THE CASSINI MISSION Ka-BAND TWT

A. N. Curren, J. A. Dayton, Jr., R. W. Palmer,
K. J. Long, and D. A. Force
NASA Lewis Research Center, Cleveland, OH 44135

C. E. Weeder and Z. A. Zachar
Hughes Aircraft Company, Torrance, CA 90509

W. L. Harvey
Jet Propulsion Laboratory, Pasadena, CA 91109

ABSTRACT

A 10-watt, 32 GHz TWT is being developed and space-qualified for delivery to the Jet Propulsion Laboratory (JPL) for incorporation into the Ka-Band Transmitter Package for the Cassini Mission. The TWT program is a collaboration between NASA Lewis Research Center (LeRC), Hughes Electron Dynamics Division, and JPL. The Cassini Mission is planned for launch to the environment of Saturn in 1997. Designated Hughes 955H, the TWT has demonstrated an overall saturated efficiency in excess of 40 percent. To achieve this performance, several LeRC-developed technologies, including computer-aided advanced designs of the helix and the multistage depressed collector (MDC), along with suppression of secondary electron emission from the MDC electrodes, were used in the TWT design. An engineering model TWT and two flight model TWT's have been fabricated, packaged, and performance-tested for delivery to JPL. The production of flight hardware as a part of a program which originally was intended as a research effort has resulted in reduced overall costs and a shortened delivery schedule. This development demonstrates the value of vacuum electron devices in low-power microwave applications, frequently conceded to solid state devices in system planning.

INTRODUCTION

This project to develop a high-efficiency low-power traveling wave tube amplifier operating at 32 GHz, the frequency allocated for use in the Deep Space Network, began as a research and technology effort at LeRC. The original intent was to include in the design of the TWT the most advanced high-efficiency technology and to identify the most effective MDC electrode material from among three candidates: high-purity isotropic graphite, machined OFHC copper, and ion-textured OFHC copper. Proposals were received in 1989 from the Watkins-Johnson Company (W-J) and Hughes, and contracts were awarded in 1990 to Hughes and Varian Associates, which had acquired the W-J space TWTA activity. In 1991, Hughes acquired the Varian/W-J space TWTA activity and the parallel efforts were combined. In 1992, JPL and LeRC entered into a Memorandum of Agreement to expand the original research demonstration to include delivery of an engineering qualification model TWTA and the flight model TWT's for the Cassini Mission. Most of the mechanical and thermal design, along with fabrication and testing of the TWT's, has been done by Hughes. LeRC has contributed the electrical designs of the slow wave circuit and MDC, and treated the MDC electrodes to reduce secondary electron emission. LeRC has also managed the contract with Hughes for development of the engineering models of the TWT, the electronic power conditioner (EPC) and engineering qualification model TWTA, along with the flight models of the TWT. JPL has specified system requirements and is managing the contract with Hughes for fabrication of flight models of the EPC and flight TWTA integration.

Achieving the goal of very high efficiency, more than doubling the efficiency of Ka-band TWT's currently available at the required power level, will enable the Ka-band experiment package on Cassini which includes a gravity wave experiment. This goal has been reached by the inclusion of a unique LeRC-supplied helix dynamic velocity taper (DVT) design and advanced MDC design along with ion-texturing of the electrode surfaces and innovations in mechanical and thermal design, fabrication, and testing introduced by Hughes.

TWT DESIGN FEATURES

Fig. 1 displays a simplified longitudinal section view of the 955H TWT and lists some of the significant features. In the TWT, the beam produced by the electron gun passes through the helical interaction section and the final magnetic section where it is refocused for optimum entry into the MDC. The spent beam is then collected at potentials depressed from the circuit potential. Specific features of the TWT are described in the following paragraphs.

Electron gun: The electron gun is a brazed assembly with an anode isolated from ground and incorporating an M-type cathode. This cathode consists of a sintered tungsten pellet matrix impregnated with BaO (5 parts), CaO (3 parts), and Al_2O_3 (2 parts) and is osmium-coated. The alternating current cathode heater draws less than 3.5 watts and uses a single lead wire with the return leg being the molybdenum-rhenium cathode support cylinder itself. With a current loading of approximately 1 A/cm^2, the cathode is operated at 960 C.

Helix Dynamic Velocity Taper (DVT): A key feature of the TWT is the DVT. As fig. 2 (ref. 1) indicates, the interaction section consists of a section of constant-pitch helix from the signal input port to the sever, followed by another section of helix to the beginning of the DVT helix. The pitch in the input section was designed for optimum gain from small-signal theory (ref. 2). Immediately after the sever and preceding the DVT, a short section of synchronous constant-pitch helix causes gradual growth of signal strength and tighter bunching of the beam. The DVT is characterized by a continuous non-linear reduction in helix pitch from its initial synchronous value to near the end of the circuit. The circuit was designed at LeRC using a two-dimensional large-signal computer code originally developed by Detweiler (ref. 3). The reduction in pitch slows the circuit wave, resulting in better synchronization between the circuit wave and the electron bunches in the electron beam than can be realized with a constant-pitch helix. The circuit ends with a short section of constant-pitch helix causing the favorable energy exchange to be continued over a greater length. The overall active length of the interaction section, including the sever, is 4.504 inches, and the helix inside diameter is 0.023 inch. The copper-plated tungsten helix is 0.003 inch x 0.006 inch tape supported by anisotropic pyrolytic boron nitride rods.

Magnetic Structure: The electron beam is confined within the helix by means of a magnetic field imposed by a periodic permanent magnet stack. The ability to machine relatively thin (0.060 inch) samarium cobalt magnets with accuracy now permits fabrication of a short-pitch magnetic stack which in turn provides for beam stability with minimum electron beam scalloping. The magnetic circuit is extended by three additional magnets between the output waveguide and the entrance to the collector to optimize the spent electron beam for efficient collection.

Multistage Depressed Collector (MDC): The design of the four-stage MDC (ref. 4) was performed at LeRC with the use of a computer program developed by Herrmannsfeldt (ref. 5), modified to include the effects of the secondary electron emission characteristics of the electrode surfaces (ref. 6). Fig. 3 (ref. 1) shows, in half-diameter section, the MDC envelope and electrode configurations. The calculation procedure predicts the electron trajectories within the MDC. Shown in the figure are the predicted trajectories of eighty rays of electrons for the saturated RF output power condition along with lines of constant potential. Also indicated are the predicted trajectories of secondarily-emitted electrons. The electrodes are numbered in order from the spent electron beam entry port. Note that very few if any electrons in the beam impinge the last conical electrode which is held at cathode potential.

The design collector electrode voltages and currents for the saturated RF output power conditions and the DC beam condition are presented in Table I. Note that for the DC beam condition most or all of the electrons impinge electrode 3.

The MDC fabrication utilized a modular assembly procedure. Each collector module is symmetrical, made up of the central copper electrode brazed inside a high-purity alumina ring insulator which in turn is brazed inside a kovar outer shell. This construction concept permitted the copper electrode surfaces to be treated at LeRC for secondary electron emission suppression. The modules were fabricated at Hughes, sent to LeRC for treatment, and then returned to Hughes for final MDC assembly. The four individual electrode modules were stacked and welded between a base polepiece and an end-cap fitted with vacuum feedthroughs. Each of the electrodes was individually electrically connected through an axial feedthrough. Fig. 4 shows a set of four of the individual modules as they were received at LeRC. They are shown in a sealed shipping container inerted with dry nitrogen. The direction of the spent beam entry into the MDC is from left to right.

The treatment applied to the copper collector active surfaces at LeRC to suppress secondary electron emission results in a highly-textured surface (ref. 7). It is characterized by a uniform array of densely-packed copper spires averaging about 6 micrometers in height with spacing about 4 micrometers. Since the projections are themselves copper, the surface is suitably robust for the electrode application. A scanning electron microscope photomicrograph of the surface morphology is shown in fig. 5.

TWT PERFORMANCE RESULTS

A photograph of an unpackaged 955H TWT is shown in fig. 6. The electron gun is located at the left and the covered multistage depressed collector assembly is at the right in the figure. Experimental test results for the engineering model TWT and the two flight tubes are shown in Table II. Fig. 7 displays the saturated RF output power for the TWT's across the operating frequency band. During the program, MDC's were fabricated which used untreated copper, high-purity isotropic graphite, and textured copper in separate assemblies. These MDC's were essentially dimensionally-identical and were mated with development TWT's having similar performance characteristics. While these devices are not identical, there is a clear enhancement of overall efficiency demonstrated from the introduction of secondary electron emission suppression by using graphite or textured copper electrodes, with a small advantage to the textured copper. The mass of the flight-packaged TWT is 750 grams. The mass of the EPC to which the Engineering Model TWT is mated to form an engineering qualification model TWTA is 2.67 kilograms for a total TWTA weight of just slightly over 7.5 pounds.

CONCLUDING REMARKS

The TWT development described here represents a significant advance in achieving high efficiency for low power amplifier tubes at this frequency level. It was shown that the textured copper electrodes have a significant efficiency advantage over untreated copper electrode surfaces and a modest advantage over high-purity isotropic graphite electrodes. Further, the delivery of flight hardware directly from a research demonstration program has resulted in reduced overall costs and shortened delivery schedules.

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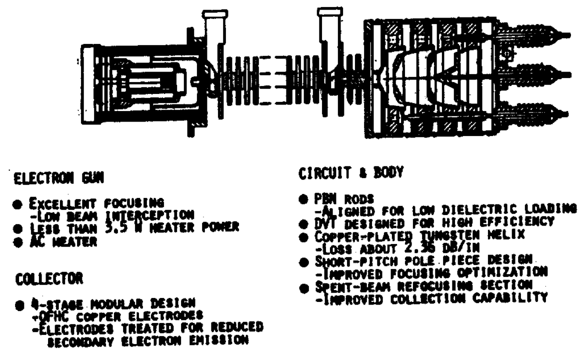

Fig. 1. - 955H Ka-band TWT design features.

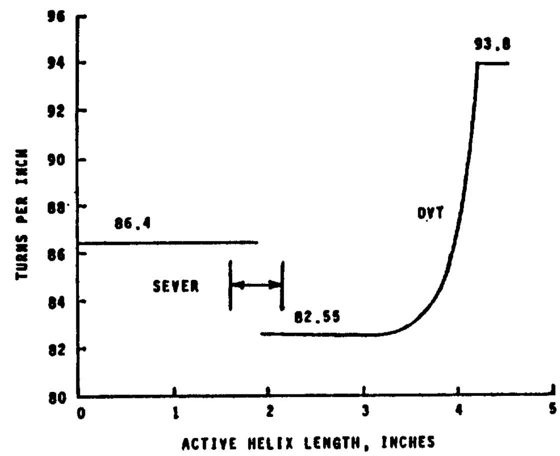

Fig. 2 - Helix turns-per-inch distribution.

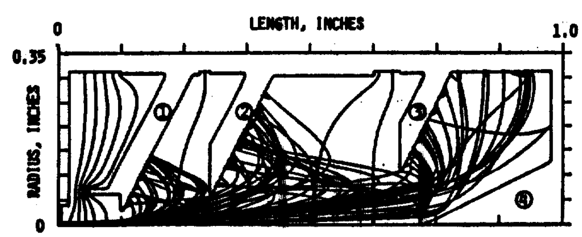

Fig. 3 - Predicted MDC electron trajectories for saturated RF output power.

Table I - MDC Electrode Voltage and Current Distribution

Electrode Number	Voltage, kv	Current, mA	
		Saturated RF Output	DC Beam Condition
Polepiece	0	0	0
1*	-3.195	3.570	0
2	-3.650	5.775	0
3	-4.850	4.550	14.000
4 (Spike plate)	-5.255	0.105	0
	Totals:	14.000	14.000

*Electrodes numbered from polepiece

Fig. 4. - Untreated MDC electrode modules in shipping container.

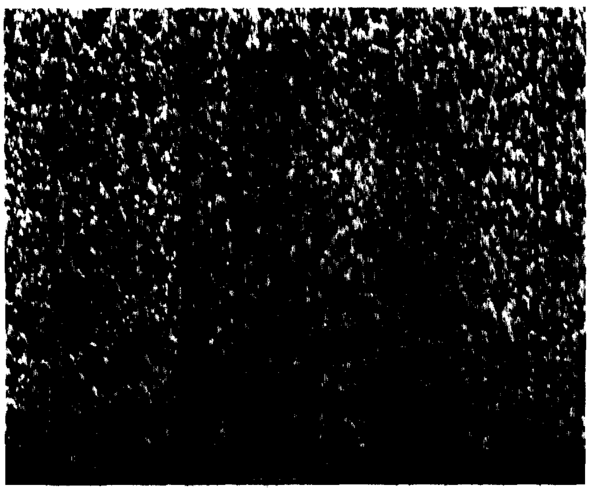

Fig. 5. - SEM photomicrograph of ion-textured copper surface.

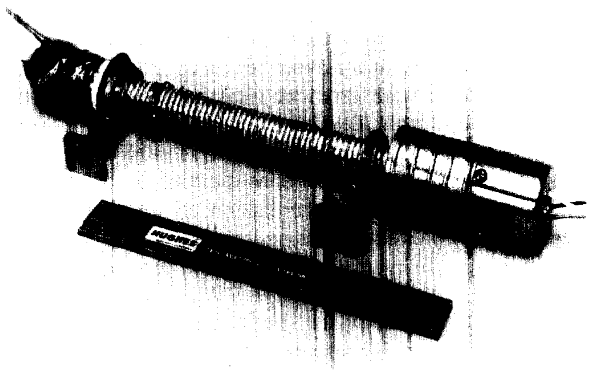

Fig. 6. - Unpackaged development 955H TWT.

Table II - Engineering and Flight Model 955H TWT Test Results at 32 GHz, Saturated RF Output Power

	Eng. Model	Flt. Model 1	Flt. Model 2
Helix voltage, V	5220	5130	5076
Helix current, mA	0.19	0.0056	0.0074
Beam current, mA	14.37	15.10	16.27
MDC electrode 1 voltage, V*	2082	1999	2031
current mA	2.55	2.90	4.13
MDC electrode 2 voltage, V	1753	1739	1625
current, mA	7.71	7.57	7.13
MDC electrode 3 voltage, V	690	688	762
current, mA	3.90	4.36	4.68
MDC electrode 4 voltage, V	0	0	0
current, mA	neglig	neglig	neglig
Total dc power, W	27.46	26.64	28.58
Saturated rf output power, dBm	40.56	40.30	40.66
Saturated rf output power, W	11.39	10.72	11.64
Saturated gain, dB	47.51	40.67	41.37
Beam efficiency, percent	15.2	13.8	14.1
Overall efficiency (incl. heater), %	41.5	40.2	40.7
Heater power, W	4.87	3.28	3.37
Gun perveance, E-6	0.037	0.036	0.039

*MDC electrode voltage shown is difference between helix (cathode) and electrode potentials

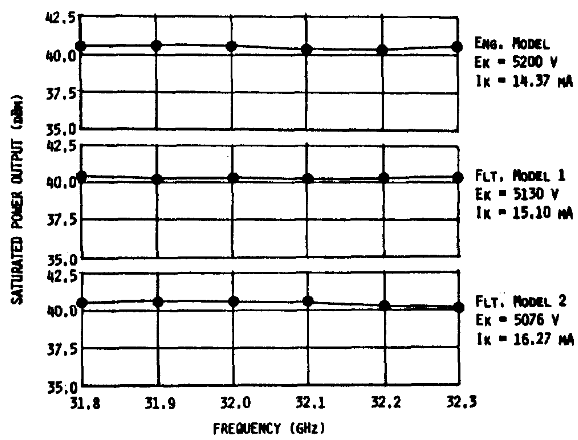

Fig. 7. - Saturated RF output power across operating band.

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