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EXPERIMENTAL PERFORMANCE OF A SMALL SIZE TWO STAGE DEPRESSED COLLECTOR FOR A 4.8-9.6 GHz HIGH PERFORMANCE TWT

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16. Abstract

Three simple small size two-stage depressed collectors were designed and experimentally evaluated in conjunction with a 330 to 520 watt CW, 4.8 to 9.6 GHz traveling wave tube (TWT). Each of the three designs produced a minimum collector efficiency of 80.0 percent considering saturated TWT operation at the maximum rf output power frequency and at band edges. The highest minimum collector efficiency produced was 80.5 percent with a two-stage depressed collector of 4.8 cm diameter by 7 cm high internal dimensions.

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EXPERIMENTAL PERFORMANCE OF A SMALL SIZE TWO STAGE DEPRESSED

COLLECTOR FOR A 4.8-9.6 GHz HIGH PERFORMANCE TWT

by P. Ramins and T. Fox

Lewis Research Center

E-8920

SUMMARY

In a joint USAF-NASA program, Lewis Research Center is carrying out an efficiency improvement program on traveling wave tubes for use in electronic countermeasure systems by applying multistage depressed collector (MDC) and spent beam refocusing techniques developed at Lewis.

Previous analytic work and experimental MDC optimization in conjunction with a 330 to 520 W, 4.8 to 9.6 GHz bandwidth TWT led to a demonstrated two stage MDC efficiency of 82 percent at the maximum rf output power point (ref. 1). However, the MDC geometric design was rather complex, consisting of multiple collecting elements at the two depressed potentials between ground and cathode potentials.

An attempt has been made to simplify the MDC design considerably without significant loss in MDC efficiency. Each of the designs tested produced a minimum MDC efficiency of 80 percent considering the maximum power output point (near mid-band) and the band edges. The highest minimum efficiency obtained was 80.5 percent with a two stage MDC of 4.78 cm (1.88 in.) diameter by 7.0 cm (2.75 in.) high internal dimensions. The geometric design of this MDC is very simple and should be readily adaptable to practical TWT's used in ECM systems.

INTRODUCTION

In a joint USAF-NASA program, Lewis Research Center is carrying out an efficiency improvement program on traveling wave tubes (TWT's) for use in electronic countermeasure (ECM) systems by applying multistage depressed collector (MDC) and spent beam refocusing techniques developed at Lewis.

Previous analytic work (ref. 1) involving TWT performance analysis, refocusing system analysis, and MDC analysis led to specific refocusing system and MDC designs for a 700 W (total rf power conversion), 4.8 to 9.6 GHz TWT, and predicted a two-stage MDC efficiency of 82 percent and a four-stage MDC efficiency of 85 percent.

An experimental program was conducted to evaluate and optimize the TWT/Refocusing System/MDC performance (ref. 1). This led to demonstrated

STAR category 33

MDC efficiencies of 82 and 84 percent for a two- and four-stage MDC, respectively. These results were obtained with a single rather complex MDC geometric design consisting of six collecting elements (electrodes), shown in figure 1. These include electrodes at ground and cathode potentials. The number of MDC stages is defined as the number of distinct voltages needed to operate the TWT/MDC other than ground and cathode potentials. In the four-stage configuration, the four intermediate collecting elements were operated at four different voltages; in the two-stage configuration, they were electrically connected as two pairs.

In a continuation of the joint USAF-NASA program an experimental program was conducted to simplify the two-stage MDC geometric design very considerably without significant loss in MDC efficiency. The results of this program are reported below.

EXPERIMENTAL TWT

The Teledyne MEC TWT type No. M5897C as modified for use in this program and its performance characteristics are shown in figure 2. A refocusing system consisting of two coils has been added, and the TWT is mounted on a 10 inch ultra high vacuum (UHV) flange. The UHV valve shown (ref. 2) was designed to keep the TWT under vacuum during MDC installation and changes, facilitating startup and enabling many collector changes without cathode activation problems. However, the valve failed previous to these tests and the TWT had to be back-filled with gaseous nitrogen for MDC changes and subsequently rf processed under pulsed conditions.

Originally, the TWT had an undepressed collector mounted on a matching 10-inch UHV flange. An identical matching flange exists on the vacuum system used for subsequent tests.

TWT PERFORMANCE

The TWT exhibited very large rf losses, the effective circuit efficiency being less than 70 percent at some frequencies. Moreover, as reported in reference 1, at one point, the TWT performance was found to have changed slightly, leading to unacceptably high body power at some frequencies. Thereafter (and during this test program), the TWT was operated only at the band edges and at the maximum rf output power frequency, 8.4 GHz.

The large rf losses of this TWT over most of the frequency band reduce substantially the improvement obtainable in the overall efficiency by means of a depressed collector. At the low band edge the overall efficiency at the fundamental frequency is additionally limited by the large amount (up to 30 percent) of harmonic power generated.

MDC TESTS

During these tests, various MDC's are added to the TWT and the performance evaluated. The MDC test setup is shown in figure 3. The MDC is mounted directly on the UHV flange which houses the TWT/Vacuum Valve. Each MDC plate is thermally and electrically isolated and is water cooled. The spent beam power recovered by each MDC plate as well as the thermal power dissipated on each plate are measured. A vacuum feed through drives a variable length spike. Since the refocusing coils and pole pieces are external to the vacuum, they can be manipulated while the TWT is operating.

During an MDC test, the following are varied to optimize performance: individual collector stage voltages; refocusing coil currents; refocusing coil/polepiece locations; variable spike length. A novel data acquisition system is used to optimize MDC performance under various conditions (frequency, level of saturation, etc.). This system provides an analog real time readout of P (recovered) as any of the above are varied. Maximizing P (recovered) is identical to maximizing the true MDC efficiency. Data on all tests is obtained with an automated data acquisition system. A steady state is established and 100 scans are taken on all measurements and averaged to improve accuracy.

The power flow diagram for the TWT with an MDC is shown in figure 4. A part of the beam power appears as measured rf output power P(O), while a part is dissipated on the TWT body as the sum of rf losses in the TWT and intercepted beam power in the forward direction, P(BODY). The rest enters the MDC. A part of P(Coll in) is recovered as electric power while a part is dissipated as thermal power on the MDC plates.

MDC efficiency is defined as P(recovered)/P(coll in) where P(coll in) is defined as $V_k I_k$ - P(o) - P(BODY). Care must be taken that the measured body power does not include dissipated thermal power from backstreaming electrons, or exaggerated MDC efficiencies will result. Backstreaming electrons produced by the MDC must be charged against the collector. In these MDC tests, it is believed that almost all of the returned power due to backstreaming electrons is dissipated on the water-cooled undepressed plate and the air cooled refocusing section tunnel, and, therefore, does not contribute materially to the measured body power.

As reported in reference 1, all active collecting surfaces of the MDC shown in figure 1 were coated with a secondary electron suppressing material (soot). A similar coating of soot was applied to all active collecting surfaces of the three collectors (figs. 5 to 7) whose performance is reported here.

MDC TEST RESULTS

MDC 1WX6 is shown in figure 5. This design was produced with the aid of a simple electrolytic tank for solving Laplace's equation (the space charge forces in this collector are negligible). Comparing this design to MDC 1WX5 (fig. 1), it can be seen that two of the intermediate collecting elements have been removed entirely and vertical electrode sections have been added to the remaining ones as partial compensation and for purposes of limiting the internal (active) MDC volume. The nonintercepting defocusing electrode (at ground potential in 1WX5 was electrically isolated so that its potential could be varied. The MDC apertures were unchanged.

MDC performance was evaluated with the defocusing electrode at both ground potential and that of the first active stage. MDC performance was optimized at 4.8 GHz saturated output and then at 8.4 GHz saturated output. The TWT/MDC performance is shown in tables I to IV.

Operating at 8.4 GHz saturated output, a steady, but small, improvement in MDC efficiency was noted as the potential of the defocusing electrode was varied from ground potential to that of the first active electrode. Operating at 4.8 GHz, the MDC efficiencies were identical. Therefore, the removal of the defocusing electrode (an intermediate case) can be expected to change the results only slightly, a few tenths of a percent in MDC efficiency at most.

Comparing the results to those of MDC 1WX5 (ref. 1) the minimum MDC efficiency considering the three frequencies was lower by 1.0 percent. The MDC efficiency, when optimized at 4.8 GHz and at 8.4 GHz was lower by 1.3 and 2.0 percent, respectively. Several considerations indicated that the aperture in the first active collecting element was too small and that MDC 1WX6 was providing some undesired dispersion, especially when the defocusing electrode was operated at ground potential.

MDC 1WX7 is shown in figure 6. The defocusing electrode has been removed entirely and the aperture in the first active plate has been enlarged.

The TWT/MDC performance is shown in tables V and VI. The results are quite comparable to those of MDC 1WX6. The minimum MDC efficiency and that when optimized at 8.4 GHz are 0.1 percent lower while the MDC efficiency optimized at 4.8 GHz is 0.3 percent higher. Some steady corona was noted around some of the insulators resulting in some efficiency loss.

MDC 1WX8 is shown in figure 7. Both the undepressed and first depressed electrodes have been extended as shown to closer approximate the electric field distribution of MDC 1WX6 when the defocusing electrode was operated at the potential of the first depressed plate and also to define the internal (active volume) of the MDC with conducting boundaries. This latter condition is desirable so that insulators need not be exposed to electron bombardment. The conical electrode has been reduced in diameter and insulator shielding improved.

The internal size of MDC 1WX8 is 1.88 inches in diameter by 2.70 inches high.

The TWT/MDC performance with MDC 1WX8 is shown in tables VII and VIII. The efficiency of MDC 1WX8 is approximately half a percent higher than those of 1WX6 and 1WX7, but still somewhat below that of MDC 1WX5. The performance of 1WX5 and 1WX8 are compared in table IX. The largest loss in MDC performance, 1.6 percent, occurred for optimization at 8.4 GHz saturation, the maximum prime power point. The corresponding reduction in overall efficiency is 1.4 percent. In terms of the highest minimum efficiency considering the three frequencies and for optimization of performance at 4.8 GHz, however, the efficiency loss was much less, 0.6 and 0.8 percent, respectively.

Some performance details including collector currents, voltages, and thermal dissipation are given in appendix A. The refocusing system details and refocusing magnetic field profile are given in appendix B of reference 1.

CONCLUDING REMARKS

A small (4.78-cm diam by 7.0-cm high internal size) two-stage MDC of simple geometry produced a minimum MDC efficiency of 80.5 percent in conjunction with a 330 to 520 watt broadband TWT. This MDC was water cooled and demountable in nature for purposes of diagnostics and experimental convenience, respectively. However, only the geometric design of the internal (active) parts of the MDC has an effect on MDC performance, and this MDC design should be readily adaptable to practical conduction cooled TWT's used in ECM systems.

However, it must be stressed that the reported performance figures are those of the inseparable TWT/Refocusing System/MDC combination. In this program the MDC design was adapted to the TWT (and its own individual as well as class peculiarities) and refocusing system (and its limitations and limited range of variability). Therefore, in adapting this MDC design to practical conduction cooled TWT of this specific TWT type, the need for some additional experimental optimization of MDC design should be anticipated. Of course, for other types of TWT's, entirely new refocusing system and MDC designs may be needed to produce optimum results.

APPENDIX A

DETAILS OF MULTISTAGE DEPRESSED COLLECTOR PERFORMANCE

The performance details of MDC 1WX8 optimized at 8.4 GHz (saturation) are given for frequencies of 4.8, 8.4, and 9.6 GHz (saturation).

(1) Frequency, 4.8 GHz (saturation)

	Voltage, kV	Current, mA	Recovered power, W	Thermal power dissipated, W
Cathode	-9.45	434.4	----	----
Body	----	18.9	----	155
rf load	----	-----	----	[a]413
Collector:				
1	0	26.3	0	158
2	-5.13	148.4	761	179
3	-8.67	227.9	1976	195
4	-9.45	12.4	117	51
Total		415.0	2854	583

[a]P(FUND) = 295 W.

(2) Frequency, 8.4 GHz (saturation)

	Voltage, kV	Current, mA	Recovered power, W	Thermal power dissipated, W
Cathode	-9.45	433.9	----	----
Body	-----	11.8	----	213
rf load	-----	-----	----	519
Collector:				
1	0	24.0	----	146
2	-5.13	208.3	1069	218
3	-8.67	168.8	1464	176
4	-9.45	20.5	194	62
Total		421.6	2727	602

(3) Frequency, 9.6 GHz (saturation)

	Voltage, kV	Current, mA	Recovered power, W	Thermal power dissipated, W
Cathode	-9.45	434.4	----	---
Body	-----	11.6	----	187
rf load	-----	------	----	334
Collector:				
1	0	17.5	----	114
2	-5.13	157.7	809	213
3	-8.67	236.1	2047	205
4	-9.45	9.9	94	45
Total		421.2	2950	577

REFERENCES

1. Ramins, Peter; Kosmahl, Henry G; and Fox, Thomas A.: Design and Performance Evaluation of Small, Two- and Four-Stage Depressed Collectors For A 4.8- to 9.6-GHz, High Performance Traveling Wave Tube. NASA TM X-73486, 1976.

2. Gilmour, A. S., Jr: Study of Miniaturized UHV Gate Valves. Rome Air Develop. Center (Job Order No. 956731), 1975.

TABLE I. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX6 with defocusing electrode at body potential (optimized for 4.8 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a]- no MDC, percent	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:			
Saturation	7.1	23.9	81.1
-3 dB (nominal)	3.6	18.9	86.2
-6 dB (nominal)	1.8	11.3	87.3
-9 dB (nominal)	.9	6.6	88.9
8.4:			
Saturation	12.7	35.6	78.3
-3 dB (nominal)	6.3	26.7	83.7
-6 dB (nominal)	3.2	16.6	85.2
-9 dB (nominal)	1.6	9.4	86.3
9.6:			
Saturation	8.2	29.1	82.1
-3 dB (nominal)	4.1	19.8	84.8
-6 dB (nominal)	2.1	12.2	86.4
-9 dB (nominal)	1.0	7.2	88.2
DC beam			91.5

[a]Based on rf output power at the fundamental frequency.

TABLE II. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX6 with defocusing electrode at body potential (optimized for 8.4 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	22.7	79.8
-3 dB (nominal)	17.4	85.0
-6 dB (nominal)	10.1	85.9
-9 dB (nominal)	5.8	87.6
8.4:		
Saturation	36.5	79.5
-3 dB (nominal)	25.8	83.3
-6 dB (nominal)	15.7	84.5
-9 dB (nominal)	9.1	85.5
9.6:		
Saturation	27.8	81.4
-3 dB (nominal)	19.0	84.0
-6 dB (nominal)	11.6	85.2
-9 dB (nominal)	6.3	87.0
DC beam		89.1

[a]Based on rf output power at the fundamental frequency.

TABLE III. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX6 with defocusing electrode at potential of first active stage (optimized for 4.8 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	23.1	81.1
-3 dB (nominal)	18.2	85.6
-6 dB (nominal)	11.0	86.9
-9 dB (nominal)	6.3	88.0
8.4:		
Saturation	35.8	78.9
-3 dB (nominal)	26.7	83.8
-6 dB (nominal)	16.5	85.3
-9 dB (nominal)	9.5	86.2
9.6:		
Saturation	28.9	81.7
-3 dB (nominal)	20.2	84.7
-6 dB (nominal)	11.7	86.0
-9 dB (nominal)	7.0	87.7
DC beam		91.3

TABLE IV. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX6 with defocusing electrode at potential of first active stage (optimized for 8.4 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	22.7	80.4
-3 dB (nominal)	17.5	85.4
-6 dB (nominal)	10.4	86.3
-9 dB (nominal)	6.5	87.5
8.4:		
Saturation	37.3	80.1
-3 dB (nominal)	26.9	83.7
-6 dB (nominal)	16.1	84.6
-9 dB (nominal)	8.9	86.0
9.6:		
Saturation	29.3	82.1
-3 dB (nominal)	20.4	84.5
-6 dB (nominal)	11.6	85.3
-9 dB (nominal)	6.7	87.0
DC beam		90.3

[a]Based on rf output power at the fundamental frequency.

TABLE V. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX7 (optimized for 4.8 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	23.9	81.4
-3 dB (nominal)	18.3	85.4
-6 dB (nominal)	11.2	86.9
-9 dB (nominal)	6.7	88.4
8.4:		
Saturation	35.5	78.7
-3 dB (nominal)	25.5	82.7
-6 dB (nominal)	15.9	84.6
-9 dB (nominal)	9.3	86.2
9.6:		
Saturation	28.1	81.7
-3 dB (nominal)	18.7	84.5
-6 dB (nominal)	11.4	85.5
-9 dB (nominal)	7.0	87.6
DC beam		90.9

[a]Based on rf output power at the fundamental frequency.

TABLE VI. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX7 (optimized for 8.4 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	22.4	80.0
-3 dB (nominal)	17.2	85.2
-6 dB (nominal)	9.9	85.7
-9 dB (nominal)	5.8	87.3
8.4:		
Saturation	36.7	80.0
-3 dB (nominal)	25.9	82.4
-6 dB (nominal)	15.7	84.1
-9 dB (nominal)	9.4	84.9
9.6:		
Saturation	27.9	81.4
-3 dB (nominal)	19.2	83.4
-6 dB (nominal)	10.9	84.9
-9 dB (nominal)	6.5	86.4
DC beam		89.7

[a]Based on rf output power at the fundamental frequency.

TABLE VII. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX8 (optimized for 4.8 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	24.9	81.6
-3 dB (nominal)	19.3	86.1
-6 dB (nominal)	11.8	87.5
-9 dB (nominal)	7.0	88.3
8.4:		
Saturation	36.2	79.7
-3 dB (nominal)	26.3	83.5
-6 dB (nominal)	16.9	85.7
-9 dB (nominal)	10.2	87.1
9.6:		
Saturation	28.2	82.3
-3 dB (nominal)	19.5	85.0
-6 dB (nominal)	12.1	86.6
-9 dB (nominal)	7.4	88.2
DC beam		89.9

[a]Based on rf output power at the fundamental frequency.

TABLE VIII. - TWT/2 STAGE MDC PERFORMANCE

[MDC 1WX8 (optimized for 8.4 GHz (saturation).)]

Frequency, GHz	Overall efficiency[a] with MDC, percent	Collector efficiency, percent
4.8:		
Saturation	23.6	80.5
-3 dB (nominal)	17.8	84.8
-6 dB (nominal)	10.5	85.8
-9 dB (nominal)	6.2	87.5
8.4:		
Saturation	37.6	80.5
-3 dB (nominal)	26.5	83.2
-6 dB (nominal)	16.1	84.7
-9 dB (nominal)	9.4	85.2
9.6:		
Saturation	28.8	82.0
-3 dB (nominal)	19.8	84.7
-6 dB (nominal)	11.4	85.4
-9 dB (nominal)	6.4	86.8
DC beam		89.4

[a]Based on rf output power at the fundamental frequency.

TABLE IX. - COMPARISON OF MDC PERFORMANCE

[MDC 1WX5 and MDC 1WX8.]

Saturated operation at all frequencies.

I. MDC efficiency optimized at 4.8 GHz (saturation)

Frequency	4.8 GHz	8.4 GHz	9.6 GHz
Collector efficiency MDC 1WX5 (ref. 1)	82.4%	80.2%	83.4%
Collector efficiency MDC 1WX8	81.6%	79.7%	82.3%

II. MDC efficiency optimized at 8.4 GHz (saturation)

Frequency	4.8 GHz	8.4 GHz	9.6 GHz
Collector efficiency MDC 1WX5 (ref. 1)	81.1%	82.1%	83.3%
Collector efficiency MDC 1WX8	80.5%	80.5%	82.0%

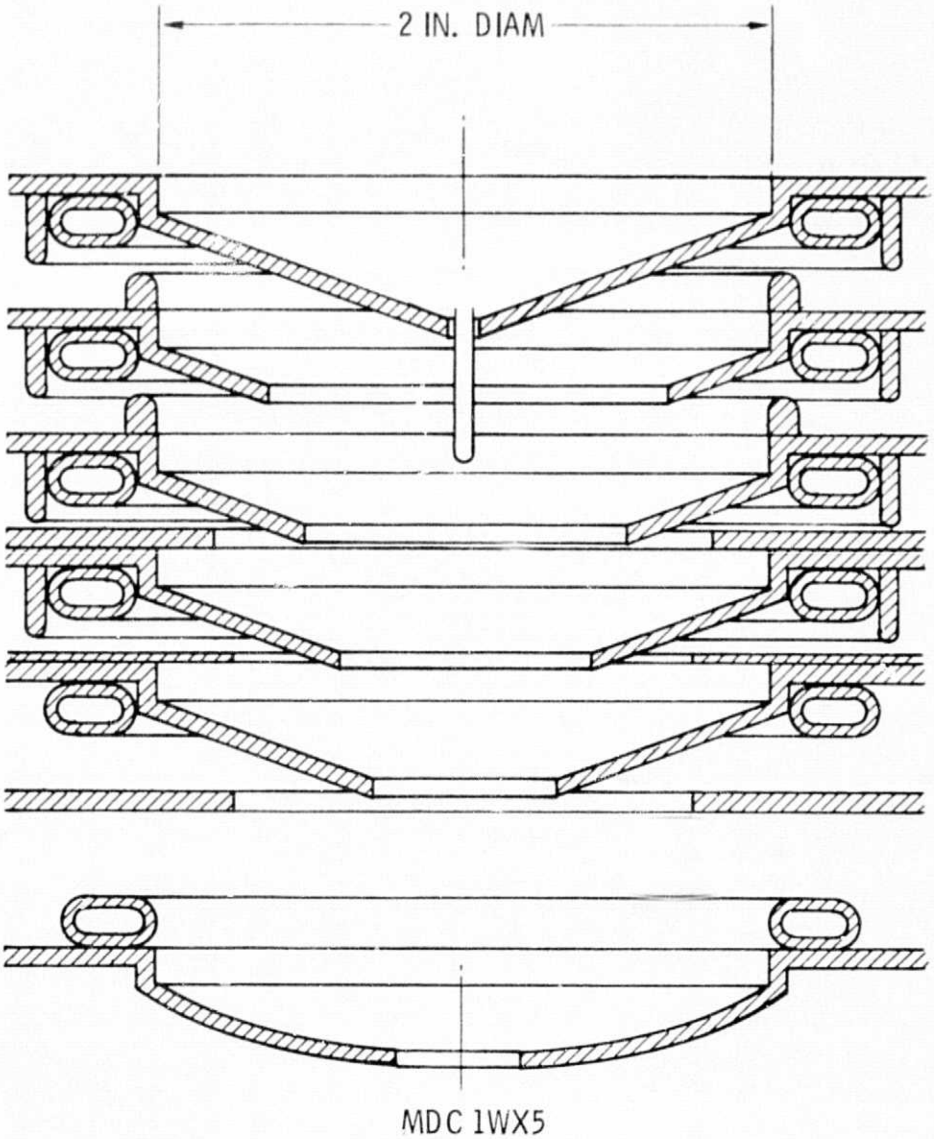


Figure 1.

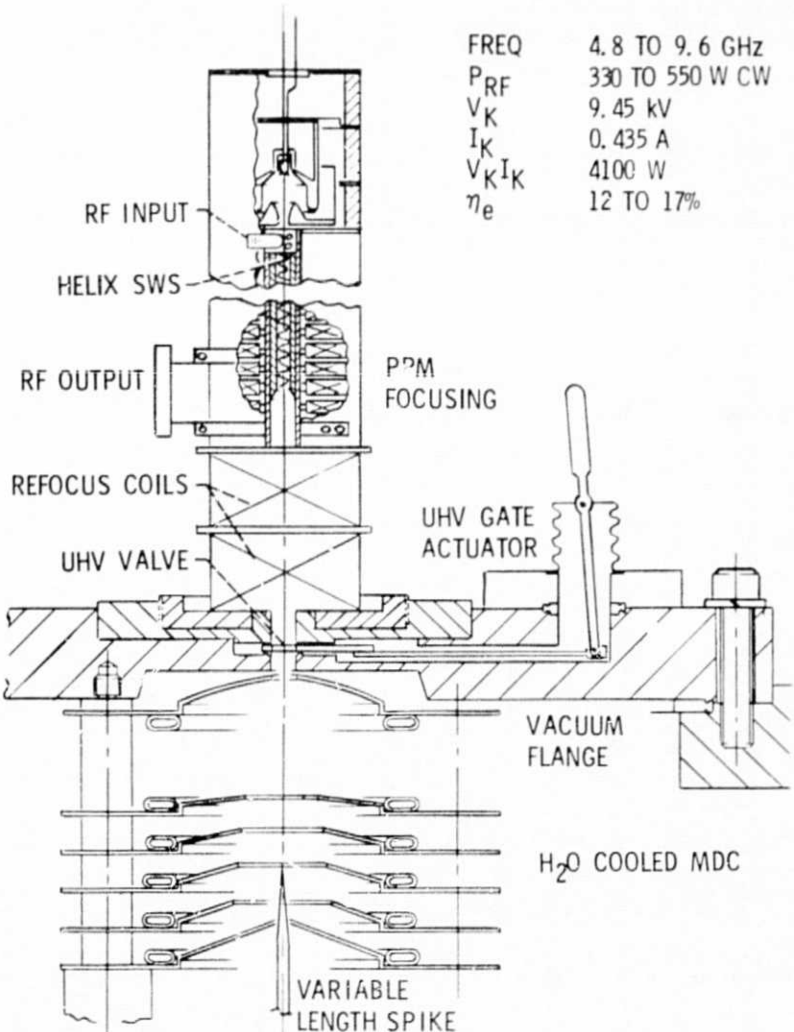


Figure 2. - MEC TWT typ. no. M5897C schematic.

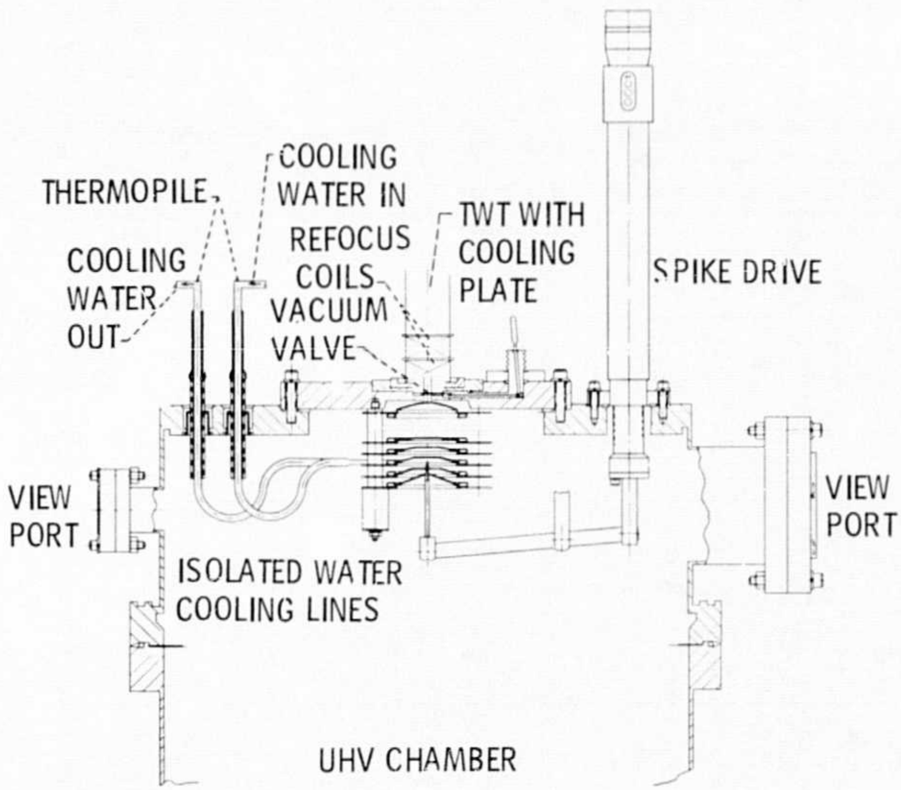
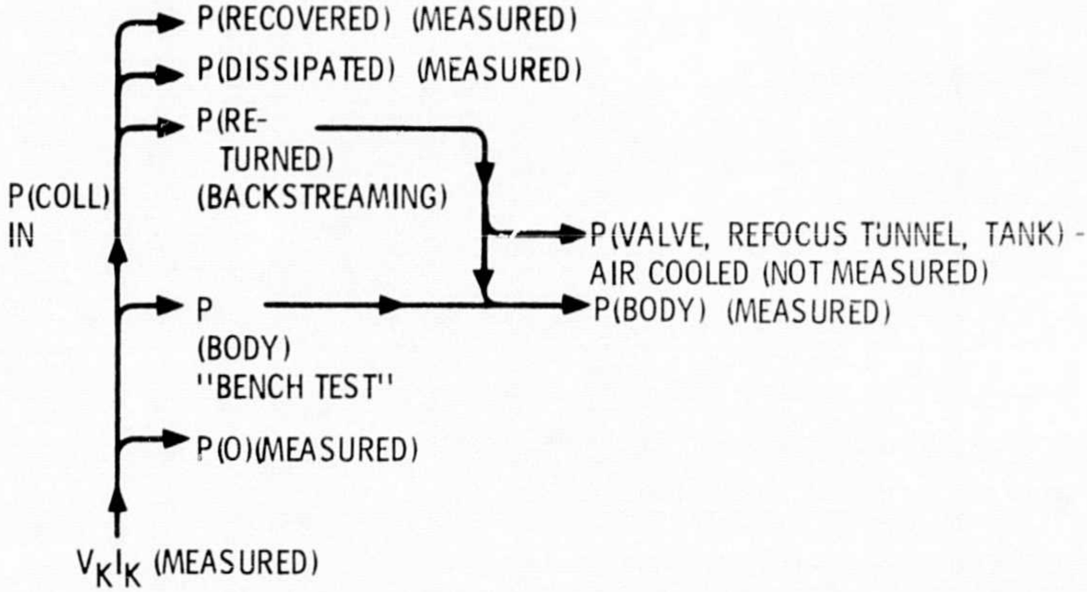
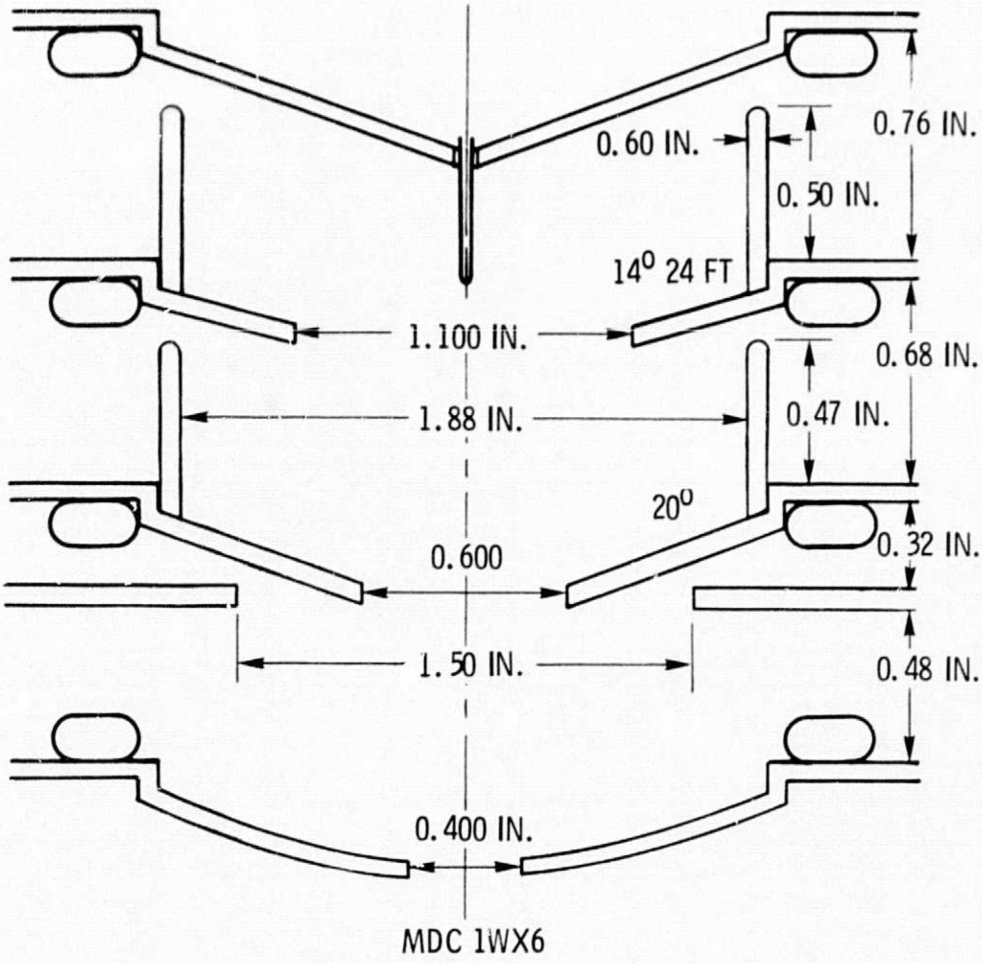


Figure 3. - Schematic of the MDC measuring system.



(APPLIES WHEN TWT PERFORMANCE IS REPEATABLE FROM TEST TO TEST.)

Figure 4. - Power flow diagram TWT with LeRC MDC.



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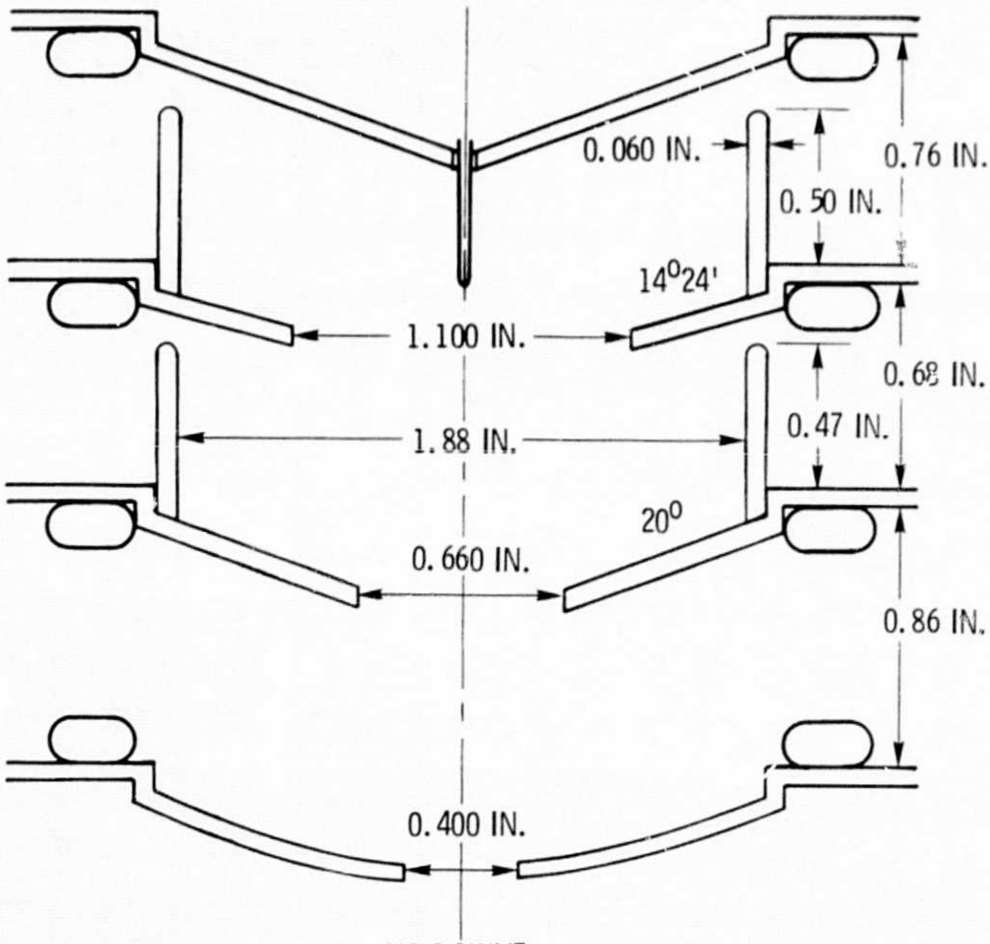
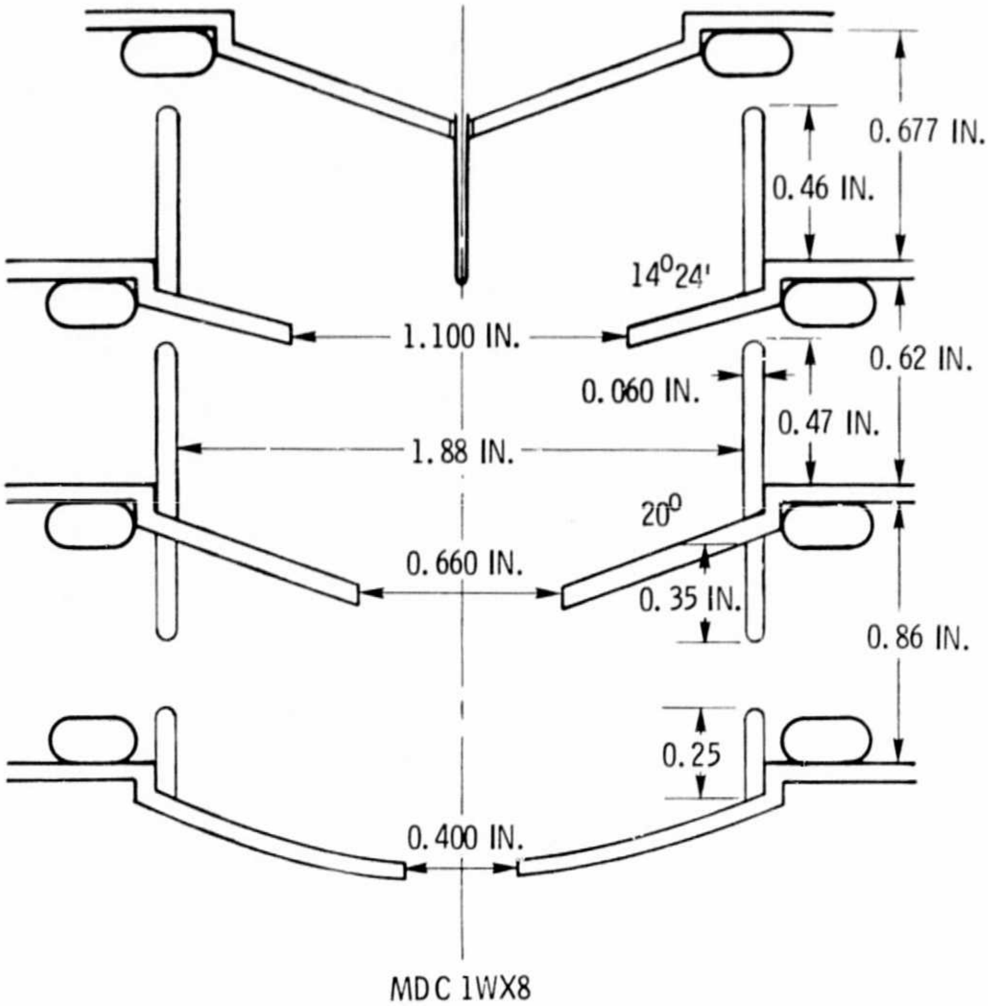
MDC 1WX6

Figure 5.



MDC 1WX7

Figure 6.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MDC 1WX8

Figure 7