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60 GHz Monolithic Active Antenna Array

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I. Introduction

Many quasi-optical, plane-wave-fed, transmission-mode amplifiers have been demonstrated to date [1 – 3], recently also at millimeter-wave frequencies [4 – 5]. Here we present a monolithic 60-GHz quasi-optical amplifier antenna array, the output side of which is shown in Figure 1(a). An input plane wave is received by the slot antennas in the ground plane, capacitively coupled through the GaAs substrate to microstrip PHEMT amplifiers, and radiated in transmission by patch antennas.

II. Design

The unit cell of the amplifier is shown in more detail in Figure 1(b). The amplifier uses a $0.1 \times 100 - \mu$m PHEMT designed by Martin Marietta Laboratories – Baltimore (MML–B). We use a microstrip amplifier circuit, with a slot antenna feeding the input and the output feeding a patch antenna. Although this requires a thinned substrate for the ground vias, it has the advantage that the output patch is a unidirectional radiator.

The most important step in designing active antenna amplifiers is to make the transistor unconditionally stable. We employ the stabilization network demonstrated in [6] as shown in Figure 1(b). An additional advantage of this approach is that the gate bias can also be brought in anywhere beyond the open stub without affecting device performance. All of the bias lines are meandered to provide higher impedance at high frequencies, and each line has shunt capacitors to ground within every unit cell of the design. These features help prevent bias-line oscillations. The device has been made unconditionally stable from 100 MHz to 100 GHz, and the simulated peak gain is 7.6 dB at 60 GHz with a 9.5% 3-dB bandwidth into constant 75 Ω loads. We have chosen to use 75-Ω microstrip lines to facilitate circuit layout.

The antennas are also designed to be matched to 75 Ω at the design frequency, although their resonant nature only allows the match to be made over a small bandwidth. This small matching bandwidth is the limiting factor for the bandwidth of the array. The patch was designed using multi-port network analysis [7] which results in a patch measuring 687 μm in the resonant direction and 400 μm along the radiating edges, and a theoretical efficiency of 25.7%. To get the 75-Ω impedance, the patch is fed on the non-radiating edge 270 μm away from the radiating edge. The patch also provides the means of biasing the drain of the transitor through the null at the center of the non-radiating edge. The slot design chosen was that of an antiresonant slot. The design of the slot was done using *WireZeus* [8]. It is 1065 μm long and 211 μm wide, and is fed 33 μm from the center. The reactance of the slot is canceled by that of the 150 μm open stub to provide a 75 Ω impedance at 60 GHz.

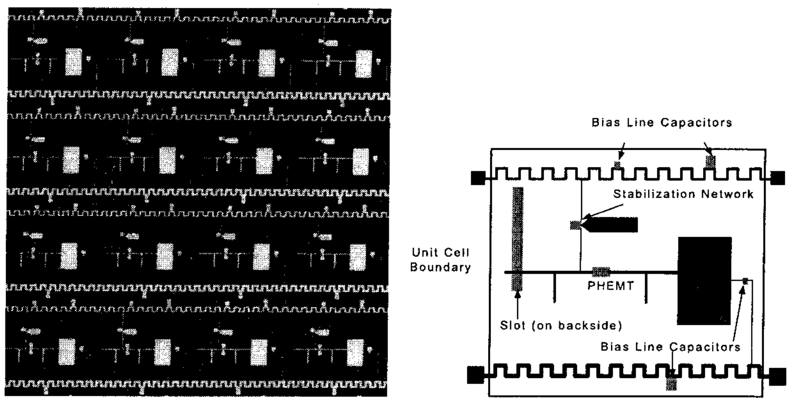

Figure 1: Amplifier array (a) photograph and (b) unit cell. The period of the array is 2.5 mm, which is $\lambda_0/2$ at 60 GHz.

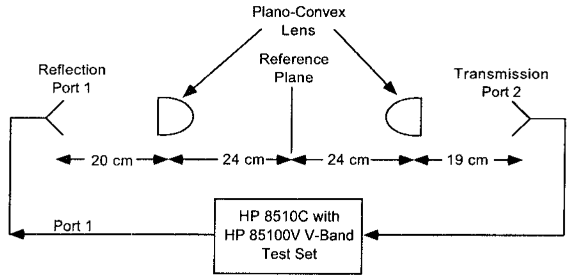

Figure 2: Measurement configuration for 60 GHz amplifier array

III. Array Measurement

The array, fabricated by MML–B on 100-μm thick GaAs, is 10 mm square. It is tested in a free-space setup using the set-up shown in Figure 2. The lenses are broadband plano-convex dielectric lenses with focal lengths of 14 cm. In order to provide a measure of the losses inherent in the measurement system, an aperture the size of the amplifier array is placed at the reference plane and measurements of the power through the system are taken. The aperture is then replaced with an array holder without any aperture in order to measure the reflection level.

After these measurements, the transmitting horn is rotated 90° in order to match the polarization of the array antennas, and the array is placed at the reference plane. The array shows about an 18 dB on/off ratio, and has a positive ratio from 57.5 to 60.65 GHz. As can be seen from the measurements in Figure 3, etalon effects due to cavity modes in the measurement configuration were not calibrated out. We are currently working on this problem.

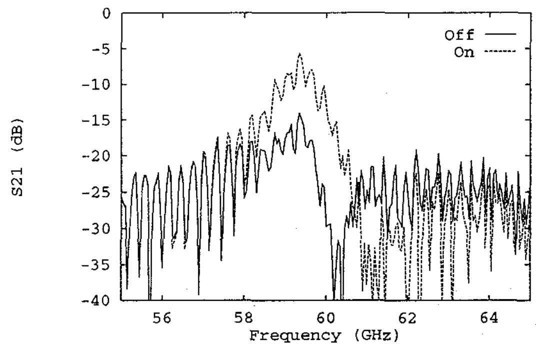

Figure 3: Measured on and off responses for 16-element array

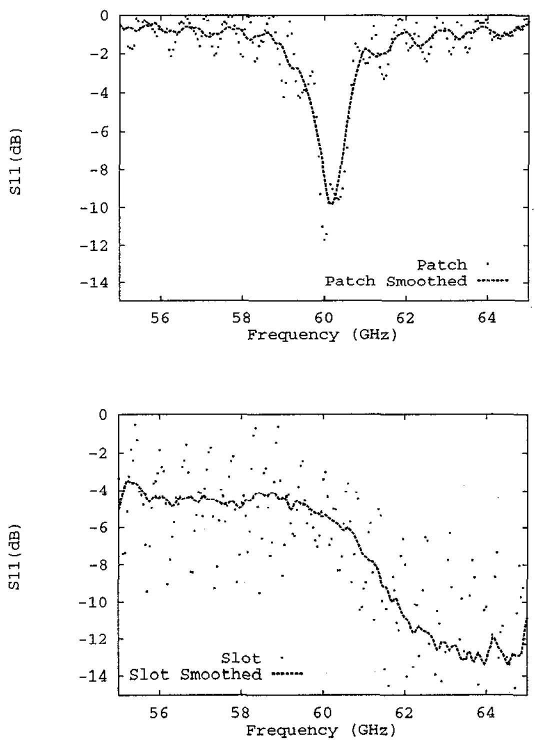

Figure 4: Antenna reflection measurements for (a) patch and (b) slot. The measured data (dots) and data smoothed over a 5% bandwidth (dashed line) are shown.

Reflection coeffecients from both sides of the array were measured with the amplifiers off in order to quantify the resonant frequencies of the antennas. Figure 4 shows the measured reflection coefficient, with respect to an array holder without any aperture, of the patch side and slot side of the array. The patch antennas are resonant at 60 GHz, but the slot antennas are resonant higher in frequency. This antenna mismatch greatly reduces the system gain of the array, which demonstrates the importance of using a passive array for calibration [9] and design validation.

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REFERENCES

[1] T. Mader, J. Schoenberg, L. Harmon, and Z. B. Popović, "Planar MESFET transmission wave amplifier," *Electr. Letts.*, vol. 29, pp. 1699–1701, Sept. 1993.

[2] 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 Let.*, vol. 4, pp. 112–114, Apr. 1994.

[3] 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, Orlando, FL.

[4] J. Hubert, J. Schoenberg, and Z. B. Popović, "High-power hybrid quasi-optical Ka-band amplifier design," in *IEEE MTT-S Int. Microwave Symp. Dig.*, May 1995, pp. 585–588, Orlando, FL.

[5] C.-M. Liu, E. A. Sovero, W. J. Ho, J. A. Higgins, M. P. DeLisio, and D. B. Rutledge, "Monolithic 40-GHz 670-mW HBT grid amplifier," in *IEEE MTT-S Int. Microwave Symp. Dig.*, June 1996, pp. 1123–1126, San Fransisco, CA.

[6] J. S. H. Schoenberg, S. C. Bundy, and Z. B. Popović, "Two-level power combining using a lens amplifier," *IEEE Trans. Microwave Theory Tech.*, vol. 42, pp. 2480–2485, Dec. 1994.

[7] A. Benalla, C. Thng, and K. C. Gupta, *CAD of Microstrip Patch Antennas*, Microstrip Designs, Inc., 1993.

[8] B. D. Popović, *CAD of Wire Antennas and Related Radiating Structures*, Wiley, Inc., New York, 1991.

[9] J. Schoenberg, T. Mader, B. Shaw, and Z. B. Popović, "Quasi-optical antenna array amplifiers," in *IEEE MTT-S Int. Microwave Symp. Dig.*, May 1995, pp. 605–608, Orlando, FL.