A Dielectric Slab Waveguide With Four Planar Power Amplifiers

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Abstract. A hybrid dielectric slab beam waveguide with four MESFET amplifiers employing quasi-optical power combining is reported for the first time. Up to 10 dB power gain is obtained at 7.4GHz. Measurements for power gain, amplifier gain, insertion loss and transverse power distribution are presented. The fabrication technique employed is suitable for planar MMIC circuits.

1. Introduction

Quasi-optical power-combining is a promising method to combine the power from multiple solid-state devices in the microwave and millimeter wave region. A number of quasi-optical structures have been reported including wave beam type [1], grid type [2], microstrip weak coupling type, [3], and hybrid dielectric slab beam waveguide type (HDSBW) [4,5] for power combining. In all cases, power from the radiating elements is combined in free space or in a dielectric over a distance of many wavelengths. The HDSBW system has the advantage of being two-dimensional and is thus more amenable to photolithographic reproduction than the conventional open quasi-optical power combining structures. In this paper, a HDSBW amplifier is reported for the first time, with four MESFET power amplifiers located between lenses as shown in Figure 1. Up to 10 dB power gain is obtained at 7.4GHz.

2. Quasi-optical Slab Power Combiner System

The HDSBW system with MESFET amplifiers and two thin convex lenses is shown in Figure 1. The waveguide system is built as a confocal system so that the guided waves are focused and reiterated periodically. The dielectric slab is Rexolite (ϵ = 2.57, tanδ = 0.0006 at X-band), and its dimensions are 27.94 cm wide, 114.16 cm long, and 1.27 cm thick. The lenses are fabricated from Macor (ϵ = 5.9, tanδ = 0.0025 at 100 kHz) with radius=30.48 cm, and the focal length,

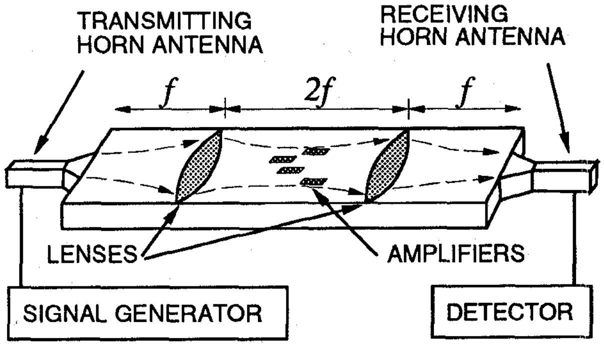

Figure 1: Hybrid dielectric slab beam waveguide (HDSBW) system with MESFET amplifiers.

f, is 28.54 cm. The lenses are inserted into the waveguide with a spacing of 57.08 cm. The aperture width of both horn antennas is 9 cm, designed to be the spot size of the slab beammode near the aperture. Energy propagates in a quasi-optical mode along the waveguide, passes the lenses and is reiterated in the middle area of the waveguide. The beam in that area has the strongest field strength and its width is close to that of the beam width near the radiator. Four MESFET amplifiers are located in this area to amplify the guided energy.

The MESFET amplifier unit is shown in Figure 2 employing one HP ATF-10235 MESFET. The dimension of this amplifier is 7 cm x 1.5 cm. This design is derived from the fin-line oscillator described by Meinel [6] and active slotline notch antenna by Leverich, et. al [7]. The essential structure of the amplifier includes two end-fire Vivaldi antenna tapers which are gate-receiver and drain-radiator. The amplifiers are designed specifically to eliminate surface-of-slab to ground-plane resonance, thus oscillation does not occur when there is no energy radiated from the trans-

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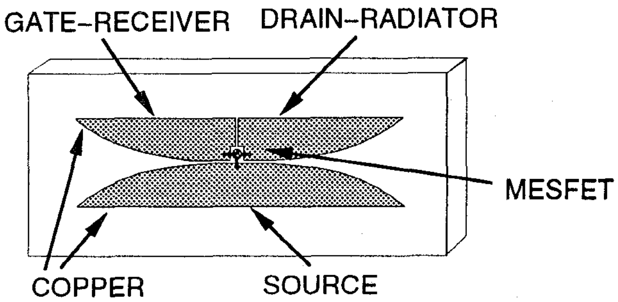

Figure 2: The planar MESFET amplifier.

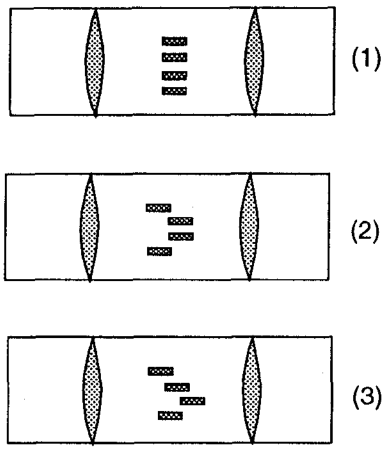

Figure 3: Amplifier configurations.

mitting horn. In the middle area of the waveguide, the refocused guided waves have the narrowest beam width and the strongest field strength. Therefore, amplifiers located in this area amplify the guided energy efficiently. By moving the locations of the amplifiers, different amplifier and power gains are obtained.

3. Measurement and Discussion

Figure 3 shows three different configurations for the MESFET amplifiers on the dielectric slab. In each configuration, the amplifiers are biased with two groups of drain voltage, V_{ds} and gate voltage, V_{gs} to measure the amplifier gain and the power gain. The bias voltages and the distance between amplifiers were carefully adjusted to avoid mutual-coupling oscillation and to obtain the largest gain in each configuration. To arrange the configurations, an amplifier was first moved around the middle area on the waveguide to get the highest gain. Then, the second amplifier was carefully moved close to the first one, and the bias was adjusted to get the highest gain and avoid oscillations due to strong mutual coupling. Similarly, the third and fourth amplifiers were added to the system.

The amplifier gain and power gain for three different configurations are shown in Figures 4-9. The largest amplifier gains obtained for configurations 1, 2, and 3 were 11 dB, 13.8 dB, and 8 dB, and the largest power gains were 7 dB, 11 dB and 5 dB respectively. This data shows that this 4-amplifier array is effective for the HDSBW in the frequency range from 7 GHz to 8.5 GHz. These figures show that the higher V_{ds} is , the higher the gain is in each location. Amplifier gain is the ratio of the output power with and without bias applied. Power gain is the ratio of the output power with the amplifiers on to that with the amplifiers removed from the surface of the slab. Insertion loss was calculated by subtracting the power gain from the amplifier gain.

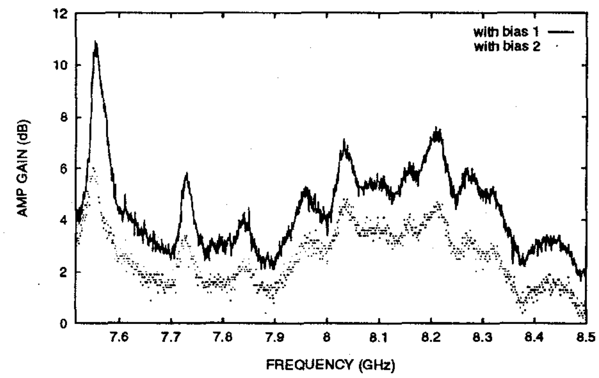

Figure 4: Amplifier gain for configuration 1.

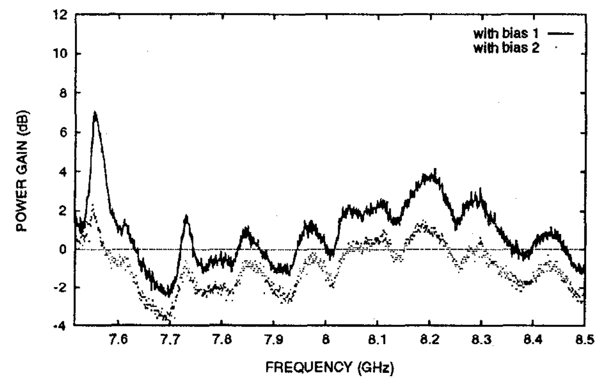

Figure 5: Power gain for configuration 1.

The guided waves are originally a TE slab beammode, and when the amplifier patches are placed on the slab surface, they perturb the beammode, causing some losses, which reduce the total received power. The field strength for a fixed position is a function of radiating frequency. Field strength also varies as a function of position for a fixed frequency. Therefore, changing the frequency or the location of amplifiers results in the input energy of the amplifiers being different, and hence the receiving power varies. The insertion loss is shown in Figure 10 for the various cell locations. This loss varies with frequency and location. The causes of insertion loss were further examined by plotting the field profile using the technique shown in Figure 11.

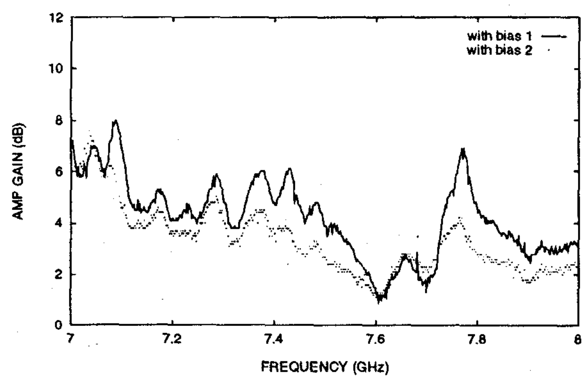

Figure 6: Amplifier gain for configuration 2.

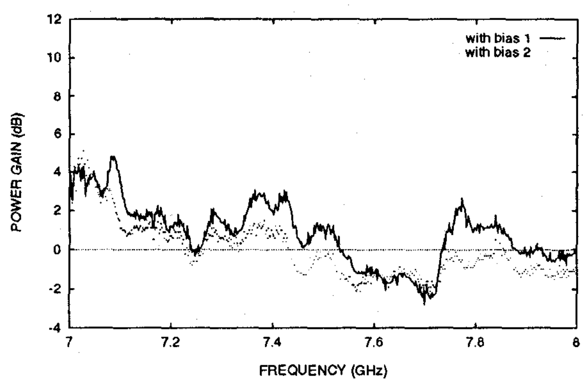

Figure 7: Power gain for configuration 2.

The power distribution across the HDSBW was measured using a small sensor antenna built on RT/Duriod substrate. The amplifiers were put in configuration 3 to supply maximum energy into the slab. Measurements were made at an operating frequency of 7.372 GHz with an amplifier gain of 10.1 dB. The power distribution was measured by moving the sensor antenna along the y-axis from 11.5 cm to -11.5 cm. The power distributions on the slab are plotted in Figure 12 for amplifiers on, amplifiers off, and no amplifiers located on the slab. Comparing the field distributions for amplifiers off and no amplifiers on the slab, the power decreases by a constant value of about 4 or 5 dB in the -5 cm $< y <$ 5 cm region. This is because all the amplifiers were located here. However, amplification more than compensates this insertion loss. Therefore, the total beammode energy increases. However, the amplifier gain varies greatly in the region -6.5 cm $< y <$ 11 cm from a maximum of about 32dB at $y = 5$ cm to a minimum at $y = 0$ cm of about 10 dB. Since the amplifiers are not located symmetrically about the z-axis, the power increases more in the $y > 0$ region than in the $y < 0$ region. Unequal amplification and phase shift of the individual amplifiers may also contribute to the non-symmetrical amplification gain.

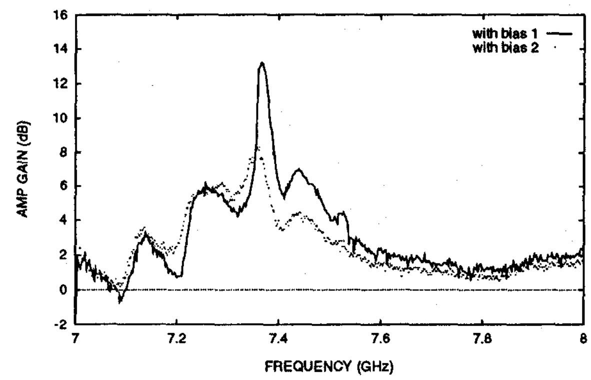

Figure 8: Amplifier gain for configuration 3.

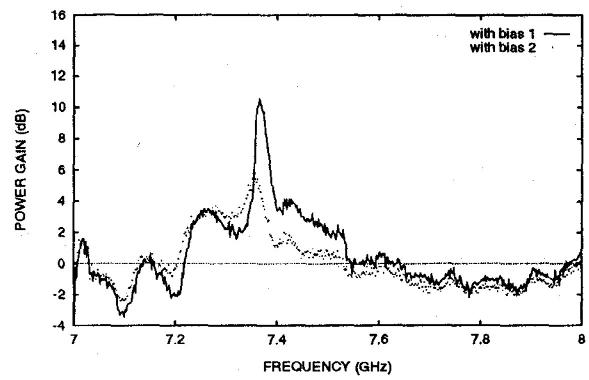

Figure 9: Power gain for configuration 3.

4. Conclusions

For the first time, we have demonstrated a planar amplifier array in a HDSBW using quasi-optical power combining with a maximum amplifier gain of 13 dB at about 7.4 GHz.

Four MESFET amplifiers were located on the slab waveguide near the middle area to amplify the guided energy efficiently. The amplifiers are easily made by photolithographic techniques. By selecting appropriate locations, insertion loss can be reduced significantly. The power difference between the distribu-

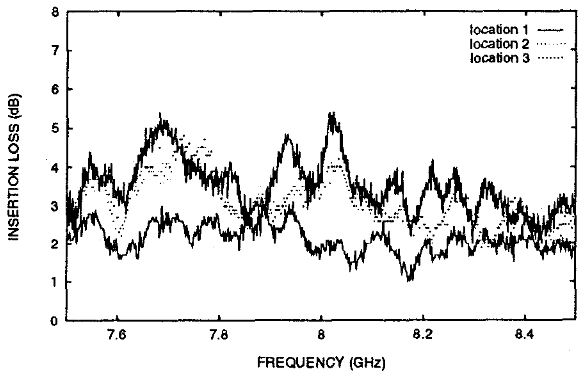

Figure 10: Insertion loss.

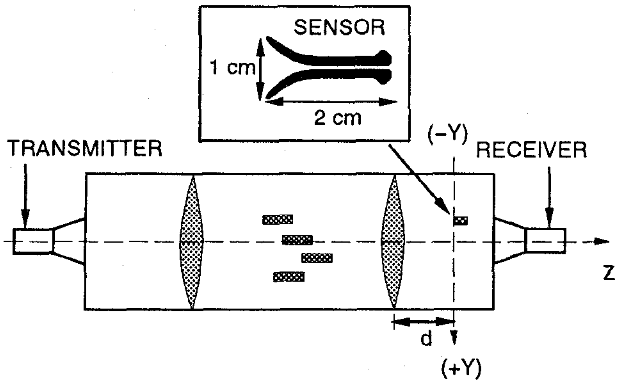

Figure 11: Measurement of power distribution.

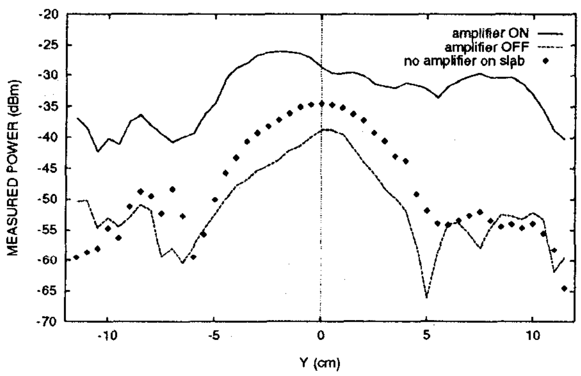

Figure 12: Power distributions across the top of the HDSBW measured at 7.372 GHz at d= 18.2 cm as shown in Figure 11.

tions of the slab mode with amplifier on and off increases greatly with a maximum increase of approximately 32dB. The amplifier gain overcomes the insertion loss and results in net gain. This planar amplifier is suitable for use with the HDSBW system and can be applied to planar MMIC circuits.

Acknowledgment

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