A PHEMT Based Monolithic Plane Wave Amplifier for 42 Ghz

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Abstract

We report the design and operation of a monolithic Plane Wave PHEMT amplifier operating at millimeter wave frequencies. The array is made up of input slot antennas (5 x 7 array) and output patch antennas (4 x 8 array) polarized in orthogonal directions. An array of PHEMT amplifiers (7 x 8) placed between the two antennas amplifies and reradiates the input signal. The amplifier was placed in an oversized waveguide in order to avoid diffraction losses of a free space system. Gain of the amplifier was 3 dB at 42 GHz without any corrections for internal fixture losses. The amplifier results correlate well with computer model predictions of the antenna structures. These results prove the feasibility as well as the manufacturability of this approach.

Introduction

Achieving efficient power combination at frequencies above 30 GHz depends critically on achieving low loss transmission lines. Methods to minimize this dependence are sought. Plane Wave Amplifiers (PWA) are arrays of amplifying devices arranged to intercept and amplify mmWave signals in wave or beam form. Each active device is capable of receiving energy through an input antenna and, after amplification, retransmitting the signal from a second antenna. These PWAs offer a method of obtaining efficient power combination by spatial power combination after radiation from an output antenna array instead of in an orthodox power combiner network employing microstrip line.

A U-Band Waveguide PWA

The PWAs described in this work are transmission mode amplifiers where the signal incoming wave impinges on one side of the wafer which holds the array and the output wave is radiated from the opposite side along the same propagation direction but with a change of polarity. The convenience of the transmission mode is primarily in the separation of the input and output signals on two sides of the planar array of amplifying devices, an important factor in achieving a stable amplifier [1]. Transmission mode grid amplifiers have recently demonstrated gain at 40 GHz using gaussian beams propagating in free space [2]. This report is about a guided wave PWA, WPWA, where the beam is in a closed waveguide as illustrated in Fig. 1. This waveguide is described in more detail in reference [3].

A cross section diagram in Fig. 2 illustrates the amplifier cell of the WPWA. The GaAs chip is placed on an aluminum nitride chip carrier that doubles in function to provide a heat removal path and also electrically loads the slot antenna to have gain toward the signal source. The amplifier cell has a microstrip form consistent with normal microwave and mmWave MMICs. The signal is captured on the input side by the slot antenna in the ground plane of the microstrip. The signal is matched into the amplifying device by proper selection of the position of the pickup loop with respect to the slot center. The two-stage PHEMT amplifiers are depicted in the layout diagram of Fig. 3, which shows that each amplifier is one of a pair that together drive a patch antenna, orthogonal polarized with respect to the incoming wave, in push-pull to radiate the output wave. The PHEMT amplifier uses two stages to achieve a predicted gain of at least 7 dB at 44 GHz over a 10% bandwidth. The devices have subquarter micron gate lengths and are 80 and 160 microns respectively in gate width.

Measurements of the WPWA at 44 GHz

The PWA were tested in a waveguide test fixture shown in Fig. 1. The fixture consists of two transitions from U-band waveguide (WR19) to the

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cross section of the amplifier (~ 10 x 10 mm). In such a test, calibration of zero gain is achieved by removing the test fixture and connecting the input and output flange of the network analyzer. The waveguide approach eliminates any diffraction losses. A polarizer was placed downstream from the amplifier plane; i.e., along the output guide. Its function was to reflect any fraction of the input wave that leaked past the input slot antenna. This polarizer's position was adjustable and provided a small amount of input tuning.

Prototype WPWA amplifiers were tested in the 40 to 60 GHz region. Typical results are illustrated in Fig. 4. Positive gain (S21) is seen from 41 to 43 GHz with a maximum gain of 3 dB at 42 GHz. The return loss of the input side guide is also illustrated in the figure, which shows that the maximum return loss from the input port to the plane wave amplifier is 15 dB at 43 GHz. The gain is skewed to lower frequency than intended by the patch antenna; a circumstance that can be improved by simple adjustment of the patch design.

The power handling capability of the array amplifier was tested by measurement at 42 GHz. The maximum power measured in the output guide was just over 0.26 Watt, which works out to be 5 mW per amplifier. Under this circumstance, the gain was reduced by 1 dB and the DC input power was 10 Watts supplied from 5 Volt drain voltage. The apparent power output is roughly an order of magnitude below expectation. The explanation is that the Waveguide was not yet dielectrically loaded to make the incident power density uniform over the whole chip of some 50 cells; the power is virtually zero at the edges and at a maximum in the middle. At 1 dB compression, the only cells giving full output power are those in the very center of the guide. This may be rectified by dielectrically loading the guide (see ref[3]) to make power density of the incoming wave uniform out to the edges of the array.

Conclusions

Power gain at 42 GHz from monolithic PHEMT based Plane Wave Amplifier has been demonstrated. The feasibility of the array amplifier has been demonstrated and the validity of the concept of the transmission mode quasi-optical amplifier established at mmWave frequencies where antenna sizes allow this integrated active antenna concept to be used. The power levels demonstrated are low due to nonuniform feed power density, but these levels are expected to be raised ultimately by an order of magnitude. As has been demonstrated, this technique may be applied with equal ease to PHEMT or HBT [3] active device amplifiers.

Acknowledgment

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References

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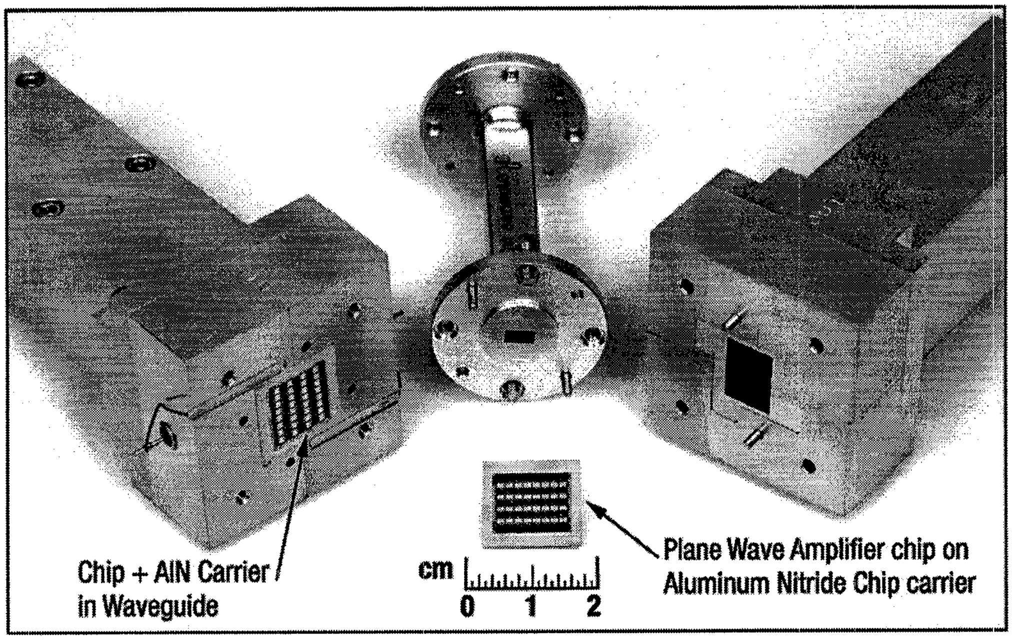

Fig. 1 Amplifier test fixture disassembled to show the amplifier IC mounted. For comparison, a standard WR19 flange is also shown. Both sides of the fixture taper down to a WR19 flange from the amplifier section shown.

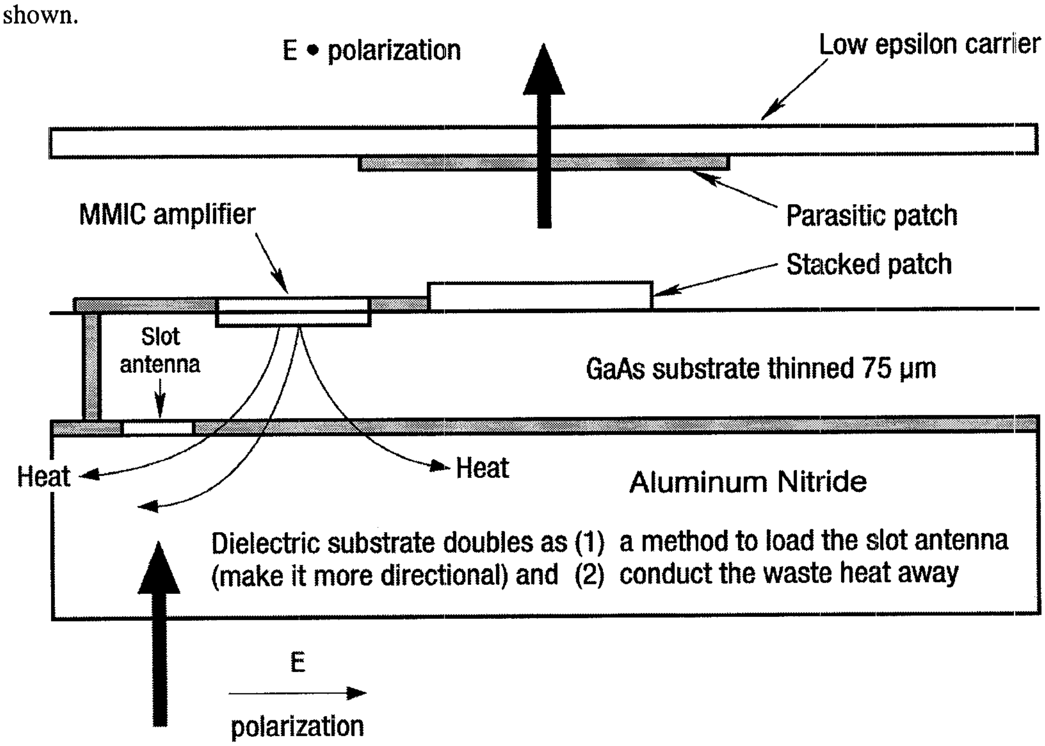

Fig. 2 The elementary cell of the Waveguide PWA. The input signal is coupled by a slot antenna to the microstrip format MMIC which drives a patch antenna from its output port. The output patch antenna is tuned by a parasitic patch and the input slot antenna is loaded by a slab of AlN dielectric.

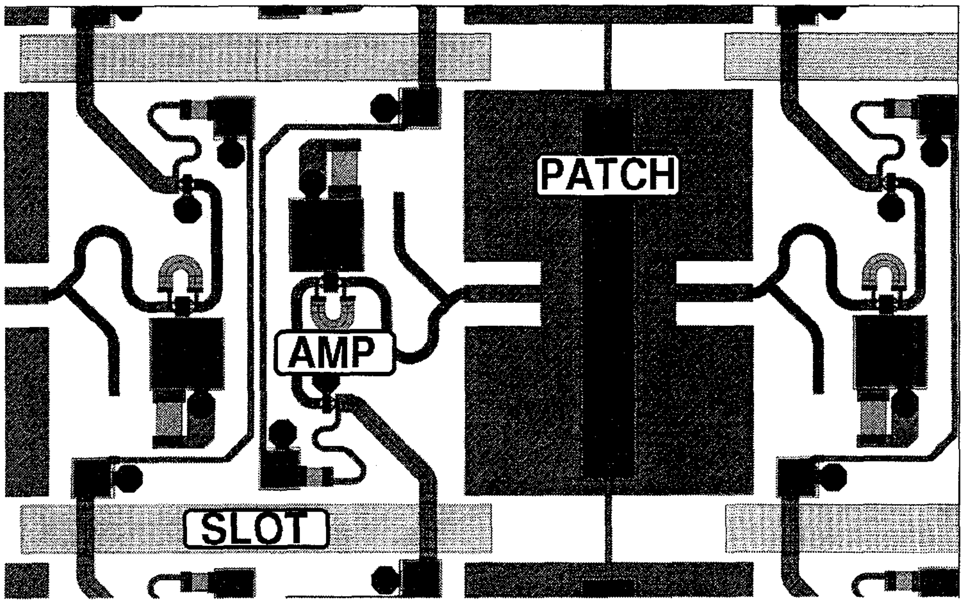

Fig. 3 Layout of the power amplifier cell. The output patch antenna is driven in push-pull by outputs from two PHEMT amplifiers, each of which receives its input from a nearby slot antenna in the microstrip ground plane. Amplifier inputs are in anti-phase. Patch dimension is 1200 by 860 microns.

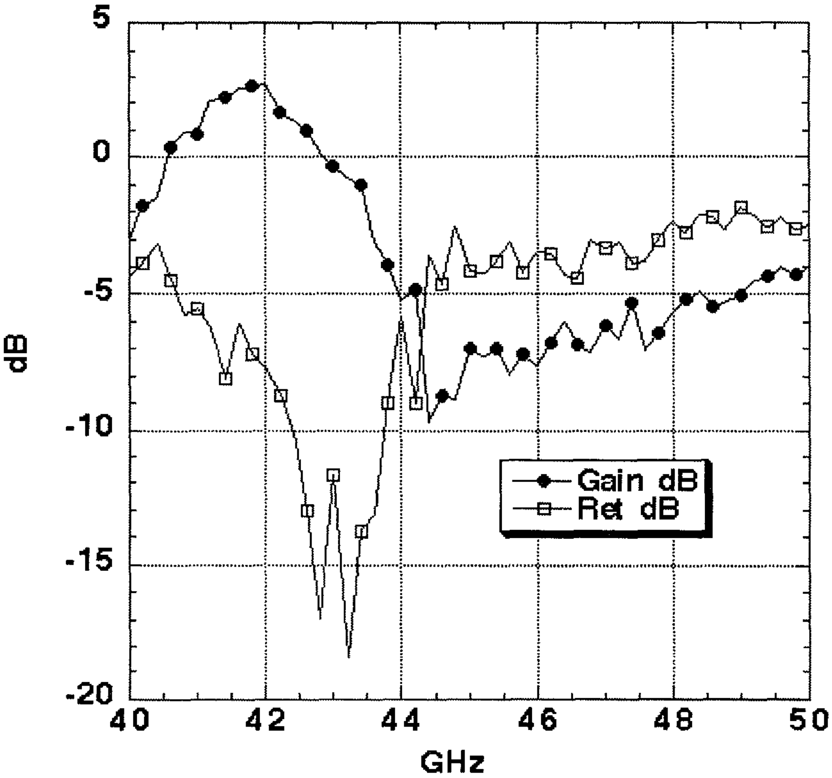

Fig. 4 Gain in an early form of the Patch-Slot WPWA. The gain is 3-dB at the point of maximum response of the patch and slot antennas; i.e., 42.0 GHz. Return loss in the input guide is minimized at 43 Ghz.