T/R Module Architecture Tradeoffs for Phased Array Antennas

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Abstract

Active phased array radars typically require solid state T/R modules with high output power, low noise figure, high third order intercept (TOI), and sufficient gain in both transmit and receive. Since the T/R module cost is 40–60% of the antenna cost, it is imperative to use an architecture that meets all requirements with a minimum number of MMIC chips. In this paper we examine several T/R module architectures, analyze their performance, provide a tradeoff between different performance parameters, and recommend an architecture for a given set of requirements.

Introduction

Active phased array radars have power and low noise amplification distributed at the antenna aperture, reducing the effect of losses in the distribution network for both transmit and receive. To take full advantage of this property, T/R module performance must be optimized in several key areas. In transmit, efficiency, output power and power gain are particularly important. In receive, gain, noise figure, third order intercept, dynamic range, and amplitude and phase accuracy are significant design drivers. Requirements on these parameters flow from antenna requirements and architectural considerations.

Because the central transmitter has been eliminated, the T/R module must have sufficient transmit gain to allow a reasonably low input power for a given output power. In receive, a high gain first stage LNA reduces the noise contribution from secondary stages. In the same way, high module gain reduces the noise impact of the down stream corporate feeds, time delay units, and receivers. At the same time, the modules must provide a high TOI to meet dynamic range requirements and maintain radar performance in a high interference environment. The module must also supply supply low error, high precision phase and amplitude control for low sidelobe beam steering, usually with multi–bit MMIC phase shifters and digital attenuators or variable gain amplifiers. The selected module architecture must simultaneously satisfy these requirements, some of which conflict.

In particular, the tradeoff between receive gain, noise figure (NF), and TOI will drive most of the module architecture choices. The high first stage gain desired for NF minimization directly conflicts with the need for high TOI. Function blocks must be distributed prudently in the T/R module to optimize all of these parameters.

Candidate Module Architectures

Three possible module architectures are considered. The first features completely separate transmit and receive chains, The second shares only a few components between chains. The third, the common–leg approach, shares major functional groups between transmit and receive. For this discussion, the receive gain is held to 30 dB, and the same receiver protection and T/R duplexing is used in each case.

The block diagram for the separate T/R chain module is shown in Figure 1 and spreadsheet performance budgets for receive in Table 1. It requires a separate corporate feed for transmit and receive, but a single connection to the radiating element.

The block diagram for a module with the phase shifter shared between transmit and receive is shown in Figure 2, with receive performance budgets in Table 2. It features a single corporate feed

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for both transmit and receive, and a single connection to the radiating element.

The block diagram for a common–leg module is shown in Figure 3, with receive performance summarized in Table 3. It also uses a common beamformer for both transmit and receive and a single radiating element connection, but shares much of the receive chain with the transmit side.

Comparison of Architectures

For the constant receive gain cases studied here, there are some obvious differences in noise figure and TOI performance, as well as in module and antenna complexity. Each of the architectures studied have advantages and disadvantages, which will be weighted differently for different applications.

The separate T/R chain module provides that best TOI performance of the cases studied, at some cost to noise figure. The complexity, and thus cost, of this module is greater that in the other cases. It requires separate beamformers in the antenna and includes redundant phase shifters, which will increase the MMIC count. It is a conservative design, allowing considerable electrical and physical separation between transmit and receive functions if necessary.

With its gain heavily front loaded, the common phase shifter module noise figure is 0.25 dB better than the other cases, but with 8 to 9 dB worse input TOI. A significant amount of integration is possible, with a single MMIC containing gain block, phase shifter, VGA, switch, and pre–driver providing an attractive implementation. One drawback to this configuration is the high (40 dB) internal gain level, which increases the risk of leakage–induced instability. More care will be needed in this module to provide the necessary isolation.

The common leg module equals the noise figure of the separate chain module, with a slight (1 dB) degradation in the TOI. However, the common leg common components, including the switches, gain blocks, phase shifter, and VGA, can be integrated into a single MMIC, resulting in a compact, reduced cost design. The single beamformer connection simplifies the antenna architecture as well. Since the VGA is common to both chains, it provides the capability of transmit amplitude tapering at no additional cost. Adequate switch isolation must be provided, and care exercised in the common leg amplifier lineup to meet receive gain, noise figure, and TOI requirements while providing adequate driver power and compression characteristics to the power amplifier chain.

Conclusions

Different antenna systems have different requirements, and will therefore set different priorities in performance tradeoffs. The common phase shifter module will be attractive in a system with rigorous requirements on system sensitivity. If system linearity and dynamic range is more important, the separate T/R chain module provides the best performance, but with increased complexity and system cost. The common–leg approach provides most of the TOI performance of the separate T/R chain with a significantly increased level of integration and lowered system cost.

Figure 1: Block Diagram: Separate Transmit and Receive Module

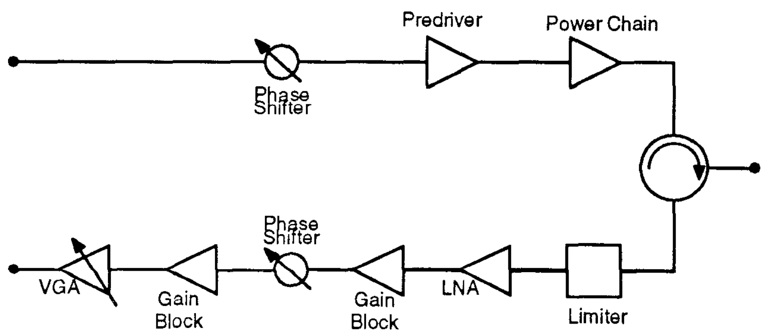

Table 1: Receive Performance: Separate Transmit and Receive Module

Component	Component Performance			Cumulative Module Performance			
	Gain (dB)	Noise Figure (dB)	Output TOI (dBm)	Gain (dB)	Noise Figure (dB)	Input TOI (dBm)	Two Tone IMD (dBc)
Circulator	–0.5	–	–	–0.5	0.50	–	–
Limiter	–0.5	–	–	–1.0	1.00	–	–
Low Noise Amp	20.0	1.5	20.0	19.0	2.50	1.0	72.0
Gain Block	6.5	4.5	22.0	25.5	2.56	–4.8	60.4
Phase Shifter	–10.0	–	–	15.5	2.62	–4.8	60.4
Gain Block	6.5	4.5	22.0	22.0	2.74	–6.1	57.9
Variable Gain Amp	8.0	8.0	25.0	30.0	2.81	–8.6	52.9

Figure 2: Block Diagram: Shared Phase Shifter Module

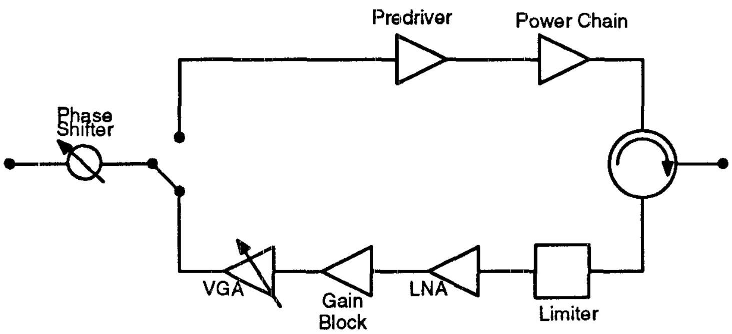

Table 2: Receive Performance: Shared Phase Shifter Module

Component	Component Performance			Cumulative Module Performance			
	Gain (dB)	Noise Figure (dB)	Output TOI (dBm)	Gain (dB)	Noise Figure (dB)	Input TOI (dBm)	Two Tone IMD (dBc)
Circulator	–0.5	–	–	–0.5	0.50	–	–
Limiter	–0.5	–	–	–1.0	1.00	–	–
Low Noise Amp	20.0	1.5	20.0	19.0	2.50	1.0	72.0
Gain Block Amp	14.5	4.5	22.0	33.5	2.56	–11.7	46.5
Variable Gain Amp	8.0	8.0	25.0	41.5	2.56	–17.8	34.5
Switch	–1.5	–	–	40.0	2.56	–17.8	34.5
Phase Shifter	–10.0	–	–	30.0	2.56	–17.8	34.5

Figure 3: Block Diagram: Common Leg Module

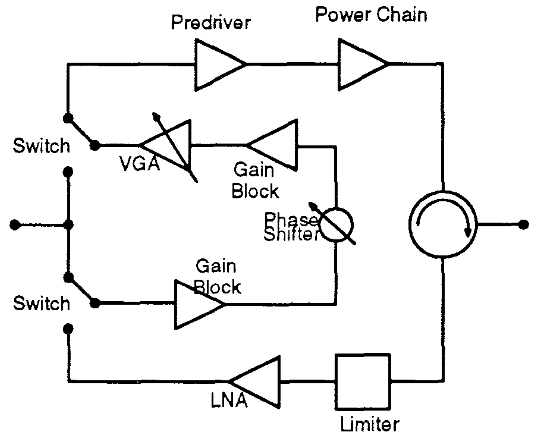

Table 3: Receive Performance: Common Leg Module

Component	Component Performance			Cumulative Module Performance			
	Gain (dB)	**Noise Figure (dB)**	**Output TOI (dBm)**	**Gain (dB)**	**Noise Figure (dB)**	**Input TOI (dBm)**	**Two Tone IMD (dBc)**
Circulator	–0.5	–	–	–0.5	0.50	–	–
Limiter	–0.5	–	–	–1.0	1.00	–	–
Low Noise Amp	20.0	1.5	20.0	19.0	2.50	1.0	72.0
Switch	–1.5	–	–	17.5	2.51	1.0	72.0
Gain Block Amp	8.0	4.5	22.0	25.5	2.59	–4.8	60.4
Phase Shifter	–10.0	–	–	15.5	2.65	–4.8	60.4
Gain Block Amp	8.0	4.5	22.0	23.5	2.77	–6.5	57.0
Variable Gain Amp	8.0	8.0	25.0	31.5	2.82	–9.5	51.0
Switch	–1.5	–	–	30.0	2.82	–9.5	51.0