BROADBAND WAVEGUIDE-BASED SPATIAL COMBINERS

Angelos Alexanian and Robert A. York

Department of Electrical and Computer Engineering
University of California at Santa Barbara

ABSTRACT

We are presenting broadband, waveguide-based, spatial combiners. An array of tapered slotlines is inserted between rectangular waveguides. Results for a 2x4 active array at X-band are presented, indicating good combining efficiency and thermal properties as well as excellent bandwidth. To increase the device packing density and remove the lower cutoff frequency of the rectangular waveguide a coaxial combiner is also proposed. A radial arrangement of tapered slotlines is placed between two flared coaxial lines. 64 elements are combined with low combining loss over the 5 to 20 GHz band.

INTRODUCTION

Spatial power combining [1] addresses the efficiency limitations of conventional combining schemes for large numbers of devices, and therefore allows current solid state technology to potentially compete with traveling wave tubes. Solid state devices offer low cost and good reliability.

Conventional planar combining arrays have thus far demonstrated limited power, small bandwidths [2-4] and poor thermal management. We have proposed 3-dimensional quasi-optical arrays [5] which resolve the bandwidth limitations of previous designs. Two waveguide based combiners are examined. An array of tapered slotlines is inserted between two rectangular waveguides and a radial arrangement of slotlines is placed between flared coaxial lines [6-9].

In the first case a high power (2.4 Watt output) 2x4 array module is demonstrated (fig.1). This amplifier covers the 8 to 12 GHz band (40% bandwidth). The approach offers excellent input/output isolation and provides more room for additional device integration. A demand for higher device packing density has prompted the coaxial combiner. A radial array of tapered slotlines is inserted in a flared coaxial line (fig.2). The dominant mode in this structure is TEM and is not restricted by a lower frequency cutoff. A 1.3 dB (max) insertion loss was observed for a 64 element array over the entire 5 to 20 GHz band.

RECTANGULAR WAVEGUIDE COMBINER

The proposed power combiner scheme is based on a 2D array of tapered slotlines partially enclosed in a metallic waveguide. This geometry produces a three-dimensional structure. As shown in figure 1 the array is placed between two rectangular waveguides (one for input, another for output). The suggested method offers excellent input/output isolation and heat removal capacity. It provides more room for complicated circuitry by extending in the direction of wave propagation. For integration of three terminal devices a transition from slotline to microstrip or coplanar waveguide has to be employed. This degrades the performance of the combiner slightly, however unlike conventional

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combiners, this loss is not compounded as more active elements are added. Prior to active array development we measured passive (2x4 element) slotline arrays and arrays with slotline to microstrip transitions. The second shows slightly higher insertion loss yet both array configurations exhibit broadband transmission and low return loss . The array consists of four 10 mil thick Aluminum Nitride “cards” each with two slotline elements. Each “card” has a 3.4 micron layer of gold and is patterned with standard photolithographic techniques. The slotline taper is based on a simple cosine function. The card is about 2 inches long and 0.4 inches wide so that it fits in standard WR-90 waveguide (0.4 inches x 0.9 inches).

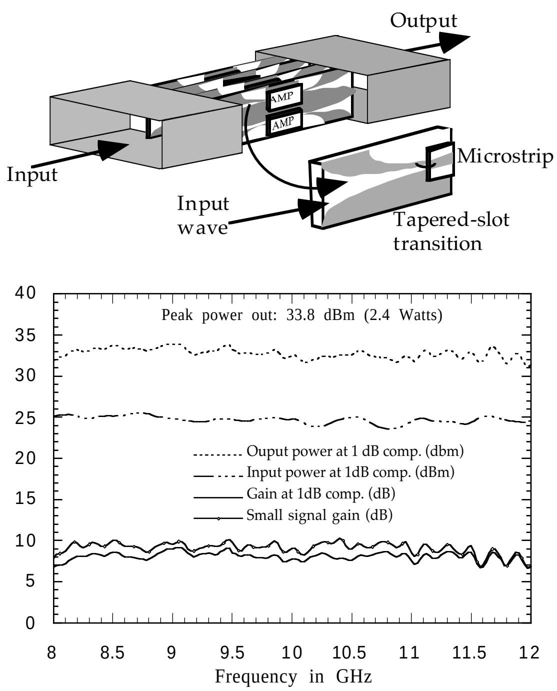

Figure 1 - Topology and measurements for high power 2x4 amplifier.

An amplifier module (fig.1) with 2.4 Watt output and 9 dB gain at 1 dB gain compression was demonstrated using the above approach. The microstrip lines in the passive array are replaced by high power GaAs MMIC amplifiers donated by Texas Instruments. The expected output was 3.6 Watts according to the device specifications, corresponding to a combining efficiency of 70% The module covered the 8 to 12.4 GHz band with ~1 dB gain variation (fig.1). It is the first spatial combiner, to our knowledge, to exhibit such broadband performance. Heat sinking issues were also addressed. As before the substrate of choice is AlN for its high thermal conductivity (κ = 1.7 W cm^{-1} $^{o}C^{-1}$). Metal (Al) carriers were employed not only for structural rigidity but also to extract heat more efficiently. The measurement was pulsed with a low duty cycle to allow the MMICS to cool down. Continuous operation resulted in 0.5 to 1 dB gain degradation.

Each device dissipated 2.25 Watts and the total thermal resistance was estimated to be 47.5 ^{o}C/W. The temperature increase from heat sink to device is 107 ^{o}C. If we assume that the heat sink was at room temperature then the device reached 132 ^{o}C which is very close to the maximum allowed channel temperature of 150 ^{o}C (as listed in the MMIC specification sheet). This would explain the small degradation in performance when the amplifiers were biased continuously.

COAXIAL COMBINER

The rectangular based power combiner is subject to the low frequency cutoff of the waveguide. This makes the amplifier design more challenging since the circuits have to be unconditionally stable out of band. Also the number of active elements that can be inserted is limited by the small aperture of the standard X-band waveguide. A coaxial TEM line has no lower frequency cutoff limit. The cards can be placed radially in the coax. By increasing the radius one can, in principle, accommodate as many active elements as necessary.

The passive structure is illustrated in figure 2. The combiner is terminated on either side by commercially available type-N connectors. The dimensions of the (1.77 inches long) center

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section are chosen so as to accommodate 32 cards radially.

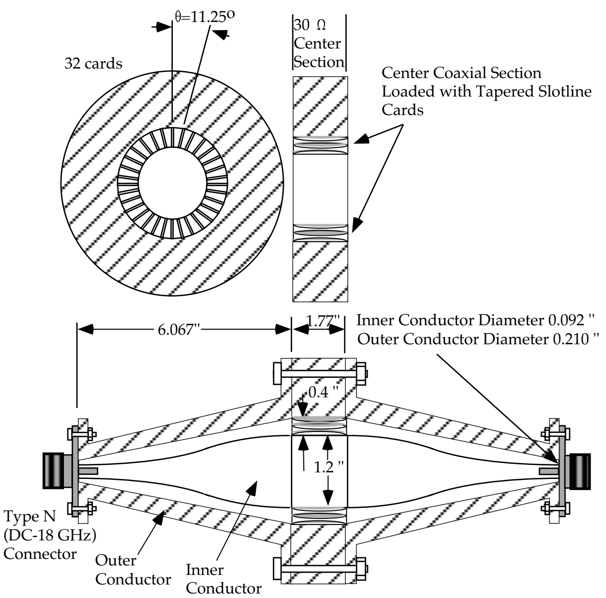

Figure 2 - Flared coaxial line system, designed to accommodate 32 cards.

These cards are identical in size and slotline taper design to those employed in the rectangular waveguide approach. Under these constraints the impedance of the center section is on the order of 30 Ω.

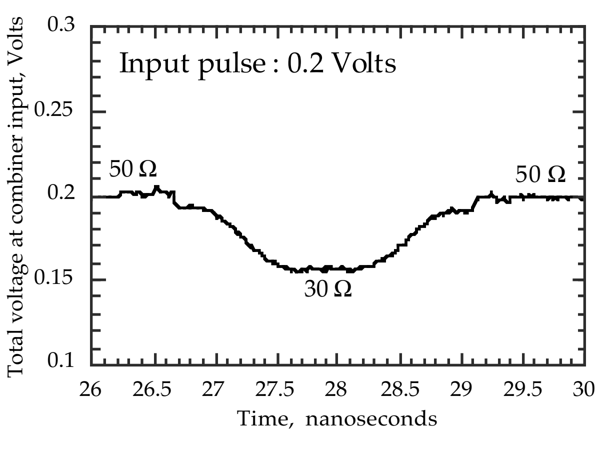

Figure 3 - Impedance profile through TDR measurement for the flared coaxial line (no cards).

The purpose of the coaxial tapers is to match this impedance to the 50 Ω input and output lines. A taper optimized for low reflections based on a triangular distribution [10] was applied. Initial measurements were for an empty coaxial line (no cards inserted). TDR measurements show an impedance change distributed over the length of the matching sections (fig.3). Frequency domain measurements show low insertion loss up to X-band (fig.4a)

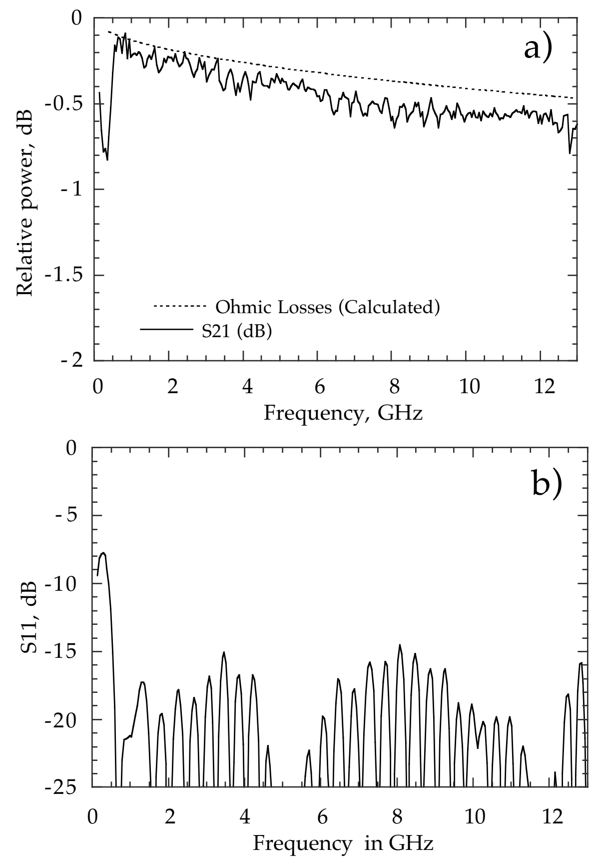

Figure 4 - Measured insertion loss a) and return loss b) for the ampty flared coaxial line (empty coaxial line- no cards)

Theoretical predictions for the ohmic loss [10] in this structure agree to within 0.1 dB with the measured insertion loss (fig.4a). The loss per impedance taper is actually half of that shown in figure 4a. Return loss for this flared coaxial line is below -15 dB from 1 to 13 GHz (fig.4b).

The measurements were repeated on the flared coaxial line with 32 cards inserted in a radial fashion. Since each card had 2 slotlines (fig.5) the array combined 64 elements. The average insertion loss was on the order of 1.5 dB with a 1 dB ripple superimposed on the response (fig.6). The module includes both a power combiner and a splitter making the actual combining efficiency half of the total insertion loss. The array covered the 5 to 20 GHz band.

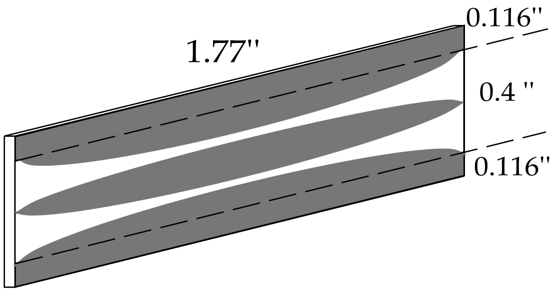

Figure 5- 10 mils thick Aluminum Nitride "card" (substrate) with slotline tapers. Slotline narrows down to 26μm (56Ω). Substrate above the top dotted line and below the bottom one is inserted in waveguide walls.

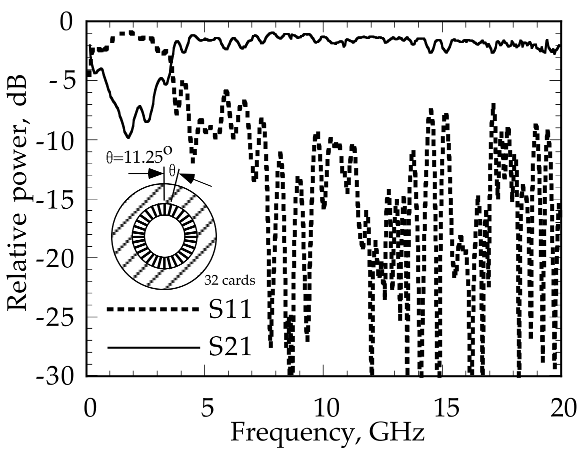

Figure 6 - Measured insertion and return loss for coaxial combiner with 32 substrates (64 elements)

CONCLUSION

We are presenting two waveguide-based power combining approaches. Both employ tapered slotlines. In the first case a 2x4 array is fed by rectangular waveguide. In the second a 32x2 radial array is placed between two flared coaxial lines. The second approach employs a TEM line and therefore is not hampered by a waveguide cutoff frequency. Also, the radial geometry can accommodate significantly more cards and therefore has the potential for higher power

ACKNOWLEDGMENTS

We would like to thank Texas Instruments for their gracious contribution of GaAs high power MMIC amplifiers. This work is supported by DARPA MAFET contract N66001-96-C-8625.

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