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NASA TECHNICAL MEMORANDUM

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AN 82 TO 84 PERCENT EFFICIENT, SMALL SIZE, 2 AND 4 STAGE DEPRESSED COLLECTOR FOR OCTAVE BANDWIDTH HIGH PERFORMANCE TWT'S

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AN 82 TO 84 PERCENT EFFICIENT, SMALL SIZE, 2 AND 4 STAGE DEPRESSED COLLECTOR*

FOR OCTAVE BANDWIDTH HIGH PERFORMANCE TWT'S

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E-9021

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.

Analytical Program

In the analytical part of the effort, three-dimensional electron trajectories are computed throughout the slow-wave structure of the TWT (10 to 18 percent electronic efficiency, 4.8 to 9.6 GHz bandwidth, and 330 to 550 W continuous wave power output). Trajectory computation continues through the spent-beam refocuser and the depressed collector. Both refocusing system and MDC designs are produced by reiterative computations. Collector efficiency, collector losses and overall efficiency are computed.

The refocusing system designed for this TWT allows a controlled beam expansion to the point that space charge becomes negligible at the MDC entrance. Simultaneously, the standard deviation of the radial velocity (angular spread) is reduced.

The summary of spent beam parameters before and after refocusing is shown in figure 1. Initial and final radii, axial velocities and angles of trajectories are shown. Three important results may be extracted from the table: The average final beam radius is 2.7 times larger than the radius before refocusing, secondly all negative angles disappeared after refocusing and, thirdly, the standard deviation has been reduced by a factor of 2.4 for the exit angles. Thus, the beam became more laminar and is much less dense due to refocusing.

The three-dimensional theory for ideal tubes with symmetric, circular, and optimally refocused beams predicts MDC efficiencies at mid-band of 82 and 85.5 percent for the two and four stage MDC's, respectively, designed for this TWT.

*Paper presented December 7, 1976 at the IEDM, Washington, D.C.

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The application of computer programs and some experimental results permit a pretty accurate determination and identification of collector losses, shown in figure 2. The use of larger collector sizes and more depressed stages than present AF constraints allow would push the collector efficiency above 90 percent for ECM TWT's.

The Secondaries

In spite of the fact that most electrons are collected in regions of negative fields which suppress secondaries, a small percentage of primaries hit the unfavorable side of plates and some elastically reflected primaries are also generated. Both groups of secondaries cause a loss in η_{col} of 2-4 percent.

Experimental Program

The Teledyne-MEC TWT type No. M5897C as modified for use in this program and its performance characteristics are shown in figure 3. A refocusing system consisting of two coils (eventually to be replaced by a permanent magnet) has been added, and the TWT is mounted on a 10-inch UHV flange. A matching flange exists on the vacuum system used for MDC tests. The UHV valve was designed to keep the TWT under vacuum during MDC installation and changes, facilitating startup and enabling many collector changes without cathode activation problems.

Prior to collector tests, the spent beam is analyzed for the distribution of its angular and axial energy. Figure 4 shows the result. Note that the computed curve did not include the taper whose presence and parameters were unknown to us. The taper gives rise to the second plateau, whose presence is very beneficial to the design of efficient collectors with only a few stages.

During an MDC test, with the TWT operating, 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 maximiziag 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.

An experimental program was conducted to optimize the TWT/Refocusing System/MDC performance. This led to demonstrated MDC efficiencies (at maximum rf output frequency of the TWT) 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 5. 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 4 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.

An experimental program aimed at simplifying the geometric design of the two stage collector led to the design shown in figure 6.

The same collector with plots of a few equipotential lines is shown in figure 7. Note the presence of convergent lenses in the vicinity of the electrodes and on the axis at a normalized potential of 0.5. These convergent lenses are useful in very small size collectors-to prevent excessive beam spreading, but are not required in larger size collectors for maximum efficiency.

The performance of the MDC's, optimized at 8.4GHz (the maximum rf output point), is compared in figure 8. The TWT/MDC performance at and below saturation is shown in figures 2 to 4. For these tests, all MDC active collecting surfaces were coated with a secondary electron suppression coating (soot).

Very substantial efficiency enhancement was demonstrated by each of the MDC's. The simplified two stage design should be readily adaptable to practical TWT's used in systems. The size of the collector is: 5 cm diameter by 7 cm high (inside dimensions). Further small improvements are possible.

Trajectory	RI	VI	AI	RF	VF	AF
1	0.556E+00	0.771E+00	0.783E+01	0.600E+00	0.774E+00	0.197E+01
2	0.516E+00	0.796E+00	0.282E+01	0.971E+00	0.797E+00	0.395E+01
3	0.409E+00	0.801E+00	-0.312E+01	0.170E+01	0.802E+00	0.496E+01
4	0.554E+00	0.808E+00	-0.194E+01	0.152E+01	0.808E+00	0.582E+01
5	0.353E+00	0.809E+00	-0.526E+01	0.203E+01	0.812E+00	0.442E+01
6	0.551E+00	0.816E+00	0.630E+01	0.676E+00	0.818E+00	0.159E+01
7	0.454E+00	0.828E+00	0.104E+01	0.112E+01	0.828E+00	0.397E+01
8	0.205E+00	0.837E+00	0.370E+00	0.151E+01	0.839E+00	0.300E+01
9	0.541E+00	0.839E+00	0.291E+01	0.867E+00	0.840E+00	0.332E+01
10	0.445E+00	0.843E+00	0.267E+01	0.980E+00	0.845E+00	0.289E+01
11	0.672E+00	0.846E+00	0.585E+01	0.574E+00	0.847E+00	0.206E+01
12	0.335E+00	0.855E+00	-0.392E+01	0.183E+01	0.857E+00	0.471E+01
13	0.249E+00	0.859E+00	-0.199E+01	0.166E+01	0.861E+00	0.397E+01
14	0.328E+00	0.864E+00	0.140E+01	0.122E+01	0.866E+00	0.301E+01
15	0.744E+00	0.866E+00	0.445E+01	0.596E+00	0.866E+00	0.326E+01
16	0.381E+00	0.866E+00	0.247E+01	0.197E+01	0.868E+00	0.261E+01
17	0.164E+00	0.883E+00	0.124E+00	0.162E+01	0.886E+00	0.306E+01
18	0.550E+00	0.897E+00	0.399E+01	0.775E+00	0.899E+00	0.182E+01
19	0.266E+00	0.898E+00	0.395E+00	0.138E+01	0.900E+00	0.330E+01
20	0.271E+00	0.915E+00	0.452E+00	0.143E+01	0.916E+00	0.367E+01
21	0.322E+00	0.921E+00	0.104E+01	0.123E+01	0.922E+00	0.307E+01
22	0.392E+00	0.928E+00	-0.390E+01	0.175E+01	0.929E+00	0.519E+01
23	0.517E+00	0.932E+00	-0.994E+00	0.116E+01	0.932E+00	0.471E+01
24	0.418E+00	0.938E+00	-0.252E+01	0.145E+01	0.939E+00	0.497E+01
25	0.525E+00	0.952E+00	0.483E+01	0.873E+00	0.954E+00	0.806E+00
26	0.256E+00	0.954E+00	-0.905E+00	0.147E+01	0.955E+00	0.383E+01
27	0.334E+00	0.982E+00	0.883E+00	0.114E+01	0.893E+00	0.303E+01
28	0.574E+00	0.101E+01	0.245E+01	0.772E+00	0.101E+01	0.191E+01
29	0.350E+00	0.101E+01	0.542E+00	0.116E+01	0.101E+01	0.314E+01
30	0.569E+00	0.103E+01	0.282E+01	0.793E+00	0.103E+01	0.152E+01
31	0.559E+00	0.109E+01	0.304E+01	0.861E+00	0.109E+01	0.114E+01
32	0.563E+00	0.111E+01	0.232E+01	0.815E+00	0.111E+01	0.142E+01
Average =	0.435E+00	0.898E+00	0.111E+01	0.118E+01	0.900E+00	0.319E+01
Standard deviation =	0.139E+00	0.835E-01	0.307E+01	0.394E+00	0.832E-01	0.126E+01

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Figure 1. - Electron spectrum before and after refocusing.

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	LOSS, %
1. FINITE NO. OF ELECTRODES 2-4 COMPARED WITH INFINITE NO.	10-5
2. RADIAL VELOCITY SORTING	3
3. VERY LARGE ANGLES (>6°) & VERY SMALL ANGLES (<0.25°)	2-4
4. SECONDARIES ON CONE & ELSEWHERE	2.8-4.8
5. ASYMMETRY & NONCIRCULARITY OF THE BEAM*	
6. NONIDEAL TUBES*	
7. NO REFOCUSING AT ALL	9

CS-79026

*LOSSES DUE TO THIS CAN VARY WIDELY.

Figure 2. - Identification of collector losses.

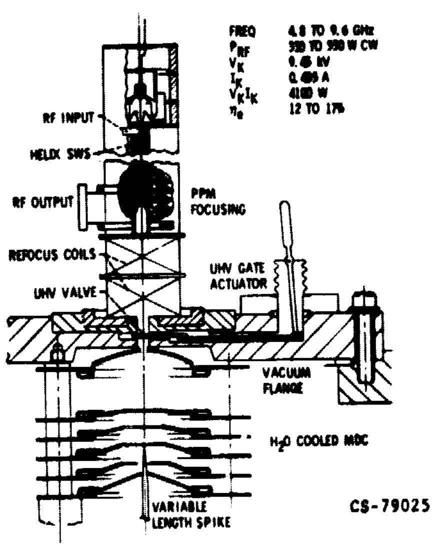

Figure 3. - MEC TWT typ. no. M5897C schematic.

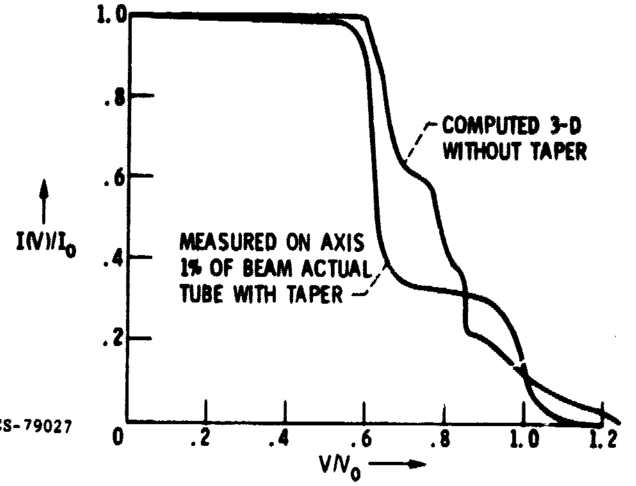

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Figure 4. - Computed and measured energy distribution curve for the 4.8 - 9.6 GHz MEC 500 watt CW TWT.

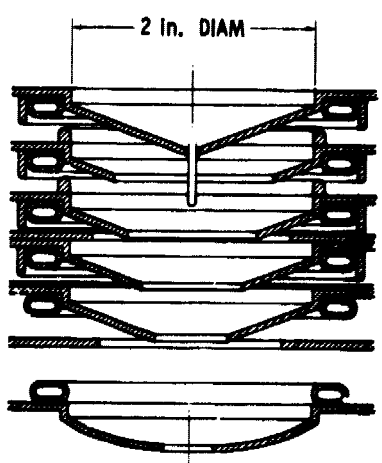

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Figure 5. - Experimental 2- and 4-stage collector.

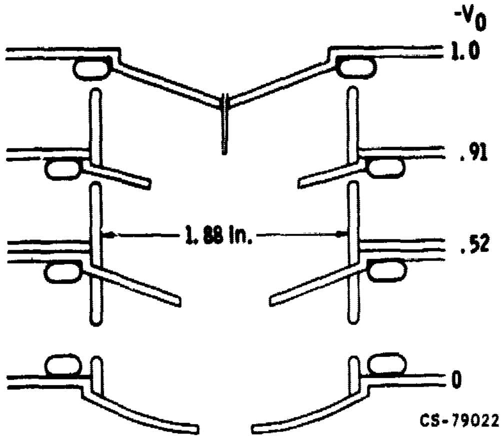

Figure 6. - Simple geometry, 2-stage collector.

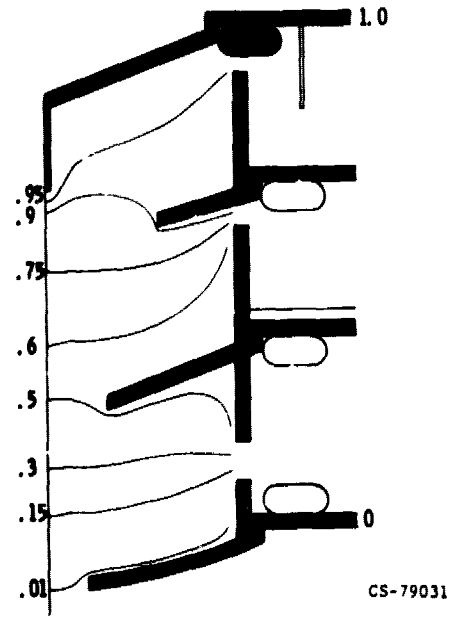

Figure 7. - Simple geometry, 2-stage collector.

	OVERALL EFF, NO MDC, %	OVERALL EFF, WITH MDC, %	COLLECTOR EFF, %
SIMPLE TWO STAGE MDC	12.7	37.6	80.6
COMPLEX TWO STAGE MDC	12.7	39.0	82.1
FOUR STAGE MDC	12.6	41.6	84.2

*MDC EFF OPTIMIZED AT 8.4 GHz (SATURATION). CS-79024

Figure 8. - TWT/MDC performance.

FREQUENCY, GHz	OVERALL EFF* - NO MDC, %	OVERALL EFF WITH MDC, %	COLLECTOR EFF, %
4.8:			
SATURATION	6.9	23.2	81.1
-3 dB (NOMINAL)	4.2	17.5	85.8
-6 dB	2.0	10.1	86.1
8.4:			
SATURATION	12.7	39.0	82.1
-3 dB (NOMINAL)	6.3	27.5	84.5
-6 dB (NOMINAL)	3.2	16.9	85.1
9.6:			
SATURATION	8.5	30.7	83.3
-3 dB (NOMINAL)	4.3	20.4	84.9
-6 dB (NOMINAL)	2.2	12.1	85.3
DC BEAM			90.1

*BASED ON rf OUTPUT POWER AT THE FUNDAMENTAL FREQUENCY. CS-79028

Figure 9. - TWT/2-stage MDC performance. (Optimized at 8.4 GHz (saturation).)

FREQUENCY	OVERALL EFF*- NO MDC, %	OVERALL EFF* WITH MDC, %	COLLECTOR EFF, %
4.8:			
SATURATION	6.9	24.8	83.2
-3 dB (NOMINAL)	3.4	19.0	87.2
-6 dB (NOMINAL)	1.8	10.9	88.0
-9 dB (NOMINAL)	.9	6.5	89.4
8.4:			
SATURATION	12.6	41.6	84.2
-3 dB (NOMINAL)	6.4	30.1	86.4
-6 dB (NOMINAL)	3.1	18.6	87.4
-9 dB (NOMINAL)	1.6	10.9	88.1
9.6:			
SATURATION	8.5	32.9	85.2
-3 dB (NOMINAL)	4.3	23.9	87.2
-6 dB (NOMINAL)	2.2	13.9	87.8
-9 dB (NOMINAL)	1.1	8.1	88.7
DC BEAM			90.8

*BASED ON rf OUTPUT POWER AT THE FUNDAMENTAL FREQUENCY. CS-79029

Figure 10. - TWT/4-stage MDC performance. (Optimized at 8.4 GHz (saturation).)

FREQUENCY, GHz	OVERALL EFF*- NO MDC, %	OVERALL EFF* WITH MDC, %	COLLECTOR EFF, %
4.8:			
SATURATION	7.2	23.6	80.5
-3 dB (NOMINAL)	4.2	17.8	84.8
-6 dB (NOMINAL)	1.9	10.5	85.8
-9 dB (NOMINAL)	.9	6.2	87.8
8.4:			
SATURATION	12.7	37.6	80.5
-3 dB (NOMINAL)	6.4	26.5	83.2
-6 dB (NOMINAL)	3.1	16.1	84.7
-9 dB (NOMINAL)	1.6	9.4	8[illegible].2
9.6:			
SATURATION	8.1	28.8	82.0
-3 dB (NOMINAL)	4.1	19.8	84.7
-6 dB (NOMINAL)	2.0	11.4	85.2
-9 dB (NOMINAL)	1.0	6.4	86.8
DC BEAM			89.4

*BASED ON rf OUTPUT POWER AT THE FUNDAMENTAL FREQUENCY. CS-79030

Figure 11. - TWT/2-stage MDC performance. Simplified MDC design; optimized for 8.4 GHz (saturation).