TU3F-58

PLANAR LENS AMPLIFIER

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Abstract - **A quasi-optical power combining transmission amplifier with a focal point feed has been developed for increasing the power level available from solid-state devices. The focal point feed improves power coupling efficiency over that of a plane-wave feed. Both the receive and transmit sections of the amplifier are fabricated on a single substrate, making monolithic millimeter-wave integration possible. A 7-PHEMT, 10 GHz amplifier is presented, demonstrating a 29 dB isolation figure and up to a ±30° scan angle with less than 2.5 dB power variation.**

1 Introduction

Free space power combining is a technique for producing a significant amount of power at high frequencies from a large number of solid-state devices. Both self-locked [1] and injection-locked [2] oscillator power combiners have been demonstrated. A transmission amplifier has been demonstrated in which the input-to-output isolation is provided by polarization separation [3]. Recently, a polarization-flexible transmission-wave amplifier array was reported in [4]. Both amplifiers require a feed location in the array's far-field, and thus the aperture captures only a small fraction of the total incident wave power due to diffraction losses. A more efficient input is a focal point feed, in which the transmission amplifier works analogously as a planar Rotman lens with active device amplification. Passive lenses using arrays of input and output antenna elements fabricated on separate substrates have been reported [5,6]. We present an active planar lens amplifier with a focal point feed for improved input power coupling. The lens is fabricated on a single substrate containing receive and transmit arrays of microstrip patch antennas, and pseudomorphic high electron mobility transistor (PHEMT) amplifiers.

2 Lens Amplifier Design

A 7-element linear array was designed for 10 GHz using a 0.787 mm-thick Arlon substrate with $\varepsilon_r = 2.2$. The lens amplifier, as shown in Figure 1, has an array of receive and transmit patch antennas on opposite sides of the substrate. Each common-source PHEMT amplifier is coupled and matched to its input and output patch elements with microstrip lines. A substrate via connects each amplifier's output to its transmit-side patch. Alternating ground planes effectively isolate input and output sides of the amplifier structure, allowing input and output wave polarizations to be arbitrarily selected. In the amplifier presented, orthogonal polarizations are chosen for ease of measurement.

The lens amplifier element topology is shown in Figure 2. Receive and transmit elements are microstrip patch antennas with a non-radiating-edge feed. This is preferable to a radiating-edge feed because the element is more compact and the input impedance may be arbitrarily set. An input impedance of 100 Ω was chosen. The patches were designed using multi-port network modeling software [7]. Avantek ATF-35576 PHEMTs were selected for their high gain and low bias power requirements. The PHEMTs are impedance matched for gain to the 100 Ω characteristic impedance of the microstrip delay lines using single-stub matching sections. The gate bias network is similar to that described in [8], providing unconditional stability for the PHEMTs. The gate bias network consists of a 90° section of 150 Ω microstrip line, terminated by a 90° open stub with 70 Ω impedance in parallel with a 100 Ω chip resistor connected to the gate bias line. The 1 pF chip capacitor acts as a bypass for the bias line, and RF couples the chip resistor to the feed-side ground plane. Drain bias is provided through the RF null of the transmit patch. Each microstrip delay line has the same number of discontinuities (mitred bends) for reproducible control of phase delay.

The lens' focal length to diameter (F/D) ratio was chosen to be 2.0 in order to match the radiation pattern of the feed horn. The inter-element spacing is $0.75\lambda_o$ on the transmit side, and the focal length is 27 cm. Since the input and output arrays are planar, the only Rotman lens design parameters are the relative distance between receive and transmit elements, and the electrical line length connecting them. Following [5], the relative location of the input-side elements to the output-side elements is

$$\rho = r\left[\frac{F^2 - r^2\sin^2\theta_o}{F^2 - r^2}\right]^{1/2} \tag{1}$$

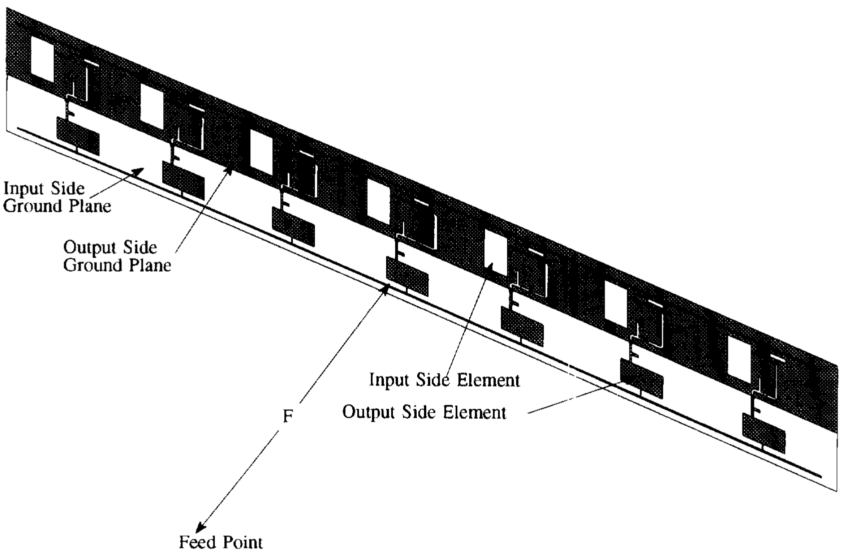

Figure 1: The 7-element planar lens with focal point feed. The substrate contains receive and transmit arrays of patches, isolating ground planes, and PHEMT amplifiers. A horn illuminates the lens' input side from the focal length F = 2D, where D is the lens width. Alternating ground planes isolate the receive and transmit sides of the lens.

where ρ and r are, respectively, the distances from the lens center to the input and output elements, F is the focal length, and θ_o is the focal point angle off of broadside. The expression for the electrical line length, W, is

$$W=F+W_o-1/2[F^2+\rho^2-2\rho F\sin\theta_o]^{1/2}-1/2[F^2+\rho^2+2\rho F\sin\theta_o] \qquad (2)$$

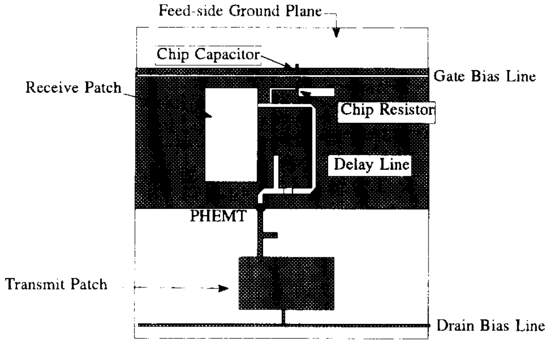

Figure 2: Topology of a single element pair. The gate bias network, consisting of the resistor, capacitor, and open stub, provides unconditional stability for the common-source PHEMT amplifier, which is matched for gain to the 100Ω characteristic impedance of the delay line. The drain bias is provided through the RF null of the patch.

where W_o is an arbitrary constant electrical length. The center element of the feed and aperture arrays of the lens is considered to be on the lens axis. The transmit-side inter-element spacing is fixed, and thus the receive element location is a function of its corresponding transmit element position away from the lens center. The electrical line length required for the delay line is also a function of distance away from the lens center, with the longest delay line required for the center element. Electrical line length was converted into microstrip phase delay in the lens design, and as seen in Figure 1, the delay line length decreases away from the lens axis.

3 Lens Amplifier Performance

From a feed point distance of 27 cm, the lens was first tested with the center 5 elements biased, and then with all 7 elements biased. The resulting output power is 3.1 dB higher for 7 elements than for 5 elements biased. This is 0.2 dB above the theoretical increase of 2.9 dB (= $10\log_{10}(7/5)^2$) expected from a uniformly driven array factor, and indicates that the lens is uniformly illuminated and that its effective area increased. Figure 3 shows the array's maximum output power at 9.70 GHz, which is 3% below design frequency due to the lower than expected resonant frequency of the microstrip patch antennas. The array's isolation, defined as the biased-on to biased-off transmission power ratio, is 29 dB at center frequency. Figure 4 shows the effect of feed distance G on the radiation pattern of the lens, with the feed horn located at broadside and G ranging from 22 cm to 30 cm. The 22 cm feed location produces about 5 dB more power than at 30 cm, but the beamwidth is 18° compared to

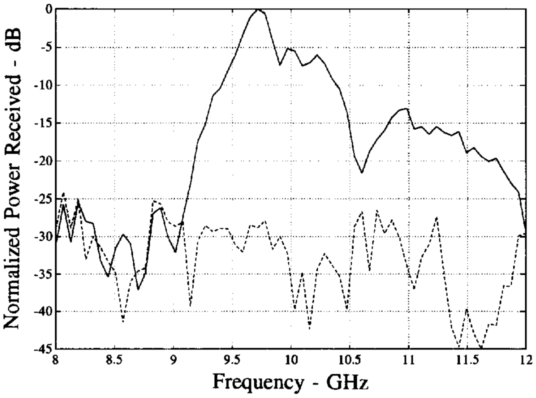

Figure 3: Frequency response plots of the lens amplifier in the (solid line) biased-on and (dashed line) biased-off conditions. The center frequency is 9.7 GHz and the isolation is 29 dB. The narrow-band peak in the frequency response shows the influence of the patch antennas on bandwidth.

14°, respectively. The theoretical beamwidth for a 7-element uniformly illuminated array is 14.6°. The wider beamwidth for the 22 cm feed location indicates that more feed power is illuminating the center element. The side lobe level is about -12 dB, close to the -12.6 dB level for a 7 element uniformly driven array. The cross-pole ratio is 19.4 dB for the 22 cm feed location, and 14.0 dB for the 27 cm feed location.

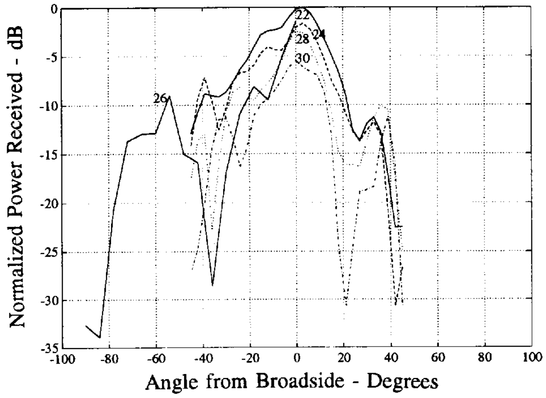

Figure 4: Antenna patterns of the 7-element lens amplifier with feed distance ranging from 22 cm to 30 cm. The lens has 5 dB more gain at the 22 cm feed location compared to the 30 cm location. A broadside-to-endfire sweep for the 26 cm feed distance is included.

The lens preserves the incident phase of the input wave, so it may be fed with a progressive phase angle for beamsteering. Figure 5 shows measured radiation patterns for a feed point of 26 cm and feed angles of 0°, 15°, and 30°. This shows a 60° scanning angle with less than -2.5 dB of main lobe power variation. Side lobe levels increase with increased scan angle, as expected, due to non-uniform illumination of the input elements.

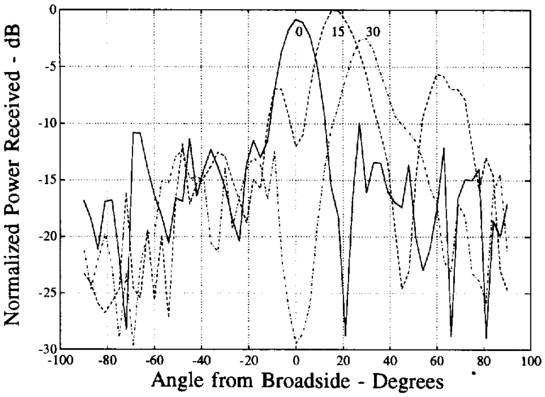

Figure 5: Beamsteering pattern for the lens at feed angles of 0°, 15°, and 30°. Main lobe peak power are within 2.5 dB of each other, with increased side lobes at the higher angles.

4. Conclusions

A 7-element planar lens amplifier has been designed, fabricated, and demonstrated. The center frequency is 9.7 GHz, and the isolation is 29 dB. A total scan angle of 60° with main lobe power variation of less than 2.5 dB was measured. The lens is useful for amplifying, focusing and beamsteering applications.

5. Acknowledgements

We gratefully acknowledge the support of the Army Research Office and the National Science Foundation, the Air Force Institute of Technology Civilian Institution Program for fellowship support of Jon Schoenberg, and Daniel T. McGrath and Carlyle J. Sletten supporting comments on the feasibility of the lens amplifier.

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