High Power V-Band Power Amplifier Using PHEMT Technology

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Abstract

A Millimeter wave power amplifier has been developed using power MMIC based on 0.15 Micron T gate pseudomorphic HEMT technology. A basic building block power module with 700 mW of output power has been demonstrated which covers 59.5 to 63.5 GHz Eight such modules have been power combined using a novel Radial combiner to achieve 3.8 Watt output power level with more than 31 dB gain. This is the highest V-band power reported in the literature to date. With the demonstration of the low loss power combining schemes and the basic building block power module, levels of up to 10.0 Watts can be easily achieved by using higher order of combining.

Introduction

60 GHz is the frequency of choice for cross link and covert communications. In the past the transmitter components in these frequencies were usually based on Impatts or TWTAs and suffered from poor reliability. Recent technical advances using super-lattice HEMTs structures have resulted in devices which exhibit greater than 0.6mW/mm output power density with greater than 25% power added efficiencies. Using different levels of low-loss planr and radial combiners, several of these devices can be combined to realize units up to 10 Watts in the near future in V-band frequencies. This paper reports on a 700 milliwatt output power module which can serve as a building block for higher power SSAs. Eight such power modules have been combined using a novel Radial combining scheme to generate 3.8 Watts This power level is the highest reported in the literature at these frequencies. The basic components as well as details about the power module and the combining schemes are described in this paper.

Device Technology

The basic device used for the MMIC development for this application is the pseudomorphic HEMTs (InGaAs/GaAs). These HEMTs offer the advantage of higher breakdown voltage and higher current density to produce more power than the conventional (GaAlAs/GaAs) HEMTs. These devices are fabricated by using MBE material and E-beam lithography to provide higher efficiencies and gain at millimeter wave frequencies. Although higher power devices have been demonstrated at these frequencies, the basic building block device selected for this MMIC development is a 320 micrometer gate width device, with a 0.15 micron "T" gate structure. This building block device was selected on the basis of optimal impedance matching to maximize gain, bandwidth, power output and efficiency. Figure 1 shows the picture of the basic device.

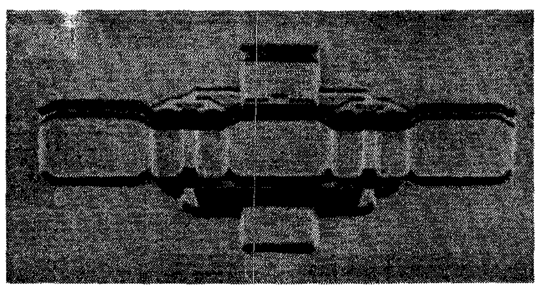

Figure 1. V-Band Pseudomorphic HEMT Device

MMIC DEVELOPMENT

The MMIC development started with a detailed characterization of the above described device. Once the large signal model was developed the input and output matching networks were designed to achieve the maximum gain and output power with minimum VSWR.

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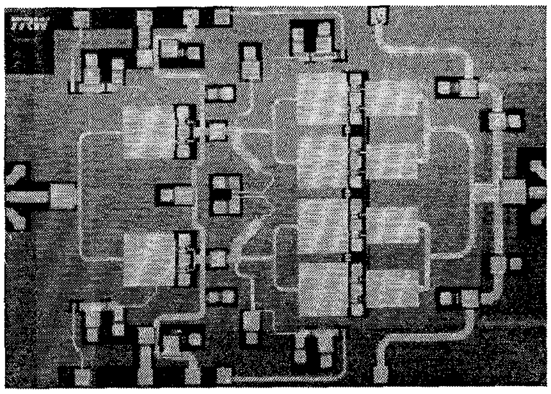
Two stages of amplification were used to achieve sufficient gain from the MMIC chip to enable efficient module and unit architectures. The MMIC first stage had a source periphery of 640 micrometer using two 320 micrometer building block devices. The output stage used a 1280 micrometer device using four 320 micrometer building block devices. The interstage matching network was optimized to maximize the power transfer from the 1st to 2nd stage. The overall power density of 0.26 milliWatts/ millimeter was achieved from the MMIC chip. Figure 2 shows a picture and the R.F. performance of the MMIC circuit used for this application. This MMIC chip is capable of delivering 335 milliwatts with 11.0 dB linear gain. The power added efficiency at the chip level was 10.5 %. Currently efforts are underway to improve the power added efficiency of the chip.



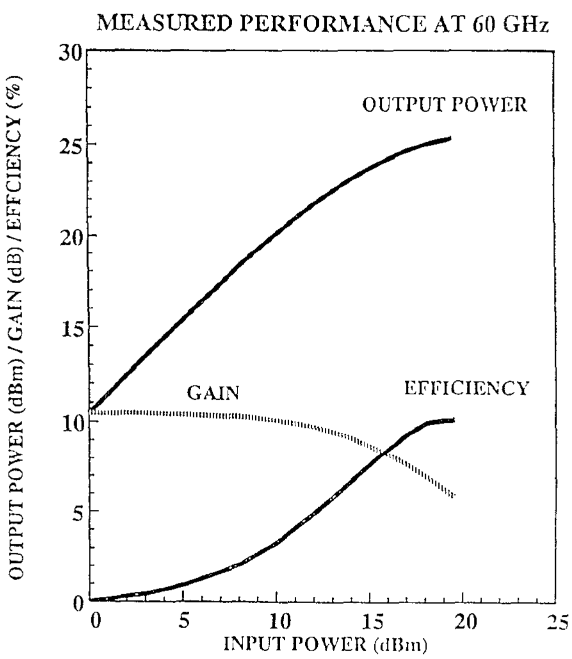


Figure 2. MMIC Photograph and its R.F. Performance

The MMIC used for this application has a highly reproducible design. One wafer which was used to build the high power modules had 176 sites, out of that 118 were DC. good. The output power requirement from this chip was 320 milliwatts and compressed gain of 7 dB. Out of 118 DC. good chips 78 passed the R.F. screening criterion, resulting in 45% R.F. yield.

PLANAR COMBINER

Millimeter wave planar power combiners have been developed at 44 GHZ and at 60 GHZ. Several combiners including 3-way, 4-way and 5-way, using a tapered line construction have been demonstrated with extremely low loss. Tapered line combiners are MMIC compatible and do not suffer the parasitics usually associated with Wilkinson and Nagai type combiners. Figure 3 shows the picture of back-to-back realization of a 3-way planar combiner. The 3-way combiner used for this application was realized on 5 mil thick polished alumina. The photograph also shows the impedance taper required to convert to 150 ohm and back again to 50 ohm. Two deposited thin film resistors are used to give the planar combiner good port-to-port isolation and VSWR. Figure 4 shows the measured performance of two back-to- back, divider/combiner combination. It shows less then 1.0 dB insertion loss per combiner , and greater than 16 dB port isolation. The divider and combiners were laid out in a way that phase from all the three amplifiers was equal at the combining port. An alumina substrate was selected due to its ease in manufacturing although it has higher losses compared to quartz.

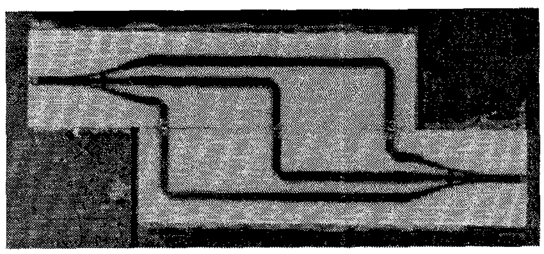


Figure 3. Back-to Back 3-Way Combiners

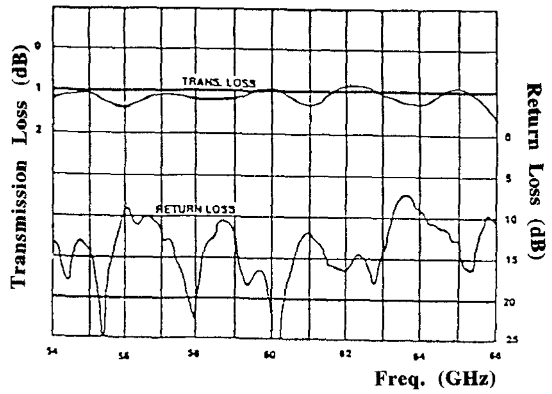


Figure 4. Divider/Combiner Transmission and Return Loss

Power Module Development

The power module design was chosen to achieve maximum power output, while allowing wide bandwidth. The block diagram of the module is shown in fig 5. It consists of a single MMIC chip driving 3 identical MMIC amplifiers using a 3-way power divider. The output power is combined using an identical power combiner in a way that the phase at the combining port is equal. For selecting the MMIC chips to be used the whole wafer was probed and mapped for the small signal parameters. The chips with closely matching phase and gain were selected for the module construction. The transfer characteristics of the power module are shown in fig 6, which shows that at module level 730 milliWatts was achieved with more than 12.8 dB power gain

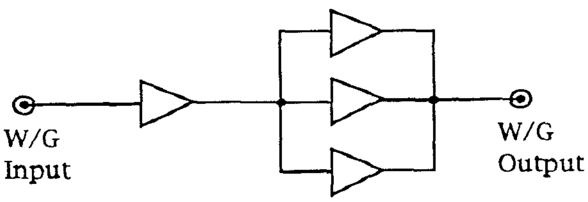


Figure 5. Power Module Block Diagram

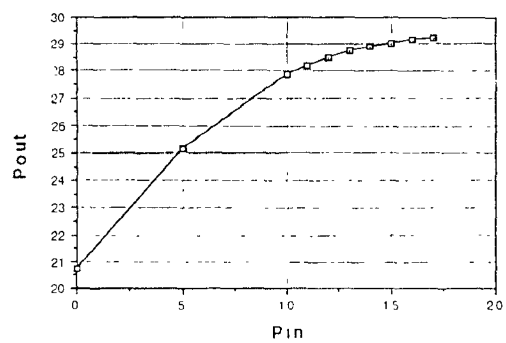


Figure 6. Power Module Transfer Charcteristics

Radial Combiner Design

The splitter/combiner design for the SSPA consists of an 8-way raidal splitter that feed eight amplifier modules. The modules in turn feed an 8-way combiner. Figure 7 shows a cross section of the splitter/combiner. The input rectangular waveguide feeds into a coaxial line which in turn feeds into the radial splitter. The signal is distributed to the 8 modules, amplified, and then combined in the radial combiner at the coaxial output, which is then coupled to the output rectangular wafeguide. Machined radial slots in the ground planes of the radial waveguide are filled with lossy material. the slots improve the input-to-input port isolation, providing graceful degradation of output power in the event of module failure.

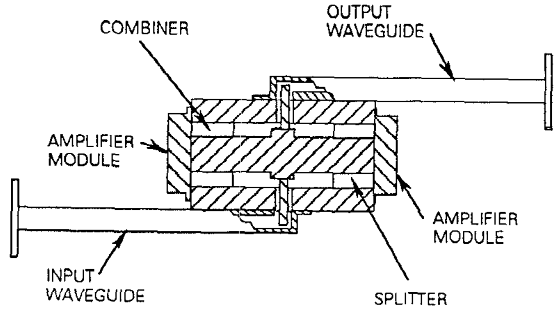


Figure 7. Radial Combiner/Splitter and Amplifier Assembly Cross Section

Amplifier Design

In order to achieve the highest combining efficiency from a combiner all the modules should be phase matched. Several power modules were built and characterized for amplitude and phase. Eight modules with an average output power of 730 mW milliWatts were selected and combined using the above explained radial combiner. To achieve maximum combined power the phase of the modules has to be equal. All the modules selected for this application were within 5 degrees of each other. Fig. 8 shows the photograph and the frequency response of the amplifier. The output characteristics of the amplifier are shown in Fig 9. The overall unit achieved 3.8 Watts output power with approximately 31 dB gain at 61.5 GHZ.

The unit was developed with flight qualifiable process for immediate flight insertions. The unit provides EMC filtered spacecraft buss interfaces with an electronic power converter and provides all required spacecraft telemetry functions.

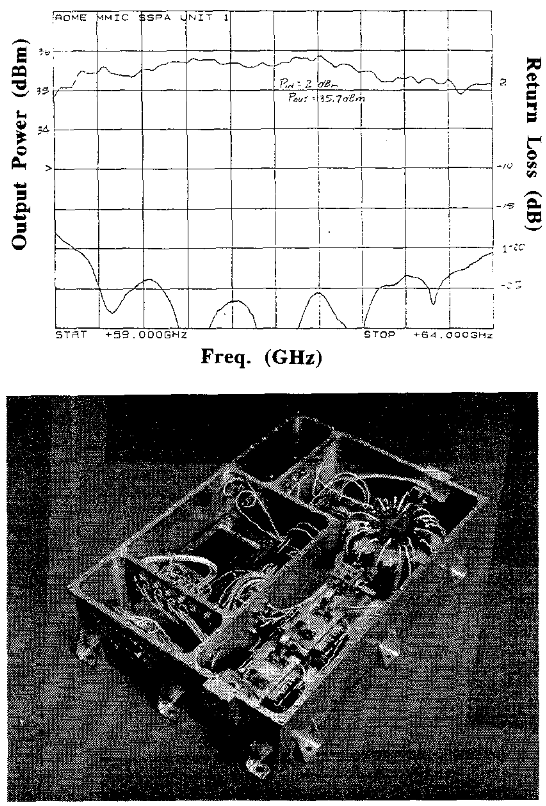


Figure 8. Amplifier Photograph and its Frequency Responce

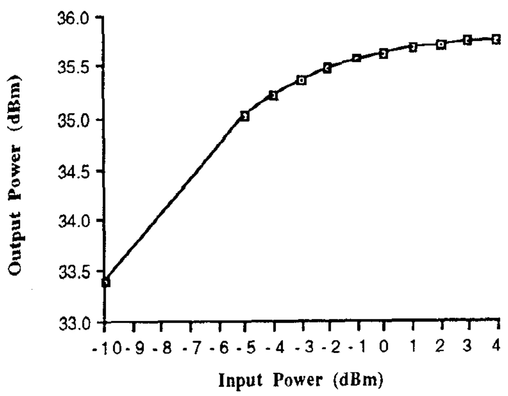


Figure 9. R.F. Performance of the Unit Amplifier

Conclusions

State of the art MMIC results have been demonstrated at the unit level in V-band. The design techniques used are very flexible and modular This approach can provide high output power while preserving bandwidth, gain and efficiency. These modules can now be used with higher order wave guide combiners to achieve even higher power levels in the near future.

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