AN X-BAND 2 kW CW GaAs FET POWER AMPLIFIER FOR CONTINUOUS WAVE ILLUMINATOR APPLICATION

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Abstract

The development of a solid state power amplifier (SSPA) for a continuous wave illuminator (CWI) application at X-band is described. The amplifier produces 2 kW of CW output power at 1 dB gain compression over a 2.5 percent bandwidth with a DC-RF efficiency better than 15 percent. Low-loss power combining is implemented using a hybrid serial and corporate combiner structure in waveguide medium. The SSPA has been designed to operate in environmental conditions specified for naval military vessels.

1.0 Introduction

The function of a CWI illuminator is to illuminate an air-borne enemy target with microwave energy from a naval combat vessel to help guide an intercepting missile with an on-board radar receiver to find its target. The current systems use multi-cavity klystron tubes for producing the RF power in the order of kilowatts. Klystron systems are narrow band and have very limited MTTF of the order of a few tens of hours, in addition to being fragile for environments deploying CWI. This paper presents the development of an all solid state GaAs FET power amplifier with 2 kW CW output power over a 2.5 percent bandwidth at X-band to replace klystron systems. The solid state alternative also has the advantage of graceful degradation. This is the first time a CW solid state power output of this magnitude has been reported. Additionally, the amplifier has been designed and constructed to meet the specifications of extreme environmental conditions encountered by sea-borne CWI systems.

2.0 Design

Various power combining methods were considered and a design evaluation was carried out to determine the optimum solution from the perspectives of ease of manufacturing, size and form factor constraints, modularity and ease of access to modules, thermal efficiency, transportation and installation in confined spaces. The final line-up of the SSPA is shown in figures 1a, 1b and 1c. The SSPA consists of an RF driver stage, RF power amplifier section, and the output power monitoring section. The main features are as follows:

- The RF power amplifier section consists of sixteen identical serial amplifier modules (SAMs), whose output powers are combined using a sixteen-way divider/combiner using hybrid four-way serial and four-way corporate topologies (Figures 1b and 1c).
- Each SAM consists of thirteen identical power amplifier modules (PAMs) whose output powers are combined in a thirteen-way serial power divider/combiner using waveguide combiners, with an identical PAM at the divider input driving the thirteen PAMs (Figure 1a)

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- Each PAM consists of two amplifier stages and has waveguide input and output ports. The PAMs use internally matched commercial GaAs FETs - a 5 W device driving a 15 W output device. Additional matching at the input, output, and between stages is provided using microstrip matching circuits on duroid substrate. A drop-in isolator is used at the output of each PAM.

- Each PAM has a bias and status monitoring board, and requires a positive and a negative DC supply. Supply sequencing is centrally in the SAM power supply. Each SAM is supplied by two switched mode power supply units (PSU) with each PSU supplying one half of the SAM (seven PAMs). Each PAM consumes approximately 60 W of DC power.

A forward and reflected power monitor which uses cross-guide couplers has been provided at the output. A waveguide transfer switch has been provided such that the RF output can be switched either into the antenna or into a dummy load.

3.0 Analysis

The amplifier system was extensively analysed using statistical yield analysis techniques for evaluating the expected performance of the SSPA due to tolerances in the various parameters of the system. HP EESof TOUCHSTONE was used for the analysis.

- The coupler parameters used in the modelling and analysis are isolation (25 dB), coupled port return loss (25 dB), excess insertion loss (0.05 dB), direct port phase tolerance (360±2.5°), and coupled port phase (0±2.5°). The coupling variation is modelled by including a tolerance of ±2% in the even mode impedance and keeping the characteristic impedance constant.

- The parameters of the PAM used in the analysis were: gain 12±0.2 dB, phase 360±10°, input return loss 15 dB, input return loss phase 150±180°, output return loss 20 dB at 0°, and reverse gain –20 dB at 0°.

This analysis verified that the target output power could be achieved with commercial off-the-shelf devices on a statistical performance prediction basis.

4.0 Construction

The entire RF power amplifier section of the SSPA has been designed to use only four separate types of modules - a 16-way corporate-serial divider (CSD), a corporate-serial combiner (CSC), SAM, and PAM, to reduce the parts count and spares carried. The PAMs have been designed to be field replaceable in a few minutes requiring just a screwdriver.

The SSPA system is pressurised with dry air to prevent moisture condensation inside the system.

The SSPA parts have been designed as part of the total mechanical structure of the SSPA with some additional minor mechanical supporting structure. Vibration and shock analysis was performed on the structure using ALGOR finite element software.

The cooling is provided in each of the SAMs by a heat exchanger system, which uses de-ionised water in the sealed portion and exchanges with sea water.

The RF section of the SSPA measures 740mm x 820mm x 1720mm high. The overall dimensions including the PSU, the controller, and the cooling system are 860mm x 2380mm x 1720mm high.

5.0 Test Results

The results of the thirteen-way serial divider/combiner connected back to back using waveguide bridges instead of PAMs is shown in Figure 2. The insertion loss is 0.9 dB for the combination.

The measured results of the sixteen-way hybrid serial-corporate divider/combiner is shown in Figure 3. The insertion loss is 1.7 dB for the combination.

A minimum power output of 51.2 dBm from each SAM has been achieved. The graceful degradation characteristics of the SAM were tested by removing PAMs one by one, and terminating the corresponding ports on the SCD with short circuits. The SAM soft failure behaviour was according to predictions.

A photograph of the RF power amplifier section is shown in Figure 4. Preliminary test results are given in Table 1, below. Further tuning of the phase relationship between the SAMs is being carried out at the time of the writing to improve the output power.

Table 1

Freq.	P1dB dBm	P2dB dBm
fo -125MHz	62.78	62.88
fo	63.01	63.16
fo +125MHz	62.97	63.15

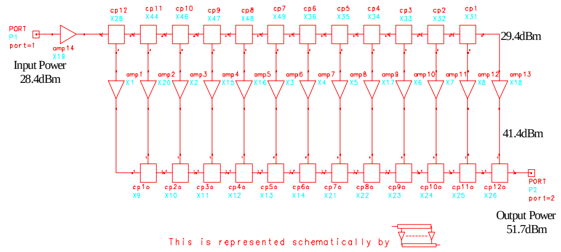

Figure 1a Schematic and nominal power levels for first level (13 way serial) combined section

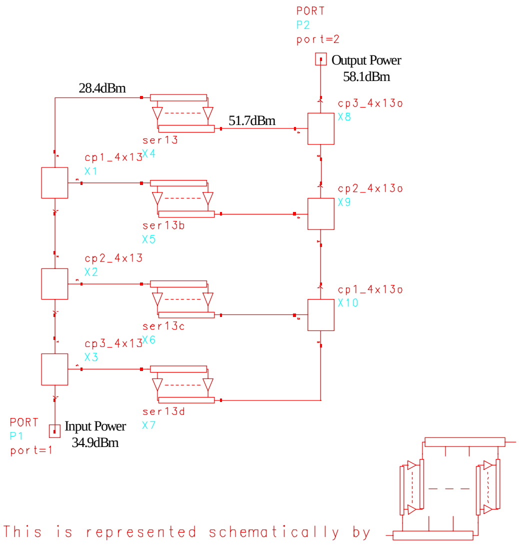

Figure 1b. Schematic and nominal power levels for second level (4x13-way serial) combined section

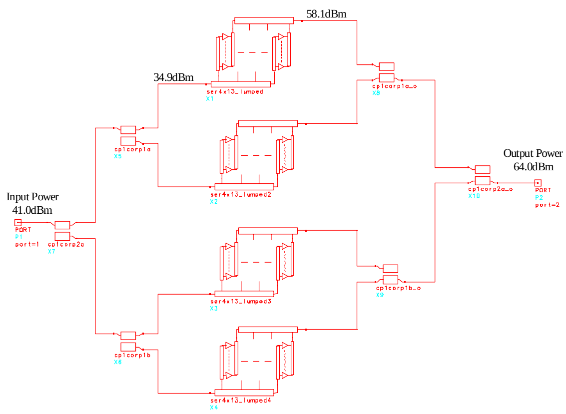

Figure 1c Schematic and nominal power levels for third and final (4x4x13-way serial) combined section

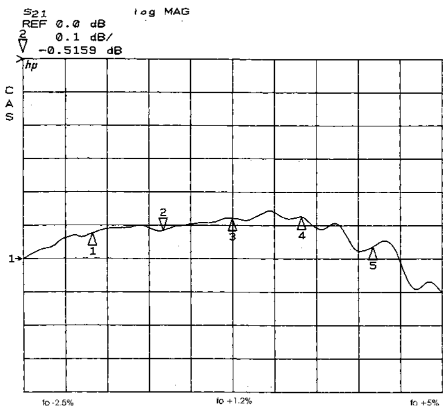

Figure 2 Measured insertion loss of thirteen-way serial divider/combiner connected using waveguide bridges instead of PAMs.

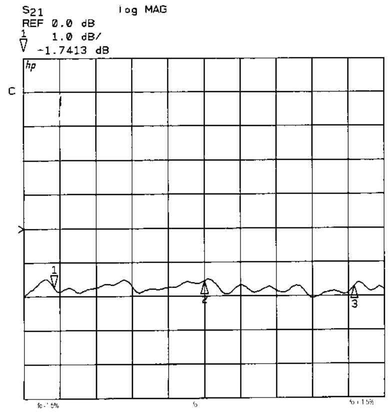

Figure 3 Measured Insertion Loss of sixteen-way hybrid serial-corporate divider combiner. Measurement includes loss of 100mm lengths of semi rigid cable used to join ports in divider and combiner.

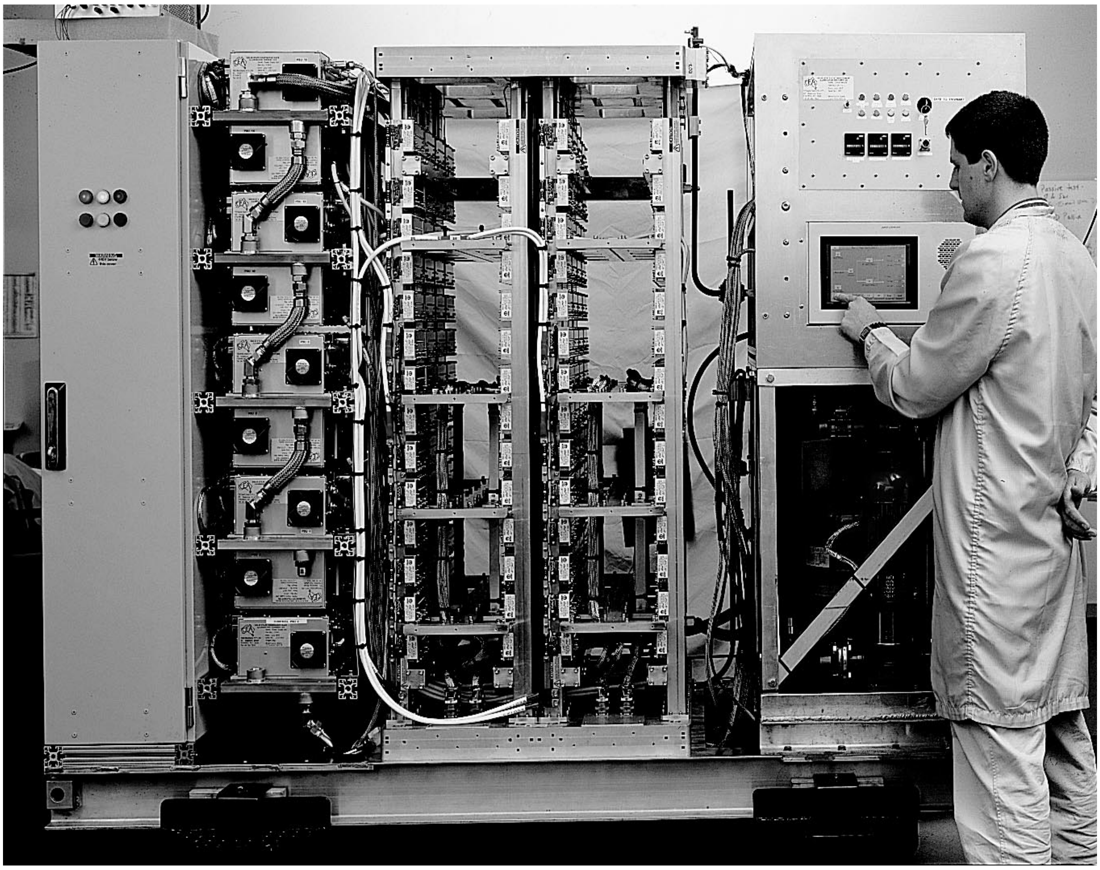

Figure 4: Photograph of the SSPA