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MULTI-BEAM TRANSMIT RECEIVE MODULE FOR USB AND SGLS BAND SATELLITE LINKS.

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ABSTRACT

The development of a low cost Transmit-Receive module (T/R) for the next generation of Phase Array Antennas for the Air Force Satellite Control Network has been achieved. The T/R module consists of dual transmit channels each capable of 30 dBm output power, a 4-Bit phase control and a 4-Bit amplitude control. In addition, beam switching and on board digital control has been implemented. The dual receive channels exhibit a 2 dB Noise Figure associated with a gain of 30 dB per channel. Each channel exhibits four bit phase shift and five-bit amplitude control. In addition to the control functions, built-in test circuits have been incorporated to monitor the health and status of the RF devices. This function utilizes a micro-controller to output digital data for each of the power and low noise amplifiers on command, via A/D converters. The bandwidth of the T/R module has been increased by a factor to encompass both the Unified S-Band (USB) and Satellite Ground Link System (SGLS). The transmit-receive functions are combined at the output via a ceramic resonator diplexer comprised of a bandpass-band stop filter. The control of the T/R module is conducted via a single Field Programmable Gate Array (FPGA) through a GPIB controller. The T/R module has been designed to meet the cost objective for an array with 55000 T/R modules. To this end the paper will detail the performance and innovative methods used to achieve the price performance goals.

INTRODUCTION

The development of a low cost T/R module for the next generation of Phase Array Antennas for the Air Force Satellite Control Network has been achieved. Low cost component design and implementation are critical in developing a practical phase array antenna. Combined RF, digital and monolithic circuits are important but not the only critical issue. This T/R module differs from the previous modules, Ref.1, Ref2, in that this modules has a wider frequency band associated with the transmit section. In addition,

diplexers are utilized between each transmit and receive section. Both left-hand and right-hand polarization is used in a special polarization matrix.

Affordable antenna arrays operating at microwave frequencies are envisioned to consist of active modules that employ microwave integrated circuits located at each radiating element of the aperture. The antenna system consists of separate receiver and transmit aperture capable of rapid beam motion. The transmitter antenna should be capable of high radiation power levels and the receiver antennas must achieve high G/T ratios. Beam agility and high-radiated power levels in association with the close spacing between the radiators drive the antenna design. The requirement for fast beam switching will require digital control circuits to calculate phase shift settings. A high RF radiated power level developed from closely spaced RF amplifiers generates very large heat densities. This forces the transmit antenna to increase in area to where beam pointing accuracy limits the array size. The great number of elements in the array emphasizes the need to develop a practical method of distributing control signals throughout the array. A Geo-Disic Spherical Phase Array Antenna is considered for Air Force Satellite Communication network. Implicit in the system function array is the need to operate the array in full duplex operation. Additionally the array should be capable of controlling fundamental radiation characteristics such as beam width, beam size, sidelobe levels and radiated power, in order to realize different antenna characteristics required by the various satellites. The array aperture consists of a large number of radiating elements that are spaced approximately half a wavelength at the upper end of the operational frequency band. The frequency response and excitation of each element in the aperture can be independently controlled. The aperture can be fully or partially utilized either to direct energy over a large volume or intentionally directed in a certain direction. Additionally, radar and communications require both transmission and reception of energy where as ESM and ECM systems require only reception of energy. The capability of the array to provide transmit and receive functions simultaneous and to rapidly alter the set of configurations is possible due to active element control circuit. The active control circuits allow the Phase Array Radar to control their radiation characteristics. The aperture can be uniformly illuminated to achieve maximum gain or tapered illuminated to achieve low sidelobes or shaped beam. The combination of the variable attenuator and phase shifter permits the array illumination to be modified and the antenna beam to be scanned in any direction. The filter specifies the portion of the aperture used by a particular system. The phase shifter, the variable attenuator and the amplifier are components that have been developed in MMIC (Microwave Monolithic Integrated Circuit technology), in the last decade.

The requirement of high degree of isolation between transmit and receive channels focused the effort to investigate the exact performance that can be achieved from the low-cost ceramic diplexing filters. In addition, low cost MMIC based power amplifiers for transmit channel have been used. Other effort was directed towards the design of a low-cost phase shifters. Due to the bandwidth of the transmit section a broadband phase shifter using low pass and high pass filter sections was designed. The receive band phase shifter was based on the switched line methodology.

Other important factors that were considered in the development of the T/R module were:

- T/R module's interface with beamformer
- Hot condition Operation
- Polarization Diversity
- Dual Transmit and Receive Channels to allow multi beam operation
- Low Cost with Justification
- High Isolation between Transmit and Receive Channels
- Digital Control on Board
- Ruggedness and Reliability
- Built in Test

System Block Diagram

The block diagram for the Transmit/ Receive module is detailed in Figure 1. The transmit section of the T/R module consist of two control circuits at the input, each comprising of a 4-BIT digital phase shifter and a 4-BIT digital attenuator, which are combined in a Wilkinson power combiner. The output of the combiner is amplified in a driver amplifier and fed into a 90-degree hybrid through a single pole double throw switch. The quadrature outputs of the hybrid are amplified via MMIC amplifiers to a power output of in excess of 30 dBm and transmit through diplexer ceramic filters.

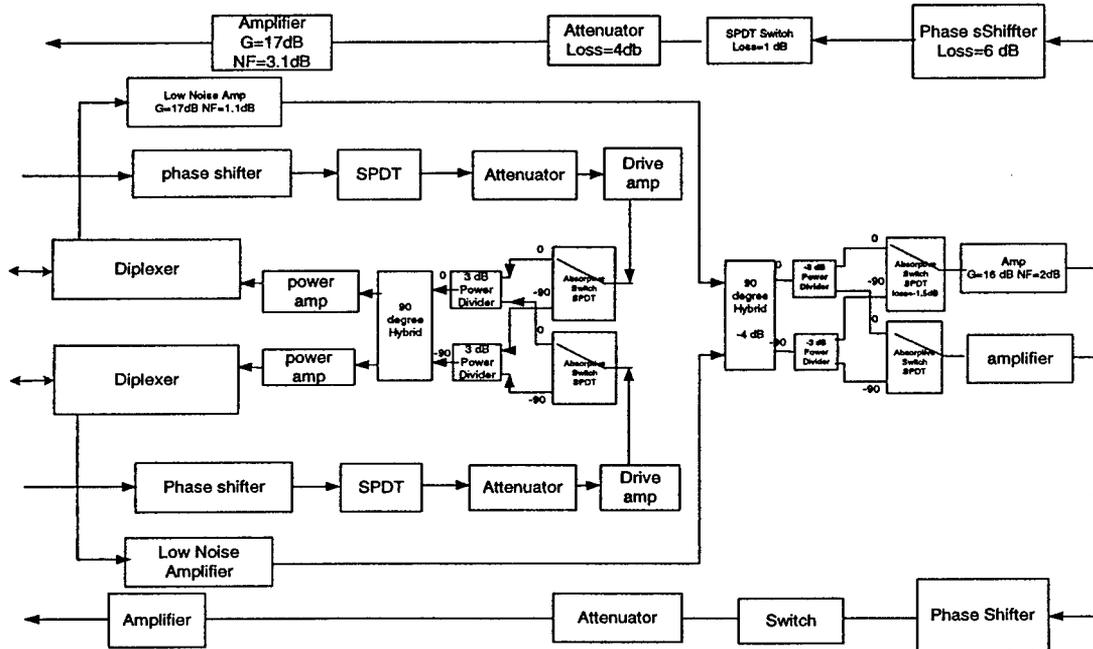


Figure 1: The block diagram of Transmit/Receive module

The specification for the transmit and receive sections of the T/R module are detailed below.

Table I: Specification for Transmit Channel

PARAMETER	SPECIFICATIONS
Frequency	1.75-2.1GHz
Gain	20dB
Power output per channel	30dBm
Phase shift	360°
Control	Electronics
Retrofit	Change in Hot condition
Efficiency	> 40 %
Spurious Levels	<-85
Attenuation	3 to 10 dB

Table II: Specification of Receive Channel

PARAMETER	SPECIFICATIONS
Frequency	2.2-2.3 GHz
Gain	30dB
Noise Figure	1.2dB
Phase shift	360°
Attenuation	30dB min

The main components of the Transmit/Receive module are:

- Ceramic diplexer with high rejection
- Low noise MMIC amplifiers
- High Power MMIC driver and Power MMIC Amplifiers
- Quadrature and in phase hybrids
- 4-Bit Transmit and Receive digital Phase Shifter
- 4-Bit Digital Control Attenuators for Transmit and Receive channel
- Polarization selection
- Xilinx digital controller
- PIC controller for Built-In-Test
- RS-485 and PCI interface

Diplexers

Two diplexers are required to maintain optimum performance. The transmit side of the diplexer filter, inserted after the transmit amplifier, prevents wideband noise from entering the receiver, and degrading performance. The receive section of the diplexer, prevents the coupled transmit signal from degrading the linearity of the receive Low

Noise Amplifier (LNA). The diplexer filters are made of high Q ceramic resonators. Two types of diplexers were investigated. The first consisted of a bandpass- bandpass type of response to provide at least 60 dB of rejection at the crossover point between the bands. This filter provided a loss of 1 dB in the transmit pass band and 1.5 dB in the receive path. To maintain a reasonable noise figure an insertion loss of 1 dB was allowed in the receive section. We then investigate d a diplexer with a bandstop bandpass type of diplexer. This filter provided an insertion loss of 1 dB in the receive band consists of six resonators in a coaxial structure. The transmit section loss was 0.5 db with a rejection of 55dB at the crossover frequency. The bandstop filter consisted of three sections of notch filtering using ceramic technology.

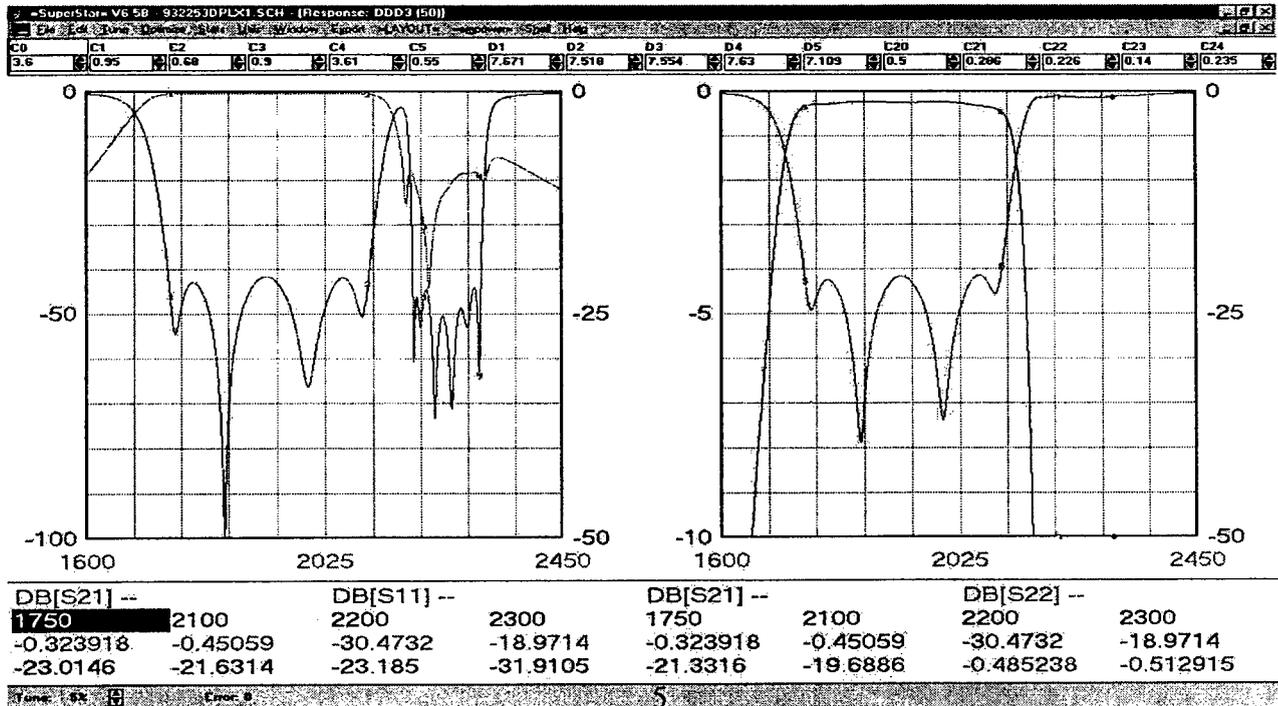
Table III: Specification of Transmit Filter

PARAMETER	SPECIFICATIONS
Frequency	1.75-2.1 GHz
Insertion loss	1.0dB Max
Return loss	<-15dB
Rejection at 2.15 GHz	<-50

TABLE IV: Specification of Receive Filter

PARAMETER	SPECIFICATIONS
Frequency	2.2-2.3 GHz
Insertion loss	1.0dB Max
Return loss	<-15dB
Rejection at 2.15 GHz	<-50

The simulated response of the filter is detailed in Figure 2.



Low Noise MMIC Amplifier

The Low noise amplifier can either be designed or use a MMIC amplifier. For a frequency of 2.2 to 2.3 GHz, a low noise MMIC amplifier developed for the satellite radio market has been used. The device provides a gain of 18 dB with an associated noise figure of 1 dB. It is based on E-D MESFET process and consumes very low current.

5 Bit Transmit and Receive Phase Shifters

A phase shifter design based on the MMIC switch incorporating a single double pole double throw was procured from Marconi. This device essentially replaces two single pole double throw switches. The component count reduced from 10 devices per phase shifter, (Total 40 for T/R module) to 5 devices per phase shifter (20 per T/R module). The design of the Transmit and Receive channel phase shifters was detailed in Ref 1. The insertion loss of the phase shifter was measured at 8 dB with a total change in insertion loss of 0.4 dB in all phase states.

The transmit phase shifters were designed based on low-pass, high-pass filter sections switched between paths. The phase shifter provided 22.5, 45, 90 and 180-degree phase shifts with an error of 10 degree for the 180 degree bit. Total amplitude change for the phase shifter was less than 1 dB for all phase states. The receive phase shifters were based on the switch line approach and exhibited an insertion loss of 6 dB. Again the total amplitude change was less than 1 dB for all phase states. This is shown in figure 3.

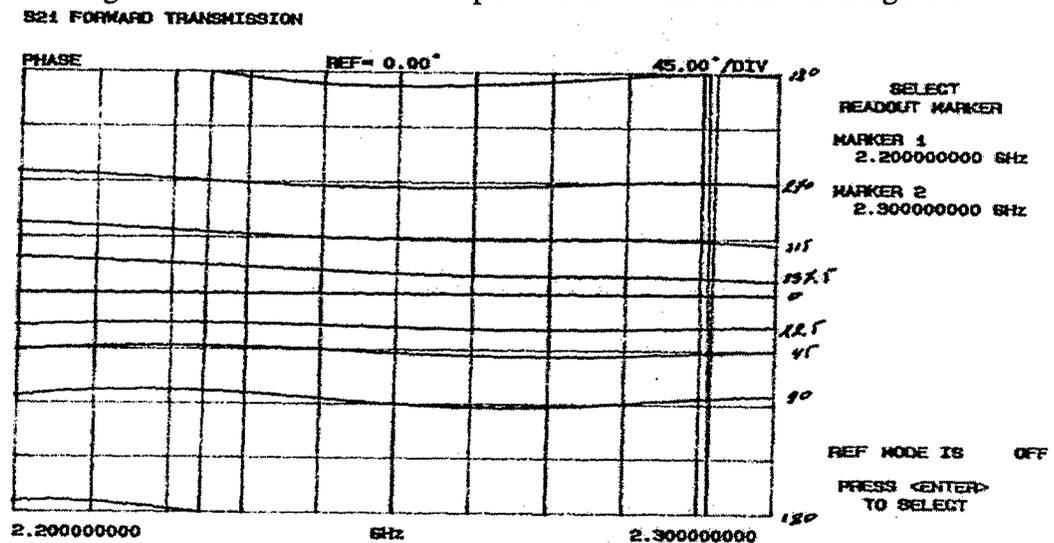


Figure 3 (a) Phase shifter measurements

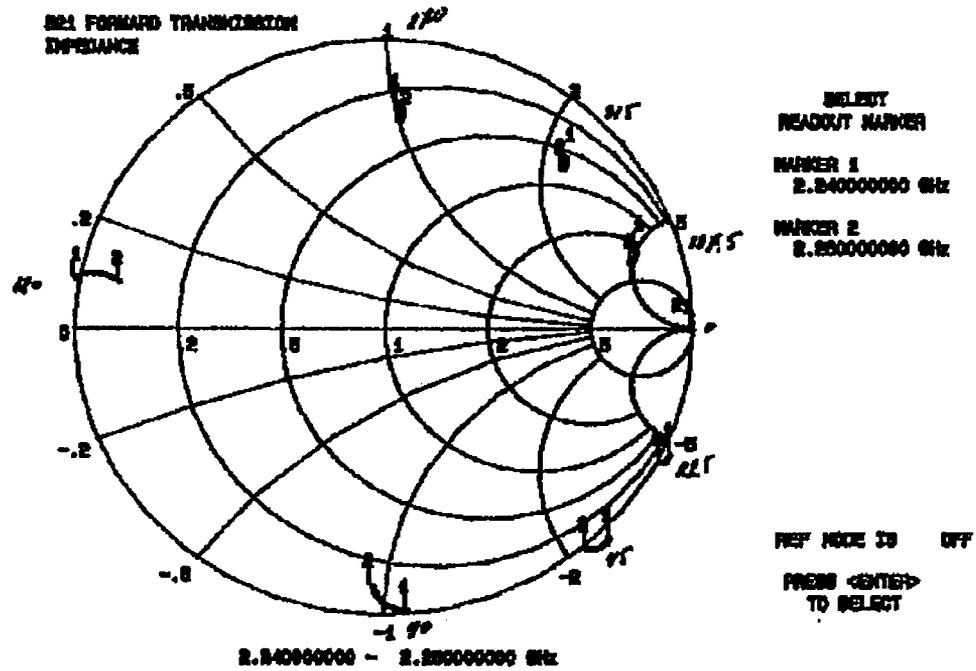


Figure 3: The measured performance of receive channel phase shifter

Polarization Switching

A scheme for polarization switching has been incorporated into the T/R module. The details are shown below in Figure 4. Both LH and RH polarization is achieved in the transmit and receive section of the module. Typical incorporation in the receive section is detailed in Figure 5

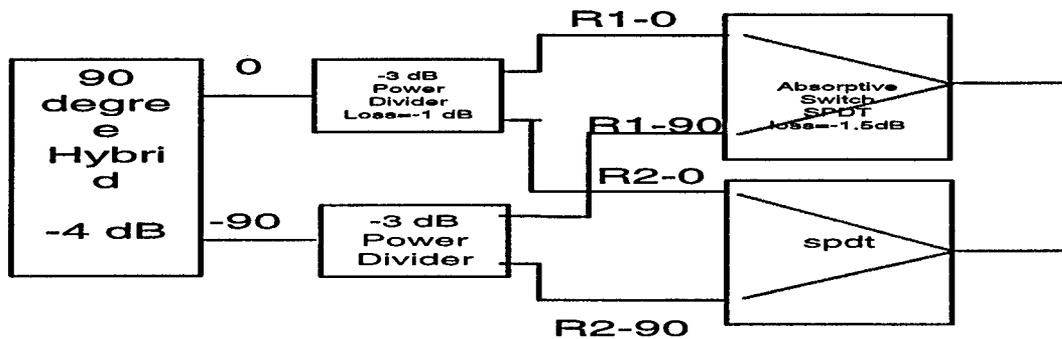


Figure 4: Polarization Switching schematic

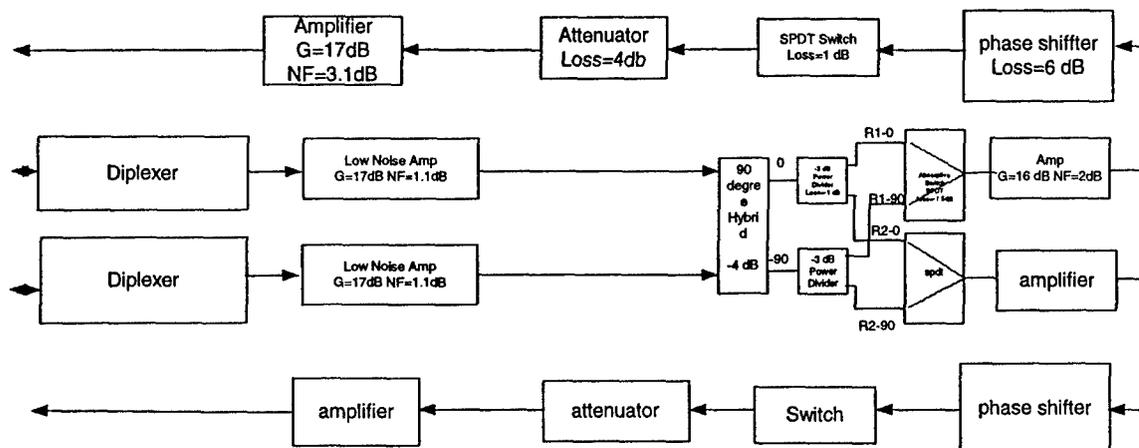


Figure 5: Polarization switching in receives section

Xilinx digital controller

The purpose of the serial to parallel bus arbitrator is to accept serial commands and unit address data and pass these commands to a parallel bus connected to a uniquely addressed unit. The input signals to this circuit are data, clock, latch and enable; the outputs are 16 parallel command lines connected to a single programmable unit. Four addressable units are grouped into a single Transmit/Receive module. In order to avoid hardware redundancy, one unit can be addressed with a base address and the remaining three can be indirectly addressed. In addition, to compensate for data and clock line fan out for a large number of modules, a single module can act as a "Master" module for several modules by buffering the clock, data and latch lines. 32 bits of serial data is clocked into a 32-bit wide shift register. Command data is stored in bits 0 to 15 and the desired unit's address is stored in bits 16 to 31 allowing for 65536 possible units. Once all 32 serial bits are stored in the shift register, a unit with a matching address is determined to exist, and the latch line is subsequently set high for a clock pulse, commands are latched out to the addressed 16 line parallel bus. In each unit, the channel is indirectly addressed 0-3 by subtracting the module's base address from the intended unit's address. The serial to parallel bus arbitrator circuit is now ready to receive the next serial stream of data. Details are shown in Figure 6.

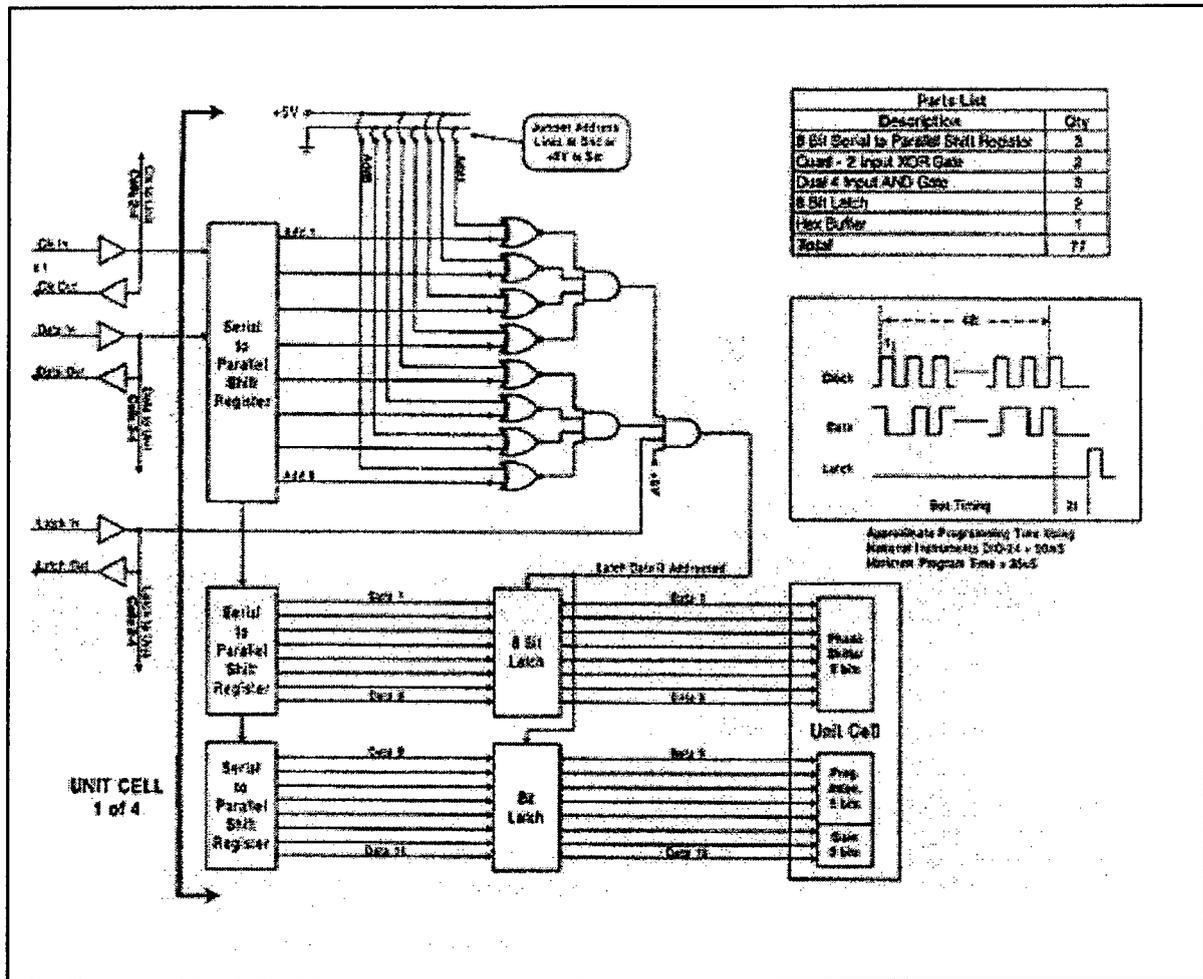


Figure 6: Serial Bus Topology for 200 T/R modules maximum:

T/R Module Layout

The original T/R module layout was conducted in a manner where the Inputs/Outputs (I/O) from the beam former was on the opposite end, to the antenna Output/Input respectively. Later, it was clear that the I/O from the beam former to the antenna output/input needs to be on the same side to allow module exchange in the hot condition. The width of T/R module was restricted to a maximum of 3 inch. The RF board was fabricated using grounded coplanar technology to reduce coupling and grounding effects. The control board was fabricated on Multilayered FR-4 substrate.

The completely assembled Transmitter (TX) section of the T/R module with the associated control circuitry is shown in Figure 7. The Receiver (RX) board is shown in Figure 8.

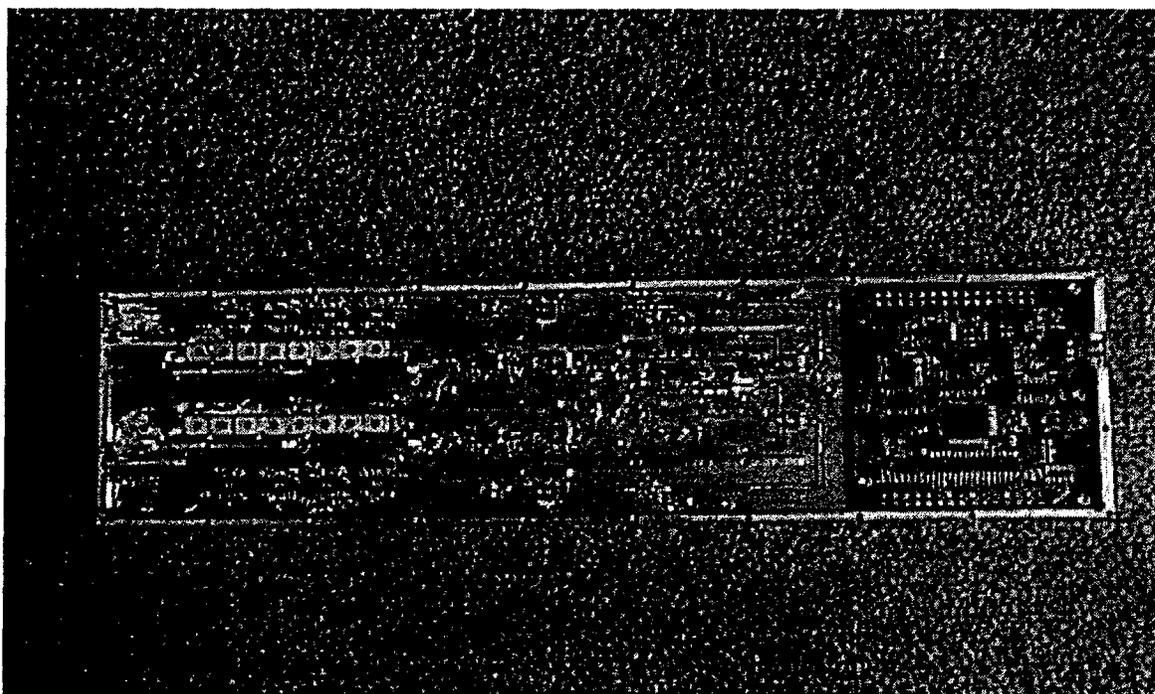


Figure 7: TX Section of the TR Module

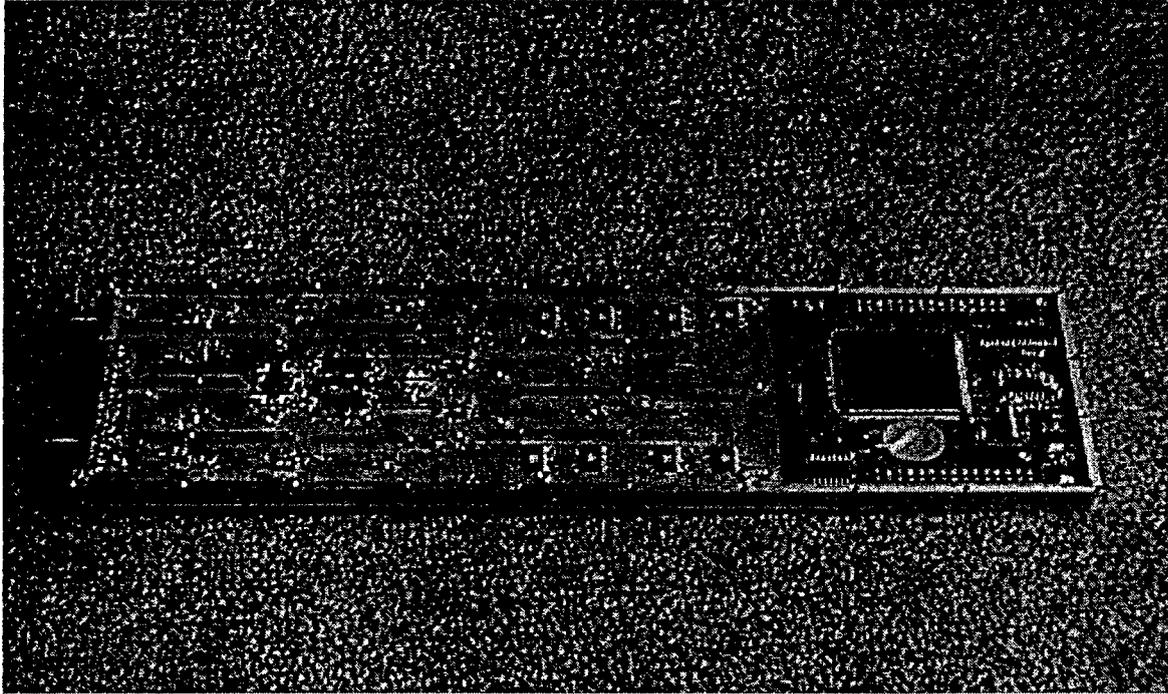


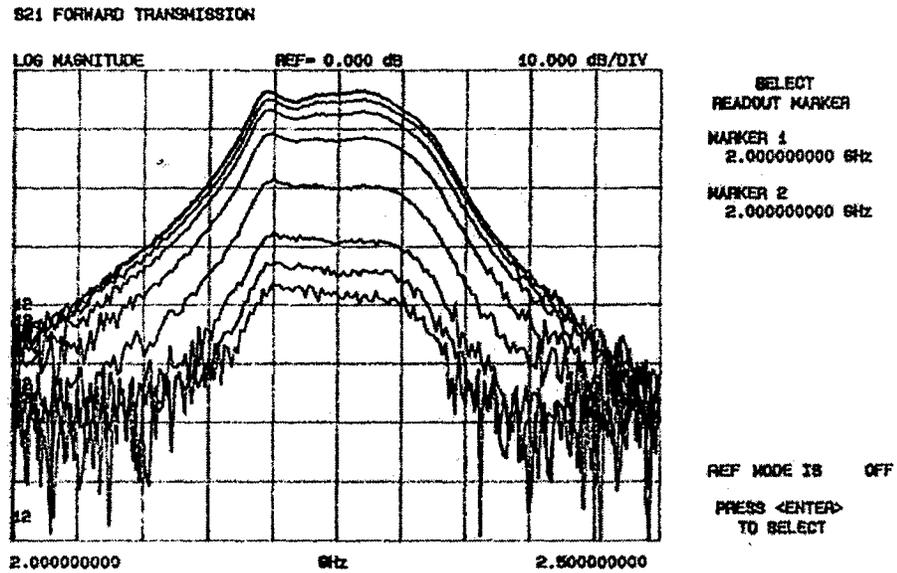
Figure 8: RX section of T/R Module

Design To Cost

The design to cost of the T/R module has been conducted from project initiation. From onset, the cost associated with the components without any compromise in the performance has been the guiding rule. The availability of the active devices for the PCS market has really influenced the cost of amplifiers and phase shifters. Added with novel design and layout, the design to cost goal is near reality.

Measured Data

Measured data for the transmit/ receive module has been taken and detailed below.



Receive channel
 Input 1 to Output 1 In band step Attenuation
 0, 1, 2, 4, 8, 16, 24, 28, 31 (dB)
 S/N 3507

Figure 9: Receive Channel Amplitude Control

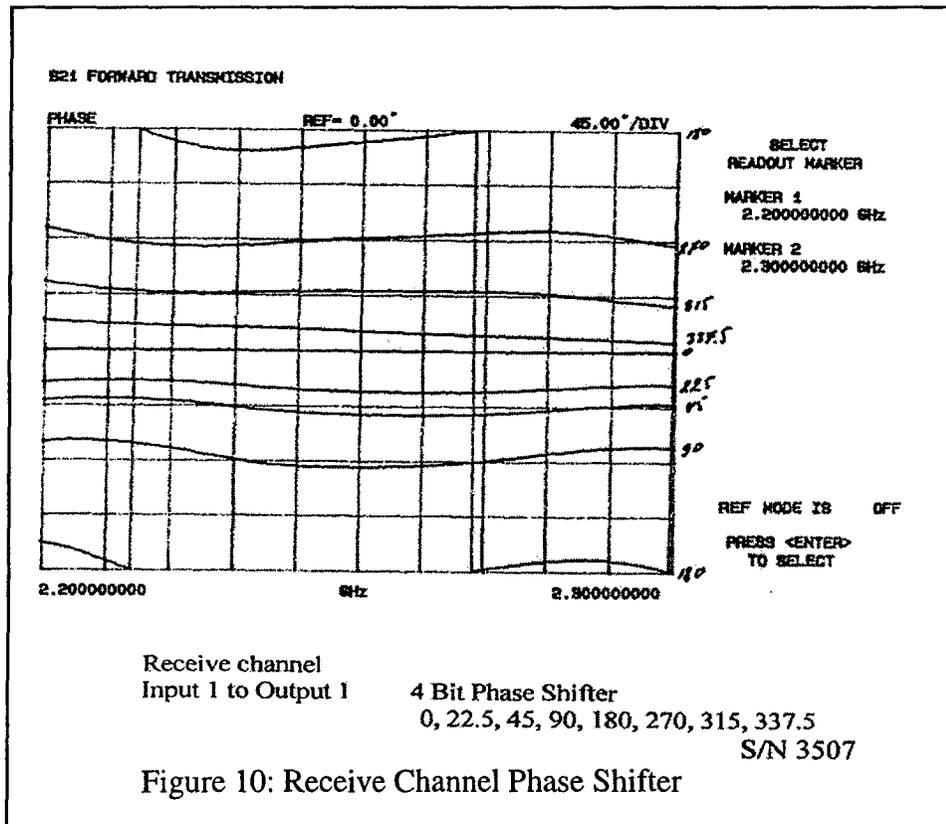
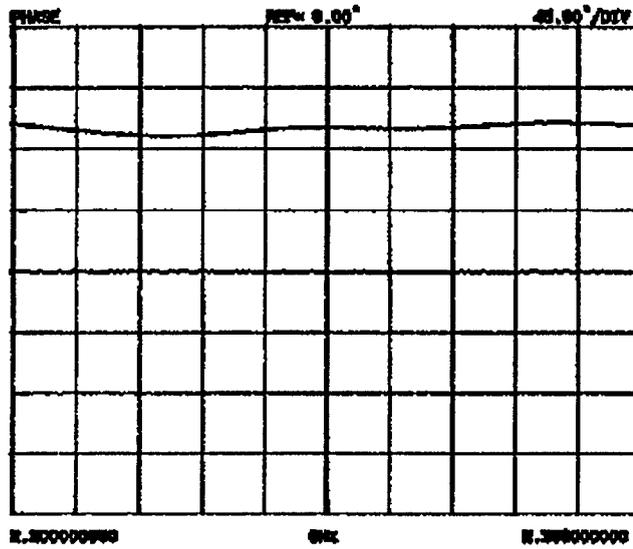


Figure 10: Receive Channel Phase Shifter

REF FORWARD TRANSMISSION



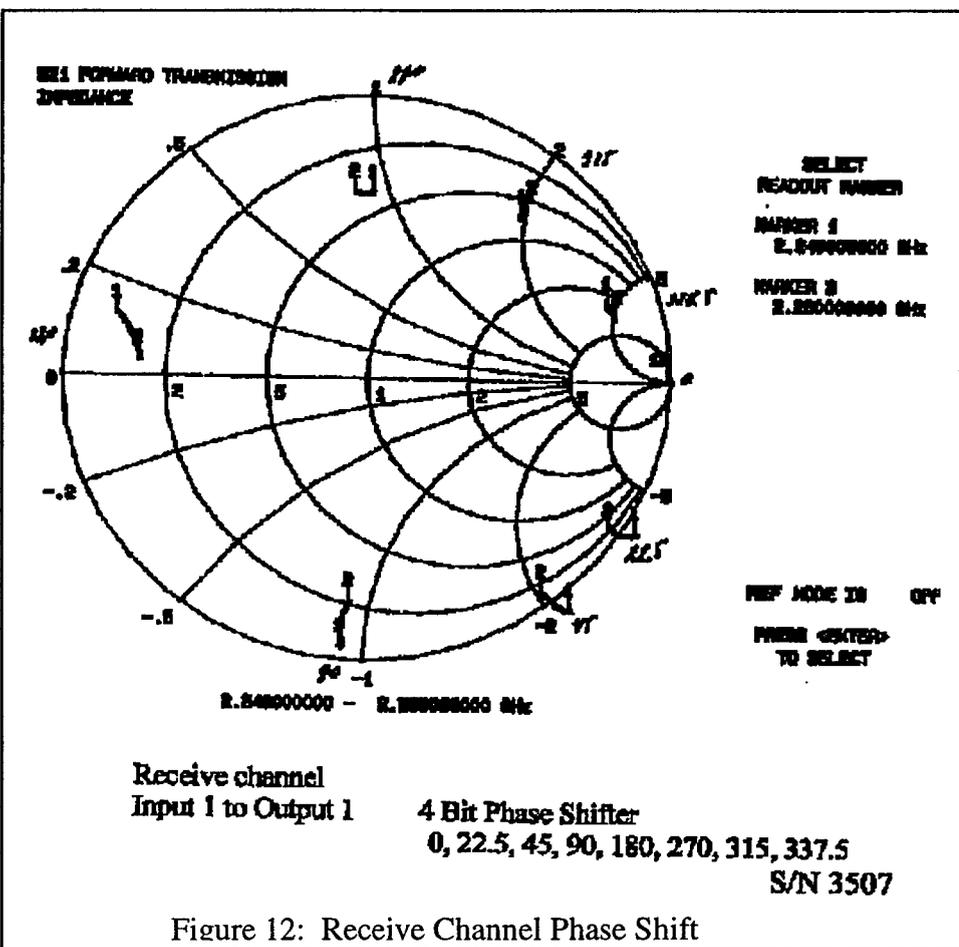
SELECT
READOUT MARKER
MARKER 1
2.80000000 MHz
MARKER 2
2.80000000 MHz

REF MODE IS OFF
PWR CENTER TO SELECT

Receive channel
Input 1 to Output 1 Switch Polarization
0, 90

S/N 3507

Figure 11: Receive Channel Switch Polarization



SELECT
READOUT MARKER
MARKER 1
2.80000000 MHz
MARKER 2
2.80000000 MHz

REF MODE IS OFF
PWR CENTER TO SELECT

Receive channel
Input 1 to Output 1 4 Bit Phase Shifter
0, 22.5, 45, 90, 180, 270, 315, 337.5

S/N 3507

Figure 12: Receive Channel Phase Shift

CONCLUSIONS

A T/R module has been developed for the USB-SGLS band operation. T/R modules were fabricated and tested. A design to cost exercise was conducted to ensure a low cost product. In the transmit section a power output of 30 dBm per channel, with a 4-BIT phase shifter and a 4-BIT attenuator, and polarization switching has been achieved. An overall gain of 30 dB was achieved. In the receive channel a noise figure of 2dB was measured with an overall gain of in excess of 20 dB. This channel also included 4-BIT phase shifter and 4-BIT attenuators. In its present form, the T/R module is reproducible. The next phase of development will focus on extending the T/R module for SGLS and USB frequencies.

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