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EFFICIENCY ENHANCEMENT OF OCTAVE-BANDWIDTH TWT'S BY THE USE OF MULTISTAGE DEPRESSED COLLECTORS

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16. Abstract

A small size two and four stage depressed collector was evaluated in conjunction with a 4.8 to 9.6 GHz TWT of 325 to 675 W power output. In spite of large fixed TWT losses, very significant efficiency enhancement was demonstrated with both the two and four stage MDC. The improvement in the overall efficiency ranged from a factor of 2.5 to 3.0 for the two stage MDC and a factor of 3.0 to 3.5 for the four stage MDC. An overall efficiency of 37.0 to 44.3 percent (average of 41.2 percent) across the frequency band was demonstrated with the use of harmonic injection.

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E-9335

SUMMARY

In a joint USAF-NASA program, Lewis Research Center is currently 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.

A small size two and four stage depressed collector was evaluated in conjunction with a 4.8 to 9.6 GHz TWT of 325 to 675 W power output and a beam of 0.5 micro perv. The MDC performed well even though its design had been optimized for a TWT of identical design but considerably less output power. In spite of large fixed losses (rf losses, interception losses, and harmonic power generated) very significant efficiency enhancement was demonstrated with both the two and four stage depressed collector. The improvement in the overall efficiency ranged from a factor of 2.5 to 3 for the two stage collector and a factor of 3 to 3.5 for the four stage collector. At saturation, two stage collector efficiencies of 78 to 81 percent and four stage collector efficiencies of 82 to 84 percent were obtained across the frequency band. An overall efficiency of 37.0 to 44.3 percent (average of 41.2 percent) across the frequency band of 4.8 to 9.6 GHz was demonstrated with the use of harmonic injection. The TWT failed due to presently undetermined causes before the completion of the optimization program.

I. 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 (refs. 1 and 2) involving TWT performance analysis, refocusing system analysis, and MDC analysis led to specific refocusing system and MDC designs for a 700 W (peak 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 (refs. 1 and 2). Considerable experimental optimization of the MDC design was required, in part due to the use of imperfect TWT input data for the initial computation of TWT performance. This experimental program led to demonstrated 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

The TWT modified for use in these tests (Teledyne MEC Type No. 5897C S/N 101) exhibited unexpectedly large circuit losses, the effective circuit efficiency being less than 70 percent at some frequencies. Based on cold helix measurements, circuit efficiencies of about 85 percent were expected, indicating the possibility that S/N 101 was not a typical example of its class and had either been damaged in some way or deviated from the intended design.

It was concluded from the test program that with circuit efficiencies of 85 percent or more, overall TWT efficiencies in excess of 40 percent appear possible across most of the octave bandwidth, where no harmonic power is generated.

In a continuation of the joint USAF-NASA program, the MDC and refocusing system were added to a TWT (S/N 103) of identical design. TWT and MDC performance were evaluated at various power levels across the octave bandwidth. The results of these tests are reported below. The TWT failed (apparently, from a failure of the weld between the helix and output coupler) before the test program was completed.

II. EXPERIMENTAL TWT

The Teledyne MEC TWT Type No. M5897C S/N 103 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. 3) 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, no valve gate was available for this test and the TWT had to be back-filled with gaseous nitrogen for MDC installation and subsequently rf processed under pulsed conditions.

This TWT, delivered by Teledyne MEC, had an undepressed, thermally isolated water cooled collector mounted on a matching 10 inch vacuum flange. This special collector was required for the "bench test."

III. EXPERIMENTAL PROGRAM

A. Bench Test

The purpose of the bench test is to document the performance of the TWT with an undepressed spent beam collector so that TWT performance changes, if any, due to the MDC can be determined and so that accurate MDC efficiency measurements can later be made. The rf load, TWT body, and collector are all thermally isolated and water cooled. Thermal power to each is measured by a combination of flowmeter and thermopile. Part of the I^2R losses in the air-cooled refocusing coils show up in the body cooling loop, but this small contribution is subtracted by an offset technique. Since the collector is undepressed, the power returned to the TWT by any backstreaming electrons is negligible. The measured P_{body} is, therefore, the sum of the total rf losses in the TWT and the interception losses. In order of identify the contribution of each to P_{body}, an assumption must be made about the average energy of the intercepted electrons.

B. Multistage-Depressed Collector Test

The MDC test set up is shown in figure 3. The TWT is mounted on a matching flange on an ultrahigh vacuum system. The MDC is mounted directly on the UHV flange, which houses the TWT/vacuum valve. Each MDC electrode is thermally and electrically isolated and is water cooled. The spent beam power recovered by each MDC electrode, as well as the thermal power dissipated on each electrode, is measured. A vacuum feedthrough drives a variable-length spike. Over its range of variability, the length of the spike significantly affects the electric field distribution within the collector, and its optimum length can be established quickly and easily for each MDC configuration. Since the refocusing coils and pole pieces are external to the vacuum, they can be manipulated and moved over their designed range of variability while the TWT is operating. Together with variation of the refocusing coil currents, this enables the rapid optimization, within limits, of the refocusing field profile. Once established, this profile can be synthesized with a permanent magnet refocusing system.

A typical experimental collector is shown in figure 2. This particular fully demountable mechanical design was chosen for experimental convenience. Water cooling (and calorimetry) of each collector electrode separately was chosen for diagnostic purposes and to provide information for the eventual thermal design o. a conduction-cooled MDC.

The internal (active) volume of the MDC is that within the inner diameter of the cooling lines (i.d. of 5.1 cm (2.00 in)). The electrode geometries within this volume are critical to the MDC performance, but the passive electrode support structure outside is not. Extensive thermal and mechanical design changes will have to be made to adapt these MDC's to practical TWT's.

In order to obtain complete and accurate MDC performance evaluations, it is necessary to determine the final power distribution in the system. This distribution is shown in figure 4 in the form of a power flow diagram for the TWT with a LeRC depressed collector.

Part of the beam power appears as measured rf output power and part is dissipated on the TWT body as the sum of rf losses in the TWT and intercepted beam power in the forward direction. The rest enters the collector. Part of this power is recovered as useful electric power and part is dissipated as thermal power on the collector plates. Also, with a depressed collector, the possibility exists of backstreaming electrons returning significant power to the TWT body. Since any backstreaming produced by the collector must be charged against its efficiency, this additional body power must be evaluated or exaggerated collector efficiencies can result. This can be done by comparing the body power measured during the bench test and the MDC test.

In this particular experimental setup, most of the backstreaming electrons are collected on the water cooled undepressed collector electrode or on the long, air cooled, refocusing section tunnel, and do not contribute materially to the measured body power. The collector efficiency is defined as recovered power divided by the power into the collector. It can be seen that, with this experimental approach, the power into the collector can be computed from measured quantities. Therefore, true collector efficiencies can be determined without any assumptions.

A novel data acquisition system is used to optimize collector efficiency under various operating conditions. This system provides an analog real-time readout of the recovered power as any of the system variables are changed while the TWT is operating. These variables are the individual collector stage voltages, the refocusing coil currents, the polepiece locations, and the spike length.

Maximizing recovered power is identical to maximizing the MDC efficiency. Once the optimum combination of operating condition is found, an automated data acquisition system is used for actual data taking.

IV EXPERIMENTAL RESULTS

A. Bench Test Results

The rf output power at the fundamental frequency, the TWT body losses (sum of rf losses and interception losses) and total fixed TWT losses (sum of TWT body losses and harmonic power generated) versus frequency are shown in figure 5. In order to calculate the circuit efficiency of the TWT (circuit efficiency is defined as the ratio of rf power output at the load terminal at a given frequency to the total rf power generated within the tube at the same frequency) it is necessary to make an assumption about the average energy of the intercepted electrons. Table I shows the circuit efficiency of S/N 103 for average intercepted electron energies of 0.6 eV_0 (slowest electrons), 0.8 eV_0 (average electron energy at the higher output power levels) and 1.0 eV_0, where V_0 is the cathode voltage. Where harmonic power is generated, the circuit efficiency is based on the total rf power generated. Since the intercepted current of S/N 103 is in the range of 1.5 to 2.5 percent, the assumed average intercepted electron energy can make a significant difference in the computed circuit efficiency.

However, it is clear that at midband, the circuit efficiency is considerably lower than the 85 percent anticipated. Moreover, over a significant part of the frequency spectrum (including the range 6.0 to 6.4 GHz), the circuit efficiency is below 80 percent.

These low circuit efficiencies plus the significant intercepted current of S/N 103 substantially limit the improvement in the overall efficiency obtainable with a depressed collector.

Table II shows the calculated MDC efficiencies needed to obtain overall efficiencies (based on rf power generated at the fundamental frequency) of 40, 45, and 50 percent. Clearly, with S/N 103 and small collectors of few stages, overall efficiencies in the range of 50 percent cannot be expected and harmonic injection is needed to even approach 40 percent overall efficiency in the frequency range of 4.8 to 6.2 GHz.

S/N 103 generates significantly more rf power than S/N 101 in the frequency range of 6.4 to 9.6 GHz. The peak electronic efficiency exceeds 19 percent (compared to 17 percent for S/N 101). While this aids in obtaining high overall efficiencies, reduced MDC efficiencies can be expected when operating S/N 103 at saturation.

B. Multistage Depressed Collector Test Results

Following the "bench test," MDC 1WX5 (ref. 1) was added to S/N 103 and the combination evaluated. The MDC was operated as both a two stage and four stage collector. Two types of optimizations were stressed: maximizing overall efficiency across the frequency band when operating at or very near to saturation; and, minimizing the prime power required when operating at the rated rf power output of 400 W at the fundamental frequency, across the frequency band (except at 4.8 GHz where S/N 103 produced only 330 W). Overall efficiency based on both the rf power generated at the fundamental frequency $P_{(FUND)}$, and on the total rf power generated, $P_{(TOT)}$, was determined, the latter being indicative of performance approachable with excellent harmonic suppression.

The TWT failed before completion of the test program. A fairly complete optimization was obtained with input drive at the fundamental frequency. Only very limited data were obtained with harmonic injection (with input drive at both the fundamental and second harmonic frequencies).

1. Comparison of MDC Performance with S/N 101 and S/N 103

In order to evaluate the repeatability in MDC performance with two TWT's of identical design, S/N 103 was operated at 8.4 GHz at an rf output level corresponding to an electronic efficiency of 17.0 percent. MDC 1WX5 geometric design was optimized for this operating point with S/N 101. The MDC performance was reoptimized with S/N 103 at this point. Setting up of completely identical conditions was not possible because the TWT operating cathode voltages and currents differ somewhat and the refocusing systems are not identical.

The results are shown in table III. The measured rf powers differ because of differences in circuit efficiency and beam power. The MDC performance is quite comparable. The MDC operating voltages (each set optimized for each TWT) were similar indicating that the two spent beams have somewhat similar velocity distributions.

For slightly higher rf power levels, the MDC efficiency dropped steadily indicating this MDC design is not optimum for higher TWT electronic efficiencies.

2. Performance at Saturation

Based on initial tests and an evaluation of fixed TWT losses, saturated operation at 6.4 GHz was selected as the operating point for MDC optimization. Data was then taken (at this fixed set of operating conditions) across the frequency band at or very near (within a few watts) saturation.

The overall efficiency based on $P_{(TOT)}$ and the MDC efficiency vs frequency are shown in figure 6. The same results are listed in tabular form in appendix A. With the four stage MDC, overall efficiencies range from 37.0 to 44.3 percent. Over much of the band, the overall efficiency based on $P_{(TOT)}$ exceeds 40 percent. The MDC efficiency ranges from 81.7 to 84.3 percent.

With the two stage MDC, the overall efficiency based on $P_{(TOT)}$ ranges from 32.5 to 40.7 percent. The MDC efficiency ranges from 77.8 to 81.1 percent.

The overall TWT efficiency based on $P_{(FUND)}$ (for the same set of data as above) is shown in figure 7. The same results are listed in tabular form in appendix A. In the range 4.8 to 6.2 GHz, this overall efficiency is substantially lower than that based on $P_{(TOT)}$ because of the large amount of harmonic power generated by S/N 103.

As discussed previously, and can be seen from figure 5, the very large fixed TWT losses (including harmonic power) in the frequency range 4.8 to 6.2 GHz preclude the achievement of high overall efficiency without harmonic injection.

Both with the two stage and four stage MDC, the optimum set of collector voltages with S/N 103 differ significantly from those with S/N 101, indicating that, at saturation, the spent beam velocity distribution differs substantially between S/N 101 and S/N 103. The four stage MDC voltages with S/N 103 are spread out much more evenly between the cathode voltage (V_0) and 0.5 V_0. Therefore, it seems that the velocity distribution at saturation no longer exhibits two peaks, which for S/N 101 made the two stage MDC almost as good as the four stage MDC.

With S/N 103, the difference between two and four stage MDC efficiencies is three to four percentage points.

3. Performance at $P_{(FUND)} = 400$ W

An experimental program was conducted to minimize the prime power needed to operate the TWT across the frequency band 4.8 to 9.6 GHz at the rated output power (at the fundamental frequency) of 400 W.

Optimizing the MDC performance at 4.8 GHz or 5.2 GHz was indicated, the former giving the lowest overall efficiency because of the low output power (330 W), the latter resulting in the highest total rf power generated (540 W) in order to produce 400 W at 5.2 GHz.

The TWT and MDC (two and four stage) performance is shown in figure 8 and appendix B. The four stage MDC was optimized at 4.8 GHz, saturated output. The overall efficiency based on $P_{(FUND)}$ ranges from 28.3 to 39.0 percent. If S/N 103 generated 400 W at 4.8 GHz, a minimum overall efficiency in excess of 30 percent could be expected. The improvement in the overall efficiency due to the four stage MDC is by a factor of 3.5 to 4. The four stage MDC efficiencies range from 84.6 to 86.5 percent.

The two stage MDC efficiency was optimized at 5.2 GHz. The overall efficiency ranges from 25.2 to 34.1 percent. The improvement in the overall efficiency due to the two stage MDC is by a factor of 3.0 to 3.5. The two stage MDC efficiencies range from 81.5 to 83.5 percent.

4. Experiments with Harmonic Injection

Only very limited experiments were performed using harmonic injection due to failure of S/N 103 shortly after the testing was started. Much of the limited testing performed was done at 4.8 GHz (the worst point in terms of relative amount of harmonic power generated).

At 4.8 GHz, harmonic injection was found to be very effective not only in reducing the relative amount of harmonic power generated, but also in substantially increasing the output power at the fundamental frequency. Without harmonic injection, S/N 103 simultaneously generated 330 W at 4.8 GHz and 155 W at 9.6 GHz. With harmonic injection rf power output at 4.8 GHz was raised to 530 W and that at 9.6 GHz reduced to 48 W.

At other frequencies, the gains were smaller but the testing had only begun. At 6.4 GHz, where only a few watts of harmonic power are generated, harmonic injection resulted in significantly decreasing the TWT body power.

The results in terms of the overall efficiency based on $P_{(FUND)}$ as a function of frequency are shown in figures 7 and 8. A dramatic improvement is evident. It is believed that with extensive optimization, the overall efficiency could be increased to 40 percent or more across much of the lower part of the frequency band. However, a minimum overall efficiency (based on $P_{(FUND)}$) of 37 percent was demonstrated across the frequency band of 4.8 to 9.6 GHz.

At the $P_{(FUND)}$ = 400 W level data were obtained only at 4.8 GHz (previously, the worst point). The overall efficiency was raised from 28.3 to 37.3 percent. It is believed that significant improvement could also be obtained up to 6.4 GHz, as it was for saturated operation.

5. Prime Power Required

The prime power required by S/N 103 at saturation versus frequency is shown in figure 9. A maximum of 1600 W is required with a two stage collector and 1450 W with a four stage collector. If only 400 W at the fundamental frequency is needed across the band, the prime power required can be decreased to 1370 W and 1220 W for a two and four stage MDC, respectively, without the use of harmonic injection. The prime power required versus frequency is shown in figure 10. Limited testing with harmonic injection indicated that the prime power required (using a four stage MDC) could be reduced by approximately an additional 80 W.

V. CONCLUDING REMARKS

A small size two and four stage depressed collector was evaluated in conjunction with a 4.8 to 9.6 GHz TWT of 325 to 675 W power output. In spite of large fixed TWT losses, very significant efficiency enhancement was demonstrated with both the two and four stage MDC. The improvement in the overall efficiency ranged from a factor of 2.5 to 3.0 for the two stage MDC and a factor of 3.0 to 3.5 for the four stage depressed collector. An overall efficiency of 37.0 to 44.3 percent across the frequency band of 4.8 to 9.6 GHz was demonstrated with the use of harmonic injection.

The MDC design was optimized for a TWT of lower electronic efficiency. Consequently, significant improvement in performance could be expected with further optimization of MDC design. However, with a TWT of such low electronic efficiency and small collectors of relatively few stages, in order to obtain very high efficiencies (in the range of 50 percent) the fixed TWT losses would have to be reduced.

APPENDIX A

I. PERFORMANCE (AT SATURATION) OF S/N 103 WITH A 4 STAGE DEPRESSED COLLECTOR - BASED ON TOTAL RF POWER GENERATED.

Frequency, GHz	Overall efficiency without MDC, %	Overall efficiency with MDC, %	Collector efficiency, %
4.8	11.6	40.6	84.3
5.2	13.1	43.5	84.1
5.6	13.6	42.2	83.1
6.0	12.7	40.3	83.2
6.4	12.8	39.2	82.4
6.8	14.9	43.4	81.7
7.2	14.8	42.9	82.0
7.6	14.9	44.3	82.8
8.0	15.4	44.3	82.2
8.4	15.0	43.8	82.7
8.8	14.1	43.0	83.4
9.2	12.7	40.4	83.8
9.6	10.7	37.0	84.3

II. PERFORMANCE (AT SATURATION) OF S/N 103 WITH A 2 STAGE DEPRESSED COLLECTOR - BASED ON TOTAL RF POWER GENERATED.

Frequency, GHz	Overall efficiency without MDC, %	Overall efficiency with MDC, %	Collector efficiency, %
4.8	11.3	35.8	80.6
5.2	13.2	38.9	80.0
5.6	13.4	38.3	79.7
6.0	12.8	36.6	79.3
6.4	12.9	36.0	79.3
6.8	15.0	39.4	77.8
7.2	14.8	38.7	78.1
7.6	15.0	40.0	79.2
8.0	15.2	40.7	79.6
8.4	14.7	39.1	79.1
8.8	13.7	38.6	80.4
9.2	12.3	35.8	80.6
9.6	10.4	32.5	81.1

III. PERFORMANCE (AT SATURATION) OF S/N 103 WITH A 4 STAGE DEPRESSED COLLECTOR - BASED ON RF OUTPUT POWER AT THE FUNDAMENTAL FREQUENCY.

Frequency, GHz	Overall efficiency without MDC, %	Overall efficiency with MDC, %	Collector efficiency, %
4.8	7.9	27.7	84.3
5.2	9.7	32.4	84.1
5.6	11.7	36.4	83.1
6.0	11.5	36.6	83.2

IV. PERFORMANCE (AT SATURATION) OF S/N 103 WITH A 2 STAGE DEPRESSED COLLECTOR - BASED ON RF OUTPUT POWER AT THE FUNDAMENTAL FREQUENCY.

Frequency, GHz	Overall efficiency without MDC, %	Overall efficiency with MDC, %	Collector efficiency, %
4.8	7.9	25.0	80.6
5.2	9.9	29.2	80.0
5.6	11.7	33.4	79.7
6.0	11.8	33.6	79.3

APPENDIX B

I. PERFORMANCE (AT $P_{(FUND)} \approx 400$ W) OF S/N 103 WITH A 4 STAGE DEPRESSED COLLECTOR - BASED ON RF POWER GENERATED AT THE FUNDAMENTAL FREQUENCY.

Frequency, GHz	Overall efficiency without MDC, %	Overall efficiency with MDC, %	Collector efficiency, %
4.8	7.9	28.3	84.8
5.2	9.5	33.0	84.8
5.6	9.5	34.7	84.7
6.0	9.6	34.8	84.6
6.4	9.6	35.9	85.0
6.8	9.5	37.4	84.9
7.2	9.5	37.8	85.5
7.6	9.6	38.2	85.7
8.0	9.5	38.4	86.0
8.4	9.6	39.0	86.4
8.8	9.5	38.9	86.5
9.2	9.5	37.5	86.0
9.6	9.6	36.2	85.3

II. PERFORMANCE (AT $P_{(FUND)} \approx 400$ W) OF S/N 103 WITH A 2 STAGE DEPRESSED COLLECTOR - BASED ON RF POWER GENERATED AT THE FUNDAMENTAL FREQUENCY.

Frequency, GHz	Overall efficiency without MDC, %	Overall efficiency with MDC, %	Collector efficiency, %
4.8	7.8	25.2	81.6
5.2	9.5	29.5	81.5
5.6	9.6	31.5	82.1
6.0	9.4	30.8	81.8
6.4	9.6	33.2	82.6
6.8	9.5	33.9	82.4
7.2	9.6	34.1	82.8
7.6	9.6	34.0	82.6
8.0	9.6	33.7	83.0
8.4	9.5	34.3	83.4
8.8	9.7	34.5	83.5
9.2	9.6	32.5	82.6
9.6	9.6	31.6	81.8

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TABLE I. - CIRCUIT EFFICIENCY (BASED ON TOTAL RF POWER GENERATED) AT SATURATION OF MEC TWT M5897C S/N 103

Frequency GHz	Circuit efficiency, %		
	($^a\bar{E} = 0.6\ eV_o$)	($\bar{E} = 0.8\ eV_o$)	($\bar{E} = 1.0\ eV_o$)
4.8	84.3	87.1	90.0
5.2	86.4	88.9	91.4
5.6	83.0	85.2	87.6
6.0	75.7	78.0	80.4
6.4	74.8	76.6	78.5
6.8	82.3	84.0	85.8
7.2	79.5	80.9	82.2
7.6	80.2	81.6	83.1
8.0	78.8	80.0	81.4
8.4	76.8	78.1	79.5
8.8	76.0	77.3	78.8
9.2	73.8	75.3	76.8
9.6	73.7	75.4	77.2

$^a\bar{E}$ is defined as the average energy of the intercepted electrons.

TABLE II. MDC EFFICIENCY[a] REQUIRED TO PRODUCE

HIGH OVERALL EFFICIENCY WITH S/N 103

[Based on bench test results and rf power generated at the fundamental frequency.]

Frequency GHz	Required MDC efficiency, %		
	Overall efficiency = 40%	Overall efficiency = 45%	Overall efficiency = 50%
4.8	95.1	97.4	99.2
5.2	90.1	93.4	95.9
5.6	85.7	89.7	92.9
6.0	87.5	91.2	94.3
6.4	82.6	87.1	90.7
6.8	75.6	82.3	86.6
7.2	76.8	82.2	86.6
7.6	76.0	81.6	86.1
8.0	76.5	82.1	86.6
8.4	78.8	84.0	88.2
8.8	80.9	85.7	89.5
9.2	84.6	88.6	91.9
9.6	87.7	90.9	93.5

[a]Computed from:

1. Overall efficiency $= \dfrac{P_{rf}}{(P_{rf} + P_{(body)} + (\text{collector dissipation}))}$

2. Collector dissipation = P(collector) [1 - (collector efficiency)] (see fig. 4).

TABLE III. - PERFORMANCE COMPARISON

OF S/N 101 AND S/N 103 WITH

MDC 1WX5 (4 STAGE)

	S/N 101	S/N 103
rf power[a]	513 W	561 W
Body power	198 W	208 W
Overall efficiency	41.6%	44.3%
Collector efficiency	84.2%	85.1%

[a]At an electronic efficiency of 17.0% at 8.4 GHz

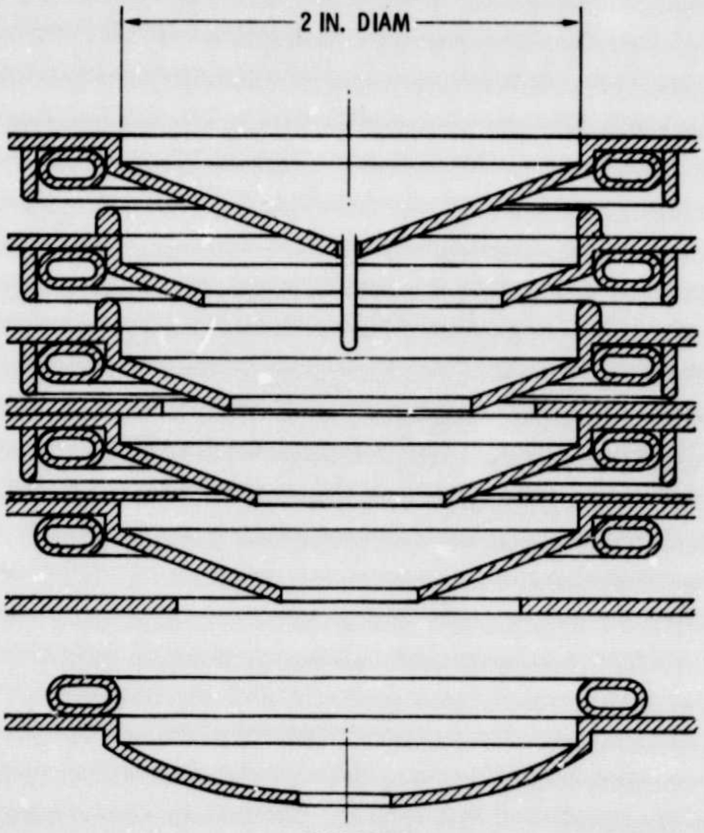


Figure 1.

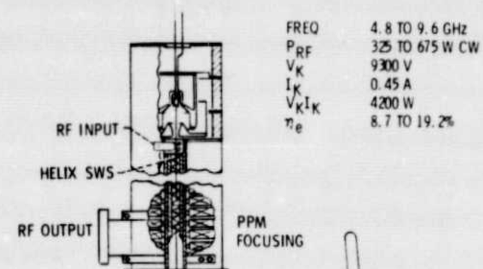


Figure 2. - MEC TWT typ. no. M5897C schematic with LeRC MDC.

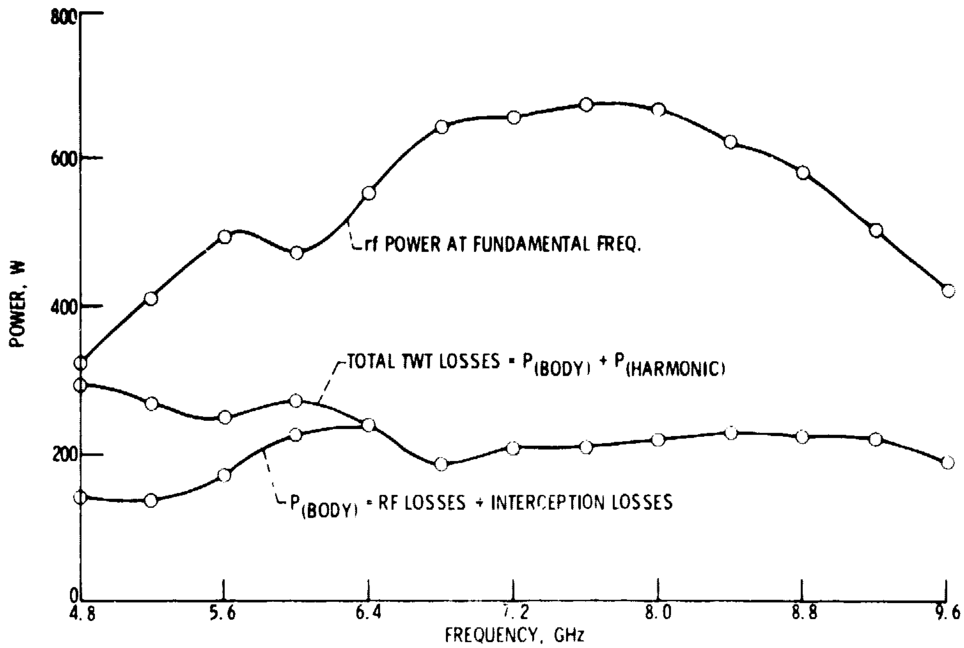
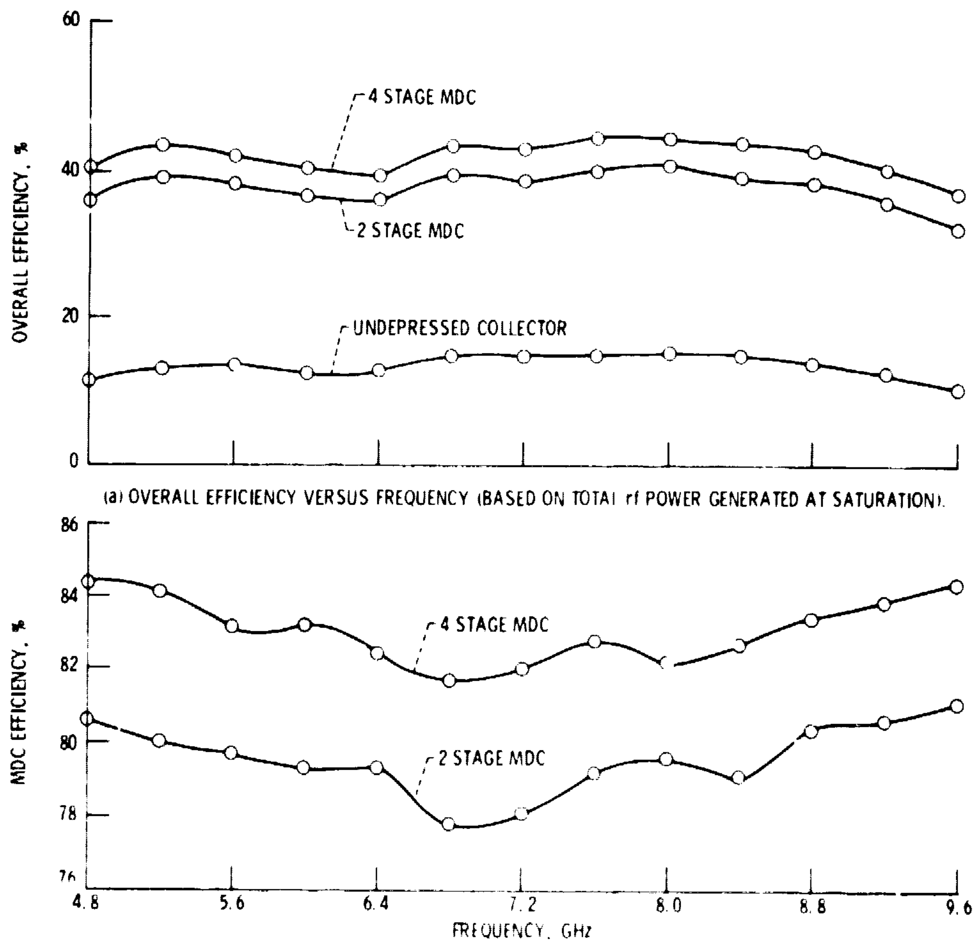


Figure 5. - rf Power and TWT losses versus frequency MEC TWT M5897C S/N 103 (at saturation).



(b) FFICIENCY VERSUS FREQUENCY (AT SATURATION).

Figure 6. - S/N 103 with MDC 1Wx5.

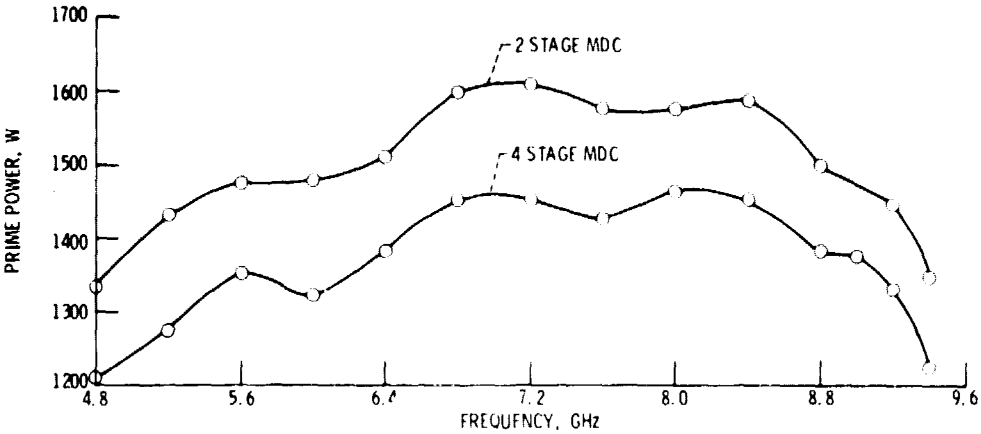


Figure 9. - Prime power required versus frequency (at saturation). S/N 103 with MDC 1Wx5.

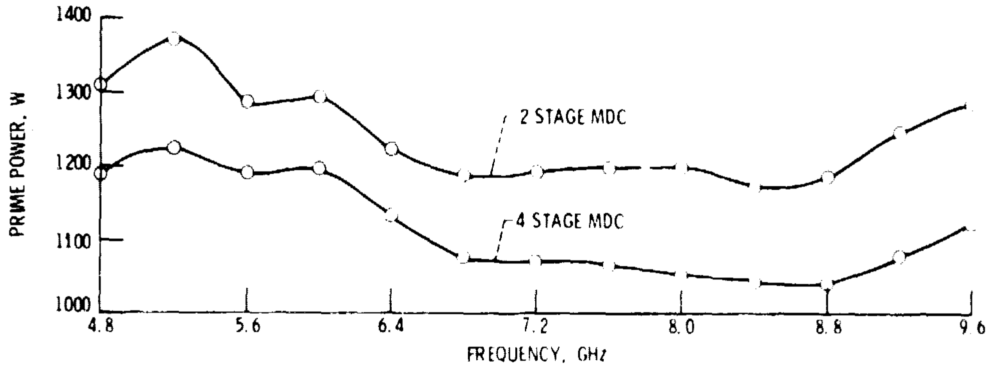


Figure 10. - Prime power required versus frequency at 400 W rf power at the fundamental frequency. S/N 103 with MDC 1Wx5.