44-GHz Monolithic Plane Wave Amplifiers

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***Abstract*—A Plane Wave Amplifier is an array of small power amplifiers that accept input signals via input antennas and radiate amplified output signals from an output antenna. Such array amplifiers promise a method of efficient power at EHF. This concept has been experimentally explored in the 40–50 GHz band and gain over acceptable bandwidths has been measured.**

I. Introduction

PLANE Wave Amplifiers (PWA's) are arrays of amplifying devices arranged to intercept and amplify millimeter-wave 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. PWA's (including grid and other transmission wave amplifiers [1]–[3]), offer a method of obtaining the efficient power combination at EHF. This is done by spatial power combination after radiation from an output antenna array.

II. A Q-Band Waveguide PWA

The most convenient array amplifier is a transmission mode amplifier, illustrated in Fig. 1, shown at the top of the next page. 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 [4]. Transmission mode Grid Amplifiers have recently demonstrated gain at 40 GHz using gaussian beams propagating in free space [5]. This report is about a guided-wave PWA, WPWA, where the beam is in a closed waveguide designed to maintain a uniform power density across the array of active amplifying devices.

A square waveguide is selected for the WPWA. The power distribution is altered by placing a low epsilon dielectric at the guide sidewalls, creating the E field forms illustrated in Fig. 2. An added benefit of the dielectric loaded waveguide is the waves are incident on the array amplifier at closer to normal incidence.

A cross-section diagram in Fig. 3 illustrates the amplifier cell of the WPWA. The amplifier has a microstrip form consistent with normal microwave and mmWave MMIC's. 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 amplifying devices are HBT's of 120 square μm of emitter area connected in a common base configuration. These devices normally provide 6 dB maximum available gain at 40 GHz. The HBT output drives a patch antenna on the top surface of the GaAs. This patch antenna is oriented to provide a change of polarity for the outgoing signal. The performance of the patch antenna is augmented by the presence of a parasitic patch, also illustrated in Fig. 3.

III. Measurements of the WPWA at 44 GHz

Prototype WPWA amplifiers were tested in the 40–50 GHz region. The first generation amplifiers were designed with the peak response of the slot and patch antennas in the 49–50 GHz region. Measurements of S21 of an amplifier array with bias on and off are shown in Fig. 4. A positive gain is obtained at 49.5 GHz. The presence of a significant ripple in the gain was traced to the leakage of the input signal into the output waveguide.

Redesign of the input and output antenna systems to the 44-GHz region resulted in the amplifier characteristic shown in Fig. 5. In this figure, the S21 and the S11 of a waveguide installed array amplifier is depicted over the band 40–50 GHz. The gain under bias reaches −0.50 dB and the S11 shows a good match at the design frequency. The gain ripple is removed through the use of a downstream polarizer that tunes and matches the input port(s). The ratio of S21 with bias to S21 with no applied dc voltage is 15 dB. The S21 is limited by the quality of the amplifying devices. Despite the lack of positive gain, the array amplifier shows a bandwidth that is approaching 2 GHz or 5%. The amplifier gain was normalized by comparing to similar measurements with an empty waveguide of the same cross-section as the amplifier. In order to facilitate experimentation (inserting polarizers) there was a short break (8 mm) in the waveguide. The losses due to diffraction effects and/or insertion loss from tuning elements (polarizers, parasitic patches, high dielectric materials, etc.) were not removed. Although the calculated gain could have been underestimated by a couple of db, nevertheless it gives a good approximation of the more practical "flange-to-flange" gain as well as the potential bandwidth of the amplifier.

IV. Conclusion

Obtaining power gain at millemeter waves from monolithic PWA's is feasible. Amplifier arrangements that provide gain at 40–50 GHz have been designed and fabricated. The real benefit from such amplifiers will come with the demonstration of efficient power combination. This task will be a combination of antenna improvement and device to antenna matching. The key developments will be in the area of antenna characterization and modeling and the further development of HBT and PHEMT devices for high yield in large array chips.

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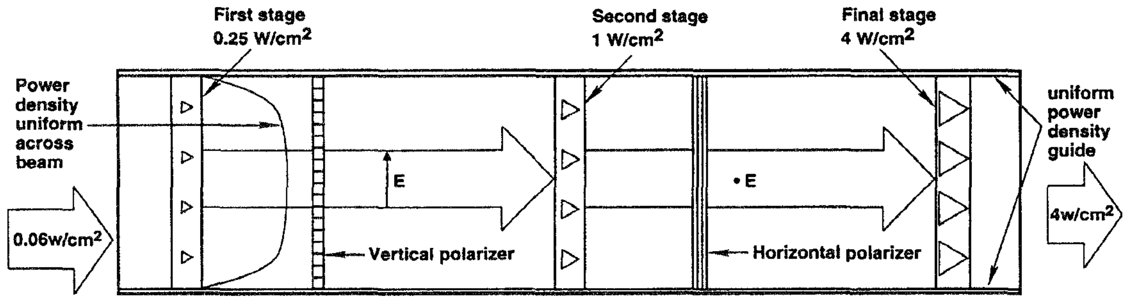

Fig 1. The concept of an array amplifier in a waveguide. The waveguide must present a uniform power density across the array amplifier.

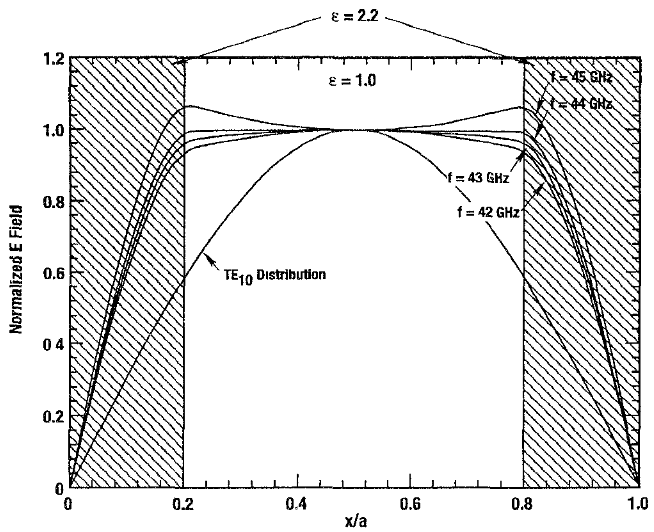

Fig. 2. The electric field form in the dielectric loaded waveguide. The dielectric loading is used to make power density more uniform.

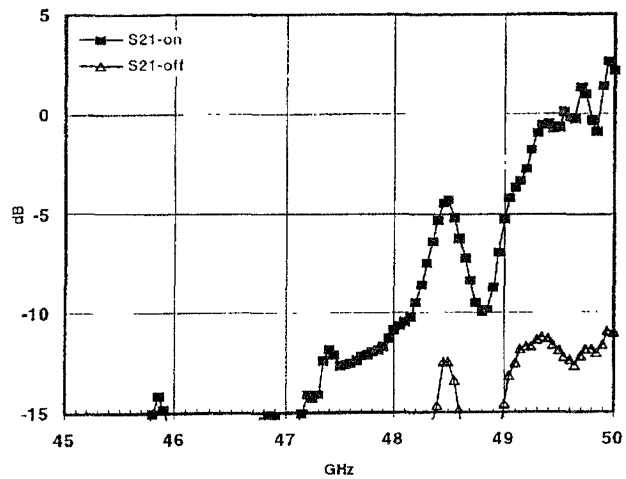

Fig. 4. Gain in an early form of the Patch-Slot WPWA. The gain is 3–4 dB at the point of maximum response of the patch and slot antennas, i e , 49.5 GHz Large gain ripple due to forward leakage of the input signal is observed. S21 bias on to S21 bias ratio is just about 15 dB.

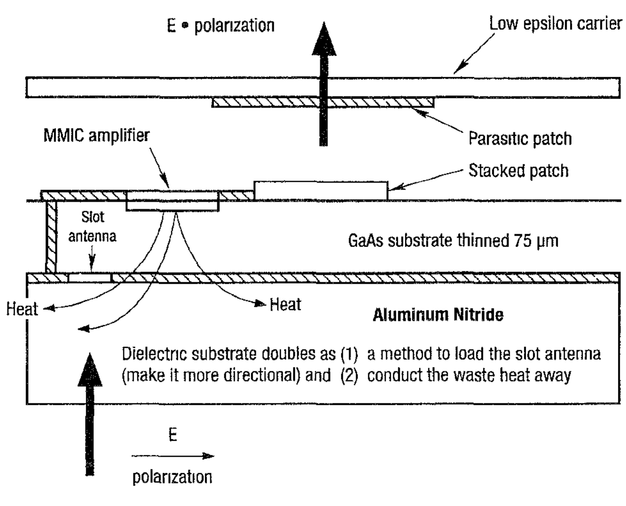

Fig. 3. The elementary cell of the Waveguide PWA The input signal is coupled by a slot antenna to the microstrip format MMIC, which drives a patch antenna from its output port The output patch antenna is tuned by a parasitic patch and the input slot antenna is loaded by a slab of AlN dielectric

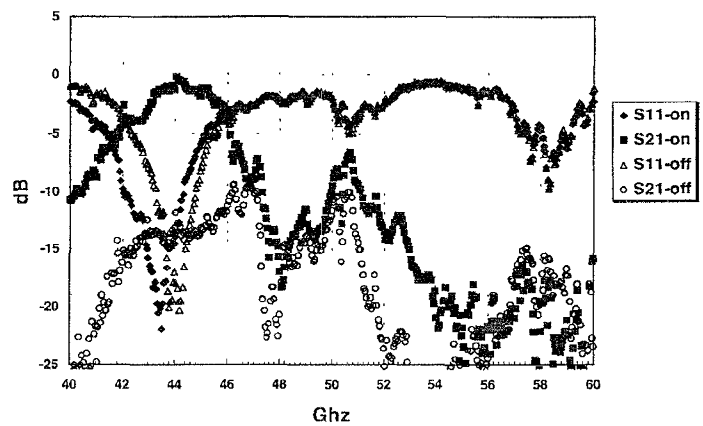

Fig. 5. Gain and input return loss of the amplifier when the antenna are tuned for maximum response at 44 GHz. The S21 bias-on to S21 bias-off ratio is over 15 dB. The use of polarizers removes the gain ripple effect observed in the first designs.

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