

LN82 22738

## POWER AMPLIFIERS (TUBE)

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The microwave tube devices that have been proposed to meet the SPS transmitter requirements of very high efficiency, low mass, long life, high temperature operation, and low radio frequency interference are the klystron, magnetron, amplatron, and two new devices, the gyrotron and the photoklystron. The klystron and the magnetron in its directional amplifier form are the furthest advanced and have received the most attention. The klystron approach proposes a 70 kilowatt design with depressed collectors and recycled DC power for high efficiency and a heat pipe system to radiate the heat. The magnetron directional amplifier approach proposes an efficient 3-5 kilowatt tube scaled from the microwave oven magnetron and an attached radiator made from pyrographite to passively radiate heat.

The operating principles of the klystron and the crossed field device in either its magnetron or amplatron configuration are shown in Figure 1. In the klystron the energy of the power supply is converted into kinetic energy of the electron stream. The electron stream is then velocity modulated so that the electrons bunch together. These bunches are then abruptly slowed as they pass through the output cavity and most of their energy is converted into microwave energy. The left over energy may be partially extracted in the form of DC power from a series of depressed collectors. The DC power is reprocessed and added to the power feeding from the power supply.

The crossed field device works on a different principle in that the electrons are just given a small amount of kinetic energy to become synchronous with the microwave circuit. From that time on there is a direct conversion of the potential energy of the power supply into microwave energy.

The microwave generator's ability to operate efficiently and to dispose of waste heat by operating at a high temperature dominate the design of the microwave transmitter. Figure 2 shows the amount of microwave power that can be radiated per unit area as a function of the efficiency and operating temperatures of the tube, and indicates the comparative capability of crossed field generators, klystrons, and solid state devices.

The maximum efficiency that has been achieved from a klystron is 75% while the efficiency that has been achieved by both magnetrons and amplatrons is in the 83 to 85% range. Top efficiency from a klystron after a substantial development program is expected to be 85%. A similar effort could increase the crossed field device efficiency to 90%.

Because this symposium places emphasis upon recent technology developments much of the remainder of this extended abstract will review an ongoing investigation of a power scaled version of the microwave oven magnetron as a potential generator for the SPS.

A principle item of interest is the noise measurements that have recently been made on the common microwave oven magnetron. Making use of a special measuring technique in which a high-power, narrow-band notch filter rejects all but one part in 100,000 of the carrier signal to permit a spectrum analyzer to be exposed to the full level of the noise output, signal to noise ratios of 180 to 190 dB/Hz in selected tubes have been measured. The measurement sensitivity is still limited at frequencies outside of a 60 MHz band centered on 2450 MHz by the residual noise level of the spectrum analyzer. To place these measurements in perspective, such high ratios means that an 8 gigawatt SPS transmitter would radiate less than 2.5 milliwatts of noise for each megacycle of the frequency spectrum.

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Difficult-to-make harmonic measurements have been obtained on the magnetron with two different measurement techniques. Jet Propulsion Lab. measurements indicated -55 dB, -65 dB, and -68 dB for the 2nd, 3rd, and 4th harmonics, while the Raytheon measurements indicated -71 dB, -85 dB, and -86 dB. These levels are lower than those expected for klystrons but are still orders of magnitude above what would be acceptable without making special frequency allocations for these harmonics or making extensive use of filters which would badly compromise efficiency and mass of the SPS.

To develop an experimental model of the SPS transmitting antenna architecture the microwave oven magnetron has been combined with a ferrite circulator, a section of slotted waveguide radiator, and a control system to force the amplitude and the phase of the radiated output to follow phase and amplitude references. The amplitude control arrangement is shown in Figure 3.

The amplitude reference is set and the amplitude of the output is maintained to within + 4% of the reference over the voltage and current operating range of the magnetron directional amplifier as indicated by the data of Figure 4. Figure 4 also shows how the amplitude control feature can be used to accommodate the tube to large variations in the characteristics of the solar cell array. In this context the amplitude control feature could replace much of the complex power conditioning associated with changing from one DC voltage to another at high power levels that would otherwise be necessary.

Similarly, the phase of the radiated power as measured by a probe placed in front of the slotted waveguide radiator is controlled to within + 1 degree of the reference over the operating range of the magnetron directional amplifier.

The amplitude and phase control has been achieved with solid state circuitry. The mass and cost of these devices is acceptable to the SPS but special arrangements must be made to keep them at an ambient temperature below 125°C by mounting them on the slotted waveguide radiator and using it as a heat sink as necessary. Thermal separation of the waveguide radiators from the microwave generators is accomplished by a blanket of insulation.

Special problems still remain in a transition from the experimental system just reviewed and application to the SPS. The ferrite materials in the circulator are not suitable for high temperature operation in space. A "Magic T" arrangement is an alternative but a design in which phase and amplitude control are maintained without placing solid state sensors in a high temperature environment has not been experimentally verified. Similarly the motor driven coaxial phase shifter which was used to correct for phase shift through the tube to maintain the reference phase at the output is probably not acceptable for space use.

Long life is an important requirement imposed upon the generator in the SPS. Magnetrons that are expressly designed for the SPS are expected to have a very long life. Such expectations are supported by optical measurements of low cathode operating temperature in the microwave oven magnetron. At the 400 watt microwave output level these temperatures are sufficiently low to indicate lifetimes of tens of years. In scaling to the SPS requirements, tube designs with potential lifetimes of fifty or more years can be expected.

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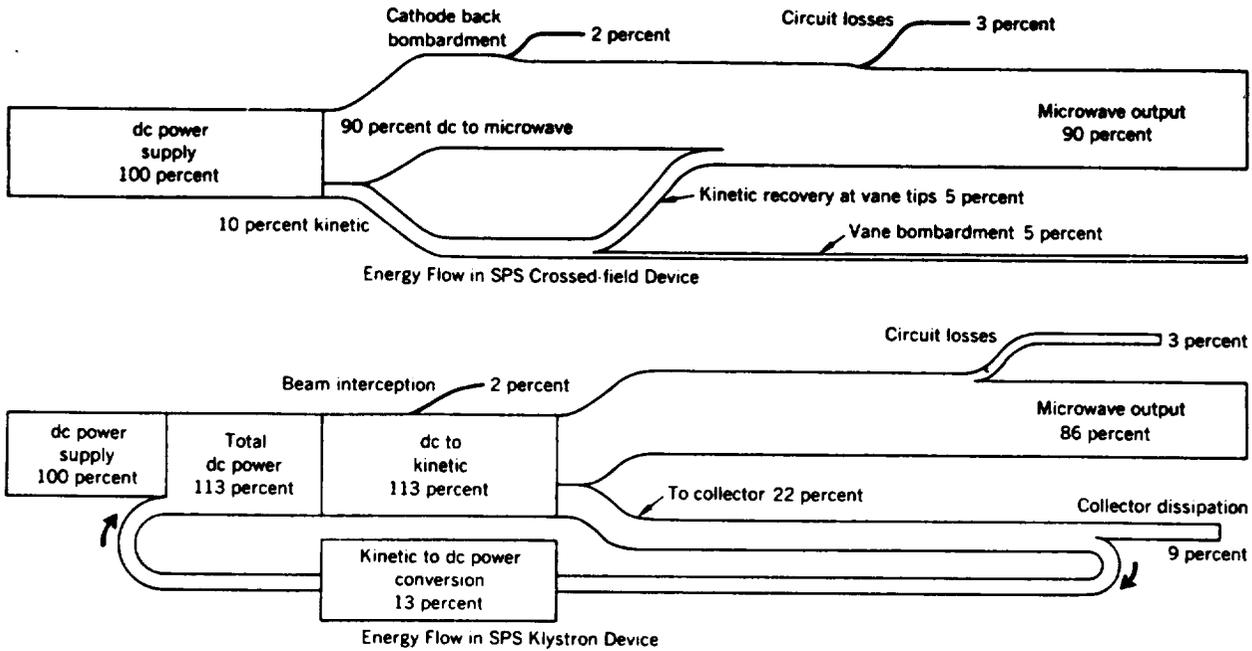


Figure 1. Comparison of DC-RF Conversion Operations for Crossed-Field (Top) and Linear-Field (Bottom) Beam Devices.

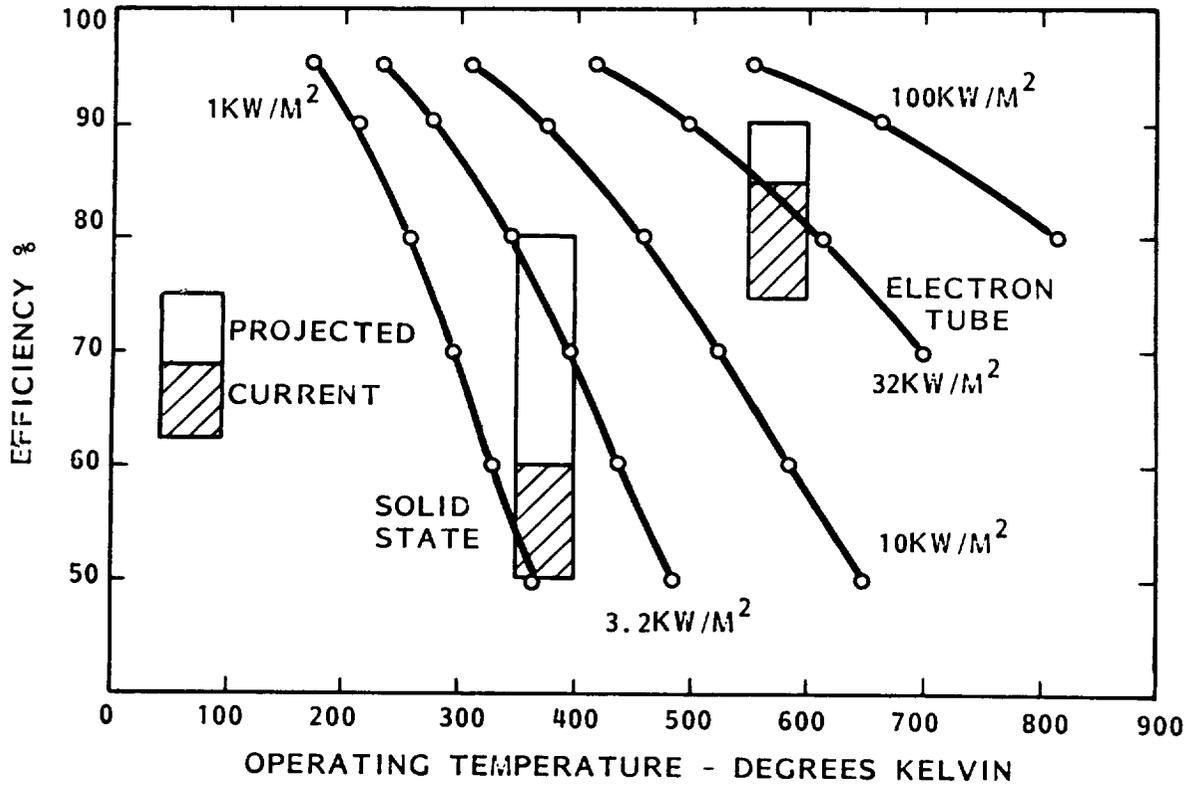
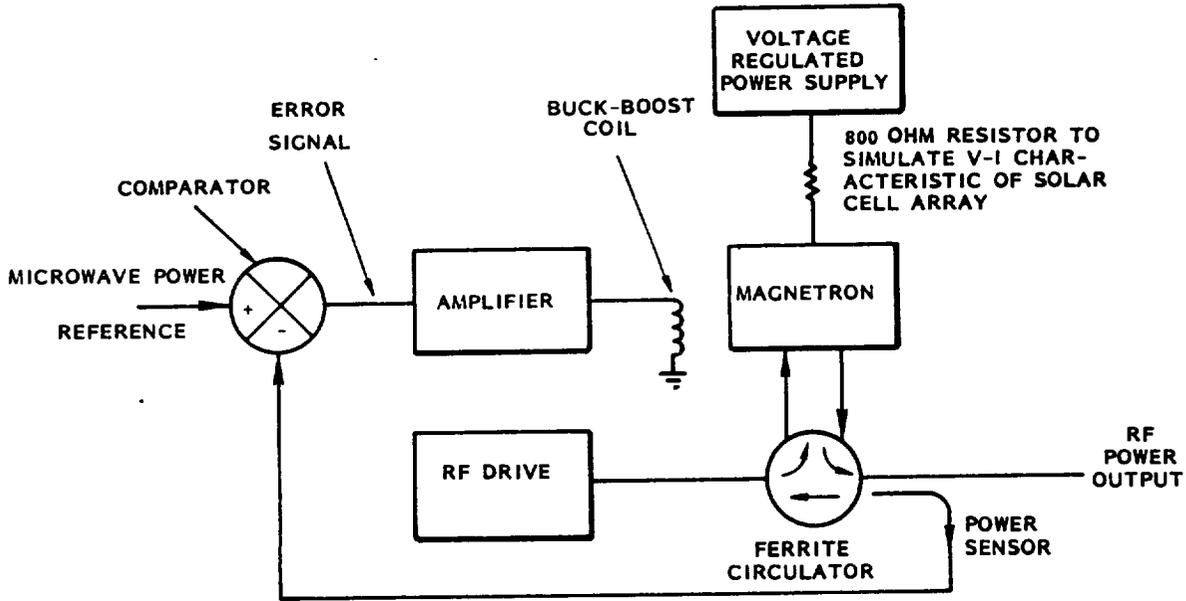


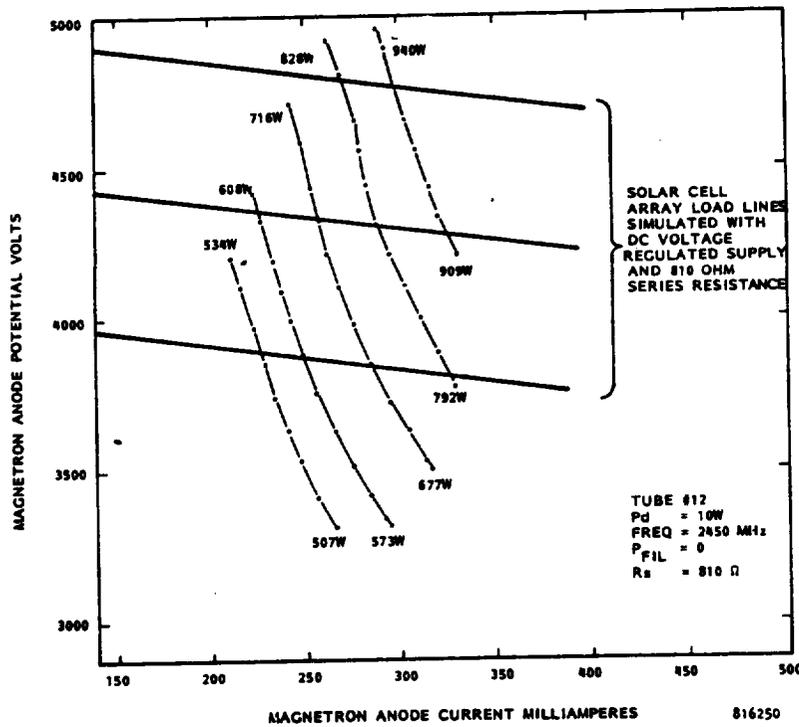
Figure 2. Contours of Microwave Power Outputs as Function of Efficiency and Operating Temperature of Microwave Generators. 813693

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Figure 3. Test Arrangement for Evaluation of Amplitude Control.



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Figure 4. Experimental Data Showing Five Amplitude Tracking Curves Corresponding to Five Different Settings of the Power Reference.