ANALYSIS OF A PASSIVE SPATIAL COMBINER USING TAPERED SLOTLINE ARRAY IN OVERSIZED COAXIAL WAVEGUIDE

Pengcheng Jia, Yu Liu, Lee-Yin Chen, Robert A. York

Electrical and Computer Engineering Department
University of California at Santa Barbara

ABSTRACT

Tapered finline or slotline array has shown a wide bandwidth from 8 to 12 GHz in rectangular waveguide based spatial power combiner, but its bandwidth is still limited by the cutoff frequency of the rectangular waveguide. In this paper, tapered slotline array in the oversized coaxial waveguide is analyzed and fabricated. A much wider bandwidth of more than 12GHz is achieved. Spectral domain method (SDM) is used to model the passive structure. The modeling shows good agreement with the HP HFSS simulation, and is vindicated by the experiment result. The tapered slotline array in oversized coaxial waveguide also shows little dispersion and low higher modes over the 4-16 GHz bandwidth. It proves that slotline array in oversized coaxial waveguide is a good candidate for wideband high power combiner.

INTRODUCTION

The tapered transmission lines have shown good impedance matching over a wide passband [1]. This property is shown in the rectangular waveguide power combiner using intense tapered finline array, which has achieved a wide passband from 8 to 12 GHz [2]. But the cutoff characteristics of the rectangular waveguide restrict the lower frequency operation of the system. This complicates amplifier design, as active circuits must be unconditionally stable out of band. And in this configuration the slot line array is fed by a TE10 mode, and hence dispersion becomes a problem.

To overcome the defects, a coaxial power combiner was first proposed by Angelos Alexanian and Robert York [3]. A flared coaxial line is loaded radially with tapered slotlines along the direction of wave propagation. Each input slotline provides a gradual transition from the coaxial TEM field to a planar transmission line, for compatibility with standard microwave integrated circuitry. After passing through an active or passive circuit, the signal is coupled back into the coaxial line using a similar tapered slot transition.

The geometry of the taper is chosen to minimize reflections and optimize impedance matching and bandwidth. The tapered slot structure is inherently broadband and provides excellent input/output isolation. In turn the coaxial environment supports a TEM mode that has no lower frequency cutoff. The above features guarantee broadband performance. The novelty of our design compared to previous schemes lies in the introduction of tapered slot transitions in a radial configuration. The energy is distributed evenly to each slotline taper around the coax. The dispersion is small and the linearity would be improved greatly. Furthermore the radial arrangement allows for high device packing density. The inner and outer radius of the flared line can be chosen to accommodate as many devices as needed to meet the specific power demand.

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STRUCTURE OF COAXIAL WAVEGUIDE SLOTLINE ARRAY

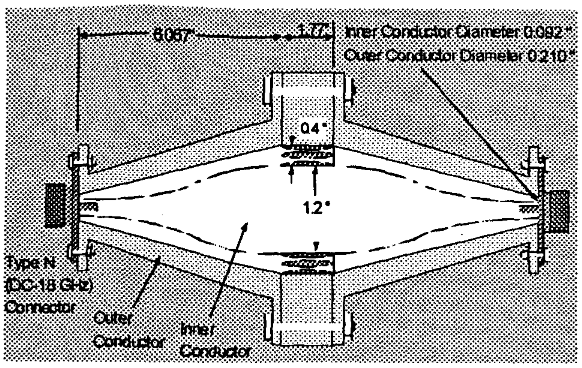

Figure 1 Schematic of flared coaxial waveguide with intense slotline array (from type N connector to 30 Ohm line)

As shown in Figure 1, an optimized coaxial waveguide taper is applied at both end to transform from a standard 50 Ohm type N connector to the flared coaxial line. Reflection caused by the waveguide transition is minimized. The inner radius of the enlarged portion of the coaxial line was chosen to be 0.6 inch, and the outer radius is 1 inch, corresponding to a 30 Ohm line, which provides better matching with the slotline array.

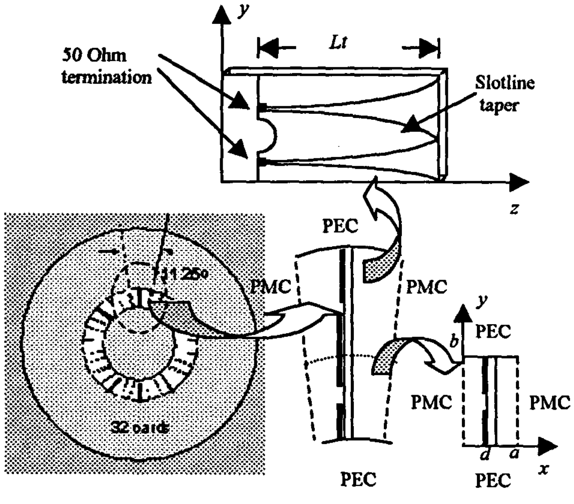

Figure 2 The cross section of flared coaxial waveguide with 32 cards inside

To maximize the isolation between input port and output port, 32 cards are needed inside the coax, and better than -20dB isolation is achieved. Each cards have 2 slot line, and could carry 2 MMIC power amplifiers. That means a maximum of 64 MMIC power amplifiers could be integrated into this system.

MODELING OF SLOTLINE ARRAY IN COAXIAL WAVEGUIDE

32 grooves were machined in the walls of the coax along its length. We assume perfect contact between the slot line and waveguide walls. As shown in Figure 2, the structure is reduced to a waveguide cell for analysis purpose, with PEC (Perfect Electrical Conductor) and PMC (Perfect Magnetic Conductor) boundary conditions applied according to the symmetry. Each waveguide cell has 2 slotlines inside, and a PEC boundary condition is applied to divide it into 2 unit cells. To achieve the same characteristic impedance, each one has the same outer radius to inner radius ratio. Due to the small size of the unit cell, it is approximated by a parallel plate waveguide cell. Then SDM (Spectral Domain Method) can be applied to analyze the field.

SDM for rectangular waveguide finline array is elaborated in [4], only key steps are pointed out in this paper. In the spectral domain approach, the electric fields and currents are Fourier transformed via:

$$\tilde{E}_i = \frac{1}{b}\int_0^b E_i \cdot e^{j\alpha_n y} dy; \qquad (1)$$

where $\alpha_n = \frac{2n\pi}{b}$ for all odd modes, including dominant one, and $\alpha_n = \frac{(2n-1)\pi}{b}$ for all even modes.

By applying the interface conditions at x=d, we could obtain two algebraic equations:

$$Y_{yy}\tilde{E}_y + Y_{yz}\tilde{E}_z = j\omega\mu_0\tilde{J}_y,$$
$$Y_{zy}\tilde{E}_y + Y_{zz}\tilde{E}_z = j\omega\mu_0\tilde{J}_z. \qquad (2)$$

The Y matrix can be derived in a convenient and intuitive way using an equivalent transmission line concept [5]. The unknown aperture fields E_y and E_z were expanded in terms of a basis set of rectangular pulses ξ_i and η_i, then Fourier transformed to

$$\tilde{E}_y(\alpha_n) = \sum_{i=1}^{N_y} c_i\tilde{\xi}_i(\alpha_n),$$
$$\tilde{E}_z(\alpha_n) = \sum_{i=1}^{N_z} d_i\tilde{\eta}_i(\alpha_n). \qquad (3)$$

Substituting (3) into (2) gives a homogeneous matrix equation. The propagation constants and effective permittivity over the normalized gap was then found from the characteristic equation. To verify the simulation result of SDM, the structure was simulated by HP HFSS. Good agreement was found as shown in Figure 3, which validated the approximation for this structure. The theoretical analysis also proves that the dominant mode of propagation along the slotline array is Quasi-TEM mode. The second higher mode excited by the oversized structure is more than 10 dB lower than dominant mode, and third higher mode is 30 dB lower.

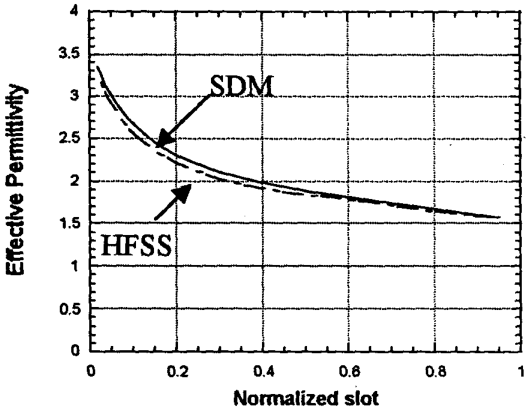

Figure 3 Effective permittivity @ 8GHz from SDM and HP HFSS

Effective permitivity of different frequencies was computed and compared with the rectangular waveguide finline array. As shown in Figure 4, the dispersion of the coaxial waveguide was small over a 12 GHz bandwidth. This shows that the coaxial waveguide slotline array is a good candidate for wideband applications.

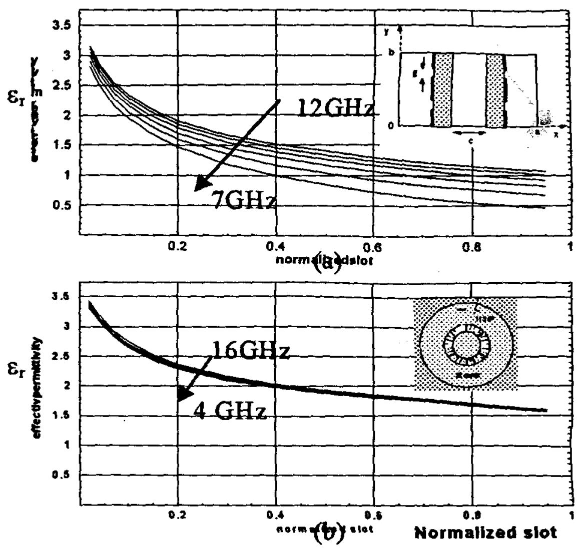

Figure 4 – Dispersion over wideband
(a) X Band rectangular waveguide power combiner (b) Coaxial power combiner

EXPERIMENT RESULT

To verify the simulation result, a 32 tapered slotline array was fabricated. In order to integrate with solid state devices, the end of the slotline needs to be matched to 50 Ohm. The taper, shown in Figure 2, uses the shape of $Exp[Sin(\frac{\pi z}{2L_t})]$, where Lt is the length of the taper. The bandwidth is determined by the length of the taper line: the longer Lt, the lower cutoff limit. So we chose Lt as 1.2 inch. The opening of the slotlines have the same inner radius to outer radius ratio. So energy could be distributed evenly to the upper taper and lower taper. The end of the slotlines are terminated with 50 Ohm thin film resistors, which has low parasitic inductance.

The S parameter measurements were performed. After compensating the insertion loss of waveguide transition, the return loss was plotted in Figure 5. It showed that the return loss was lower than −10dB from 4 to 16 GHz. The result was also compared with HP HFSS simulation. Good agreement proved that this structure can be used for wideband power combiner.

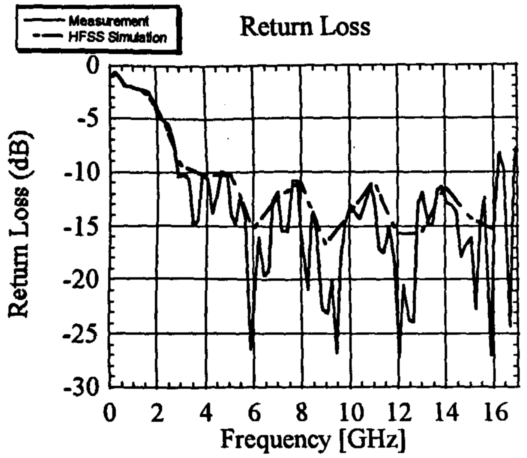

Figure 5 – Measurement and HFSS simulation of return loss for 32 cards passive slotline array with 50 Ohm load

The shape of the taper is chosen for easier analysis. After the verification of the experiment result, an optimize taper will be applied for better impedance matching at shorter taper length.

CONCLUSIONS

A coaxial waveguide power combiner was analyzed and measured. Modeling based on SDM has shown good agreement with the HP HFSS simulation result. We achieved return loss lower than −10 dB over 4-16 GHz bandwidth with 50 Ohm termination at the end of the taper. The structure also demonstrated low dispersion property. The system could integrate a maximum of 64 MMIC power amplifiers. We could combine the tapered slotline with solid state devices well, and good efficiency and high output power will be achieved by this novel structure.

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