A CPW-Fed Microstrip Patch Quasi-Optical Amplifier Array

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***Abstract*—A quasi-optical power-combining amplifier array based on coplanar waveguide (CPW)-fed microstrip patch antennas is introduced in this paper. Both the transmit and receive antennas employ CPW-fed patches. This amplifier is not only compatible with monolithic-microwave integrated-circuit implementations, but can also provide a greater bandwidth than circuits based on conventional microstrip-fed patch antennas. A 4 × 4 amplifier array was designed and constructed at X-band. Results for the gain and power compression are also presented.**

***Index Terms*—Amplifier, CPW, quasi-optical, spatial.**

I. INTRODUCTION

MANY PAPERS [1]–[7] have been presented that demonstrate quasi-optical power combining utilizing grids, coplanar waveguide (CPW)-fed slots, and microstrip-patch-based quasi-optical amplifiers. At millimeter-wave frequencies, the use of CPW transmission lines is preferable for monolithic-microwave integrated-circuit (MMIC) implementations. CPW transmission lines are also necessary to avoid vias, specifically in the construction of amplifier arrays requiring substrates such as diamond- or ceramic-based materials (for heat sinking purposes). Quasi-optical amplifiers, which utilize the advantages of CPW transmission lines, typically have slot antennas as the radiating elements. Since slot antennas radiate equally in the front and back directions, polarizers are typically used to regain the energy radiated in the undesirable direction. This is done by providing constructive interference between the forward radiated fields and the reflected back radiated fields. In this paper, a new design for quasi-optical amplifiers, based on CPW-fed microstrip patch antennas, is presented. This design eliminates the need for polarizers, while maintaining the benefits of CPW transmission lines at millimeter- wave frequencies. The elimination of polarizers is made possible by using CPW-fed microstrip patch antennas, which provide front-to-back radiated power ratios on the order of 20 dB [8].

In addition to presenting a new quasi-optical amplifier array topology, hard electromagnetic feed horns, as proposed in [9], are used to form a closed quasi-optical amplifier system. These horns provide a means of efficiently splitting and combining the power equally among the active devices in the array. In this paper, the design and construction of a 4 × 4 CPW-fed microstrip amplifier array is presented. The passive and active array losses are investigated, and power and gain measurement results for the hard horn excitation of these arrays are given.

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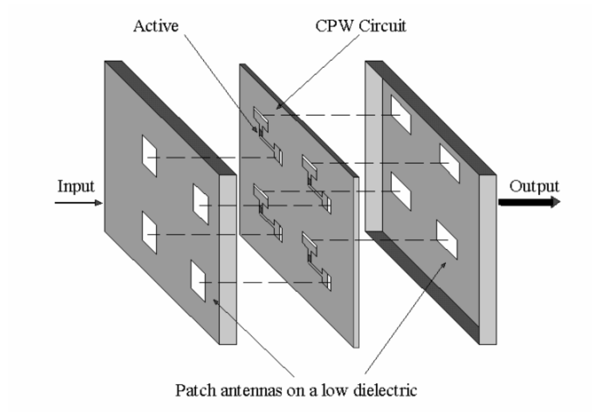

Fig. 1. CPW-fed microstrip patch quasi-optical amplifier array.

II. DESIGN

A simplified diagram of the CPW-fed microstrip patch quasi-optical amplifier array is shown in Fig. 1. A signal, transmitted from a source located to the left-hand side of the array, is received by the microstrip patch antennas on the first layer. The signal is then coupled to slot antennas located on the second layer, where it is amplified and coupled to the patch antennas located on the third layer. The receiving and transmitting antennas are placed orthogonally to each other in order to minimize any mutual coupling. A perspective view of the double-layer CPW-fed microstrip patch antenna is shown in Fig. 2, while a detailed view of the passive unit cell construction is shown in Fig.3. The CPW-fed microstrip patch antennas were designed based upon the results found in [8] and [10]. The design process began with a simple microstrip patch antenna design based on personal computer-aided antenna design (PCAAD). This was followed by simulating a slot-fed microstrip patch antenna using HP Momentum. In this process, the length and width of the slot were varied until resonance occurred at the desired frequency of operation. The slot was then matched to 50 Ω using a quarter-wave transformer. The antenna and slot dimensions were slightly different for the receiving and transmitting layers due to the addition of the CPW substrate on the transmitting side.

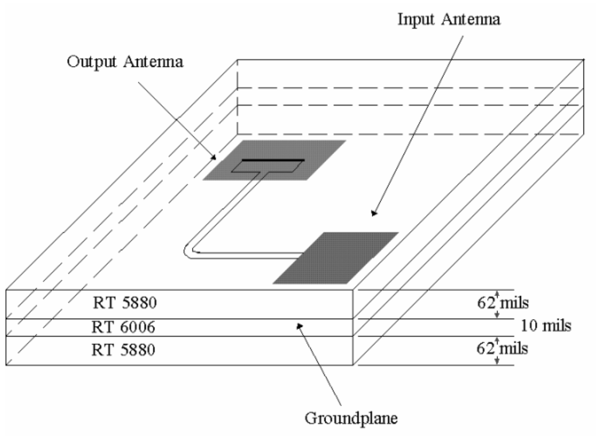

Fig. 2. Perspective view of the CPW-fed microstrip patch antennas.

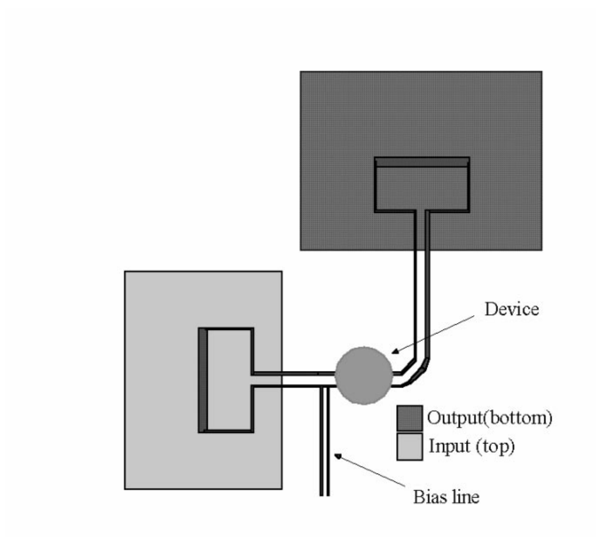

Fig. 3. Unit cell of the CPW-fed microstrip patch quasi-optical amplifier array.

The complete unit cell, including the biasing circuitry, was simulated using HP Momentum. Rogers 6006 with $\varepsilon_r = 6.15$ and thickness of 10 mil was used for the CPW substrate. Rogers 5880 with $\varepsilon_r = 2.2$ and thickness of 62 mil was used for the patch antenna substrates placed above and beneath the CPW substrate. The simulated return loss for both the input and output antennas is shown in Fig. 4. Both antennas show 10-dB bandwidths of greater than 600 MHz. Additionally, the front-to-back radiated power ratio for the input and output antennas is 20 and 15 dB, respectively. These results are illustrated by the simulated radiation patterns given in Figs. 5 and 6.

III. Experimental Results

A 4 × 4 amplifier array, shown in Fig. 7, was constructed based on the unit cell design discussed previously. The active devices used are Mini-Circuits ERA1 matched monolithic amplifiers. These devices are designed to provide 10 dB of gain from dc to 8 GHz. In our experiments, these devices are used above their design frequency, providing an acceptable gain of approximately 9 dB at 10 GHz. The spacing between the array elements is 800 mil or 0.68 λ in air.

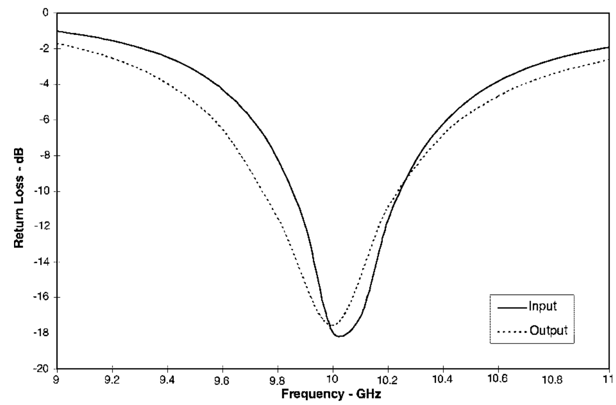

Fig. 4. Simulated return loss for the input and output CPW-fed microstrip patch antennas.

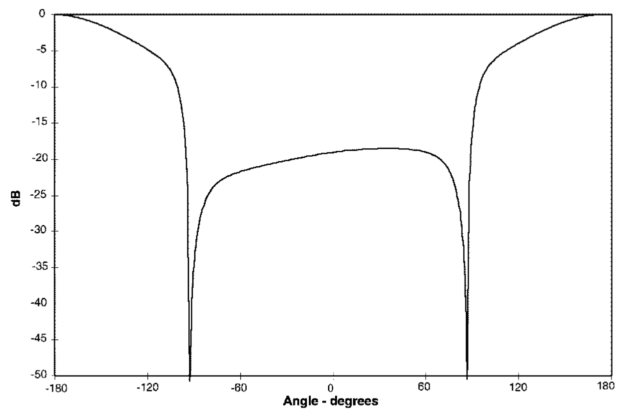

Fig. 5. Simulated E-plane radiation pattern for the input antenna.

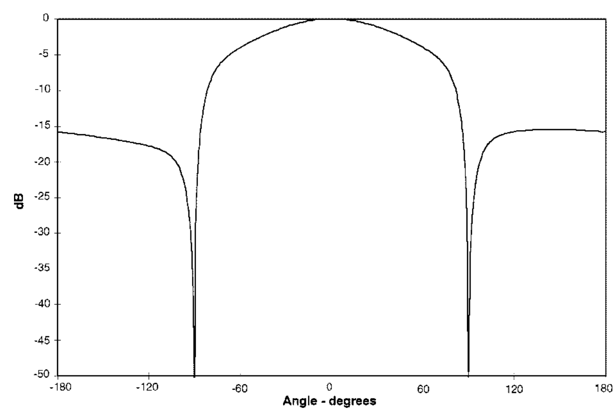

Fig. 6. Simulated E-plane radiation pattern for the output antenna.

Before measuring the passive array, as illustrated in Fig. 8, the insertion loss of the copolarized horns was measured with the horns spaced approximately 1 cm apart. The measured insertion loss was found to be 1.2 dB over a bandwidth greater than 2 GHz about the center frequency of 10 GHz. However, the return loss across this band was better than 20 dB. The insertion loss is associated with the hard electromagnetic horns and dielectric lenses used to correct the magnitude and phase errors. As mentioned earlier, the hardened horns radiate with a uniform power distribution across the horn's aperture. This does incur some additional loss associated with the dielectrics used along the sidewalls of the horn since some of the energy

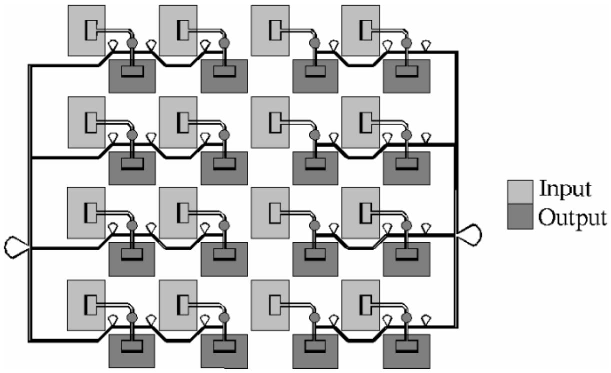

Fig. 7. 4 × 4 CPW-fed microstrip patch quasi-optical amplifier array.

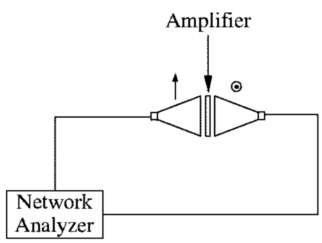

Fig. 8. Measurement setup. Two cross-polarized horns are used to couple energy to the quasi-optical amplifier array.

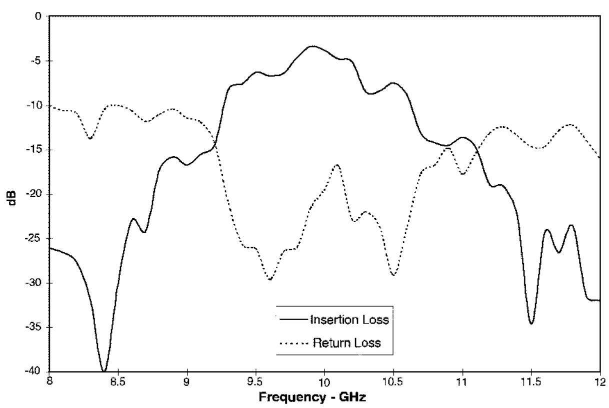

Fig. 9. Measured insertion loss and return loss of the passive 4 × 4 CPW-fed microstrip patch quasi-optical amplifier array.

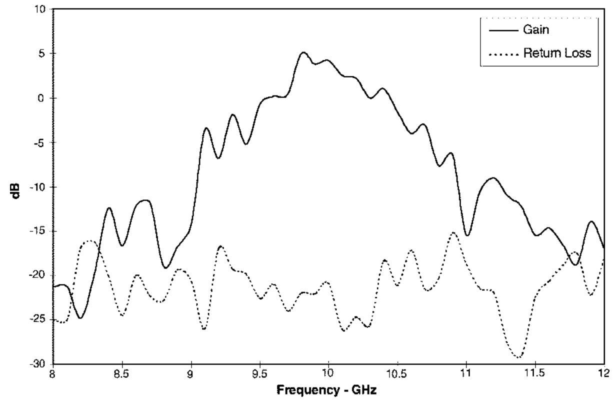

Fig. 10. Measured gain and return loss of the active 4 × 4 CPW-fed microstrip patch quasi-optical amplifier array.

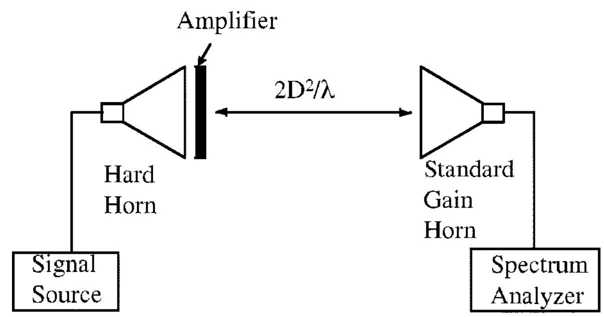

Fig. 11. Measurement setup for the far-field radiation pattern.

will flow inside the dielectrics and is effectively lost. In addition, dielectric lenses are used to create a uniform phase front at the aperture and also incur some losses. The passive array was then placed between the two cross-polarized horns since the array input and output antennas are cross polarized. Both the input and output horns are placed in the reactive near field of the antenna array. This causes a minimal disturbance to the antennas since the fields at the horn's aperture resemble those of free space. Spill-over losses are also minimized by placing the antenna array at the horn's aperture. The results of the active antenna measurement are shown in Fig. 9. The insertion loss was found to be 3.4 dB at 9.9 GHz with a 3-dB bandwidth of 600 MHz. This gives an insertion loss of 2.2 dB due to the passive array. The return loss is again better than 15 dB across the entire bandwidth, indicating that the passive array is operating as expected.

The active array was then placed in the horn-to-horn setup and its performance was measured. The overall gain for the 4 × 4 amplifier array with hard horn feeds included was measured to be 5.0 dB at 9.8 GHz with a 3-dB bandwidth of 400 MHz, as shown in Fig. 10. Considering 2.2- and 1.2-dB losses associated with the passive array and hard horns, respectively, the device gain is 8.4 dB, which is consistent with expectations. As mentioned, the ERA1 devices are designed to operate below 8 GHz. The reduced gain at higher frequencies can cause the reduction in bandwidth. The bandwidth of the active array is lower than the bandwidth of the passive array by 200 MHz. The active arrays return loss is better than 15 dB across the band. In fact, the active arrays return loss is better than the return loss for the passive array. This is because the amplifying devices are unilateral and, therefore, isolate the input and output antennas. This prevents the out-of-band reflections from the output antennas from reaching the input side.

In addition to the amplifier gain, radiation patterns as well as the arrays power compression were measured. The measurement setup for the radiation pattern is shown in Fig. 11, and the measured radiation patterns are shown in Figs.12 and 13. The simulated results are for a coax-fed microstrip patch antenna array. However, the actual array elements are excited differently because of the capacitively coupled CPW slots. This is a contributing factor for the discrepancy between the measured and simulated radiation patterns.

The uniform E_y-field distribution provided by the hard electromagnetic horns is illustrated in Fig. 14. The setup is illustrated in Fig. 8 for the amplifier power compression measurement. The results of this measurement are illustrated in Fig. 15. The 3-dB compression power is 17.7 dBm. A single device under 3-dB compression in a 50-Ω system provided 10 dBm

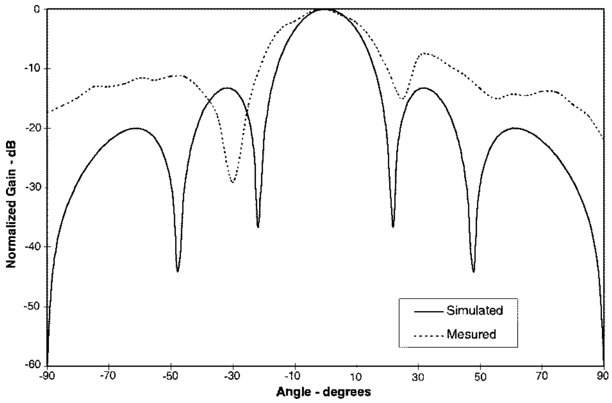

Fig. 12. Simulated and measured E-plane radiation patterns.

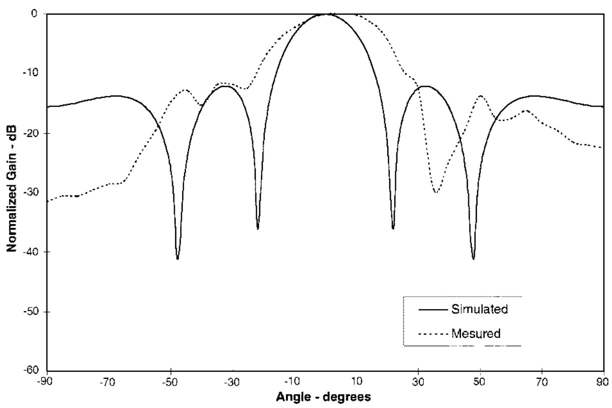

Fig. 13. Simulated and measured H-plane radiation patterns.

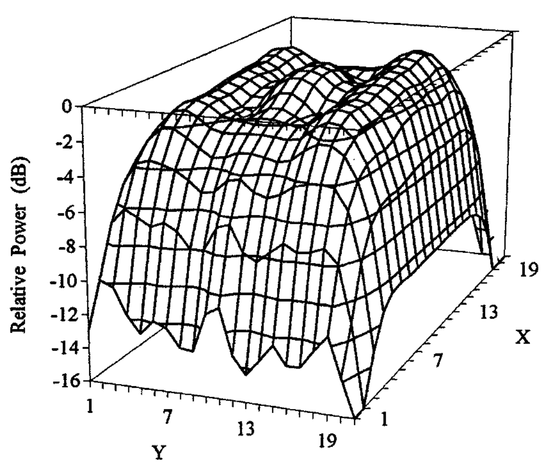

Fig. 14. Normalized power distribution of an electromagnetically hardened horn.

of power at 10 GHz. Therefore, the maximum power obtainable from the 16 device array under 3-dB compression after taking into account the output array losses is 19.4 dBm. The difference between the expected and measured power compression can be attributed to the amplitude and phase errors of the hard horn. The effect of the phase and amplitude variations in hard horn excitations of quasi-optical arrays is discussed in [11].

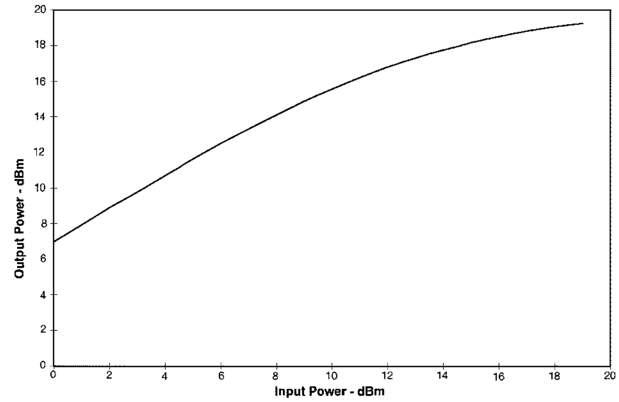

Fig. 15. Measured power compression curve of the 4 × 4 quasi-optical amplifier array constructed with CPW-based unit cells.

IV. Conclusion

A CPW-fed microstrip patch quasi-optical power-combining amplifier array is introduced. A 16-element passive and active array were designed and measured. The passive array demonstrated an insertion loss of 3.4 dB. The active array showed 5.0 dB of gain at 9.8 GHz with a 3-dB bandwidth of 400 MHz. This amplifier is not only compatible with MMIC implementations, but can also provide a greater bandwidth than circuits based on conventional microstrip-fed patch antennas.

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