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THE 200 WATT SHF TRANSMITTER EXPERIMENT PACKAGE

by R. Alexovich
Lewis Research Center
Cleveland, Ohio

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by R. Alexovich
Lewis Research Center
National Aeronautics and Space Administration
Cleveland, Ohio

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ABSTRACT

This paper describes a 200 watt S.H.F. Transmitter Experiment Package that incorporates a traveling wave tube utilizing a multi-stage depressed collector for efficiency enhancement. This experiment is being developed by the NASA Lewis Research Center for flight testing on the Communications Technology Satellite.

INTRODUCTION

Recent examples of communication satellites such as live coverage of the winter olympics in Japan and the President's vist to China have been impressive demonstrations. However, these examples illustrate the limitation of present technology to point-to-point communication. As long as satellites are capable of radiating only a few tens of watts, the ground transmitters and receivers will be expensive to build and operate. Few Terminals will be built and the value of the satellite communication system will be limited, much as the telephone system would be if there were only a handful of subscribers who could afford the service. The most direct way of eliminating this obstacle to the development of satellite communications systems is to increase the power radiated from the satellite. With increased power, communication satellite systems will be able to graduate from point-to-point transmission to the point to area transmission needed for broadcast satellites.

The key to increased rf power for communication satellite systems is the development of high power microwave amplifiers with high efficiency. As rf power output increases the importance of high efficiency will be emphasized. For high power satellites, the efficiency of the transmitter directly determines the size of the solar array, thermal radiator, and the weight of the power processing system for the transmitter.

The purpose of the CTS transmitter experiment is to develop and demonstrate communication technology for future high power communication satellite applications.

The CTS transmitter experiment package (TEP) is a 200 W rf output microwave power amplifier and power processing system. The technical objectives of the experiment are:

(a) to demonstrate in space an output stage stage tube (OST) operating with efficiency $\geq 50\%$ and an rf output power 200 W at a frequency of 12 GHz,

(b) to demonstrate reliable high-efficiency performance of a TEP for 2 years in a space environment, and

(c) to obtain fundamental data for further advancement in the state-of-art of high power microwave amplifier operations in space.

The TEP will be used as an rf output power amplifier in one channel of the CTS communication transponder, shown as TWT-3 in fig. 1. It consists of a 200 W rf output traveling wave tube (TWT) with a multi-stage depressed collector (MDC), collector enclosure and support power processing system (PPS). Assembly of these elements are depicted in fig. 2. The approach to achieve an overall efficiency of 0.5 for the combined TWT and MDC utilizes two techniques. A velocity taper technique is used to enhance the interaction efficiency of the TWT. This is combined with a ten stage depressed collector, a concept developed by the LeRC to enhance the efficiency of linear beam microwave amplifiers.[1,2]

TWT

The TWT is a class of linear-beam microwave amplifer's which converts dc electrical power into rf power through the medium of an electron beam. The TWT can be seen in fig. 3. The electron beam is formed by means of a convergent electron gun containing a thermionic emitting cathode. The electrons within the beam are then accelerated from the cathode to the anode region to a velocity of approximately 1/5 the speed of light and pass through the interaction region of the tube. The interaction region of the tube is composed of cylindrical cavities, coupled to form a lumped-element transmission line called a slow wave structure. Beam focusing is obtained by periodically placed permanent magnets. The input rf wave interacts with the beam as it passes through the tunnel and the kinetic energy of the beam is converted to rf energy.

The average velocity of the beam decreases as its kinetic energy is converted to rf energy. This phenomena, if uncorrected, would cause the circuit wave to fall out of synchronism with the beam velocity, resulting in reduced TWT efficiency. In this TWT synchronism is maintained by changing the circuit wave velocity of the transmission line or slow wave structure. This is done in two sections of the structure by decreasing the spacing between cavity walls. This can be seen in slow wave structure construction near the output waveguide. The basic TWT efficiency is thus increased by this mechanism.

The beam, after passing through the interaction region of the tube, enters the region of the MDC. A refocusing solenoid is used to control the diverging electron beam and establish desired MDC entry conditions.

MDC

The MDC is a device which is used to further increase the efficiency of the microwave power amplifier. This is accomplished in principal by converting the kinetic energy, remaining in the spent electron beam, to potential energy thereby reducing the power required to operate the tube. The spent electron beam which enters the collector region of the tube is no longer monoenergetic, but has a range of velocities due to rf interaction in the slow wave structure. The MDC sorts the electrons according to velocity, reduces their velocity to near zero, and collects the electrons on electrodes at near zero velocity.

The multistage depressed collector consists of a set of electrodes as shown in fig. 4. The electrode surfaces are shaped to produce equipotential surfaces. The field configuration they produce, when connected to fixed, selected potentials established by the PPS, causes the beam electron trajectories to follow paths as shown in fig. 5. Apertures for passage of the beam electrons are sized to collect the electrons near the apex of their trajectories, thereby converting the electron beam kinetic energy to potential energy (ref. 2).

The use of the multistage depressed collector not only results in a higher efficiency at tube saturation, but also the curve of tube efficiency is no longer a linear function of output power, but remains at a high value even when the tube operates in the linear range, 4 to 6 dB below saturation. This allows for considerable communications system flexibility, as multichannel operation can be accomplished with less dc power required than was previously expected for such systems.

The input power P_{in} required to operate the TWT and ten stage depressed collector is given by

$$P_{in} = \sum_{n=1}^{10} V_n I_n$$

where V_n in the n^{th} collector electrode voltage, with respect to the cathode, and I_n is the n^{th} electrode current. This may be compared to a TWT with a single stage, undepressed collector. The power required to operate the tube is given by $P^1_{in} = V_o I_o$

$$\text{where} \quad I_o = \sum_{n=1}^{10} I_n \quad \text{and} \quad V_o \geq V_n$$

Therefore it can be seen that

$$P_{in} < P^1_{in}$$

The residual kinetic energy in the collector electrons is dissipated as waste heat and raises the temperature of the collector electrodes. This waste heat is radiated to the collector enclosure and from the enclosure to space.

PPS

The power processing system provides the proper operating voltages and regulation required by the TWT and MDC, fault sensing and protection for the TEP, and control for remote start up and shutdown. A simplified schematic of PPS can be seen in fig. 6. Separate inverters are provided for the cathode heater, anode, two sets of collector electrodes, and the cathode supply. The latter requires high regulation 0.1% and low ripple 0.01% to achieve proper gain, and preclude modulation of rf output respectively. Energy pumped inverters are used, operating at a switching frequency of 30 kHz, and with an input spacecraft bus voltage of 67V.[3] Regulation is achieved by pulse width modulation of the switched primary voltage.

TEP PERFORMANCE

The TEP must have communication specifications which permit it to be used for wide band communications. Specifically for transmission of single and multichannel television and high rate data transmission. Communications performance for the TEP is listed in table I.

Table I

Saturated rf power output, W	200
Center frequency, GHz	12.0805
Frequency range (3 dB), MHz	85
Saturated gain, dB	33
Gain variation (small signal, dB)	3
Gain compression (dB)	6
Overall efficiency, percent	50
Maximum noise, dB	40
Harmonic output (WRT fund), dB	-30
Spurious output (WRT fund), dB	-37
Phase deviation, deg/MHz^2	0.2
Load VSWR	1 25:1
Input waveguide	WR 75
Output waveguide	WR 75

The overall efficiency of the TWT and MDC is expeted to be 0.50 or better. This high efficiency will be achieved through the use of velocity taper of the TWT slow wave structure to enhance its efficiency and the use of a ten stage depressed collector to further reduce power required for tube operation.

The PPS will use an energy-pumped inverter operating at 30 kHz to provide the multi-kilovolt power required by the TWT and MDC. This approach is expected to yield a PPS efficiency of 0.85.

REFERENCES

1. F. E. Kavanagh, R. E. Alexovich, and G. J. Chomos, "Evaluation of Novel Depressed Collector for Linear-Beam Microwave Tubes," NASA TM X-2322, 1971.

2. H. G. Kosmahl, "A Novel Axisymmetric, Electrostatic Collector for Linear Beam Microwave Tubes," NASA TN D-6093, 1971.

3. F. Gourash, A. G. Birchenough, P. F. Pittman, R. J. Ravas, and W. G. Hall, "Development and Performance of Pulse-Width-Modulated Static Inverter and Converter Modules," NASA TN D-6511, 1971.

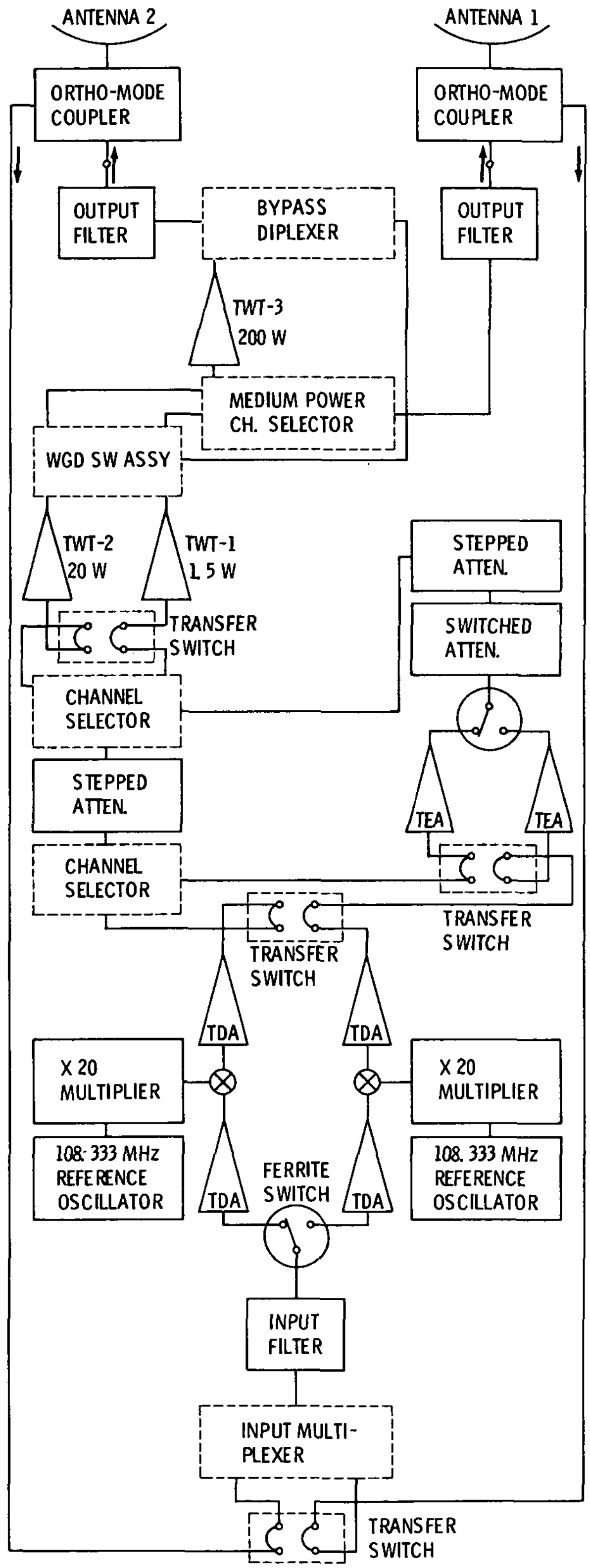

Figure 1. - CTS communications transponder.

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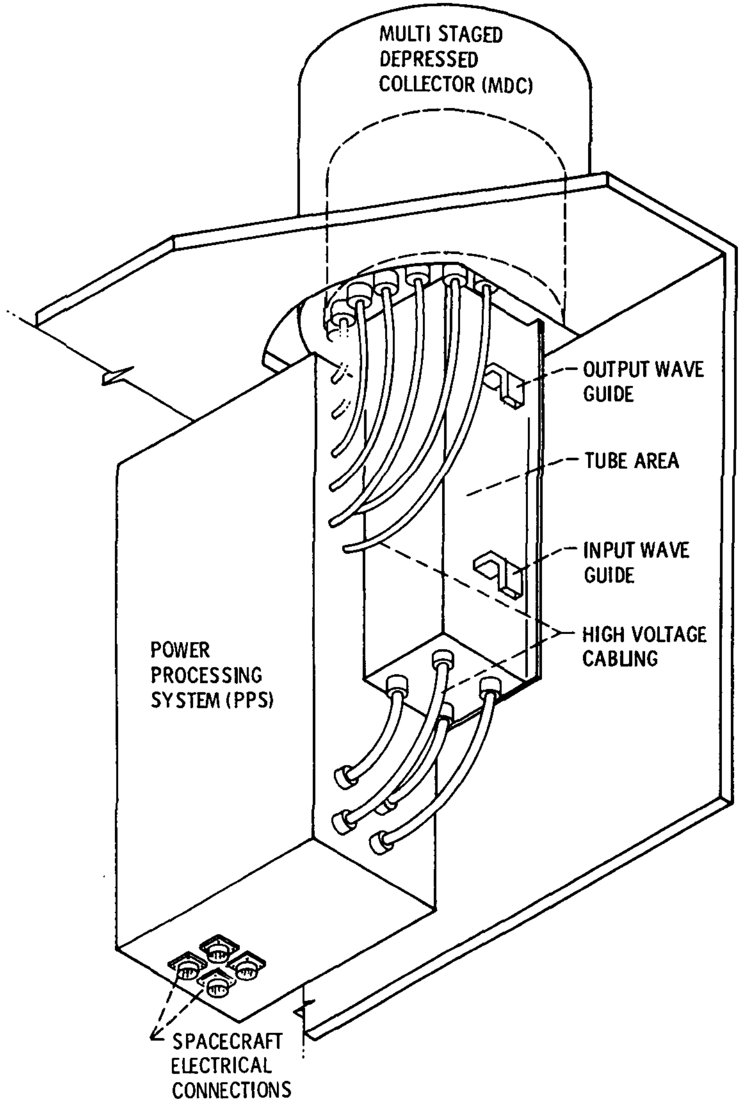

Figure 2. - CTS transmitter experiment package.

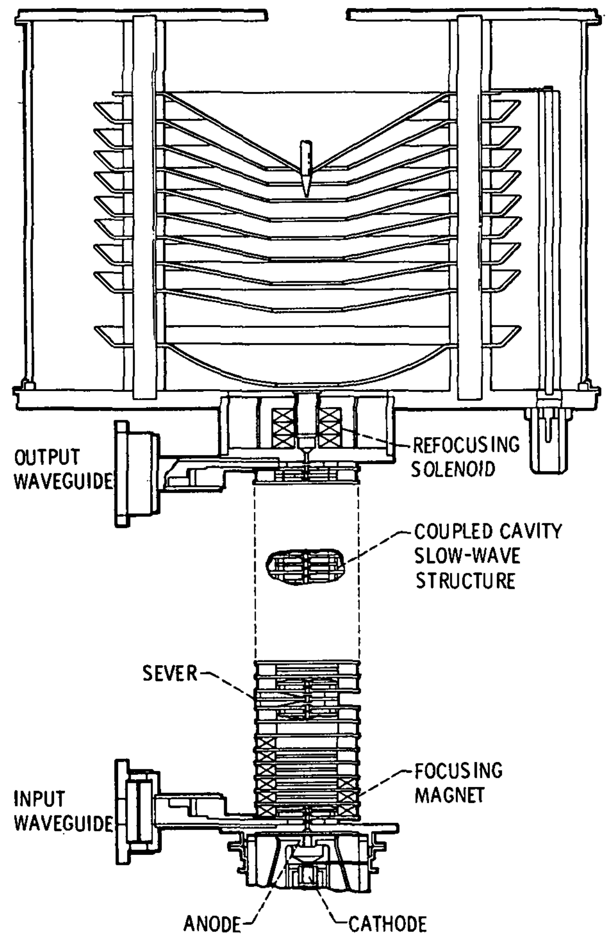

Figure 3. - Coupled cavity trajectory wave tube multi stage depressor collector.

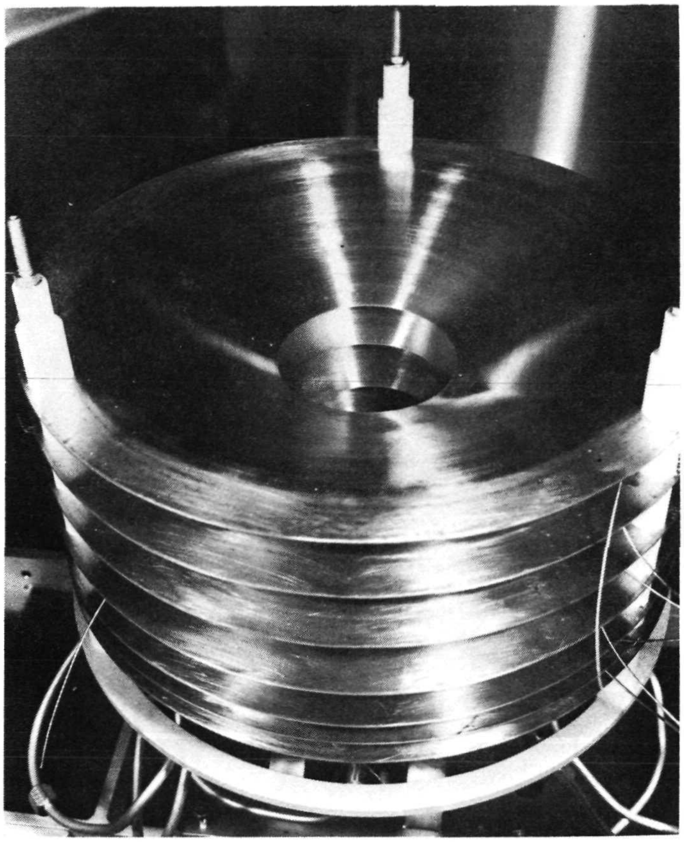

Figure 4. - MDC electrode assembly with top electrode removed.

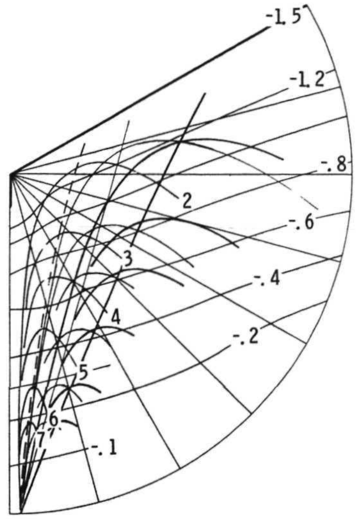

Figure 5. - Electron trajectories in MDC.

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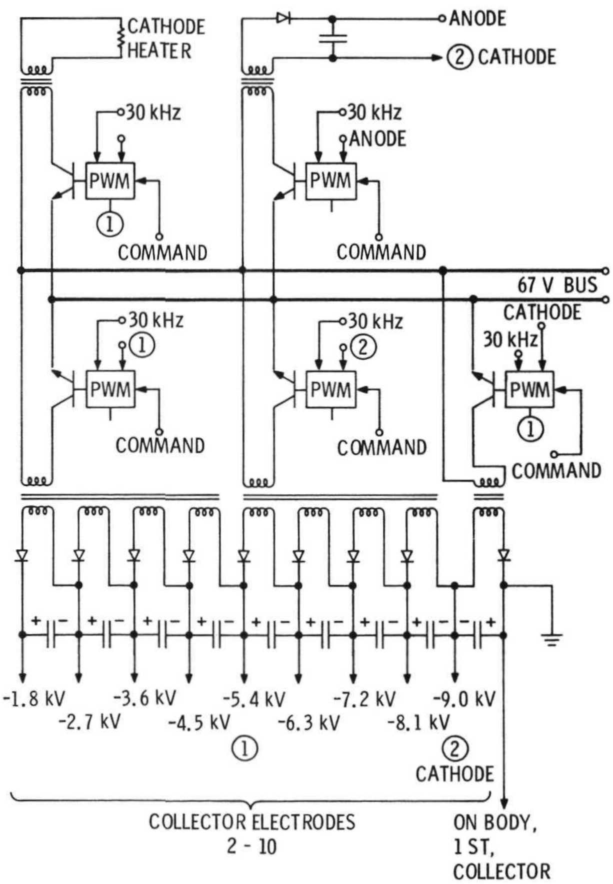

Figure 6. - Simplified schematic of PPS.