A Quasi-Optical Dielectric Slab Power Combiner with A Large Amplifier Array

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Abstract

A two-dimensional quasi-optical hybrid dielectric slab beammode waveguide (HDSBW) with a 5×4 MMIC amplifier array is demonstrated. Performance of this 2D concave-lens HDSBW system including amplifier gain and total system loss, input power vs output power and surface field patterns are presented. methodology for the future planar quasi-optical (QO) power combiners.

I.Introduction

Several architectures employing solid-state devices have been developed for QO power combiners. Among them, the 2D HDSBW power combiner has the advantage of small size, light weight and perhaps more easily fabricates in monolithic technology. In our previous paper [2], a 4×1 MESFET amplifier array was located underneath the slab with a maximum amplifier gain and output power of 19.5 dB and 5 dBm, respectively. Even though the gain is high, the output power level is not enough for the practical applications of this system. A principle problem with this system is excessive loss. In this paper, the HDSBW with a large MMIC amplifier array shown in Fig. 1 (a) is investigated for higher output power, and excessive system loss is identified and substantially reduced. Measured date shows that this concave-lens HDSBW system has the maximum amplifier gain, system gain and output power of 30 dB, 14 dB and 14.68 dBm at 8.828 GHz, respectively.

II. System Description and Loss Mechanism

The HDSBW system with a 5×4 amplifier array underneath the slab is shown in Fig. 1 (a) with $d1$ = 15.6 cm, $d2$ = 40 cm and $d3$ = 15.4 cm. The slab is 1.27cm thick and 27.94 cm wide. The relative dielectric constant is $\epsilon_r = 2.55$ for the slab and is $\epsilon_{ant} = 10.5$ for the antenna substrate. The concave lens is an air region with a radius 30.48 cm, and is used for less beammode scattering loss (see [2]). The amplifier unit shown in Fig. 1 (b) has two Vivaldi antennas and sits in a metal carrier to amplify the guided TE beammodes. The amplifier unit employs two cascaded MMIC chips (Mini-Circuits ERA-1). The carrier not only stops the radiation of the antenna leaking through the antenna substrate, but also provides a good heat sink for the amplifier chips. As the antenna sitting inside a carrier, its S_{11} differs from that of the old taper antennas which were used in our previous work. Hence the variation of S_{11} of the antenna should be carefully considered again to ensure matching between the antenna and MMIC chip. By iteratively using the MoM method simulator developed by Nuteson *et al.*, [1], the antenna was optimized for operation around 9 GHz as shown in Fig. 2 (a). The normalized $|S_{21}|$ of the

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antenna-to-horn path for the system with and without a metal cover is shown in Fig. 2 (b).

For the system without the amplifiers, its passive system loss is about 5±1 dB over the operation frequency range. As the system is with amplifier unbiased, the insertion loss due to the amplifiers is about 2.5±1 dB. The total system loss can be obtained by adding the passive loss with the insertion loss. Through the experiment we have identified three major sources of loss, and each of which is (1) scattering loss into the open region above the slab; (2) fractional capture of power by the horn and non-optimum horn design; (3)discontinuity at the lens resulting in both reflective loss at the dielectric interface. In essence, discontinuities have a much greater effect on scattering in a system without a metal top than a system with a metal top. So the strategy was to use a parallel plates to reduce scattering.

III. Performance of the HDSBW Amplifier System

For the purpose of raising the output power level, more amplifier units are added into the slab system and they are arranged to be a 5×4 array. The area of this array is 12 cm wide and 30 cm long. The whole concave lens system is also covered by a 12-inch-wide metal plate. Since the flatness of the metal plate located above the system largely affected the input wave, E_{in}, and output wave, E_{amp}, of each amplifier unit, a heavy block was placed on this plate to adjust the flatness to tune the E_{in} so that all E_{amp} will have coherent output amplitudes and phases. In Fig. 3 (a), the amplifier gain and loss for the system with a "adjusted" metallic top is shown with the maximum amplifier gain of 30 dB at 8.828 GHz as P_{in} = -3 dBm. The output power vs frequency is shown in Fig. 3 (b) and the system gain is about 7.5 dB as P_{in} = -3 dBm. Note that the bandwidth of the positive system gain is 70 MHz, and this emphasizes that the system performance not only depends on the ability of the amplifier array but is also highly sensitive to the flatness of the plate.

The P_{out} vs P_{in} at 8.828 GHz is shown in Fig. 4 (a). The maximum output power is about 9 dBm as P_{in} = -6 dBm and P_{in} = 10 dBm, and the system gain ($P_{out} - P_{in}$) has a maximum value of 14 dB with P_{in}= -6 dBm. The system gain decreases with $P_{in} \geq$ -6 dBm. The measured $|E_y|$ patterns are plotted in Fig. 4 (b). The profile of $|E_y|$ (Amp ON) is about 10 to 18 dB above that of $|E_y|$ (No Amp) for the $-1 \geq y \geq 9$ cm region. The amplified $|E_y|$ has a dip in the middle and looks like the second-order Gaussian beammode. Since the horn aperture is from -4.5 cm to 4.5 cm, then only some part of the amplified energy is received. By counting the power outside the horn, an additional gain of 5.68 dB could be added to the output power, and the maximum P_{out} becomes 14.68 dBm. Comparing the output power of 5 dBm in [2], an improvement of 9.68 dB for the output power level has been successfully achieved.

IV. Conclusion

A 2D HDSBW amplifier system with a 5×4 MMIC amplifier array is demonstrated. The driving-point impedance and the energy transfer the between antenna and the horn has been optimized and improved. System performance including the amplifier gain and system gain, system loss due to the lenses and amplifiers, the patterns of combined power, and output power level are discussed. This 5×4 MMIC amplifier system generates almost 10 times output power than that from the system with a 4×1 MESFET array.

References

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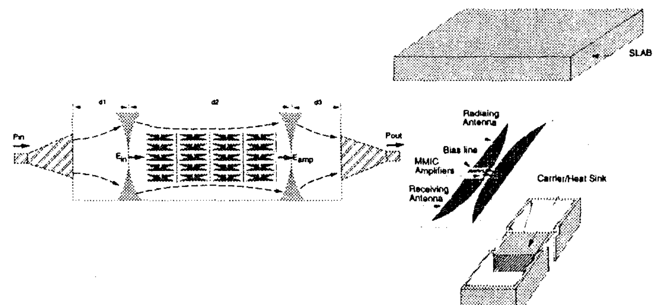
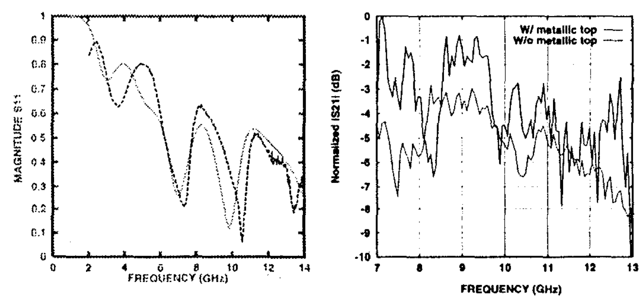
[2] H. Hwang, T W. Nuteson, M. B. Steer, J. W. Mink, J. Harvey, and A. Paollela, "Two-dimensional quasi-optical power combining system performance and component design ," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 927-930, June 1996.



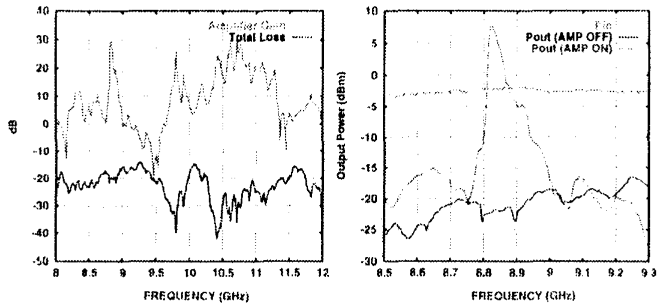
(a) (b)

Figure 1: (a)A concave-lens HDSBW with a 5×4 amplifier array underneath a thin slab. (b) An antenna unit sits inside a carrier underneath the slab system.



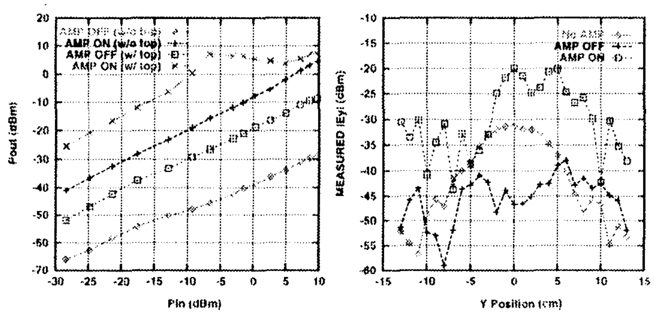
(a) (b)

Figure 2: (a) Measured (dashed line) and simulated (solid line) S_{11} for the Vivaldi antenna. (b) Normalized $|S_{21}|$ between a single Vivaldi antenna and the horn.



(a) (b)

Figure 3: (a)Amplifier gain and total loss for the system with a 5×4 array. (b) P_{out} vs frequency for the system with a 5×4 array.



(a) (b)

Figure 4: (a)P_{in} vs P_{out} at 8.828 GHz. (b)Measured $|E_y|$ patterns for the system with a 5×4 array working at 8.828 GHz.