Transmit/Receive Modules for 6 to 18 GHz Multifunction Arrays

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Abstract

A high density, complex MMIC Transmit/Receive module is presented with applications for 6 to 18 GHz multifunction phased arrays. It features a dual polarization, high dynamic range architecture, a state-of-the-art family of MMIC chips (269 mm^2 total GaAs area), and advanced MMIC packaging techniques. Modules will be demonstrated in a broadband subarray.

Requirements for multifunction phased arrays combining broadband signal acquisition, response, and transmit functions into the same steerable array, place great demands on the technological disciplines used in their implementation. A high performance MMIC T/R module is presented featuring both vertical and horizontal polarization, a 5 bit phase shifter, 10 dB of amplitude adjustment with minimal associated phase shift, Built-In-Test, a compact digital interface and power conditioning hybrid, and dense MMIC content (269 mm^2 of GaAs - 60 mm of gate periphery). The module uses advanced packaging techniques and measures 2.7"x1.1"x0.35". The peak measured output power of the module is 1 W, with the nominal transmit and receive gains measuring 30 dB and 25.0 dB respectively. Four modules are being integrated into a dual polarized subarray, composed of tapered notch printed antenna elements, which can be incorporated into larger linear arrays.

Module Architecture

A major impact of multifunction system requirements is a complex module architecture. High output power, high spurious free dynamic range, precise amplitude and phase control, and dual polarization must be obtained over the full 6 to 18 GHz bandwidth. The module development described here represents a substantial advancement over the prototype T/R module, whose block diagram appears in figure 1 and was presented last year [1]. This work features improved MMIC chips, the addition of dual polarization capability, and a greatly reduced housing size. The block diagram of this advanced T/R module appears in figure 2. Both

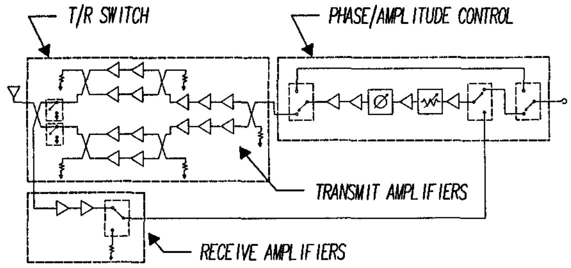

Figure 1. Single Polarization T/R Module Block Diagram

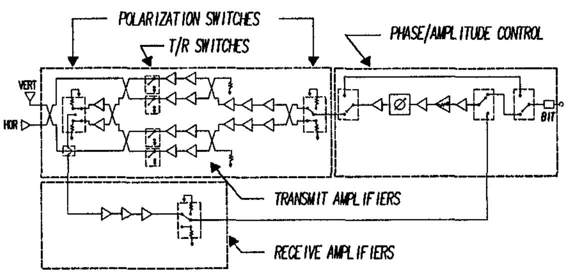

Figure 2. Dual Polarization T/R Module Architecture

vertical and horizontal antenna polarizations are available in either receive or transmit mode. Polarization and transmit/receive mode switching at the antenna ports are both obtained at virtually zero insertion loss penalty by incorporating optimized MMIC shunt reflective switches in the transmit amplifier 4-way power combining network. High intercept amplifiers are interspersed with lossy components in the receive path to obtain a wide spurious free dynamic range. The vector modulator circuit is common between both transmit and receive functions and provides 32 states of phase shift and 10 dB of gain adjustment for amplitude tapering of the array. A 60% size reduction, adequate for linear array applications, was achieved and critically spaced packaging for two dimensional arrays has been shown to be feasible with a different module layout.

Improved MMIC Chips

Several of the MMICs within the module were redesigned for improvement of critical parameters. The module features new distributed amplifier gain stages redesigned for self bias operation at 50% Idss. The amplifiers in the power section have 5.4+/-0.4 dB of gain and a 1 dB gain compression point of +23 dBm minimum over the 2 octave band. The amplifiers were designed with gate bias access to permit shutdown of the amplifiers during receive mode, thus minimizing DC power consumption.

The phase shifter [2] has been reduced in size by 50% in order to decrease cost. The new size is .133"x.256". The RMS phase and amplitude errors for all 5 bits of the reduced size phase shifter over the entire 4:1 band are 4.5 degrees and 0.53 dB respectively. The amplitude variation at any frequency over the 2 octave band is 2.9 dB and the worst case input and output VSWRs are 2.3:1.

The T/R switch on the output is configured from 4 SPST switches. Each SPST switch follows one of the power amplifier stages and utilizes two shunt 600 um FETs. The matching networks were optimized for embedding in the Lange power combiners. The insertion loss is less than 0.85 dB from DC to 18 GHz. The isolation over the 4-18 GHz band is greater than 25 dB, and the on-state match is better than 1.4:1. The switch and its performance are illustrated in figure 3. Polarization switching is accomplished with strategically placed matched switches. In transmit mode, polarization switching occurs at the input to the power amplifier so that power combines into the appropriate antenna port. Likewise in receive mode the tandem receive amplifiers are switched into the receive path according to the choice of polarization, thus avoiding switch loss impact on noise figure.

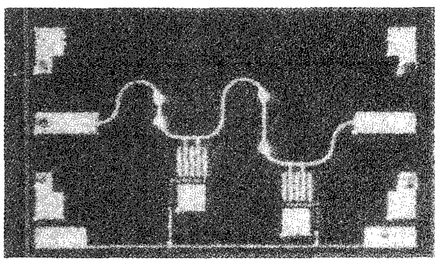

Figure 3. a) 4-18 GHz SPST MMIC Switch

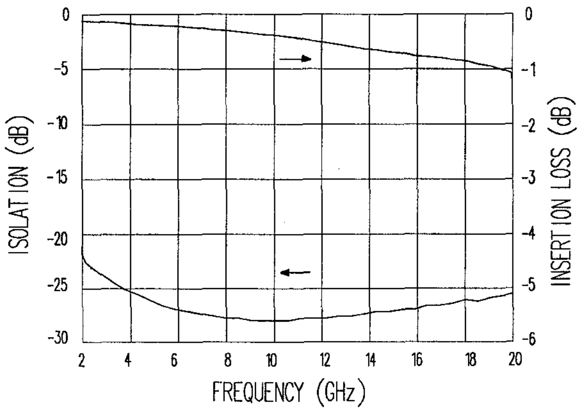

Figure 3. b) Insertion Loss and Isolation of SPST Switch

A dual gate variable gain amplifier is used to provide gain adjustment for amplitude tapering of the array. The maximum gain of the circuit is 6.5+/-0.5 dB over the 6-18 GHz band. It has a full 10 dB range of linear adjustment, an associated insertion phase variation of less than 9 degrees, and input and output VSWRs better than a 2:1.

Built-In-Test (BIT) is a requirement in virtually all new electronic systems. A BIT MMIC has been developed which consists of a Schottky diode coupled loosely to a transmission line by a resistor-capacitor network. The insertion loss is <1.5 dB and the VSWR is <1.4:1 through 18 GHz. The BIT MMIC was added to the module at the electronics port to test for functioning of the RF circuitry.

Digital Interface and Power Conditioning

The excessive number of DC and control inputs (20 for this module) cannot be accomodated due to the small module size. Therefore a digital interface and DC voltage regulator thick-film hybrid was designed and implemented on BeO, reducing the number of I/O pins to seven. The interface circuitry has a verified operation frequency of 4.3 MHz which translates into a module update time of less than four microseconds. The circuit allows the module to be loaded with its next state while the present state remains unchanged. This feature allows the modules in an array to be loaded with a single serial line and then updated simultaneously thereby reducing the array update time to less than 1 usec. The module is insensitive to noise generated on the input lines because of embedded regulators and digital control signals. The interface circuitry will also allow high speed data transfer over distances of up to 100 feet. The digital architecture can be expanded to include on board memory chips to store the module state, module temperature characteristics, or calibration data. A photo of the board appears in figure 4.

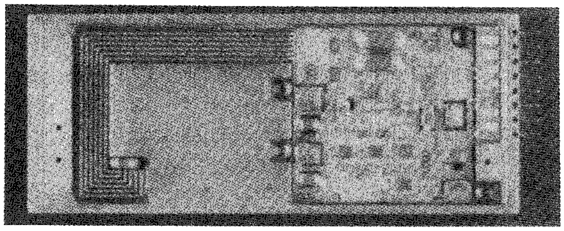

Figure 4. DC Side of T/R Module

Mechanical and Packaging Techniques

A major goal of the module development was to achieve a size compatible with linear phased array requirements. The volume reduction of the advanced T/R module over the previous version is 60%. It is a dual cavity housing with the RF on the top side and the DC on the bottom. The RF side of the completed module is shown in figure 5. To reduce the size of the module, the number of RF carriers was reduced by roughly half. This required multiple chips to be assembled onto the carriers, which are soldered rather than screwed down to the housing. The housing material is aluminum (suitable for laser sealing) and the carriers are fabricated from .010" copper-tungsten. The carriers were kept small to minimize the effects of thermal expansion mismatch. Better matched materials are being investigated for future applicability. In order to eliminate rework due to chip infant mortality failures, all chips are burned in for 24 hours. Groups of chip carriers are simultaneously burned-in on a specially designed fixture.

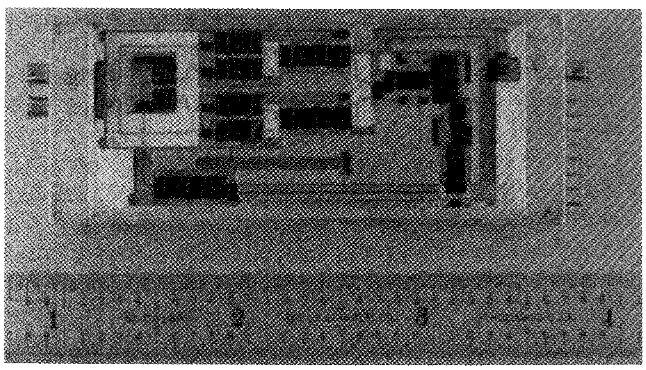

Figure 5. RF Side of T/R Module

Performance Results

Measured results of the module indicate that the nominal gains in the transmit and receive modes are 30 dB and 25 dB respectively. The results are shown in figure 6.

The worst case match at the electronics port, for either the transmit or receive state, was a 3.0:1, while at the antenna port it was a 2.6:1, again for either mode. The measured output power of the module was 30 dBm at the low end of the band, while dropping off to no less than 24.8 dBm over the rest of the band. A plot of the power is shown in figure 7. The normalized attenuation and phase shift plots are shown in figures 8 and 9. The phase shift over the 10 dB attenuation range is less than 6.5 degrees (figure 10), while the amplitude variation due to changing phase states is +3/-2 dB (figure 11). The phase and amplitude errors are critical as they degrade performance and greatly complicate calibration in an array. The isolation between the receive and transmit states is 6 dB minimum. For a 10 MHz video bandwidth, the dynamic range of the module is 60 dB. The detected output level from the BIT at 12 GHz for a module input level of 1 mW is 59 mV. The DC power required for transmit is 12V @ 4.6A, and 15V @ 0.38A. Module efficiency will be improved by using reactively matched power MMICs. These devices will increase the module output power to 1.5W and will require only 3.0 A.

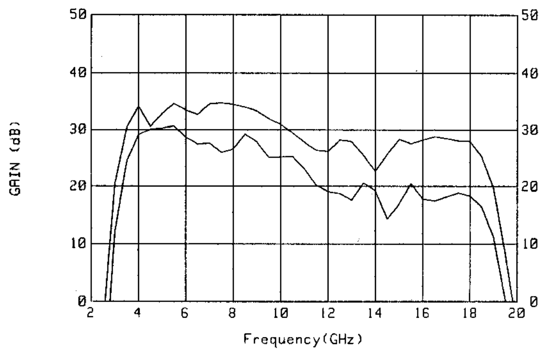

Figure 6. Transmit and Receive Gains

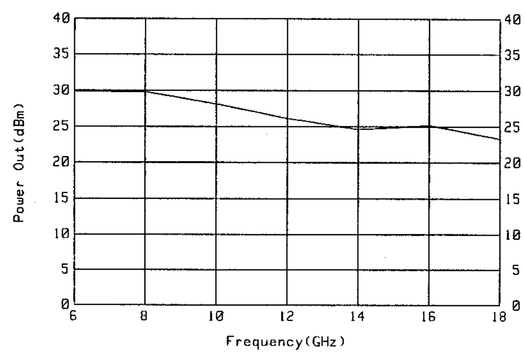

Figure 7. Saturated Output Power

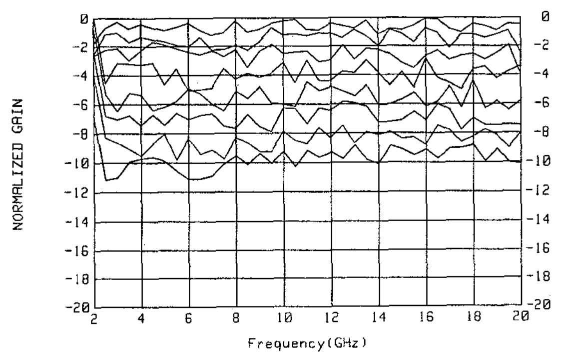

Figure 8. Normalized Attenuation

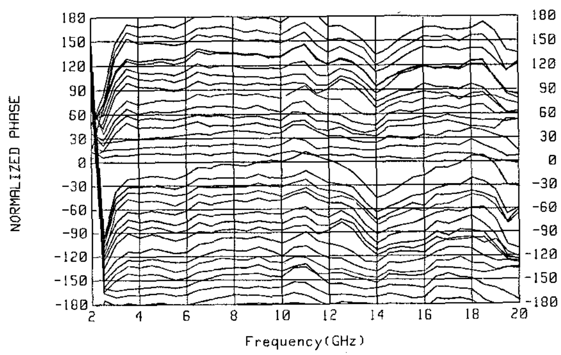

Figure 9. Normalized Phase (32 States)

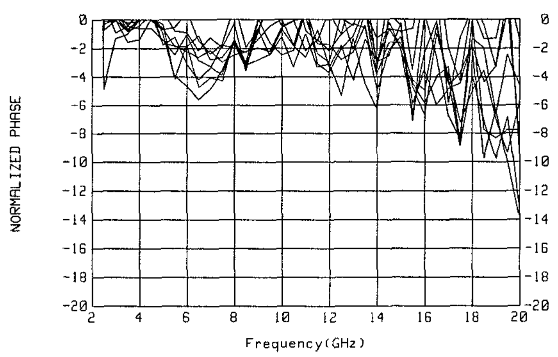

Figure 10. Phase Variation with Changing Attenuation

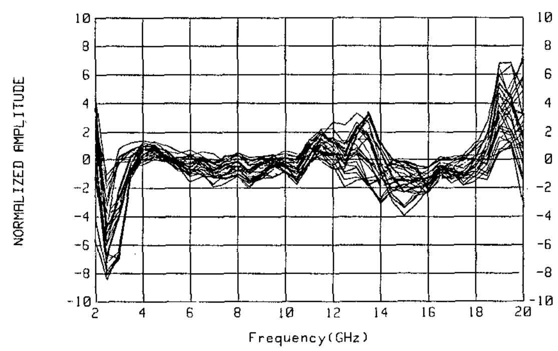

Figure 11. Amplitude Variation with Changing Phase

Dual Polarized 1x4 Subarray

Four of these T/R modules are being incorporated into a dual polarized, four element subarray, which can be used in larger multifunction, steerable linear arrays. Both the vertically and horizontally polarized radiating elements consist of tapered notches printed on standard teflon/fiberglass. An example of the radiation pattern from the four element dual polarized subarray is shown in figure 12. The half power beam width at midband (11 GHz) is 34 degrees. This is a typical value for either polarization over the entire 6 to 18 GHz bandwidth.

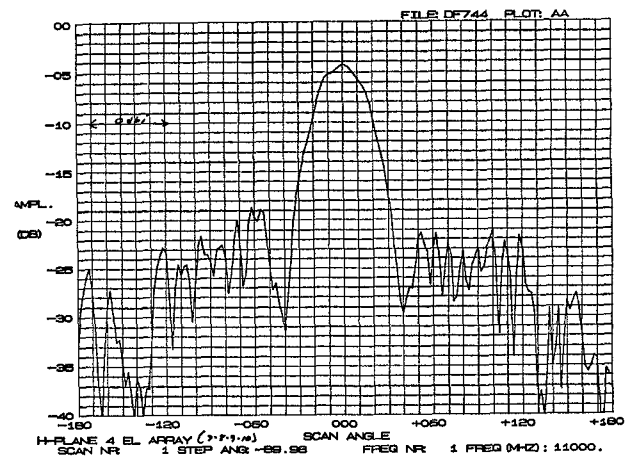

Figure 12. Four Element Subarray Pattern

Summary

Broadband multifunction active antenna arrays represent an increasingly important requirement for MMIC based T/R modules. An advanced broadband MMIC T/R module is presented incorporating state-of-the-art MMIC chips and packaging techniques. The module features a low insertion loss switch, a reduced size 5 bit phase shifter, a new Built-In-Test capability, redesigned high power amplifiers, and two polarization modes. Also presented are the packaging techniques used to make a small module that is densely populated with MMICs and yet manufacturable. Four T/R modules are being combined into a dual polarized 1x4 electronically steerable subarray. Improvements in circuit performance and packaging techniques are ongoing to make the broadband multifunction T/R module producible and affordable in large quantities.

References: 1) D. Meharry, et.al., 1988 MTT-S Digest, pp 115-118. 2) D. Boire, et.al., 1988 Monolithic MTT-S Digest, pp 69-73.