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Design of Microstrip Patch Antenna with Superstrate for Airborne Applications using IE3D

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1

***Abstract*—This paper investigate the characteristics of square shaped, probe fed, Circularly polarized patch antenna when covered with dome shaped superstrateat 1.575GHz.In order to obtain hemispherical radiation pattern for airborne applications, the conventional patch antenna is coverd by a superstrate with dielectric constant of 2.18 and thickness of 30mil. The antenna is simulated using IE3D software. The results are analyzed and discussed in terms of return loss, radiation pattern, axial ratio and beamwidth.Thesuperstrate thickness and dielectric constant are critical parameters which governs the beamwidth of the proposed antenna.**

Index Terms: **Microstrip patch antenna, RHCP, Superstrate, hemispherical radiation pattern, Return loss, IE3D simulation**

I. INTRODUCTION

Global Positioning System(GPS) is a satellite based network that provides Precision 3D position and velocity estimates by tracking the Time-of-Arrival (ToA) of spread signals.For GPS based spacecraft altitude determination a receiving antenna is required which should have superior rejection of multipath signal[1]. If the receiving antenna is unable to reject the multipath signals, it results in a significance amplitude and phase distortion. As GPS signals are Right Hand Circularly Polarized (RHCP).odd rejections are Left Hand Circularly Polarized (LHCP).Hence, use of antenna with a good rejection of LHCP signals can potentially eliminate the multipath effects arising from different reflections[2]. To have better discrimination between direct and reflected system, the GPS satellite transmits Right hand circularly polarized signal,which has the property of becoming left hand circularly polarized after the reflection from the ground. This account for the main requirement of right hand circular polarization and the high cross polarization ratio on thereceiving antenna.Circular polarization can be achieved by various methods, of which one is to feed theprobe along the patch diagonal. The shape of the radiation pattern of the receiving antenna is plays an important role in the design specifications.The GPS receiver to be used for airborne applications one of the important electrical requirements of the antenna is its radiation pattern.

Since all the GPS satellites are in the upper hemisphere and the location of the satellite is unknown the receiving patch antenna in the GPS receiver should have omnidirectional radiation pattern or Hemispherical radiation pattern to cover the upper hemisphere. This helps in capturing the signals from all visible satellites and further helps in locating the user position using GPS receiver.

Microstripantenna are most desirable for this type of applications due to its several advantages over other antennas.consists of radiating patch on the one side of the substrate having the ground plane on other side. The major advantages are light weight, low profile, conformable to planar and non-planar surfaces and easy to fabricate. The antenna is suitable for high speed vehicles, aircrafts, space crafts and missiles because of low profile and conformal nature of characteristics [3]-[5], The dielectrics Superstrate protects the patch from climatic conditions and environmental hazards and improve the antenna performance.

The researchers [3]-[8]have investigated the input impedance of circular and square patch with dielectric Superstrate (radome). The different circular and square patch microstrip antennas are investigated by many researchers. K.M.Luk et al, [10] has reported the investigation of the effect of dielectric cover on a circular microstrip patch antenna.The resonant frequency of patch is decreased while bandwidth is slightly varied. Hussain.A et al, [11] has discussed the microstrip antenna performance covered with dielectric layer. He found the simulated results which show that the antenna resonant frequency is reduced as the dielectric layer thickness is increased; however the gain is decreased as dielectric layer thickness is increased. R.K.Yadav et al, [12] has observed that the resonant frequency lowers and shift in resonant frequency increases with the dielectric constant of the Superstrates, in addition, it has also been observed that return–loss and VSWR increases, however bandwidth and directivity decreases with the dielectric constant of the Superstrates. Hussein Attia et al, [13], discussed that a microstrip patch antenna can be designed to achieve the highest possible gain when covered with a Superstrate at proper distance in free space.

The transmission line analogy and cavity model are used to deduce the resonance conditions required to achieve the highest gain. Samer Dev. Gupta et al, [14] has discussed the design of multi dielectric layer based on different thickness and permittivity of the Superstrate layer has significant effect in gain and efficiency. The proper choice of thickness of substrate and Superstrate layer results in significant increase in gain.

We have designed the square patch microstrip antenna based on the transmission line model and simulation is done using IE3D full wave EM simulator. The substrate and Superstratematerial are of different dielectric constant. The effect of dome shaped dielectric Superstrates on the parameter such as beam-width, return loss and Axial ratio has been investigated. The obtained results show that the 3dB beamwidth can be increased by properly choosing the dielectric constant value and thickness of the superstrate.Results also show that the return loss and axial ratio are well within the range for operating the antenna in the designed frequency.

II. PROBE FEED SQUARE MICROSTRIP PATCH ANTENNA.

AAntenna Construction and Theory

A microstrip patch antenna consists of a very thinmetallic patch placed a small fraction of awavelength above a conducting ground-plane.The patch and ground-plane are separated by adielectric. The patch conductor is normally copper andcan assume any shape, but simple geometries generallyare used and this simplifies the analysis andperformance prediction. The patches are usually photoetched on the dielectric substrate. The substrate isusually non-magnetic. The dielectric constants of thesubstrate are normally in the range of 2.2 <*r* ε < 12,which enhances the fringing fields that account forradiation, but higher values may be used in specialcircumstances. Due to its simple geometry, the square or rectangular patch is the most commonly used microstripantenna. It is characterized by its length L, width W andthickness h, as shown in Figure 1.

The simplest method of feeding the patch is by a coplanar microstrip line, also photo etched on the substrate. Coaxial feeds are also widely used. The inner conductor of the coaxial-line (sometimes referred to as a probe) is connected to the radiating patch, while the outer conductor is connected to the ground-plane.The antenna described here is a probe-fed square microstrip patch antenna covered by a dome shaped superstrate designed to operate at a frequency of 1.575 GHz.

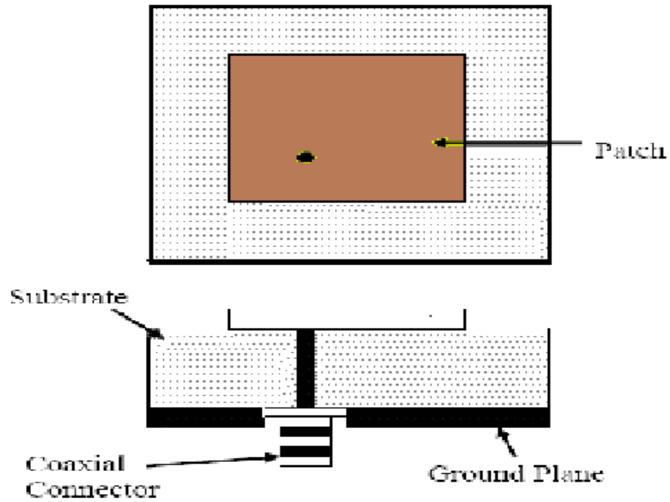

Fig1. Probe feed Square patch antenna.

BProposed Antenna Specificationsand itsFeed

Fig.2 shows the geometry of proposed patch antenna covered with dome shaped superstrate.The antenna under investigation the square patch antenna dimensions are W=L=2.895cm and feed point location 1.59cm.The substrate with dielectric constant of ε_r=10 and thickness of 100mil,and for the superstrate dielectric constant of ε_r=2.18 and thickness of 10mil were used.The antenna designed center frequency is 1.575 GHz.The loss tangent is 0.002.The dielectric constants and thickness of both substrate and superstrate are plays important role in the antenna design process.

In many applications Circular polarization is desired.Microstrip antennas can be designed to radiate circular polarization withsingle feed.It is possible to excite two modes with one feed perturbation in the single patch shape.Also a square patch with diagonally truncated corners and fed at the center of one of its sides are the bestfor GPS applications.[15]. Both RHCP and LHCP can be achieved by this technique. Our proposed antenna has been fed diagonally to produce Right hand circularly polarized wave.

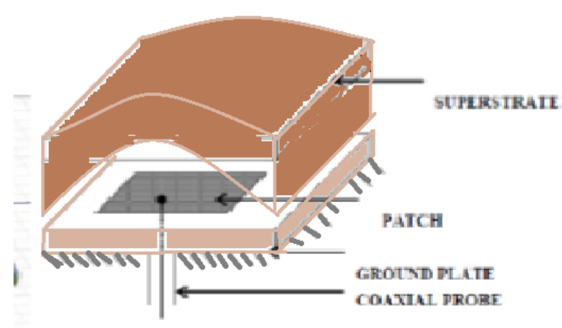

Fig 2. Structure of proposed patch antenna covered with dome shaped superstrate.

C. Design Equations

The following are the equations formulated for a layer of patch with superstrate[15].According to our antenna specifications antenna dimensions and other parameters can be changed to get optimized result using these equations .

The Resonance frequency is given by

$fr = c/(2(L+\Delta L)\sqrt{\in eff}$(1)

where $\in eff$ is the effective dielectric constant.

L is the length of the patch

The dimensions of the patch along its length have been extended on each end by distance ΔL due to fringing field.

$$\in_{eff} = \in r' - (\frac{(\in r' - \in e)}{(1+p(f))}(2)$$

$p(f)$-frequency dependent term.

The term $\in r'$ relative permittivity is found by

$$\in r' = (2 \in e - 1 + A)/(1 + A)(3)$$

Where $A = \sqrt{\left(1 + \frac{12h1}{W}\right)}$

The effective permittivity $\in e$ is given by

$$\in e = \in r_1{}^2(q_1 + q_2)^2/(\in r_1)(q_1 + q_2)) + \in r_2\,(1 - q_1 - q_2)^2/\in r_2(1 - q_1 - q_2 - q_3 + q_3)(4)$$

Where $q_1 = (½)\{(1+\pi/4)-(h_1/We)*(\ln(2We/h_1)\sin(\pi/2)+\cos(\pi/2))\}$

$q_2 = 1-q_1-(h_1/We)\ln((\pi We/h_1)-1)$

$q_3 = 1-q_1-q_2-((h_1-Ve)/(2We))\{\ln[(2We)/2h_{12}-h_1+Ve*\cos(\pi Ve/2h_1)+\sin(\pi Ve/2h_1))]\}$

in which the effective width (We) and the quantity(Ve) are given by

$We = W+(2h_1/\pi)\ln[17.08((W/2h1)+0.92)]$(5)

$Ve = (2h_1/\pi)\tan^{-1}(2\pi/\pi We-4h_1)(h_{12}-h_1)$(6)

The optimized results of return loss and radiation pattern can be obtained by changing the patch antenna dimensions for the given specifications.

The relations for Half power beam width in E and H planes respectively are given by

$\Theta_E = 2\sin^{-1}\{7.03/3Ko^2L^2+Ko^2h^2\}^{1/2}$(7)

$\Theta_H = 2\sin^{-1}\{1/2+KoW\}^{1/2}$(8)

Where

$Ko = 2\pi/\lambda o$, $\lambda o = c/f$, $L = \lambda o/2\sqrt{\varepsilon re}$

III. Simulation Results and discussions

The software used to perform all simulations is Zealand Inc's IE3D. IE3D is a full-wave electromagnetic simulator based on the method of moments. It analyzes 3D and multilayer structures of general shapes. It has been widely used in the design of MICs, RFICs, patch antennas, wire antennas, and other RF/wireless antennas. It can be used to calculate and plot the *S* parameters, VSWR, current distributions as well as the radiationpatterns. The square shape microstrip antenna with superstrate specified above has beenanalyzed by the Zeland IE3D evaluation version 14.0.

The following specifications are used in our simulation.Frequency of operation1.575 GHz (L1 band),the dielectric constant of the Substrate(εr_1) is 10 and the dielectric constant of the superstrate(εr_2) is 2.18.The thickness of substrate and superstrate are 2.54cm (100mil)h_1,and 0.762cm(30mil)h_2 respectively.The input impedance is 50 ohms and the bandwidth : 20 MHz (1.575 +/- 10) GHz.The patch antenna will generate right handed circularly polarized wave.The dimensions of the patch are 2.895cm x2.895cm and the loss tangent is 0.002.

A. Radiation Pattern:

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial co-ordinates which are specified by the elevation angle (θ) and the azimuth angle (φ).It can be plotted as a 3D graph or as a 2D polar or Cartesian slice of this 3D graph. It is an extreme parameter as it shows the antenna's directivity as well as gain at various points in space.The following figures (3-6) shows the 2Dradiation Pattern Gain Display(polar plot) of the proposed antenna with and without superstrate

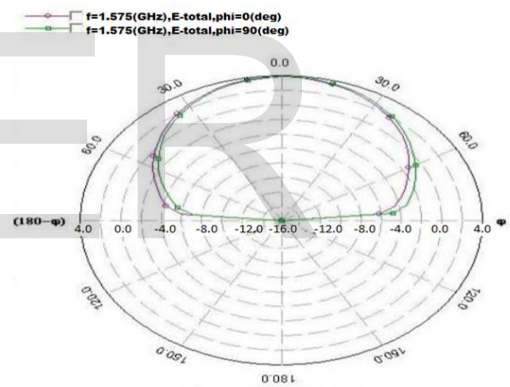

Fig.3. Elevation Pattern Gain Display(2D polar plot)without superstrate

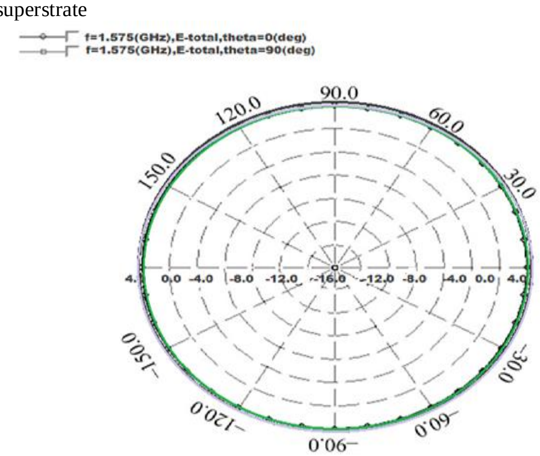

Fig.4. Azimuth Pattern Gain Display(2D polar plot)without superstrate

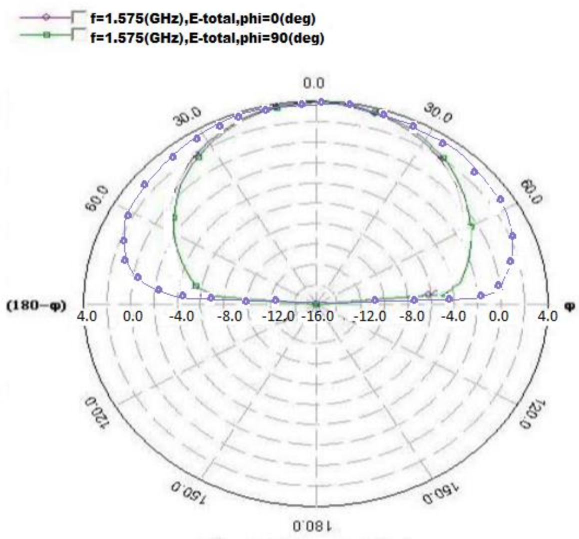

Fig.5. Elevation Pattern Gain Display(2D polar plot)with Superstrate

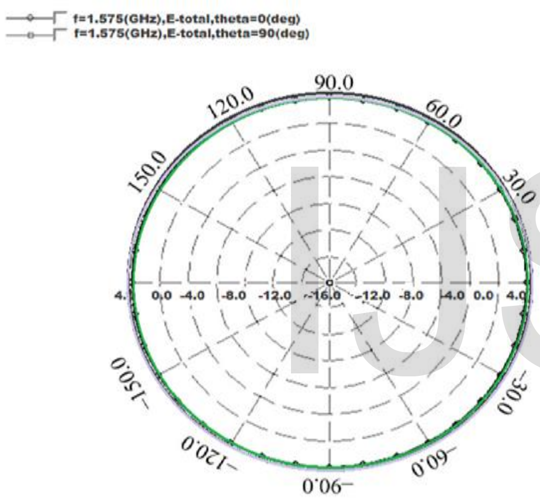

Fig.6. Azimuth Pattern Gain Display(2D polar plot)with Superstrate

In the elevation pattern 3dB Half power beam width without superstrateis about 70^{o}and with superstrate is about 140^{o}Thisspacial reception pattern is near hemispherical.We also studied through simulation that the HPBW become narrower or wider depending upon the dielectric constant and thickness of the Superstrate.so for our design values provides wider beamwidth.

B. Return Loss

In order for any given antenna to operate efficiently, the maximum transfer of power must take place between the feeding system and the antenna.Return loss is a parameter and it is related to both standing wave ratio (SWR) and reflection coefficient (Γ). Increasing return loss corresponds to lower SWR. Return loss is a measure of how well devices or lines

4

are matched. A match is good if the return loss is high. A high return loss is desirable and results in a lower insertion loss.Return loss is used in modern practice in preference to SWR because it has better resolution for small values of reflected wave.The IE3D simulated Return loss Plot of proposed antenna with and without superstrate are shown in fig.7 and fig.8.

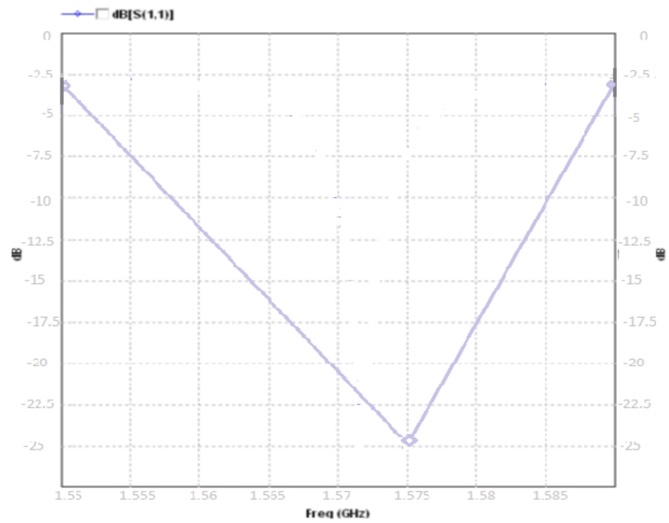

Fig.7.Return Loss at 1.575 GHz without superstrate

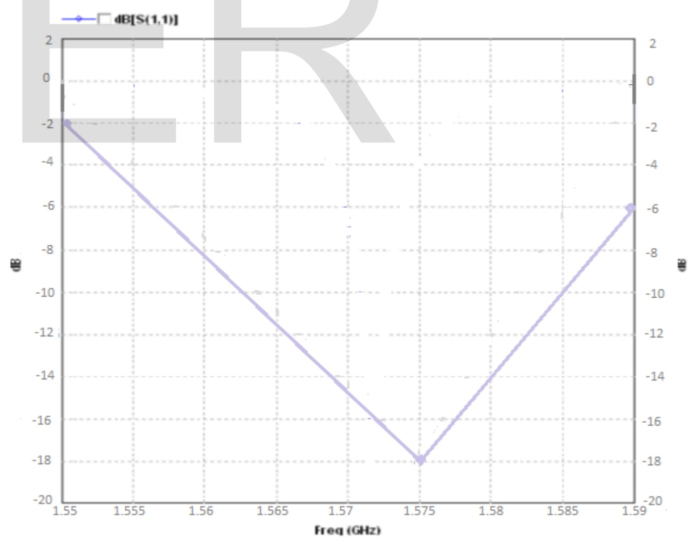

Fig.8 Return Loss at 1.575 GHz with superstrate

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The center frequency is selected as the one at which the return loss is minimum. The bandwidth can be calculated from the return loss (RL) plot.The return loss for our design is -24dB and -18db respectively for with and without superstrate.The simulated frequency range for measurement of VSWR < 2 are from 1.560 GHz to 1.580 GHz, thus

resulting in a bandwidth of 20 MHz.We also found that the return-loss first increases with increasing the thickness of the dielectric Superstrate and decreases further.

C. Axial Ratio

For circular polarisation the purity of the polarisation is specified in terms of axial ratio.The result of our Axial ratio plot with respect to frequency is shown in fig.10

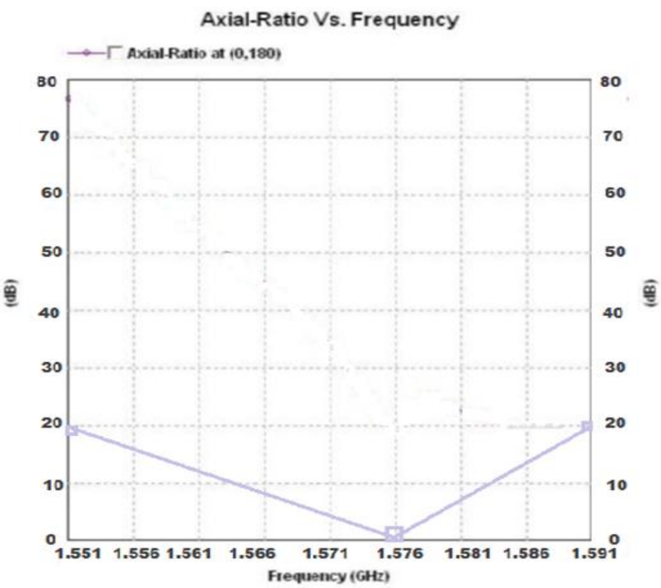

Fig 9 Axial Ratio Vs Frequency plot

Axial ratio plot of the proposed antenna it is found that the axial ratio in dB at resonant frequency (1.575GHz) is around 2dB(Less than 3dB is acceptable range) for our case and the axial ratio BW is 3.11%.

IV CONCLUSION

A beamwidth broadening technique for the microstrip patch antenna has been presented.The has shown that a wide beam radiation pattern can be obtained with the help of superstrate. We also found that the return-loss first increases with increasing the thickness of the dielectric Superstrate and decreases further. The polarization bandwidth we get sets the range over which our proposed antenna's operation is approximately circularly polarized. This technique can also be applied topatch antenna array system, where both gain and broad beamwidthspecifications of the antenna are important.

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5

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