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Design of Microstrip Patch Antenna Characteristics Using Hemispherical and Spherical Dielectric Lens

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ABSTRACT
In this paper a study of the directive gain enhancement obtained using a dielectric lens placed in the near field of radiating elements is discussed. The design and results of a single element patch antenna along with hemispherical and spherical lens radiating in rectangular and square antenna are detailed. The design is done using HFSS, which is used for the primary radiator-lens combination. Lenses reduce the size of the composite antenna while providing sufficient collimation comparable to a much larger array of apertures without compromising on the bandwidth. The results obtained are compared in terms of directivity, VSWR, impedance and return loss. The microstrip patch antenna is designed to resonate at a frequency of 5.5GHz (5.35GHz-5.5GHz) for rectangular patch and frequency of 4.35GHz (4.35GHz-4.5GHz) for square patch with FR4 substrate.
Keyword: Microstrip patch antenna, Finite element method, Dielectric Lens, HFSS

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I. INTRODUCTION

In wireless applications such as WiMAX, smart antenna, mobile communication and satellite communication applications there is a requirement for high gain antennas[1]. High gain from antenna can be achieved by increasing the number of elements forming an antenna array. The antenna array can be a series array or a parallel array. From the array principles; doubling the number of elements in the array can produce a gain of approximately 3dB is a known fact. If the numbers of elements in the array are increased, then mutual coupling between them increases and gain of the array decreases[2]. The mutual coupling can be controlled by maintaining a distance of half wavelength between the centers of the antenna elements. In applications, where size is the constraint, array with many antenna elements can't be designed. In such applications the lens antenna is included as a secondary source for increasing the directive gain without compromising the bandwidth[3].

Lenses are primarily used to collimate incident divergent energy to prevent it from spreading in undesired directions[4]. By properly shaping the geometrical configuration and choosing the appropriate material of the lenses, they can transform various forms of divergent energy into plane waves. They can be used in most of the same applications as are the parabolic reflectors, especially at higher frequencies. Their dimensions and weight become exceedingly large at lower frequencies. Lens antennas are classified according to the material from which they are constructed, or according to their geometrical shape[5].

The microstrip patch antenna is simulated with HFSS software and optimized to get a good impedance matching and VSWR at a frequency 5.5 GHz (C Band). The lens antennas are designed such that they can cover the primary radiator exciting it. The size of the hemispherical lens and spherical lens is chosen such that they do not diffract the field of the microstrip patch and same time they cover the single patch antenna. The distance between the patch antenna and the lens is chosen so that at that distance VSWR is minimum.

II. HEMISPHERICAL AND SPHERICAL LENS ANTENNAS

The major advantage of using a hemispherical or spherical lens antenna [6] is its non-dependency on the focal length. This implies the non-dependency on frequency. Therefore the lens is an inherent broadband which can work up to several GHz. In other words an S-band, X – band and L-band radiators can be placed in front of this lens simultaneously and collimation can be expected. The appropriate number of dividers and other microwave devices must be kept to avoid interferences with other radiators. The restriction of the lens design is the size of the radiator.

III. DESIGN OF MICROSTRIP PATCH AND LENS ANTENNA

A Microstrip Patch Antenna consists of a radiating patch of a specific geometry on one side of the dielectric substrate and a ground plane on the other side as shown in fig1 [1]. The design of the three patch geometries use FR4 Epoxy as the substrate which has a relative permittivity (er=4.4) and Loss Tangent (0.02).

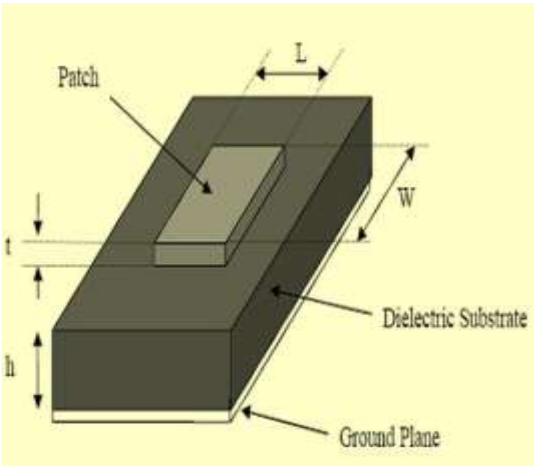

Fig 1. General structure of microstrip patch antenna

A single patch microstrip antenna is first designed and optimized in C band range of frequencies. . The design formulas of a microstrip patch antenna are utilized from the literature [1]. Equations (1) and (2) used to find the radiation pattern of the patch antenna in H plane and E plane.

H plane pattern,

$$\frac{\mathrm{Sin}\,(\frac{K_0 w}{2}.\cos\theta)}{\frac{K_0 w}{2}.\cos\theta}\;.\,\mathrm{Sin}\theta \qquad (1)$$

E Plane pattern

$$\frac{\mathrm{Sin}\,(\frac{K_0.h.\cos\emptyset}{2})}{\frac{K_0.h.\cos\emptyset}{2}}\;.\,\mathrm{Cos}(\frac{k_0.L}{2}\cos\emptyset) \qquad (2)$$

Where,
W - Width of the patch antenna in mm.
h - Height of the substrate in mm.
L - Length of the patch in mm.
∅- Azimuth angle, θ - Elevation angle

A low loss microwave substrate FR4 of dielectric constant (4.4) is used for designing a single patch. The dielectric lens is a secondary radiator, the lens dimensions are based on the primary radiator dimensions. The dielectric material, Teflon of low loss (0.002) with dielectric constant of 2.1 is used. The rectangular microstrip patch is designed with substrate dimension of 64.3x65.9 mm^2 and patch dimension of 10.7x12.3 mm^2, the thickness of the patch is 0.1 mm. The dimension of the antenna can be reduced by choosing the substrate material with more dielectric constant value.

The square microstrip patch is designed with substrate dimension of 64.3x64.3 mm^2 and patch dimension of 10.7x10.7mm^2, the thickness of the patch is 0.1 mm. The dimension of the antenna can be reduced by choosing the substrate material with more dielectric constant value.

The co axial feeding is used for excitation with inner radius of the co axial feed is 0.625 mm. The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates (h > 0.02λo). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems and for a thick dielectric substrate, which provides broad bandwidth.

The radius of the lens is 46.5 mm and the distance between the patch antenna and the lens (10mm) is chosen so that at that distance VSWR is minimum (<2). Finally on rectangle and square patch antenna, the hemisphere and spherical lens are placed and the results are obtained.

IV. DESIGN WORK

HFSS uses the finite element method for performing calculations. This method is implemented by creating a mesh that breaks down a structure into small cells. Choosing the mesh parameters and selecting the frequencies at which the structure will be solved are the two most important parameters of setting up the solution. In order to calculate the full three-dimensional electromagnetic field inside a structure and the corresponding S-parameters, HFSS employs the finite element method (FEM). FEM is a very powerful tool for solving complex engineering problems, the mathematical formulation of which is not only challenging but also tedious. The basic FEM is the basis of simulation in HFSS.

Case 1. Design of Rectangular patch with hemisphere lens

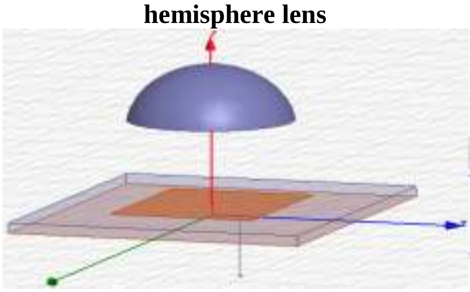

Fig 2. Hemisphere lens with Rectangular patch

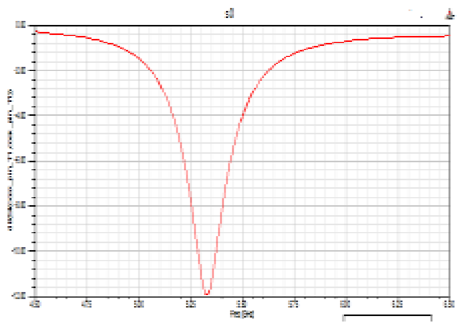

Fig. 3. Simulated Return Loss

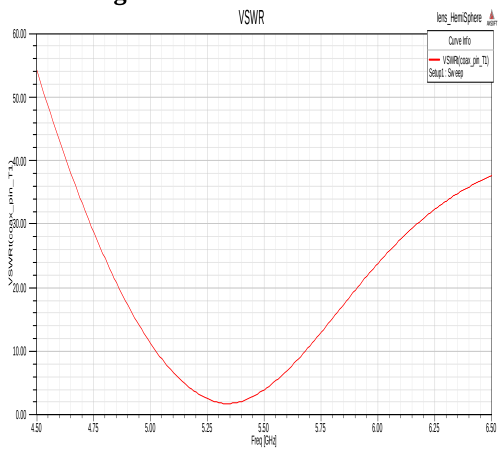

Fig. 4: Simulated VSWR

Radiation Pattern

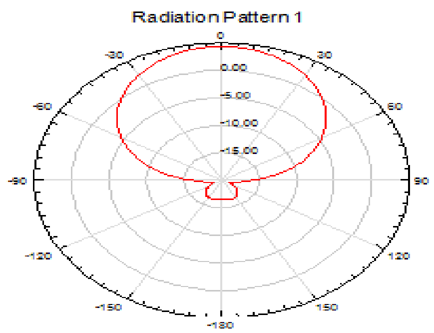

Fig 5. At phi -0 degree Freq – 5.5GHz

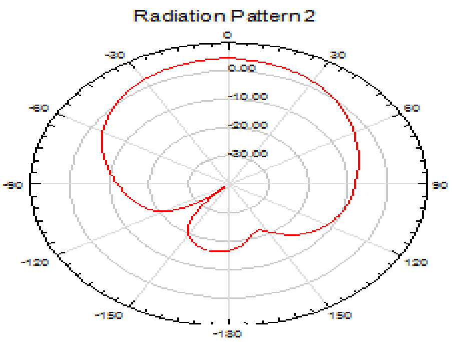

Fig 6. At phi -90 degree Freq – 5.5GHz

Case 2.

Design of Rectangular patch with spherical Lens

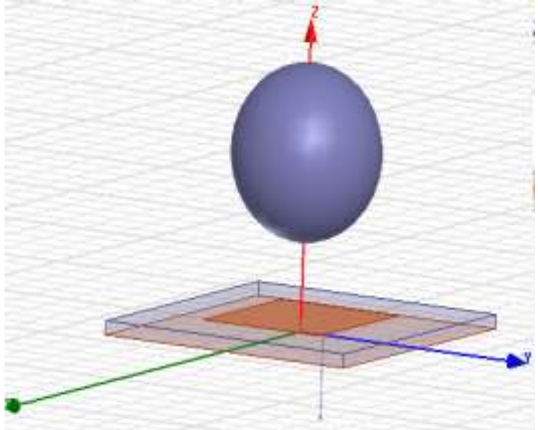

Figure 7: Design of Spherical Lens

Return Loss (S11)

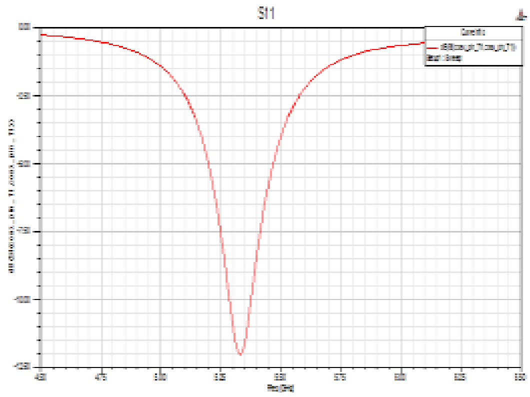

Fig.8 : Simulated Return Loss

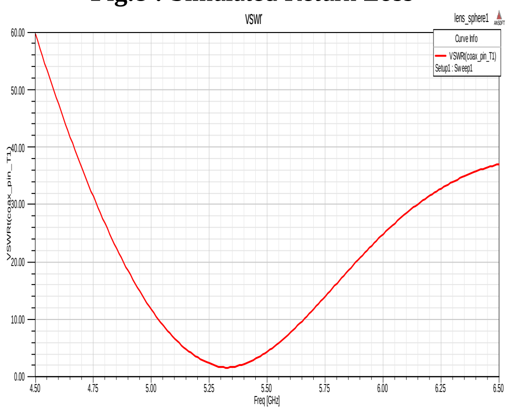

Fig 9. Simulated VSWR

Spherical Radiation Pattern

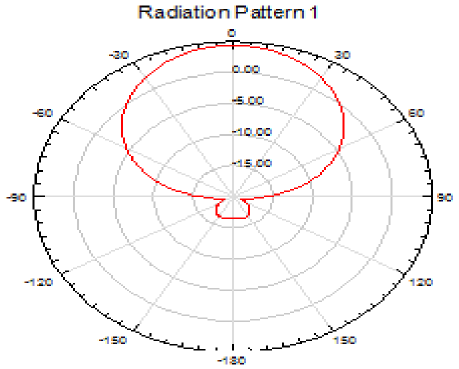

Fig 10: At phi -0 degree Freq – 5.5GHz

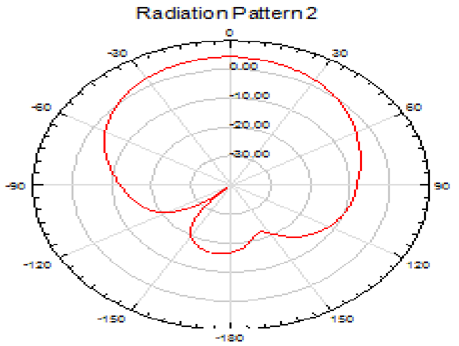

Fig 11. At phi -90 degree Freq – 5.5GHz

Case 3.
Design of Square patch with Hemi-spherical Lens

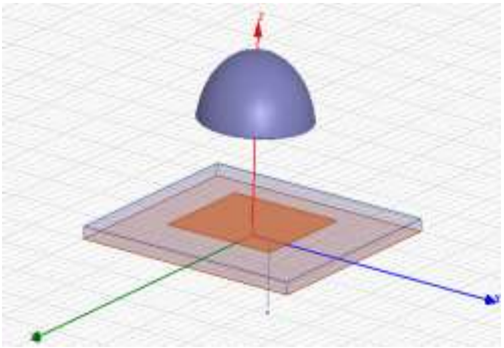

Figure 12: Design of Hemispherical lens with square patch

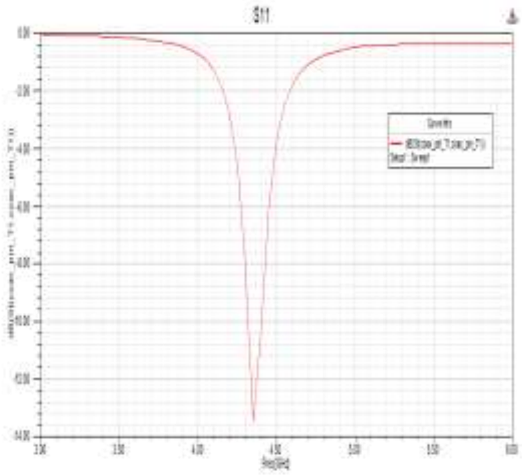

Fig 13: Simulated Return Loss

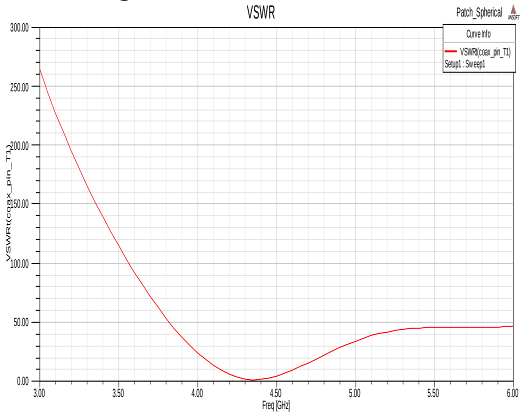

Fig 14. Simulated VSWR

Case 4.
Design of Square patch with Spherical Lens

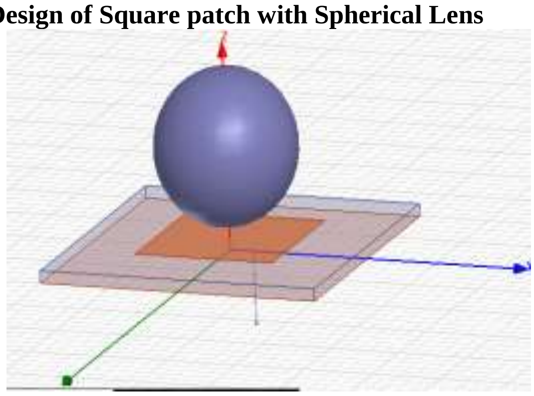

Fig 15: Spherical Lens using Square patch

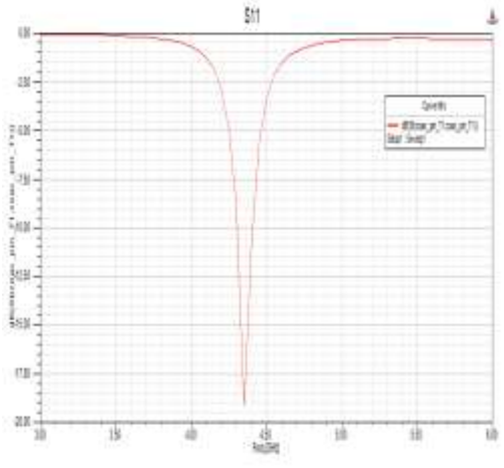

Fig 16: Simulated Return Loss

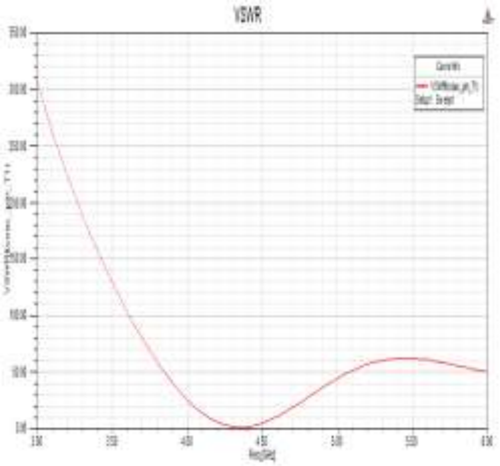

Fig 17. Simulation VSWR

Table 1: Comparison of the Simulated Results using Rectangular patch

Antenna Combination	Directivity/ Gain (dB)	VSWR	Impedance (Ohms)	S11 parameter (dB)
Single patch	3.96	1.82	50.00 Ω	-10.83
Hemispherical lens	7.97	1.77	50.00 Ω	-11.93
Spherical lens	8.39	1.75	50.00 Ω	-12.17

Table 2: Comparison of the Simulated Results using Square patch

Antenna combination	Directivity/Gain (dB)	VSWR	Impedance (Ohms)	S11 parameter (dB)
Single patch	3.91	1.59	50.00 Ω	-12.78
Hemispherical lens	7.46	1.53	50.00 Ω	-13.48
Spherical lens	7.53	1.24	50.00 Ω	-19.17

V. CONCLUSION

In this paper, the parametric study that is done on Microstrip Patch Antenna using Hemispherical and Spherical dielectric Lens. Ansoft HFSS v-13 software tool is used to implement and simulate the designs of the antenna. At first, the rectangular microstrip patch antenna is designed at 5.5GHz and Square Microstrip Patch is designed at 4.5GHz using some basics concepts of electromagnetic. 5.5GHz and 4.5GHz frequency is chosen because it is used for wireless communication applications like Wi-Max, WLAN, Wi-Fi, etc. The microstrip patch antenna is fabricated with FR4 substrate and lens antennas are fabricated with Teflon having very low loss Teflon material. A common feed that is coaxial probe feed is used. The simulation results show the directivity of a patch, hemispherical lens and Spherical Lens antenna. The spherical lens antenna directivity simulation shows it can provide better collimation compared to hemispherical lens and single patch antenna. The lens antenna with patch antenna can be used for wireless applications.

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