TRANSCEIVER MODULE FOR AN L-BAND ADAPTIVE ARRAY ANTENNA*

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Abstract

An integrated transceiver module is described that was designed for adaptive array use. The element combines high peak power (100 watts), low noise receiver (3.5 dB noise figure, 28 dB gain) with a digital gain controller and phase shifter. Significant advances in microwave integrated circuits fabrication and performance arise from using a cost effective standard circuit fabrication approach to the module design.

Introduction

Although extensive development on active phased array elements has occurred during the last ten years, it has only been during the past few that the technology has been cost effective. Even at that, only for high UHF and L-band frequencies do the dollars per watt of transmitted power and microwave integrated circuits fabrication cost allow serious consideration of the solid-state phased array element for large systems use. This consideration, however, now can be coupled with the unique system capability of adaptive array techniques to fully utilize the solid-state transceiver capability. An adaptive array, employing electronic phase and amplitude control at the element level, can scan the microwave antenna pattern and, simultaneously alter sidelobe position and width. In this manner, increased radar and communications array performance is obtained by reducing sidelobe contribution to the received signal. These systems demand new requirements on the transceiver module in performance and manufacturing tolerances with the explicit desire that cost not be increased. It is the design and performance of such an element, that employs microwave integrated circuits fabricated by both thick and thin film techniques, a radically new assembly and interconnection technique and an attempt at standardizing circuit layout to reduce design cost, that this work addresses.

Description of the Transceiver

The transceiver was designed for a radar application and is shown schematically in Figure 1. The digital gain control element is unique to this transceiver design and allows adaptive weighting of the received signal across the array. Because of the interdependence of amplitude and phase errors in antenna pointing accuracy, systems specifications require that any phase change with attenuator setting and gain change with phase shifter setting be minimized. As a result, the gain controller is a series of four pi-pad attenuators using thin film resistors and high quality PIN diode switches. This attenuator directly follows a three-stage low noise amplifier using two hybrid coupled HP35866E transistors as the front end and two transistor output stages to obtain 36 dB of gain. The phase shifter is a four-bit loaded line design where the

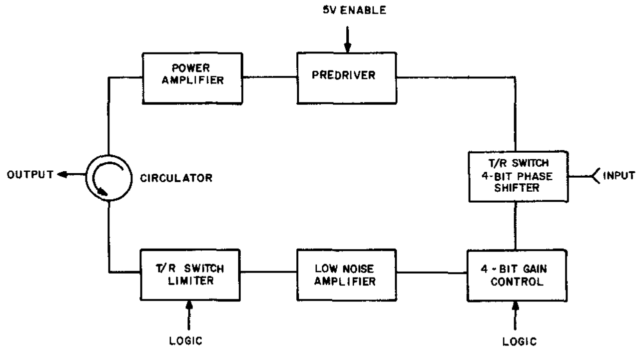

Figure 1. Block Diagram of L-Band Solid-State Transceiver

two most significant bits were obtained using thin film Lange couplers. Performance requirements measured on the module are summarized in Table 1.

TABLE 1. TRANSCEIVER PERFORMANCE CHARACTERISTICS

Frequency	1.235 to 1.365 GHz
Transmitter	
Power	100 W peak (min)
Pulse Width	4 to 330 μs
Duty Factor	10%
Efficiency	40%
Receiver	
Noise Figure	3.4 dB max
Gain (1 dB BW)	28 dB
Dynamic Range	-25 dBm @ 1 dB gain compression
Phase Shifter (4-bit)	22.5°, 45°, 90°, 180°
Loss	2.7 dB (avg)
Loss Variation	0.4 dB rms
Accuracy	5° rms, 8° peak
Gain Control (4-bit)	1.5 dB, 3 dB, 6 dB, 12 dB
Loss	3.0 dB
Phase Variation	5° rms, 8° peak
Accuracy	0.5 dB rms, 1.0 dB peak
Intrapulse Noise	-116 dBc/Hz
Size	4.0" x 5.5" x 1.1"
Weight	1.1 pounds

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Microwave performance in the module is intimately determined by the microwave integrated circuit fabrication, circuit interconnections, and mechanical interfaces. Figure 2 shows the assembly "blown up" to reveal the MIC substrates in the two levels of construction. All small signal circuits are fabricated by thin film metal removal techniques on standard size substrates (1.5" x 1.5" x 0.025") and are located in the upper layer of the module. Each circuit is mated with a 2-mil thick carrier of gold-plated brass to provide an intimate electrical ground at the periphery, and to provide insensitivity of the circuits to temperature and vibration. The power amplifier circuits are fabricated from thick film circuits on alumina and are located on the lower cover. The two layers are effectively isolated electrically and thermally to satisfy the requirements of the array environment. All dc power and logic signals are distributed by a teflon glass printed circuit board mounted on the lower side of the main chassis structure. The signals to the digitally controlled circuits above are filtered by feedthrough connectors that have been gold-plated to allow connection by 1 mil gold wire to the circuits. This assembly technique was very instrumental in reducing assembly and repair difficulties and maintaining the circuit performance on all states of the adaptive control.

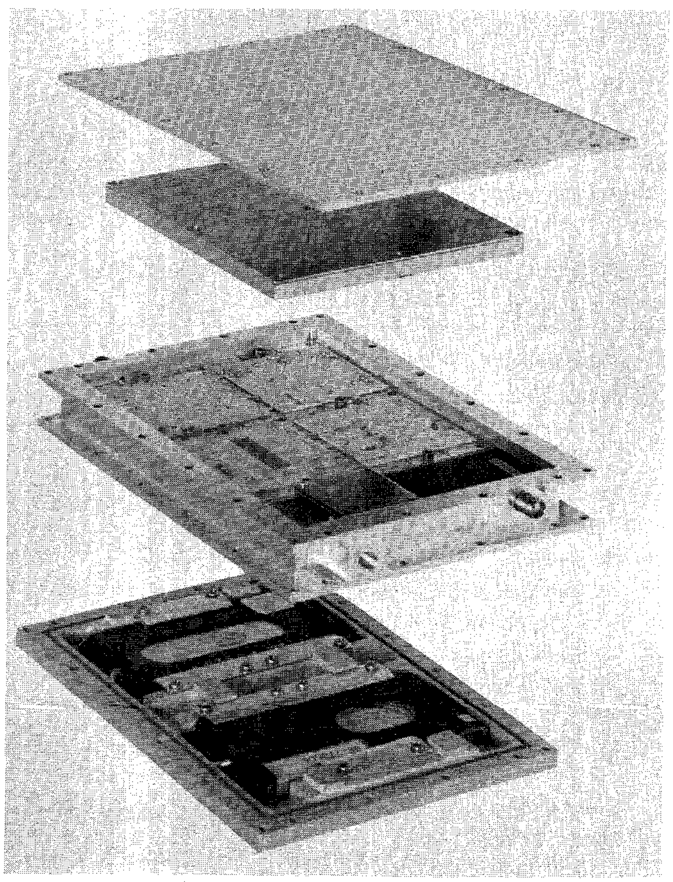

Figure 2. Solid-State Transceiver Module

The power amplifier is located on the bottom cover and consists of two separate substrates as shown, each combining three hermetically sealed transistors. The output amplifier is constructed similar to the amplifiers used in the TPS-59 radar, however with an output of 112 watts (peak) obtained using two PHI8348 transistors coupled by 3 dB Wilkenson combiners.* The predriver is a three-stage series amplifier with approximately 22 dB gain. Microwave signals are coupled to the predriver from the phase shifter, and from the power amplifier to the stripline/circulator interface using coaxial transitions between levels of the module. A beryllium copper spring from the coax to each amplifier serves as a reliable mechanical interface that was designed to be part of an impedance transformation from 50 ohms of the coax to 25 ohms used in the power amplifiers. Measurements across the frequency band show that the transitions have less than 0.1 dB loss and 1.2:1 VSWR.

Final assembly of the module is made by placing the aluminum cover over the small signal circuits as shown in Figure 2. This cover has four chambers to isolate the individual circuits and provide a mechanical and electrical ground interface. Transition between substrates is accomplished with 25 mil thick microstrip "jumpers" between the circuits, connected by gold wire bonds. These transitions have similarly been designed to give better than 1.1:1 VSWR over the band of operation. Finally the top and bottom covers, each of which has captured O-ring seals, are mated with the main chassis. This interface was designed to give maximum repairability for this developmental element, while providing an acceptable RFI and moisture seal for the assembly.

Module Performance

The overall module measured performance was given in Table 1. However, the operation of the phase and gain control functions, which are significant contributions of the module, will be examined in more detail. Figure 3 shows the pass band gain of the transceiver from 1.0 to 1.5 GHz and the effective gain at each of the attenuator settings. The uniformity of the attenuation with frequency was possible due to computer design of the circuits to present a maximum of 1.2:1 VSWR load condition to the single-ended output of the low noise receiver. If the load impedance had been

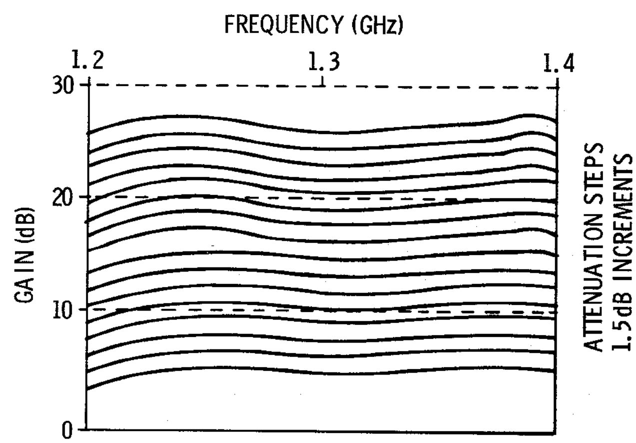

Figure 3. Module Receiver Gain versus Attenuator Settings

*R.J. Naster and W.H. Perkins, "Solid State Power Amplifiers for L-Band Phased Arrays," Microwave Journal, July 1975.

more variant, the module gain would have been frequency dependent, depending on the magnitude and phase of the attenuator return loss characteristics. The insertion phase of the module was measured across the design band and remained uniform with frequency for each phase setting within 1 degree rms. The total insertion phase change with attenuation state had a maximum ±4 degree shift.

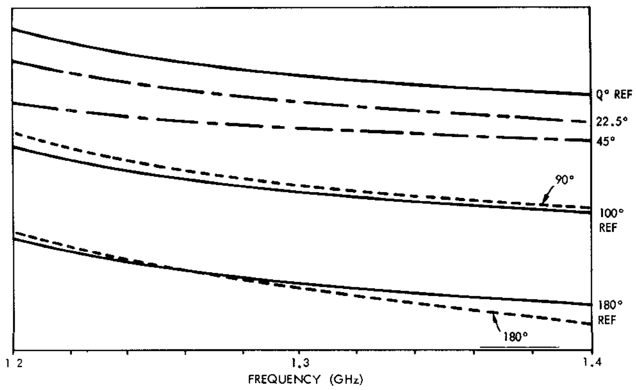

Figure 4. Transceiver Module Phase Performance with Variation of Phase Shifter

Figure 4 shows the phase change with frequency for the various phase shifter settings. This phase shift and the gain were maintained with a load VSWR variation up to 2:1 in any phase. The standard deviation of receiver gain with phase shifter settings was 0.4 dB maximum at any frequency within the band.

Conclusions

A transceiver module has been demonstrated that satisfies the systems requirements of an adaptive array antenna and has the microwave and mechanical design for cost effective fabrication. This transceiver demonstrates that reliable high power microwave amplification can be obtained from parallel operation of only two transistors, simultaneously with a high purity, low noise receiver capable of both amplitude and phase weighting in the array environment. The performance of this module demonstrates that it is capable of both weighting functions in a dynamic environment, with controls consistent with systems requirements.