

Design aspects of Phased Array Antenna at L-Band

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Abstract – The multiple object tracking is done using Phased Array Radar. Phased array antenna, Digital receiver, Data processing system is the major systems of the Phased Array Radars. Phased array antenna consists of an array of radiating elements and each element is connected to a phase shifter. The phase shifters control the phase of the radiated signals at each element to form a beam at the desired direction. This paper deals with design aspects of Phased array antenna and to study its properties. Based on the study, simulations are carried out on 1X4 array and the same is fabricated for testing to analysis the results.

Keywords: phased array antenna, phase shifter, 1X4 array

I. INTRODUCTION

Phased Array Radar finds wide applications in the areas of space research and defense, particularly for multi target tracking. The advantages of Phased Array Radar are specifically considered for multiple target long range tracking in skin mode, elimination of mechanical errors and instantaneous beam positioning capability.

Phased Array Antenn

The Phased Array Antenna is one of the most important subsystems in Phased Array Radar. This Phased array antenna consists of an array of radiating elements and each element is connected to a phase shifter. The phase shifters control the phase of the radiated signals at each element to form a beam at the desired direction. Beam forming network, commonly called a feed network is used to distribute the output signal from the transmitter to the radiating elements and to provide the required aperture for beam shape and side lobe control. The phase shifter drivers provide the required control, bias currents and voltages for each phase shifter for steering the beam to the desired angle. The details of Phased Array antenna and its design calculations are detailed in this report.

Design parameters of phased array antenna Total field of array is determined by the vector addition of the fields radiated by the individual elements. To provide directive patterns, it is necessary that fields from the elements of the array interfere constructively in the desired direction and interfere destructively in the remaining space.

Following are the design parameters to be considered while designing a phased array antenna

- i. Geometrical configuration of overall array (circular, rectangular and elliptical).
- ii. Relative displacement between the elements.
- iii. Excitation amplitudes and phase of the individual elements.
- iv. Radiation pattern of individual elements.
- v. Number of elements in array.
- vi. Beam width, Gain or directivity.
- vii. Side Lobe Level.

TR module:

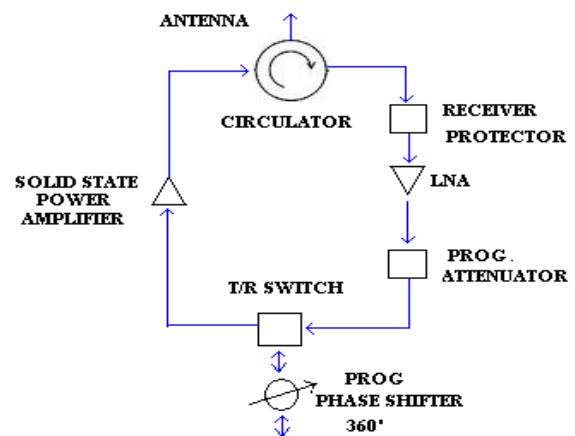


Figure: TR Module

Ideally, the TR module would contain amplifiers for transmit and receive states as well as for electronic phase shifting for both states. Thus it would carry out four RF functions, namely power amplification, phase shift, low noise amplification and switching. Because of the fact that the active aperture uses individual TR module at the array radiating elements, this configuration can be substantially more efficient on the basis of overall prime power versus detection capability. For the same effective radiated power, the active aperture configuration can be smaller and lighter than the conventional system. Fig above shows the block diagram of individual TR module. It consists of a solid state power amplifier (SSPA) in transmitter path and LNA in receiver path. Programmable phase shifter is common for both transmitter and receiver path. TR switch connects the phase shifter to SSPA and LNA during transmitting and receiving respectively. Programmable attenuator is used for beam shaping.

Phase shifter

Diode phase shifter and ferrite phase shifters are the two commonly used phase shifters. The diode phase shifters use PIN diodes to provide phase shifting. This is achieved by switching in different line length across the transmission line. These are low power devices, which are available in digital form. In ferrite phase shifters, phase shifting is achieved by varying the current in the drive wire inserted

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longitudinally through the center core of the torrid to provide transverse magnetization.

Radiating Elements

Basically the radiators are of four types

- i. Open ended waveguide radiator
- ii. Dipole radiator
- iii. Waveguide slot radiator
- iv. Micro strip patch radiator

Micro strip antenna consists of four parts

- i. A very thin flat metallic region called the patch
- ii. A dielectric substrate
- iii. Ground plane
- iv. A feed, which supplies RF power to the radiating element

The micro strip patch antenna has following advantages.

- i. They are low profile antennas.
- ii. They are easily comfortable to non planar surfaces.
- iii. They are very easy and inexpensive to manufacture in large quantities using modern printed circuit techniques.
- iv. When mounted to a rigid surface, they are mechanically robust.
- v. They are versatile elements in the sense that they can be designed to produce a wide variety of patterns and polarizations depending on the mode excitation and the particular shape of the patch used.

Beam Width:

Beam width in AZ and EL planes can be calculated with the diameter of the array antenna in both axis and the frequency of operation (wavelength).

$$\theta = \frac{51\lambda}{d} = \text{Beam width}$$

For an array antenna of dimension 10.4m×5.4m, El & AZ beam widths would be 2.4 deg and 1.0 deg respectively.

Scan Angle:

AZ: ± 60deg EL: ± 45deg

Element Spacing:

To have a wide covering angle in AZ & EL without grating lobe the elements has to be placed denser. It should follow

$$\frac{D}{\lambda} = \frac{1}{|1 + \sin\theta_{\max}|}$$

Where

d is the Array spacing mts

λ is the Wavelength and mts

θ_{max} is the Maximum scanning angle deg

For an L band micro strip array antenna (10.4m X 5.4m), 96 elements in the horizontal plane (along 10.4m side) and 48 elements in the vertical plane (along 5.4m side) can be accommodated with a spacing of 0.52 λ.

Antenna Gain

Approximate gain of the array antenna can be given by

$$G = 4\pi\eta A_e / \lambda^2$$

Where, η □ is the Efficiency of the antenna (Typically 65%) and

A_e is the Aperture area of the antenna

Gain (approx.): 40 dB (for 65 m2 elliptical excitation)

Total number of elements in (10.4 m X 5.4 m) area = 96×48=4608.

Total power for this configuration when 200W TR module is used = 1.26 MW.

Approximately 4608 elements can be excited in elliptical area of 65 m2

Total power radiated in this configuration is = 4608 X 200 = 921.6 KW

Active Phased Array Antenna

A Phased Array Antenna is a combination of number of individual antennas, or radiating elements in which there is a control of phase and power of signal applied at each antenna resulting in a wide variety of possible radiation patterns. Its radiation pattern is determined by the amplitude and phase of the current at each of its elements.

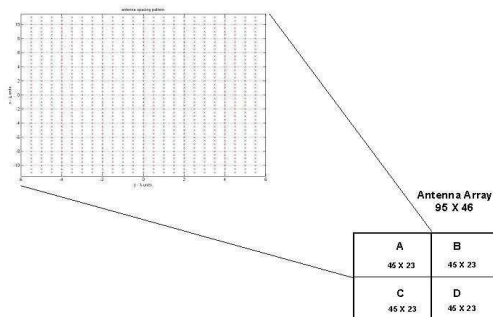


Figure: Array of radiating elements

The Phased Array Antenna has the advantage of being able to have its beam electronically steered in angle by changing the phase of the current at each element. A typical phased array antenna might have several thousand individual radiating elements using diode phase shifters that allow the beam switching from one direction to another direction in several microseconds or less.

The physics behind phased arrays are such that the antenna is bi-directional, that is, they will achieve the same steerable pattern in transmit as well as receive.

Active Phased Array Antenna and Design Calculations

The RF energy is radiated by no. of radiating element (4140 elements at 200W). The total combined energy forms a higher beam. The angle of the beam with reference to the plane of array of elements depends in the phase difference between the input signals of the each element in the array. The beam can be switched by simply controlling the phase shifter at the input of each element.

The RF signal (L-band, 1.35 GHz) is generated with a required pulse width and PRF. The pulse is transmitted through the array in the required direction. Initially the antenna array is positioned in the required AZ and EL position using the servo system from which Electronic beam steering is used up to AZ± 60 and El ± 45 to cover total Hemisphere. The transmitted pulse is received by the same antenna array. Mono pulse Technique is used to get sum, ΔAZ and ΔEL of the target, from the reflected signal. The reflected signal is converted to IF and processed for removing noise, clutter etc. From the processed signal, the SNR is estimated and target is detected. To improve the SNR of the Rx signal the LFM pulse compression technique is employed. The detected target information is stored in Data Processing and Display system (DPDS). The ΔAZ and ΔEL and SNR data is used to predict the next position of the target with reference to time of next update. The beam is positioned in the expected target direction in next PRT. The reflected signal is processed and position is updated in the DPDS. Also the target continuous positions are displayed on

the display monitor for the Radar operator. Such different positions are refined using Kalman filter and target track is drawn. For each detected target, tracks are updated on the Monitor Display. The selected target information is can be transmitted to the central computers system for further usage. Also the target information is displayed in different formats for the radar operator to take any real time decisions throughout the process.

II. ELECTRONIC STEERING:

A phased array is a directive antenna made up of a number of individual antennas, or radiating elements. Its radiation pattern is determined by the amplitude and phase of the current at each of its elements. The phased array antenna has the advantage of being able to have its beam electronically steered in angle by changing the phase of the current at each element. The beam of a large fixed phased-array antenna therefore can be rapidly steered from one direction to another without the need for mechanically positioning a large and heavy antenna. A typical phased array radar for microwave radar might have several thousand individual radiating elements using, for example, ferrite or diode phase shifters that allow the beam to be switched from one direction to another in several microseconds, or less.

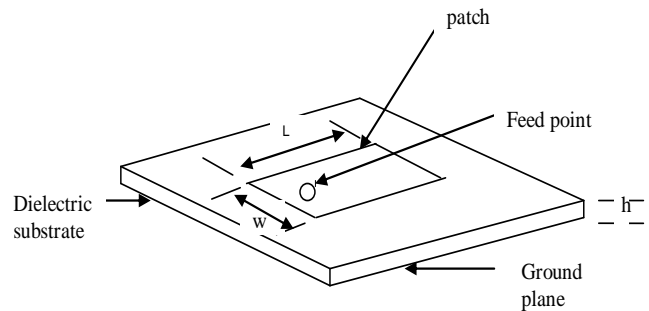
Electronically steerable phased arrays are of interest because they can provide

- Agile, rapid beam steering.
- Potential for large peak and large average power. Each element can have its own transmitter. The power aperture product can be large, especially at lower frequencies.
- Multiple-target tracking. This can be accomplished either by generating multiple, simultaneous, independent beams or by rapidly switching a single beam to view more than one target in sequence.
- A convenient means to employ solid-state transmitters.
- Convenient shape for flush mounting or for blast hardening.
- Control of the aperture illumination because of the many antenna elements available.
- A lower radar cross section, if properly designed.
- Operation with more than one function (a multifunction radar), especially if all functions are best performed at the same frequency.

III. MICROSTRIP PATCH ANTENNAS:

A Microstrip patch antenna is a thin square patch on one side of a dielectric substrate and the other side having a plane to the ground. The patch in the antenna is made of a conducting material Cu (Copper) or Au (Gold) and this can be in any shape, rectangular, circular, triangular, and elliptical or some other common shape. The basic antenna element is a strip conductor of length L and width W on a dielectric substrate with constant ϵ_r ; thickness or height of the patch being h with a height and thickness t is supported by a ground plane. The rectangular patch antenna is designed so as it can operate at the resonance frequency. The length that is for the patch does depend on the height, width of the patch and the dielectric substrate.

Geometrical configuration of Rectangular Micro strip Antenna



The rectangular micro strip antenna is the rectangular patch mounted on a dielectric substrate of thickness h , shown in Figure,

Micro strip patch antenna consists four parts.

A very thin flat metallic region called the patch dielectric substrate

Ground plane

A feed, which supplies RF power to the radiating element
Feed may be coaxial feed and inset feed.

Dimensions of the Rectangular Patch

The dimensions, bandwidth and gain of the microstrip patch antenna are determined by the operating frequency of the antenna, the relative dielectric constant, and thickness of the substrate material.

The following formulas are based on the transmission line model:

The width and length of a rectangular micro strip patch are given by,

$$W = \frac{C}{2f_r} \left[\frac{\epsilon_r + 1}{2} \right]^{-1/2}$$

$$L = \frac{C}{2f_r \sqrt{\epsilon_e}} - 2\Delta l$$

Where

C is the speed of light (m/s)

f_r is the operating frequency, MHz

ϵ_r is the relative dielectric constant and

ϵ_e is the effective dielectric constant

$$\epsilon_e = \left[\frac{\epsilon_r + 1}{2} \right] + \left[\frac{\epsilon_r - 1}{2} \right] \left(1 + \frac{12h}{W} \right)^{-1/2}$$

$$\Delta l = 0.412h \frac{(\epsilon_e + 0.3) \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_e - 0.258) \left(\frac{W}{h} + 0.8 \right)}$$

Where h is the Dielectric thickness in cm.

Bandwidth

The bandwidth of a microstrip antenna is defined in terms of the antenna's quality factor (Q) as follows:

$$BW = \frac{VSWR - 1}{Q \sqrt{VSWR}}$$

Where VSWR is less than a specified value (VSWR=1.5) at the operating frequency.

Typically, microstrip antennas have bandwidths on the order of a few percent of the operating frequency. The bandwidth

is dependent on both the relative dielectric constant and thickness of the substrate. Thicker substrates and lower values of dielectric constant, give larger bandwidths. This can be found from return loss of the patch results.

Substrate Selection

A dielectric substrate is a main constituent of the microstrip structure, whether it is microstrip line, or an antenna. For MSA applications, thicker substrate with a low dielectric constant is preferred to enhance the fringing fields and hence the radiation. Another important parameter is its loss tangent ($\tan \delta$). The $\tan \delta$ the dielectric loss, which increases with frequency. For a higher efficiency of the antenna, the substrate with a low $\tan \delta$ should be used; this is costlier than the substrate with high $\tan \delta$. Therefore, judicious selection of the substrate is required with consideration of the application and frequency of operation. Various substrates from the MSA point of view are described below. Synthetic and composite materials are commonly used substrates for MSA applications. These have low ϵ_r and low $\tan \delta$ and are available at various thicknesses. Generally, they are soft materials and can be bent conform to the host surface. Some of the most common synthetic substrate are Teflon (popularly known as PTFE (polytetrafluoroethylene)), polypropylene, and polystyrene. The composite materials are made by adding suitable fiberglass, quartz, or ceramic in synthetic or organic materials.

Glass-epoxy substrate, commonly used in PCB, is referred as FR4. It is one of the cheapest and most universally manufactured substrates. Its application is generally restricted to the low frequency range of up to 1 GHz because of high dielectric loss. However, for testing new designs, the antennas are fabricated on this substrate at higher frequencies also to reduce cost. To make the size of the antenna compact in the UHF range and for many other specific applications, substrate with a high ϵ_r is used. Some of the high ϵ_r substrate materials are ferromagnetic, ceramic and semiconductor materials.

Ferrite and YIG are the main ferromagnetic materials. The magnetic permeability (μ_r) of these substrates can be changed by varying the biasing magnetic field, which is utilized to tune the resonance frequency of the MSA. Besides having high ϵ_r , these materials have high μ_r , leading to further size reduction in MSAs. The most commonly used ceramic substrate is alumina, which has very low loss brittle. The semiconductor materials are silicon and gallium arsenide (GaAs), which have a high ϵ_r . The substrates of synthetic and composite materials are suitable for designing MSAs, but the cost of these substrates is high. New varieties of substrates are available with reasonably low $\tan \delta$ with prices as low as one fourth of the prices of the synthetic and composite substrates, allowing for reductions in the cost of the MSA. To sum up, the choice of the substrate is the first step in the successful design of an MSA. Besides electrical and mechanical parameters, there are many other physical and chemical properties of the substrates, including flexibility, power handling capability, chemical resistance, ruggedness, strain relief, bondability, and nonporous ness. These factors also influence the decision of the selection of the substrate.

For micro strip antennas the dielectric constants are usually in the range of 1.03 to 12. Dielectric constants in the lower end of the range can give as better efficiency, large bandwidth; loosely bound electric field for radiation into

space, but at the expanse of large element space. Some of the available substrates and their dielectric constants are given below in Table.

IV. CONCLUSION

Based on the study of design aspects of Phased array antenna, simulations are carried out to design a rectangular patch microstrip antenna and study its response. The radiation pattern is carried out on 1X4 array and the same is fabricated for testing to analyze the results. Results are matching with the simulations. Hence this design can be applicable to any size of the array. A Microstrip Line fed Rectangular Microstrip Patch Antenna with the dimension parameters h -1.57mm, L - 85mm, W - 87mm with a dielectric constant of 2.2 at an operating frequency of 1.35GHz is tested and found that this can be as an optimized design.

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