Quasi-Optical Amplifier Array using Direct Integration of MMICs and 50 Ω Multi-Slot Antennas

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Abstract — A new 50 Ω planar antenna structure is presented for finite thickness dielectric substrates. Direct integration of these antennas and commercial MMICs amplifier chips is explored for quasi-optical power combining. A prototype 4 × 4 array demonstrated 10 dB gain with 4% bandwidth @ 11 GHz with no matching networks.

I. Introduction

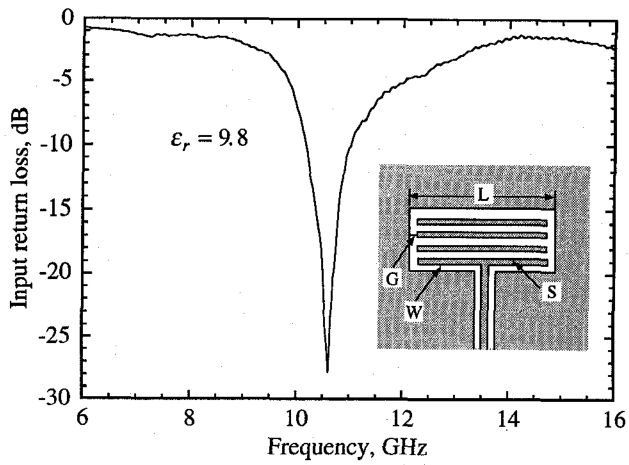
Quasi-optical amplifier arrays have shown promise as high power sources using solid-state devices in the millimeter-wave regime. In this spatial combining scheme, each device and amplifier circuit is coupled to antennas, such that the power is combined coherently in free space. A convenient way of designing these quasi-optical arrays would use antennas with 50 Ω input impedance since they can be integrated directly with off-the-shelf MMICs without any matching networks—for example, oscillators, amplifiers, and mixers, which are usually designed for a 50 Ω environment. This paper presents a novel five-slot coplanar-waveguide (CPW) fed antenna on $\varepsilon_r = 9.8$ substrate which shows a 50 Ω input impedance. An amplifier array using these antennas and commercial HBT gain blocks, developed by Rockwell Science Center, was fabricated and tested. This array shows 4% bandwidth @ 11 GHz with 8 dB gain, which is expected from these gain blocks.

II. 50 Ω Antennas

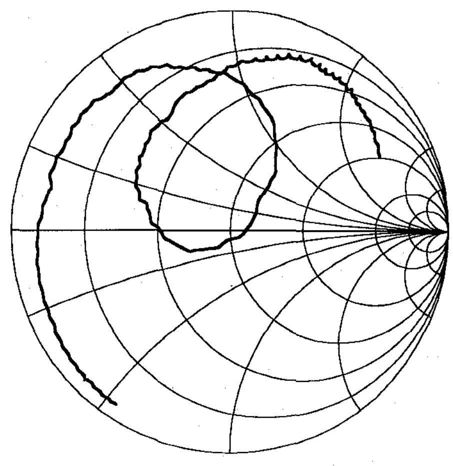
It is well established that the input impedance of N-element slot antenna, $Z_{in,N}$, is given by

$$Z_{in,N} = \frac{Z_{slot}}{N^2} \tag{1}$$

where Z_{slot} is the input impedance of a single slot antenna. The use of additional slots allows us to "engineer" the input impedance of the antenna over a wide range. We have explored this concept theoretically using the Finite-Difference Time-Domain method (FDTD) [1], and experimentally on both low and high dielectric constant substrates. Since high-ε_r materials are used in monolithic design, we concentrate here on Alumina substrates with $\varepsilon_r = 9.8$. A 10 GHz folded-slot antennas on 0.635 mm Alumina has a theoretical impedance of ≈ 300 Ω [1]; this implies that five slots would yield approximately a 50 Ω impedance according to (1). Using the results from [1], a 10 GHz five-slot antenna was built and measured using a Cascade Microtech wafer probing



(a)



(b)

Figure 1 : The frequency response of the five-slot antenna with 50Ω input impedance. The frequency range in (b) is from 5 GHz to 15 GHz.

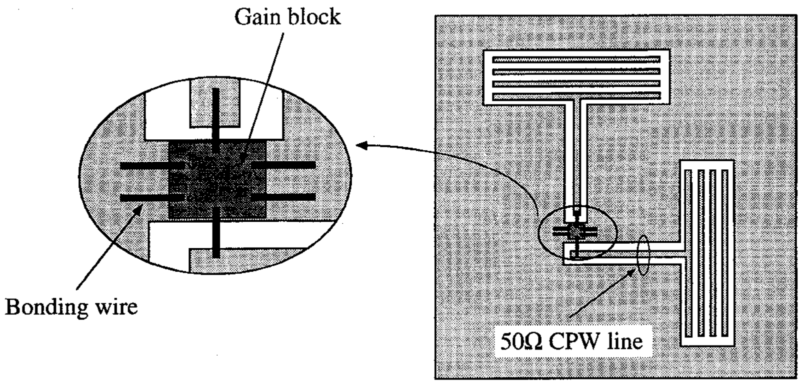


Figure 2 : Drawing of the amplifier single cell. The input and output of the gain block are connected to five-slot antennas using bonding wires and 50Ω CPW lines.

setup, with the result shown in figure 1. The length and the width of the slots are L=7.2 mm and W=G=0.3 mm, respectively; the separation of the two slots is S=0.3 mm. The -10 dB bandwidth is ≈ 10%, which is relatively wide compared with conventional antennas on high dielectric constant substrates. From figure 1(b), this antenna has an input impedance of 58 Ω @ 10.5 GHz, which is close to what we predicted.

III. Amplifier Array

The 50 Ω antenna structure allows us to directly integrate commercial MMIC chips that are designed for a 50 Ω input/output impedance. To explore this idea, we constructed quasi-optical amplifier cells, shown in figure 2, by bonding a typical MMIC amplifier block between two five-slot antennas described above, without any external matching networks. Notice that these two antennas are polarized orthogonally to isolate the input and output signals as well as to avoid the oscillation due to mutual coupling between antennas. Both a 10 dB Rockwell HBT gain block and a similar 20 dB HBT gain block were tested. These two devices were first characterized using HB 8510B with a Cascade wafer probing setup and have approximately 10 dB gain around 10 GHz, with a unity-gain cutoff of approximately 18 GHz. The two amplifier cells were then measured in a oversized square waveguide using an HP 8720 network analyzer, as shown in figure 3. This measurement setup allows us to obtain the gain of these amplifier cells directly without using the Friis transmission equation [2]. The two waveguide horns were machined to make a smooth tapered transition from standard X-band waveguide to a one inch square aperture. The middle section is a one inch square waveguide; this allows the propagation of signals with both vertical and horizontal polarizations. Notice that there is a polarizer in front of the amplifier cell in order to direct the output radiation in the forward direction; this also provides some tuning for better match. Figure 4 shows the frequency responses from the HP 8720 for both cells. The peak gains for both case are about 7 dB, which is smaller compared to the measurement from single device alone (10 dB). This dif-

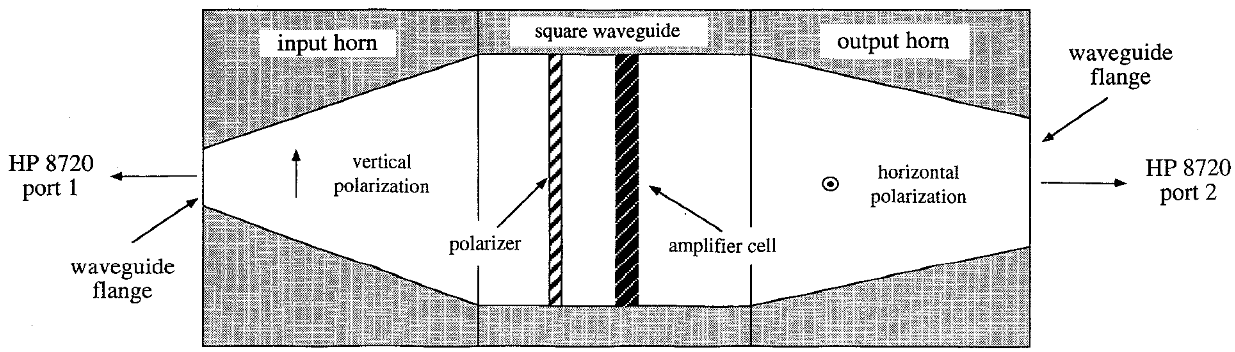


Figure 3 : Illustration of the waveguide measurement setup for the amplifier cells. The middle section is a one-inch-square waveguide which allows the propagation of vertical and horizontal signals, as indicated in the figure.

ference could be due to the insertion loss of the waveguide flange. It is clear that in the range where $S_{21} > 1$, the input match is fairly good. The 3 dB bandwidth is $\approx 4\%$ for both cases.

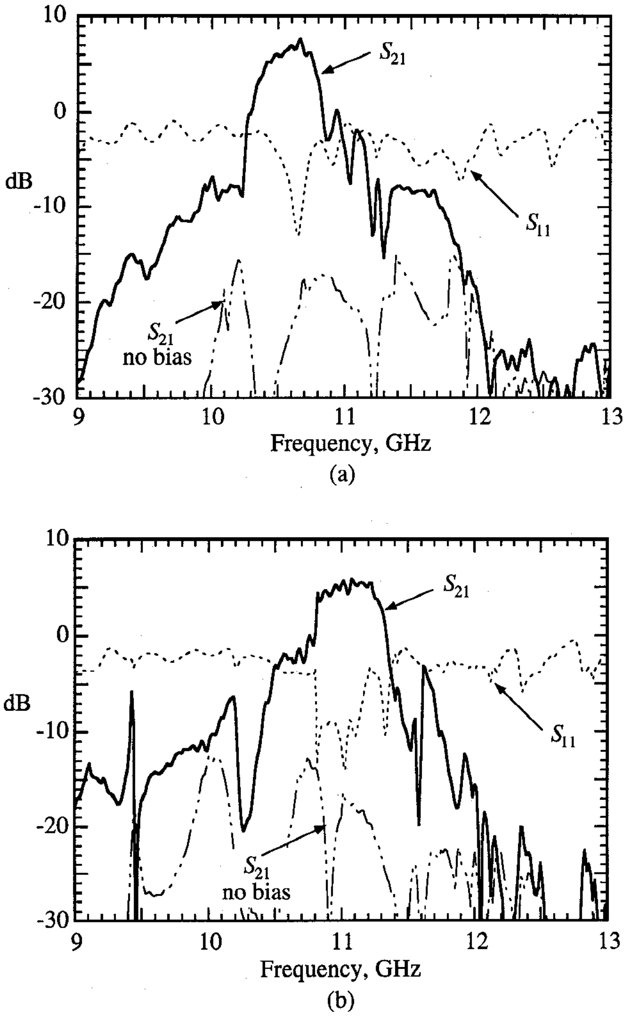


Figure 4 : The measured frequency response of the amplifier cells using (a) 10dB gain block. (b) 20dB gain block.

Using these antennas and 20 dB gain blocks, a 4x4 amplifier array was built. This array was measured in free space using the technique described in [3] since it can not fit into the waveguide. A polarizer was also used in this measurement for better matching. The gain curve of this array is shown in figure 5. The Effective Isotropic Power Gain (EIPG) [4] for this array is 35 dB. Using an estimated array directivity of 13.5 dB gives a peak gain of approximately 8 dB, which is close to what we expected from these gain blocks (10 dB at 10 GHz). The 3 dB bandwidth is 4% @ 11 GHz. The reason for the narrower bandwidth of these amplifiers compared to that of the antenna described in previous section is due to the use of two antennas per unit cell, and the non-uniform gain of the amplifier in this frequency range. The bandwidth of the circuit could be significantly broadened using matching elements to adjust the off-resonance reactance of the antennas, but this was not considered a priority for the purpose of this paper, which was to explore direct integration of MMICs and the novel planar antenna.

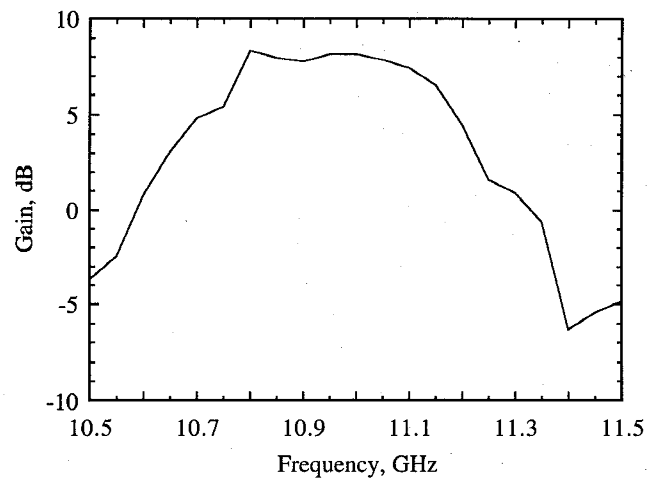


Figure 5 : The gain curve of the 4x4 amplifier array.

IV. Conclusions

A CPW-fed five-slot antenna with 50 Ω input impedance was described in this paper. This antenna is preferable for MMICs because it can be fabricated with a single mask step, and no backside processing (via holes) is required for integration with devices; more importantly, it can be integrated directly with off-the-shelf MMICs because of its 50 Ω input impedance. This advantage is demonstrated by an amplifier array and two single cells using this antenna and gain blocks. Future work will include applying the idea of impedance scaling to the design of a broadband quasi-optical HBT amplifier array at U-band.

V. ACKNOWLEDGMENTS

This work was supported by ARPA and Rockwell Science Center, Thousand Oaks, California.

VI. REFERENCES

[1] H.S. Tsai and R.A. York, "FDTD Analysis of CPW-Fed Folded-Slot and Multiple-Slot Antennas on Thin Substrates," submitted to *IEEE Trans. Antennas Propagat.*, Oct. 1994.

[2] C.A. Balanis, *Antenna Theory: Analysis and Design*, Wiley: New York,1982.

[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 and Guide Wave Lett.*, vol. 1, No 11, Nov 1991.

[4] H.S. Tsai, M.J.W. Rodwell and R.A. York, "Planar Amplifier Array with Improved Bandwidth Using Folded Slots", *IEEE Microwave and Guided Wave Lett.*, vol. 4, pp. 112-114, Apr. 1994.