A Ka-Band Monolithic Quasi-Optic Amplifier

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Abstract—**Recent advances in the development of a Ka-Band quasi-optic amplifier are reported. The amplifier consists of a two-dimensional array of PHEMT power amplifiers, each of which is coupled to individual input and output slot antennas. The array of 112 amplifiers (49 mm total gate periphery) is organized into pairs operating in push-pull between a 7×8 array of input slots and an 8×8 array of orthogonal output slots. The total chip size is 12.8 mm by 13.4 mm and has a thickness of 75 μm. It is fabricated with standard MMIC processing techniques. The amplifier provided gain from 37.5 GHz to 39.5 GHz with a peak gain approaching 9 dB at 38.6 GHz. The maximum measured output power is 29 dBm.**

I. Introduction

Quasi-optic amplifiers [1–7] provide a practical solution to the problem of power-combining the output of more than a few amplifiers. Traditional techniques for power combining work up to a modest level of complexity. Beyond that level, the combining losses become significant. Quasi-optic power combining, on the other hand, has a high combining efficiency, approaching 100%, independent of the number of elements [8]. A second important characteristic of these amplifiers is their tolerance to failure of individual array elements (graceful degradation). In addition, the planar nature of two-dimensional quasi-optic circuits makes them particularly amenable to conventional semiconductor wafer processing technology.

The design of a millimeter-wave quasi-optic array amplifier presents many challenges. Foremost, is the need to accurately model the quasi-optic embedding circuit to provide the desired impedances to the active devices in the array and to avoid unwanted feedback that can lead to stability problems. Additionally, the amplifier packaging is critical if one is to preserve combining efficiency and provide adequate thermal management. In this paper we also describe a unique waveguide package that is both compact and suitable as a drop-in replacement for systems that are designed to use a conventional waveguide tube-type amplifier.

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II. Quasi-Optic Amplifier Design

The basic design of the amplifier unit cell is shown schematically in Figure 1. The input radiation field arrives normal to the array of input slot antennas. It couples to a microstrip line and from there to a MMIC power amplifier. The output from the amplifier is re-radiated by the output slot antennas orthogonal to the input wave polarization. The amplifier is a wave transmission system such that the signal travels in one side and out the other side. The identical input and output slot antennas are defined as slots in the ground plane of the GaAs microstrip circuit. The antennas are uniformly spaced in both the horizontal and vertical directions by the unit cell spacing (1.6 mm). The overall dimensions of the chip are 12.8 mm by 13.4 mm. The antennas are in such close proximity that one must account for the mutual interaction of adjacent elements. Extensive

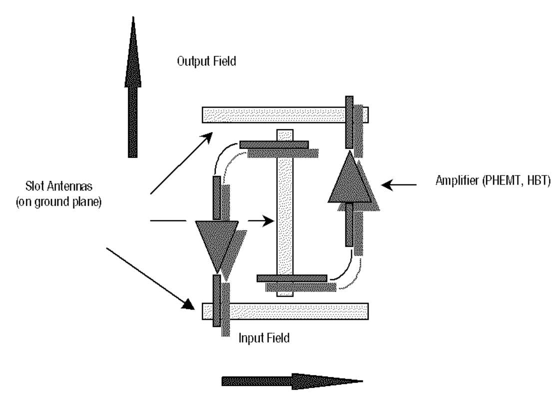

Figure 1. Schematic of the plane-wave amplifier unit cell. Each unit cell consists of input and output slot antennas, microstrip antenna feeds, and two MMIC amplifiers.

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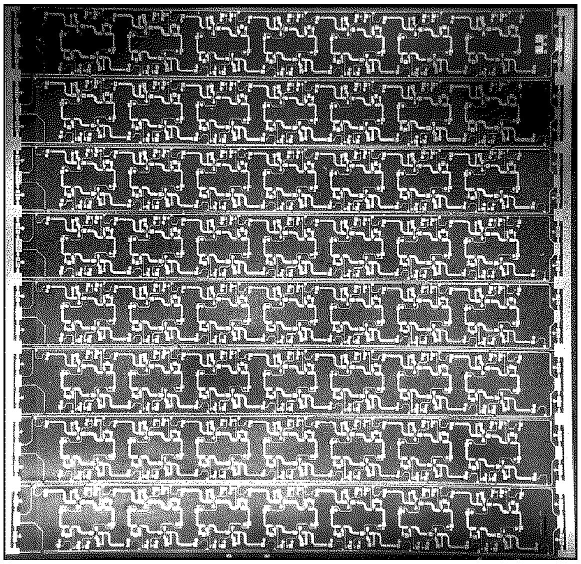

Figure 2. Photograph of the fabricated quasi-optical plane wave amplifier. The amplifier consists of an array of 56 unit cells in 8 rows and 7 columns with a total of 112 individual MMIC power amplifiers.

electromagnetic simulation was used to model the antennas, feeds, and quasi-optical package.

A photograph of the completed plane wave amplifier chip is shown in Figure 2. The amplifier consists of an array of input slot antennas (8×7) and an array of output slot antennas (8×8) in the ground plane of a microstrip system. Between these input and output antenna arrays are a set of 2×56 cell amplifiers arranged such that each input antenna drives two amplifiers in anti-phase. Similarly, each output

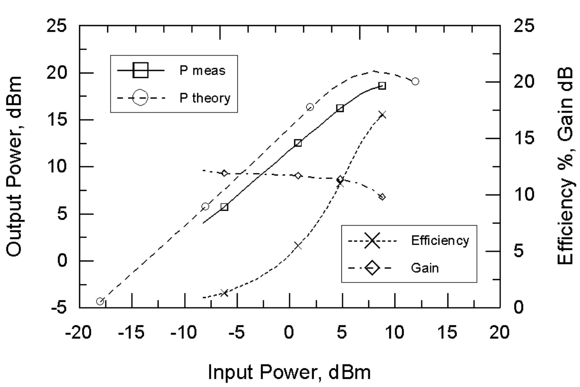

Figure 3. Measured output power, gain, and power-added efficiency of a single unit cell amplifier MMIC at 35 GHz. The theory is predicted using a non-linear harmonic balance simulation.

antenna is driven by two amplifiers in anti-phase forming a push-pull system. Each amplifier consists of a two-stage PHEMT microstrip design with an 80 μm device driving a 320 μm output stage. Figure 3 illustrates the measured power characteristics of a single cell amplifier measured in a 50 Ω system. Each MMIC is capable of 80 mW of output power with a corresponding gain of 12 dB. Thus, the potential output power from such a quasi-optical chip with all devices driven equally is in excess of 5 Watts.

III. Fabrication

One of the basic goals of the project was to maintain standard PHEMT MMIC fabrication techniques, consistent with the ultimate goal of a low cost, high volume fabrication of power amplifiers. The material used for this work was 3 inch wafers of MBE grown double-heterojunction PHEMT layer systems. The 0.18 μm gate was defined using a Cambridge 10.4 Electron Beam Lithography machine. The wafers were thinned to 75 μm, through-the-substrate vias were etched where needed and back-side ground metal was electroplated. The last step was the definition of the slot antennas (1.42 mm×0.1 mm) in the ground plane.

IV. Experimental Results

The amplifier was mounted on an aluminum-nitride carrier which in turn was mounted in a rectangular section of waveguide with the same cross-section as the quasi-optical amplifier. The rectangular guide transition was mounted between two cross-polarized linear-taper horns that match to standard WR28 waveguide flanges (Fig. 4). The fixture design is very similar to the one described in [9]. Polarizers were used as isolators, effectively making the quasi-optic amplifier unidirectional.

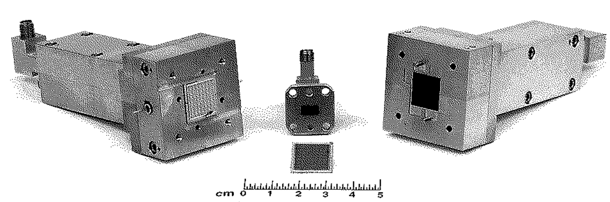

Figure 4. A photograph of the rectangular waveguide test fixture used to mount the quasi-optical amplifier. The test fixture also provides dc bias and thermal management. The amplifier is mounted between two cross polarized linear-taper horns. Standard WR28 waveguide flanges are used to connect the external input and output signals to the horns.

The amplifier drain was biased to 3.5 V and a total current in excess of 10 A was drawn by the amplifier. The amplifier has a very large total gate width of approximately 49 mm. Consequently a dc probe is necessary to isolate non-functional cell amplifiers prior to rf testing. Non-functional amplifiers are isolated by cutting their drain supply lines. Yields of working cells have typically been in excess of 90%.

Effective thermal management is critical given the large power dissipation of the amplifier. A simple passive thermal management system using an aluminum-nitride carrier is employed in this system and maintains the maximum temperature rise of devices in the middle of the array to no more than 50° C above the substrate edge.

The measured gain is plotted in Figure 5. A broad band of gain is observed between 37.5 GHz and 39.5 GHz with a gain peak at 38.6 GHz approaching 9 dB. These values are "flange-to-flange" measurements with 0 dBm drive level, and the figures include fixture losses which, are measured to be less than 0.5 dB at these frequencies. Preliminary power measurements have been made under the same conditions. The peak measured output power is 29 dBm (Fig. 6). This result is lower than anticipated due to the non-optimized field distribution at the input and output planes. The fundamental mode of a metallic waveguide has a cosine-squared distribution. To achieve maximum power output it is necessary to make the fields approach the characteristics of a plane wave. In an oversized waveguide, this can be accomplished by dielectrically loading the walls and by using appropriate phase compensating elements. This task is currently in progress.

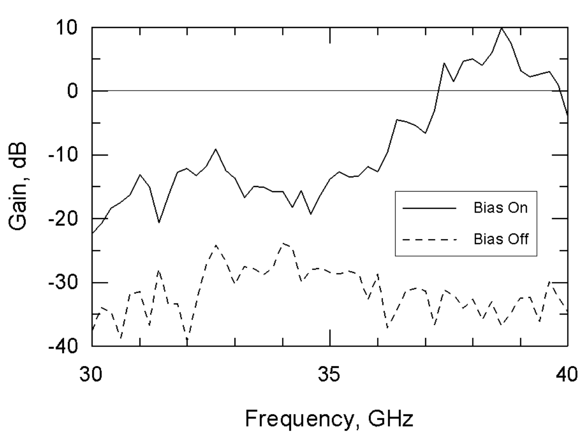

Figure 5. Measured small-signal power gain of the completed plane wave amplifier.

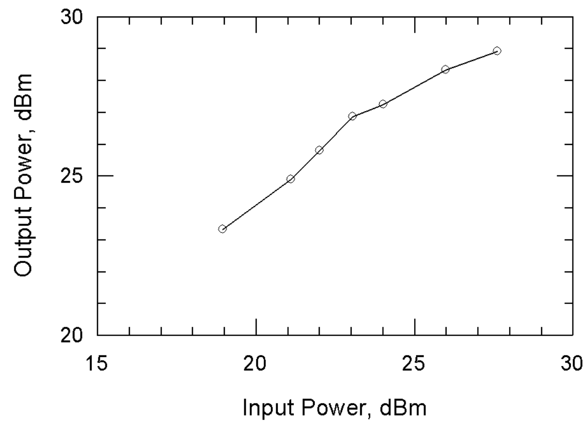

Figure 6. Measured output power versus input power for the plane-wave amplifier. Power measurements are made at the WR-28 waveguide flanges of the test fixture.

V. Conclusion

A Ka-Band quasi-optic amplifier consisting of a two-dimensional array of PHEMT power amplifiers, each of which is coupled to individual input and output slot antennas, is reported. The array of 112 amplifiers (49 mm total gate periphery) with a total chip size of 12.8 mm by 13.4 mm provided gain from 37.5 GHz to 39.5 GHz with a peak gain approaching 9 dB at 38.6 GHz. The maximum measured output power is 29 dBm.

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