A Quasi-Optical Amplifier

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***Abstract*—A quasi-optical amplifier suitable for Gaussian-beam applications is presented. The amplifier is based on the integrated horn antenna and uses polarization duplexing to isolate the output beam from the input beam. A prototype hybrid amplifier is reported here with a measured gain of 10.5 dB at 5.92 GHz. The amplifier design is uniplanar, compact, and is compatible with the fabrication process of HEMT transistors at millimeter-wave frequencies.**

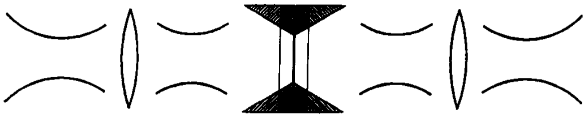

Fig. 1. Schematic view of the quasi-optical amplifier. A horn extension can be placed at the aperture of the horn to increase the directivity and the Gaussian-coupling efficiency.

I. INTRODUCTION

MILLIMETER-WAVE amplifiers are currently based on waveguide designs for applications above 26 GHz. The amplifiers employ a GaAs or InP HEMT chip with an appropriate waveguide-to-microstrip or waveguide-to-cpw (coplanar waveguide) transition [1], and are hard and expensive to fabricate above 100 GHz. It is therefore important to integrate the transistor amplifier directly with a radiating structure (e.g., planar antenna or grid) which results in a monolithic amplifier that is inexpensive and can be easily scaled to millimeter-wave frequencies. This approach has been pioneered by Kim and Rutledge in a recent paper on a 50-element grid amplifier [2]. We have extended this approach to a single-element amplifier that is well suited for low-noise systems (Fig. 1) or a space-fed waveguide array.

II. QUASI-OPTICAL AMPLIFIER DESIGN

The integrated horn antenna forms the building block of the quasi-optical amplifier [4]. It consists of a dipole probe suspended in an etched pyramidal horn in silicon (or GaAs). The quasi-optical amplifier employs a differential amplifier at the apex of two perpendicular dipole-probes inside the horn cavity [3]. The vertically-polarized dipole is the input port to the differential amplifier and the horizontally-polarized dipole is the output port of the amplifier. Two polarizing grids are used for isolation at the input and output ports.

A close up view of the dipole probes and differential amplifier is shown in Fig. 2. The chip transistors used are NEC 32100 with a maximum available gain of 14 dB at 6 GHz. The gates of the two transistors are connected to the vertical dipole (input probe) using bond wires and their drains are connected to the horizontal dipole probe (output probe). The transistor source terminals are connected together using a symmetrical cross pattern at the apex of the dipoles. Two 1-K Ω and 100-Ω resistors are connected to the tips of the vertical and horizontal antennas, respectively, for bias considerations. A 100-Ω bias resistor is connected to the source terminal and the dc source connection is achieved using a very narrow line as shown in Fig. 2. A dc ground is printed all around the antenna structure and bypass capacitors are used on the dc bias lines to suppress low-frequency oscillations. The active substrate is a 1.25-mm thick Duroid (Rogers Corp.) with $\epsilon_r = 10.5$. The polarizing reflectors are printed on very thin Duroid substrates (0.35-mm thick) with $\epsilon_r = 2.2$. All metalizations are etched in copper and the transistors, resistors and capacitors are surface mounted on the Duroid substrate.

The equivalent impedance at the gate and drain terminals is half the antenna input impedance. The impedance of the input and output dipoles can be independently adjusted by choosing the length of the dipole probes inside the horn cavity, and the positions of the grid reflectors behind the dipoles (see [4] for more detail). In this design, both antennas are chosen to be nearly 0.4-λ_0 long in a cavity cross-section of 0.6 λ_0 and the polarizing reflectors are placed 0.14-λ_0 behind the dipoles. The horn aperture is chosen to be 1.35 λ_0. This aperture dimension is compatible with quasi-integrated horn designs having 20-dB or 23-dB directivities and high Gaussian-coupling efficiencies (see [5]). The measured impedance including the effect of the bias resistors at the tip of the dipole antennas is around $(90 + j30)$ Ω for the input dipole and $(70 + j50)$ Ω for the output dipole. This results in a calculated differential gain of 12.5 dB at 6 GHz with a 3-dB bandwidth of 450 MHz.

It is also possible to place the differential amplifier and the polarizing grids in a square waveguide [6]. In this case, the input mode is TE_{10} and the output mode is TE_{01}. The impedance of the vertical and horizontal probes can be easily measured or electromagnetically modeled. This configuration is ideal for a space-fed waveguide amplifier.

III. MEASUREMENTS

The quasi-optical amplifier was measured in a plane-wave test set-up shown in Fig. 3. The amplifier gain, G, is defined by

$$P_r = GP_t\left(G_tA_e/4\pi r^2\right)\left(G_rA_e/4\pi r^2\right) \qquad (1)$$

where P_r and P_t are the received and transmitted powers and G_t and G_r are the corresponding gains of the transmitting

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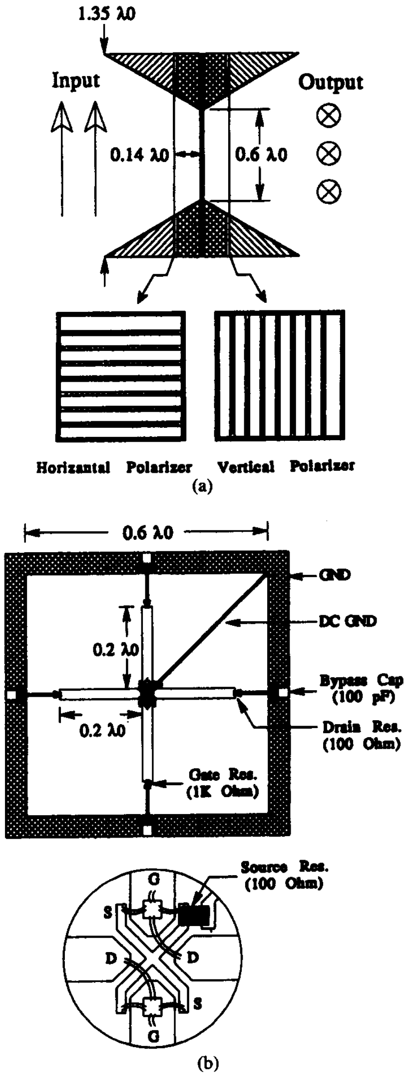

Fig. 2. Detailed side view (a) and front view (b) of the quasi-optical amplifier.

and receiving standard gain horns. A_e is the effective area of the integrated horn structure [7] (estimated to be 75 ±3% of the horn aperture) and r is the distance between the "device under test" and the transmitting (or receiving) horn. The plane-wave measurement system can be calibrated by making a measurement with the quasi-optical amplifier removed (see [2] for more details). The first term in parentheses relates the power radiated by the transmitting horn to the power *available* at the terminals of the input dipole. The second term in parentheses relates the power *radiated* by the output dipole to the power received by the receiving horn. This expression is similar to the one used in [2] except that we use the effective area A_e and not the physical area of the quasi-optical amplifier.

As can be seen, this definition separates the amplifier gain from the input and output wave-coupling characteristics. It is also applicable to quasi-optical amplifiers employing wire antennas (such as dipoles, slot antennas, helical antennas,...) for coupling the input and output power. When operated as a Gaussian-beam amplifier, the physical area is of no importance and it is the Gaussian-beam coupling efficiency between the quasi-optical amplifier and the Gaussian-beam system that should be used.

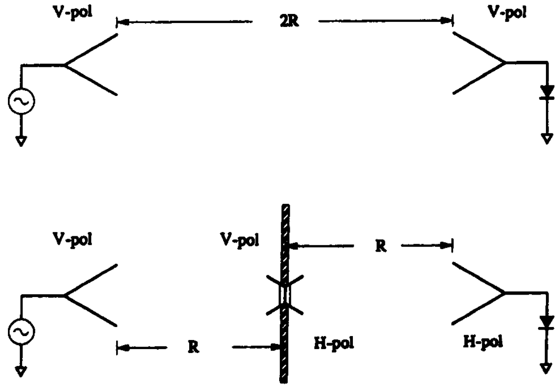

Fig. 3. The plane-wave measurement experiment.

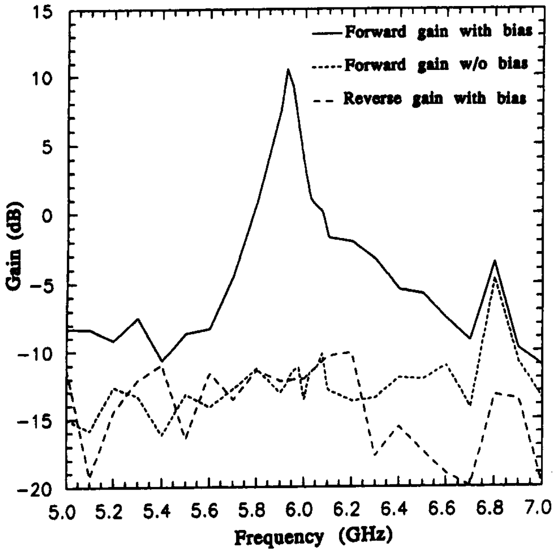

Fig. 4. The measured gain of the quasi-optical amplifier at 6 GHz.

Fig. 4 shows the measured gain of the quasi-optical amplifier. In our experiment, the distance r was 250 cm insuring a good far-field condition. The amplifier oscillated at 18 MHz when the transistors were biased at the same conditions. We attribute this oscillation to having bonded two NEC 32100 chips with different dc characteristics and the large inductance on the drain due to the long bond wires used. This parasitic series inductance is estimated to be around 0.6–0.8 nH resulting in a series impedance around $j20\ \Omega$–$j25\ \Omega$ at 6 GHz. The transistors were biased separately with $I_{d1} = 8.7$ mA, $I_{d2} = 4.4$ mA and resulted in maximum measured gain of 10.5 dB (Fig. 4) and a 3-dB bandwidth of 80 MHz. The output power was checked on a 10-MHz to 26-GHz spectrum analyzer and showed no spurious oscillation. The amplifier is linear and is polarization dependent on the input channel. The reverse gain is at least 20 dB lower than the forward gain at 5.9 GHz. The gain dropped to −20 dB when the input polarization was changed by 90°. Also, the polarization purity in the output port was better than 25 dB.

IV. CONCLUSION

In this letter, we reported a single-element quasi-optical amplifier that is based on a novel integrated antenna. Every effort was made to render the unit compatible with standard mm-wave fabrication techniques. The dipoles and transistors can be easily integrated on a GaAs or silicon wafer (100-μm thick at 94 GHz). Most important, the design is single-moded and therefore can be used in existing mm-wave systems as a low-noise amplifier stage before the RF mixer or as an amplifier stage in the transmitting circuit. Also, the unit can be suspended in a waveguide for the design of a millimeter-wave space-fed waveguide amplifier.

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