A 16 WATT K_u BAND GaAs FET POWER AMPLIFIER

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ABSTRACT

An experimental power amplifier using GaAs FETs was built and tested. This power amplifier delivered 16 watts of RF output power in mid Ku-Band. It employed 88 GaAs FET devices and demonstrated 40 dB of gain with 12% DC to RF efficiency. The design considerations of power output, efficiency, bandwidth, size and thermal description are discussed from the viewpoint of potential space application. Also discussed are combining philosophy and package layout. Actual experimental results are presented.

INTRODUCTION

GaAs FET amplifiers are now key components in many applications on satellite communications systems. Power FET amplifiers at C band have replaced TWTAs on some satellite transmitter applications with anticipated excellent reliability. This paper describes the development and performance of a power amplifier using GaAs FETs at Ku band for potential satellite applications. The design goals were to demonstrate the feasibility of a multiwatt FET amplifier by efficiently combining space qualifiable lower power devices.

To achieve higher power output capability from FET devices, chip level combining or circuit level power combining is necessary, especially at X-band and above. Many methods are currently in use for chip level and circuit level device combining. For optimum reliability, devices for this application are procured in single chip form mounted on specially designed carriers and combined at the circuit level. A planar circuit combining scheme was chosen as the baseline design to optimize thermal distribution, compactness and for spacecraft interface mounting considerations. A four way low loss waveguide combiner was used in the final combining of four identical 4 watt amplifier chains producing a total of 16 watts centered at 15.0 GHz with an associated gain of 40 dB , a 1 dB bandwidth of 750 MHz and peak DC to RF efficiency of 12.5% for the total unit. Each identical 4 watt amplifier chain consists of a preamplifier/driver with +25 dBm output at over 30 dB associated gain and a 4 watt output module with approximately 12 dB of gain. Coaxial splatters provide the initial input power division. A block diagram of the complete amplifier chain is shown in Figure 1.

MODULE AND DRIVER DESIGN

The complete amplifier is designed about a modular approach. The basic building block for both the preamplifier/driver and 4 watt output amp is an integrated balanced gain module that utilizes Lange type interdigitated 3 dB couplers combining two single stage identical FET devices. The balanced design provides good VSWR across the desired bandwidth and allows modules to be directly cascaded or paralleled without the need for external isolators between stages. A block diagram of a balanced module is shown in Figure 2. Maintaining good VSWR between stages is essential at the higher power levels as device impedances change under increasing drive levels. For a given output, a balanced amplifier approach allows the use of a lower power device. The lower power, shorter gate devices have lower device Q's and greater bandwidth, have inherently higher gains, and provide more efficiency in power applications. At the higher frequencies, large gate periphery devices become inefficient due to the difficulty in providing an equal phase front across the whole gate periphery which now represents a large fraction,of the carrier wavelength. Balanced amplifiers also physically provide improved thermal distribution.

The complete balanced module consists of input/output Lange couplers on .025" alumina substrates mounted on Kovar carriers,integrated with 2 copper FET carriers. These FET carriers include the matching circuits and are designed to minimize parasitic components of gate to source inductance and to provide optimum heat transfer. The preamplifier/driver consists of four balanced gain modules cascaded in series without interstage isolators. Each of the lower power gain modules produced 8.5 dB of linear gain with .2 dB variation across a 1 GHz bandwidth. FETs used in the first three stages had a gate width of 300 um, and are biased with a drain voltage between 3 and 5 volts. The last stage of the driver contained a higher power device operating in the linear region. Power output for the complete preamp/driver was +25 dBm with .25 dB variation across 1 GHz bandwidth with over 30 dB of gain.

POWER AMPLIFIER MODULE AND PLANAR COMBINER

The four watt power amplifier module was realized by efficiently combining four 1 watt balanced gain modules in the final output. The four output modules are driven by two 1 watt modules which in turn are driven by a single 1 watt module for a total of 3 stages of amplification. Each 1 watt module produces slightly over 1 watt with over 4 dB gain over 1 GHz bandwidth. The devices employed in the power modules have a total gate width of 2500 um in an interdigitated structure operating at 8 volts, .25A. To prevent cavity resonances within the amplifier housing, the housing was channelized with walls which also provided placement for the DC bias feedthrus. A maximum of 90°C channel temperature for the GaAs FETs is the design goal for long term reliability. The major contributor in thermal resistance of the amplifier is still the FET device itself. Housing and FET carrier design are nevertheless crucial to minimize channel temperature. FET carriers and module carriers are made of OFHC copper and are integrated with gold eutectic solders. Amplifier housings are aluminum.

A four way planar combiner design was chosen over non-planar designs such as radial combiners. This design allows all amplifier surfaces to be easily mounted to heat transfer plates. Several types of planar combiners are possible for microstrip implementation including binary combinations of Lange, Wilkenson and branch line couplers. The binary Lange combination was used for several reasons. A single Lange coupler had low measured junction loss (< .15 dB), is small in size, has good repeatability and broadband VSWR. The primary contribution to loss in the planar combiner is from the length of line travel in microstrip. The total insertion loss of the planar combiner ranged between .6 and .8 dB. Measured VSWR at all ports was less than 1.2:1. A low loss microstrip to waveguide transition was developed for the output of each power module. The transition consists of a printed waveguide probe extending from the microstrip into the broadwall of the waveguide in the direction of the E field. The electric and magnetic fields about the end of the probe must have the same general form as the desired fields in the guide for best energy transfer. This type of transition is relatively difficult to treat analytically and was designed empirically. The transitions were matched from 13.5 to 16.5 GHz; return loss was greater than 25 dB. Each transition measured less than 0.1 dB loss. Low insertion loss (0.1 dB) waveguide isolators completed the power amplifier section.

AMPLIFIER INTEGRATION AND PERFORMANCE

Each individual preamplifier/driver and 4 watt output amp module are assembled and tuned independently. The gain variations between each preamp/driver are minimized by adjusting bias levels of the early gain stages. This is to minimize amplitude mismatches and to equalize gain compression characteristics when combining parallel chains of amplifiers. Variations in the performance between power amp modules were small. The power amplifier section utilizes a total of seven balanced power modules as shown in Figure 3. All one watt modules are individually tuned. To optimize performance, modules with the highest power output are placed in the final output. Each integrated power amp module produced slightly over 4 watts with an associated gain of 11 dB and a 1 dB bandwidth between 800 and 900 MHz.

The next step in the integration is the mating of the preamp/driver to the power module. Typical performance seen from these units was 4 watt output power with 41 dB of associated gain. Bandwidth was nearly the same as the output module, In this configuration the amplifiers can be treated as complete solid state amplifiers or they can be further combined to achieve higher powers. Further combining at these power levels require low loss waveguide combining. A binary combination of short slot waveguide couplers provided the final low loss, highly efficient means of summing the powers of four 4 watt chains, The loss of each short slot waveguide coupler was less than 0.1 dB and difficult to measure when silver plated. Two 8 watt units with over 40 dB gain were integrated and tested before final integration into one 16 watt unit. The final integrated amplifier shown in Figure 4 delivered 16 watts of rf power at 15 GHz with an associated gain of 39 dB with a 1 dB bandwidth of 750 MHz. The power added dc to rf conversion efficiency was 12.5% at mid band. The performance curves are presented in Figure 5. The output of the amplifier was checked for spurious outputs from 2 to 18 GHz. No spurious outputs were seen down to 70 dB below the carrier.

No oscillation power was detected on the output of the amplifier with no rf drive or under rf turn on conditions. Intermodulation distortion was measured using a carrier separation of 5 MHz. The carrier to third order intermod ratio was approximately 15 dB at full drive power. The intermodulation data is presented in Figure 6.

Since these amplifiers utilize balanced modules and many modules are paralleled, these power amplifiers possess an inherent graceful degradation characteristic in the event of a device(s) failure. As an example since the final stage is stressed harder than the previous stages, an analysis was run to evaluate the expected degradation in case of one random FET failure in any of the final stages. The expected loss in power of a 4, 8 and 16 watt amplifier are 1 dB, .5 dB, and .3 dB respectively. This graceful degradation is another inherent advantage in using lower power devices for high reliability amplifier applications.

CONCLUSIONS

The feasibility of producing multiwatt Ku Band power FET amplifiers with lower power (.5W) devices has been demonstrated by effectively utilizing efficient planar and waveguide combining techniques. Four independent 4 watt amplifier chains were built and tested and combined to form two 8 watt amplifiers. These were again combined to realize a 16 watt amplifier centered at 15 GHz with nearly 40 dB of associated gain. A planar packaging scheme to maintain low thermal resistance to spacecraft-radiators and repeatable, reliable circuit implementation were primary considerations for potential space applications. Further improvements in performance can be directly realized as device development, performance and repeatability are advanced.

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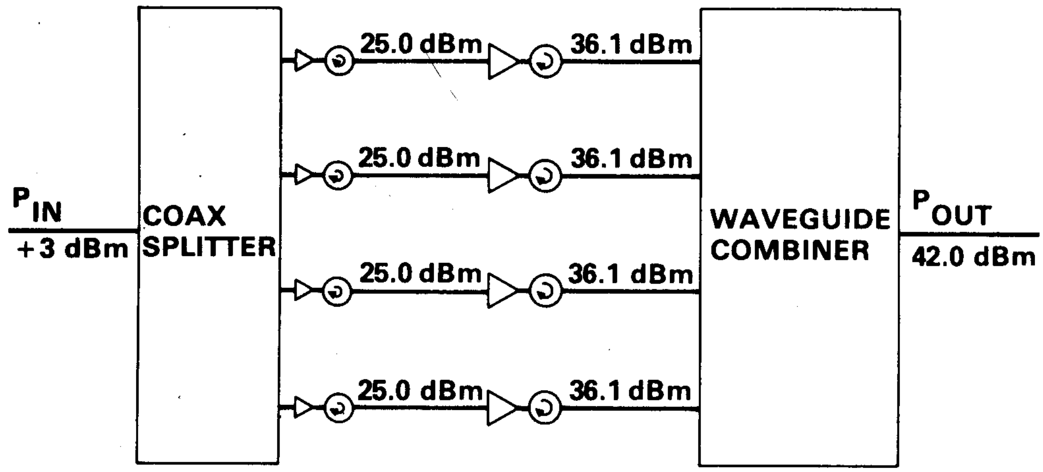

FIGURE 1 - 16 WATT AMPLIFIER BLOCK DIAGRAM

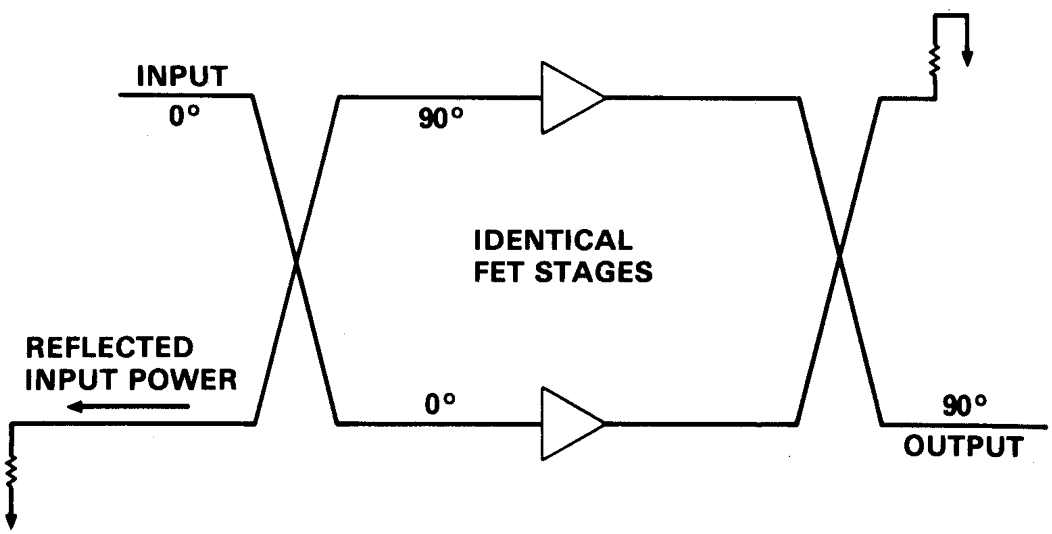

FIGURE 2 - BALANCED AMPLIFIER CONFIGURATION

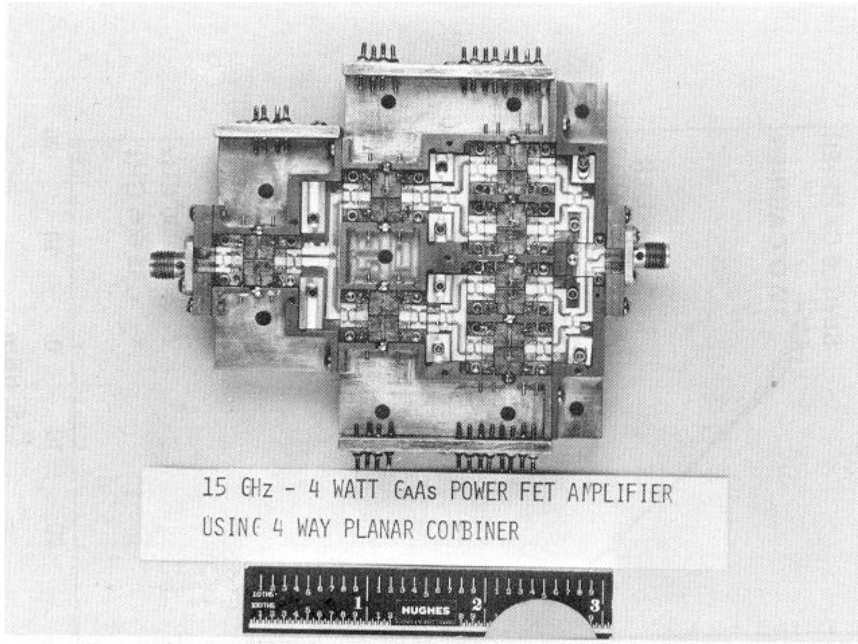

FIGURE 3 - 4 WATT GaAs FET POWER AMPLIFIER

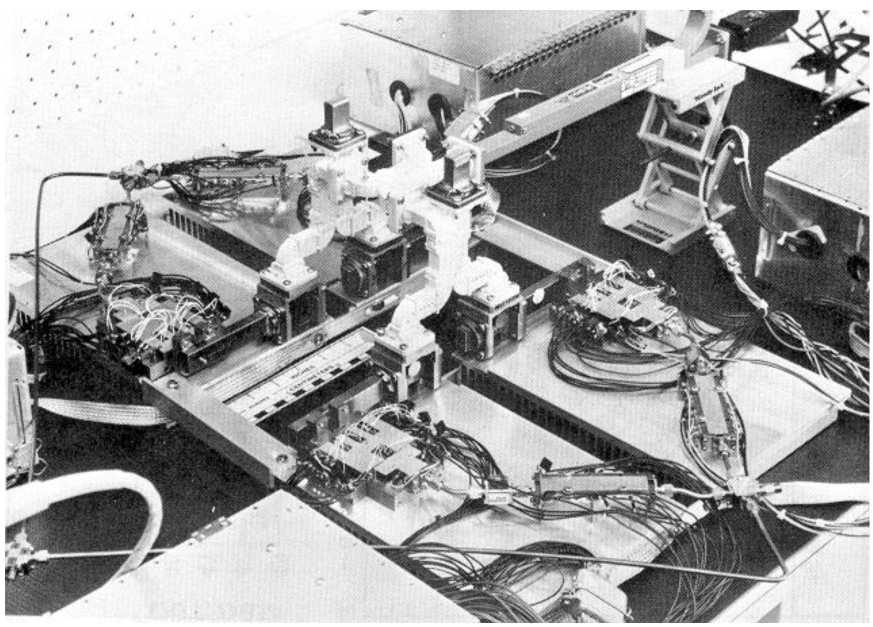

FIGURE 4 - INTEGRATED 16 WATT GaAs FET POWER AMPLIFIER

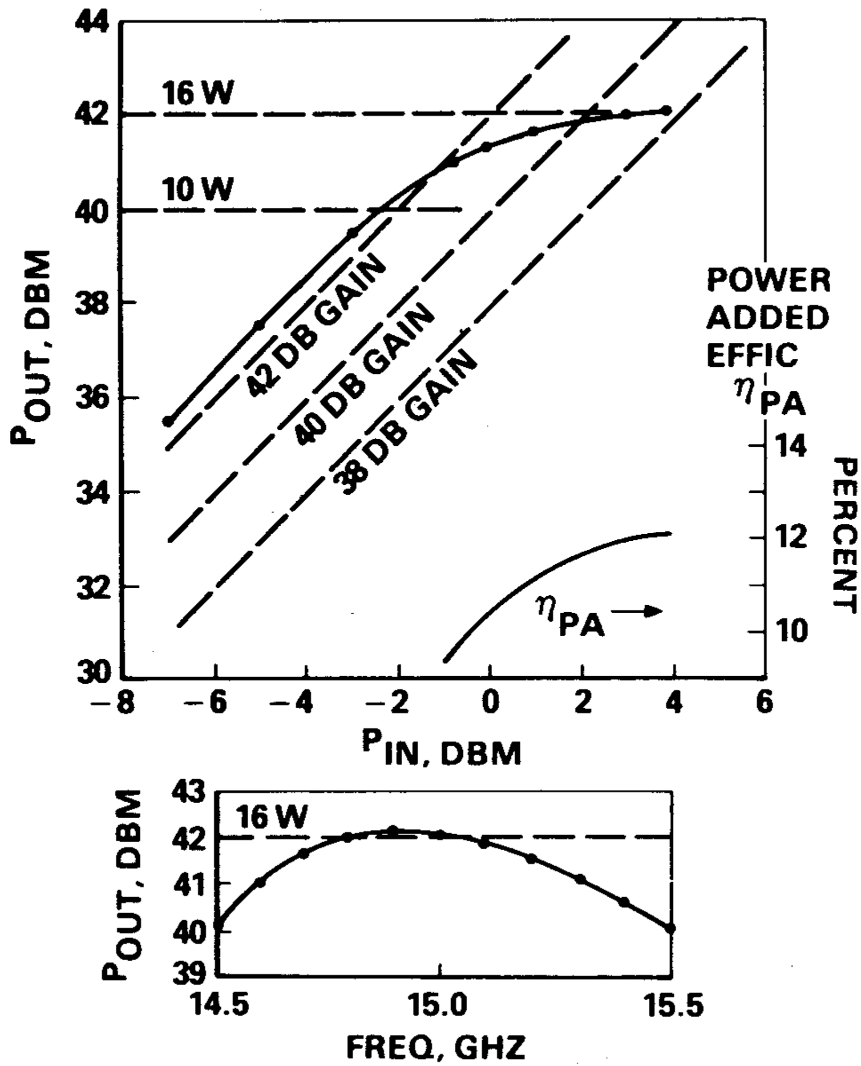

FIGURE 5 - 16 WATT PERFORMANCE OF GaAs FET POWER AMPLIFIER

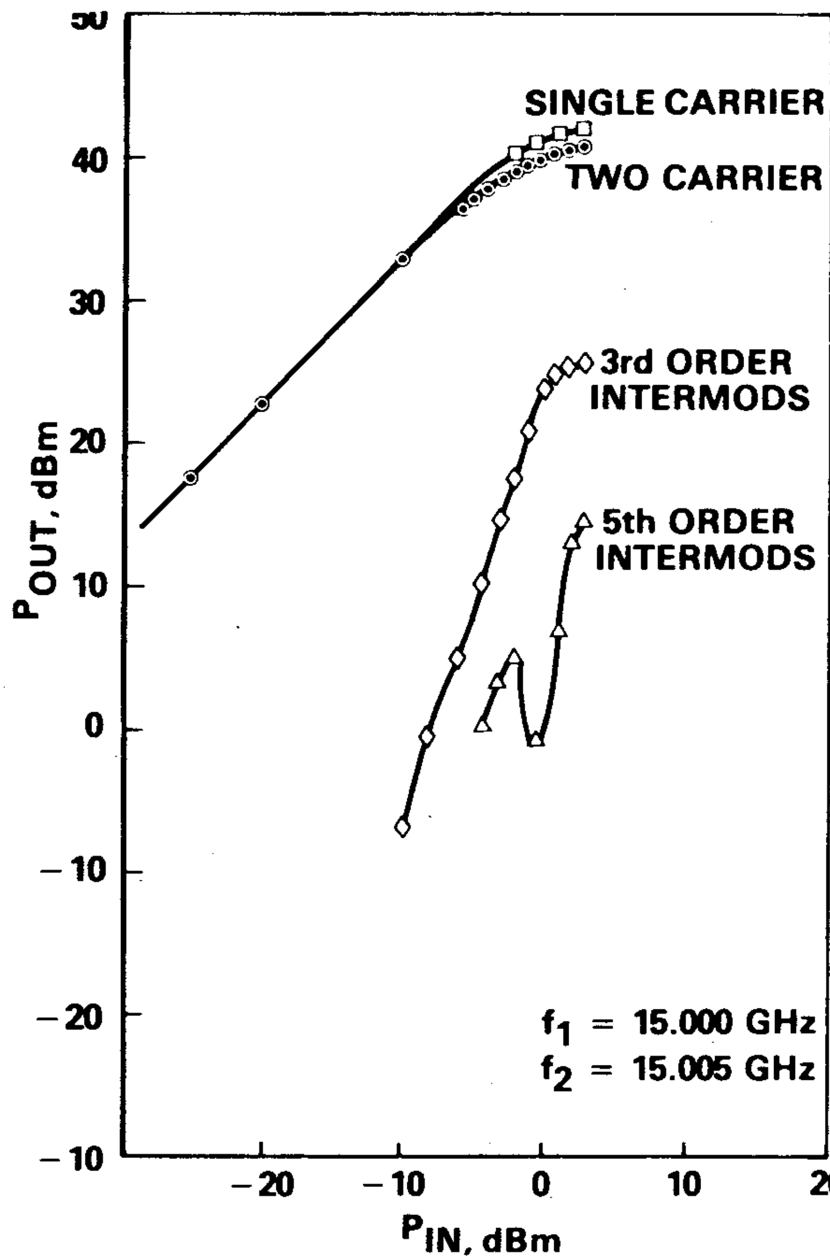

FIGURE 6 - INTERMODULATION DATA ON 16 WATT AMPLIFIER