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# Performance Analysis of Pentagon Shaped Microstrip Patch Antenna with Different Substrate Materials

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***Abstract:*** ***Microstrip patch antennas are the handiest antennas for the present trend of applications in communications. The well-known beneficial mechanical characteristics (low profile, light weight, planar but conformal to non-planar structures, easy to fabricate), flexibility in terms of electromagnetic parameters like radiation pattern, gain, impedance, polarization and low cost are the key features for the success of such antennas. High efficiency antennas are essential to cater the requirements of various military oriented space vehicles like spacecraft, aircraft, satellite and missile applications where dimensions of installation are important as size, weight, performance, ease of installation and easy integration to the circuit. Microstrip antenna array are most apt for such applications, but the limitation of such antennas are gain and the bandwidth. The order of gain is low for patch antenna which is generally in the choice of 1-2dB.To increase gain and bandwidth factors the utilization of material with low dielectric constant having greater thickness is employed. However, this generates surface waves. So, proper thickness of substrate is selected. In this paper, microstrip patch having pentagon shape uses probe feed technique for various substrate materials such as Roger's RT/Duroid 5880 (tm), Roger's RO4003 (tm) and $FR_4$ epoxy. The results of the three substrate designs are acquired for the resonant frequencies 6.5 GHz, 6.6 GHz, and 6.7 GHz respectively. The whole analysis is carried out using Ansoft HFSS software version 17.0. The characteristics like bandwidth, amplification factor (gain), return loss and radiation patterns of the different antenna are assessed, related and the same are presented at the end.***

***Index Terms:*** ***Microstrip patch antenna, Pentagon Shape, Substrate materials, Gain, Bandwidth, Return loss, Radiation pattern.***

## I. INTRODUCTION

Microstrip patch antenna is most commonly used in the present trend of communication world.

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Microstrip antennas are most widely used in the high frequency range of microwave variety because of simplicity, minimalism, compatibility and ease of being integral part, also used to construct either as individual elements or as arrays.

The Microstrip patch antenna was initially presented by Deschampsin 1953. However they were made popular and were developed in the 1970's by Munson and Howell. The patch antenna can be designed by 2D or 3D; this consists of a ground plane and radiating patch to either side of the substrate. By photo etching, radiating elements and feed lines are connected by printed circuit technology with precise contour. A printed circuit (photolithographic) technology with a precise low contour can be utilized in manufacturing process [1]. The patch for radiation can be designed in various geometrical shapes. Radiating patch is designed, using different shapes such as square, circular ring, rectangular, pentagon, hexagonal etc. There are different patterns obtained for different feeding techniques. For analysis, Transmission Line and Cavity models are used. Microstrip arrays are poor to emit strongly above a limited range of frequencies and cannot be used at high powers in coaxial line, waveguide. Santanu Kumar Behera has advised (PSO) particle swarm optimization algorithm in conjunction with the (MOM) method of moments to obtain the geometric parameters of the antenna performance. L-Shaped design was suggested by A. Deshmukh for obtaining large impedance. Z. M. Chen expanded the frequency range of the L-shaped antenna whereas K. F. Lee used half sized U-slot for improving performance patch. S. C. Gao proposed uniplanar photonic band gap construction for increasing gain and frequency range. M. Khodier proposed stacking techniques for increasing the bandwidth.

## II. PRINCIPLE OF WORKING

The principle of working of the microstrip antenna is explained as follows. The substrate has high and low electric fields on either side with zero value as mean position. With respect to the varying phase of the function, the field signs vary accordingly on either sides of the patch. The electric field lines extent towards the boundaries of the patch, referred as fringing fields useful for radiating the patch. The fundamental mode of rectangle shaped patch is $TM_{10}$.

The resonant frequency ($f_r$) of a patch antenna depends on size of the ground plane, impedance of patch, thickness and $\varepsilon_r$ of substrate. There are numerous applications of patch [2]. M. Abbaspour [3] chosen star shaped patch for increasing impedance bandwidth. Sumanpreet Kaur Sidhu [4] made comparison for various shapes of patch antenna designed with FR4 in support of X band. Pentagon shaped antennas are proven to produce better results in terms of bandwidth and return loss. Pentagonal microstrip patch gives better performance than the rectangular patch antenna. Pentagonal [5] and elliptical shaped radiating patches are not explored by many researchers. Authors preferred pentagonal shape patch and ground plane for coplanar antenna designs. Pentagonal geometry is one of the different shapes for microstrip antennas capable of producing both circular polarization and linear polarization. Pentagonal patch antenna is considered with proper thickness of the substrate for improving bandwidth of antenna .The characteristics of the pentagonal patch antennas are analyzed with different substrate materials and is a need for optimization of this type antenna in order to integrate it within the compact communication equipment and devices. This has opened large interest for developing the compact antennas and their miniaturized techniques.

## III. ANTENNA DESIGN

The pentagon shaped microstrip antennas using Probe feed technique is designed with HFSS version 17.0 software. The substrate material used for the proposed antennas is shown in Table 2. Table 1 shows the three projected pentagon shaped patch design dimensions [6].

**Table 1: Dimensions of the substrate**

| Type | X (mm) | Y (mm) | Z (mm) |
|---|---|---|---|
| Design A<br>Design B<br>Design C | 100 | 90 | 3 |

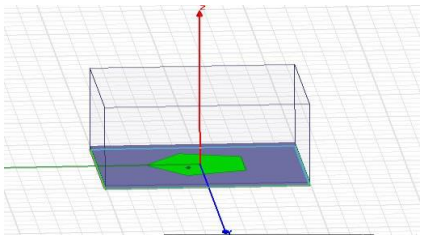
Table 2 summarize the patch width (in mm), the equivalent $f_r$ (in GHz).

**Table 2: Patch width and $f_r$ for proposed antenna design**

| Type | Substrate material | Patch width(mm) | $f_r$ (GHZ) |
|---|---|---|---|
| Design A | Roger's RT / Duroid 5880 (tm) | 26.86 | 6.5 |
| Design B | Roger's RO4003 (tm) | 26.86 | 6.6 |
| Design C | $FR_4$ Epoxy | 26.86 | 6.7 |

Table 3 summarizes the simulated antenna designs in Ansoft HFSS.

**Table 3: projected antenna designs using Ansoft HFSS software.**

| | |
|---|---|
| Design A<br>Design B<br>Design C |  |

**DESIGN EQUATIONS**:

1. The width for patch is determined with the following equation,

$$w = \frac{c_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}}$$

Where, $w$= Width of the patch
$c_0$= Speed of light
$\varepsilon_r$= value of the dielectric substrate

2. The value of the effective dielectric constant ($\varepsilon_{reff}$) is calculated from,

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2}, \frac{w}{h} > 1$$

3. The length (L) for patch is determined with the equation,

$$L = \frac{c_0}{2f_r\sqrt{\varepsilon_{reff}}} - 2\Delta L$$

4. Due to fringing, electrically the size of the antenna is increased by an amount of ($\Delta$L) and is determined from

$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{reff}-0.258)\left(\frac{w}{h}+0.8\right)}$, Where '$h$'= height of the substrate

5. The characteristic impedance can be written as,

$$Z_0 = \frac{120\pi}{\sqrt{\varepsilon_{eff}}\left(1.393 + \frac{w}{h} + \frac{2}{3}ln\left(\frac{w}{h} + 1.444\right)\right)}$$

6. Ground plane length and ground plane width are given are calculated by,

$$L_g = L + 6h$$
$$W_g = W + 6h$$

7. Height of a substrate is given by,

$$h = \frac{0.0606\lambda}{\varepsilon_r}$$

8. Feed line length is calculated by,

$L_f = \frac{\lambda_g}{4}$; Where, $\lambda_g = \frac{\lambda}{\sqrt{\varepsilon_{reff}}}$ is guided wavelength

## IV. SIMULATION RESULTS

For the projected antennas, the characteristics like bandwidth, return loss, radiation pattern and gain are presented in this paper. The return loss expresses the mismatch between media. The bandwidth is the range of frequencies over which the antenna performance is acceptable with an SWR less than 2. At a fixed distance from the antenna, power radiated with respect to direction is radiation pattern. Gain of an antenna is precise with reference antenna, may be an isotropic antenna or λ/2 antenna and this method is known as called as gain transfer technique. Table 4 shows the results obtained for Design A using Roger's RT/ Duroid 5880 (tm) substrate. The return loss graph for Design A is shown in figure 1. From the graph it can be observed that the least return loss is -22.92 dB at $f_r$ of 6.5 GHz. Figure 2 and 3 shows the gain plot and radiation pattern obtained for Design A.

**Table 4: Design A outputs**

| Characteristic | Obtained Values |
|---|---|
| $f_r$ (GHz) | 6.5 |
| Return Loss (dB) | -22.92 |
| Gain (dB) | 6.97 |
| Bandwidth (GHz) | 6.38-6.61 |

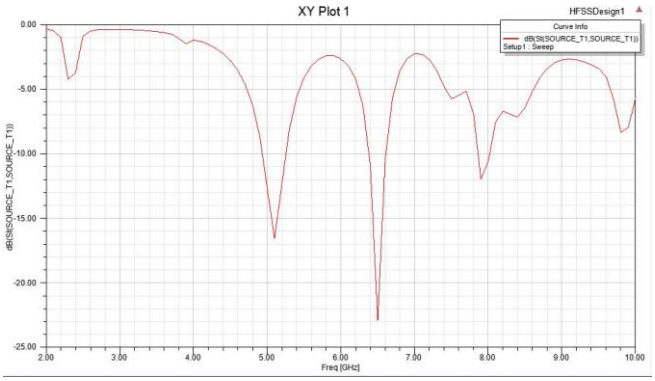



**Figure 1: Plot for Return loss of Design A**

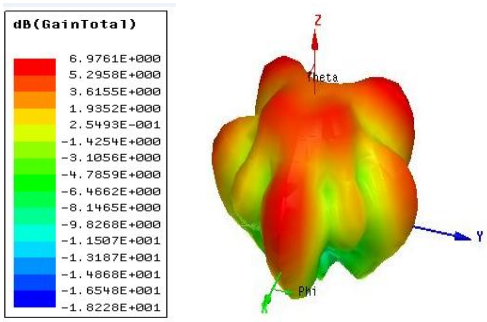



**Figure 2: Plot for Gain of Design A**

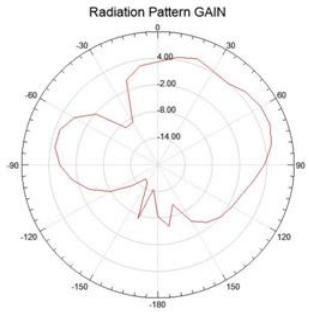



**Figure 3: Radiation pattern of Design A**

The results obtained for Design B using Roger's RO4003 (tm) substrate is publicized in table 5. Figure 4 shows the return loss plot having the least return loss of -27.91 dB at $f_r$ of 6.6 GHz. The gain plot and radiation pattern obtained for Design B are shown in figure 5 and figure 6.

**Table 5: Results for Design B**

| Characteristic | Obtained values |
|---|---|
| $f_r$ (GHz ) | 6.6 |
| Return Loss (dB) | -27.91 |
| Gain (dB) | 6.27 |
| Bandwidth (GHz) | 6.47-6.74 |

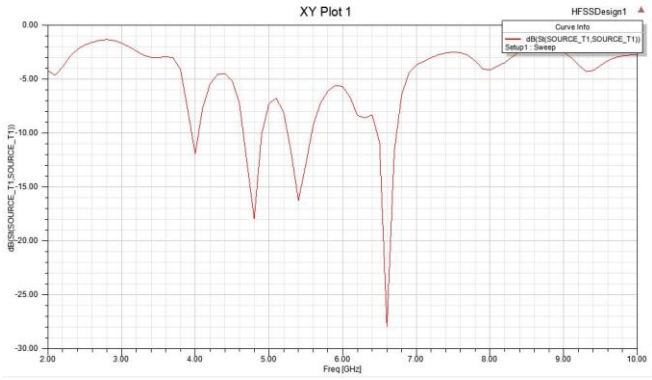



**Figure 4: Plot for Return loss of Design B**

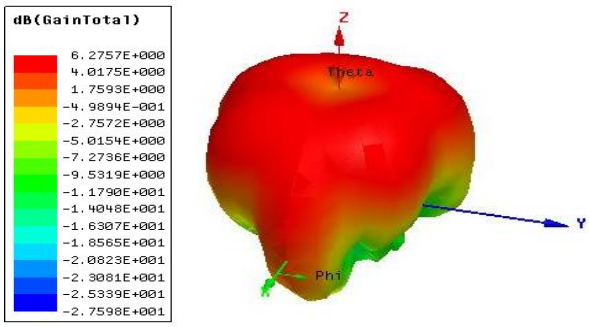



**Figure 5: Design B Gain plot**

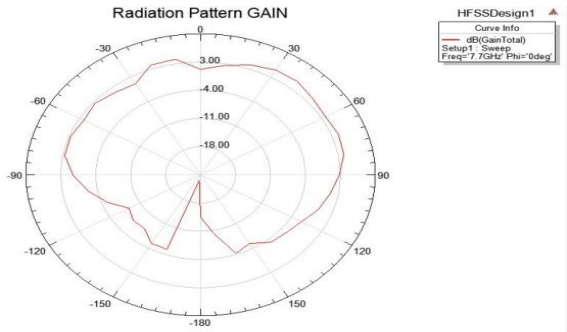



**Figure 6: Design B Radiation pattern**

Table 6 shows the results obtained for Design C using $FR_4$ epoxy substrate. The return loss graph is obtainable from figure 7. It is inferred that the minimum return loss is -16.14dB at the $f_r$ of 6.7 GHz. Figure 8 shows the gain and Figure 9 shows the radiation pattern obtained for Design C. The obtained gain is 6.30 dB.

**Table 6: Design C outputs**

| Characteristic | Obtained values |
|---|---|
| $f_r$ (GHz ) | 6.7 |
| Return Loss (dB) | -16.14 |
| Gain (dB) | 6.30 |
| Bandwidth (GHz) | 6.64-6.81 |

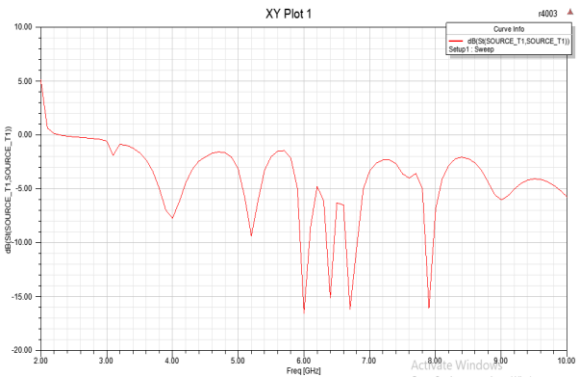



**Figure 7: Plot for Return loss of Design C**

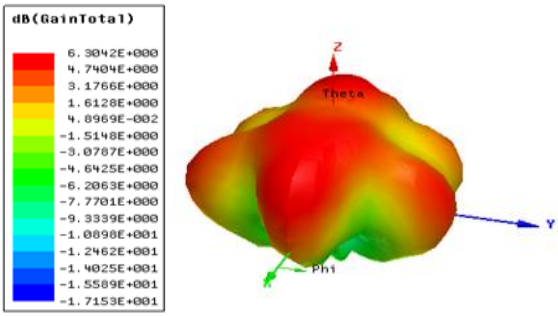



**Figure 8: Plot for Gain of Design C**

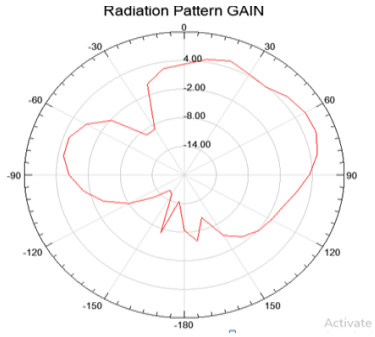



**Figure 9: Design C Radiation pattern**

The following Table 8 shows the comparison of Design A, Design B and Design C obtained for resonant frequencies 6.5 GHz, 6.6 GHz and 6.7 GHz respectively in which Probe feed technique is used and different substrate materials namely Roger's RT/ Duroid 5880 (tm), Roger's RO4003 (tm) and $FR_4$ epoxy for the design. Design A for $f_r$ of 6.5 GHz gives the enhanced performance in terms of gain compared to other two proposed antenna designs**.**

**Table 8: Comparison of Results for Design A, Design B and Design C**

| **Characteristics** | **DESIGN A** Roger's RT/ Duroid 5880 (tm) | **DESIGN B** Roger's RO4003 (tm) | **DESIGN C** $FR_4$ epoxy |
|---|---|---|---|
| $f_r$ (GHz) | 6.5 | 6.6 | 6.7 |
| Return loss (dB) | -22.92 | -27.91 | -16.14 |
| Gain (dB) | 6.97 | 6.27 | 6.30 |
| Bandwidth (GHz) | 0.23 | 0.27 | 0.17 |

## V. CONCLUSION

From the results obtained, the pentagon shaped microstrip patch antenna with three different substrate materials with Probe feed technique, it is observed that the Design A with an operating frequency of 6.5 GHz gives a gain, of 6.97 dB, Bandwidth of 0.23GHz and return loss of -22.92 dB.Design B gives a gain of 6.27 dB, bandwidth of 0.27GHz, and returns loss of -27.91 dB at fr of 6.6 GHz.Design C gives a gain of 6.30 dB, bandwidth of 0.17 GHz at $f_r$ of 6.7GHz. From the results obtained tabulated in table 8 Design A provides better performance in terms of gain with an acceptable values of Bandwidth and return loss.

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