A TRANSMIT-RECEIVE SPATIAL AMPLIFIER ARRAY

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ABSTRACT

A transmit-receive spatial power combining amplifier array is introduced. The amplifier unit cell utilizes one antenna for both transmit and receive modes. Orthogonal ports of a microstrip patch antenna provide isolation between transmitter and receiver ports. Results from a 3x3 transmit-receive amplifier array design at 10 GHz are presented. The measured gains for transmit and receive modes were 8.2 and 6.9 dB, respectively.

INTRODUCTION

Recently there has been great interest in the development of spatial power combining amplifiers for millimeter-wave power generation [1]-[12]. One of the important issues involved in the construction of low cost millimeter-wave spatial power combining systems is the design of transmit-receive arrays. It is very desirable to integrate both the transmitter and receiver on the same wafer. Since the major part of the array real estate is occupied by the radiating elements, it is important to use the same antennas for transmission as well as reception. So far most researchers' effort has been confined to the design and construction of transmitting amplifier arrays. (the authors have become aware of a recent work towards the construction of a bi-directional amplifier [13].)

In this paper a transmit-receive double-layer spatial amplifier is presented. This is based on our previous work with double layer amplifier arrays [7, 8, 9]. The general concept for a transmit-receive array of this kind is shown in Fig. 1. Here one can take advantage of the isolation between the two orthogonal edges of a microstrip patch antenna to provide isolation between the transmit and receive amplifiers.

The input signal (horizontally polarized) is incident upon the surface of the spatial amplifier using a hard horn feed. The input signal is received by an array of patch antennas and amplified. It is then coupled to the second layer where it is re-transmitted into free space by the second layer patch antenna array having vertical polarization. The horizontally polarized incoming signal is received by the same patch antennas on the second layer. It is amplified and then coupled

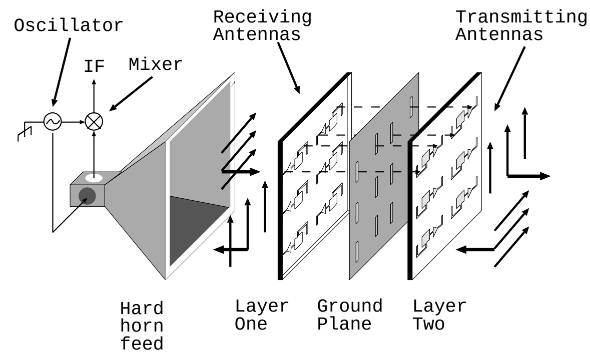

Figure 1: Perspective view of a transmit-receive double layer spatial amplifier.

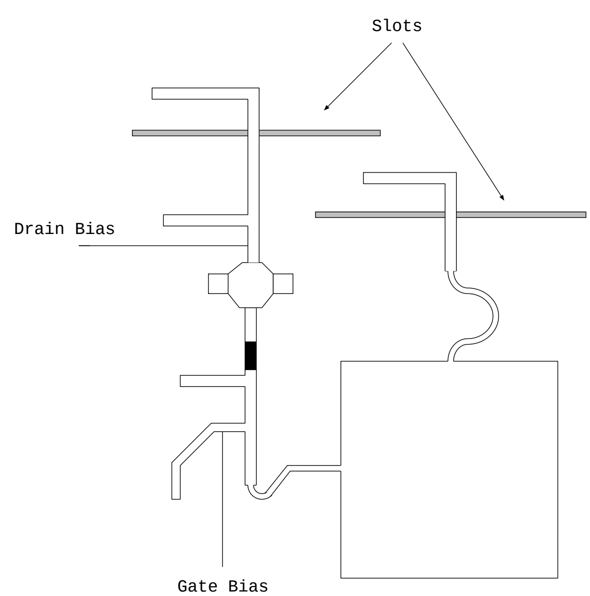

Figure 2: Unit cell of the transmit-receive spatial amplifier array.

to the first layer where it is radiated with a vertical polar-

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ization into the hard horn feed. Isolation provided by the orthogonal edges of patch antennas (25 dB) is enough to isolate the receiving and transmitting amplifiers. Therefore T/R switches are not required for this purpose. An orthomode transducer [14] placed at the input to the hard horn allows for well defined transmit and receive ports. It must be mentioned that the 25 dB of isolation provided by orthogonal ports of patch antennas is not enough to prevent the receiver from being saturated while the transmitter is on. Therefore the transmitter and receiver cannot operate simultaneously. However during reception, the transmitter should be switched off to prevent the receiver from being saturated. This method is commonly used in millimeter-wave transmit-receive modules currently in production [15]. One can envision the use of rectangular patch antennas instead of square patch antennas for transmission and reception at two different frequencies. Systems requiring duplex millimeter-wave communication may achieve enough isolation by using extra bandpass filters (duplexer) for simultaneous operation of transmitter and receiver. In this paper experimental results obtained from a 3x3 transmit-receive spatial amplifier array designed at 10 GHz are presented.

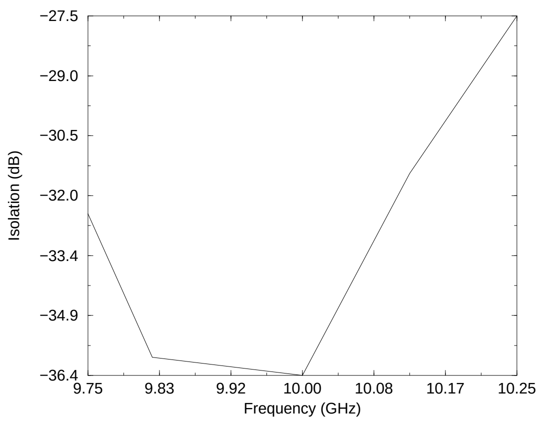

Figure 3: Simulated isolation of orthogonal ports of patch antenna vs. frequency.

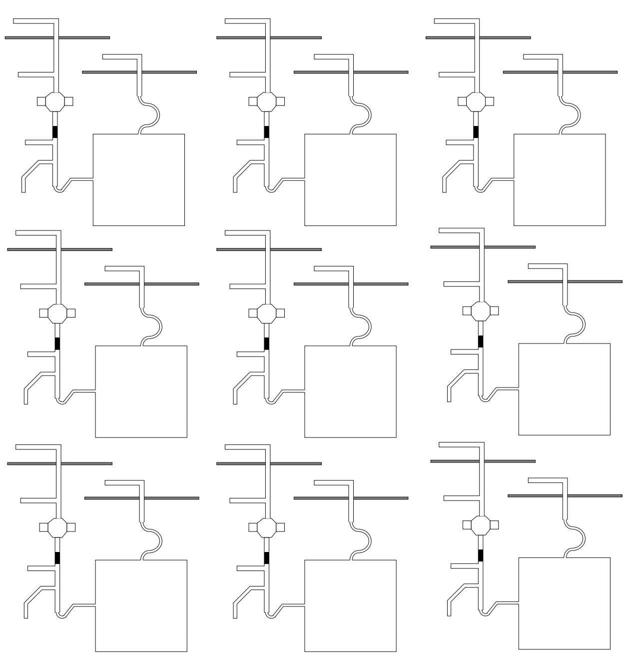

Figure 4: A 3x3 transmit-receive spatial amplifier array.

DESIGN

Fig. 2 shows the unit cell of the transmit-receive spatial amplifier array designed to operate at 10 GHz. In this

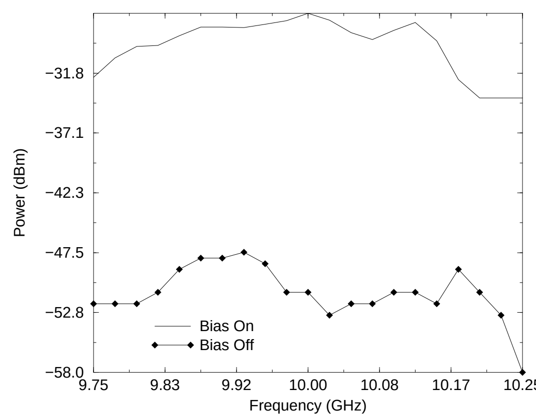

Figure 5: Biased and unbiased gains for the receiver mode of a 3x3 transmit-receive spatial amplifier.

design, either side of the double-layer amplifier array can transmit or receive, but for simplicity we will refer to one layer as the transmitting layer and the other as the receiving layer. Both transmit and receive amplifiers were stabilized using 3Ω resistors connected in series with the gate. Microstrip line widths were chosen to match resistor and transistor lead widths, providing a characteristic impedance of 110Ω. Consequently the matching circuit is based on 110Ω impedance lines. The slot transition was also designed to meet this characteristic impedance. Furthermore, the slot transition provides a low-loss, wide bandwidth (X-band) coupling to the second layer [9]. However, at low frequencies the two amplifier layers are completely isolated, since the slot cannot couple energy from one layer to the other at these frequencies. The antennas are matched to 110Ω via quarter-wave transformers. Simulation results, obtained

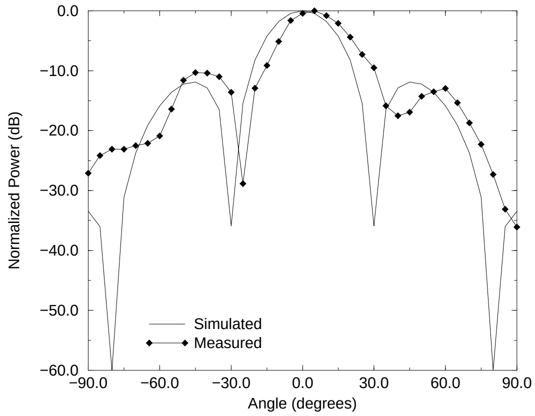

Figure 6: Theoretical and experimental H-plane patterns for a 3x3 transmit-receive spatial amplifier.

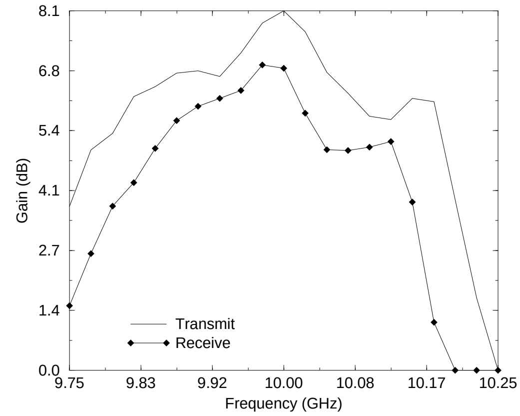

Figure 8: Transmitting and receiving mode gains for a 3x3 transmit-receive spatial amplifier.

from $MicrowaveExplorer^{TM}$, for the isolation provided by the orthogonal edges of a square patch antenna at 10 GHz are shown in Fig. 3. The transmit-receive array consists of 9 unit cells. The only additional features are 43Ω resistors along the gate bias lines, added to prevent low frequency oscillations. Both sides of the amplifier array are mirror images of each other. The unit cell was fabricated on 31 mil thick $\epsilon_r = 2.33 RT Duroid^{TM}$ substrate. The amplifiers were designed using general purpose HEMT devices (Fujitsu FHX06LG) for both transmit and receive modes of operation. The drawings of the circuit masks for the 3x3 array are shown in Fig. 4.

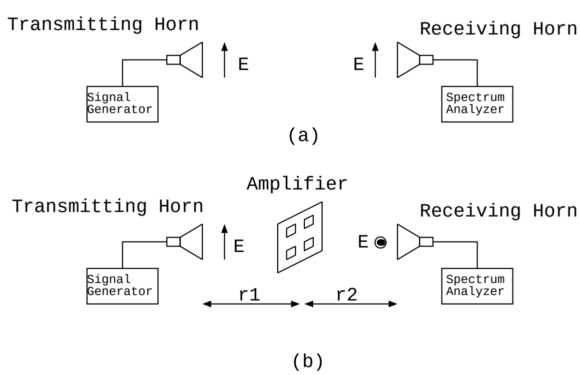

Figure 7: Measurement setup used to determine the gain of spatial amplifiers. (a) Calibration. The two horn antennas are co-polarized with the amplifier removed from the path of the signal. (b) Gain measurement. The two horn antennas are cross- polarized and the amplifier is placed in the path of the signal.

EXPERIMENTAL RESULTS

The measurements were performed based on a far-field setup discussed in [8]. It consists of two horn antennas located in the far field of the amplifier array ($d > 2D^2/\lambda = 30cm$, where D is the largest linear dimension of the circuit). The measurement setup is shown in Fig. 5.

Transmit and receive gain measurements are shown in Fig. 6. Maximum gains of 8.2 and 6.8 dB were measured for transmit and receive modes, respectively. In addition, gain curves for both cases are centered at the design frequency of 10 GHz. The dissimilarity between the measured gains can be attributed to device parameter variation and fabrication errors. The 3 dB bandwidth for transmit and receive modes are 400 and 350 MHz, respectively. On-off ratios, measurements taken with the amplifiers biased and unbiased, are also given to illustrate the isolation between transmit and receiver layers, as shown in Figs. 7 and 8. As seen in the figures, on-off ratios for both sides are greater than 25 dB. Figs. 9 and 10 illustrate radiation patterns for both the E-plane and H-plane at the design frequency, 10 GHz. The amplifier array has a measured beamwidth of about 60 degrees in both planes, which is consistent with simulated results.

CONCLUSION

A transmit-receive spatial power combining amplifier array is presented. For transmission, a vertically polarized plane wave is received from the transmitting horn, amplified and re-transmitted as a horizontally polarized plane wave into free space. For reception, a vertically polarized plane wave is received from free space, amplified and re-transmitted to the receiving horn. A single patch antenna is used for recep-

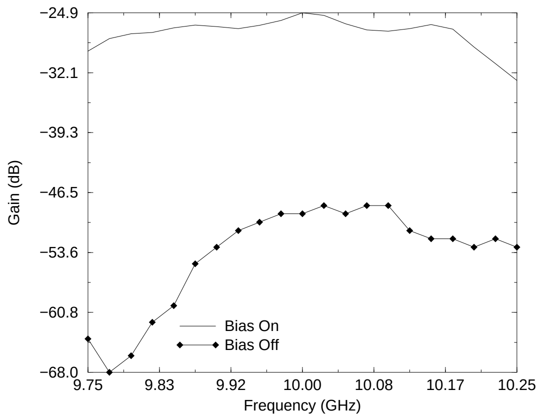

Figure 9: Biased and unbiased gains for the transmitter mode of a 3x3 transmit-receive spatial amplifier.

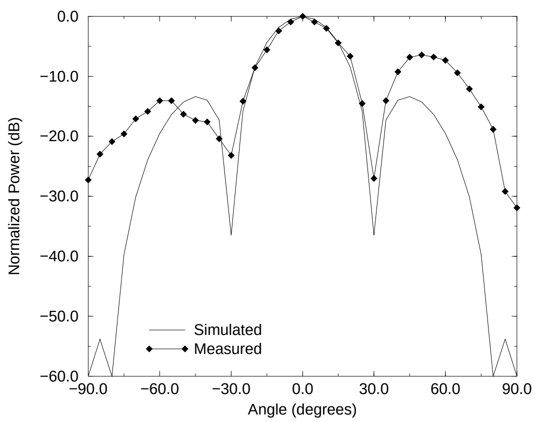

Figure 10: Theoretical and experimental E-plane patterns for a 3x3 transmit-receive spatial amplifier.

tion and transmission through good isolation of two orthogonal edges, greater than 25 dB. Stable gains of 8.2 and 6.9 dB are obtained for receiving and transmitting modes at 10 GHz, respectively.

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