A Two-Stage Spatial Amplifier with Hard Horn Feeds

Toni Ivanov, *Student Member, IEEE,* and Amir Mortazawi, *Member, IEEE*

***Abstract*— A spatial amplifier consisting of two stages, with each stage employing nine HEMT's, has been developed. The coupling to and out of the spatial amplifier is accomplished by placing it in the reactive field of two hard horn antennas. The hard horns' improved aperture field uniformity ensures the simultaneous saturation of most of the active devices across the amplifier array. The amplifier has a small signal gain of 16.2 dB at 9.98 GHz and produces 90 mW at a 2-dB compression point.**

I. Introduction

DIFFERENT types of quasi-optical amplifiers have been reported in the literature. First, grid amplifiers were introduced [1], [2]. Subsequently, amplifier arrays employing discrete printed antennas were reported [3]–[8]. An 18-HEMT two-stage microstrip patch antenna array amplifier was presented in [7]. The input and output power were determined by far field measurement of a reference power and the amplified power. To determine the amplifier's gain, the measured powers were corrected for the $1/r^2$ losses and input and output antenna array gains [7]. In [8] it was demonstrated that reactive field coupling (the spatial amplifier was placed close to the aperture of the horns) can be used to couple energy to and out of a spatial amplifier circuit. Recent advances in the theory of hard electromagnetic surfaces [9] have lead to the development of feeds with enhanced aperture efficiency [10]. In this letter, a closed-system spatial amplifier with hard horn feeds is demonstrated.

II. Design and Experimental Results

Two hard pyramidal horns were designed and constructed to couple the input and output signals to and out of the spatial amplifier, as shown in Fig. 1. The amplifier circuit is placed close to the aperture of both horns.

The spatial amplifier consists of two stages each having nine general purpose Fujitsu FHX06LG HEMT's arranged to form a 3×3 array. A perspective view of the amplifier implemented using microstrip circuits is shown in Fig. 2. Each stage is fabricated on a separate microstrip layer. The two layers are placed back to back. The output of the first stage is coupled to the input of the second stage via microstrip to slot transitions, therefore the two stages of the spatial amplifier are electrically isolated. The microstrip-slot-microstrip transitions are essentially transparent to the signal. The receiving and transmitting patch antennas are isolated from one another by a common ground plane.

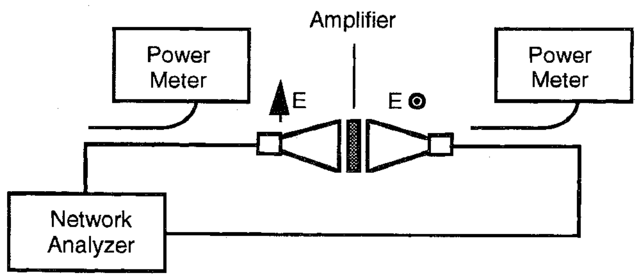

Fig. 1. Measurement setup. Two cross-polarized horns are used to couple energy to the spatial amplifier.

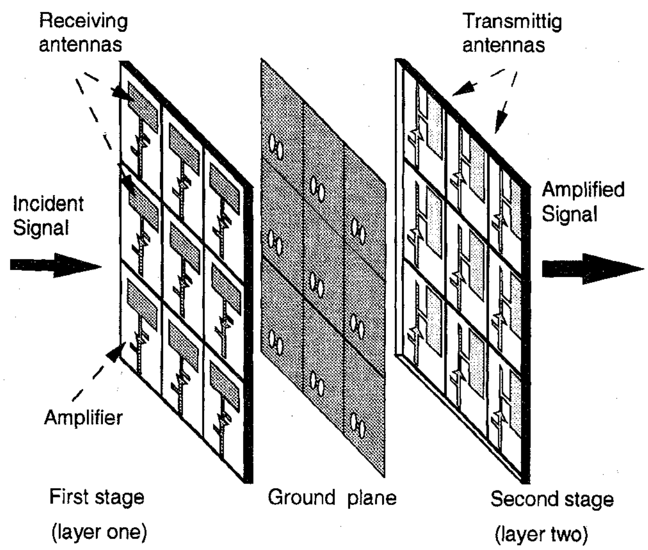

Fig. 2. Perspective view of a two-stage, double-layer, back-to-back spatial amplifier.

Fig. 3(a) and (b) shows the unit cell of the two-stage spatial amplifier. It employs microstrip patch antennas to receive the input signal and to radiate the amplified signal into free space. To design the amplifier, the simultaneous conjugate match suceptances are provided to the input and the output of the active devices by open circuited stubs.

The input conductances of the microstrip antennas are transformed into simultaneous conjugate match conductances using quarter wave transformers. The circuit was fabricated on RT/Duroid with $\varepsilon_r = 2.33$ and thickness of 31 mils. The devices were biased at $V_{ds} = 2.7$ V and $I_d = 20$ mA.

Manuscript received August 16, 1995. This work was supported by Lockheed-Martin Corporation.

The authors are with the Department of Electrical and Computer Engineering, University of Central Florida, Orlando, FL 32816 USA.

Publisher Item Identifier S 1051-8207(96)00914-2.

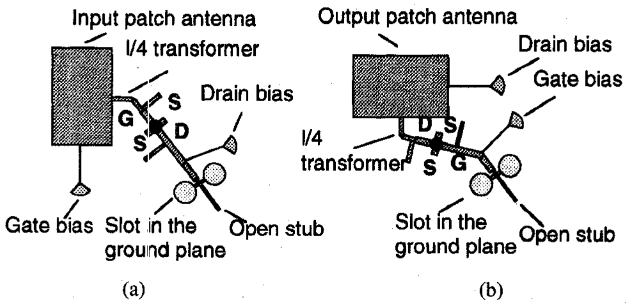

Fig. 3. Layout of the unit cell. (a) Input layer. (b) Output layer.

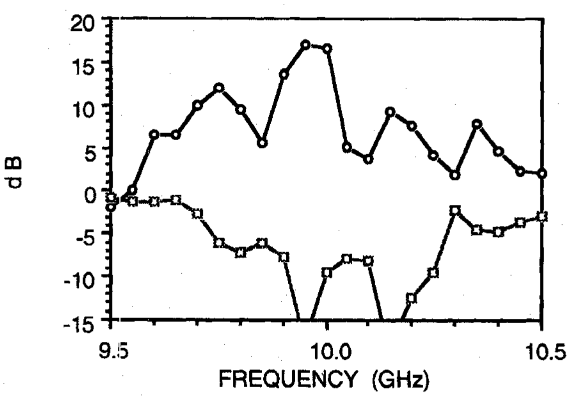

Fig. 4. Gain and return loss of the spatial amplifier excited with regular pyramidal horns. —O— Gain. —□— Return loss.

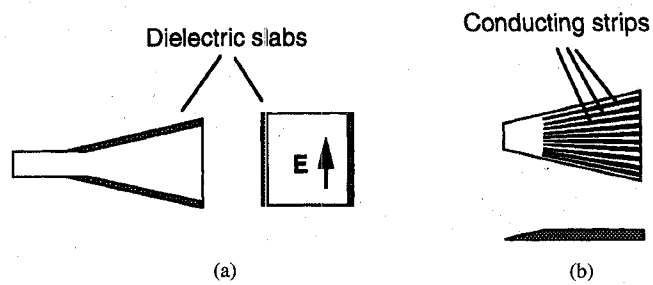

Fig. 5. (a) Schematic of electromagnetic hard pyramidal horn. (b) Geometry and strip layout of the dielectric slabs.

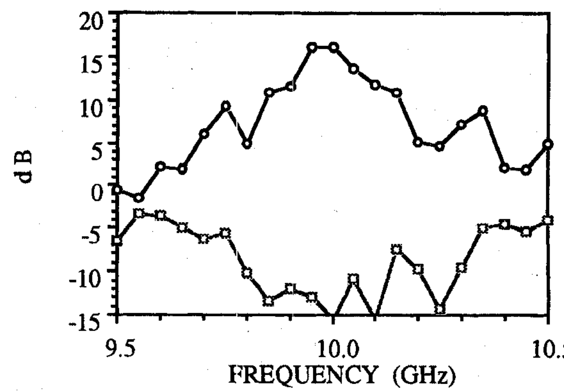

Fig. 6. Gain and return loss of the spatial amplifier excited with electromagnetic hard pyramidal horns. —O— Gain. —□— Return loss.

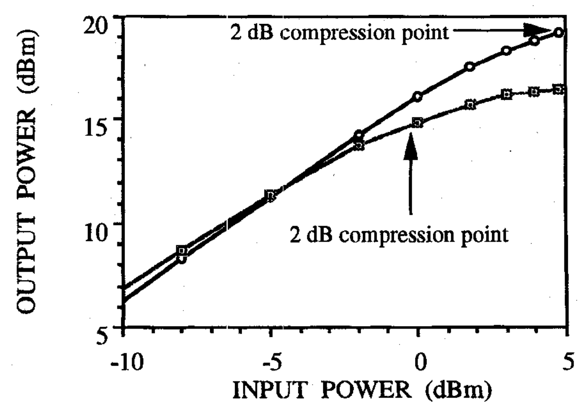

Fig. 7. Gain compression curves for regular horn and hard horn systems. —□— Regular horn. —O— Hard horn.

The measurement setup is shown in Fig. 1. The calibration was performed by connecting the flanges of the waveguide couplers together (therefore any losses introduced by the feed horns are considered to be a part of the amplifier losses). Initially, regular pyramidal horns were used to couple energy to and out of the circuit. The gain and the return loss of the spatial amplifier versus frequency are shown in Fig. 4. A maximum small signal gain of 17 dB was measured.

The amplifier gain compression curve is shown in Fig. 7. At 2-dB compression, the circuit provided 30 mW of output power, which is less than one third of the power expected from the spatial amplifier. This indicates that due to the nonuniform power distribution across the aperture of the horn antenna, only the center column of active devices can be saturated. In order to increase the power-added efficiency it is necessary to saturate all devices simultaneously, hence a feed with uniform aperture fields must be used. One possible solution is to use an electromagnetic hard pyramidal horn as a feed.

As the next step, two pyramidal horns employing electromagnetic hard surfaces were designed and constructed [Fig. 5(a)]. Two dielectric slabs with $\varepsilon_r = 2.2$ were placed along the E-walls of each horn. The slabs' thickness d was obtained using the following formula [9]:

$$d = \frac{\lambda_o}{4\sqrt{(\varepsilon_r - 1)}}.$$

The slabs have conducting strips on the surface as shown in Fig. 5(b). The strips' layout was optimized to improve the uniformity of the aperture fields.

The spatial amplifier's performance while placed in a hard horn system was measured. The gain and the return loss of the circuit versus frequency are shown in Fig. 6. A maximum small signal gain of 16.2 dB at 9.98 GHz was obtained.

The ripples in the gain curves (Figs. 4 and 6) may be attributed to small partial reflections from the surface of the spatial amplifier circuit.

The gain compression characteristics of the amplifier with regular and hard horn feeds are compared in Fig. 7. In the latter case the output power at 2-dB compression is 90 mW. This indicates almost uniform excitation of the active devices across the spatial amplifier surface. The output power at 2-dB compression obtained when the circuit is excited with hard horns is 4.8 dB larger than the output power obtained with regular horns. The insertion loss, obtained when the devices were not biased, was measured to be greater than 25 dB for both cases.

III. Conclusion

A closed-system spatial power-combining amplifier by employing hard horns was demonstrated. The spatial amplifier was constructed on a double layer back to back microstrip circuit. The ground plane provides an effective isolation between the receiving and the transmitting antenna arrays, as well as serving as a heat sink in the design of high power amplifiers. The spatial amplifier provided a 16.2 dB of gain at 9.98 GHz. The output power was measured to be 90 mW at 2-dB compression.

Acknowledgment

The authors would like to thank T. Duffield for many helpful discussions. The authors would also like to acknowledge Fujitsu Corporation for the donation of the devices and Rogers Corporation for the donation of the substrate materials.

References

[1] M. Kim, J. Rosenberg, R. P. Smith, R. M. Weikle, J. B. Hacker, M. P. De Lisio, and D. B. Rutledge, "A grid amplifier," *IEEE Microwave Guided Wave Lett.*, vol. 1, no. 11, pp. 322–324, Nov. 1991.

[2] M. Kim, E.A. Soverro, J. B. Hacker, M. P. De Lisio, J.-C. Chiao, S.-J. Li, D. R. Cagnon, J. J. Rosenberg, and D. B. Ruttledge, "A 100-element HBT grid amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 41, no. 10, pp. 1762–1771, Oct. 1993.

[3] T. Mader, J. Schoenberg, L. Harmon, and Z. B. Popovic, "Planar MESFET transmission wave amplifier," *Electron. Lett.*, vol. 29 no. 19, pp. 1699–1701, Sept. 1993.

[4] C. Y. Chi and G. M. Rebeiz, "A quasi-optical amplifier," *IEEE Microwave and Guided Wave Lett.*, vol. 3, no. 6, pp. 164–166, June 1993.

[5] H. S. Tsai, M. J. W. Rodwell, and R. A. York, "Planar amplifier array with improved bandwidth using folded slots," *IEEE Microwave Guided Wave Lett.*, vol. 4, pp. 112–114, Apr. 1994.

[6] N. J. Kolias and R. C. Compton, "A microstrip-based unit cell for quasi-optical amplifier arrays," *IEEE Microwave Guided Wave Lett*, vol. 3, no. 9, pp. 330–332, Sept. 1993.

[7] T. Ivanov, and A. Mortazawi, "Two stage double layer microstrip spatial amplifiers," in *IEEE MTT-S Int. Microwave Symp. Dig.*, May 1995, pp. 589–592.

[8] T. Ivanov, A. Balasubramaniyan, and A. Mortazawi, "One and two stage spatial amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. 43, no. 9, Sept. 1995.

[9] P.-S. Kildal, "Definition of artificially soft and hard surfaces for electromagnetic waves," *Electron. Lett.*, no. 24, pp. 168–170, 1988.

[10] P.-S. Kildal, "Bandwidth of a square hard horn," *IEE Proc.*, pt. H, vol. 135, no. 4, pp. 275–278, Aug. 1988.