FUTURISTIC RADAR SEEKERS : THE AESA APPROACH

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New generation of Active Radar Seekers for missile applications require a fast responding angle tracker to counter high velocity, highly maneuverable targets. Current generation of Radar *Seekers have been using conventional gimbaled antenna configuration.* Due to the mechanical inertia of the gimbaled antenna system, capability of steering a narrow beam with high speed and precision is limited apart from limited RF power handling capability. This also leads to slow reaction time since each function i.e., acquisition, tracking and guidance are to be accomplished by the same antenna. It also requires specific antenna characteristics, transmitter power as well as receiver sensitivity to achieve the desired performance. Consequently, current radar seeker technology is looking for alternative approaches like Active Electronic Scanning Array (AESA) configuration.
This paper brings out the emerging trends in Radar seeker technology with respect to latest developments in components, sub systems as well as implementation aspects.

INTRODUCTION

Active Radar Seekers have been used in missiles with the ultimate objective of achieving hit to kill strategy in the terminal guidance phase of the missile flight. It is an application specific compact missile borne monopulse tracking radar whose antenna is mounted on a gyro stabilized platform in order that the antenna is isolated/ decoupled from the body movement of the missile.

So far, the conventional gimbaled antenna configuration have been very popular. However, the ever demanding requirements tend to get rid of the electromechanical stabilization system to be replaced by Active Electronically Steerable Array (AESA) antenna system with associated beam control network. Such a compact AESA seeker is possible to be realized using T-R modules using MEMS – MMIC approach.

2. CONVENTIONAL RADAR SEEKER

A typical gimbaled antenna Active Radar Seeker(ARS) is shown in fig 1 below:

Figure 1: conventional active radar seeker

The basic blocks comprising the ARS is shown in Fig 2 below:

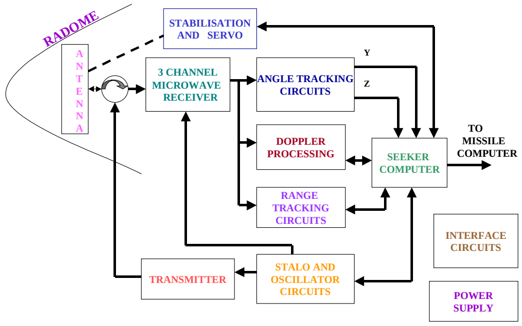


Figure 2: Active Radar Seeker – Basic Blocks

In figure 3, the operation of ARS has been shown in relation to the On-Board Computer (OBC) responsible for overall guidance of the missile which is self-explanatory.

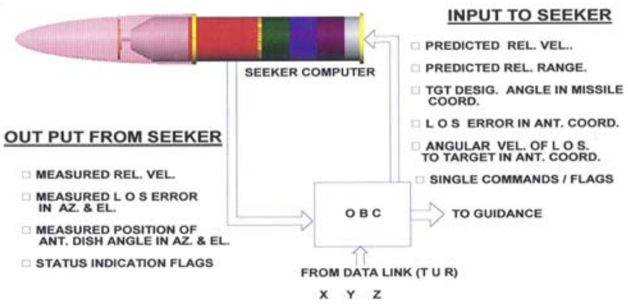


Figure 3: Active Radar Seeker

The primary information, required for accomplishing homing guidance, is the computation of the rate of change of line of sight to the target with respect to the missile. This is provided for, by keeping a continuous track of the missile in terms of angle by the Monopulse tracker. Additional target information, like range and/or relative velocity in terms of Doppler frequency shift is used to identify a particular target from among other targets including clutter, if any.

However, it must be accepted that, it is the response of the electro-mechanical servo system which ultimately determines the overall seeker performance in terms of speed and precision. The key parameter in this regard is the mechanical inertial of the payload of the servo system i.e., the antenna system. Therefore, the current seeker technology, with conventional gimbaled antenna, employs low weight (<500 gms) slotted planar array antenna system with low outline (thickness <5 mm). Still, the response of the servo system is limited within 250^{0}/sec for a step input designation while catering for an LOS rate upto 30^{0}/sec, for a reasonable antenna diameter (approx 300 mm) in spite of tight mechanical tolerances. Also, this occupies relatively more space and power consuming.

The second constraint, of the conventional gimbaled antenna seeker, originates from an entirely different phenomenon. This is due to achievable radome error slope within required scan angles caused due to the presence of radome versus the limit of radome error slope permissible to ensure adequate missile stability and acceptable miss distance.

For this reason, the radome error slope measurement data is highly important and two distinct methods are used to limit the error slope as described below:

a) The error slope is continuously measured during radome fabrication and appropriately corrected. In this case, each radome is cleared after conducting the test with a standard seeker antenna as reference.
b) A complete data of radome error slope measurement in all possible planes is stored in the seeker computer which is used in the digital signal processor for appropriate compensation, bringing down the radome error slope effect within acceptable limits. However, in this case, the particular radome-antenna combination becomes an unique pair. If either the radome or the antenna is damaged, the measurement of radome antenna need be re-done.

3. THE ACTIVE ELECTRONIC SCANNING ARRAY (AESA) SOLUTION

It is evident from above that the conventional gimbaled antenna seeker is not only sluggish and radome antenna performance dependant but also potentially vulnerable to electronic countermeasures.

In order to overcome the above mentioned limitations, the first step solution is to adopt phased array technology so that the antenna beam can be formed and steered by amplitude and phase control essentially by a beam control network. This approach has the additional advantage of producing a null in the direction of a jammer to reduce the vulnerability to jamming situations. This electronically scanned antenna philosophy is equivalent to rotating the antenna radiating the signal energy generated by the seeker transmitter. The fundamental difference is that, electronic scanning provides instant beam switching across a sector of coverage without physically moving the antenna as against the fact that conventional antenna must be physically moved by means of electric motors coupled through mechanical drive mechanism.

In fifties, the electronically scanning phased array radars were surface based radars due to their greater complexity, size, weight and cost, being not affordable as well as suitable for airborne applications. However, with the advent of the new technologies like MIC, MMIC etc., it has been given more attention in recent years for airborne applications also.

4. THE AESA CONCEPT

As already discussed, the AESA is intended to perform the broad functions of

- Scanning a certain volume of space
- Detection, acquisition and tracking of targets

- Provide measurement of parameters related to target mainly with respect to angular location

In addition, the agility of the beam formed by the electronically scanned array provide the following extra advantages:

- Multiple target tracking by an inertia-less antenna
- High angle search/track rate
- A variety of searches such as medium range, long range etc.,
- Illumination control
- High distributed power and spatial power combining

Phased array antennas are categorized into passive and active. Passive arrays use a central transmitter and receiver, but have phase shift capability at each radiating element. In active arrays, the high power generation for transmit and low noise amplification on receive are distributed, as is the phase control at each radiating element. In an active array, a transmit/receive module (TRM) is used at each element to provide amplitude and phase control. The distributed transmit / receive concept leading to the development of T/R modules are of primary interest for all futuristic seeker applications though complex and expensive. Each such T/R module has its own power amplifier in the transmit chain as shown in figure 4. thus, making each element active and the name Active Electronic Scanning Array (AESA) refers to a number of such modules complete with radiating elements (patch antenna or slots) forming the radiating beam in space through appropriate phase and amplitude control by a Beam Control Network (BCN).

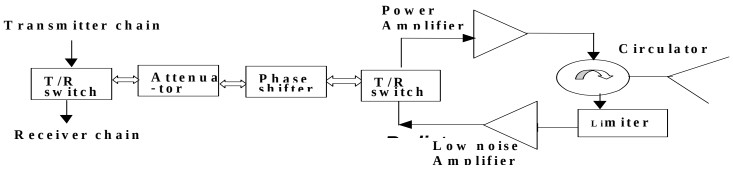


Fig-4 TYPICAL T-R MODULE

We note that the important parameters to be considered for the design of AESA are frequency, power output of the T/R module, antenna aperture, maximum scan angle, radar cross section, overall noise figure, signal-to- noise ration, transmit and receive losses, power dissipation and finally the illumination efficiency. Among these, the T/R module plays the most crucial role as it provides the final stage of power amplification for the transmit signal while low noise amplification for the received signal. Apart from these, it controls the phase and amplitude of the signals to electronically steer the antenna beam. Further, in view of the fact that a large number of T/R modules will be required (typically 1000), the cost per module plays an important role in the design trade off. In fact, this concept was not popular in view of conventional technologies like co-axial, waveguide, MIC etc., for development in view of high cost as well as packaging and integration problems. However, with the tremendous advances in MMIC technology coupled with newer and newer developments in MEMS based RF systems, attempts have been made to develop the MEMS – MMIC seeker for all futuristic applications.

This paper is mainly focused on the Electronic scanning phased array antenna with different configurations such as Hybrid MMIC i.e. GaAs and MEMS plus Hybrid MMIC. It is very clearly brought out that the modern technologies are essential for the realization of AESA seeker.

The required size of the T/R module, fulfilling all the functions have been realized, in two or three MMIC chips integrated in a single package. The GaAs MMIC T/R module configuration is shown in fig 5.

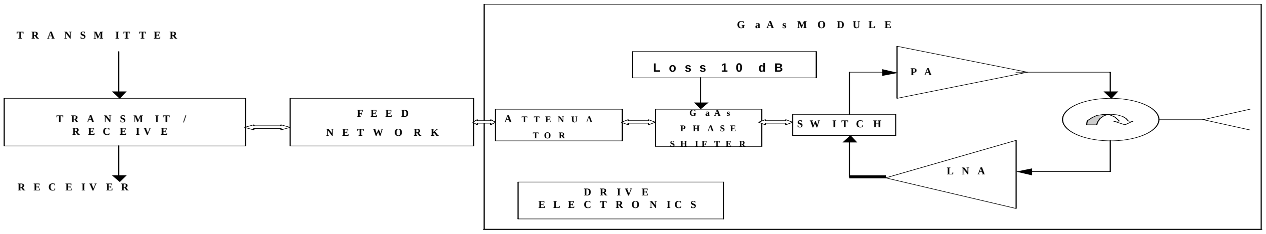


Fig-5 T/R MODULE MMIC (GaAs) BASED APPROACH

In this configuration the main lossy component is the Phase shifter which gives an insertion loss of 9 to 10 dB at Ku band. Since this is common for both transmitting and receiving chains, it is required to provide more power from transmitting source and more gain from receiver amplifier. To overcome this problem, alternate approach and the present state-of-the-art technology is to use a MEMS based realization of the phase shifter. In this approach, the GaAs phase shifter is replaced with MEMS phase shifter which gives only 1 dB insertion loss at Ku band. This gives an advantage of about 8 times less requirement of transmitting power and 9 dB more dynamic range in the receive chain. The MEMS configuration of the T/ R module is given in fig-6.

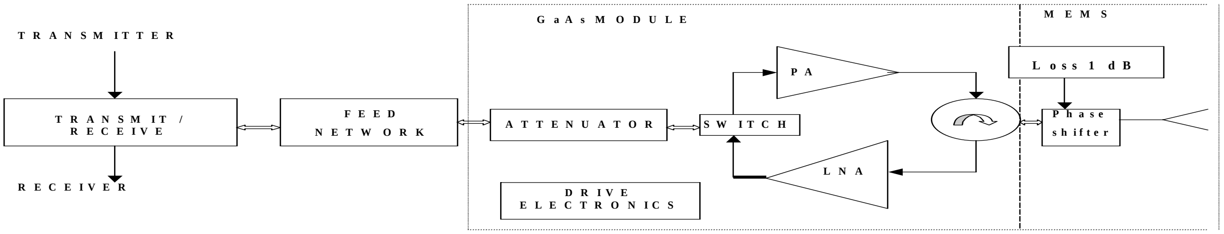
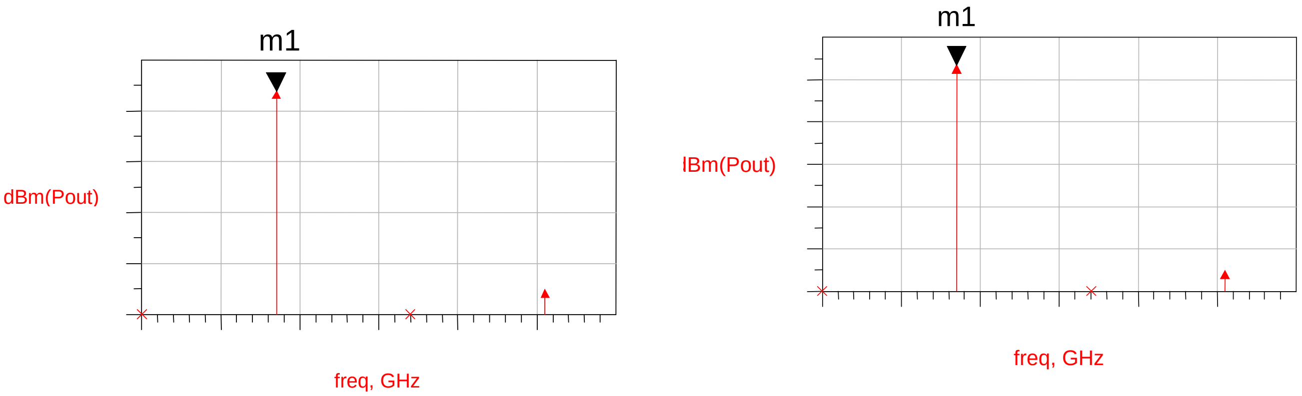


Fig-6 T/R MODULE HYBRID MMIC(GaAs)+ MEMS

The T/R module system design and simulation has been carried out using CAD tools like MATLAB, Agilent EESOF ADS. The electrical performance of the T/R modules in two approaches is given in fig-7.



GaAs APPROACH – INPUT POWER = + 12dBm

MEMS APPROACH – INPUT POWER =+ 2 dBm
RECEIVER CHAIN: 9 dB ADVANTAGE WITH MEMS

Fig-7 POWER OUTPUT

The simulation has been carried out for a single T/R module. For the same power at the output of a T/R module, it is required to apply +12 dBm input power in case of GaAs based MMIC approach, whereas only +2 dBm input power is required for MEMS+ MMIC approach. It indicates that each MMIC phase shifter needs 9 dB additional power than MEMS phase shifter approach which gives about 1 dB loss. Also other factors which decide against the GaAs based approach, are the performance degradation and higher dissipation. AESA which combines the advantages of lower power consumption, better agility and reliability, would require a blend of multiple technologies like MEMS, MMIC, microstrip transmission medium, coplanar transmission medium, digital control electronics.

CONCLUSIONS

In this paper, the importance of the AESA in the present scenario have been attempted to be brought out. The main design specifications, basic design and the basic constituent parts of the AESA were given briefly. The most important constraint of the AESA i.e. size of the T/R module have been also indicated. The importance of the new technologies i.e. MMIC/MEMS were discussed. The advantage of MEMS phase shifter i.e 8 times less drive power while transmitting over GaAs phase shifter is illustrated. In view of these observations, with new technology implementation, the AESA will be the futuristic radar seeker solution.

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