Multi-function Phased Array Radars (MPAR)

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Abstract

In this paper, various developments like advancement in T/R modules, impact of usage of COTS components and sub-array concept in the realization of active phased array Radar are discussed. Concept of dense network of small range Radar is also presented. At the end, modifications required in Phased Array Radar to realize MPAR are given.

Nomenclature

GaAs = Gallium Arsenide  
SiGe = Silicone-germanium  
MTBF = Mean Time between Failure  
LNA = Low Noise Amplifier  
COTS = Commercial Off-the-shelf  
GaN = Gallium Nitride  
SPDT = Single Pole Double Throw  
LTCC = Low Temperature co-fired Ceramics

1. Introduction

Post Second World War, radar system configuration has been changing towards performance improvement to meet demanding requirements and also witnessing of diversification of its applications. The objective of a multi-function phased array radar (MPAR) is to use a single radar type to carry out the multifunction such as weather surveillance, civil aviation, military and homeland security applications. The MPAR consists of electronically steerable antenna with multi-beam capability. Implementation of the MPAR system could obviate the need of separate radar systems to support the individual functions. This could permit reduction in the total number of different radar types and numbers of radar units required to meet the nation’s requirements.

2. Conventional Radar

Long range conventional microwave radar has a centralized transmitter as shown in Fig 1, producing high peak power, which requires high DC voltage power supply. The RF output is fed through a duplexer to antenna by a pressurized waveguide. A tracking Radar, will have a pencil beam that is used to track targets by the use of a mechanical tracking mount, whereas in a surveillance applications, will produce a fan shaped beam, with a fixed elevation illumination profile and the azimuth scanning being achieved by rotating the antenna.

In this configuration, typically, 90% of the prime power and 80% of the effective transmitted power is lost. The noise figure of the receiver is high because of high loss between antenna and receiver.
3. **Active Phased Array Radar**

An Active Phased Array Radar as shown in Fig 2, consists of many radiating elements and Transmit/Receive (T/R) modules mounted behind them. The beam scanning is achieved electronically by proper shifting phase between the radiating elements.

The main advantages of the active phased Array Radar compared to conventional Radar are given as:

- Wave guide can be replaced with low-loss cables.
- Graceful degradation performance with components failures.
Improved detection sensitivity by improving noise figure.
Prime power requirements are also greatly reduced.
Improved detection sensitivity in the presence of clutters.
MTBF is better for solid state electronics.
Electronic scanning is faster than mechanical scan thereby tracking multiple targets.

3.1. Impact of COTS technology

During second half of the 20th century, new technologies were evolved in semiconductor field, targeting applications in space and military fields. Whereas, around first half of 21st century, new technologies are being evolved for commercial applications, such as wireless and base stations, because of the huge markets. These technologies are later find applications in defense and space, in order to reduce cost of realization. The advantages of usage of COTS components:

- Availability of highly integrated devices at lower cost.
- Continuous upgradation.

The radar engineers must thank emerging communication systems that are providing stimulus to develop state of the art microwave components, ADCs, DACs, and DSPs.

3.2. Transmit/Receive Modules (T/R)

Transmit and receive modules are key elements in active phased array radar system as shown in Fig 3.

Fig 3: Block diagram of T/R module

Mainly, it has a receive path, a transmit path and a common path. The T/R modules, using GaAs MMICs are in mass production, with higher quantities in L, S, C & X-bands. Important features of the T/R module are higher output levels, broader bandwidth, increased power added efficiency (PAE), higher operating voltage, low-noise figure,
precise amplitude and phase control, low mass and good thermal behavior over wider temperature range\textsuperscript{[1]}. Typically, thousands of T/R modules are required for phased array radar. Hence, T/R module has a big impact on cost and weight of the entire system.

There is continuous improvement in yield by using proven LTCC technology for T/R modules, driver amplifier (DA) and high power amplifier (HPA) mounted on heat sink. Common arm in T/R module is realized using core chips of CMOS, SiGe or GaAs technology. Today, T/R modules for active phased array radar application are commercially available.

3.3. Impact of GaN technology

The advantages of High frequency GaN devices are availability of high efficiency power amplifiers, higher gain per stage, easier impedance matching and wider bandwidth. Because of availability of high power SPDT and robust LNA, complete T/R module can be realized using MMICs technology. Due to higher breakdown voltage of the GaN devices compared to GaAs devices the supply voltage can be significantly increased which leads to an additional increase in efficiency on system level, because of lower losses in power supply. X-band T/R modules with 4.0 Watts power output, noise figure of about 3.5dB with size of less than 15x15x8mm\textsuperscript{3} and weight less than 4.0 grams are available in the market\textsuperscript{[1]}.

3.4. Digital Array Radar

Phased array radars, recently adopted digital beam forming at sub array level as shown in Fig 4. The present number of Sub arrays is in the order of 1\% to 2\% of the total number of T/R modules.

![Fig 4: Block diagram of Digital Array Radar](image-url)
Theoretically, the maximum SNR should increase by $10\log N$, where $N$ is the number of sub arrays\textsuperscript{[2]}. The digital beam forming provides the ability to scan with a cluster of beams and simultaneously processing of each beam provides an appropriate speed improvement in tracking. Further, by employing the COTS components, it is possible to manufacture digital receiver modules with affordable cost.

4. **Small Radar Technology**

Long-range radars are fundamentally incapable of providing low level coverage due to the curvature of the earth. The new approach is to use large numbers of small low power radars operating on short ranges of tens of kilometers, as dense radar network\textsuperscript{[3]}. Using above mentioned technologies, low power phased array radars can be realized with affordable cost. This dense network can serve for both weather surveillance and tracking application. These radar can be mounted on existing communication towers, sides of buildings or on rooftops.

5. **Multi-function Phased Array Radar (MPAR)**

MPAR will combine the different functions of various radar networks into a single multi-function network. There are separate radar networks such as

- Aircraft surveillance radar
- Doppler weather radar
- Weather surveillance radar

Each of the radar network can perform a single mission. Phased array radar technology is the only known technology available that could possibly meet the combined requirements of all the existing networks. Phased array radar technology promises enhanced benefits compared to the reflected dish radar technology employed by current radars.

5.1. **MPAR development challenges**

The main challenge in an MPAR development is to implement dual polarization technology on phased array radar. Currently, weather radars have a dual polarization capability that is required for weather forecasting and warning of severe weather events. Dual polarization radars transmit energy in both horizontal (H) and vertical (V) planes. Dual polarization data can provide additional benefits such as improved radar data quality, mitigation of ground clutter and possible improvements to aircraft detection\textsuperscript{[4]}. Development of T/R elements and dual polarization antenna panels are required for phased array radars. Dual polarization phased array must maintain isolation between the H and V channels, while scanning electronically in both azimuth and elevation directions. The H and V fields become coupled with each other when scanning off-broadside of a phased array as shown in Fig 5. Phased array radar will need to compensate for the polarization coupling in order to meet the performance requirements. The T/R module configuration is required to transmit and receive V & H components separately. High power four port diversity switch is required for V and H components.
6. Conclusion

By adopting latest technologies as mentioned, it is possible to realize an MPAR with affordable cost. The MPAR, in near future, will replace the existing radars that are used for weather and tracking application.

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References


