20 WATT SPATIAL POWER COMBINER IN WAVEGUIDE

Nai-Shuo Cheng, Angelos Alexanian, Michael G. Case*, Robert A. York

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

*Hughes Research Laboratories
Malibu, CA 90265-4799

ABSTRACT

In this paper, we present the continued effort in the development of broadband waveguide-based spatial combiners. A 20W result at X-band is reported. The combiner was implemented by using eight commercial GaAs MMIC amplifiers in a rectangular waveguide environment. A new combiner design is proposed to alleviate, if not eliminate, various technical problems and further improve the power performance. Resulting simplification in analysis also enable us to better characterize the combining circuits. The preliminary result suggests promising outlook in performance improvement.

INTRODUCTION

In our previous work[1], a 2.4W result has been reported for a waveguide-based power combiner. In addition, a coaxial combining scheme with low combining loss was also proposed. Continued research work has been performed for combiners based on a similar topology. More effort has been put towards using higher power MMIC amplifiers, improving heat removal property and characterizing passive structure, given that higher power performance was desired.

CONCEPT

The topology of the 20W broadband power combiner was based on the design previously proposed by Alexanian and York[1]. The power combiner consists of a 2D array of active antennas, which consist of tapered slotline sections, wire-bonded with high power MMIC amplifiers, as shown in Figure 1. These "antenna cards" were mounted onto a small metal test fixture, for both mechanical support and heat removal, and inserted between two standard X-band waveguides. Thermal grease was applied between antenna cards and the test fixture to enhance heat sinking property of the combiner.

In order to obtain high output power from a power combiner, it is desired to integrate large number of high power amplifiers in the combining circuit, which will, however, incur the issue of thermal management since the heat generated by DC power will degrade the amplifier performance. As a result, high combining efficiency is required when high output power is preferred. For our topology, more room can be obtained, in the direction of wave propagation, to accommodate more active devices and the combining loss will not be compounded when the number of active devices increases, as opposed to the case of conventional power combiner.

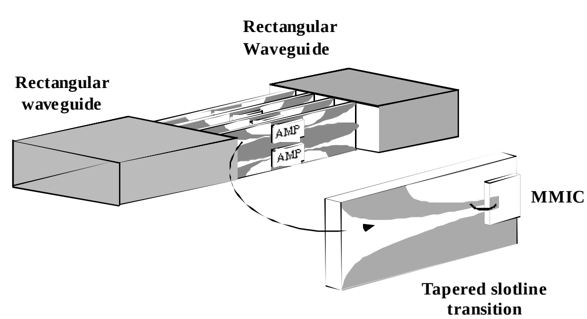

Figure 1 – Topology of spatial combiner

POWER-ADDED EFFICIENCY

The relationship between power-added efficiency and system parameters, such as gain and combining loss, is investigated for better understanding what approach can be adopted to promote combining efficiency.

It can be shown that the power added efficiency (PAE) of a power combiner has the following general form,

$$\eta = \eta_a \frac{GL_{in} L_{out} - 1}{(G-1)L_{in}} \qquad (1)$$

where is the PAE for the combiner, $_a$ is the PAE for a single amplifier, G is the power gain, L_{in} is the input loss, and L_{out} is the output loss.

If the gain is reasonably large (G >> 1 and G >> 1/ $L_{in}L_{out}$), then Equation (1) becomes,

$$\eta \approx GL_{out} \qquad (2)$$

The PAE of a power combiner is degraded only by the output loss of the combiner, when compared to the PAE of a single amplifier. As for the case of spatial power combiner, the combining loss remains fixed as opposed to the case of corporate power combiner, where the combining loss adds up quickly when the number of active devices increases, which can be further exemplified by Figure 2.

Let's assume that the output combining loss for a spatial combiner is less than 0.5dB and the output loss for a corporate combiner is 0.1dB per stage. The PAE for a corporate combiner will be smaller than that is for a spatial combiner if more than two stages are employed. It is obvious that spatial power combining scheme is favored in high power application where integration of large number of active devices is required.

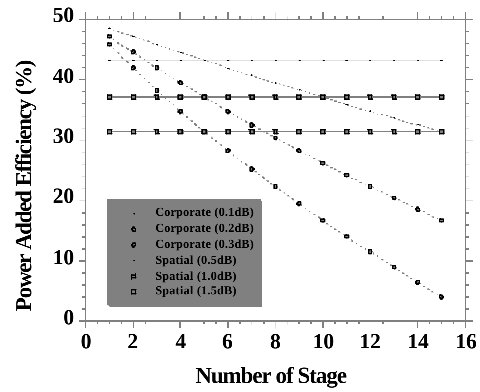

Figure 2 – The comparison of PAE between corporate and spatial power combiners. PAE of a single device ($_a$) is assumed to be 50%. The solid and dotted lines represent output loss per stage for corporate and spatial combiners, respectively.

MEASURED RESULTS

A 2 4 array was fabricated by using 10-mil thick aluminum nitride substrates with 3.4 micron layer of gold. The actual layout of an "antenna card" is illustrated in Figure 3. Eight GaAs TGA8286-EPU MMIC power amplifiers, with 5W output power and 37% power-added efficiency at 2 to 3-dB gain compression point, were used in the combining circuit. Under CW operation, 20W (maximum) output power and 9 dB gain covering 8.5 to 10.5 GHz band were demonstrated, as shown in Figure 4. The input RF power was 34 dBm and DC power 96 watts. The calculated combining efficiency is about 50% and power-added efficiency 18%. No thermally induced degradation in output power was observed during the measurement, indicating acceptable heat-sinking property of the combiner.

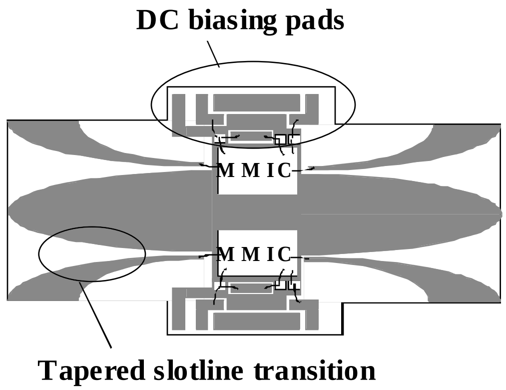

Figure 3 – Actual layout of a single card

In order to assure continuous current flow from waveguide to slot line, good electrical contact between the waveguide wall and the slot line metal has to be made. However, this sometimes leads to disastrous card breakage problem since additional stress is introduced when the edges of the cards are inserted in the waveguides.

Without individual monitoring, the DC bias current flowing through each MMIC power amplifier was drawn from the same power supply, which may degrade the power performance because all the amplifiers are probably not under the same bias condition. As a result, some DC current monitoring and limiting circuit should be used to solve this problem especially when a large number of active devices are integrated.

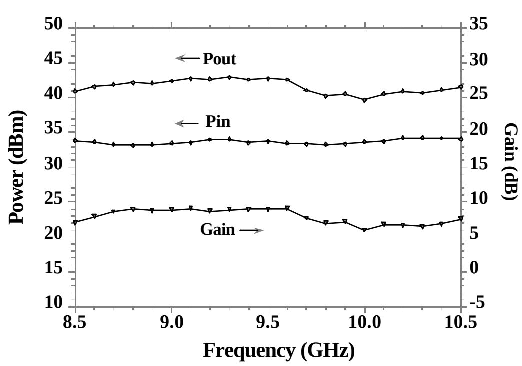

Figure 4 – Measurement result for the power combiner with 2 4 array

NEW COMBINER DESIGN

In an effort to alleviate the problems that were encountered previously, a new combiner design was proposed, as shown in Figure 5. Two MMICs and the input/output tapered slotline sections were epoxy-mounted, separately, on to each metal carrier, which serves the same role as the "antenna cards" did in the previous design. Two biasing strips, made of aluminum nitride, were also attached to each carrier between the tapered slotlines and the MMICs. DC bias lines and RF microstrip lines, which were wire-bonded to both MMICs and the slotlines, are shown on the top of the biasing strips. A metal housing is constructed when all the components are stacked together. Rectangular openings are formed to make contact and connection with standard X-band waveguides. All the components are held in tight position with screws.

This new combiner improves the previous design in a variety of ways. First, a good electrical contact is made between the slotline metal and the waveguide wall. Secondly, thermal property of the combiner is greatly improved because of the efficient heat conducting paths created right underneath the MMICs. In addition, the metal housing serves not only as a robust mechanical support, but also as a perfect heat sink. Moreover, the previous card breakage problem can be eliminated since the test fixture holds all the components in position and makes good alignment with the external waveguides. Furthermore, the slotlines are now enclosed in a rectangular metallic housing and become a finline structure, which reduces the complexity in analysis. As a result, optimal tapered finline transition can be designed for making good impedance matching between the slotlines and the MMICs, and thus minimizing combining loss.

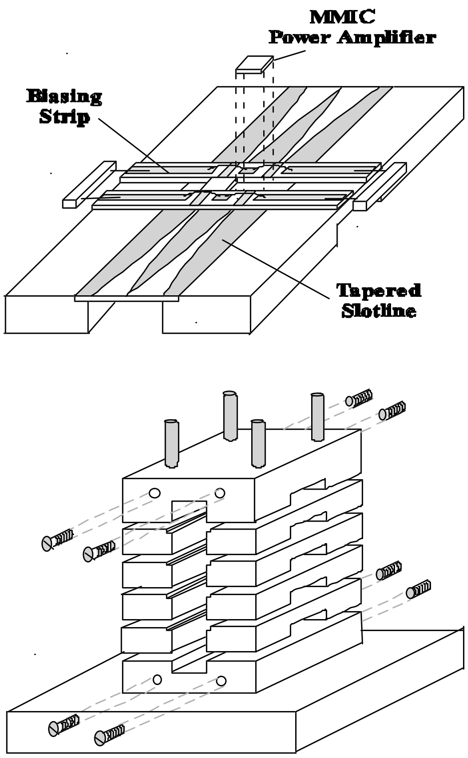

Figure 5 – New power combiner design

A return-loss measurement was performed to preliminarily characterize the new power combiner. A tapered finline transition was design based on the spectral domain technique[2]. All the input slotlines were terminated with chip resistors, instead of

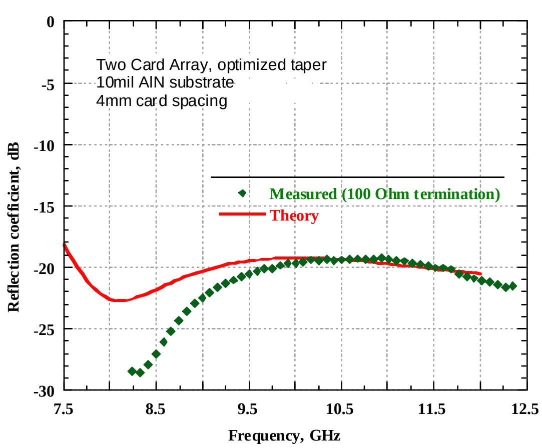

Figure 6 – Comparison between theory and measurement results for return loss characteristics of the new power combiner.

MMIC amplifiers. For simplicity, only a two-card system was simulated, and a comparison was made between the theory and the measurement, as shown in Figure 6. The result shows about –20dB or better return over the entire X band. The good agreement in curves suggests that optimal taper line can be design provided proper characterization is performed, which is critical for reducing combining loss and, eventually, increasing combining efficiency.

CONCLUSION

We present a broadband 20W result for the spatial combiner based on a 2D array of tapered slotline structure. A new combiner design is also presented to alleviate the previously observed problem. Improvement in power performance can be achieved by further minimizing combining loss.

Our waveguide-based combiner continues to challenge the role played by TWT in the field of high power applications, and still sees enormous room left for improvement in power performance, yet not at the expense of sacrificing the bandwidth and thermal property. Higher output power can be obtained by integrating more high power MMIC amplifiers in the combining circuit but the increase in number of active devices will not degrade the power-added efficiency provided that the power gain is reasonably large.

REFERENCE

[1] A. Alexanian, R. A. York, “Broadband Waveguide-Based Spatial Combiner” *IEEE MTT-S International Microwave Symposium Digest*, Denver, CO, USA, 8-13 June 1997

[2] T. Itoh, "Spectral Domain Immitance Approach for Dispersion Characteristics of Generalized Printed Transmission Lines", *IEEE Trans. Microwave Theory Tech.*, vol. MTT-28, no.7, pp. 733-736, July 1980

0-7803-4471-5/98/$10.00 (c) 1998 IEEE