Spatial Power Combining for Two Dimensional Structures

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***Abstract*-A hybrid dielectric slab-beam waveguide is suitable for the design of planar quasi-optical integrated circuits and devices. In this paper a 2-D quasi-optical power-combining system with convex and concave lenses was investigated. The system employs an active E-plane amplifier array consisting of Vivaldi-type antennas with MESFET and MMIC devices. The system was tested by switching the amplifier bias off and on while measuring the power with an E-plane horn. Tests were performed with a single MMIC amplifier and a 4 x 1 MESFET amplifier array. The amplifier array generated 11 dB and 4.5 dB of amplifier and system gain respectively at 7.12 GHz, and the single MMIC Vivaldi-type antenna produced 24 dB of amplifier gain at 8.4 GHz.**

I. INTRODUCTION

Spatial power combining has emerged as a promising technique for power combining at millimeter and sub-millimeter wave frequencies. One embodiment of spatial power combining is quasi-optical power combining based on the principle that radiated fields produced by an array of solid state active devices may be combined. The fields are combined utilizing wavebeam principles in free space or dielectric material to generate reliable power. Periodic refocusing of the beam is accomplished by the use of optical lenses to combine the power in a single paraxial mode. The large transverse and longitudinal dimensions of the quasi-optical structures provide significant area for the active MMIC devices and control components to be included within the structure. The most mature quasi-optical structures include grid amplifiers and resonant cavities where the power is combined in three-dimensional space (3-D) [1, 2]. However, two-dimensional (2-D) technology offers an alternative approach with significant advantages. Mink and Schwering [4] proposed a 2-D hybrid dielectric slab-beam waveguide (HDSBW) which is more amenable to photolithographic definition and fabrication, and is more compatible with the MMIC technology [5,6]. The 2-D HDSBW has reduced size and weight, and improved heat removal capability which results in lower costs.

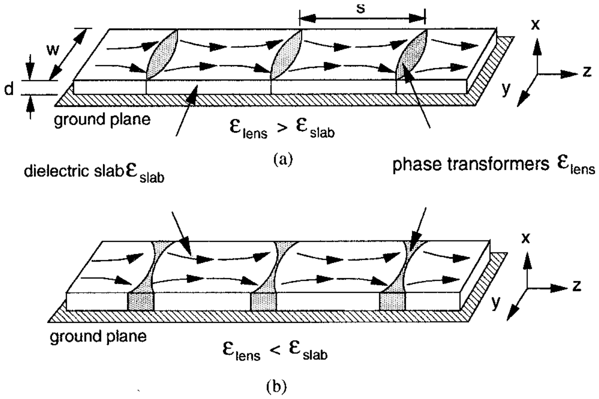

Figure 1:Passive 2D quasi-optical power combining system (a) convex lenses and (b) concave lenses.

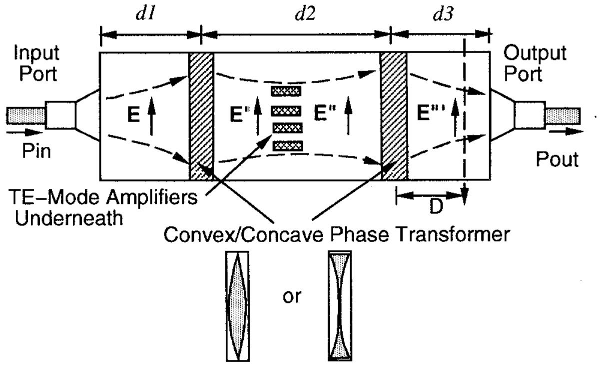

Figure 2: The HDSBW system with convex/concave lenses and 4 x 1 MESFET amplifier array.

IV. PRINCIPLES OF OPERATION

The HDSBW uses two distinct waveguiding principles to guide the electromagnetic wave [5,7]. The input energy travels in a Gaussian-Hermite mode along the slab waveguide. In the x-direction, the field distribution is that of a surface-wave mode of the grounded dielectric slab;

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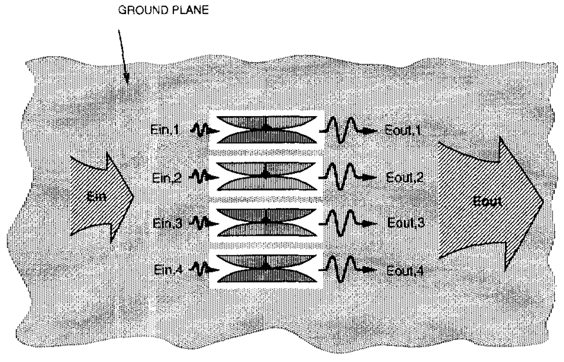


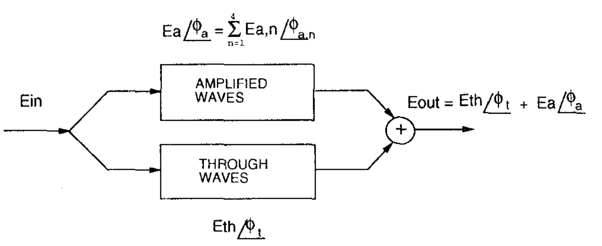
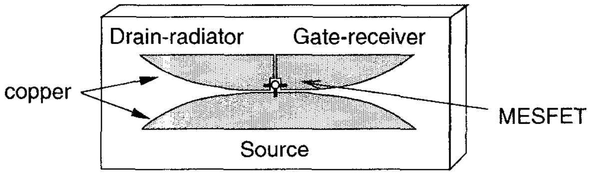


Figure 3: Wave model for 2D power combining



MESFET ampilifier on
RT/Duriod substrate

Figure 4: MESFET Vivaldi amplifier

the wave is guided by total reflection at the air-to-dielectric interface and parameters are adjusted such that energy is transmitted primarily within the dielectric. In the y-direction the field distribution is that of a wave beammode (Guass-hermite) which is guided by the lenses through periodic reconstitution of the cross sectional phase distribution. The guided modes can be either TE or TM polarized with respect to the direction of propagation whose period is the spacing of the lenses. Figure 1 shows the passive HDSBW employing two examples of periodic refocusing. Figure 1(a) shows convex lenses that are utilized to periodically reset the wavebeam phase and Figure 1(b) displays this principle by utilizing concave lenses.

The principle employed here to obtain signal amplification is similar to that of a traveling wave amplifier. An array of active elements located underneath the dielectric slab is placed in the path of the wavebeam as shown in Figure 2. Each active element consists of a pair of back-to-back Vivaldi antennas with an amplifier inserted between the two antennas. Part of the incident signal, the thru wave, passes through the dielectric slab undisturbed. The remaining signal is amplified by the array. The first Vivaldi antenna couples energy from the incident traveling wavebeam, and the second Vivaldi antenna reinserts the amplified signal back into the traveling wave beam. Maximum coupling to the array occurs when the energy from the first lens focuses energy to the input of the Vivaldi antennas. The signal is amplified by the MESFETs and is coupled by the output Vivaldi antennas to the traveling wavebeam where it combines in phase with the through signal as shown in Figure 3. Consequently, a growing traveling wavebeam mode is established within the guiding structure resuting in increased output power.

III. SYSTEM CONFIGURATION

The system configuration for the HDSBW shown in Figure 2 consists of rectangular dielectric slab made of Rexolite ($\varepsilon_r = 2.57$, $\tan\delta = 0.0006$) placed on a conducting ground plane. Two concave cylindrical lenses made of Macor ($\varepsilon_r = 5.9$, $\tan\delta = 0.0006$) with focal lengths equal to 28.54 cm were inserted between the dielectric slab. The dielectric slab dimensions length (d1 + d2 + d3), width (w) and thickness (d) were 62 cm, 27.94 cm and 1.27 cm respectively. The Vivaldi antenna MESFET amplifiers were located underneath the dielectric slab in the ground plane. Each Vivaldi antenna was fabricated using RT/Duroid 6010 substrate ($\varepsilon_r = 10.2$, $\tan\delta = 0.0028$) with the dimensions 6.5 cm x 1.5 cm. Two E-plane horns were designed and fabricated that efficiently launch and receive the required wavebeam.

V. EXPERIMENTAL RESULTS

Two tests were performed, the first utilized a 4 x 1 MESFET Vivaldi amplifier array as shown in Figure 2, and the second employed a single MMIC Vivaldi amplifier located under the dielectric slab (see Figure 6). A measure of the relative energy coupled to the amplifier array was obtained by switching the amplifier bias levels off and on while measuring the output power, P_{out},. The system performance for the active Vivaldi amplifier array was determined by the system gain and amplifier gain. This provided an indication of the incident signal that passes through the dielectric as an undisturbed traveling wave.

Figure 5 shows the total system performance of the MESFET amplifier array at 7.12 GHz using concave lenses. A plot of P_{in} versus P_{out} is indicated by AMP OFF and AMP ON respectively. The input power, P_{in} varied from -45 dBm to +10 dBm in +5 dBm increments. The power ratio between P_{out} and P_{in} was relatively constant for P_{in} less than −15 dBm, however P_{out} reached the

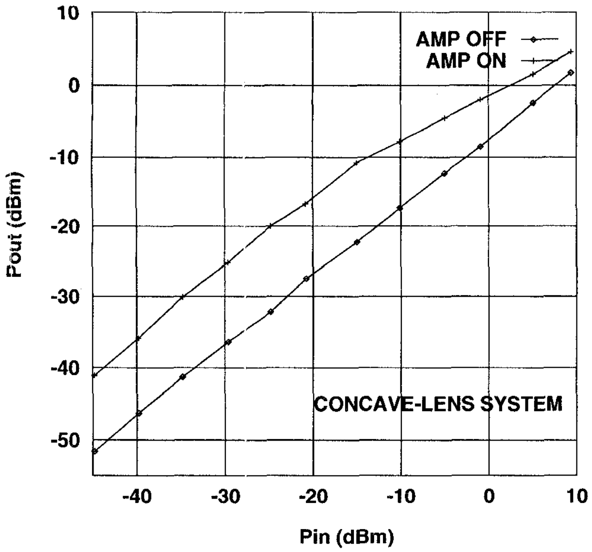


Figure 5: Input and output power of the concave-lens 4 x 1 MESFET array.

saturation condition with P_{in} greater than −15 dBm. The maximum system gain of 4.5 dB occurred at P_{in} = -15 dBm while the amplifier gain on to off measured was 11 dB.

The second test was performed with a cascaded pair of MMIC amplifiers in order to achieve higher power levels. In Figure 6, the amplifier gain of the Vivaldi amplifier was determined by placing a metal screen transverse to the Vivaldi structure. The Vivaldi amplifier and the metal wall were placed 5.5 cm and 9.7 cm respectively from the input horn. A concave lens was placed in the middle of a 40 cm dielectric slab. The slit in the metal wall allowed for only input power of the amplifier and the amplified energy to go through the system so that the amplifier gain could be measured. The amplifier gain shown in Figure 7 was determined by switching the bias voltage on and off, while measuring the power difference detected by the receiving horn. The amplifier gain indicates that more than 10 dB of gain was produced from 7 GHz to 10.4 GHz with a maximum gain of 24 dB at 8.4 GHz.

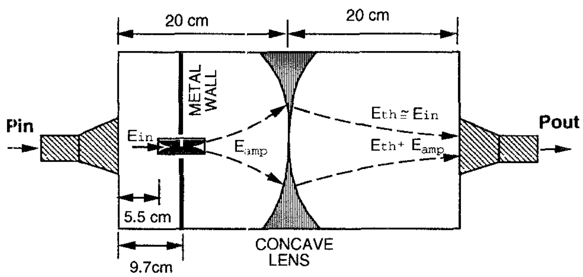


Figure 6: The concave-lens system configuration for a unit cell amplifier

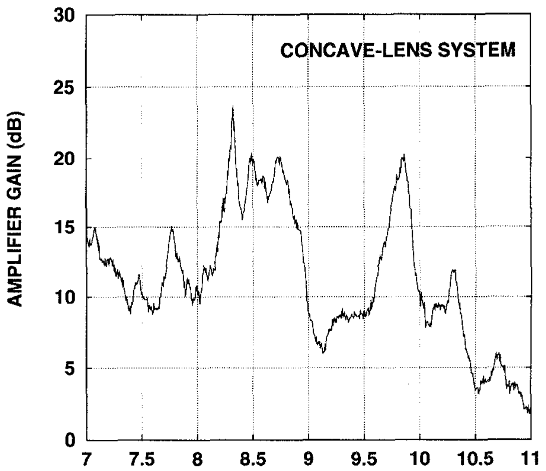


Figure 7: Amplifier gain for a unit cell amplifier with cascaded MMIC chips.

VI. CONCLUSIONS

A 2-D HDSBW spatial power combining system suitable for planar integrated circuits and devices has been presented. A system using concave lenses and Vivaldi-type antennas with MESFET and MMIC devices has been demonstrated. The 4 x 1 MESFET amplifier array produced 11 dB of amplifier gain and 4.5 dB of system gain at 8.4 GHz. Operating at 7.12 GHz, a single MMIC amplifier produced 24 dB of amplifier gain. By combining more MMIC instead of MESFETs greater power can be achieved. This paper shows that 2D spatial system is suitable for planar MMIC technology.

ACKNOWLEDGMENTS

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