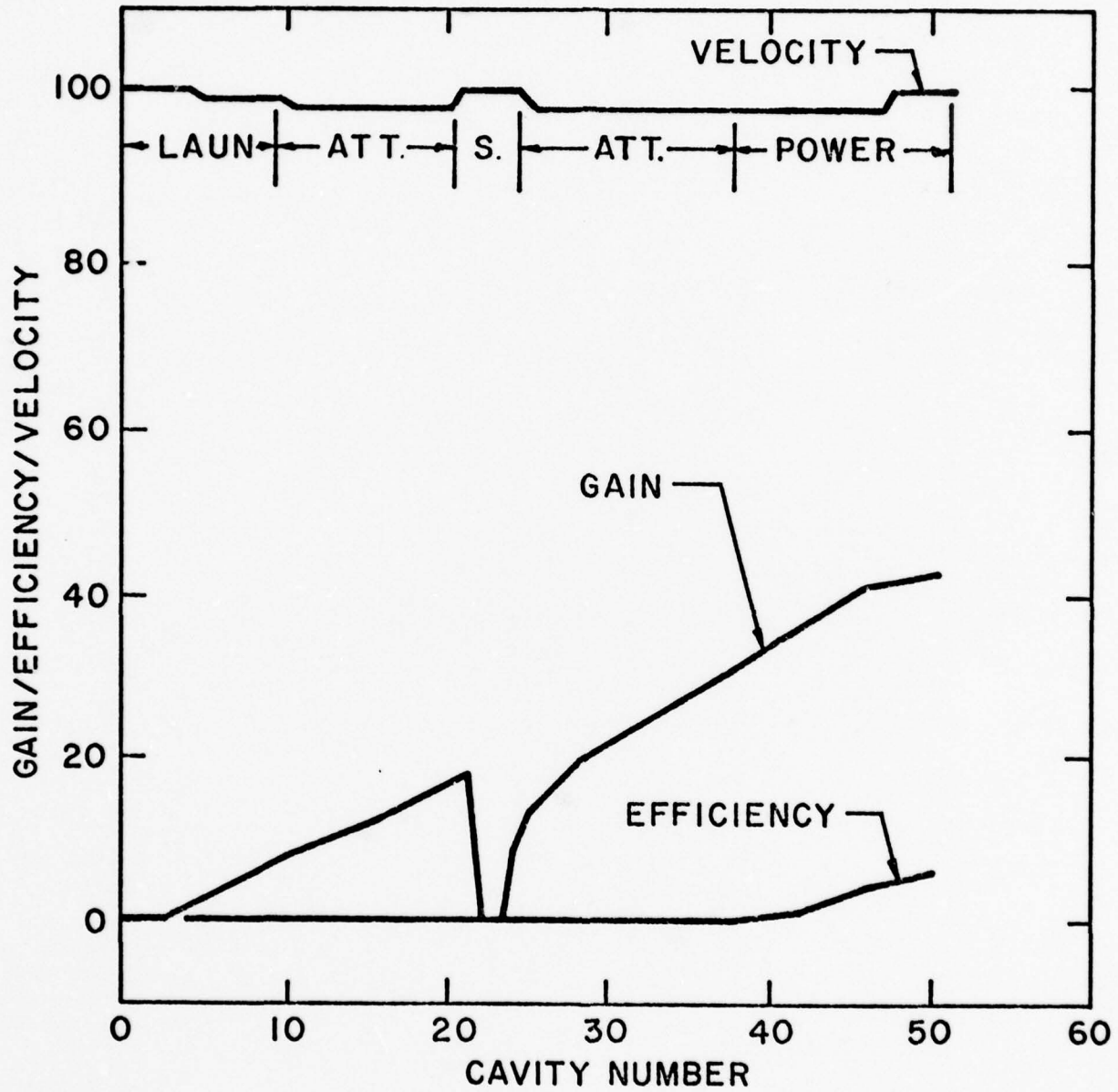
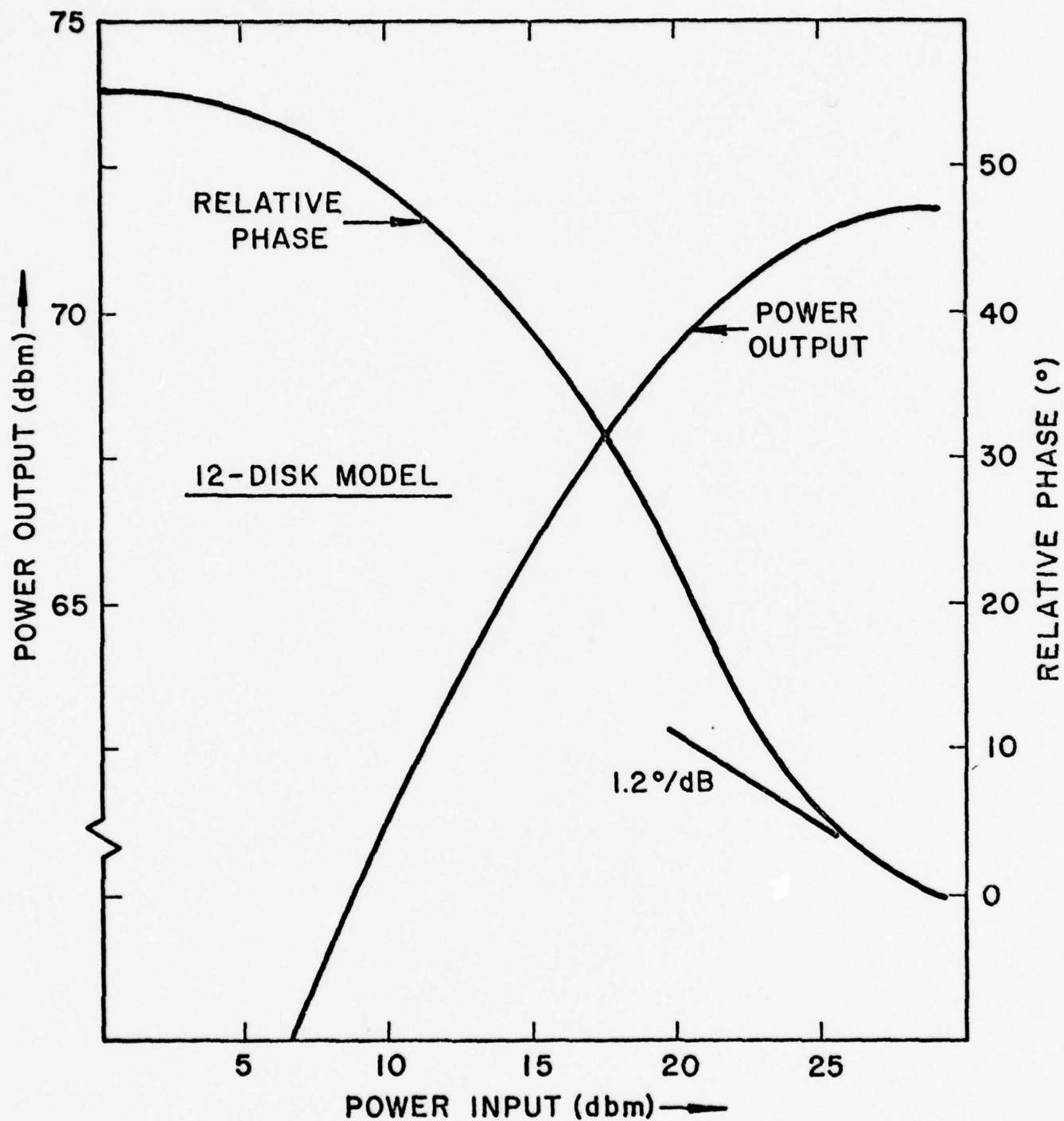


FIG.16 COMPUTER RUN AT 10.5GHz

enough. The calculated output power is 16 kW and the gain is about 41 dB. The AM-PM characteristics are shown in Figure 17. At saturation the calculated AM-PM is about $1.2^{\circ}/\text{dB}$.



POWER OUTPUT VS. POWER INPUT
 RELATIVE PHASE VS. POWER INPUT
 (UPPER BANDEDGE)

FIG. 17

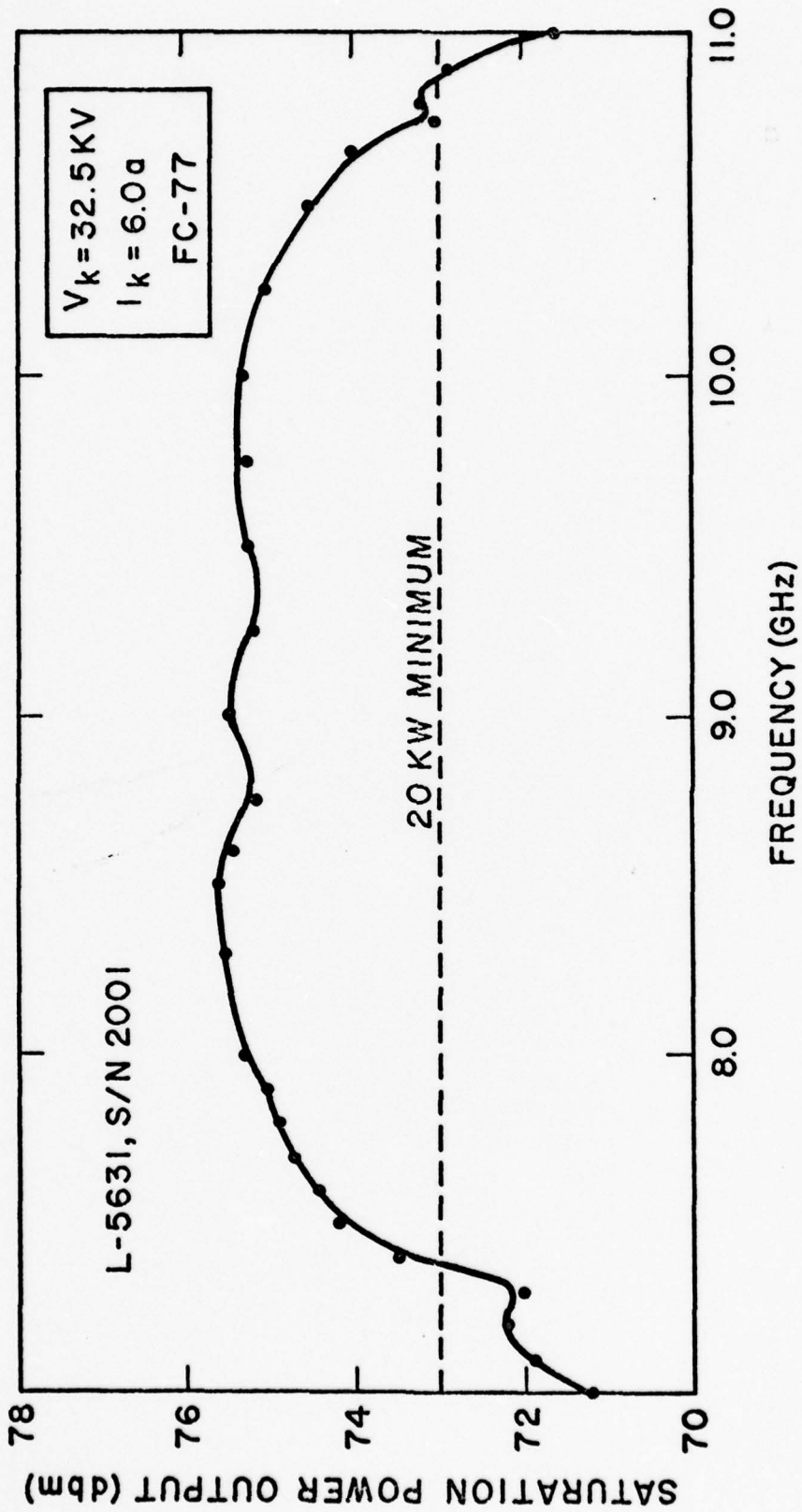
5.0 TEST RESULTS FOR S/N 2001

S/N 2001 was focused without RF at .1% duty factor. The initial transmission w/o RF was 92%. Figure 18 shows the RF performance at 32.5 kV, 6A with FC-77 in all the loss lines. The peak output power is greater than 20 kW from 7.4 GHz to 10.85 GHz. From 7.0 GHz to 11.0 GHz the peak output power was greater than 13 kW.

Figure 19 shows the small signal gain variation from 7.0 to 11.0 GHz at 31.5 kV, 32.5 kV and 33.5 kV. At 31.5 kV the gain variation is about 24 dB. At 32.5 kV corresponding to the data in Figure 18 the gain variation is about 35 dB. Note also that at 11 GHz the small signal gain is about 45 dB at 31.5; it is 35 dB at 32.5; and 25 at 33.5 kV. The sensitivity of the tube at 11 GHz is due to the high value of QC and the loss profile in the neighborhood of 11 GHz. Figure 20 shows the output power at 33.5 kV. Note the power falls off rapidly beyond 10.0 GHz.

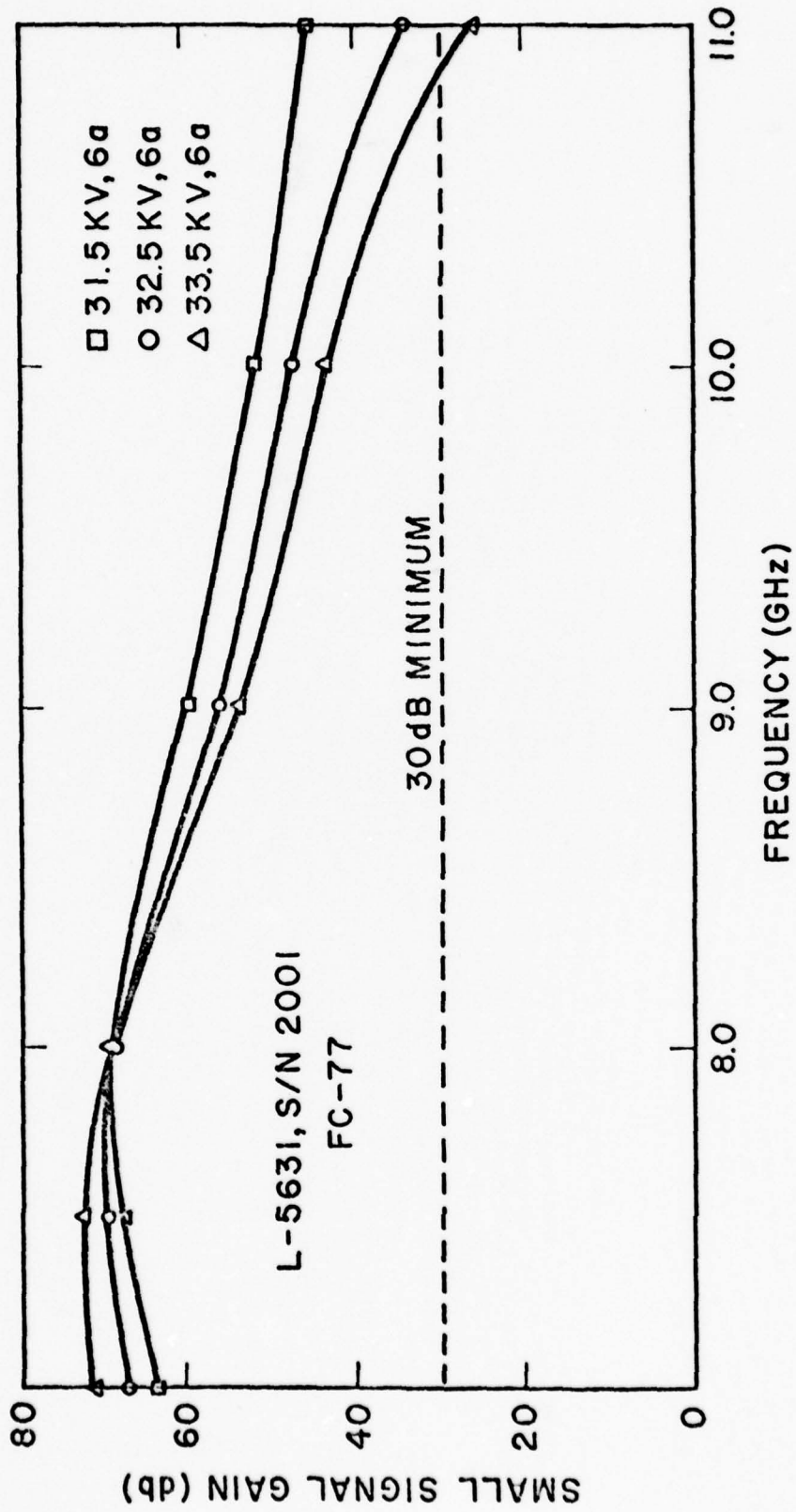
Raising the cathode voltage and current has the results shown in Figure 21. At 33.5 kV and 7A the tube meets the minimum power specification at the bandedges. The peak power is in excess of 40 kW over most of the band. The transmission for these conditions is about 92.0% without RF. Figure 22 shows the corresponding gain variation over the band is about 40 dB. Note that the minimum small signal gain is 42 dB.

The tube showed no in-band oscillations even at 8A where the small signal gain was clearly in excess of 80 dB.



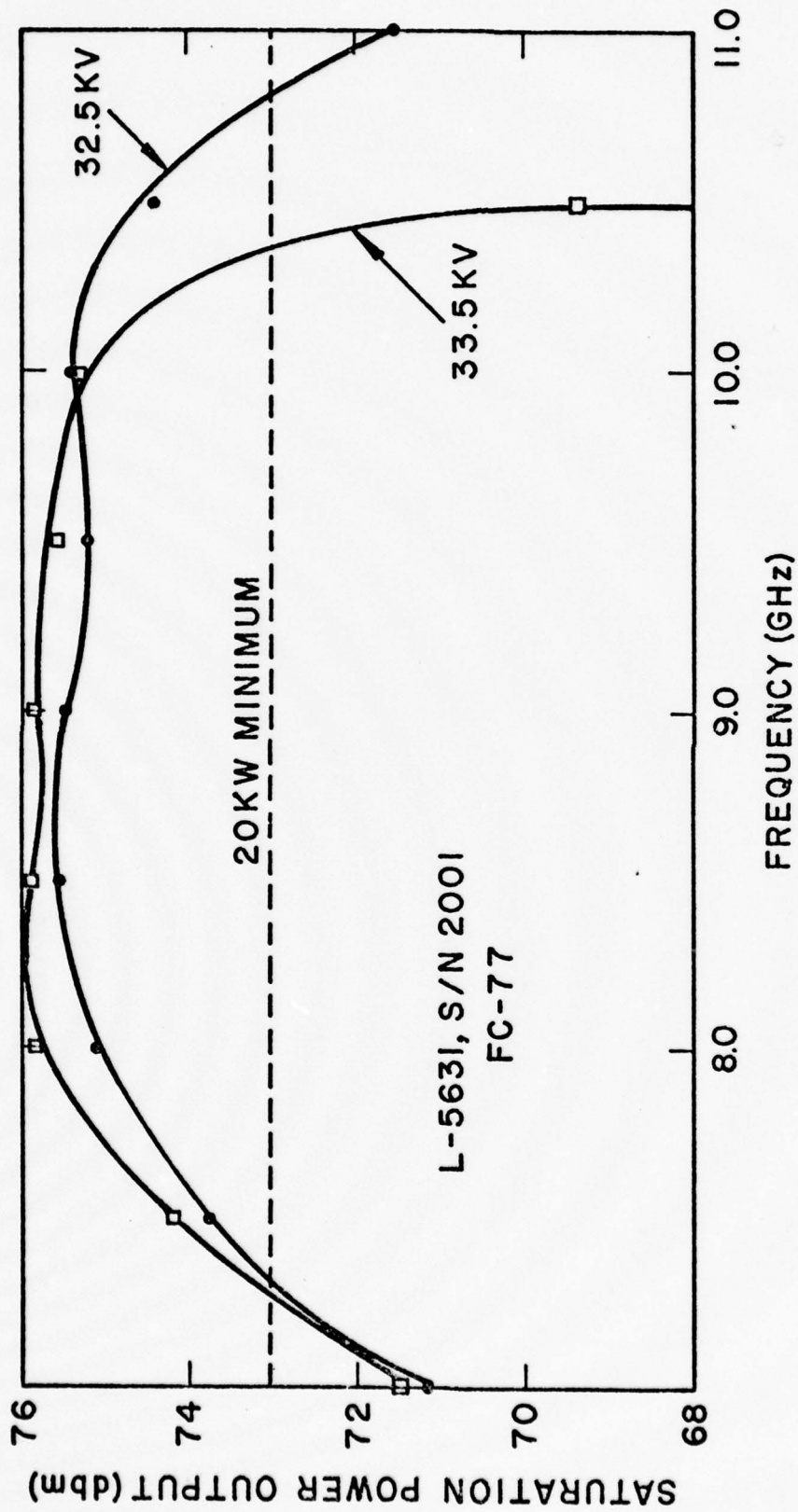
SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 18



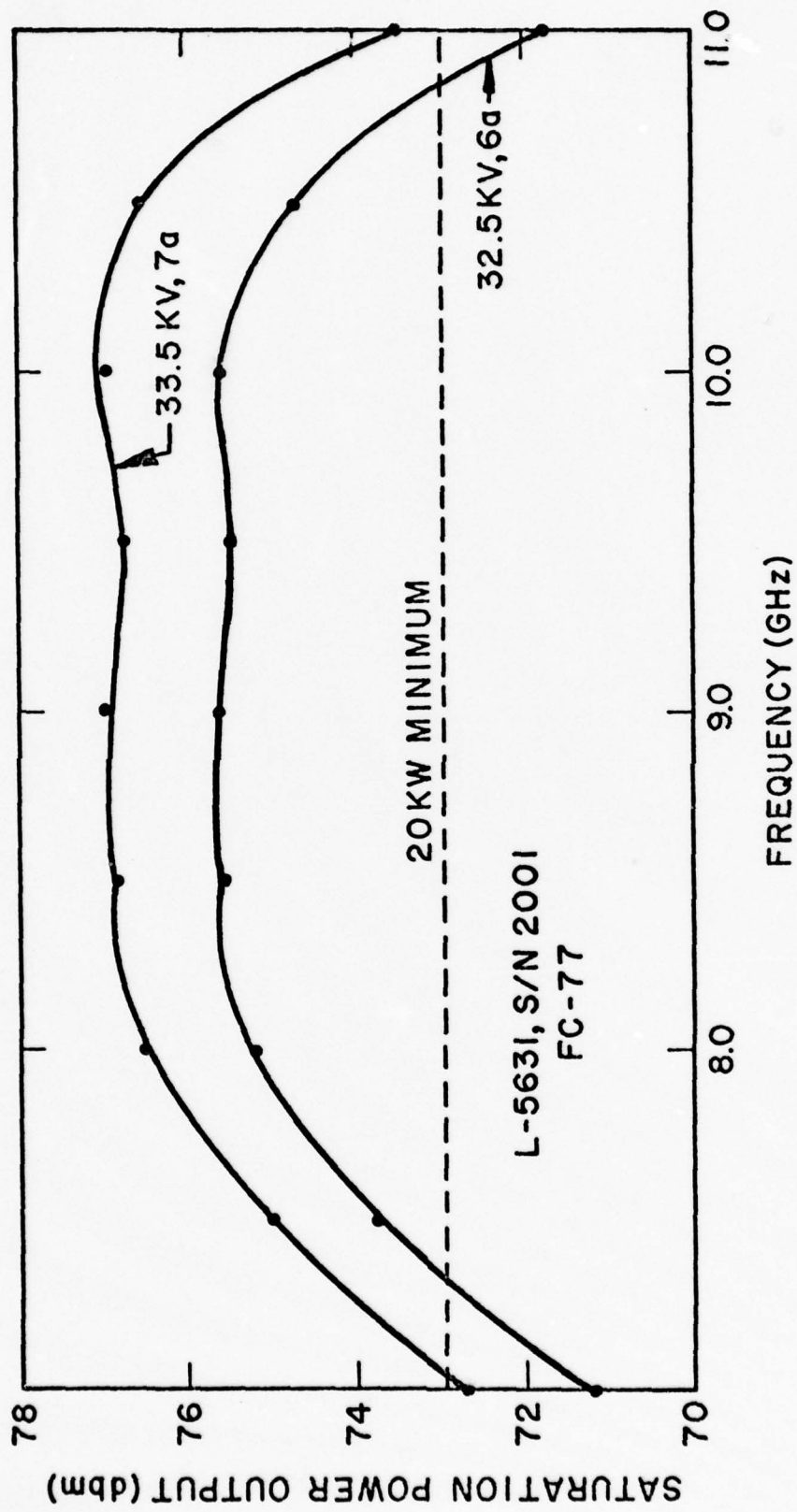
SMALL SIGNAL GAIN VS. FREQUENCY

FIG. 19



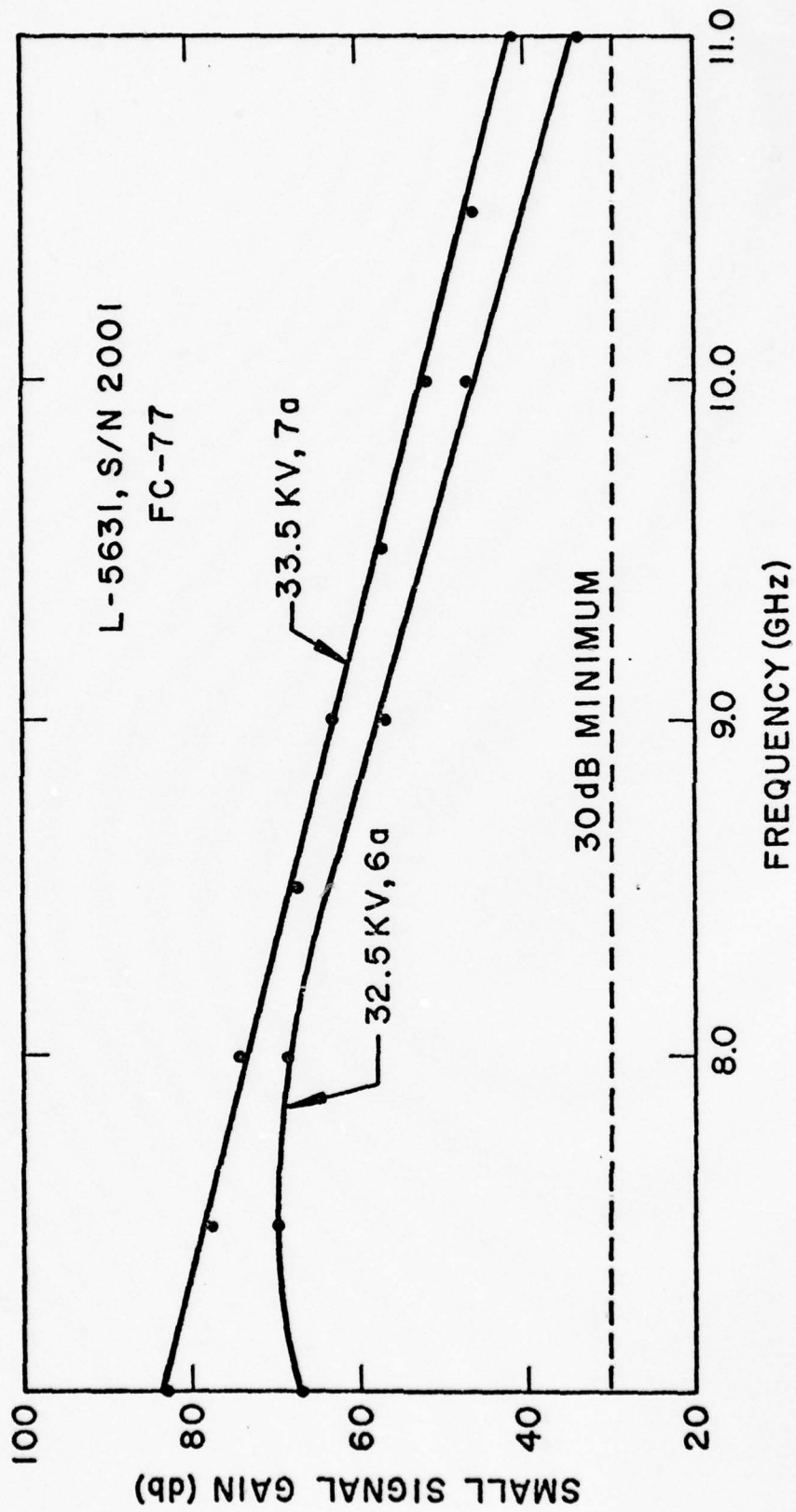
SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 20



SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 21



SMALL SIGNAL GAIN VS. FREQUENCY

FIG. 22

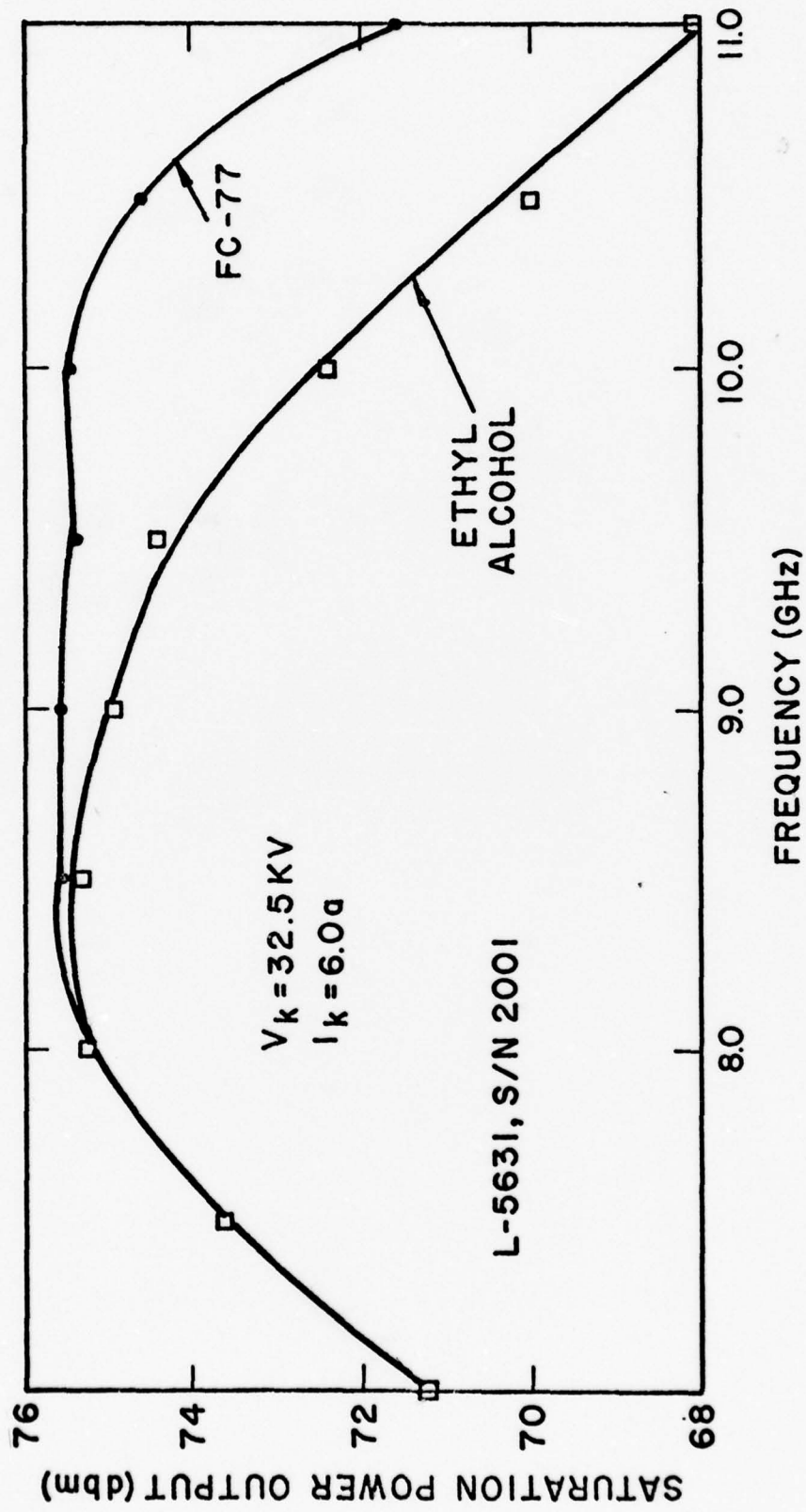
The cathode voltage could not be reduced much beyond 32.5 kV with FC-77 in the loss lines without encountering drive induced oscillations. The tube, however, was quite stable without drive down to about 31 kV at 6.0A.

In order to operate the tube at cathode voltages less than 32.5 kV different fluids were used in the loss lines. The results with ethyl alcohol are shown in Figure 23. The tube was quite stable with drive at lower cathode voltages but the performance was poor due to the high loss tangent of ethyl alcohol. Comparison with the performance of FC-77 at 32.5 kV, 6A shows that increased loss extended well into the operating band.

A suitable coolant having a low loss tangent and a slightly higher dielectric constant than FC-77 is DC-200. This fluid is currently used in Litton carcinotrons. Figure 24 shows data with DC-200 compared to FC-77. Notice that the power is lower at 11.0. Approximately 150 MHz of band has been lost for the same power output; that is, at 10.85 GHz the same power output is obtained as with FC-77 at 11.0 GHz. The tube with DC-200 is completely free of drive induced oscillations for cathode voltages as low as 31 kV.

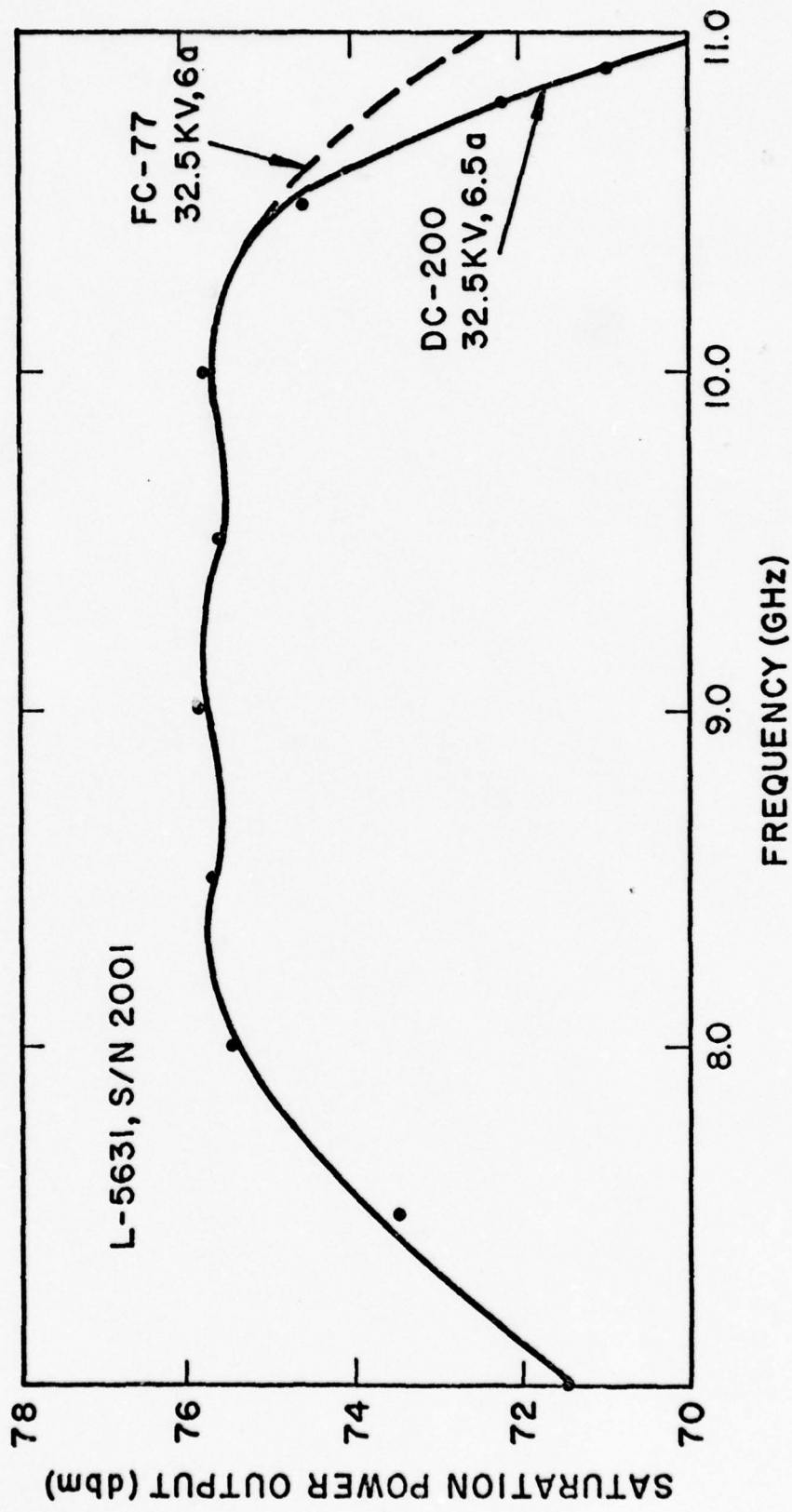
Figure 25 shows the power data for 31.5 kV, 6A. The power is lower across the band and particularly at 7.0 GHz where it is about 1 dB lower. At 11 GHz the power is nearly the same as shown in Figure 24 so that the saturated power has a more symmetric shape.

The cathode voltage was set at 31.5 kV, 6.5A and AM-PM data was taken across the band. This data is shown in Figure 26. The tube was set up at saturation and the



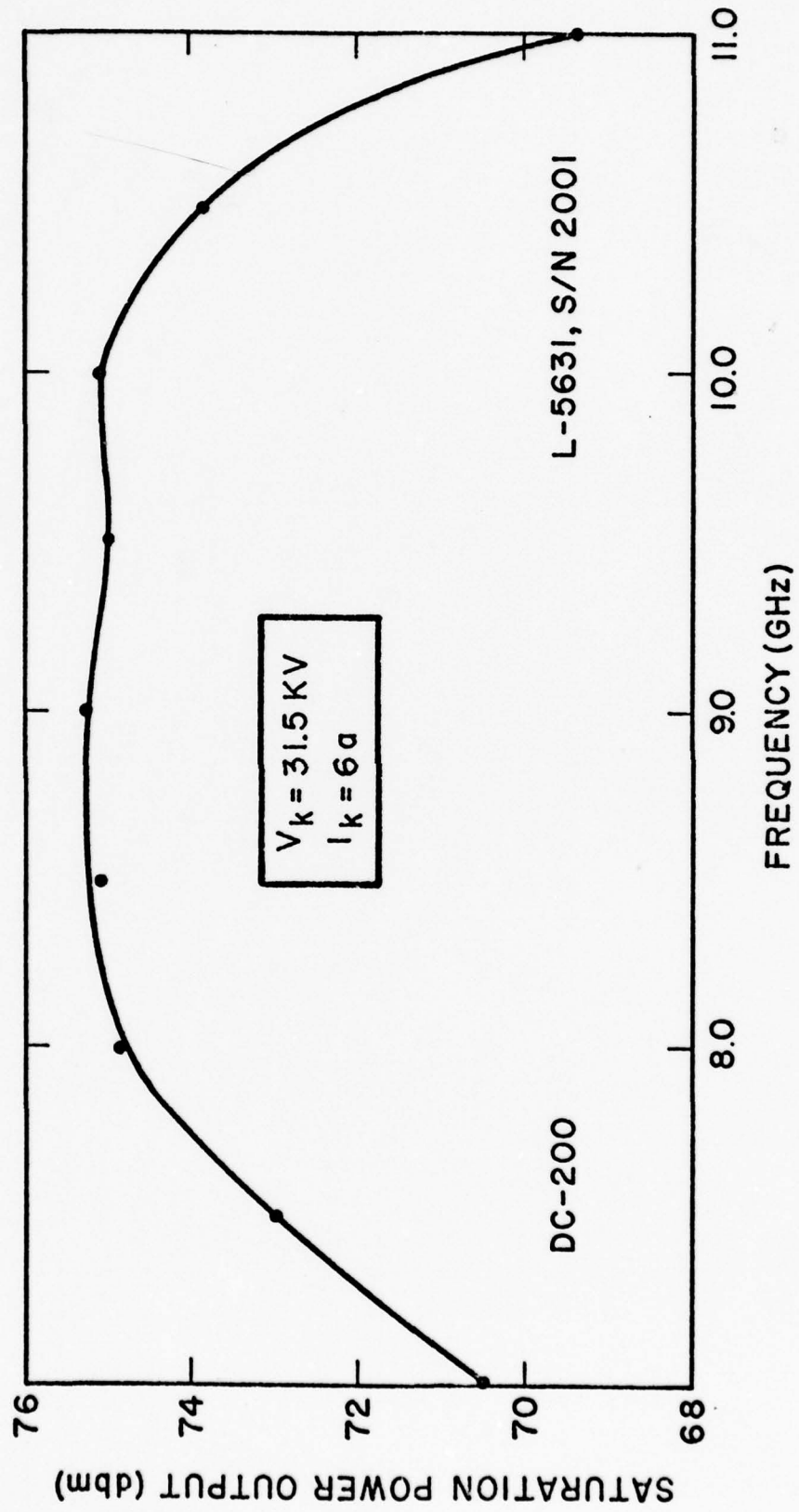
SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 23



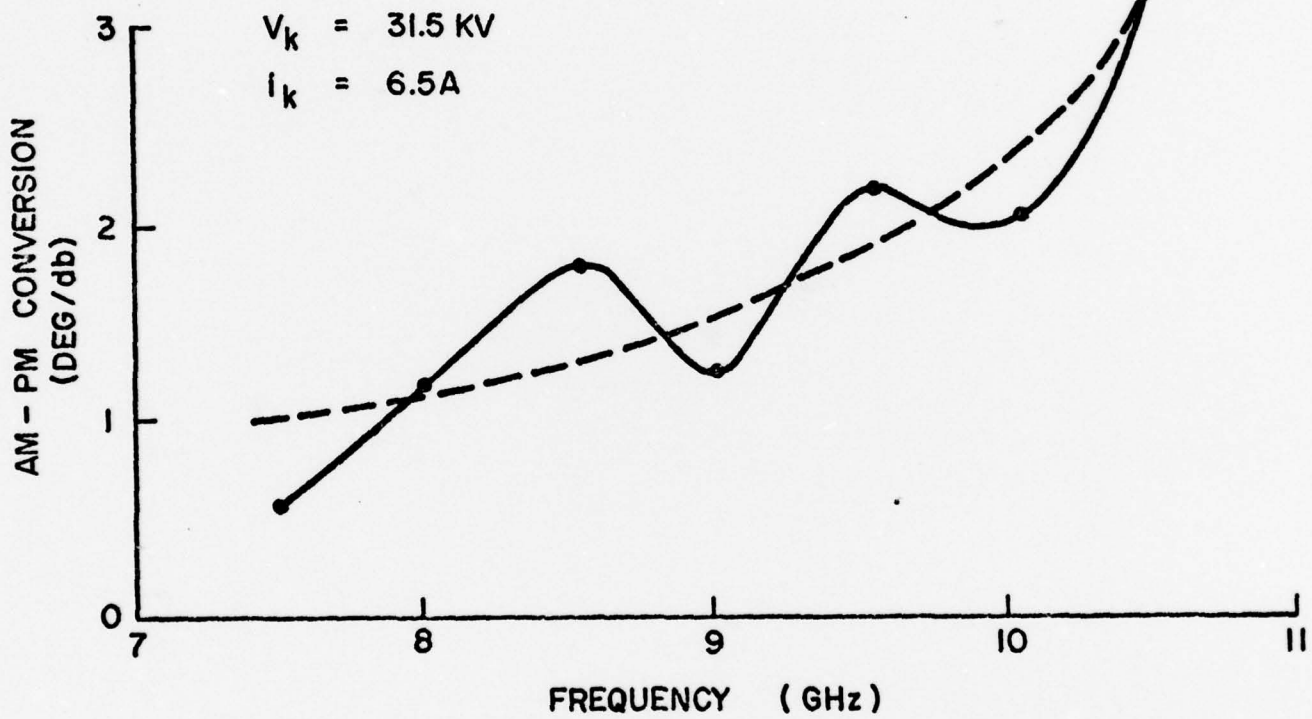
SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 24



SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 25



AVERAGE AM-PM OVER
0 TO -10db DYNAMIC
RANGE.

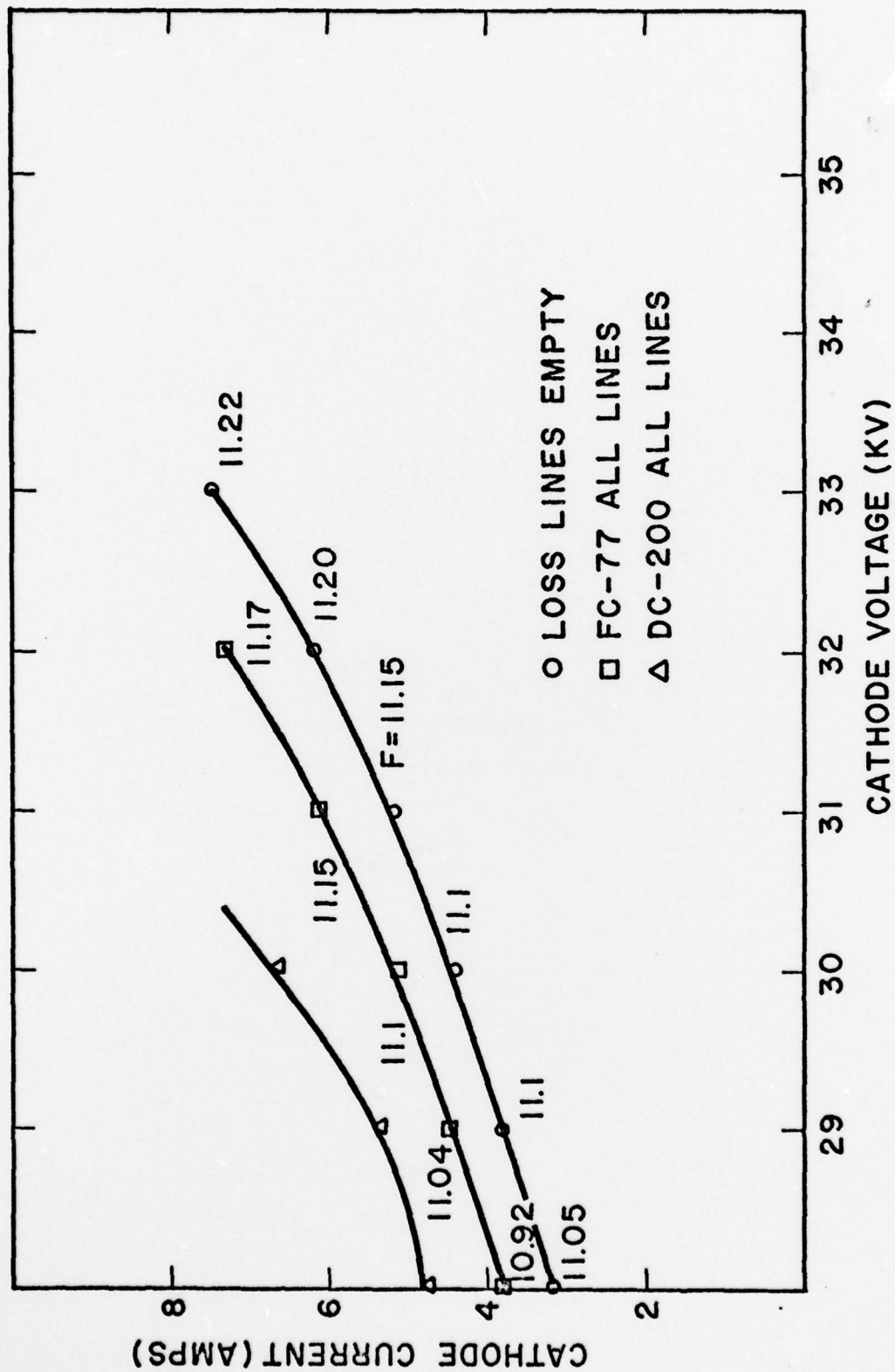
FIG. 26

drive power was reduced 10 dB. The total phase deviation over the range was divided by 10 to obtain an average AM-PM number. In the frequency region from 10.0 to 11.0 the phase deviation was large enough to make more refined measurements. The high value of AM-PM at 11.0 GHz is due to several factors:

1. The increased dielectric loading at 11.0 causes the velocity of the circuit to be lower so that the circuit is strongly overvoltaged at this frequency.
2. The impedance of the circuit is lowered considerably, thus the gain is low, the output section is too short causing sever effects.
3. The loss per unit length is increased particularly in the power section which is detrimental to AM-PM conversion.

Start oscillation data was taken for the tube and is shown in Figure 27. Oscillations occurred primarily in the input section. This was due in part to the higher current in the section, but mostly due to the poor rolloff at the high end of the band. With air in the loss lines the start oscillation current was minimum. The oscillation frequency varied from about 11.05 to 11.22. With FC-77 the oscillations had a higher threshold. With DC-200 no oscillations were observed above 30 kV. The only output section oscillation occurred near 11.0 GHz when drive was applied to the tube at particular voltage and current levels which maximized the gain at about 11.0 GHz.

The tube was final focused with DC-200 at 32.5 kV and 6.5A for full duty operation. Transmission without RF was 95%. The tube was run at 2% duty factor. There were no significant changes in the tube at 2% duty. There was a gradual .2 dB change in the power at 11.0 GHz from the snap on power value after about 20 seconds. At 1% duty about .1 dB change was seen.

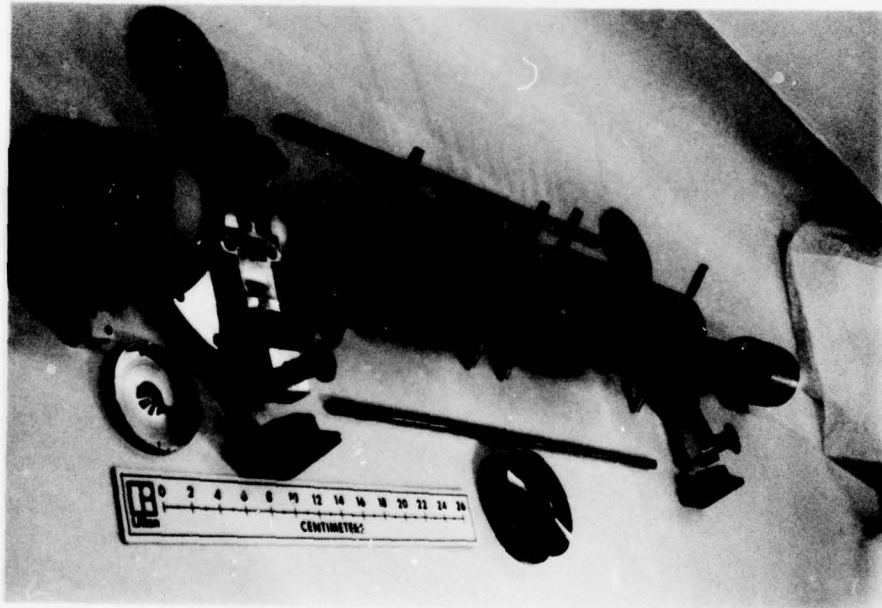


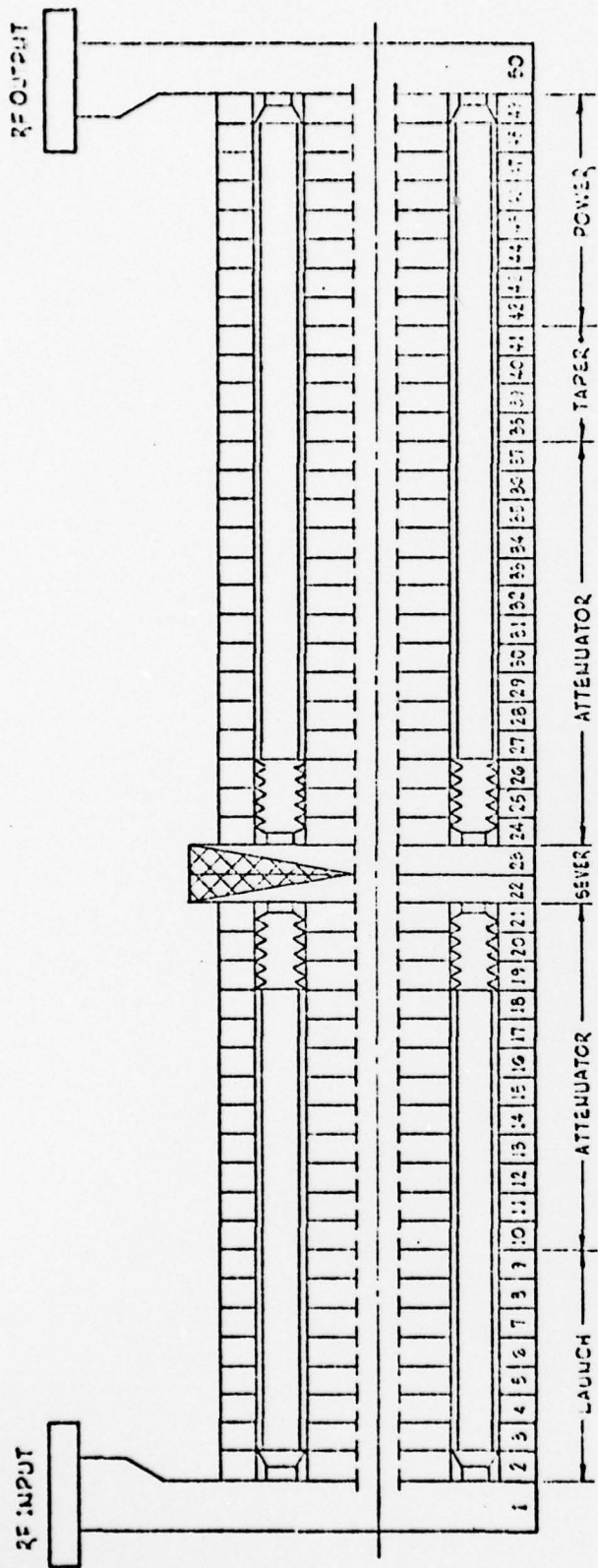
START OSCILLATION DATA (INPUT SECTION)
L-5631 S/N 2001

FIG. 27

6.0 DESIGN FOR S/N 2002

S/N 2002 was built like S/N 2001. With the exception of the loss-line sleeves all other tube parts were the same. Figure 28 shows the cavity and loss distribution chart for S/N 2002 design. The input section consisted of 20 cavities and the output section of 26 cavities. This is the same cavity distribution used in S/N 2001. The output section was composed of three subsections also as S/N 2001 with approximately the same average cavity loading. The bellows in the 2002 design has been placed at the termination end of the section. This allowed 2 more cavities at the output end to be loaded with upper cutoff loss. There were four completely unloaded cavities in S/N 2001 at the output end whereas in S/N 2002 there were only 2. This change was made to eliminate the drive induced oscillations seen in S/N 2001. This was accomplished as demonstrated in the testing of the tube (Section 7.0).





2 SYMMETRICAL (REF = 4/GdS) LOSS LINE A

UN.LD.	I/CAVITY (CENTERED)	I/CAV	W/CAV	H/CAV	DEPT	SLOT
SHT.	.260	.260	.260	.220	.200	OT-
SLVS.	.125	.125	.125	.125	.125	HEIGHT

2 SYMMETRICAL (REF = 4/GdS) LOSS LINE A

SLOT	I/CAV	H/CAV	I/CAVITY (CENTERED)	UN.LD.
WIDTH	.220	.260	.260	SHT.
HEIGHT	.125	.125	.125	SLVS.

2 SYMMETRICAL (REF = 6/BdB) LOSS LINE B

UN.LD.	HEAVY ATTENUATOR	LIGHT	UN-LOADED	SLOT
SHT.	CONTINUOUS	CONT.	SHORTED	WIDTH
SLVS.	.125	.125	SLEEVES	HEIGHT

2 SYMMETRICAL (REF = 6/BdB) LOSS LINE B

SLOT	UN-LOADED	HEAVY ATTENUATOR	UN.LD.
WIDTH	SHORTED	CONTINUOUS	SHT.
HEIGHT	SLEEVES	.125	SLVS.

FIG. 28 LOSS LINE AND SLEEVE DISTRIBUTION S/N 2002

7.0 S/N 2002 TEST RESULTS

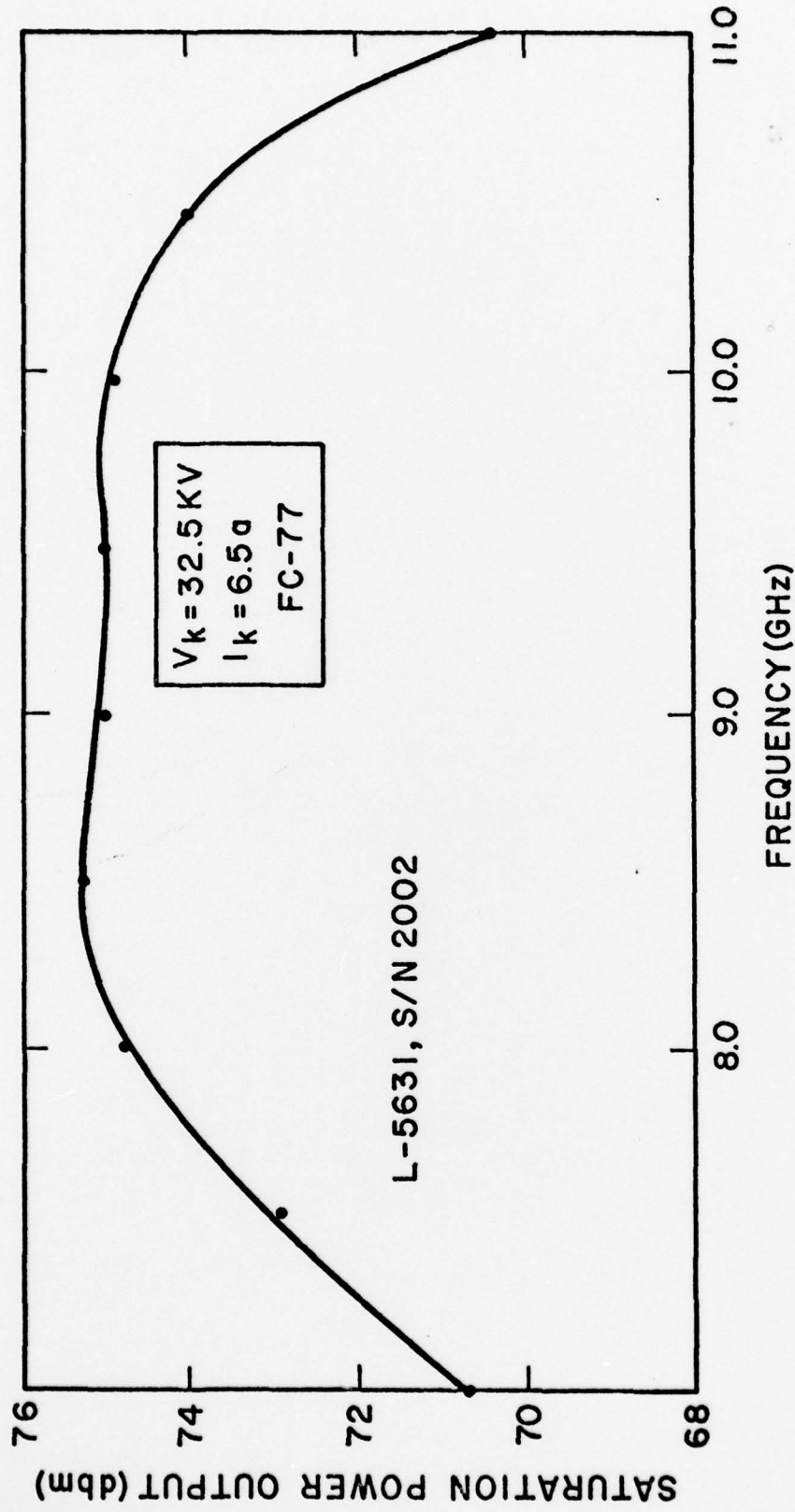
S/N 2002 was focused without RF at .1% duty factor. The transmission was 94% at 32.5 kV, 6.5A. Figure 29 shows the RF performance with FC-77 in the output loss lines. This saturated power performance is very similar to S/N 2001 as would be expected since the two tubes are of very similar design. This tube, S/N 2002, is however stable with FC-77 and shows no drive induced instabilities. (See Section 6.0)

The output power is greater than 20 kW from 7.5 to 10.7 GHz with a midband efficiency of greater than 15% with no collector depression. The bandedge power at 7.0 GHz and 11 GHz is greater than 10 kW.

Figure 30 shows the large signal gain versus frequency corresponding to the saturated output power in Figure 29. The gain maximum of 70 dB occurs at 8.0 GHz. The minimum is 36 dB at 11 GHz.

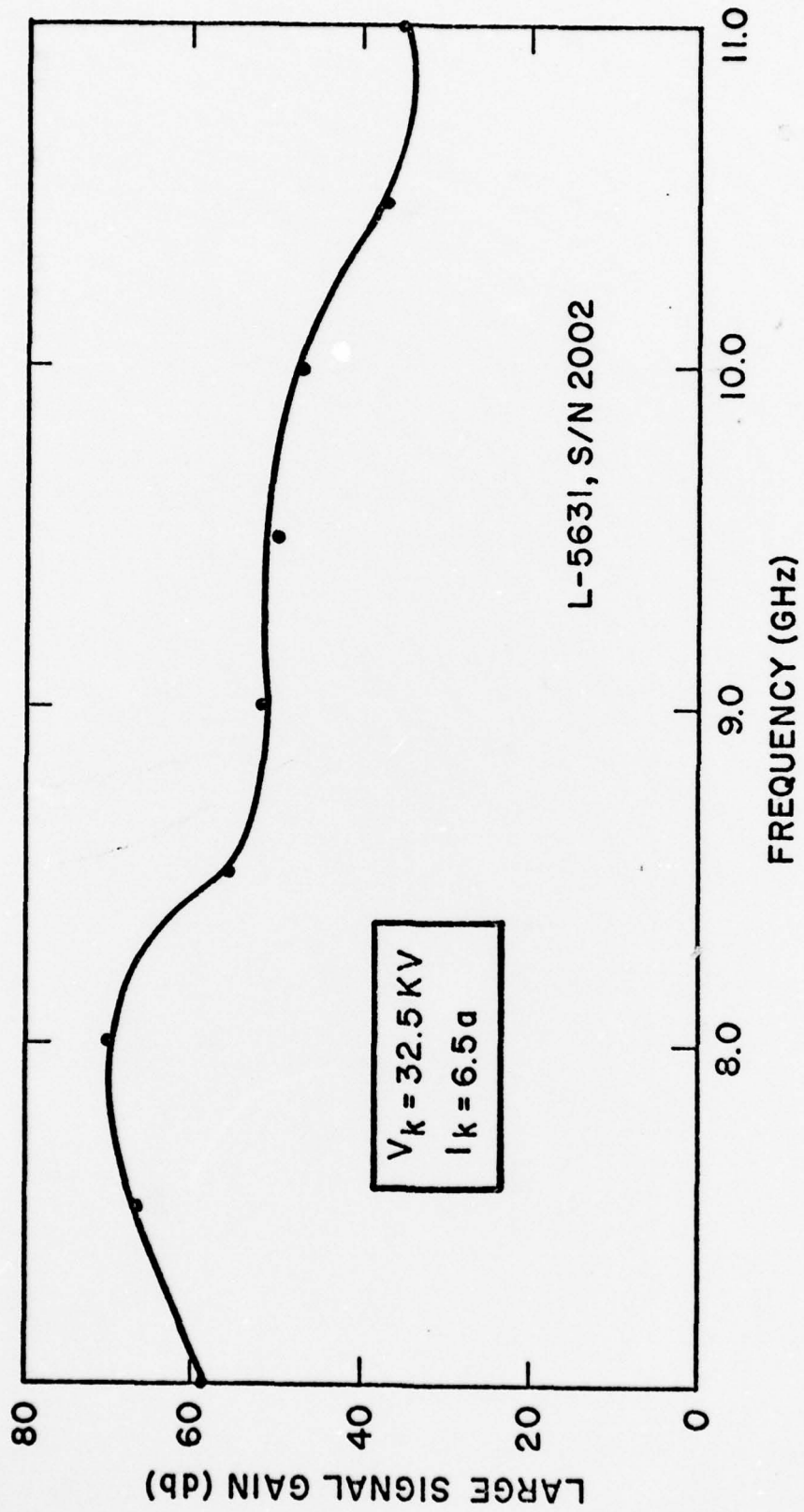
Figure 31 shows the start oscillation data for this tube. This input section is very stable. This section can be undervoltaged down to 29.5 kV at 6.4A without oscillation. In the unstable zone, the oscillation occurs around a little dip in the insertion loss. This dip can be eliminated by increasing the reference loss slightly in the loss lines, but is not a serious problem as the data shows.

The output section stability is not as good. This is because the output section is longer than the input and the rolloff is not as sharp. It is, however, sufficiently good for a stable tube at 6.5A and 31 kV.



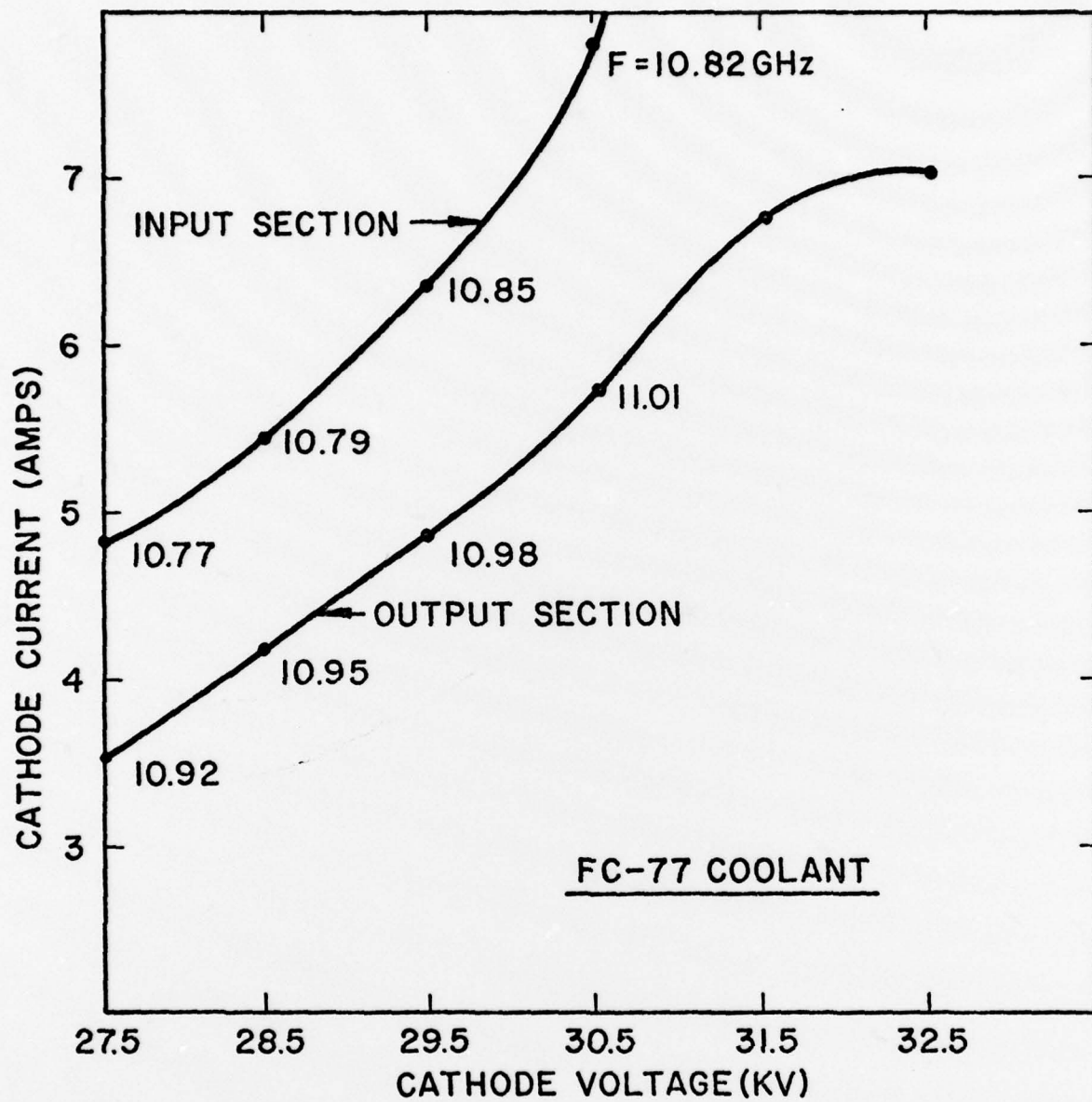
SATURATION POWER OUTPUT VS. FREQUENCY

FIG. 29



LARGE SIGNAL GAIN VS. FREQUENCY

FIG. 30



START OSCILLATION DATA
L-5631 S/N 2002

FIG. 31

8.0 CONCLUSIONS

Two wideband low AM-PM loss-line stabilized coupled cavity TWTs were built and demonstrated.

Both tubes were oscillation stable beyond the design current level.

The two tubes were of similar design and had similar electrical and RF performance.

The beam transmission characteristics were excellent, particularly for wideband tubes. Ninety-five percent transmission was measured without RF, 90% with RF.

The RF performance characteristics of these tubes are superior to current production loss button stabilized tubes. The RF efficiency is higher, particularly over the high frequency portion of the band. This is because the output sections of the loss line tubes are long enough to provide sufficient small signal gain between the circuit sever and the output cavity for good efficiency. For the same reason the AM-PM conversion for these tubes is better than the conventional loss button tubes. The gain variation across the frequency band is lower because of the high loss introduced at the low end of the band by the frequency selection attenuator sections. The RF duty factor is inherently higher because the loss lines are fluid cooled; (the RF power absorbed by the stabilization loss is a limiting duty factor for wideband tubes). The improved duty capability of the loss lines could not be demonstrated because the beam interception on the circuit was the duty limiting factor for these tubes. (The limiting duty factor of the loss lines could best be demonstrated in a solenoid version of this tube.)

Table II shows a comparison of the performance characteristics for these tubes with the design objective.

The peak power specification was demonstrated over most of the band (7.35 GHz - 10.75 GHz). Ten (10) kW minimum was demonstrated at the bandedges, 7.0 GHz and 11.0 GHz. The output power over 70% of the band was flat within $\pm .5$ dB.

The bandwidth and saturated gain exceeded the specifications.

The AM-PM distortion objective specification of $.5^\circ/\text{dB}$ was not met. An average AM-PM of $1^\circ/\text{dB} - 2^\circ/\text{dB}$ from 7 - 10 GHz was measured in the drive power region from saturation to saturation minus 10 dB. The AM-PM conversion is less for drive power greater than saturation and is higher for frequencies above 10 GHz.

The efficiency specifications of 15% was met from 8.0 - 10.0 GHz and was 7% minimum at 7.0 and 11.0 GHz.

The stability of the tubes is adequate for operation in the maximum bandwidth mode. The tubes can be undervoltaged slightly (5%). At least 10% overvoltage is possible. No regenerative oscillations were measured at any voltage. The current stability is better than 6.5 amperes.

S/N 2001 was operated at high duty factor to evaluate the average power capability of the loss lines. At 2% duty factor there was less than .2 dB change in output power fade at 11 GHz.

TABLE II
PERFORMANCE CHARACTERISTICS

Performance Parameter	Objective	Achieved	
		S/N 2001	S/N 2002
Peak Power	20 kW Min.	20 kW Min. (7.35 - 10.75 GHz) 10 kW Min. (7.0 and 11.0 GHz)	20 kW Min. (7.5 - 10.7 GHz) 10 kW Min. (7.0 and 11.0 GHz)
Bandwidth	40%	44%	44%
Frequency	X-Band	7 - 11 GHz	7 - 11 GHz
Saturated Gain	30 dB Min.	33 dB Min.	36 dB Min.
AM-PM Distortion (\pm 10 dB at Sat.)	.5 $^{\circ}$ /dB	1 $^{\circ}$ /dB-2 $^{\circ}$ /dB Avg. (10dB underdrive) 7 - 10 GHz	-
Efficiency	15% Min.	17% Midband, 7% Min. (Bandedges)	15% Midband, 7% Min. (Bandedges)
Oscillation	\pm 5% beam voltage	+ 10% - 5%	+ 10% - 5%
Stability	+ 5% beam current	+ 33%	+ 7%
Duty	.01	.02	-

9.0 RECOMMENDATIONS FOR FUTURE WORK

Further development of loss line tubes should include:

1. Improved design of the in-band attenuators.
 - a) Provide higher attenuator loss for more gain equalization.
 - b) Develop more rigidly controlled reference loss distributions.
 - c) Develop more sophisticated taper sections to improve the match of the attenuators to the unloaded sections of line.
2. Develop solenoid version to test limits of loss lines. Presently 2% duty limitation is a focusing limitation. The thermal limitation of the loss lines have not yet been established.
3. Qualification testing -- Tubes should be qualification tested to determine the suitability of the present mechanical design. Shock and vibration testing is essential to insure that the present mechanical configuration of the loss lines is adequate.

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