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Design OF 1X4 Microstrip Patch Antenna and Evaluation of its Performance

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Abstract— The multiple object tracking is done using Phased Array Radar. Phased array antenna, Digital receiver, Data processing system are 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.

Index Terms— Phased arrays, microstrip, patch antenna, ADS software, returns loss;

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 Antenna

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

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.

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

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.

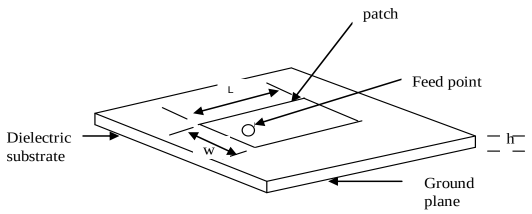
v. They are versatile elements in the sense that they can be designed to produce a wide variety of patterns and polarizations depending on the mode excitation and the particular shape of the patch used.

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 εr; 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 above fig.

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,

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

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

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

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

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

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 δ). The tan δ the dielectric loss, which increases with frequency. For a higher efficiency of the antenna, the substrate with a low tan δ should be used; this is costlier than the substrate with high tan δ. 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 εr and low tan δ 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 (polytetrafloroethylene)), 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. It 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 εr is used. Some of the high εr substrate materials are ferromagnetic, ceramic and semiconductor materials.

Ferrite and YIG are the main ferromagnetic materials. The magnetic permeability (μr) 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 εr, these materials have high μr, 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 εr. 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 δ 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 are 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, bond ability, 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 expance of large element space.

Some of the available substrates and there dielectric constants are given below in Table.

Table 2: Available Dielectric substrates

Substrates	**Dielectric constant**	**Loss Tangent at 10 GHz**	**Thermal conductivity KW/cm/ ^{0}c**
Polyethylene foam PF-2	**1.03**	**0.0001**	**0.0001**
foam PF-4	1.06	0.0001	0.00011
PTFE (Teflon)	2.1	0.0004	--
PTFE glass, reinforced	2.17 to 2.35	0.0006	--
Teflon-lass,reinforced	2.55	0.0015	--
RT – Duroid-5880	2.2-2.24	0.0005-0.0015	0.0026
RT-duroid 6010	10.2-10.7	0.0010-0.0060	0.0041
Epsilam-10	10-13	0.0020	0.0037
Alumina	9.8	0.00005-0.0003	0.37
Ferrite	9-16	0.001	--
GaAs	13	0.0006	--
Silicon	11.9	0.0004	--

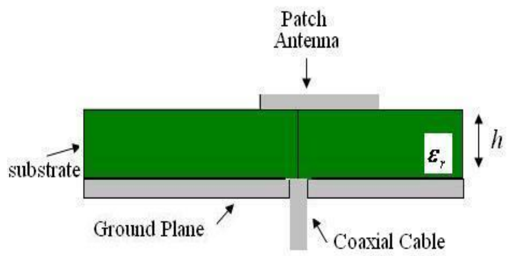


Fig: Micro strip Rectangular patch with coaxial feed

Patch parameters are calculated as follows.

Frequency (in GHz) = 1.35

Dielectric constant of the substrate = 2.2

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

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

W=88mm

L=87mm

Beam width of an array

No of Elements of the Array and array size can be calculated based on the AZ and EL beam width requirements. $\theta = \frac{51\lambda}{D}$ deg

Where θ is the beam width and D is the diameter of the array.

The expected beam width for the array is ^{0}

Antenna Array Gain

Gain of the antenna can be given by

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

The expected and simulated gain of the patch is 10.43Db

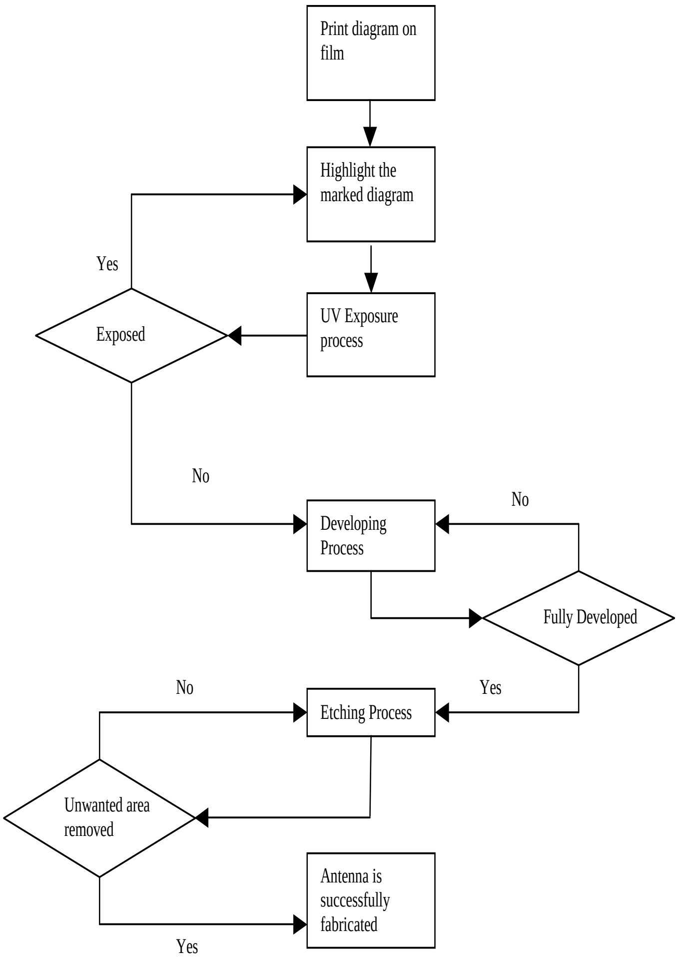
Element Spacing

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

Fabrication flow chart- Microstrip Patch Antenna



Simulation Setup and Results

The software used to model and simulate the Micro strip patch antenna is ADS (advance design system) based on the method of moments. It analysis3D and multi layer structure of general shapes. It is used to calculate and plot S-parameters return loss, mutual coupling, VSWR, antenna parameters as well as radiation patter

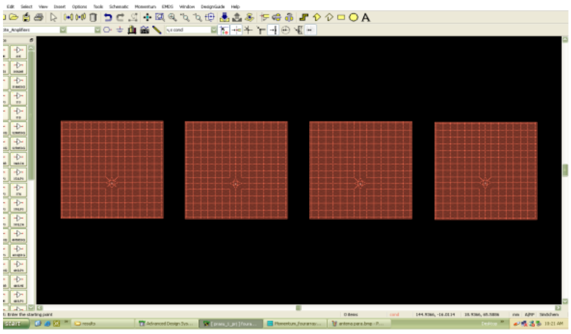


fig:1X4 microstrip patch using ADS

S11 Return Loss and Bandwidth

Using the calculated dimensions, the design is simulated in ADS software from 1.3 to 1.4 GHz.

The achieved S11 return loss of 1X4 array is as below

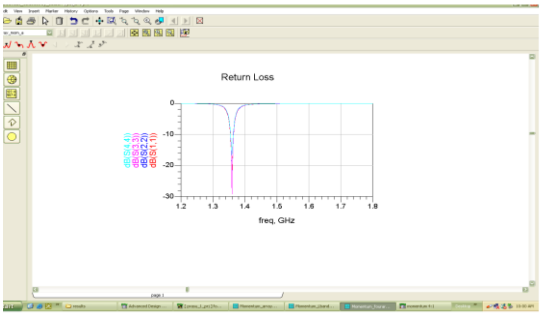
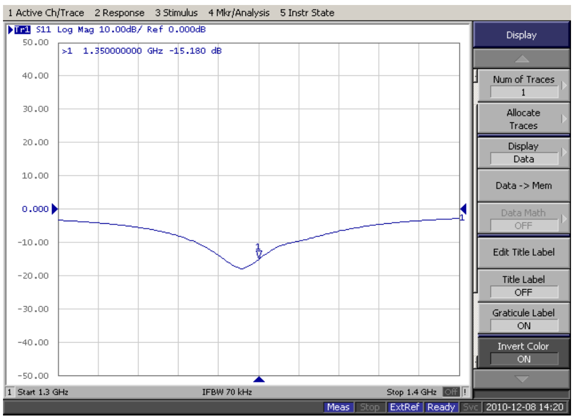


Fig: return loss graph

We can observe the return loss of the Rectangular 1X4 array patch antenna here at the1.35GHz is-20.38dB where S11 return loss is maximum. Comparing with practical output using network analyzer N5230A/E5071B we observe the return loss as -16dB at 1.35GHz as show below;



As for the **bandwidth** of the antenna, it is defined as the frequency range over which S11 is less than or equal

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to–10dB. The bandwidth can be calculated using the following equation:

$$BW = \frac{(f_2 - f_1)}{f_0} x100\%$$

Where,

f0 is the centre frequency or the frequency where S11 is minimum.

f1 and f2 are the frequencies at which S11 equals –10dB.

Applying the above-mentioned equation, the calculated bandwidth of the 1X4 array antenna is approximately about 5%

From the result below where f0 at 1.35 GHz having S11 minimum and difference between f1 and f2 at which S11 is -10db by calculating we get value of BW approx. equal to 5%

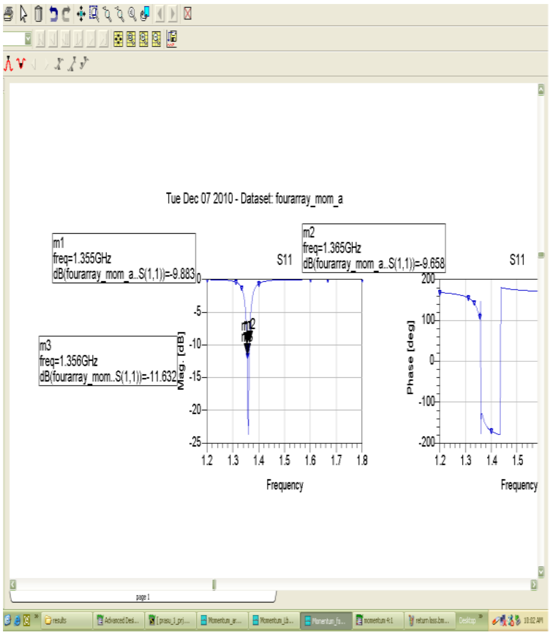


Fig: bandwidth graph

Voltage Standing-Wave Ratio

As for the Voltage Standing-Wave Ratio

(VSWR), it is defined as a measurement of the mismatch between the load and the transmission line. Therefore, the simulated VSWR for 1x4 microstrip array is below with formula;

$$VSWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} = \frac{1+S_{11}}{1-S_{11}}$$

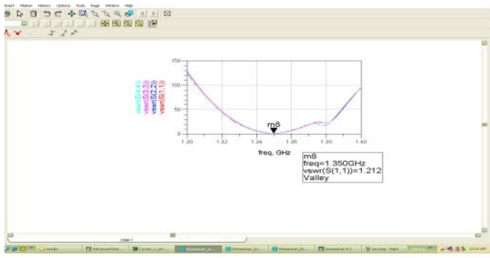


Fig: VSWR graph

This result showed that between the range of 1.3 GHz and 1.4 GHz, the VSWR of the antenna can be considered desirable as it is less than 2; the above result is 1.212 at 1.350GHz.

Mutual coupling

MSA must be placed far enough apart, which would degrade performance by increasing side lobe levels. It has been shown in literature that for an element spacing of d>/=0.5λ mutual coupling will not cause significant side lobe levels.

When two or more radiating patches are near each other, they interfere with each other depending on; radiation characteristic of each, relative separation between them and relative orientation of each antenna. This interference of energy is known as mutual coupling. Here in our

design the optimum spacing between the element is 110mm.

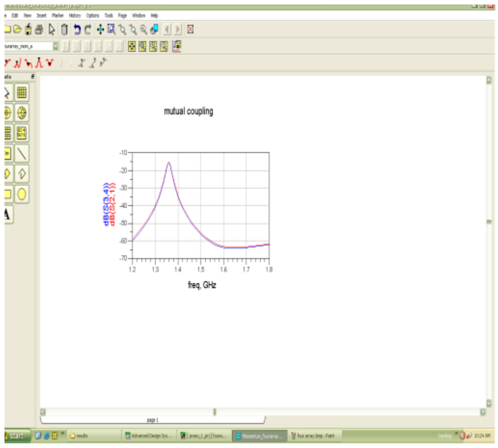
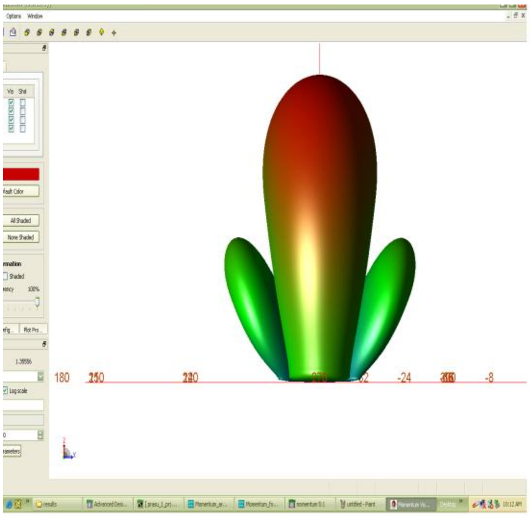


Fig: mutual coupling graph for S(2,1)&S(3,4)

3D Radiation pattern of 1X4 array antenna

The radiation pattern of a generic dimensional antenna can be seen below, which consist of side lobe, black lobes, and are undesirable as they represent the energy that is wasted for transmitting antennas and noise sources at the receiving end the pattern is below,



The Method of Moments (MoM) simulators like Momentum, thus requiring the use of full 3D simulation methods, such as Finite elements (FEM) or time domain (FDTD) approaches.

3D Current Distribution

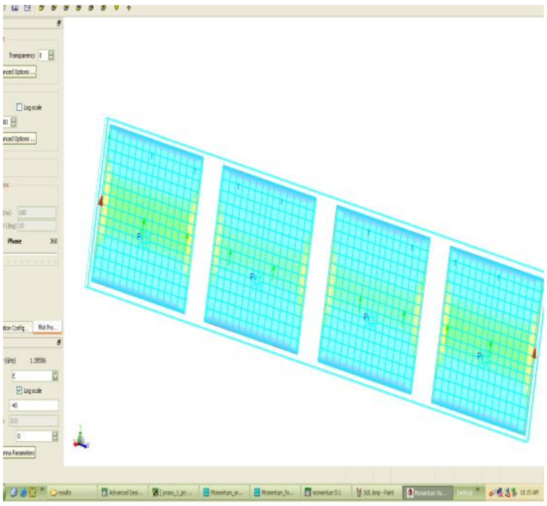


Fig**:** 3D Current Distribution

II. 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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