

White Paper

Gallium Nitride (GaN) Enabled C-Band T/R Modules

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1. Introduction

The US Department of Defense (DoD) uses phased arrays at multiple frequency bands though many common bands are S-Band, C-Band, and X-Band. Some of the deployed systems use Passive Electronically Scanned Array (PESA). These systems rely on a centrally located high power amplifier normally implemented using traveling wave tube (TWT) amplifiers. Figure 1(a) is a simplified block diagram of a PESA radar. Notice how the radar uses phase shifters at each antenna element. The PESA radar suffers from several drawbacks such as low reliability due to the traveling wave tube amplifiers (TWT) and reduced efficiency from the losses in the phase shifters and power divider network. As useful as the PESA systems have been, they are in need of an upgrade. Not only are the TWT amplifiers low reliability, they also require long lead times to purchase, and are extremely expensive. The solution is fully Active Electronically Scanned Arrays (AESAs).

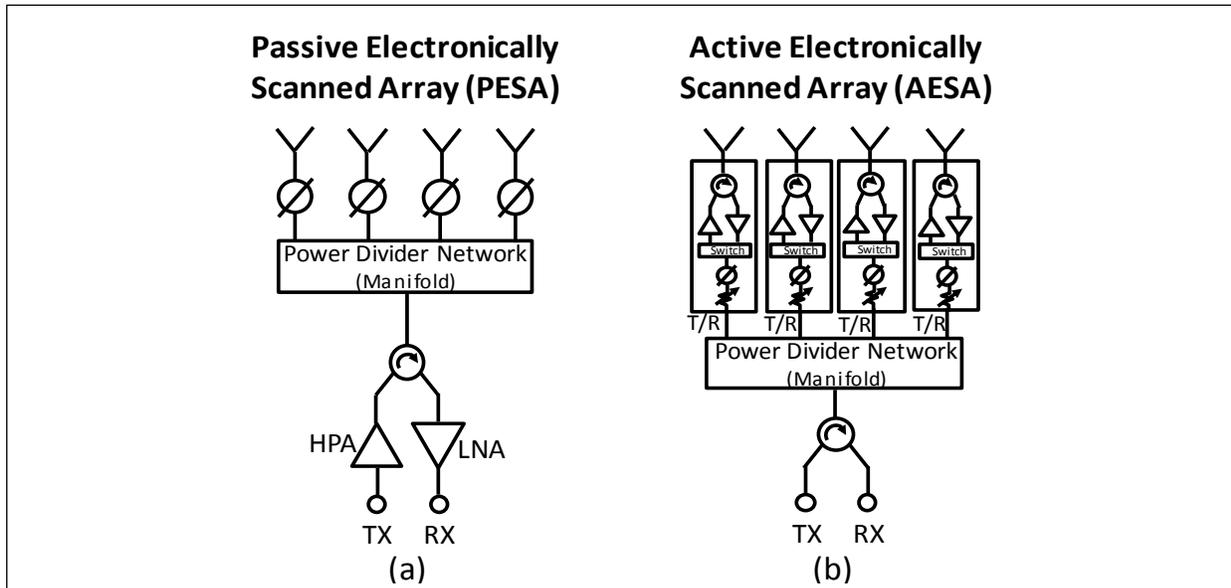


Figure 1. Comparison of (a) passive electronically scanned array (PESA), and (b) active electronically scanned array (AESA). (© 2014 Artech House. Reprinted, with permission¹).

The performance benefits of AESAs make them attractive. For instance, they offer the ability to form multiple simultaneous beams. This means that multiple simultaneous targets can be tracked which provides greater situational awareness and the ability to react to threats. Also, they are more efficient than PESAs since they don't have the extra losses associated with the power divider feed network and phase shifters. Instead, the power amplifiers are placed after the phase shifters just before the antenna element to maximize the transmitted power. An important benefit is the improved reliability. PESA arrays have lower reliability since the TWT amplifiers are a single point failure mechanism for the arrays. AESAs use transmit/receive (T/R) modules with

¹ Rick Sturdivant, Mike Harris, *Transmit/Receive Modules for Radar and Communication Systems* (Norwood, MA: Artech House, Expected December 2015).

high reliability electronics at each element in the array. T/R modules typically offer mean time to failure (MTTF) that is 10-20 years. Also, they provide a graceful degradation of the array as elements begin to fail rather than catastrophic failure that is typical of TWTs. For these reasons AESAs are the preferred choice for retrofitting existing arrays and for deployment of new systems.

One challenge for AESAs is the ability to procure affordable T/R modules and line replaceable units (LRUs). The LRU is a collection of T/R modules with beam forming networks (power combiner circuits), energy storage, and other functions. This white paper describes the specifications and block diagram that can be the foundation for an affordable solution for the procurement of T/R modules.

Specifications

A set of T/R module specifications for a C-band T/R module are shown in Table 1. It is divided into basically three sections. The first section is general specification. This contains requirements that are common to the whole module or are shared between both transmit and receive. Since this focus here is on C-Band T/R modules, the table shows a frequency range of 4-6GHz. The phase and amplitude bits refers to ability of the module to control the output phase for beam steering and amplitude for calibration and antenna pattern adjustment. The six bits of amplitude and phase adjustment describes the number of states that can exist in transmit and receive. The number of states is given by

$$\text{Number of Phase (or Amplitude) States} = 2^{\text{Number of Bits}}$$

This means that for a phase shifter with 6 bits, there will be $2^6 = 64$ different states. The same is true for the amplitude bits. The instantaneous bandwidth (IB) is dependent upon the IF bandwidth. The specification shows an IB of 10 to 50MHz. However, this will be adjusted to the needs of the overall phased array.

The second section is the receive specifications. One of the most important receive specifications is the receive noise figure. This is an important requirement since it sets the noise figure of the whole phased array. This, in turn, determines the sensitivity of the AESA to small targets or low observable targets. Therefore, the module design and component selection is conducted to minimize the noise figure. Another important parameter is the overall receive gain. The gain needs to be high enough so that the losses of subsequent components do not degrade the system noise figure. However, it cannot be too high since that can degrade the linearity of the radar receive system. The limiter protection level is shown as 50W. This limiter function level will be adjusted as the T/R module design progresses.

The third section of the specification is the transmit functions. The most important transmit function is the output power. It is shown as 25W, though high power levels are possible depending upon system cooling capacity of the array and power supply capabilities. Another

important parameter for the transmit section is the required input power. If the required input power is too high, then the drive circuitry at the LRU level can become unmanageable. The other important specification on transmit is the TX droop. As the transmit power is turned on, the output power will droop as a function of time. The droop causes a reduction in output power and a non-linearity in output signal level. The transmit specification are important for overall radar functionality.

These specifications are a good summary of a typical C-Band T/R module. Of course a full T/R module specification will be more complex, but the detailed specifications are developed in conjunction with the module and LRU design.

Parameter	Min	Typical	Max	Units	Notes/Comments
General Specifications					
Frequency Range	4		6	GHz	
Module Width		<1.5		inch	To maintain half wavelength at the antenna
Number of Phase Bits			6		LSB = 5.25 degrees
Number of Amplitude Bits			6		LSB = 0.5 dB
RMS Amplitude Error					
RMS Phase Error			5	Degree	
Input Return Loss		15		dB	Matched to 50 ohms
Output Return Loss		12		dB	Matched to 50 ohms
Instantaneous Bandwidth		50		MHz	
Data control		SPI			Control module states
Data control rate	5			Mbps	
Beam Control Transfer			400	uS	Time to complete a full beam steer instruction set.
Operating Temperature Range	-40		70		
Supply Voltage (Positive)		28		V	No regulation for HPA. Requires clean power. Regulator for low noise amplifiers
Supply Voltage (Negative)		8		V	Internal regulated to -5V
Supply Current (Positive)		~2.5		A	
Supply Current (Negative)		0.2		A	
RX Performance Parameters					
Receive Noise Figure			3.5	dB	
RX Gain		18		dB	
RX output P1dB		5		dBm	
RX Limiter Protection			50	W	Assumes 250 uS pulse
Rx Gain Variability		+/- 1.1		dB	Max over 2GHz bandwidth
TX Performance Parameters					
Output Power (Psat)			25	W	Module saturated 2dB
Input Power (dBm)		5		dBm	Required to drive HPA into saturation 2dB
Tx Gain		40		dB	
Tx Noise Figure			10	dB	
Tx Gain Variability		+/- 1.1			
Tx Harmonics		-30			
Tx PA Switch Control		0/5		V	Differential
TX Droop			0.3	dB	Drop in power due to long or short pulses

Table 1. Specification table for GaN enabled C-Band T/R module.

T/R Module Block Diagram

A simplified T/R module block diagram is shown in Figure 2 and illustrates the main functions. The transmit components are the high power amplifier (HPA) and driver amplifier (DA). They are implemented using gallium nitride (GaN), though the driver amplifier can be designed using gallium arsenide (GaAs) since its power level is typically 20-25dB lower than the output power of the HPA. For instance, a GaN HPA with an output power of 25W (44dBm) and 20dB of saturated gain will need a driver amplifier with only 0.25W (24dBm) of output power. That power level can be easily achieved with GaAs and at lower cost than GaN. MPT is currently executing on a US Army contract for which we are developing a T/R module and GaN high power amplifier. The HPA will be fabricated in GaN, but the DA may be fabricated in GaAs to reduce the overall cost of the T/R module.

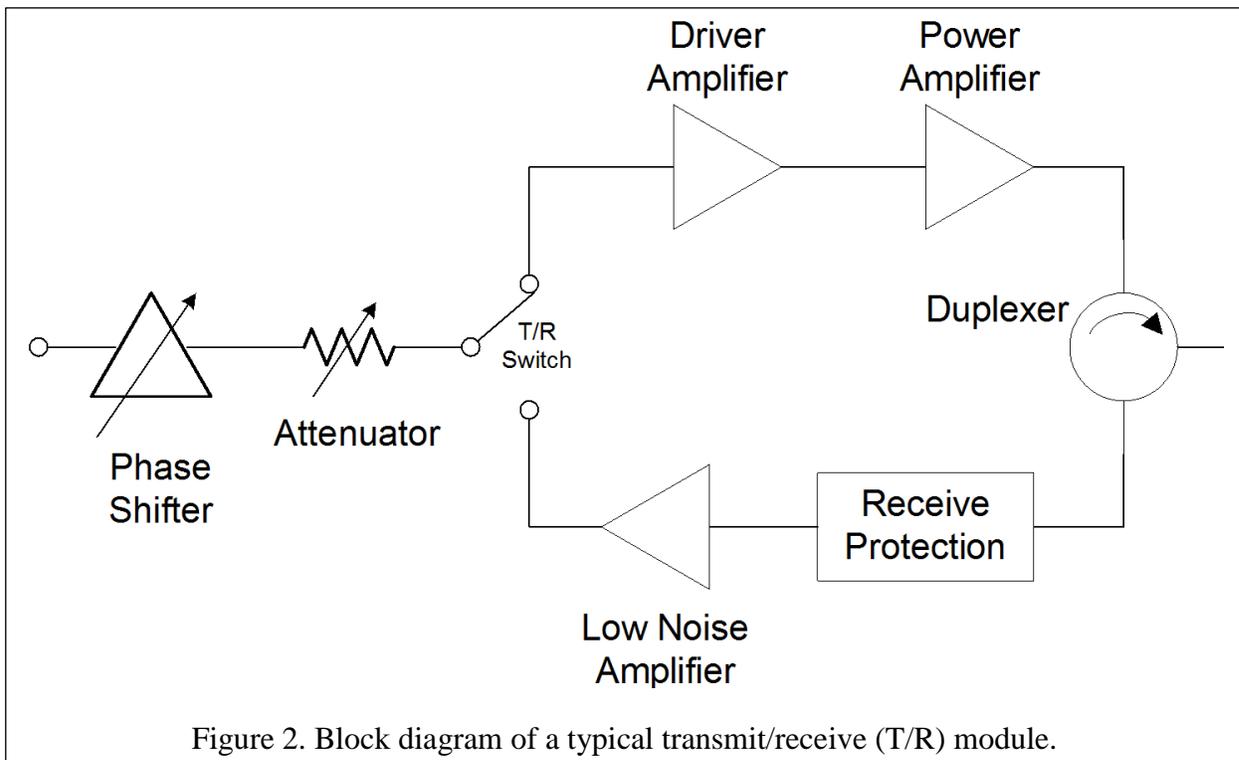


Figure 2. Block diagram of a typical transmit/receive (T/R) module.

The receive side of the T/R module uses receive protection which is normally a limiter or a limiter and a switch. The receive protection is important since it protects the T/R module from possible self-inflicted permanent damage. The damage can occur when a portion of the radar power from the HPA leaks into the receive circuitry. When this occurs, it is possible for the leakage power level to be high enough to cause permanent damage to the LNA. This can render the radar completely useless. For this reason, all T/R modules contain some form of receive protection.

The receive protection is normally implemented using vertical PIN diode limiters in GaAs. MPT is currently executed on a program for the US Navy to develop GaN based limiters

for T/R modules. Often the receive protection includes a switch but it is optional depending upon the specifications of the module.

The receive circuit also includes a low noise amplifier (LNA). It can be implemented in either GaAs or GaN and there are benefits/drawbacks to each technology solution. The benefit of GaAs is that it is low cost and offers excellent noise figure performance which is important for the radar to detect targets. Also, GaAs LNAs can be low cost since they are typically small integrated circuits. A drawback of GaAs is that it has a lower break down voltage which means that it can be more easily damaged by leakage from the high power amplifier. Normally, the limiter function is sufficient to protect the LNA, but the limiter creates additional loss in the array. One benefit of the GaN LNA has the benefit of having reasonable noise figure that approaches the levels that can be achieved by GaAs. However the greatest benefit if GaN LNAs is that they can withstand larger power leakage from the HPA. This means that a simpler and possibly lower insertion loss limiter can be used. As can be seen, the choice between a GaAs or GaN LNA is a complex one that depends on the specifications of the T/R module.

The phase shifter and attenuator functions are typically fabricated using GaAs or silicon germanium (SiGe). The benefit of GaAs is performance since it can provide high third order intercept (IP3) performance than SiGe. However, SiGe phase shifter and attenuator functions can be fabricated at much lower cost (~5 – 10X lower) than with GaAs. Moreover, SiGe can be used to implement other functions such as temperature compensation circuits, operation amplifiers, control circuits, and digital control circuits. This flexibility can be an important advantage for some T/R modules. In both GaAs and SiGe, it is very common to combine the functions into one integrated circuit. When this is done, the integrated circuit is usually called a common leg circuit (CLC). The determination of using GaAs or SiGe is a complex decision that depends on the goals and specifications of the T/R module.

T/R modules have other functions such as the HPA drain modulation circuit, regulators, switches, control circuits, energy storage capacitors, and many others. However, this summary provides an overview of the main functions of the T/R modules. It also provides some information that is useful in determining which functions should be implemented in GaN or a different technology.

Summary

AESAs offer important advantages over PESA for radar functions. This white paper discussed several of the advantages and presented a set of specifications for a C-Band T/R module. It also reviewed the block diagram of a typical T/R module and the issues involved in determining which functions should be fabricated in GaN or other technology. If there are any questions, please feel free to contact Rick Sturdivant at 310-980-3039 or rsturdivant@mptcorp.com, or Craig Parrish at 310-696-9066 or cparrish@mptcorp.com.