A Quasi-Optical Dielectric Slab Power Combiner

Huan-sheng Hwang, *Student Member, IEEE,* Todd W. Nuteson, *Student Member, IEEE,*
Michael B. Steer, *Senior Member, IEEE,* James W. Mink, *Fellow, IEEE,*
James Harvey, *Member, IEEE,* and Arthur Paolella, *Member, IEEE*

***Abstract*—Real power gain from a quasi-optical power combining dielectric slab waveguide amplifier system is reported for the first time. The system employs four MESFET amplifiers located under the slab, and a small signal gain of 10.5 dB was achieved. Measurements of insertion loss and E-field patterns are presented.**

I. Introduction

In quasi-optical power combining systems, the power from numerous solid state devices is combined into one dominant propagating mode. The most mature quasi-optical systems include grid oscillators [1], [2] and amplifiers [3], resonant cavity oscillators [4], [5], and similar structures with the common property that power is combined in free space and the system is essentially three dimensional (3-D). We have recently investigated quasi-optical systems using a dielectric slab [6]–[8] to combine the power from the active devices in a mode that is confined to a two-dimensional (2-D) dielectric slab. Using a dielectric slab rather than free space for guiding the propagating wave allows for planar MMIC fabrication.

A dielectric slab beam waveguide (DSBW) system with amplifiers is shown in Fig. 1. The DSBW system uses Rexolite ($\epsilon_r = 2.57$) for the dielectric slab and Macor ($\epsilon_r = 5.9$) for the lenses, with a radius of 30.48 cm and focal length of 28.54 cm. For the dimensions shown in Fig. 1, $d_1 = 12$ cm, $d_2 = 28$ cm, and $d_3 = 16$ cm. The width of the slab waveguide is 30.48 cm. The aperture width of both horn antennas is 9 cm, designed to be the spot size of the slab beam-mode near the aperture. Energy propagates in a TE Gaussian beammode along the waveguide, passes the lenses, and is refocused in the middle area of the waveguide. The beam in that area has the strongest field strength and its width is close to that of the beam width near the radiator. Four MESFET amplifiers, each consisting of one MESFET with two Vivaldi antennas (see Fig. 1), are located in this area to amplify the guided energy and are placed underneath the slab so that they do not distort the fields. The design of the amplifiers is discussed in [8].

In this letter, we report for the first time real power gain from the DSBW system. With an RF input power level of −15.5 dBm at 7.384 GHz, the output power was measured to be −5 dBm. This represents a 10.5 dB gain of real power from the complete system including losses due to the coax to waveguide transition, horn aperture, dielectric slab, lenses, and radiated power into free space. Adding a metallic top cover to the system to reduce the power lost from free space radiation resulted in an overall increase of 2 dB in the output power level. Measurements for amplifier gain, system gain, insertion loss, and E-field patterns are also presented. The reference planes for all of the 2-port measurements are at the coaxial line and include the coax to waveguide transition as is shown in Fig. 1. The side view of the DSBW system with a metallic top is shown in Fig. 2 ($h1 = 1.6$ cm, $h2 = 1.27$ cm).

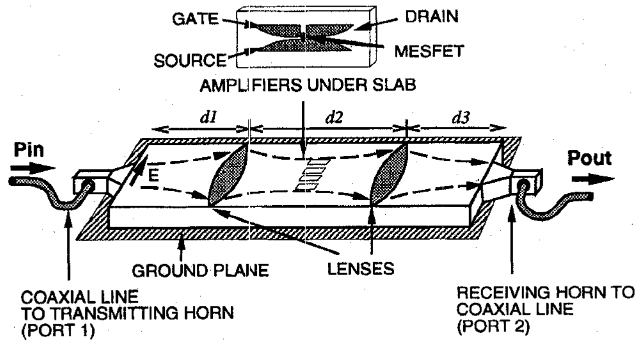

Fig. 1. DSBW system with MESFET amplifiers.

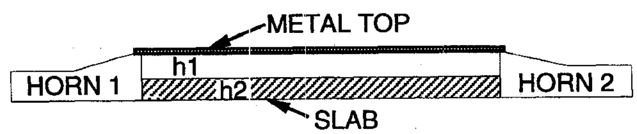

Fig. 2. Side view of system with metallic top.

II. Experimental Results

The amplifier gain of the four MESFET amplifiers in the DSBW system is shown in Fig. 3. With no metallic top cover the gain was close to 15 dB and with the cover was 12.5 dB both at a frequency of 7.384 GHz. This gain was measured by taking the ratio of the amplifiers with the dc bias on and off. Fig. 4 shows the gain of the complete system with the amplifiers turned on. The solid line is the reverse transmission $|S_{12}|$ and the dotted line is the forward transmission $|S_{21}|$. $|S_{12}|$ shows that the back scattering to the input port is very minimal, and $|S_{21}|$ showes that positive power gain is achieved

Manuscript received July 17, 1995. This work was supported in part by the U.S. Army Research Office through grant DAAL03-89-G-0030.

H.-s. Hwang, T. W. Nuteson, M. B. Steer, and J. W. Mink are with the Electronics Research Laboratory, Department of Electrical and Computer Engineering, North Carolina State University, Raleigh, NC 27695-7911 USA.
J. Harvey is with the U.S. Army Research Office, Research Triangle Park, NC 27709-2211 USA.
A. Paollela is with the Microwave and Lightwave Components Division, AMSRL-EP-MA, U.S. Army Research Laboratory, NJ 07703 USA.

Publisher Item Identifier S 1051-8207(96)00910-1.

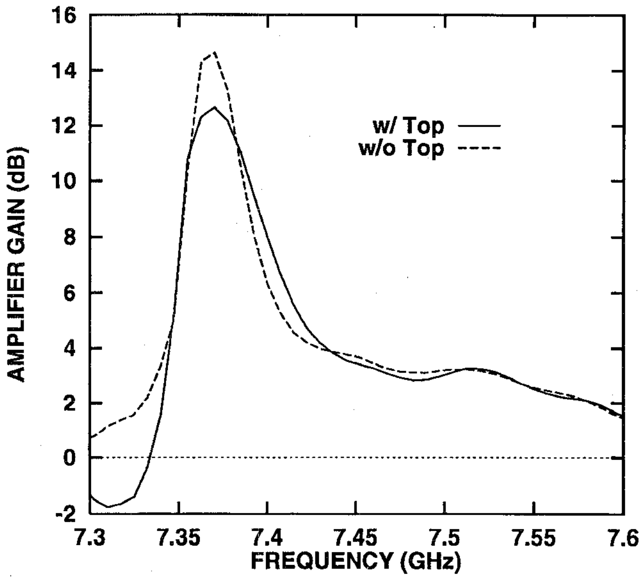

Fig. 3. Amplifier gain of four MESFET amplifiers in the DSBW system with and without a metallic top cover as $P_{in} = -10$ dBm. The gain here is the ratio of the power received with the amplifiers on (biased) to that with the amplifiers off (not biased).

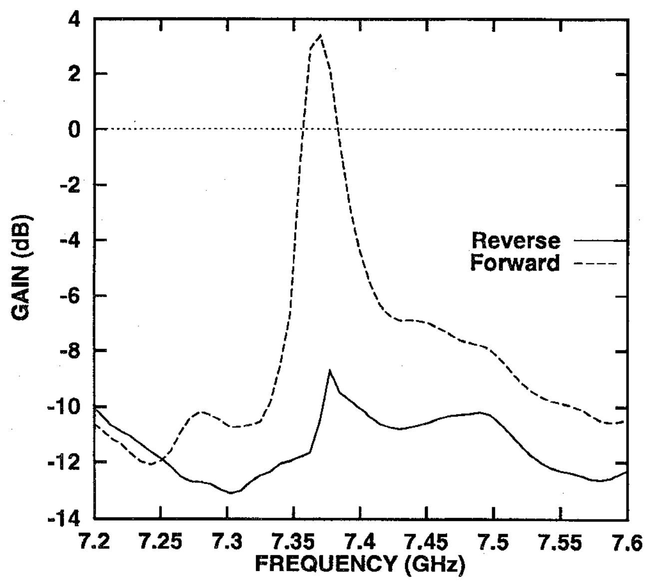

Fig. 4. Forward and reverse transmission through the DSBW amplifier system at $P_{in} = -10$ dBm. This is the real gain measured at the external ports.

through the complete system. The input power level was -10 dBm. The loss through the passive DSBW system is shown in Fig. 5. Here the amplifiers are in the system without bias. With the metallic top cover the loss is about 3.5 dB less than without the cover. Sources of loss include input/output mismatch, radiation loss of horns, insertion loss of amplifiers and lenses, which cause field scattering and diffraction. We expect to drastically reduce these losses in the future.

The main goal of this paper is presented in Fig. 6 where we achieve real power gain, $(P_{out} - P_{in})$, in the DSBW amplifier system. The measurements were taken at a frequency of 7.384 GHz where the amplifier gain was maximum.

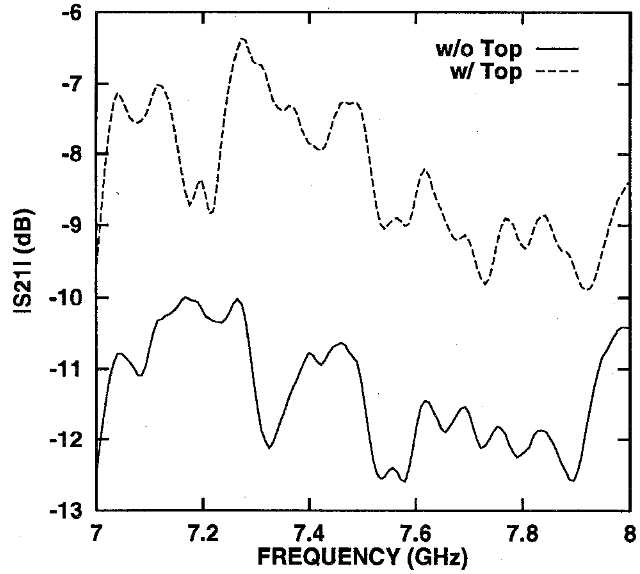

Fig. 5. Measured response of the passive DSBW amplifier system (no bias) with and without a metallic top cover. Without the cover, the system loss is 10–12.5 dB. With the cover, the system loss is 6.5–9 dB.

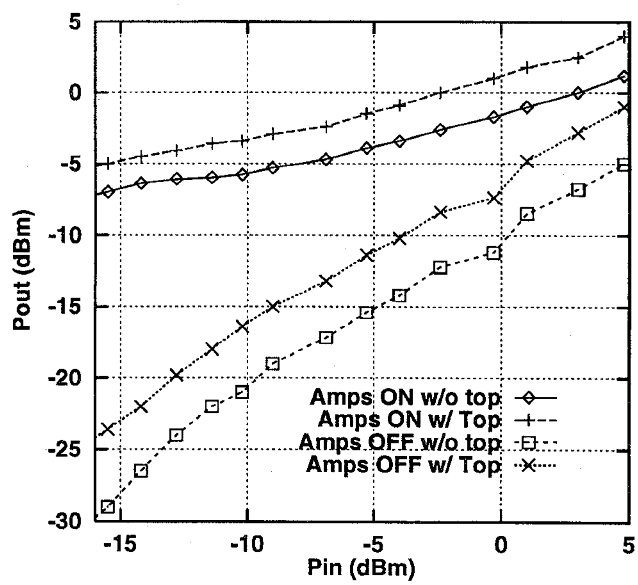

Fig. 6. P_{out} versus P_{in} of the DSBW amplifier system. Without top, the small signal gain was 8.5 dB in spite of a system loss about 11.5 dB. With top, the small signal gain was 10.5 dB in spite of a system loss about 7.5 dB.

The highest power gain achieved was 10.5 dB with top and 8.5 dB without top with the input power level at -15 dBm. When the amplifiers were turned off, the slope in Fig. 6 was close to $1:1$. As the amplifiers were turned on and P_{in} was higher than -15 dBm, P_{out} entered the saturation region, and hence the slope was less than $1:1$.

The power-added efficiency is 5.2% when the input power is at 5 dBm. This is low and is being addressed.

Fig. 7 shows the power distribution across the top of the DSBW system for three cases: amplifiers with bias, amplifiers without bias, and no amplifiers in the system. With the amplifiers biased the power distribution spreads wider across the slab, whereas with the amplifiers not biased or not in the

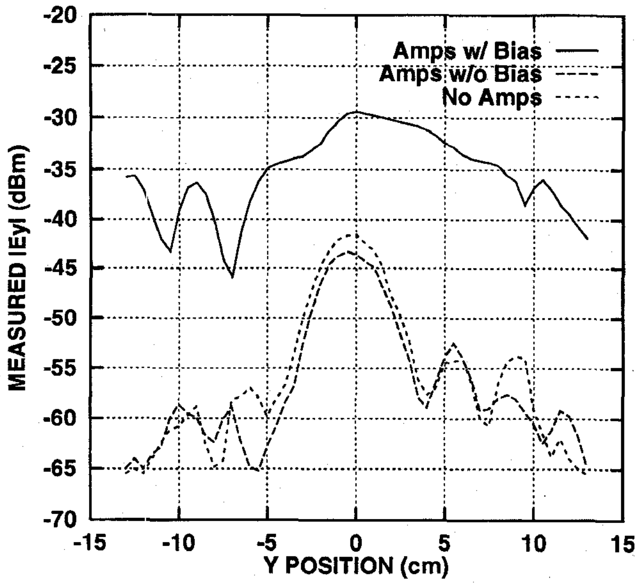

Fig. 7. Measured $|Ey|$ distribution across the top of the DSBW amplifier system.

system the power distribution has more distinctive Gaussian shape. As indicated in Fig. 7, the field distribution is little affected by the ground discontinuities due to the amplifier unit cells. In contrast, with the amplifiers on the top of the slab waveguide as in [8], significant scatter is introduced. With the amplifiers are biased, the field distribution spreads out presumably due to the additional phase delay through the amplifiers. This indicates that a refinement of the lens and/or receiver positioning and design is required to capture all the amplified energy in the system.

III. Conclusion

The real power gain using quasi-optical power combining techniques in a DSBW amplifier system was reported for the first time. The highest power gain was reported to be 10.5 dB at 7.384 GHz when the input power level was −15 dBm. The planar amplifiers are suitable for use with the DSBW system and can be applied to planar MMIC technology.

References

[1] J. B. Hacker, M. P. de Lisio, M. Kim, C.-M. Liu, S.-J. Li, S. W. Wedge, and D. B. Rutledge, "A 10-watt X-band grid oscillator," in *IEEE MTT-S Int. Microwave Symp. Dig.*, May 1994, pp. 823–826.

[2] Z. B. Popovic, R. M. Weikle II, M. Kim, and D. B. Rutledge, "A 100-MESFET planar grid oscillator," *IEEE Trans. Microwave Theory Tech.*, vol. 39, pp. 193–200, Feb. 1991.

[3] M. Kim, J. J. Rosenberg, R. P. Smith, R. M. Weikle II, J. B. Hacker, M. P. DeLisio, and D. B. Rutledge, "A grid amplifier," *IEEE Microwave Guided Wave Lett.*, vol. 1, pp. 322–324, Nov. 1991.

[4] J. W. Mink, "Quasioptical power combining of solid-state millimeter-wave sources," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-34, pp. 273–279, Feb. 1986.

[5] P. L. Heron, G. P. Monahan, J. W. Mink, F. K. Schwering, and M. B. Steer, "Impedance matrix of an antenna array in a quasioptical resonator," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 1816–1826, Oct. 1993.

[6] J. W. Mink and F. K. Schwering, "A hybrid dielectric slab-beam waveguide for the sub-millimeter wave region," *IEEE Trans. Microwave Theory Tech.*, vol. 41, pp. 1720–1729, Oct. 1993.

[7] F. Poegel, S. Irrgang, S. Zeisberg, A. Schuenemann, G. P. Monahan, H. Hwang, M. B. Steer, J. W. Mink, F. K. Schwering, A. Paollela, and J. Harvey, "Demonstration of an oscillating quasioptical slab power combiner," in *IEEE MTT-S Int. Microwave Symp. Dig.*, May 1995, pp. 917–920.

[8] H. Hwang, G. P. Monahan, M. B. Steer, J. W. Mink, J. Harvey, A. Paollela, and F. K. Schwering, "A dielectric slab waveguide with four planar power amplifiers," in *IEEE MTT-S Int. Microwave Symp. Dig.*, May 1995, pp. 921–924.