ADVANCES IN ACTIVE RADAR SEEKER TECHNOLOGY IN DEFENCE SYSTEM – A COMPREHENSIVE STUDY

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Abstract

The active radar seeker, from a engineer's view, may be defined as an application-specific compact missile-borne mono-pulse tracking radar whose antenna is mounted on a gyro-stabilized platform such that the antenna is isolated/decoupled from the body movement of the missile. The basic idea stems from the requirement of generating highly accurate target information necessary for precise homing guidance of the missile. Active radar seekers have gained wide applications in the terminal phase of missile guidance to provide hit-to-kill strategy. The superiority of radar seekers in the missile guidance has been well established since 1960s.

Till recently, coherent mono pulse radar configurations were being used extensively for air-to-air missile seekers as well as surface-to-air missile seekers. A special real-beam technique-based seekers have been employed in anti-ships and land attack systems. The features of active radar seekers have been described against different targets and background conditions also been detailed in this paper.The fact is that the seeker design is highly application specific in nature. Different types of seekers are available now based on the type of Electro Magnetic waves they use. The emerging trends in radar seeker technology have been identified with respect to ever changing threat scenario. In this

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paper, an attempt has been made to highlight the features of conventional active radar seekers and the associated current technologies, followed by the requirements of futuristic radars which have to set a trend of the radar seeker technology based on active electronically scanned array (AESA) antenna configuration.

Key words: Active Radar Seeker, Missile guidance, AESA, MEMS, Microwave radar Seekers, MIMC Based Approach.

Introduction

Rapidly advancing military technologies lead to threat advances that must, in turn, be countered with technology advances applied to naval and joint forces. These military technology advances must be implemented in a manner that allows us to meet emerging challenges rather than to react to force deficiencies. Radar technology has been found immensely helpful to meet those challenges.

Radar System

Radar stands for Radio Detection and Ranging. It is an electromagnetic system for the detection and location of objects. It operates by transmitting a particular type of waveform, a pulse-modulated sine wave for example, and detects the nature of the echo signal. Radar is used to extend the capability of one's senses for observing the environment, especially the sense of vision. Radars are also used to determine the range, angle and velocity of targets. A basic radar functioning is shown in the below figure 1.

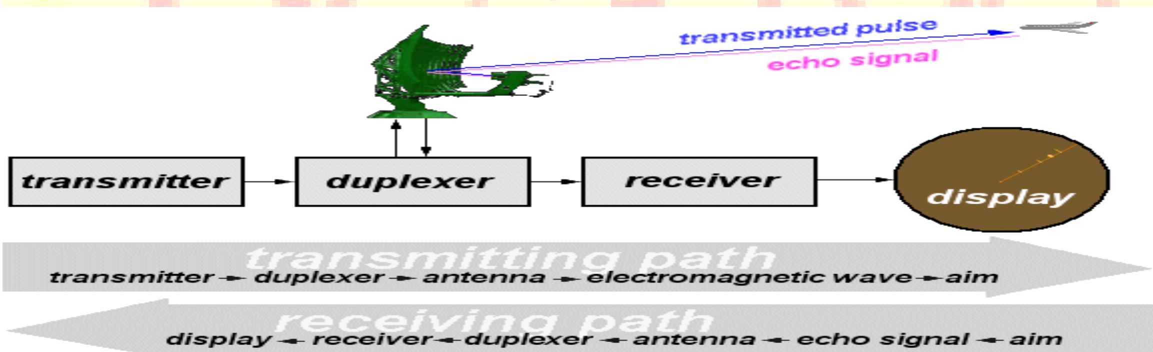

Fig.1- Radar-Basic operation

An elementary form of radar consists of a transmitting antenna emitting electromagnetic radiation generated by an oscillator of some sort, a receiving antenna, and an energy-detecting device, or receiver. A portion of the transmitted signal is intercepted by a reflecting object (target) and is reradiated in all directions. It is the energy reradiated in the back direction that is of prime interest to the radar. The receiving antenna collects the returned energy and delivers it to a receiver. At cases, a single antenna is used both as transmitter and receiver. Then a duplexer circuit is used as a switch, to differentiate the operations of transmission and reception.

The distance to the target is determined by measuring the time taken for the radar signal to travel to the target and back. The direction, or angular position, of the target may be determined from the direction of arrival of the reflected wave- front. If relative motion exists between target and radar, the shift in the carrier frequency of the reflected wave (Doppler Effect) is a measure of the target's relative (radial) velocity and may be used to distinguish moving targets from stationary objects. In radars which continuously track the movement of a target, a continuous indication of the rate of change of target position is also available.

History of Radars

The story of radar begins with radio. Without radio, radar would never have been possible. James Clerk Maxwell (1831 -1879) - predicted the existence of radio waves in his theory of electromagnetism. Heinrich Hertz, a German scientist studied all the Maxwell theories and discovered that radio waves reflected off of metallic objects. The term Radar was coined in 1940 by United Nations Navy as an acronym for Radio Detection and Ranging. Radar works in the same way that a bat uses sound to see in complete darkness. It typically operates in the microwave range in the electromagnetic spectrum, at frequencies ranging from 400MHz to 40GHz. In those days, the radars were used for detection of ships when there is fog all around.

Literature Review

Radars are being used in defence system since early 1930s. Radars were used in the World War-II to detect the hostile air crafts and missiles. Advancements in technology lead to threat advances which in turn are to be countered by the same technology. Radars which are possessed with unique type of characteristics paved a way to new techniques. Many new inventions and methodologies have come in to light making their base as radars.

In the AIAA Aerospace Design Conference, Irvine, CA February 3-6 1992, Cantrell, M., in his paper titled "Endoatmospheric LEAP" in AIAA with Paper no. 92-1215, explained about possibility of Millimeter Active Seeker Rechnology. Mr. Stimson, G. W., in his paper "Introduction to Airborne Radar," Hughes Aircraft Co. El Segundo, CA 1983, pp 577-580 enriched the information for the researchers with details of Airborne Radar Systems. Further Chang, K. and Sun, C, provided vast range of deliberations regarding millimeter wave power combination technique in inter-linking the radar seeker technology in their paper "Millimeter Wave Power Combining Techniques," IEEE Transactions of Microwave Theory and Techniques, V MTT31, no. 2, February 1983.

In the similar lines York, R., Compton, R., "Quasi Optical Power Combining Using Mutually Synchronized Oscillator Arrays," IEEE Tran. Microwave Theory Tech volume MTT39, pp 1000- 1009, June 1991 was a good research exercise proving a realistic view of future generation mechanisms. The paper from Goldsmith, P.F., "Quasi Optics in Radar Systems," which is an invited paper in Microwave Journal, pp 79-98 January 1991, provided good insight for youngsters to make future development in this field.

Rocca, P., L. Manica, and A. Massa, “An effective excitation matching method for the synthesis of optimal compromises between sum and difference patterns in planar arrays,” Progress In Electromagnetics Research B, Vol. 3, 115–130, 2008, is an exercise in Radar Systems Mathematical Interactions. Later the work of Lee, K.-C., C.-W. Huang, and M.-C. Fang, “Radar target recognition by projected features of frequency-diversity RCS,” Progress In Electromagnetics Research, PIER 81, 121–133, 2008 provides wide range information about frequency diversity. Further Qu, Y., G. S. Liao, S. Q. Zhu, X. Y. Liu, and H. Jiang, “Performance analysis of beam forming for MIMO radar,” Progress In Electromagnetics Research, PIER 84, 123–134, 2008.

Apart from all these the technical knowledge from fundamentals has been explained in the book of Skolnik, M. I., Introduction to Radar Systems, McGraw-Hill, New York, 2002, giving good view for the future implications. Elders-Boll, H., M. Herper, and A. Busboom, "Adaptive receivers for mobile DS-CDMA communication systems," Proc. of IEEE Vehicular Technology Conference, Vol. 3, Phoenix, AZ, May 1997, has provided new views and methodologies These studies have helped along with the information collected from ISRO, HAL and NAL helped to go in the new direction in the present paper.

Present Technology

The radar seekers are being used in missile guidance at terminal phase since late 1960s. This technology has been implemented in various seekers including the track-via-missile concept. Among the three configurations namely, active, semi-active and passive, active radar seekers are the most popular in all the current missile programmes owing to their flexibility of design and implementation. The active radar seeker is a missile borne mono pulse tracker. It has been serving the field of defence since the World War-II. At that time, the radars were used in the UHF range. It is a coherent radar detector. Later new methodologies came up.

Proposed Technology

Currently conventional gimbaled antenna configuration is being But due to the mechanical inertia of the gimbaled antenna system, the capability of driving a narrow beam with high speed is limited leading to slow reaction time. This paved a way for alternative approaches like Active Electronically Scanned Array(AESA) configuration and it's sub systems. The AESA concept is based on phased array theory. Such a compact AESA seeker is possible to be realized using T/R modules. T/R modules refer to transmit/receive module. Later T/R modules based on MMIC technology and MEMS technology also came up to overcome the drawbacks of the existing technology.

Radars in Missile Guidance

Missile guidance refers to variety of methods of guiding a missile or a guided bomb to its intended target. A radar guided missile is a type of anti-aircraft missile that uses reflected radar energy to guide itself towards its target. These missiles can be surface-to-surface, surface-to-air or air-to-air. Radar guided air to air missiles currently represent the best of what state of the art technology can offer, both in terms of range, accuracy and resistance to countermeasures.

Radars are being immensely used in military for the purpose of missile guidance since 1930-40s. The first practical radar system was produced in the year 1935 by Sir Robert Watson-Watt. These guided missiles were first developed during World War-II. Almost all the big Nations implemented radars in their operations. The below figure shows the radars used during World war-II by Germany and Great Britain respectively.

Fig.2- Radars during World War-II

Types of Radar guided missiles

Radar-guided missiles exist in four basic categories namely

1. command guided.
2. active homing.
3. semi-active homing
4. passive homing.

Command guided missiles:

A command guided missile has neither a radar transmitter nor a radar receiver on board. A separate radar (usually ground based) tracks both the tar<1et and the outgoing missile and computes the trajectory changes needed to guide the missile to its target. These flight commands are communicated to the missile by a data link. Command guidance may be necessary when other modes of missile guidance are inadequate because of clutter. jamming. or missile receiver sensitivity problems. Many foreign missiles employ command guidance modes because a command-guided missile does not require a complex on-board seeker system.

Active homing:

An active missile carries its own radar, complete with transmitter and receiver. Because of a small payload capacity and antenna aperture. the radar on a missile is not as powerful as a ground based or aircraft-mounted radar. To achieve long ranges on low cross-section tar<1ets. active homing must be combined with other means such as command guidance to get the missile within homing range to the target. Active missiles have the attractive features of fire-and-forget which can increase the fire power of a given fire control system. A disadvantage of active missile seekers is higher cost. since a radar transmitter is required in the missile.

Semi-active homing:

A high proportion of the world's radar missile inventories use a semi-active architecture a scheme in which the missile carries only a radar receiver. not a transmitter. The radar transmitter that illuminates the target is in a separate unit that is either ground based or airborne. This architecture has several advantages. Delivering sufficient radar energy to a target at long ranges requires high transmitter power and high-gain antennas (thus requiring a large antenna aperture). both of which are difficult to achieve on a missile constrained in weight and volume. A further advantage of the semi-active architecture is that electronic countermeasures intended to frustrate the missile are often directed back toward the radar source.

Passive homing:

A passive homing seeker guides itself by radio emissions from the target. These emissions are from the target's own radar or other on-board radiating sensors. The advantages of passive homing are that it does not require a separate illumination radar and it operates quietly(a powerful illumination signal recognized by the target is a warning of the imminent arrival of a missile).

A disadvantage is that the passive seeker depends on the presence of target emissions during homing. and these emissions are not controlled by the missile system. Another disadvantage is that the seeker must operate with a variety of different waveforms that are specific to particular targets. and these waveforms are not optimal for missile homing.

Radar guided missiles have great operating range of about 100 miles. These radar guided missiles are really useful in detecting enemy war ships or aircrafts and attacking them on spot during the war.

The below picture was the radar guided bomb development during 1943-45.

Fig.3- Radar guided bomb

After the war, radar use was widened to numerous fields including: civil aviation, marine navigation, radar guns for police, meteorology, communication and even in medicine.

The phased array antennas also came in to picture. Due to their peculiar properties, many experiments were conducted on radars to make them applicable in various fields. Present day military uses radar seeker technology.

Radar Seeker Technology

Radar and its related researches have gone through a history for more than a century. In recent years, new techniques are applied in various radar systems. The threat of electronic jamming to military radar is well known.

Seeker is an essential part of any missile. It provides accurate information regarding the target, in terms of range, relative velocity and angle.

Long range target identification and tracking is very much necessary in defence. Seeker serves this purpose of maintaining the track of the missiles and attacking them in a efficient manner. Seeker is the eye of the missile.

The seeker is a system on the missile that performs the on board target sensing for flight guidance, with the ultimate purpose of bringing the intercepted missile's warhead with in a lethal radius of the target.

It's job is to acquire and track the target until the missile impacts the target. Tracking means maintaining a track or course of certain object. These seekers generally provide bore-sight signals that are electromagnetic in nature.

These electromagnetic waves are continuous waves and travel with the velocity of light. They consist of different types of waves differentiated on the basis of their frequency bands. The general block diagram of a seeker is shown below.

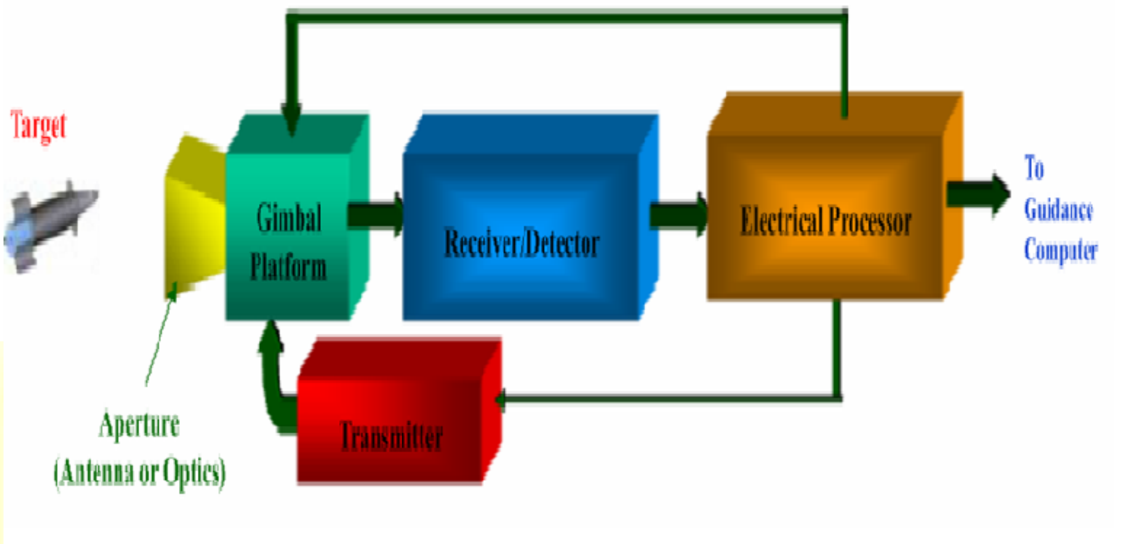

Fig.4- Seeker basic block diagram

The performance of the seeker highly depends up on which frequency band it is operated in and cut-off frequencies. It also depends on the power consumed and weather conditions as the presence of clouds and fog may reduce the velocity and frequency of the beam. The hit to kill guidance requirement primarily impacts the seeker angular tracking accuracy. In addition to it, tracking error also should be minimum for better results. The tracking error mainly depends upon the half power beam width and signal to noise ratio which in turn depends on the wavelength of the waves. Other source of angle tracking error is due to finite angular extent of the target, which can be reduced by limiting the finite angular extent with very high range resolution. Heat dissipation is another point which is to be looked in to. It occurs due to thermal shock. The remedy is to use actively cooled radomes through out the flight.

Types of Seekers

Seekers are classified into two types based position of seeker head. They are

1. Stabilized Seeker Head.

2. Strap-down Seeker.

1. Stabilized Seeker Head:

In this type of seekers, the seeker head is isolated from the missile body motion through gimbals, servo motors and rate sensors. Here a clear stabilized signal/image is presented to the seeker detector. It is of really high cost so financially it becomes a problem to use it. The complexity, size and weight are also so high in this configuration.

2. Strap-down seeker:

Here the seeker head is rigidly attached to the missile body. So it observes the same motion as the missile. Unlike the stabilized seeker, here the image/signal quality is very poor or cheap. And also the field of regard is also very less. It has limited engagement geometry. Not only the above mentioned types, classification of seekers can be done based o various grounds. There are three other configurations in seeker technology based on the functionality namely, active, semi-active and passive configurations.

1. Active: The active radar seeker has it's own radar with transmitter and receiver. It has attractive feature of Fire and Forget strategy.

2. Semi-active: It is a scheme in which missile carries only radar receiver but not radar transmitter. Here the transmitter is a separate unit that is either ground based or air borne.

3. Passive: The passive system guides itself by the radio emissions from the target. It does not require any illumination radar as in semi-active case and it acts quite.

Out of all the above mentioned types of seekers, active radar seekers are the most commonly used configuration due to its characteristics and advantageous working. Also the active radar seeker can tackle with the changing weather conditions.

Active Radar Seekers

Active radar seekers have been used in the missiles with an ultimate objective of achieving hit to kill strategy. This is the current running 'fire and forget' technology. Active radar seeker, from an engineer's point of view may be defined as an application-specific compact missile borne mono pulse tracking radar whose antenna is mounted on a gyro stabilized platform. The antenna can be isolated or decoupled from the missile whenever required. The basic idea stems from the requirement of generating highly accurate target information necessary for homing guidance of the missile. The below image is a picture of an active radar seeker.

Fig.5- Active Radar Seeker

The most extensively employed configuration of active radar seekers so far is coherent mono pulse tracker with gimbaled antenna configuration. Mono pulse radar tracker is a radar system that compares the received signal from a single radar pulse against itself in order to compare the signal as seen in multiple directions, polarizations and other differences.

When the received signals are received they are amplified separately and compared to each other, indicating which direction has a stronger return. Since the comparison is carried out during one pulse, which is typically a few microseconds, change in target position or heading will have no effect on comparison. Making such comparison requires that different parts of beam be distinguished from each other.

This results in a set of lobes, usually two, overlapping on the bore-sight. These lobes are then rotated as in a normal conical scanner. On receiving the signals are separated and one is inverted in power and then both the signals are summed. Mono pulse radars are in use since late 1960s. They are extremely high-tech, complex and expensive.

Block diagram of Active Radar Seeker

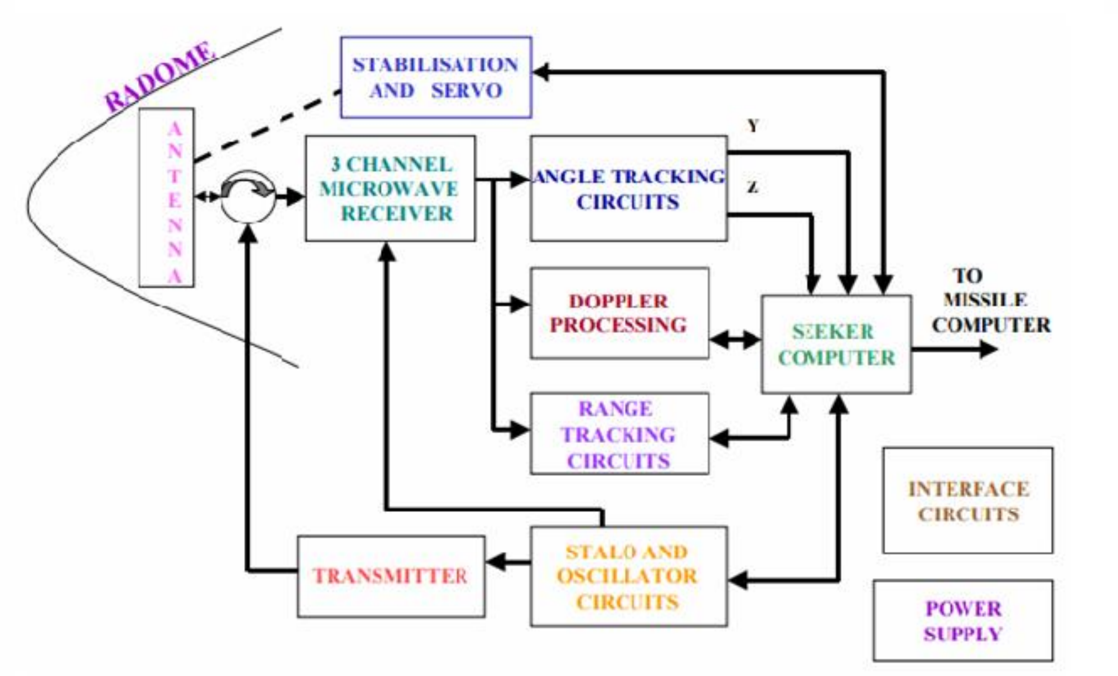

Fig.6- ARS- Basic blocks

The active radar seeker essentially consists of the above mentioned blocks. It is a coherent three-channel mono pulse master oscillator power amplifier(MOPA) system capable of tracking the targets in terms of angle as well as relative velocity. The functioning of each block is as follows.

Radome

Radome is a structural, weatherproof enclosure that protects the microwave antenna.

The radome is constructed of material that minimally attenuates the EM wave transmitted or received by the antenna.

In other words, radome is transparent to radar or radio waves. It can be in different shapes and thicknesses depending up on their specific applications. Many special manufacturing processes have been developed to reduce the radome error slope variation. The variable thickness radomes as well as thin walled radomes based on glass-filled polycarbonate technologies have been widely used along with these processes to compensate the losses.

Antenna:

An antenna or aerial is an electrical device which converts electric power into radio waves and vice-versa i.e. it functions as a transceiver. Typically the antenna consists of an arrangement of metallic conductors, electrically connected to the receiver or transmitter. Antennae can be designed to transmit or receive radio waves in all horizontal directions or preferentially in a particular direction. A slotted planar waveguide array antenna weighing less than 500gms with an integrated microwave receiver, has been extensively used in most of the present day seekers.

Transmitter:

Transmitter generates and transmits EM waves that are fed to the antenna. The master oscillator power amplifier(MOPA) configuration using traveling wave tube klystron has been extensively used. Here the transmitter is based on injection-locked magnetrons.

The solid state power amplifier driver is implemented along with microwave power amplifier. It utilizes the concept of microwave power module(MPM) where power added efficiency is maximized.

Receiver:

Receiver receives the transmitted EM waves from the receiver which receives the waves from transmitter. The present day seekers use the state-of-art triple-super heterodyne MMIC based receivers with much low noise figure (2).

Signal Processor / Data processing:

Signal processing is an enabling technology , that encompasses the fundamental theory, applications, algorithms and implementations of processing or transferring information contained in signals. It can be achieved by digital signal processors. intensive application-specific integrated circuit based processors have been developed to suit specific applications. In some radar seekers, wide dynamic range is crucial requirement. This need can be met by implementing crystal filter-based analog signal processing. Now a days system-on-chip attempt is being attempted.

Stabilization system:

The stabilization system is designed to maintain the antenna beam at a selected tilt angle relative to earth surface. The stabilization system comprises of electrical amplifiers in the receiver/transmitter interconnected with electromechanical components in the antenna. The high precision gimbaled mechanical system with low outline has been used in the gyro of the inertial navigation system providing reference for the seeker stabilization.

STALO oscillator:

STALO is an acronym for Stable local oscillator. It is a highly stable local radio-frequency oscillator used for heterodyning signals to produce an intermediate frequency in radar moving target indicators. It supplies signal to the transmitter.

The remaining angle tracking and seeker computer are used to track the angular path of the target and to record its path from time to time.

Onboard Missile Computers:

To accomplish homing guidance, a missile computer is very much essential. the first onboard computers are analog but later digital onboard computers came into picture. Before launch, the location of the target is programmed in the computer. The active radar seeker with onboard computer is shown below.

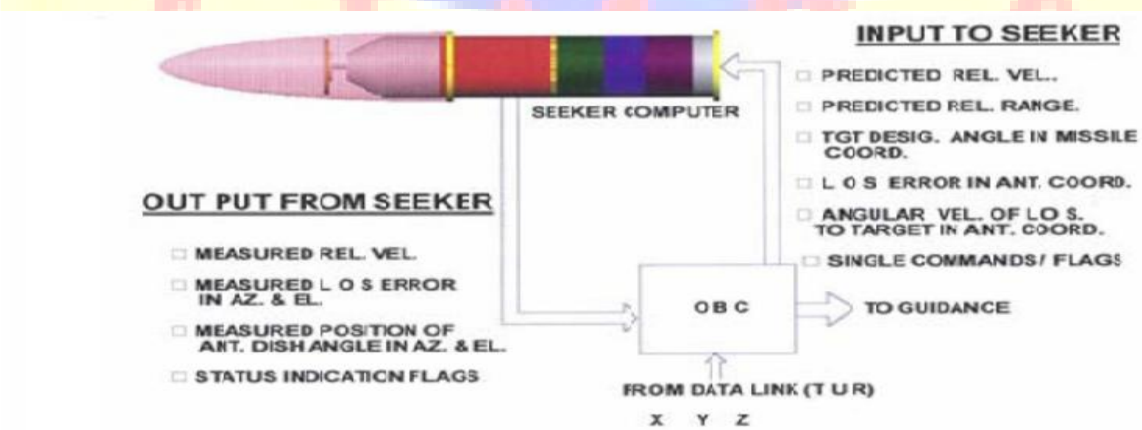

Fig.7- Active Radar Seeker with onboard computer

The onboard computer stores the maps of the missile routes and directs the missile accordingly. Necessary guidance commands must be computed by the onboard computer. It requires the rate of change of line-of-sight of target with respect to missile. By keeping continuous track of the target, the line-of-sight rate is calculated. Additional target information in terms of range and relative velocity is used to identify and track a desired target among other targets including clutter. The operation of active radar seeker has been shown in relation to the onboard computer responsible for the overall guidance of the missile.

With all these equipments, the active radar seeker is boarded on to the air craft as shown in below figure-.

Fig.8- Seeker boarded on the air craft

The missile is fired from the plane as soon as the target is detected as shown below

Fig.9- Firing of a missile

Electronic Counter Measures

ECM Techniques

However it is equally important to protect our own missile from the enemy's attack. ECM-Electronic Counter Measure technique is quite useful in this process. An electronic countermeasures are measure taken to trick or deceive radar, sonar or other detection systems, like infra-red radars. It is a series of actions taken to prevent or reduce the enemy's effective use of electromagnetic spectrum. It may be used both offensively and defensively to deny targeting information to an enemy. The system may make many separate targets appear to the enemy or make the real target appear to be disappeared or move randomly. It is frequently coupled with stealth advances so that the ECM systems have an easier job.

But there are some problems with this ECM techniques too. If tried to increase the detection range by increasing the sensitivity of the radar, it resulted in many unwanted side- effects. These unwanted disturbances, called 'natural' ECMs-clouds, ground returns from trees, mountains, etc., and un-intentional man-made ECMs-returns from buildings, water tanks, ground vehicles, etc. began to make radar scope watching quite unpleasant. Later on, the advent of intentional ECMs like jammers and chaff made radar scope watching worse. This resulted in the discovery and development of ECCM techniques.

ECCM Techniques

ECCM stands for Electronic Counter Countermeasure. It is defined as actions taken to ensure friendly use of the electromagnetic spectrum. Many ECCM features are incorporated in the radar design. Most of the ECCM techniques are based on the characteristics of transmitted radar pulse, which in turn, depends upon the radar parameters like power, frequency, PRF, pulse length, antenna gain etc.

The radar sensors, for most of the surface-to-air missiles (SAMs) as well as air-to-air missiles (AAMs), is configured as a high PRF (HPRF) pulsed (Doppler) radar frequency essentially as a Dopplertracker apart from being a basic monopulse angle tracker. However it may be noted that for anti-ship missiles, the radar waveform is for slow moving target detection and identification. Currently high/medium PRF pulsed waveforms are in use. The complex waveform design is the latest trend to combat ECM and ECCM techniques and provide automatic target recognition capability.

Changing Requirements & Drawbacks

Because of advances in radar cross-section reduction techniques and ECM, the seekers will face increasingly sophisticated threats. In fact, the advent of low radar cross section air vehicles has made countermeasures more attractive because the radiated power necessary to mask a vehicle's radar return has decreased to the point where small countermeasure devices are now practical. As mentioned above, these ECM and ECCM techniques are used both in defensive and offensive operations. With advances in ECM techniques, stealth technology and target operational performances the requirements for the seekers also changed. The following requirements need to be considered for a seeker design.

- Low peak power for reduced vulnerability of detection as well as less demanding power supply system.
- High power aperture product for increased range.
- Optimum waveform design for advanced ECCM features.
- Faster signal processing for large data handling and image processing.
- Low radar cross section detection and tracking capability to meet stealth technology advancements.
- Low weight/low volume/ high density packaging and efficient thermal management for miniaturisation.
- Multi sensor data fusion being implemented through data link.

New technologies

The above requirements have pushed the radar seeker technology to adopt new concepts and has lead to development of the following entirely new concepts

1. Noise Radar Seekers
2. MMW radar seekers

Noise Radar Seekers

Noise radar seekers refer to seekers whose transmitted waveform is random or random-like in contrast to conventional pulse, continuous, frequency-modulled continuous waveform. The most important advantage of this noise radar is its low cost. The noise radar seeker transmits a very wide band random noise signal. It always makes a copy of the signal it transmits so that it can correlate it with the received signal. To function, the seeker processors and converters must clock at >1GHz speed. This design is made possible by the recent advances in high speed digital signal processing technology. The important features of this technologies

- Extremely high bandwidth which in turn gives high range resolution.
- Simultaneous measurement of range and Doppler with high accuracies.
- Jamming resistance.
- No ambiguity.

Millimeter Wave Radar Seekers(MMW Radars)

The millimeter wave radar seekers is a better option in many seeker applications during modern times including imaging sensors. In order to achieve miniaturised seeker, evaluations are performed on them extensively during the last decade. Latest developments aim at completely solid state, highly reliable, low-cost systems. However to implement this technology complexity of the millimeter wave technology does pose a significant technical challenge. The pulsed radar system requires higher power and therefore expensive transceiver circuit to meet the signal-to-noise ratio requirement, while FMCW system offers the advantage of simple and low-cost transceiver circuitry, but has stringent transmitter/receiver requirements.

Limitations of present day seekers

Like a coin has two faces, head and tail, the active radar seekers also have some disadvantages. These disadvantages lead to many problems during the operation of the radars. So these cant be given a blind eye. They are:

Mechanical Inertia of the antenna:

In a conventional gimbaled antenna seeker, it is the response of the electromechanical servo system, which ultimately decides the overall seeker performance in terms of speed and precision. The key parameter in this regard is .the mechanical inertia of payload of the servo system, i.e. the antenna system. Also, this occupies relatively more space and has more power consumption, apart from being potentially vulnerable to electronic countermeasures. And also due mechanical inertia of gimbaled antenna system, capability of guiding a narrow beam with high speed and precision is limited.

Radome error slope:

The second constraint of the conventional gimbaled antenna seeker originates from an entirely different phenomenon. This is due to achievable radome error slope within the required scan angles caused by the presence of radome as against the limit of radome error slope value permissible to ensure adequate missile stability with an acceptable miss-distance. For this reason, the radome error slope measurement data is extremely important and the two distinct methods are used to limit the radome error slope value as described below:

In the first method, the error slope is continuously measured during radome fabrication and appropriately corrected during the process. In this case, each radome is cleared after conducting the test with a standard seeker antenna. This method can reduce the radome slope error up to 3%.

In the second method, a complete data of radome error slope measurement in all possible planes is stored in the seeker computer which is used as the digital signal processor for appropriate compensation in the angle-processing channel, bringing down the radome error slope effect within the acceptable limits. This method brings down the error value up to 1.5%.

While the above two are major drawbacks, there are some other points which cant be ignored that easily such as

- As there is only a single antenna present, all the tasks like acquisition, tracking and guidance are to be performed by the lonely antenna leading to slow reaction time. In addition to this it also requires characteristics like transmitter power and receiver sensitivity.
- Seeker sensitivity is also figured out to be one of the drawbacks of active radar seekers.

Future radar seekers will require higher sensitivity and more effective clutter rejection. These seekers will probably incorporate dual polarization sensors and multi-spectral sensors, such as a combination of infrared and radar. The future enhancements will help discriminate and reject false targets, including decoys.

Futuristic Radars- AESA

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. 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. To overcome the above limitations of existing seeker performance, the current seeker technology is looking for alternative approaches like AESA technology.

Introduction to AESA Technology

AESA stands for Active Electronic Scanning/ Steering Array. It is a type of phased array radar whose transmitter and receiver functions are composed of numerous transmit/receive modules. 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. This approach has the additional advantage of forming a null in the direction of a jamming signal source, thus reducing the effectiveness of jamming. The AESA technology has a wide range of operation. The below figure shows an AESA radar.

Fig.10- AESA Radar

Concept of AESA:

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.
- 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.

As mentioned above, AESA technology allows instant beam switching and simultaneous tracking of one or more targets. The below figure shows how AESA tracking and targeting of missiles takes place
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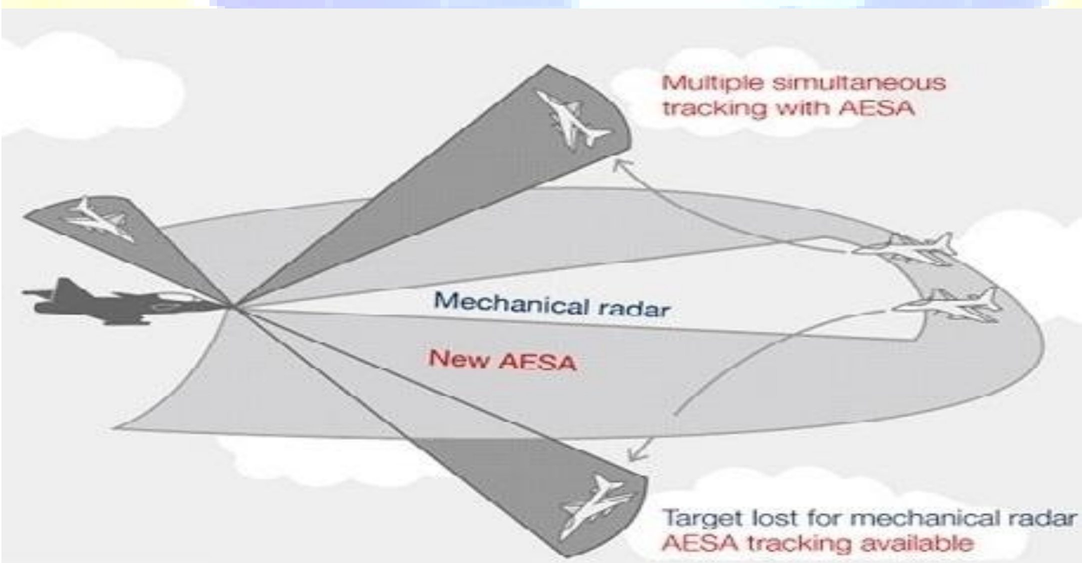

Fig.11- Tracking by AESA radar

In active electronic scanned array concept, the operation is actually accomplished by adopting phased array technique. As mentioned before, there will be large number of T/R modules in AESA radar, these modules will be arranged in the form of an array .This phased array radar concept is not a completely new one.

Concept of Phased Array Radars

The concept of phased array radar is certainly not new and its development began around 1958. Early radar transmitters and the early World War II radars used multiple radiating elements to achieve desired antenna radiation patterns. The Army's "bed spring" array, which first bounced radar signals off the moon in the mid-1940s, is an example of an early array radar.

A new initiative in the 1950s led to the use of rapid electronic phasing of the individual array antenna elements to steer the radar beam with the flexibility and speed of electronics rather than with much slower and less flexible mechanical steering. Many skeptics at that time believed a workable and affordable array radar with thousands of array elements, all working in tightly orchestrated phase coherence, would not be built for a very long time.

Scientists started working on phased-array radar development projects around 1958. The volume of radar surveillance needed to accomplish the task of detecting other satellites was clearly enormous, which meant that radars of great power, antenna aperture, and beam agility would be required. The below figure is a model of 1950s phased array radar.

One approach to solving this surveillance problem was to build a large planar array of some five thousand UHF elements. However it is not that easy to produce reliable low-cost components and to implement a radar with five thousand individual transmitter and receiver modules. Thus began a search of a variety of hybrid mechanically scanned and electronically scanned antenna-array configurations. This hybrid array concept had great power, great receiving aperture, and a rapid wide-angle scan capability.

It was configured to survey huge volumes of space, so that one installation could detect all satellites passing over up to an orbital altitude of three thousand nautical miles. Phased array antennas are categorized into passive and active. But active arrays are mostly used. 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

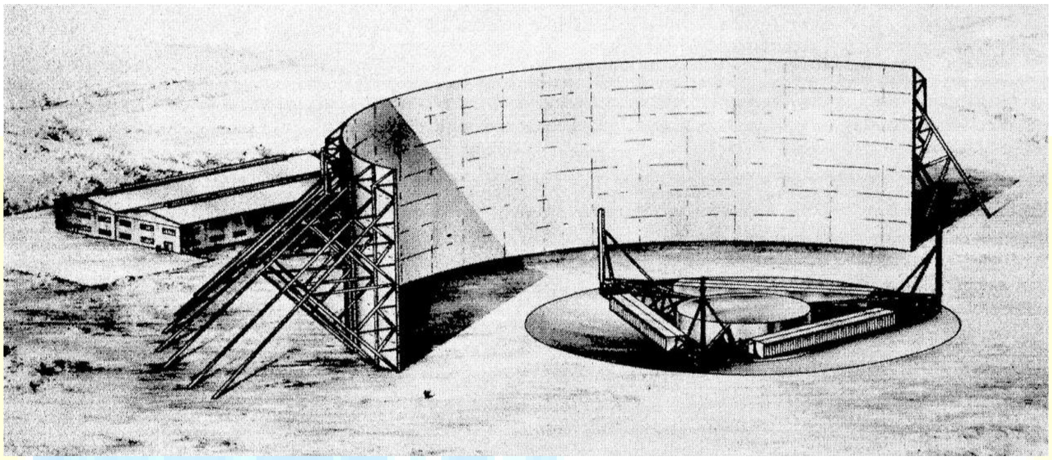

Fig.12- Phased Array Radar in 1950s

The basic functional unit of the phased array radar and in turn the entire AESA system is the small T/R module- transmit/receive module.

T/R module

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 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). This has been made possible using microwave integrated circuit, monolithic microwave integrated circuit technology.

These can be packaged within the space available for seeker application. The operation of the seeker is actually accomplished by adopting phased array technique. This approach has the additional advantage of forming a null in the direction of a jamming signal source, thus reducing the effectiveness of jamming. A typical TIR module is shown in the figure below.

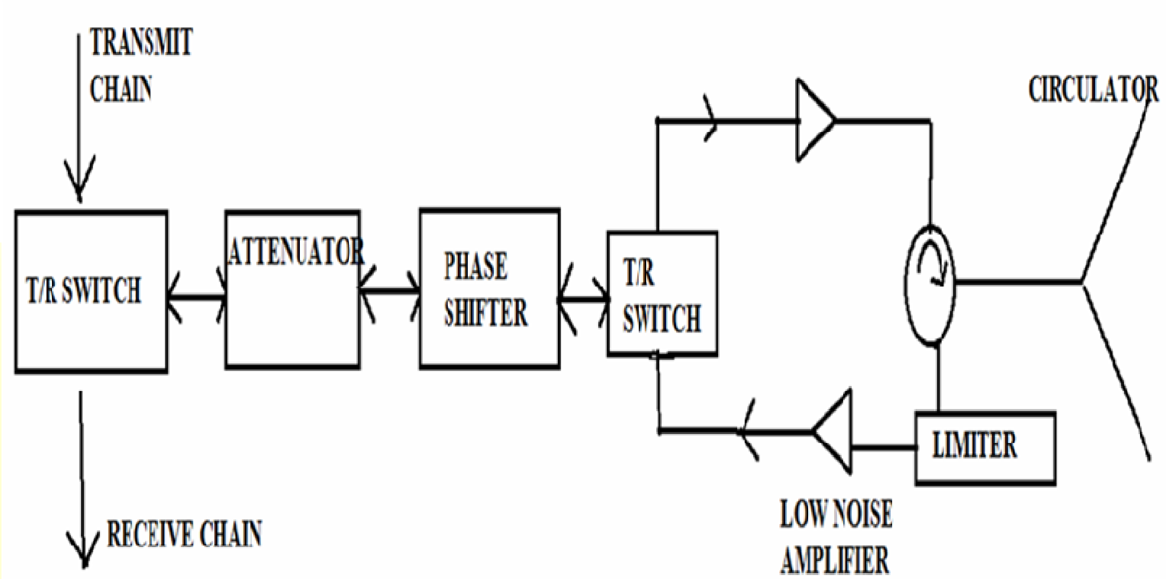

Fig.13- Typical T/R Module

The T/R module consist of a power amplifier in the transmit chain, low-noise amplifier in the receive chain in conjunction with phase shifter as well as attenuator control common to both. Therefore, overall system power efficiency is increased as both the transmit power amplifier as well as receiver low-noise amplifier are directly connected to the radiating antenna via the circulator/limiter, resulting in less RF loss. The most 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.

It is further noted that the T/R module configuration is readily amenable to coherent detection, a primary requirement for Doppler processing. T/R modules provide 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.

But the drawback with it is that this technique requires large number of transmitter and receiver modules, nearly up to 1000 in number. Thus the cost per module and their maintenance increases. To overcome it a new technology called as Hybrid MMIC took birth.

MMIC Technology

MMIC stands for Monolithic Microwave Integrated Circuit. It is a type of integrated circuit device that operates at microwave frequencies(300MHz to 300GHz). These devices typically perform functions such as microwave mixing, power amplification, low noise amplification, and high-frequency switching. Inputs and outputs on MMIC devices are frequently matched to a characteristic impedance of 50 ohms. This makes them easier to use, as cascading of MMICs does not then require an external matching network. Additionally, most microwave test equipment is designed to operate in a 50-ohm environment. MMICs are dimensionally small (from around 1 mm^2 to 10 mm^2) and can be mass-produced, which has allowed the proliferation of high-frequency devices such as cellular phones. MMICs were originally fabricated using gallium arsenide (GaAs), a III-V compound semiconductor. It has two fundamental advantages over silicon (Si), the traditional material for IC realization: device (transistor) speed and a semi-insulating substrate. Recently Silicon is also being used. Other combinations like Indium phosphide (InP), Silicon germanium (SiGe) and Gallium nitride (GaN) are also being implemented these days. These can operate at higher temperatures and at higher voltages.

T/R module based on MMIC approach

The MMIC based hybrid approach is also a bit similar to normal T/R module one. 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 only extra blocks are the drive electronics and feed network.

The typical T/R module accompanied with hybrid MMIC technology is shown in the below figure.

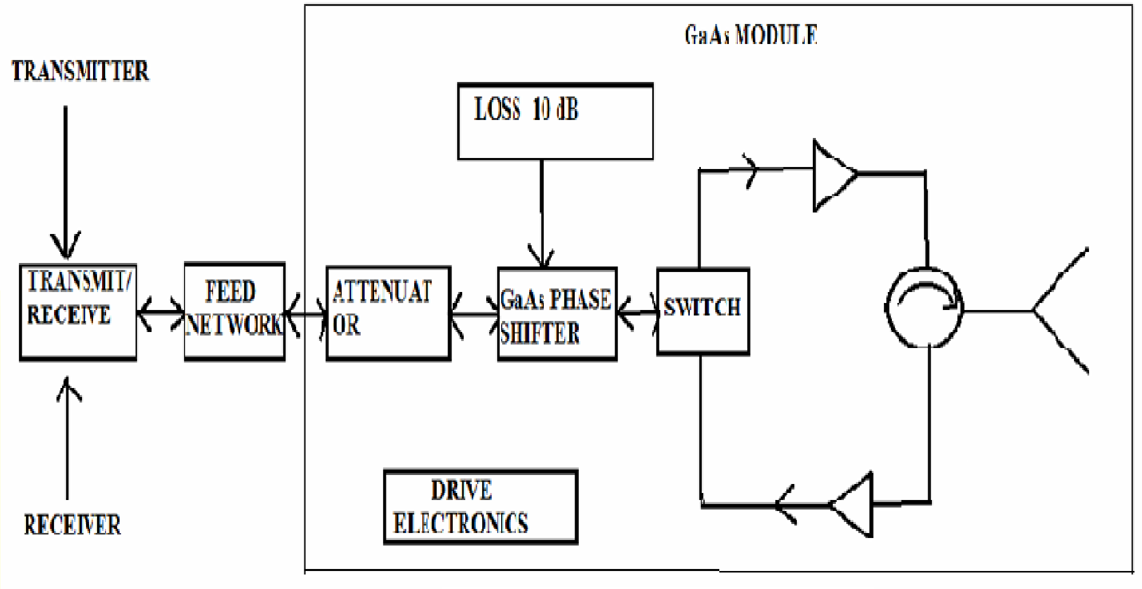

Fig.14- T/R module with MMIC based approach

In this configuration the main lossy component is the Phase shifter which is used to just shift the phase for long distance transmission. This phase shifter introduces 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. This insertion loss introduced by the phase shifter is the only disadvantage of the MMIC hybrid technology. In addition to the insertion loss, the MMIC cost is comparatively high at present times. Due to the insertion loss mentioned above, the performance also reduces. These are main drawbacks in MMIC technology. To overcome these problems, alternate approach and the present state-of-the-art technology is to use a MEMS based realization of the phase shifter.

MEMS Technology

MEMS stands for Micro Electro Mechanical Systems. It is a technology that in its most general form can be defined as miniaturized mechanical and electro-mechanical elements (i.e., devices and structures) that are made using the techniques of microfabrication. is technology of very small devices; it merges at the nano-scale into nanoelecrtomechanical sytems (NEMS) and nanotechnology. MEMS are also referred to as micro-machines and micro systems technology. MEMS are separate and distinct from the hypothetical vision of molecular nanotechnology or molecular electronics. The one main criterion of MEMS is that there are at least some elements having some sort of mechanical functionality whether or not these elements can move. MEMS are made up of components between 1 to 100 micrometers in size (i.e. 0.001 to 0.1 mm), and MEMS devices generally range in size from 20 micrometers to a millimeter (i.e. 0.02 to 1.0 mm).

The fabrication of MEMS is done by using semiconductor materials like Silicon, Polymers, Metals and Ceramics. While the functional elements of MEMS are miniaturized structures, sensors, actuators, and microelectronics, the most notable (and perhaps most interesting) elements are the microsensors and microactuators.

Microsensors and microactuators are appropriately categorized as "transducers", which are defined as devices that convert energy from one form to another. In the case of microsensors, the device typically converts a measured mechanical signal into an electrical signal. Potentially, such chips can be built in large quantities at low cost, making them cost-effective for many uses.

The below figure explains about the basic components in MEMS unit.

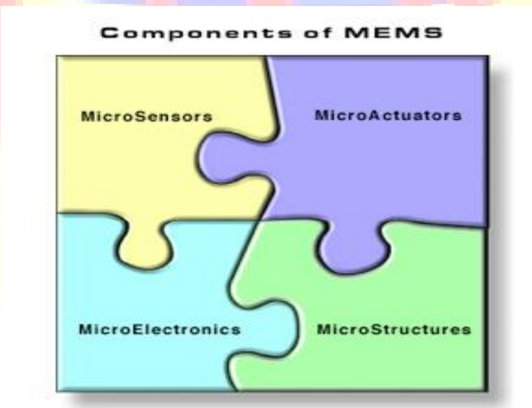

Fig.15- Components of MEMS

There are many fields which use MEMS technology. Some of them are

- Global position system sensors that can be included with courier parcels for constant tracking and that can also sense parcel treatment en route.
- Sensors built into the fabric of an airplane wing so that it can sense and react to air flow by changing the wing surface resistance; effectively creating a myriad of tiny wing flaps. - Optical switching devices that can switch light signals over different paths at 20-nanosecond switching speeds.
- Sensor-driven heating and cooling systems that dramatically improve energy savings.
- Building supports with imbedded sensors that can alter the flexibility properties of a material based on atmospheric stress sensing.

T/R module based on MEMS concept

This technology is used at Radio frequency ranges. RF MEMS components for radars include attenuators, limiters, (true-time-delay) phase shifters, transmit/receive (T/R) switches and tunable matching networks. Radar subsystems which benefit from RF MEMS technology include active electronically scanned arrays (T/R modules), passive electronically scanned arrays (lenses, reflect arrays, subarrays, and switched beamformers), and radomes. Using a bottom-up approach, the figures of merit for RF MEMS technology are related to the figures of merit for radar subsystems.

Coming to the T/R module based on MEMS technology, it is some what similar to MMIC technology. The GaAs phase shifter of MMIC seeker is replaced with MEMS phase shifter here. This helps in reducing the insertion loss that occurred due to GaAs phase shifter in MMIC. More over, MEMS gives only 1dB 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 following figure shows the MEMS technology seeker.

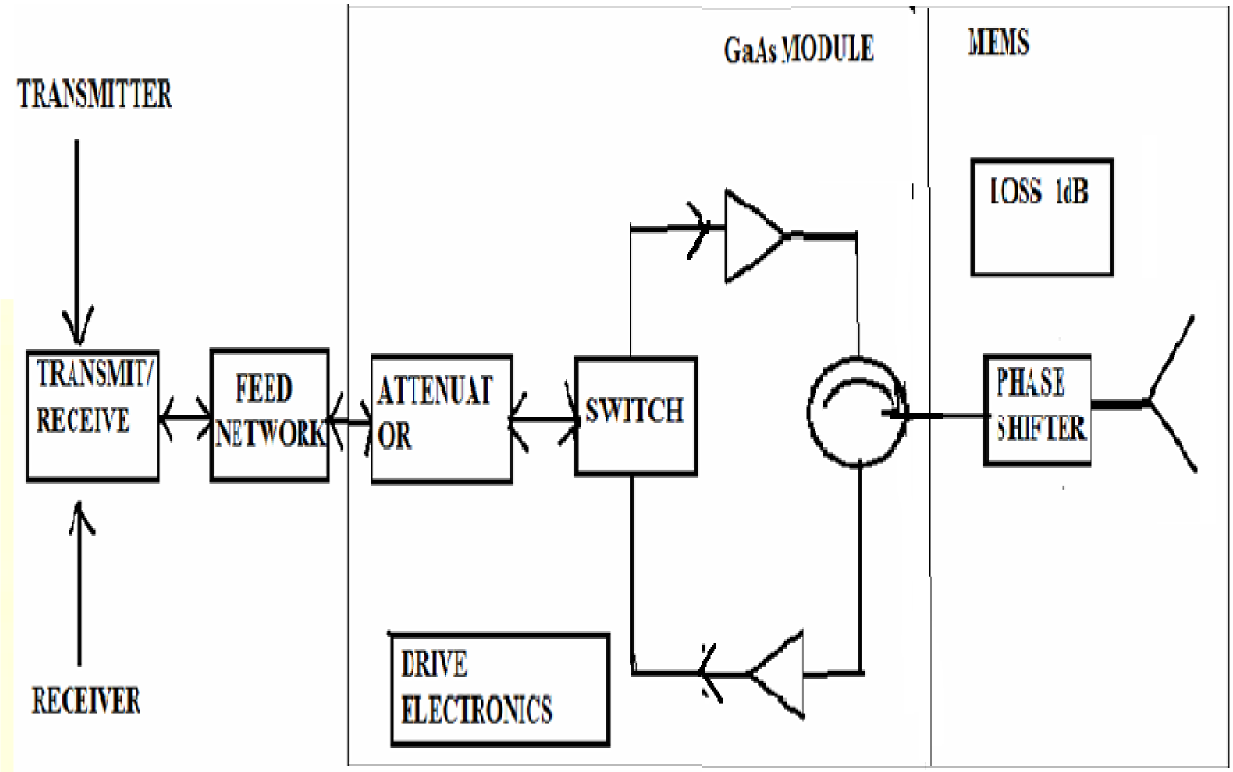

Fig- T/R module with MEMS technology

The T/R module system design and simulation has been carried out using CAD tools like MATLAB, Agilent EESOF ADS. 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.

Advantages of MEMS technology

The following are the advantages MEMS radars.

- The power loss in AESA radar accompanied with MEMS technology is negligible when compared with normal radars. It is in the order of 1dB, which can be neglected.
- As the MEMS units are very small in size and manufactured in lot, the cost of production is very less.
- Radars with MEMS technology are highly durable and reliable.
- Due to small size, MEMS units consume very less power and the heat dissipation is also very less.
- When compared to GaAs phase shifter, the MEMS phase shifter has 8 times less drive power.

Conclusion

Radar seekers technology is a fruitful method and it proved to be really advantageous in many situations. At par with the development of seekers, highly sophisticated simulation techniques and related software as well as test setups have come up, enabling complete evaluation of seeker performance under dynamic conditions. In addition, mathematical modeling and theoretical prediction techniques have matured to the extent of highly convincing and acceptable results validated through the experiments. 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 over GaAs phase shifter is illustrated. In view of these observations, with new technology implementation, the AESA will be the futuristic radar seeker solution.

Note: The Views and opinions expressed, conclusions drawn and critical analysis arrived at or any other ideas/ strategies in the above paper are of our own and do not reflect or represent the views of any of the organization

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