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Computer Aided Design of Ka-band Waveguide Hybrid Junctions for Power Combining Architectures in Interplanetary Spacecraft

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Abstract: *NASA's Prometheus program proposes using nuclear fission to provide unprecedented power capabilities for future interplanetary missions. Through nuclear fission, we can consider power-combining techniques using multiple TWTAs as opposed to multiple solid-state devices. Waveguide architectures represent one method of combining the power of multiple TWTAs and the fundamental element of waveguide combining architectures is the hybrid junction. We present the simulated transmission characteristics of four waveguide hybrid junctions designed for use in a TWT power combining system capable of producing a kW of power.*

Keywords: Hybrid Junctions; Power Combining; TWTAs; Ka-band; communications.

Future deep space missions for NASA's "Vision for Space Exploration" demand communication systems with larger bandwidths, higher bit-rates, lower bit-error-rates, and the capability to use complex digital modulation schemes. One method to improve the current state-of-the-art is to increase the total power available in the spacecraft, thereby allowing the use of techniques typically disregarded because of high power consumption. Nuclear fission, a key component of NASA's Prometheus Program [1], can provide unprecedented power capabilities. Therefore, the focus is upon RF transmission systems currently capable of producing kilowatts of output power at Ka-band frequencies.

One approach to designing a kW space transmitter is to combine the output of multiple power amplifiers. Power combining is a well-known technique, especially for solid-state devices. While successful for lower power levels, at Ka-band frequencies, combining state-of-the-art solid-state devices has not yielded output power above hundreds of

watts. In contrast, a single space TWT, such as the TWT developed by Boeing for a NASA GRC contract, can deliver over 180W at Ka-band frequencies with a power added efficiency of 59% [2]. Therefore, combining the power output from multiple TWTAs is a logical means to transmit kW in a harsh space environment. Two methods of power combining were considered for meeting the stated goals: waveguide architectures and spatial combining architectures. We chose waveguide power combining architectures for their commercial availability and ease in manufacturing. In case of amplifier failure, waveguide switches can be easily included to switch in redundant amplifiers.

The combining of two high power Ka-band traveling wave tubes has been successfully demonstrated, showing over 90% combining efficiency and a data rate over 600 Mb/sec using QPSK[3,4]. Waveguide hybrid junctions are commercially available; however, many vendors do not test for a power handling capability greater than a few watts. In addition, the tuning elements that are typically used for impedance matching (needed for maximum power transfer and power balance) are not well suited for the high powers being considered. In this power range, small structures like cones, rods and stubs can concentrate electric fields, possibly leading to RF breakdown.

In this paper, we present the simulated transmission characteristics of four waveguide hybrid junctions, which are the fundamental elements of the corporate (or binary tree) power combining system being considered. The hybrid junctions and their matching elements were chosen for high power handling capabilities. Figure 1 and Figure 2 show two examples of high power hybrid junctions and their transmission characteristics. In our work, we use the commercially available CST Microwave Studio [5] and MiG's WASPNET[6].

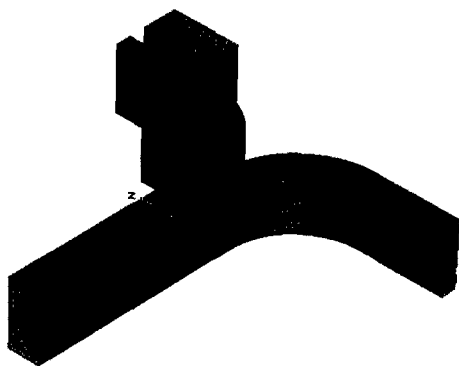


Figure 1. "Split collinear arms" Folded E-Plane Tee

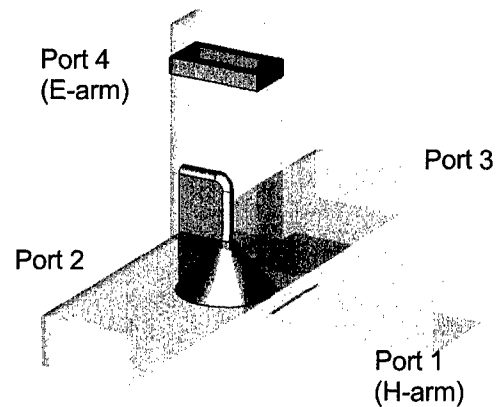


Figure 1b. Magic Tee matched by a cone-fin structure

Hybrid Junction	Insertion Loss		Reflection Loss		Isolation
	S21 dB	S24 dB	S11 dB	S44 dB	S41 dB
Magic Tee (cone-fin)	-3.156	3.426	-15.44	-9.823	-136.3
Folded E-plane Tee (split collinear arms)	-3.068	-3.073	-14.84	-19.17	-140.6

Table 1. Comparison of the simulated transmission characteristics of hybrid junctions (shown in Figure 1) constructed from WR-28 waveguide with a frequency range from 31.8 to 32.3 GHz.

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