Effect of substrate material on the performance of plano-concave patch antenna for 5G

Ribhu Abhusan Panda¹*, Priti Pragnya Satapathy², Subudhi Sai Susmitha³, Raghuvu Budhi Sagar⁴, Debasis Mishra⁵

¹,²,³ GIET University, Gunupur, Odisha, India, Pin 765022
⁴ V.S.S.U.T Burla, Odisha, India, Pin 768018

*E-mail: ribhuabhusanpanda@riet.edu

Abstract. In this article the design of a Plano-Concave patch antenna has been explored and reported. The effect of substrate material which include the dielectric with a specific dielectric constant has been analysed. Proposed shape of the patch is designed by subtracting a semi-circular patch from the conventional square patch .To analyse the effect of dielectric material on the performance of antenna , different materials with specific dielectric constant (εᵣ) like Silicon (εᵣ=11.7) , Alumina92_pct(εᵣ=9.2) , FR4 Epoxy (εᵣ=4.4) , RT Duroid (εᵣ=2.2) have been considered . The performance is considered for 5G LMDS application that includes 26.5 GHz to 29.5 GHz. The analysis has been done by considering the S-Parameter (Return loss < -10 dB), Antenna Gain, Directivity, Radiation Efficiency and surface current distribution. Table 1 provides the comparison of parameters for different substrate material.

Keywords: Plano Concave Patch, Dielectric Material, 5G LMDS, S-Parameter, Antenna Gain, Directivity, Radiation Efficiency

1. Introduction

Perturbed patch antennas have been potential ingredients for millimetre wave frequency range over last decade due to prominent advantages like small size, high bandwidth, unique shape, higher radiation efficiency etc. Many modifications have been done in the conventional patch for specific applications in last few years [1-4]. Unique concepts like implementation of metamaterial, EBG (Electronic Band Gap), Defective ground structure (DGS) and superstrate have been proposed in boost the antenna gain and directivity. [5-12] In this paper the conventional square patch has been modified in such a way that the resultant structure looks like a Plano concave lens. The frequency range has been chosen from 26.5 GHz to 29.5 GHz with the operating frequency at 28 GHz that has been considered for 5G Local Multipoint Distribution Service (LMDS) [13] one of the prominent parts of microstrip patch antenna which supress the surface waves is substrate and a specific dielectric material has been considered. Some recent works show a significant contribution of these materials to the performance of an antenna. [14-17] A comparative study has been made on different parameters taking each and every dielectric material into consideration.
2. Design of Proposed Plano Concave Patch

The proposed patch design can be done by subtracting the semi-circular patch from the conventional square patch. Each side of square patch as well as the diameter of the semi-circular patch has the value equal to the wavelength calculated from the operational frequency which is 28 GHz. The value of the wavelength is found out to be $\lambda = 21.42$ mm. Figure 1 provides the shape of the patch.

![Figure 1. Shape of the patch](image1)

2.1. Design of Antenna Using different substrate material

The proposed patch has been designed on a substrate of dimension 40mm×40mm×1.6mm and the ground plane has the same dimension as that of the substrate but the height is taken as 0.01 mm. The proposed patch has been designed and simulated in Ansys HFSS software. To analyse the effect of the dielectric material of the performance of the proposed antenna four different types of dielectric materials have been considered. The materials are Silicon with dielectric constant $\varepsilon_r = 11.7$, Alumina92 pct with dielectric constant $\varepsilon_r = 9.2$, FR4 Epoxy with dielectric constant $\varepsilon_r = 4.4$ and RT Duroid with dielectric constant $\varepsilon_r = 2.2$. Figure 2 shows the design using HFSS.

![Figure 2. The design using HFSS](image2)
3. Results
The focus is made on the resonant frequency and the return loss of the proposed patch. Figure 3 shows the Return loss Vs frequency plot where it can be clearly observed that the resonant frequency varies as the dielectric material

![Comparison of S-Parameter (Return Loss)](image)

**Figure 3.** Comparison of S-Parameter (Return Loss)

The performance of the antenna depends on the antenna gain and it has been observed that the dielectric material also effects the antenna gain so the comparison has been made. Figure 4 illustrates the comparison of peak gain and the comparison of parameters has been provided in table 1.

![Comparison of Peak Antenna Gain](image)

**Figure 4.** Comparison of Peak Antenna Gain
Table 1. Comparison of Parameters

| Material  | Dielectric Constant | Resonant Frequency (GHz) | Return Loss (dB) | Peak Gain (dB) | VSWR | Peak Directivity (dB) | Radiation Efficiency | Cost       |
|-----------|---------------------|--------------------------|------------------|----------------|------|----------------------|---------------------|------------|
| RT Duroid | 2.2                 | 28.5                     | -37.92           | 8.678          | 1.0257 | 8.71                 | 99%                 | High       |
| FR4 Epoxy | 4.4                 | 27.6                     | -30.95           | 4.52           | 1.0583 | 8.96                 | 50.43%              | Low        |
| Alumina   | 9.2                 | 28.8                     | -46.67           | 1.772          | 1.0093 | 3.21                 | 55.2%               | High       |
| Silicon   | 11.2                | 27.9                     | -33.97           | 2.355          | 1.0408 | 3.55                 | 67.19%              | High       |

From the results it can be observed that considering the cost FR4 Epoxy material can be used where as overall performance of the proposed antenna is appreciable when RT duroid material is used. Another aspect of the observed results provides an idea that using a dielectric material of high dielectric constant with this perturbed patch can no enhance the antenna gain and directivity. So by using RT duroid material having dielectric constant of the value 2.2 good results can be obtained. Considering the RT duroid material the 2D and 3D radiation patterns have been determined which has been illustrated in figure 5 and figure 6 respectively. In the figure 7 the distribution of surface current on the perturbed patch clearly indicates that the patch is radiating efficiently.

![Figure 5. 2D Radiation Pattern](image1.png)

![Figure 6. 3D Radiation Pattern](image2.png)

![Figure 7. Surface current distribution](image3.png)
4. Conclusion
The proposed Plano-concave patch with substrate including a dielectric material RT Duroid having dielectric constant 2.2 yields good results with antenna gain of 8.67 dB and resonant frequency at 28.5 GHz that can be utilised for 5G communication.

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