IF-WE-42

Bandwidth Improvement in a Tile Based Spatial Power Amplifier

Ayman Al-Zayed*, Sean Ortiz*, and Amir Mortazawi**

*North Carolina State University, Department of Electrical Engineering and Computer, Raleigh, NC, 27695,USA

**University of Michigan, Department of Electrical Engineering and Computer Science, Ann Arbor, MI, 48109,USA

Abstract — **In this paper, an enhanced bandwidth tile-based spatial power-combining array structure based on a perpendicularly-fed antenna is given. This structure has the advantage of a minimal interaction between the radiated fields and the active devices. Additionally, increased stability is provided, while delivering a robust and reliable design. Dielectrically filled miniature horn arrays were employed for both the receiving and transmitting radiating elements of this 5x5 amplifier array. A peak gain of 15.8 dB at 9.9 GHz and a 3-dB bandwidth of 13% were measured. Gain, bandwidth and power measurements are consistent with simulation predictions.**

I. INTRODUCTION

In 1986, Mink outlined comprehensively the use of active spatial power combining (quasi-optical) techniques to generate high power from active solid-state devices [1]. Since then, variety of power combining schemes has been presented in the literature. Remarkable power levels have been achieved at various frequency bands from amplifiers based on grids and arrays [2]-[4]. These spatial power combiners have been shown to have many advantages: insensitivity to single point failures that could be catastrophic in other combining configurations [8]-[9], noise figure levels comparable to those of single devices, and high output power levels resulting from the low loss spatial power combining method. However, there are some disadvantages and limitations associated with spatial power-combining techniques. Some of these limitations have been addressed by researchers, such as the removal of excess heat produced by the active devices [5]-[6], substrate mode effects that can cause low output powers and poor radiation patterns [10], narrow bandwidth and others.

The work presented in this paper focuses on improving the bandwidth of a tile-based spatial power amplifier, implementing a perpendicularly-fed antenna. This is accomplished by replacing the microstrip patch antennas of a previous design ([7]-[8]) with dielectrically filled miniature horn antennas, while all other design parameters in the amplifier remain the same. A drawing illustrating this concept is shown in Fig. 1. In the figure, the horn antennas on the left receive a signal radiated from the transmitting hard horn. The signal is then coupled to a microstrip line from the dielectric filled waveguide, which feeds the miniature horn antennas. Two dielectric filled waveguide sections reside between the microstrip line and the horn antenna. The section near the horn serves as an impedance transformer, while the other serves as a transition between the waveguide and the microstrip line. Each microstrip line then feeds a MMIC amplifier. After amplification, the signal is radiated through the output of the dielectrically filled miniature horn antenna in the same way that it was received. Finally, the signal radiated from the miniature horn antennas are collected by a receiving hard horn located at the right of the figure. The hard-horns provide a uniform amplitude and phase to the array of miniature dielectric filled horn antennas, improving the combining efficiency of the system [11]-[12]. It is worth mentioning that this horn array amplifier is very stable, due to the minimal interaction between the radiated fields and the active devices. Other advantages of this topology are the ability to use large device sizes, to cascade devices, and to individually bias them.

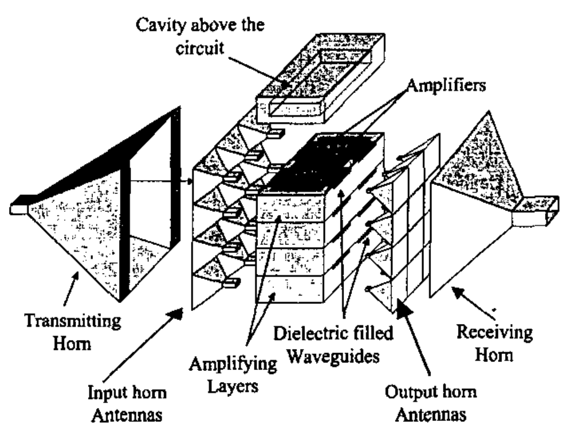

Fig. 1. Tile based spatial power amplifier with dielectrically filled miniature horn antennas.

0-7803-7239-5/02/$10.00 © 2002 IEEE

II. Design

The 5x5 spatial power amplifier presented in this paper takes advantage of the dielectrically filled miniature horn antennas as the receiving and radiating elements. These radiating elements were chosen for their potential to provide broad bandwidth. An illustration of the unit cell design is shown in Fig. 2. The signal received by the miniature dielectric filled horn will travel through a waveguide impedance transformer, and then through a second waveguide section, which provides a transition from the dielectric filled waveguide to the microstrip line. The waveguide impedance transformer uses the same dielectric as the miniature dielectric filled horn antenna. However, the second waveguide section utilizes the same dielectric as the microstrip line, by extending the microstrip line into this waveguide section.

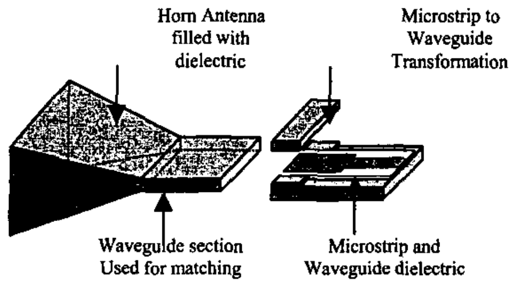

Fig. 2. Design concept of the unit cell.

The same design and hardware implemented in [8] were used for this amplifier array. However, the microstrip patch antennas were replaced by miniature dielectric filled horn antennas. In both arrays, Filtronic (LMA411) MMIC amplifiers are used to provide the gain, with each having a small signal gain of 18 dB and gain flatness of ±0.8 dB between 8.5 and 14 GHz. The output power at 1 dB compression is 17 dBm. The microstrip lines were made from Roger's TMM3 substrate with a thickness of 0.38 mm and a dielectric constant of 3.27. The waveguide impedance transformer has a height of 0.38 mm and is 11.43 mm wide.

The miniature dielectric filled horn was designed with the aid of Agilent High Frequency Structure Simulator (HFSS). The optimal horn design was chosen to give the largest bandwidth and directivity for the given aperture dimensions. The resulting length of the horn antenna (including the length of the waveguide impedance transformer) is 4.75 cm. The dimensions of the waveguide impedance transformer (which also serves as the throat of the horn) are 0.71 mm high, 14.73 mm wide, and 4.88 mm long. It should be noted that this E-Plane horn is formed by flaring the walls of the rectangle waveguide in the direction of the E-field. Paraffin wax with a dielectric constant of 2.24 at 10 GHz [13] and dissipation factor of 0.0002 is used to fill the miniature horns and the waveguide impedance transformers. Polyethylene with a dielectric constant of 2.25 is a good alternative to paraffin.

A single miniature dielectric filled horn antenna was designed, machined and tested to validate simulations. Fig. 3 shows the simulated structure using Agilent HFSS. For the simulation of a single horn, radiation boundaries were assigned to five sides of the air box (no boundary condition is assigned to the aperture side).

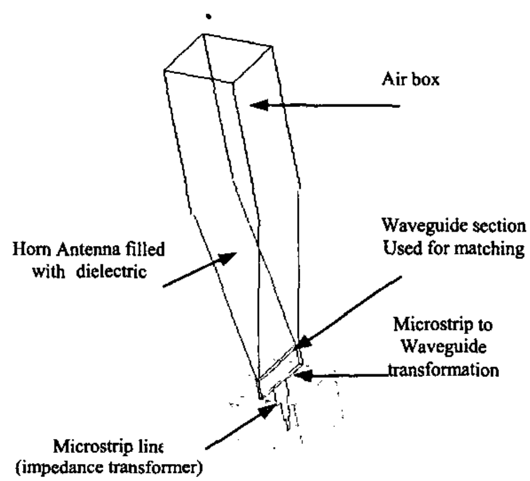

Fig. 3. Simulated structure of the dielectrically filled miniature horn antenna using Agilent HFSS

The simulated and measured VSWR of this horn is plotted in Fig. 4 and the E-plane radiation pattern at 9.22 GHz is shown in Fig. 5. A good agreement was obtained. The directivity of this horn was found to be 7 dB. The returns lose of an infinite array of horns can be found by carefully assigning boundary conditions to the sides of the air box [14].

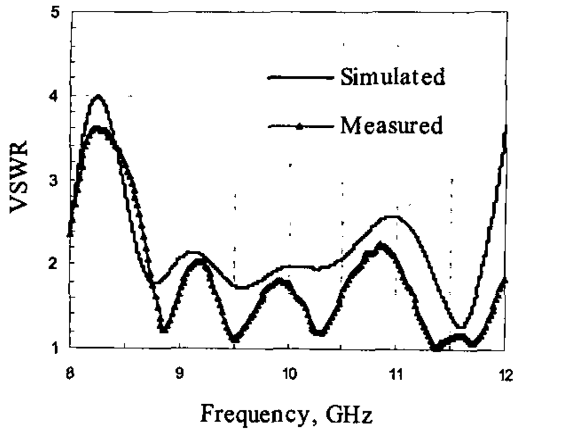

Fig. 4. The simulated and measured voltage standing wave ratio of the paraffin filled single horn.

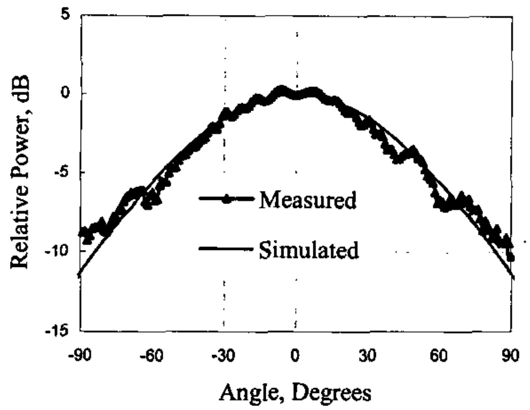

Fig. 5. The E-plan radiation pattern of a single horn antenna filled with paraffin at 9.22 GHz.

IV. Measured Results

Spatial power amplifier with 5x5 dielectric filled horn arrays was machined, assembled and measured. The small signal gain measurement was performed by placing the amplifier between two hard horns. The measured gain is shown in Fig. 6. The peak gain is 15.8 dB at 9.9 GHz, the 3-dB bandwidth is 1.32 GHz (13%) and the largest ripple is about 1.9 dB. The agreement is reasonable with simulation prediction. It is to be noted that the previously published perpendicularly fed patch array quasi-optical amplifier has a gain of 16 dB and a 3-dB bandwidth of 280 MHz [8]. The bandwidth improvement was achieved by replacing the patch arrays with horn arrays keeping the rest of the parameters the same.

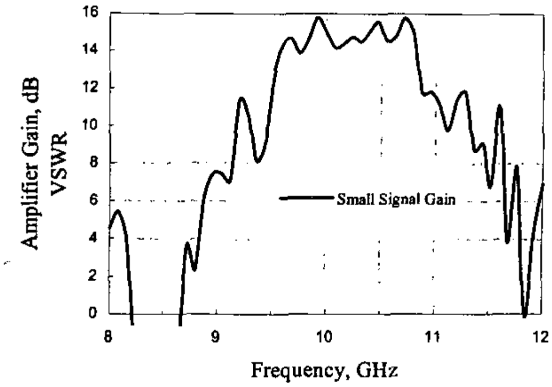

Fig. 6. Small signal gain measurement of the spatial power amplifier with dielectrically filled miniature horn antennas.

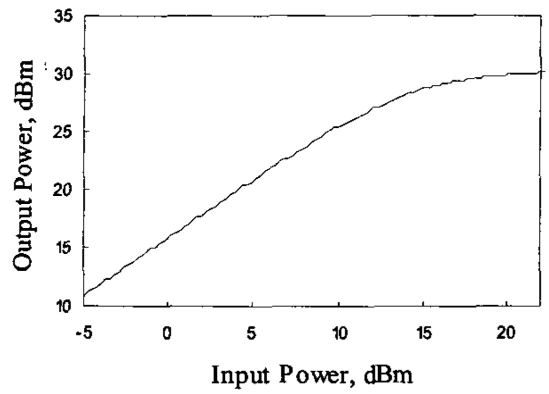

Fig. 7. Power compression curve of the 25-element spatial power amplifier.

Fig. 7 shows the output power versus the input power for the horn array amplifier. This amplifier has 27 dBm output power at 1 dB compression. A photograph of the assembled tile based broadband spatial power amplifier is show in Fig. 8.

V. Conclusion

In this paper, a broadband tile based spatial power amplifier that employs dielectrically filled miniature horn arrays was presented. Bandwidth improvement was achieved by replacing the patch arrays of an earlier design with the broadband horn antennas. This 5x5 spatial power amplifier with miniature horn arrays has a peak gain of 15.8 dB at 9.9 GHz. The 3 dB bandwidth is 1.32 GHz, which is more than 4.5 times the 3 dB bandwidth of the perpendicularly fed patch array spatial power amplifier [8]. The output power was found to be 27 dBm at 1 dB compression. The measured gain and bandwidth agreed reasonably with simulations.

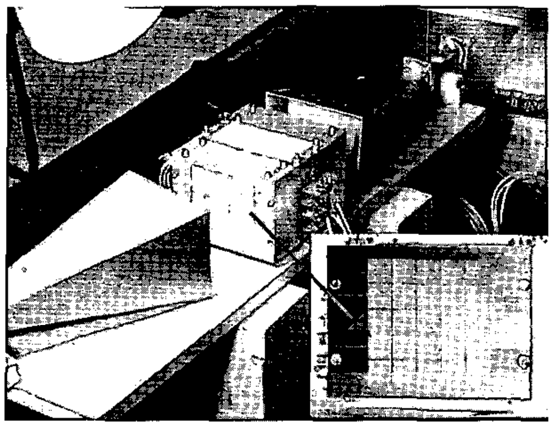

Fig. 8. Photograph of the 5x5 spatial power amplifier that employs dielectrically filled miniature horn arrays.

ACKNOWLEDGEMENT

This work is supported by an Army Research Office-MURI grant under the Spatial and Quasi-Optical Power combining DAAG-55-97-0132. The authors would like to thank Professor L. Wilson Pearson and Mr. Chris Tompkins from Clemson University for the radiation pattern measurements.

REFERENCES

[1] J. W. Mink, "Quasi-Optical Power Combining of Solid-State Millimeterwave Sources," *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-34, no. 2, pp. 273-279, Feb 1986.

[2] D. Deckman, D. S. D. Jr., E. Sovero, and D. Rutledge, "A 5-watt, 37GHz monolithic grid amplifier, HBT grid amplifier," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 805-808, June 2000.

[3] N. -S. Cheng, P. Jia, D. B. Rensch, and R. A. York, "A 120-W X-band spatially combined solid-state amplifier," *IEEE Trans. Microwave Theory and Techs*, vol. 47, pp. 2557–2561, Dec. 1999.

[4] J. Sowers, D. Pritchard, A. White, W. Kong, and O. Tang, " A 36 W, V-band, solid state source," *IEEE MTT-S MO3C-1*, vol. 1, pp. 235-238, June 1999.

[5] A. Guyette, R. Swisher, F. Lécuyer, A. Al-Zayed, A. kom. S. L. lei, M. Oliviera, P. Li, M. P. De Lisio, *Sato, K.; Oki, A.; Gutierrez-Aitken, A.; Kagiwada, R.; Cowles, J*, "A 16-Element Reflection Grid Amplifier with Improved Heat Sinking" *Int.Microwave Symp Dig.*, pp. 1839-1842, May, 2001.

[6] S. Ortiz, J. F. Hubert, L. Mirth, E. Schlecht and A. Mortazawi, "A 25 Watt and 50 Watt Ka-Band Quasi-Optical Amplifier," *IEEE Int.Microwave Symp Dig.*, pp. 797-800, June, 2000.

[7] S. Ortiz and A. Mortazawi, "A perpendicularly-fed patch array for quasi-optical power combining," *IEEE MTT-S Int. Microwave Symp. Dig.*, vol. 2, pp. 667-670, 1999.

[8] S. Ortiz, M. Ozkar, A. Yakovlev, M. Steer, and A. Mortazawi, "Fault Tolerance Analysis and measurement of a Spatial Power Amplifier," *IEEE AP-S Int. Symp.*, vol. 3, pp. 1827-1830, May, 2000.

[9] R. A. York "Some Consideration for Optimal Efficiency and Low Noise in Large Power Combiners," *IEEE Trans. Microwave Theory Tech.*, vol. 49, Issue. 8, pp. 1477-1482, August. 2001.

[10] A. Al-Zayed, R. Swisher, F. Lécuyer, A. Guyette, Q. Sun and M. P. De Lisio, " Reduction of Substrate-Mode Effects in Power-Combining arrays," *IEEE Trans. Microwave Theory Tech.*, vol. 49, Issue. 6, part 1, pp. 1067-1072, June. 2001.

[11] M. A. Ali, S. Ortiz, T. Ivanov, and A. Mortazawi, "Analysis and measurement of hard horn feeds for the excitation of quasi-optical amplifiers," *IEEE Trans. Microwave Theory Tech.*, vol. 47, pp. 479-487, 1999.

[12] M. S. Gupta, "Power combining efficiency and its optimization," *Microwave, Antennas and Propagation, IEE Proceedings H*, vol. 139 Issue. 3, pp. 233-238, June 1992.

[13] D. M. Pozar, " Microwave Engineering", 2nd John Wiley& sons, 1998.

[14] G. M. Turner, C. Christodoulou, "FDTD analysis of phased array antennas, " *IEEE Trans. Antenna and Propagation*, vol. 47, pp. 661-667, April. 1999.