ULTRA, RELIABLE
2.5 KW, SOLID STATE
L-BAND AMPLIFIER

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ABSTRACT

A 2.5 KW Solid State L-Band Amplifier has been designed to achieve 2 orders of magnitude improvement in reliability. This improvement is achieved by the use of stand-by modules controlled by performance monitoring/fault locating networks which are incorporated in RF and DC circuitry. A failed module is automatically switched out of the RF circuit and replaced with a stand-by unit. This self-healing technique maintains amplifier performance with minimum interruption time.

Introduction

Transmitters for unattended radar applications, covering periods of three months to one year, must be extremely reliable and highly efficient. Present day, L-band, bipolar transistor amplifiers can be designed to provide the output power, gain and efficiency necessary for this type of operation. However, failure rates of the transistor modules are not adequate to achieve the reliability required for these extended period of time. Two order of magnitude improvements in reliability can be achieved with the use of stand-by modules controlled by performance monitoring/fault locating networks. This concept automatically switches out a failed module and replaces it with a stand-by unit.

This paper presents the results of a development program for an ultra-reliable 2.5 KW, L-Band, solid state, transmitter amplifier utilizing the stand-by concept. Using state-of-the-art transistors the amplifier assembly has been designed for an overall efficiency of 35% and a reliability, (probability of no failure), for a three-month period of 0.9997. The pertinent parameters of the 2.5 KW amplifier are:

- Frequency 1.215 to 1.400 GHz
- Output Power 2.5 KW Peak
- Pulsewidth 100 micro-secs.
- Duty Cycle 10%
- Efficiency 35%

Amplifier Description

The 2.5 KW solid state amplifier, as shown in the block diagram of Figure 1, consists of eleven output module sin parallel, driven by a common driver module to achieve 33 dB gain. Only ten of the output modules are operating at any one time. The eleventh module is a stand-by unit that is automatically switched into the RF circuit upon failure of any one of the other ten modules. The failed module is simultaneously removed from the RF circuit to maintain the proper impedance match for the 10:1 power divider and combiner.

A sketch of the 2.5 KW solid state amplifier is shown in Figure 2. The driver and 11 output modules are located around the periphery of the stripline combiner/divider assemblies. Fins are included on each module for natural air convention cooling. Isolators are used at the input and output of each module to provide interstange isolation, and efficient power distribution and combining.

The output modules consist of two stages of amplification, with one transistor driving four in parallel for the output stage. The devices were selected after a full evaluation from all available sources for the latest high power, L-band, bipolar transistors. All of these devices were capable of $>$100 watts output power. However, to improve efficiency and maintain a junction temperature rise of less than 90^{o}C, their operating level was derated to 85 watts minimum. This was achieved by reducing input power and/or collector voltages. Additional improvements in efficiency were obtained by optimizing the device input and output impedances while maintaining 85 watts output power. A photograph of a typical output module is presented in Figure 3. A minimum output power of 310 watts is obtained over a 1215 to 1400 MHz frequency band with 14 dB gain and 42% efficiency.

The test performance of the output module over the temperature range of -50^{o}F to 125^{o}F is presented in Figure 4. The efficiency reduced to a minimum of 40.7% at 125^{o}F temperature and increased to 44.2% minimum at the cold temperature (-50^{o}F). The output power variation over all temperature and frequency conditions was only $\pm$0.3 dB. The amplifier RF pulse rise time, over the above temperature and frequency conditions, was measured at less than 60 nano-seconds. This was the limitation of the detector.

All of the modules, (output and driver), utilize a microstrip, MIC configuration for the RF and bias circuits. Thin film processing on alumina (Al_2O_3 substrates is used throughout the modules.

The driver module, as indicated in figure 5, contains two identical amplifier channels, (one operating and one stand-by). Each channel consists of a three stage transistor amplifier located between two SPDT diode switches. When a failure occurs in the operating channel, the stand-by channel is automatically switched into the RF circuit. The output power from the driver module is 120 watts minimum with a gain of approximately 21 dB.

The power divider and combiner switch assemblies are identical. They consist of a center fed, 11 arm, stripline star configuration with shunt mounted diodes, located in each arm, a quarter wavelength from the common junction. Ten of the diodes are reverse biased (pass mode) and one diode is forward bias (stop mode). This converts the star to a 10:1 reactive power divider. The input signal can be equally distributed to any 10 of the 11 outputs. The isolators placed between the modules and reactive dividers, provide the constant impedance match necessary for equal power division and proper isolation resulting in a stable amplifier.
The star configuration is the only practical, low loss approach for combining ten modules and switching in a stand-by eleventh module. These networks were fabricated in low loss air dielectric stripline.

Reliability

Based on MIL-HDBK-217B, failure rates of $1.x10^{-6}$ and $.5x10^{-6}$ were predicted for the output and driver modules respectively. These failure rates are not adequate to achieve the high relibility required for unattended operation for extended periods of time. The use of a "stand-by" concept which utilizes stand-by modules for the output and driver modules significantly improves the reliability of the overall amplifier. Figure 5 shows the results of the reliability calculations for the improvements that can be realized by the incorporation of spare modules. As can be seen, a 100:1 improvement in probability of failure can be achieved by the addition of only one spare output module for the ten operating units. The reliability (probability of no failure) with one stand-by module is very low, varying from 0.9997 for a 3 month period to 0.996 for a 1 year period.

Performance Monitor/Fault Locating (PM/FL)

To implement this concept, a performance monitoring/fault locating circuit is used to locate the failed module and automatically switch in the stand-by modules.

The major item in the PM/FL system is the RF switch matrix which permits the removal of the failed module and the replacement with a stand-by operational module. This network consists of a single pole eleven throw diode switch which is integrated into the 10:1 power combiner and divider networks with minimum loss and current drain. The network contains eleven outputs but is matched for only the ten operational output modules. The stand-by module can be switched into any one of the failed module positions. The module collector currents are used as the sensing parameter in determining module failure. This operation is accomplished in less than 1 millisecond. A schematic diagram of the electronic circuits to drive the RF switches is shown in Figure 7. The voltage across a dropping resistor is continuously monitored by a voltage comparator for each module Vcc line. When the voltage drop falls below a threshold level, the comparator activates the logic and control circuit which automatically switches out the failed module from the RF network and replaces it with the stand-by unit. The modulation for the RF signal source is also turned off during the RF switching. This interrupts the RF transmission and prevents hot switching of the diodes. This precaution was implemented to eliminate the possibility of diode or transistor failures due to hot switching. An interrupt switch is included on the panel to simulate a module failure by momentarily turning off the module current.

Conclusions

The results of this program have demonstrated the concept of self-healing as applied to a solid state, L-band, amplifier. This technique combined with the inherent high reliability of solid state devices results in an ultra reliable transmitter design. The reliability for a 3-month time period is calculated to be 0.9997, which is acceptable for unattended radar applications.

Acknowledgement

This program was supported by the Rome Air Development Center, Griffiss Air Force Base, New York The cooperation of Mr. Anthony Cardello is gratefully acknowledged.

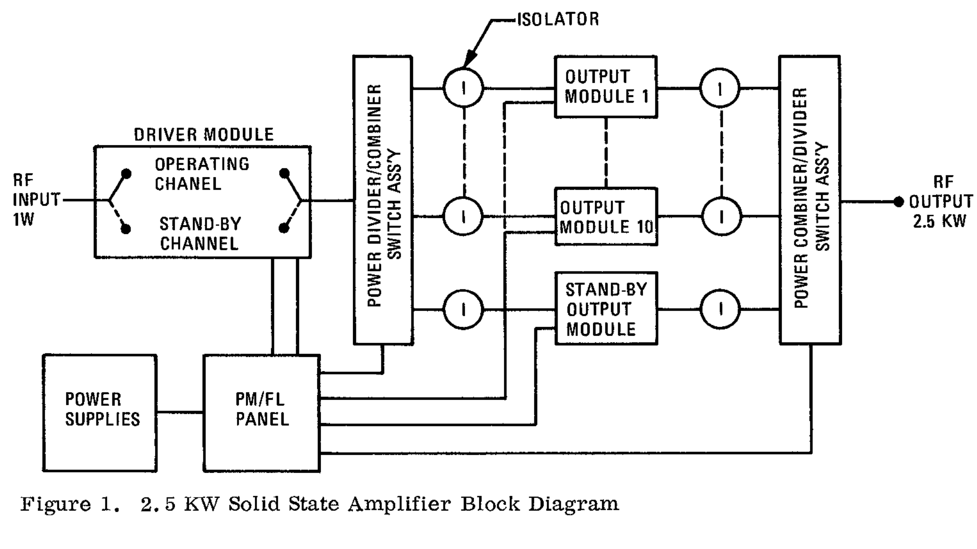

Figure 1. 2.5 KW Solid State Amplifier Block Diagram

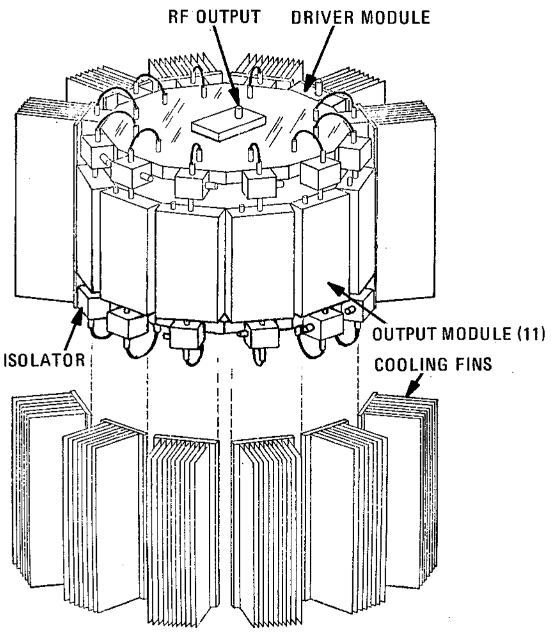

Figure 2. Sketch of 2.5 KW Solid State Amplifier

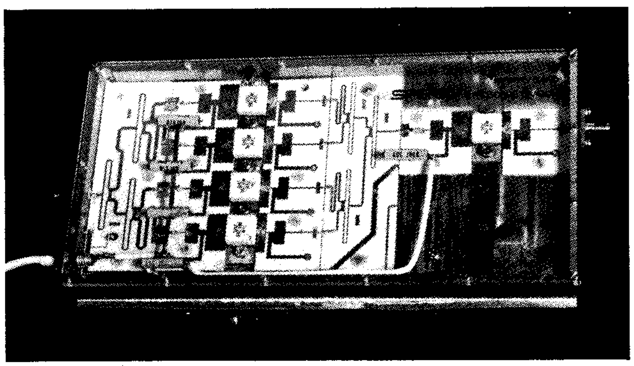

Figure 3. Photo of Output Module

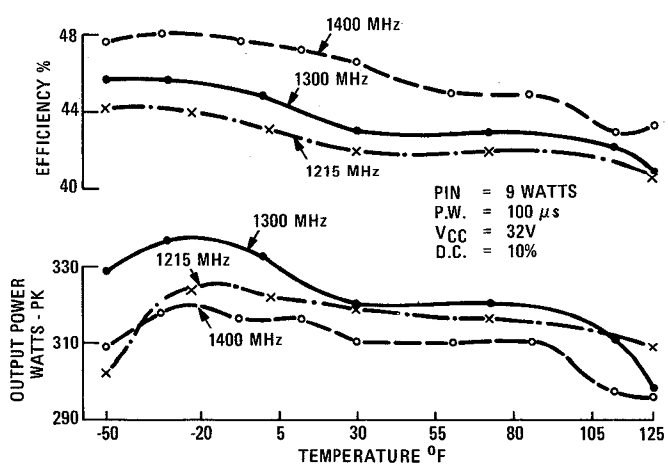

Figure 4. Output Module Temperature Test Data

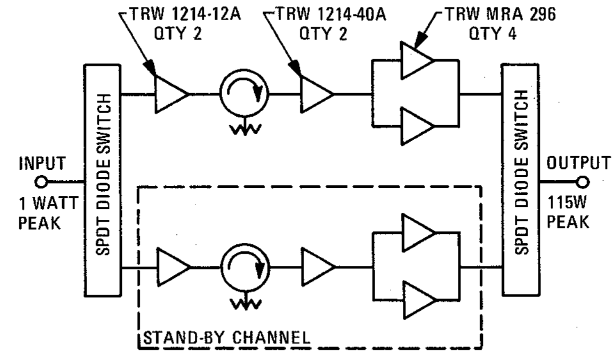

Figure 5. Schematic of Driver Module

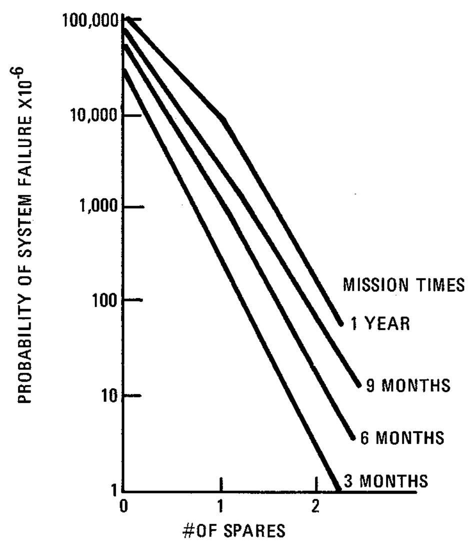

Figure 6. Probability of Failure Chart

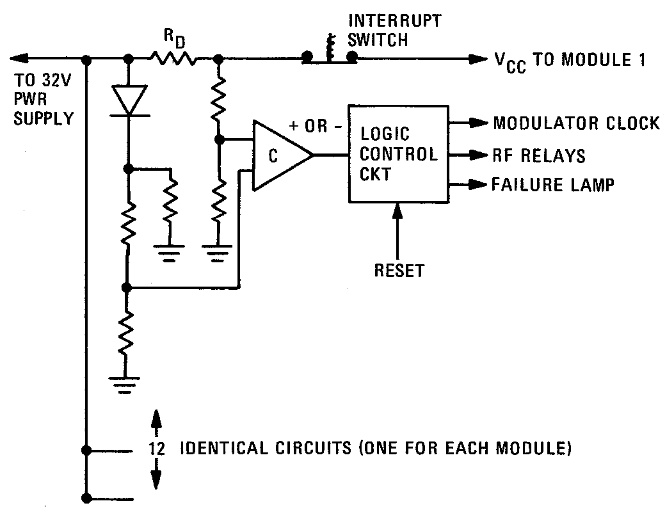

Figure 7. PM/FL Schematic