A novel broadband T/R module for phased array applications in wireless communications

Chunlei Wang, Christopher T. Rodenbeck, Matthew R. Coutant, and Kai Chang

Department of Electrical Engineering, Texas A&M University,
College Station, TX 77843-3128 USA

***Abstract* — A novel broadband T/R module with four channels used in a multi-frequency phased array transceiver for mobile satellite communications is presented in this paper. The T/R module is comprised of two receive channels at 12 and 21 GHz and two transmit channels at 10 and 19 GHz. Measured results indicate that the T/R module has excellent channel isolation of over 60 dB for the two low frequency channels and over 32 dB for the two high frequency channels, small gain and phase variations among the channels, good noise figures and 1 dB compression point output power. The module can be utilized as a building block for a multi-frequency phased array transceiver. A 4-element phased sub-array using 4 T/R modules has been demonstrated and shows that the T/R module works well.**

I. INTRODUCTION

Rapid development and progress in tele-communication and radar technology have urged increasing requirements for system performance, such as large information capacity and the ability to trace multiple mobile stations and satellites. Broadband and dual-frequency transceivers are being developed for enhancing wireless system information capacity [1]. Phased array transceivers are also being developed for tracking targets in mobile and satellite communications [2]. The T/R module presented in this paper is comprised of four frequency channels at X- and Ku-band. The two channels at 10 and 19 GHz are for the transmitter and another two channels at 12 and 21 GHz are for the receiver. These frequencies were chosen to demonstrate nature of the technology. Other frequencies can be flexibly selected by adjusting the passband frequencies of the multiplexer. The module should have many applications in phased array systems.

II. CONFIGURATION AND DESIGN

Figure 1 is the layout of the T/R module. The module consists of two novel microstrip multiplexers with suppressed 2[nd] harmonic parasitic passbands, a broadband MMIC low noise amplifier and a broadband MMIC power amplifier.

A. Low noise amplifier

The gain of the three-stage amplifier is approximately given by:

$$G = G_1 + G_2 + G_3 \qquad \text{(dB)} \qquad (1)$$

where G_n (n = 1, 2, 3) are gains of the chip amplifier at each stage. The noise figure of a multi-stage amplifier is given by [3]:

$$F = F_1 + (F_2 - 1)\frac{M_2}{M_1 G_{p1}} + (F_3 - 1)\frac{M_3}{M_1 G_{p1} G_{p2}} + \text{L} + (F_n - 1)\frac{M_n}{M_1 \prod_{m=1}^{n} G_{pm}} + \text{L} \qquad (2)$$

where F_n, M_n and G_{pn} are the noise figure, input impedance mismatch and power gain, respectively, of the n^{th} stage amplifier. Measured gain of the three-stage low noise amplifier is 27.5 and 23.5 dB at 12 and 21 GHz, respectively. Measured noise figure of the amplifier is 4.4 dB at 12 GHz and 8 dB at 21 GHz. The measured results agree very well with the calculations.

B. Power amplifier

Measured gain of the three-stage power amplifier is 20.5 dB at 10.04 GHz and 22.6 dB at 19.14 GHz. Measured output power P_{1dB} at the 1 dB compression point is 23 dBm at 10.04 GHz and 18.5 dBm at 19.14 GHz.

C. Multiplexer

The circuit layout of the multiplexer is shown in Figure 2. The multiplexer with the four channels consists of four bandpass filters with passband center frequencies of 10, 12, 19 and 21 GHz. The two channels at 10 and 19 GHz are for the transmitter. The other two at 12 and 21 GHz are for the receiver. Isolation among the four channels is required to be greater than 30 dB for the system application. The multiplexer efficiently restricts the 2[nd] harmonic parasitic passband of the 10 and 12 GHz filters

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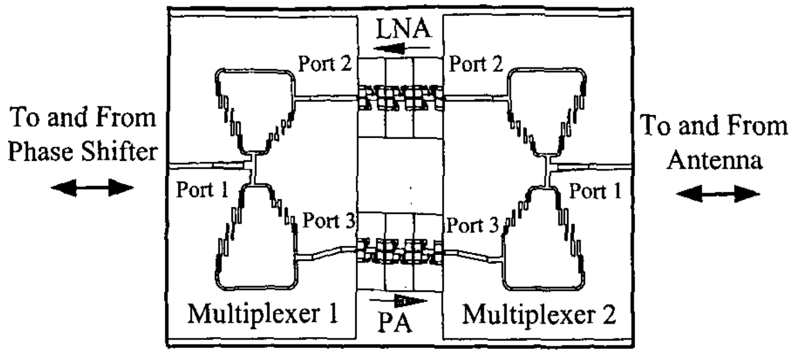

Figure 1. Layout of the T/R Module

[4]. Performance for one of the 2nd harmonic suppressed filters is shown in Figure 3, in comparison with a general

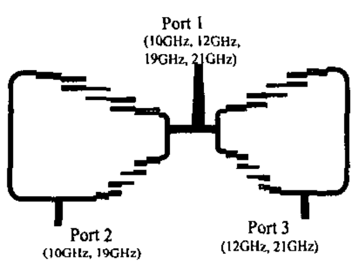

Figure 2. Layout of the four-channel multiplexer

microstrip edge-coupled bandpass filter without the harmonic suppression. Figure 3 indicates that the 2nd harmonic level is over 38 dB below the fundamental signal. The efficient suppression of the 2nd harmonic parasitic passbands allows the 19 and 21 GHz channels of the multiplexer to be insignificantly affected by the parasitic passbands that overlap with the fundamental passband of the 19 and 21 GHz channels. The multiplexer is simulated using Zeland's IE3D electromagnetic simulator [5] and measured using an HP 8510 network analyzer. The measured results indicate that the insertion losses at 10, 12, 19 and 21 GHz are 1.81, 1.90, 2.88 and 2.51 dB, respectively, and that the return loss is 20.6 dB at 10 GHz, 10.7 dB at 12 GHz, 22 dB at 19 GHz, and 16.5 dB at 21 GHz. The measured isolation for each of the channels is greater than 32 dB. Simulated and measured results agree well.

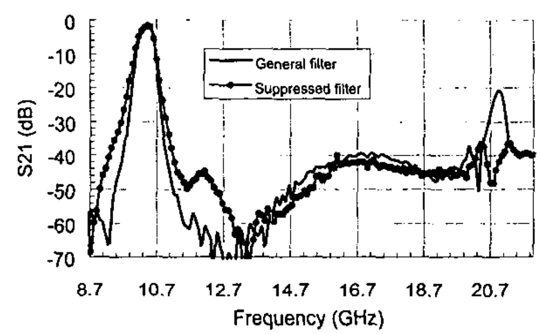

Figure 3. Measured S21 of a general microstrip edge-coupled bandpass filter and of the 2nd harmonic suppressed filter

The four filters with the different passband frequencies used in the multiplexer have exactly the same dimensions except for the lengths of their resonators. Each channel's passband frequency can be flexibly changed just by changing lengths of the resonators of the relevant bandpass filter and adjusting phase balances among all of the filters and T-junctions. Simulations show that the multiplexer works well over an even wider frequency range from 1 through 28 GHz.

III. PERFORMANCE OF THE T/R MODULE

The overall gain of the T/R module is approximately given by:

$$G = G_A - L_{M1} - L_{M2} \qquad \text{(dB)} \qquad (3)$$

where G_A is gain of the three-stage amplifier, L_{M1} is insertion loss of Multiplexer 1 and L_{M2} is insertion loss of Multiplexer 2. The noise figure of the entire T/R module is approximately calculated by:

$$F = L_{M2} + F_A \qquad (4)$$

where L_{M2} is the insertion loss of Multiplexer 2 and F_A is the noise figure of the low noise amplifier. The output power P_{1dB} of the T/R module may be calculated by:

$$P_{1dB} = P_{A1dB} - L_{M2} \qquad \text{(dB)} \qquad (5)$$

where P_{A1dB} is output power of the power amplifier at the 1 dB power compression point, and L_{M2} is insertion loss of Multiplexer 2.

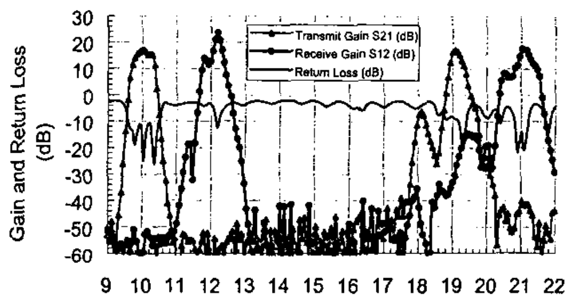

Figure 4. Measured gain, return loss and isolation of the T/R module

The measured noise figure of the T/R module is 6.4 dB at 12.185 GHz and 10.9 dB at 21. 025 GHz. Measured gain, return loss and isolation for the T/R module are shown in Figure 4. Figure 4 indicates that the measured gain of the receive channels is 23.9 dB at 12.185 GHz and 17.6 dB at 21.025 GHz, that the return loss is 12.4 dB at 12.185 GHz and 14 dB at 21.025 GHz, and that the isolation at the transmit channels is 61 dB at 10.04 GHz and 32 dB at 19.14 GHz. Figure 4 also shows that the gain and return loss of the transmit channels are 16.9 and 25 dB at 10.04 GHz and 17.2 and 11.6 dB at 19.14 GHz, respectively. The isolation at the receive channel is 62 dB at 12.185 GHz and 40 dB at 21.025 GHz. Measured output power vs. input power curves are shown in Figure 5. The measured curves indicate that the measured output power P_{1dB} at the 1 dB power compression point is 21 dBm at 10.04 GHz and 15.1 dBm at 19.14 GHz. Table 1 lists a comparison of calculated and measured results for the T/R module. The measured and calculated results agree well.

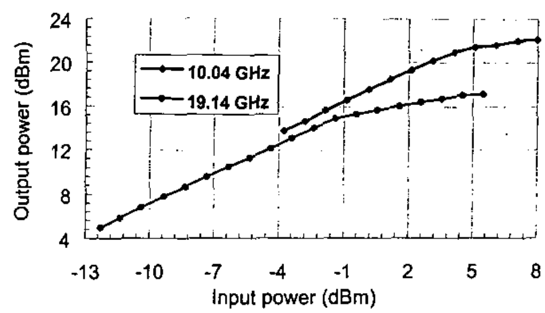

Figure 5. Output power of the T/R module

The intended application of the T/R module is in a multi-frequency phased array transceiver. The T/R module has been used to demonstrate a 4-element phased sub-array. Measured results of the four T/R modules indicate that the maximum absolute variation in gain amplitude and phase among the four T/R modules is 2.7 dB and 38.7° at 10.04 GHz, 1 dB and 38° at 12.185 GHz, 1.1 dB and 31° at 19.14 GHz, and 1.6 dB and 39° at 21.025 GHz. The maximum absolute variation in gain amplitude among the T/R modules is less than 0.5 dB when gain control circuits are adopted. The excellent amplitude and phase balance allow the phased array to achieve a low side lobe level, optimal system gain and good beam scanning. Measured results indicate that the beam scanning of the phased array is over ± 27 degrees at each of the four channels. The antennas and phase shifters used for the phased array are described in [2].

IV. CONCLUSION

A novel broadband T/R module for phased array applications in wireless communications is described in this paper. The T/R module is comprised of two novel multi-frequency harmonic-suppressed microstrip multiplexers, a broadband MMIC low noise amplifier and a broadband MMIC power amplifier. Measured results indicate that the T/R module demonstrates excellent performance over a wide frequency range from 10 through 21 GHz. The passband frequencies of the four channels of the T/R module can be flexibly changed from 2 through 21 GHz simply by adjusting the passband frequencies of the multiplexers. The T/R module has application in a multi-frequency phased array for wireless communications. The application further demonstrates that the T/R module works very well. The module should have many applications in broadband and multi-frequency communications and radar systems.

Table 1. Comparison of the calculated and measured results for the T/R module

	10.04 GHz		12.185 GHz		19.14 GHz		21.025 GHz	
	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.	Calc.	Meas.
Gain (dB)	16.74	16.9	23.68	23.9	16.84	17.2	18.98	17.6
P_{1dB} (dBm)	21.12	21			15.62	15.1		
Noise Figure (dB)			6.11	6.4			10.81	10.9

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