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Quasi-optical Power Combining Techniques for Dielectric Substrates

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1 Introduction

Several quasi-optical systems have been reported, including grid oscillators [1] and amplifiers [2], resonant cavity oscillators [3,4], microstrip-based rotator arrays [5], and dielectric slab beam waveguides (DSBW) [6] for power combining. The dielectric slab system described here has the advantage of being two-dimensional and is thus more amenable to photolithographic reproduction than the conventional open quasi-optical power combining structures. Previous investigations of the quasi-optical dielectric slab cavity and waveguide [7,8] demonstrated the suitability of this structure for the integration of quasi-optical power combining with MMIC technology.

A complete DSBW quasi-optical system, as shown in Fig. 1, could consist of the following: a source, active or injection, [7], an amplifier array [8], triplers, and a leaky wave antenna which would be used for steering the energy out of the system. Between each of the stages lenses are used to focus the guided waves for optimal field concentration on the elements in the system. In this work we present the amplifier array stage using both convex and concave lenses as shown in Fig. 2. The DSBW amplifier system incorporates four MESFET amplifiers and two thin convex/concave lenses. The waveguide system was adjusted with the transistors turned off so that the guided waves are focused near the aperture of the receiving horn. The dielectric slab is Rexolite ($\epsilon = 2.57$, $\tan\delta = 0.0006$ at X-band), and it is 27.94 cm wide, 62 cm long, and 1.27 cm thick. The convex lenses are fabricated from Macor ($\epsilon = 5.9$, $\tan\delta = 0.0025$ at 100 kHz) with a radius of 30.48 cm, and the focal length, f, is 28.54 cm. The concave lenses are air ($\epsilon = 1$) with a radius of 30.48 cm, and the focal length, f, is 40.4 cm. The aperture width of both horn antennas is 9 cm, designed to be wide enough to catch most of the amplified power. Energy emitted from the input radiator propagates in a quasi-optical TE Gaussian mode in the dielectric slab waveguide,and is focused by the first lens in the middle area of the slab. This system is designed so that the amplifier unit cells are within the beam waist (the $1/e$ field points).

The amplifier unit cells are 7 cm x 1.5 cm and employ HP ATF-10235 MESFETs. This design was derived from the active slot-line notch antenna by Leverich, et al. [9]. An amplifier unit includes two end-fire Vivaldi antenna tapers which are gate-receiver and drain-radiator, and is specifically designed to eliminate surface-of-slab to ground-plane resonance. The advantage of locating the amplifiers on the ground plane is that it reduces beam-mode perturbation, scattering losses, and reflection of the input energy due to the amplifier structure. These are problems with amplifiers mounted on the surface of the slab [8] and in the more conventional grid system.

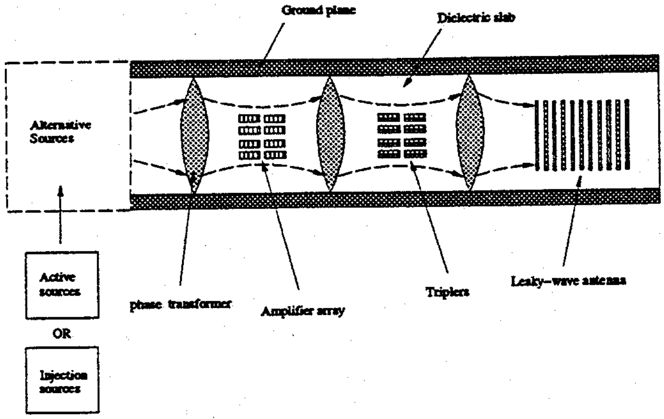

Figure 1: A dielectric slab beam waveguide system.

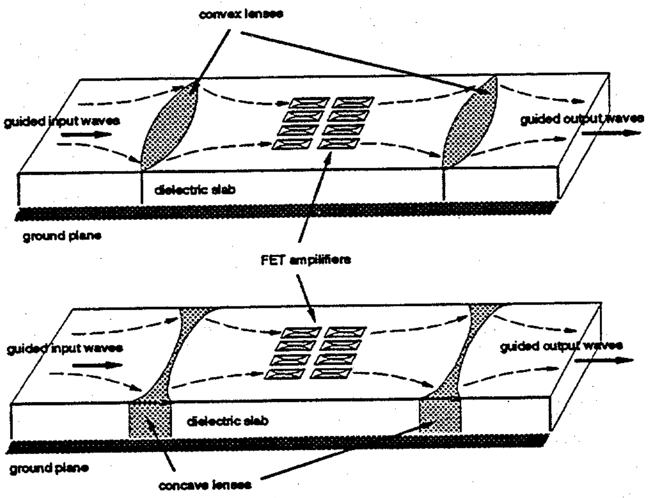

Figure 2: Amplifier array stage with convex and concave lenses.

2 Experimental Results and Discussions

Passive measurements were made on the DSBW system with no amplifiers present comparing the convex and concave lenses. The concave lens system has less loss than the convex lens system as shown in Fig. 3. Fig. 4 shows the electric field measured at a frequency of 7.28 GHz for both the convex and concave lenses. This measurement estimates the loss due to the lenses where the convex lens loss is approximately -3.66 dB and the concave lens loss is approximately -1.18 dB. This loss estimation is obtained by integrating the areas under the E-field patterns before and after lenses. In Fig. 5, the insertion loss is given for both cases where the convex lens system is showing lower loss. The reason for this is that the input wave scattered by the amplifier array goes into the air more easily for the concave lens system than for the convex lens system.

The amplifier gain, computed as the ratio between P_{out}(Amp ON) and P_{out}(Amp OFF), is shown in Fig. 6 for both concave and convex lens systems. The amplifier gain is 16 dB for the concave case and 14 dB for the convex case as P_{in} is -12.4 dbm. This implies that the concave lens system has better performance than the convex lens system. In these measurements the four MESFET amplifiers were placed on the ground plane underneath the Rexolite.

The system gain (defined as P_{out}/P_{in}) is shown in Fig. 7 for both the concave and convex systems with and without a metallic top cover. For the concave case the system gain is approximately 7.7 dB with and without the metallic top cover. For the convex case the metallic cover gives a system gain of about 6 dB and without the cover 4 dB. The reason that there is a difference in the convex system gain with and without the cover is because the passive scattering loss for the convex lens system is higher than for concave lens system. Therfeore, using a metallic cover can save more scattrering energy for convex lens system.

3 Conclusions

We have demonstrated quasi-optical power combining in a dielectric substrate with the amplifier array located on the ground plane for both a concave and convex lens system. The overall performance of the concave lens system was better than the convex lens system including passive system gain, amplifier gain, and active system gain.

Acknowledgment

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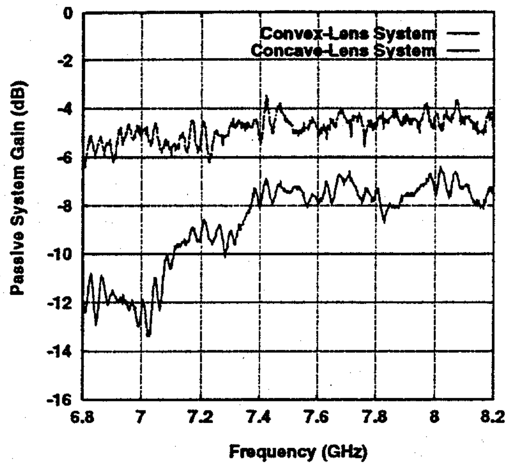

Figure 3: Passive system gain for convex-lens and concave-lens systems.

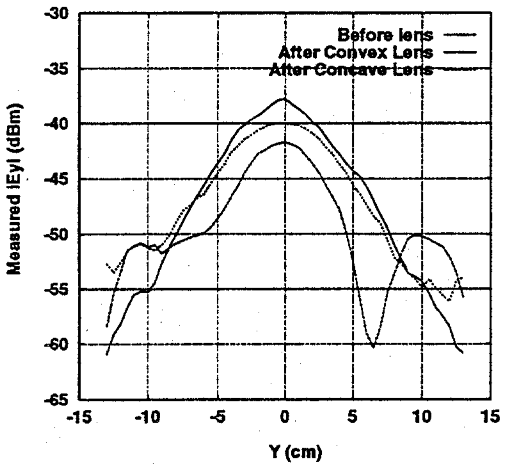

Figure 4: $|Ey|$ distributions before and after lenses.

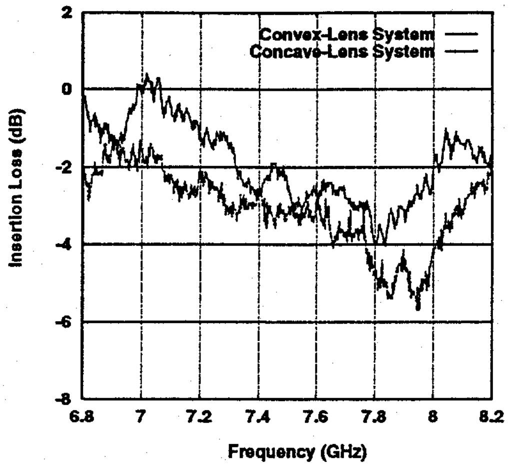

Figure 5: Insertion loss of convex-lens and concave-lens systems.

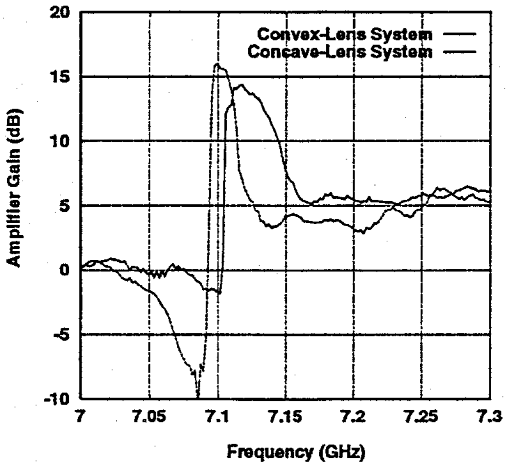

Figure 6: Amplifier gain in convex-lens and concave-lens systems.

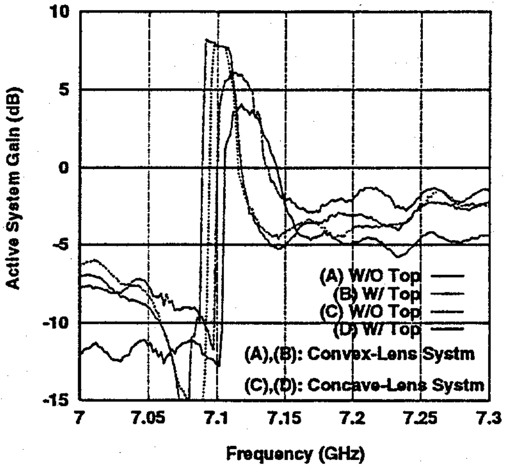

Figure 7: Active system gain for convex-lens and concave-lens systems.