Effects of added Secondary Dielectric material on the Performance of a Microstrip patch Antenna

U Bhanu chander¹, P Prakash², S Piramasubramanian³, M Ganesh Madhan⁴
¹²³⁴Department of Electronics Engineering, Madras Institute of Technology Campus, Anna University, Chennai 600044, India.

E-mail: bhanuchander210@gmail.com¹, prakashp_mit@annauniv.edu², spsnanthan@gmail.com³, ganeshmadhan@yahoo.com⁴

Abstract. Micro strip patch antennas are normally fabricated on the surface of a dielectric material. Due to various reasons, the replacement of the surface material and modifications in area are not possible, once the antenna is fabricated. In some cases, the operating frequency and bandwidth of the antenna needs to be altered without changing the substrate. This paper investigates a dual dielectric patch antenna and analyses the performances of the antenna under the combined dielectric layers inside the cavity. Initially, a patch antenna is designed for a resonant frequency with a widely used dielectric material, FR4 and after which another dielectric layer is added. The performance of the antenna is evaluated using Method of moments solver in ADS software. The thickness sharing percentage of the secondary dielectric material was linearly increased from 10% to 90% in simulation. The analysis shows an emergence of another band due to the introduction of secondary dielectric layer. Measurements also confirm the simulation results and notable change in reflection coefficient with bandwidth enhancement is observed.

1. Introduction

Micro strip patch antennas possess many advantages to fulfil the requirements of various wireless communication applications. They are characterised by low profile, planar conformable, simple structure and mechanically robust [1]. These antennas are directly printed along with active and passive components of the circuit. A major drawback of the patch antenna is its narrow band operation. Upcoming mobile applications are in need of integrated wireless services that operate in different bands. Dielectric material property directly influences the parameters like resonant frequency, gain, directivity and half power beam width [2-6]. The bandwidth and return loss of the patch antenna depends on the properties of the dielectric material [7]. Microstrip patch antennas commonly use commercial dielectric substrates such as FR4, Arlon AD250, Rogers R0 4725. They have dielectric constant in the range of 2 to 5 [8-10]. Also the patch with multiple dielectric layers was analysed by equivalent cavity model [12]. In this paper, an inset feed rectangular patch antenna was designed for 3.2 GHz resonant frequency. To observe the effect of an additional dielectric material, when it is placed along with non-replaceable primary substrate like FR4, a secondary dielectric material was inserted with a thickness sharing percentage varying from 10% to 90%. The secondary
dielectric material is the key to tuning or achieving the required additional band without changing any metrics of the already designed patch antenna.

2. Geometry of Patch antenna
The design equations used for the inset feed patch design are given below [10 - 11].

Width of the patch,
\[ W = \frac{c}{2 \times fr} \sqrt{\frac{2}{\varepsilon + 1}} \]  

Effective dielectric constant,
\[ \varepsilon_{eff} = \frac{\varepsilon + 1}{2} + \left[ \frac{\varepsilon + 1}{2} \times \left( 1 + \frac{12 \times h}{W} \right)^{1/2} \right] \]  

Effective length of the patch,
\[ L_{eff} = \frac{c}{2 \times fr} \sqrt{\frac{1}{\varepsilon_{eff}}} \]  

Actual length of the patch,
\[ L = L_{eff} - 2 \times \Delta L \]  

Due to the fringing fields, a length \( \Delta L \) need to be reduced,
\[ \Delta L = 0.412 \times h \times \frac{(\varepsilon_{eff} + 0.3)}{(\varepsilon_{eff} - 0.264)} + \frac{(\varepsilon_{eff} + 0.258)}{(\varepsilon_{eff} + 0.8)} \]  

Feeder length is,
\[ FL = \frac{c}{4 \times fr} \sqrt{\frac{1}{\varepsilon_{eff}}} \]  

Feeder width can be calculated from the line calculator in ADS tool while designing the patch antenna. This calculation is based on the equation given below.

Characteristics impedance of a micro strip patch,
\[ Z_0 = \frac{120}{\sqrt{\varepsilon_{eff} \times \left[ \frac{W}{h} + 1.393 + 0.667 \times \ln \left[ \frac{W}{h} + 1.44 \right] \right]}} \]  

Where,
\[ \frac{W}{h} \geq 1 \]

The inset feed implements the edge impedance reduction with length of insertion \( y \) which depends upon the patch length \( L \) [1]. It means that that the edge impedance of the patch vary with the length as per the equation.

\[ Z(y) = Z_e \times \cos^2 \left( \frac{\pi y}{L} \right) \]  

Where \( y \) is the insertion length, \( Z(y) \) is Impedance at the length \( y \) and \( Z_e \) is the Impedance at the edge of the patch antenna. When the insertion length \( y \) is equal to one fourth of the patch length \( L \), a minimum impedance is achieved.
\[ Z(y) = \frac{Z_e}{2} \] (9)

3. Simulation of two dielectric layers in patch cavity

A 3.2 GHz patch with FR4 (Relative permittivity 4.4) was simulated and analysed for the study of the influence of a secondary dielectric layer. The reference patch physical parameters are shown in table 1, which are derived from the equations (1) – (9).

| Antenna design parameters | Value   |
|---------------------------|---------|
| Length                    | 21.9 mm |
| Width                     | 28.5 mm |
| Feeder length             | 11.9 mm |
| Feeder width              | 3.5 mm  |
| Inset length              | 5.5 mm  |
| Height of substrate       | 1.6 mm  |

The simulated output response of the designed patch antenna is shown in the figure 1, with resonant frequency and bandwidth parameters.

![Figure 1. Reflection coefficient of 3.2 GHz patch](image)

The simulation of linear increment in secondary dielectric thickness as sharing percentage is shown in table 2. For the purpose of analysis, the thickness of the secondary dielectric (RT Duroid with relative permittivity 2.33) is increased slowly, while the primary dielectric thickness is decreased.
Table 2. Simulation scheme for two dielectric patch

| S. No | Secondary dielectric thickness sharing percentage | Fr4 mm (Primary) | RT Duroid mm (Secondary) |
|-------|--------------------------------------------------|-------------------|--------------------------|
| 1     | 10%                                              | 1.44              | 0.16                     |
| 2     | 20%                                              | 1.28              | 0.32                     |
| 3     | 30%                                              | 1.12              | 0.48                     |
| 4     | 40%                                              | 0.96              | 0.64                     |
| 5     | 50%                                              | 0.8               | 0.8                      |
| 6     | 60%                                              | 0.64              | 0.96                     |
| 7     | 70%                                              | 0.48              | 1.12                     |
| 8     | 80%                                              | 0.32              | 1.28                     |
| 9     | 90%                                              | 0.16              | 1.44                     |

The reflection coefficient of the patch (S11) is determined in the frequency domain using ADS tool. The simulation results show two modes of the patch antenna. From equation (10), the resonant frequency of the cavity with \( \mu \) permeability and \( \varepsilon \) permittivity is given as,

\[
F_r (mn) = \frac{1}{2\pi \sqrt{\mu \varepsilon}} \sqrt{\left(\frac{mn}{n}\right)^2 + \left(\frac{mn}{L}\right)^2 + \left(\frac{mn}{W}\right)^2}
\]  \hspace{1cm} (10)

where \( W, L, h \) are the corresponding width, length and height of the cavity and \( m, n, p \) are the modes of the patch [1]. The linear increment of additional dielectric share affects the cavity of the patch antenna and the response of the modes TM 010 and TM 002. The surface current density of the both modes TM 010 and TM 002 are shown in the figure 2. It shows higher values of current density in the patch edges implying radiation at the resonant frequencies.

![Surface current density of the patch antenna at mode TM 010](image1)

![Surface current density of the patch antenna at mode TM 002](image2)

A linear shift in resonant frequency occurs with an increase in dielectric share as shown in figure 3. The variation is similar for both TM 010, TM 002 modes.
Figure 3. Resonant frequency responses of both modes with Dielectric share

Figure 4. Bandwidth of the patch with Dielectric share

Figure 5. Reflection coefficient with Dielectric share
The 10dB bandwidth and reflection coefficient S11 (dB) of these two bands were captured and plotted in figures 4 and 5. The band width and reflection coefficients of that second resonant band linearly increases with the dielectric share and another does not show any remarkable change.

4. Frequency responses of fabricated patch antennas
A real time test set up is shown in figure 6, using a network analyser with a test bed for the fabricated patch. The fabricated multi-layer patches were tested with this set up one by one and results were captured for further analysis. To verify the effects of two dielectric layers, a 3.2 GHz resonant frequency patch antenna was designed, simulated and fabricated with single and multilayer mode for real time measurements. The patch antenna exhibited large amount of shift, when additional dielectric layer is introduced.

![Experimental setup for multiple dielectric patch](image)

**Figure 6.** Experimental setup for multiple dielectric patch

4.1. Relative permittivity measurement with dielectric materials
Paper, Polythene and Plastic materials were used in the place of FR4 in the designed patch, shown in Table 1, for finding their relative permittivity experimentally. Equation (10) is used to measure the relative permittivity of the replaced cavity material in the patch. The deviation from the resonant frequency (3.2 GHz), is used to derive the relative permittivity of the respective dielectric material. The resonant frequency response and the measured relative permittivity of all dielectric materials are shown in the Table 3.

| Dielectrics | Observed Resonant Frequency (GHz) | Actual Relative Permittivity (εr) |
|-------------|----------------------------------|----------------------------------|
| Paper       | 3.68                             | 3.4                              |
| Polythene   | 4.88                             | 1.8                              |
| Plastic     | 4.76                             | 1.9                              |
4.2. Experiment results for different dielectric materials

FR4 layer was kept as constant bottom layer and each one of these dielectrics namely, Paper, Polythene and Plastic were kept as top layer for measurement as shown in figure 7. Reference patch antenna with FR4 material alone is shown in the figure 8(a) and other dual dielectric fabricated patch antennas are shown in the figures 8(b) to 8(c). These fabricated patch antennas are measured in the test bed shown in the figure 6 and the observed responses of the both simulated and fabricated patch antennas are shown in the figures 9 to 11.

**Figure 7.** Experimental two dielectric layer approach

**Figure 8 (a).** Patch antenna with FR4 alone

**Figure 8 (b).** Patch antenna with paper and FR4

**Figure 8 (c).** Patch antenna with plastic and FR4

**Figure 8 (d).** Patch antenna with polythene and FR4
Figure 9. Experimental results of 42% Plastic with FR4

Figure 10. Experimental results of 90% Paper with FR4

Figure 11. Experimental results of 40% Polythene with FR4
The resonant frequency and reflection coefficient response in both resonant modes of the fabricated patch antennas are determined with respect to the additionally shared dielectric materials and shown in the tables 4 and 5. The measured bandwidths in the case of simulated and fabricated patch antenna are shown in the table 6. The frequencies corresponding to reflection coefficients higher than -10 dB and another mode for reference patch antenna are not considered and hence left blank in the respective cells of the tables. S11 indicates Reflection coefficient( at resonance) in dB, DTSP means Dielectric Thickness Sharing Percentage with FR4 material (%), Fr_1 and Fr_2 are the first and second resonant frequencies respectively and BW is 10 dB bandwidth at the resonant frequency band.

| Table 4. Simulation parameters of the patches |
|----------------------------------------------|
| Dielectrics | DTSP (%) | First Resonance (GHz) | Second Resonance (GHz) | S11 Fr_1 (dB) | S11 Fr_2 (dB) |
|-------------|----------|-----------------------|------------------------|---------------|---------------|
| FR4 (REF)   | 100      | 3.21                  | -                      | -13.815       | -             |
| Paper       | 90       | 3.917                 | 6.137                  | -13.341       | -34.1637      |
| Polythene   | 40       | 4.23                  | 6.525                  | -12.251       | -10.571       |
| Plastic     | 42       | 3.99                  | 5.958                  | -12.697       | -30.220       |

| Table 5. Measured parameters of the patches |
|----------------------------------------------|
| Dielectrics | DTSP (%) | Fr_1 (GHz) | Fr_2 (GHz) | S11 of Fr_1 (dB) | S11 of Fr_2 (dB) |
|-------------|----------|------------|------------|------------------|------------------|
| FR4 (REF)   | 100      | 3.38       | -          | -29.10           | -                |
| Paper       | 90       | 4.08       | 6.285      | -12.02           | -23.07           |
| Polythene   | 40       | 4.20       | 6.370      | -13.66           | -24.08           |
| Plastic     | 42       | 4          | 6.040      | -11.34           | -22.27           |

| Table 6. Bandwidths of the experimented patches |
|-----------------------------------------------|
| Dielectrics | DTSP (%) | Simulated | Measured |
|-------------|----------|-----------|----------|
|             |          | BW of Fr_1 (MHz) | BW of Fr_2 (MHz) | BW of Fr_1 (MHz) | BW of Fr_2 (MHz) |
| FR4 (REF)   | 100      | 39        | -         | 116      | -             |
| Paper       | 90       | 180       | 293       | 182      | 714           |
| Polythene   | 40       | 52        | 104       | 140      | 590           |
| Plastic     | 42       | 78        | 304       | 80       | 440           |
5. Conclusion
This paper discusses the effects of adding another dielectric material on the performance of a basic patch antenna. A 3.2 GHz FR4 based dielectric patch was added with another dielectric material and the effect of thickness is analysed. It leads to frequency shift with respect to the added dielectric material and also introduces a new resonant mode. RT Duroid is used as secondary material along with FR4 primary. The thickness of secondary dielectric material is linearly increased from 10–90 % in ADS simulation. Paper, Polythene and Plastic were fabricated as additional dielectric and added with FR4. The simulation and measurement results show that, adding another dielectric leads to a linear increase in reflection coefficient and 10 dB bandwidth of the new mode in high frequency region. Both resonant frequencies linearly shift with respect to the thickness and relative permittivity of shared dielectric material. Measurement results show that these resonant bands provides higher reflection coefficient and 10 dB bandwidth enhancement, while adding additional dielectric layer inside the cavity.

6. References
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