400W X-BAND GaAs MMIC CW AMPLIFIER

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ABSTRACT

This paper presents the development of a 400W CW solid-state amplifier operating over 10.0 to 10.7 GHz band. An output power of 400W is achieved by combining forty-seven 10W GaAs MMIC amplifier modules using a 47:1 low-loss waveguide combiner. Other key parameters are the measured AM noise level of -120 dBc/Hz at 1 KHz offset and -137 dBc/Hz at 10 KHz, and FM noise level of -128 dBc/Hz at 1 KHz offset and -142 dBc/Hz at 10 KHz. To the best of the authors' knowledge, 400W CW output power at X-band using GaAs MMICs is achieved for the first time.

I. INTRODUCTION

Transmitters are used in radar and communication systems as the high power source of the information coded carrier signals. Transmitters can be used for pulsed radar signals used for target detection or continuous wave (CW) signals used for target illumination and target acquisition and track (CWAT). Advanced combat systems are beginning to use time shared waveforms to achieve multifunctional designs. Interrupted CW (ICW) is being considered to permit one transmitter to support more than one missile, using a phased array antenna. The solid-state transmitter is flexible enough to easily adapt to ICW when needed, while supporting CW when the extra average power is desired. Current systems utilize TWT transmitters, which have low reliability, high life cycle cost and cannot meet the spectral purity (AM and FM noise levels) performance required for the above mentioned applications in modern radar systems.

Development of a 400W GaAs MMIC CW Amplifier is presented in this paper. Designs of a low-loss 47:1 waveguide combiner/divider network, 10W GaAs MMIC amplifier, and a distributed power supply to meet the stringent requirements of AM and FM noise levels are presented. The design is modular, and by combining several 400W amplifiers, higher power levels on the order of 2KW, 5KW, and 10KW can be achieved for form, fit and function replacing the existing TWT transmitters for shipboard/ground based radars and for future modern radars.

This modular design allows overall transmitter power to be "matched" to the system in question using fewer blocks for a shorter range radar and adding additional blocks to support a longer range higher powered system. The compact design also makes it attractive to consider for airborne applications since power/size/form/fit tradeoffs can be more easily made with a building block design than with present high power transmitters that require bulky high voltage and magnetic focusing systems.

The first use of this solid-state amplifier in a military application will be in Kauai, Hawaii during early 1995. This project will demonstrate the advantages of using elevated radar systems for low altitude cruise missile defense. The solid-state transmitter will be part of a suite of sensors and airborne equipment used to characterize forward scatter sea reflections, known to cause problems for semi-active homing missiles. The transmitter will be situated on a mountain, illuminating the sea from much greater depression angles than are typically used by surface based illuminators. Data from this experiment will be used to validate and update models predicting sea clutter interference. The experiment will depend on the inherent low noise characteristics of the solid-state transmitter to maintain the spectral purity of the illuminator signal. The compact, portable nature of this solid-state transmitter is essential to the experiment since the transmitting site must be moved several times to acquire data at various radar heights.

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II. 400W CW GaAs MMIC AMPLIFIER DEVELOPMENT

A. 400 W Amplifier Design: A block diagram of the 400W solid-state amplifier is shown in Figure 1. Input power is divided into 47 equal amplitude signals using a low loss serial waveguide divider network. Each signal is then amplified by a GaAs MMIC amplifier capable of producing 10W CW output power across a 10.0 to 10.7 GHz band. The output power of the 47 amplifiers is then combined using a low loss serial waveguide combiner to obtain an average output power of 400W across the 10.0 - 10.7 GHz band.

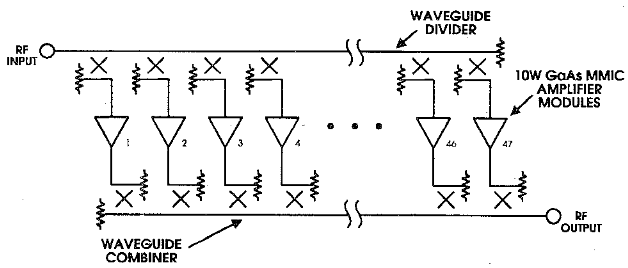

Figure 1. Block Diagram of an X-Band 400W Solid-State Amplifier

B. Waveguide Divider/Combiner: A 47:1 waveguide divider network utilizes variable crossguide couplers to obtain coupling ratios such that the input signal is divided into 47 equal signals. The combiner is similar to the divider with same coupling ratios arranged in mirror image order. Liquid cooling is used and the cold plate is integrated as part of the combiner/divider network. The port-to-port isolation is >25 dB and the insertion loss is <0.5 dB.

C. GaAs MMIC Amplifier: A 10W GaAs MMIC amplifier module* was developed using 2-stages of amplification. The total gain is 26-dB with an average output power of 10W and efficiency of 27% across the 10.0 - 10.7 GHz band. A photograph of the 10W module is shown in Figure 2. Output power performance of 47 amplifier modules as a function of frequency is shown in Figure 3. A microstrip to waveguide transition is used to facilitate the combination of all modules in the waveguide medium.

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* The 10W module was developed by COMSAT Laboratories, Clarksburg, MD.

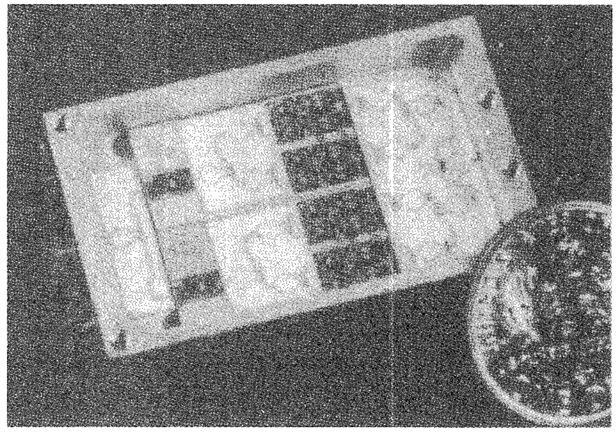

Figure 2 Photograph of a 10W GaAs MMIC Amplifier Module

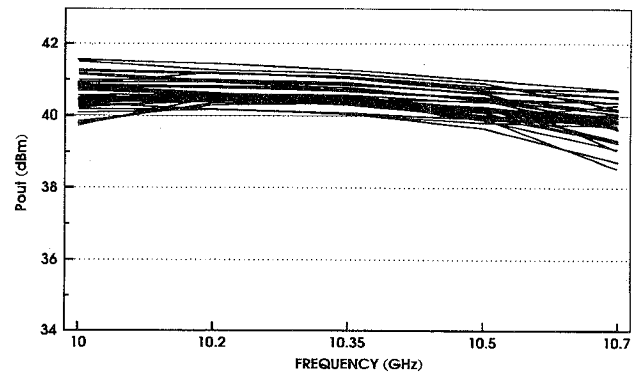

Figure 3. Output Power as a Function of Frequency for Forty-seven 10W Amplifier Modules

D. Power Supply: A distributed power supply was developed to provide high efficiency, power density, reliability and low noise. Rather than develop a centralized power supply for each system, the distributed power supply architecture continues the scheme of modularity for systems requiring different power levels. By matching the supply to the RF building block, the RF and DC components can be combined to create transmitters of any power level required.

The distributed power supply feeds the 400W amplifier as follows: the high current drain bias is fed from one DC block to a group of four MMIC modules. The lower current gate bias is fed from a common block that includes a redundant supply for reliability. The configuration of the power supply is shown in figures 4 and 5 for the drain and gate biases, respectively. Dividing the supply into smaller blocks provides a fail-soft mechanism for higher reliability. A failure in a centralized power system would cause catastrophic failure,

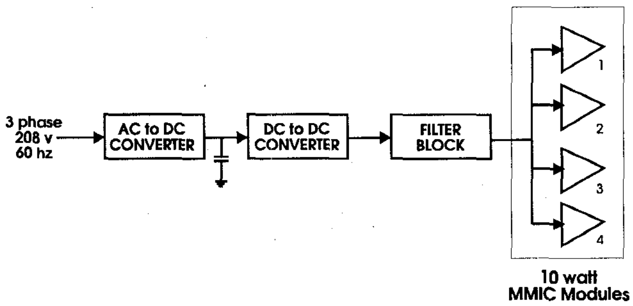

Figure 4. Configuration of the 9V Drain Bias Supply

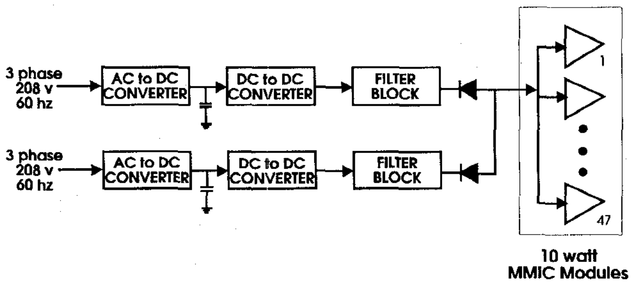

Figure 5. Configuration of the -5V Gate Bias Supply

where a failure in this distributed system will only slightly degrade the output power of the transmitter. Higher system reliability is obtained by using the distributed architecture which allows distribution of power supply weight and thermal dissipation throughout the transmitter. This further improves the isolation to shock and vibration, thus reducing microphonics and system noise.

Using DC blocks that utilize zero-current switching technology, high power density and efficiency is achieved along with low noise characteristics. These switching supplies operate at frequencies above 300kHz to provide low "close to carrier" noise. By adding additional passive and active filtering, the low and high frequency noise performance is further improved.

E. Performance of 400W Amplifier: A photograph of the complete 400W amplifier assembly is shown in Figure 6. The output power as a function of frequency is shown in Figure 7. An average of 400W output power and gain of 25 dB is achieved across the 10.0 -10.7 GHz band. Additional increases in output power are achievable when improvements are made to the RF transition from the MMIC module to the X-band waveguide. It was found that this transition decreases the output power by 0.5 dB across the frequency 10.0 to 10.7 GHz band. Presently, a microstrip interface is used to transform a 50 ohm coaxial line into the waveguide. It has been found that eliminating this transition and launching directly into waveguide will translate into high RF output power and efficiency.

The AM and FM noise performance of the amplifier is shown in Table 1. The 400W amplifier presented here is a building block for higher power transmitters. When several amplifiers having uncorrelated noise are combined, additional improvements in the noise levels are achieved.

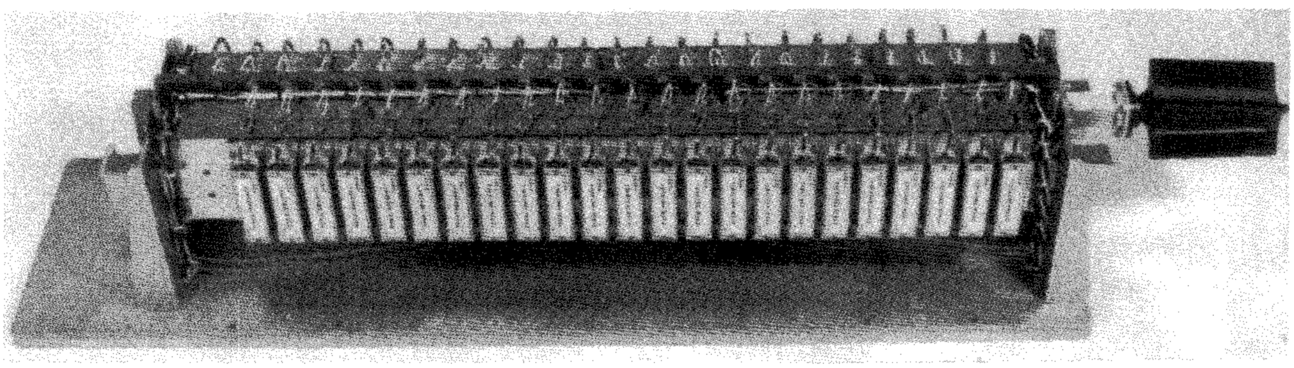

Figure 6. Photograph of the X-Band 400W Solid-State Amplifier

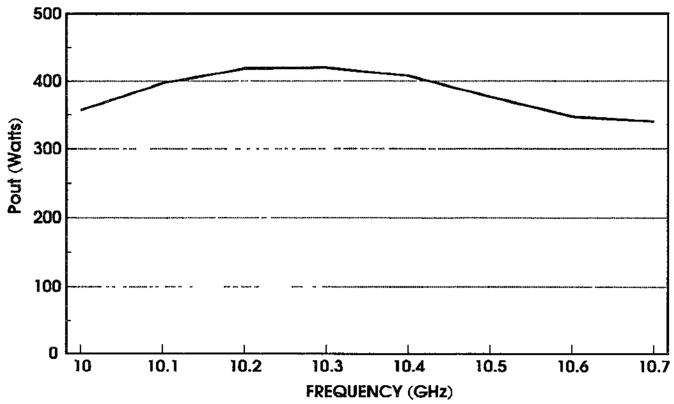

Figure 7. Output Power as a Function of Frequency of the 400W Solid-State Amplifier

TABLE 1
Measured Noise Performance of 400W CW X-Band Amplifier

Offset from Carrier	AM Noise Level	FM Noise Level
1 KHz	-120 dBc/Hz	-128 dBc/Hz
10 KHz	-137 dBc/Hz	-142 dBc/Hz

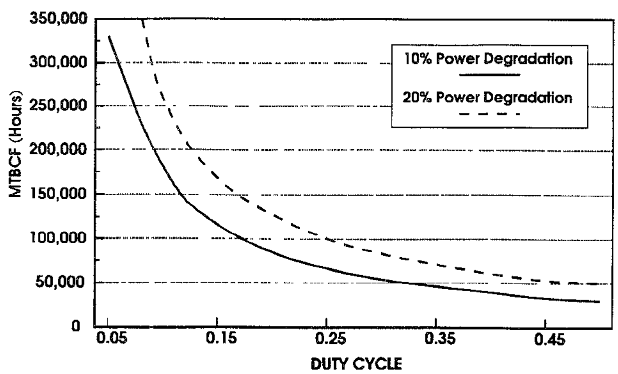

Figure 8. Mean Time Between Critical Failures of the 400W Amplifier

A reliability study was performed for the 400W amplifier. Figure 8 shows the Mean Time Between Critical Failures (MTBCF) as a function of operating duty cycle. Most CW systems use transmitters operating at low duty cycle. With a fail-soft architecture, a system is designed with power levels 10-20% higher than the threshold requirement. Thus, a certain number of components are allowed to fail before the system performance is effected. For a typical combat system (duty cycle 0.05) MTBCF is 37 years for 10% power degradations.

The design presented here can accommodate more advanced GaAs MMIC modules with higher output power levels and broader bandwidths as they become available.

III. CONCLUSIONS

The design, fabrication, development and performance of a 400W X-Band GaAs MMIC CW amplifier for modern radars has been presented. The AM and FM noise level performance achieved by this amplifier supports the requirements of future radars for advanced target illumination acquisition and track, CWI, and ICWI applications. The 400W amplifier is a building block for transmitters having power levels of 2KW 5KW, 10KW and higher. This represents a major milestone for the development of high power centralized transmitters.

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