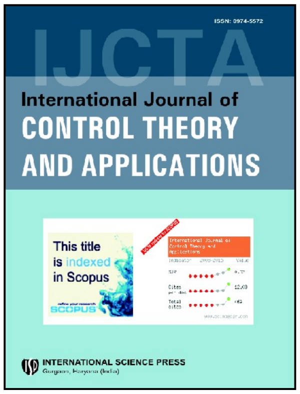


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# Enhancement of Gain and Directivity in Inset Fed Patch Antenna Using HFSS

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***Abstract:*** In Today's era of wireless communication, micro strip antennas (MSA) plays a major role in many fields like WLAN, SATCOM, Mobile communications, Military war fires and IOT by providing required gain and Bandwidth. Usually MSA (ex: rectangular micro strip antennas) suffers from low gain and return loss when there is a impedance mismatch between edge of the patch and line feed [6]-[10]. In this paper, we attempt the problem of impedance mismatch, which draws the attention to develop a technique to enhancing gain by reducing the inductive load of patch which is fed by an Inset feed. It produced better& optimized results in the given frequency range of operation.

***Keywords:*** Inset Feed, Depth, Gap, Return Loss, VSWR, Gain, Directivity, And HFSS

## 1. INTRODUCTION

Micro strip antennas of different configurations like square, rectangular, circular, trapezoidal, elliptical, etc. are widely used because of their many advantages over conventional antennas such as low cost, light weight, reproducibility, ease of fabrication, etc. the rectangular micro strip is most favorable one[1]. Importance of MSA is placed upon creating patch antennas that show broadband properties, capable of high-speed data transfer [2]. In this paper is concentrating the mismatch of impedance between patch and feed line can be reduced by inset feed method. The input impedance behavior of the inset-fed rectangular micro strip patch antenna was investigated and the deembedded resonant input resistance of the patch at the contact point between the line and the patch versus the notch depth (location of the contact point) had been found to be well-characterized by a simple shifted cosine-squared function [3]. To find the values of frequency of resonant within the given ratio of notch width for the antenna to obtain the most possible match to the feeding 50 ohm micro strip line [4]. The dependence of the input resistance on the feed position of a MSA differs when using a probe or a micro strip line feed,however the measured input resistance for the probe fed structure demonstrated the cosine squared behavior, the input resistance for the micro strip line fed patch was found to decrease at a more rapid rate [5]. By symmetrically loading a pair of shorting pins beneath a square patch, surface current density near these pins could be remarkably strengthened [6]. Observed From above all proposed methods the inductive load is dominating the performance of patch antenna, the inductive load can be reducing with external inductive load and internal developing capacitance (Notch).

The aim of this paper is attempting to the development of empirical expressions for the notch gap and depth to increase negatively the return loss of half-wavelength rectangular micro strip antennas. This method can be generate internal capacitance that is compensating the inductive load and reducing the impedance mismatch between the patch and fed line. The design had done on Ansoft HFSS v15.

## 2. DESIGN OF MICRO STRIP PATCH ANTENNA

The rectangular patch antenna design requires ground, substrate and patch. In this design FR4 epoxy material has been used for substrate, its dielectric constant value having 4.4. The substrate and the rectangular patch antenna are designed with proper geometry [4]. The design of this rectangular patch antenna has been seen from figure 1 below. This design is simulated using HFSS v 15 at multiple frequencies for return loss (S11) and Voltage Standing Wave Ratio (VSWR), Gain, directivity and pattern of radiation using previous designed formulas. The results have been observed from the following figures. Introducing a new notch gap and depth parameters modified to further improvement the return loss of rectangular patch antenna. The performance of the rectangular patch antenna has been assessed by changing the gap and depth notch on the patch for improving the return loss. By changing the notch parameters, simulating this design with HFSS we achieved a return loss of -22 dB & -52 dB, VSWR below one, Etotal of 22dB to 24dB, Gain total: 5.2dB to 5.9 dB and Directivity of 6 dB to 8 dB for constant height of substrate, a return loss of -20 to -58dB, VSWR below one, Etotal of 20dB to 23 dB, Gain total of 5.2dB to 5.9 dB and Directivity of 6 dB to 8 dB for variable height of substrate.

### (A) Design Equations

From [2]-[6], the patch antenna with inset feed design rules can be discussed. The design of transmission lines the newly define equations are given below.

#### *Case I: Constant Height of substrate for all frequencies and predefined formulas for depth and gap*

1. Depth of Notch (y0):

   $$\text{Depth(y0)} = \{0.001699\ \varepsilon_r^{7} + 0.13761\ \varepsilon_r^{6} - 6.1783\ \varepsilon_r^{75} + 93.187\ \varepsilon_r^{4} - 682.69\ \varepsilon_r^{3} + 2561.9\ \varepsilon_r^{2} - 4043\ \varepsilon_r^{1} + 6697\}\ \frac{L}{2} \quad \text{[from reference [13]]}$$

2. Gap of Notch (x0):

   $$gap(x0) = \frac{4.65 \times 10^{-12} \times v_0}{f_r \sqrt{2\ \varepsilon_{eff}}} \quad \text{[ from reference [1]]}$$

3. H=1.5 (constant)
4. Feed line length: 2* half wave length transmission line length.
5. Feed line width: transmission line width

### *Case II: Constant Height of substrate for all frequencies with proposed formulas for depth and gap*

1. Depth of Notch (y0): $\frac{\lambda}{7}$

2. Gap of Notch (x0): $\frac{\lambda}{24}$ <x0 < $\frac{\lambda}{17}$ or $\frac{w}{15}$ <x0< $\frac{w}{11}$

3. H=1.5 (constant)

4. Feed line length: 2* half wave length transmission line length

5. Feed line width: transmission line width

### *Case III: Variable Height of substrate for all frequencies (Height changes w r t input frequency) with predefined formulas for depth and gap*

1. Depth of Notch (y0):

   $$\text{Depth(y0)} =\{0.001699\ \varepsilon_r^{7} + 0.13761\ \varepsilon_r^{6} - 6.1783\ \varepsilon_r^{75} + 93.187\ \varepsilon_r^{5} - 682.69\ \varepsilon_r^{3} + 2561.9\ \varepsilon_r^{2} - 4043\ \varepsilon_r^{1} + 6697\}\frac{L}{2}$$

   [from reference [13]]

2. Gap of Notch (x0):

   $$gap(x0) = \frac{4.65 \times 10^{-12} \times v_0}{f_r\sqrt{2\varepsilon_{eff}}}$$

   [from reference [1]]

3. H = $\frac{\lambda}{12.56}$.

4. Feed line length: 2* half wave length transmission line length

5. Feed line width: transmission line width

### *Case IV: Variable Height of substrate for all frequencies (Height changes w r t input frequency) with proposed formulas for depth and gap*

1. Depth of Notch (y0): $\frac{L}{3.3}$ <y0< $\frac{L}{3}$

2. Gap of Notch (x0): $\frac{\lambda}{238}$ <x0 < $\frac{\lambda}{19}$ or $\frac{w}{152}$ <x0 < $\frac{w}{12}$

3. $H = \frac{\lambda}{12.56}$.

4. Feed line length: 2*half wave length transmission line length

5. Feed line width: transmission line width

Note: $\lambda = \dfrac{3\times10^{11}}{f_r\sqrt{\varepsilon_r}}$ mm.

Where $f_r$ is resonant frequency?

$\varepsilon_r$ is Dielectric constant for substrate.

**B. Design Models:** The design can be observed three cases from the following figures.

### *Case I: Constant Height of substrate for all frequencies and predefined formulas for depth and gap*

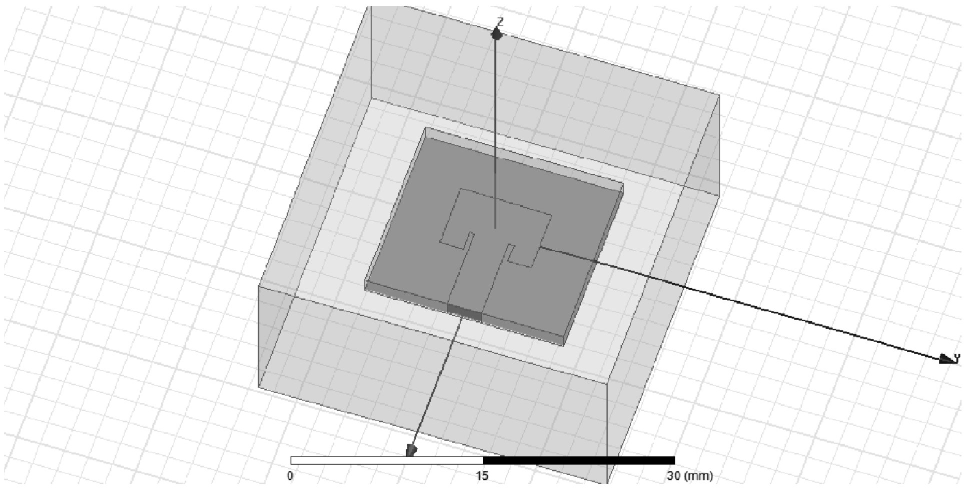


**Figure 1: The rectangular patch antenna designed with constant height and predefined formulas of depth and gap**

### *Case II: Constant Height of substrate for all frequencies with proposed formulas for depth and gap*

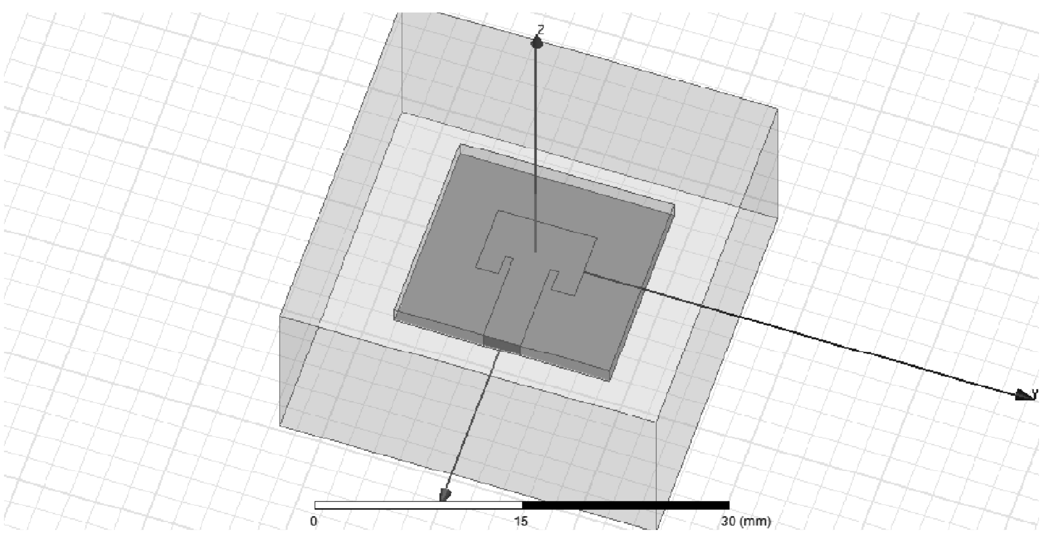


**Figure 2: The rectangular patch antenna designed with Constant height, formula depth and gap**

### *Case III: Variable Height of substrate for all frequencies (Height changes w r t input frequency) with predefined formulas for depth and gap*

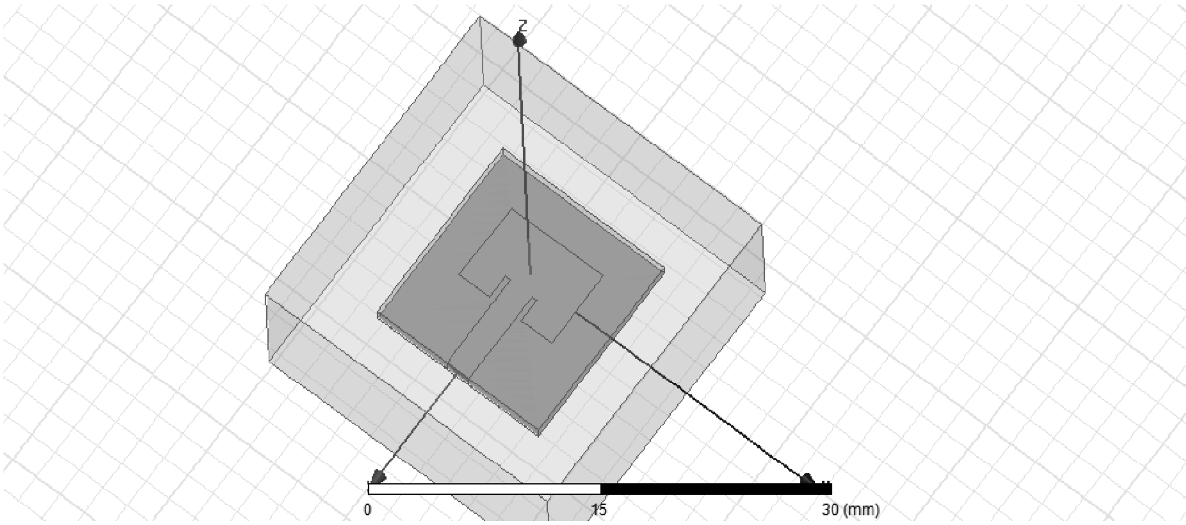


**Figure 3: The rectangular patch antenna designed with variable height and predefined formulas of depth and gap**

### *Case IV: Variable Height of substrate for all frequencies (Height changes w r t input frequency) with proposed formulas for depth and gap*

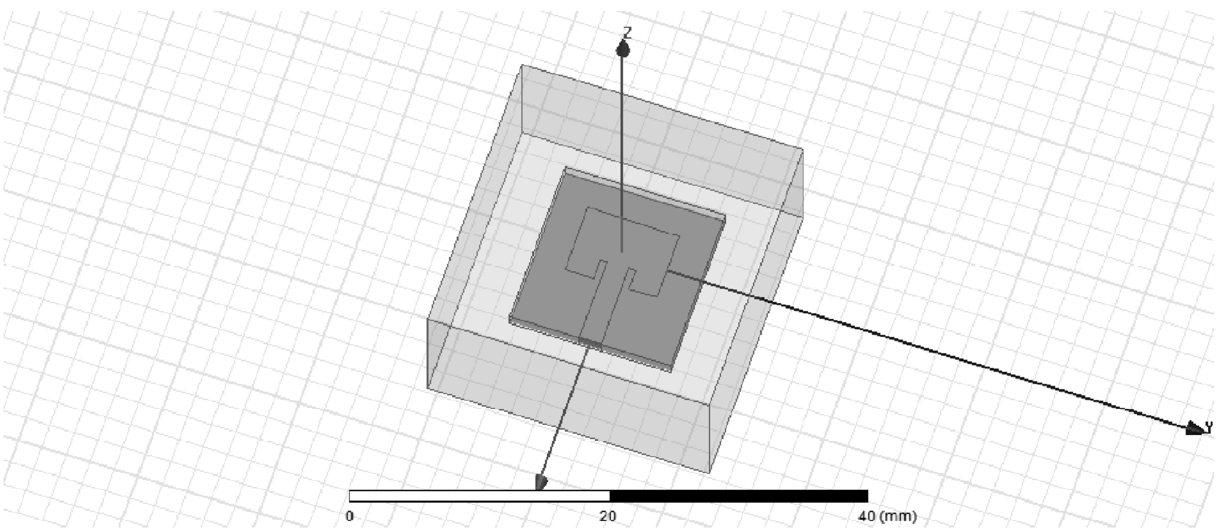


**Figure 4: Not Constant Height of substrate for all frequencies (Height changes w r t input frequency) with proposed formulas for depth and gap**

## 3. RESULTS AND DISCUSSION

### *Case I: Constant Height of substrate for all frequencies and predefined formulas for depth and gap*

### A. Return Loss

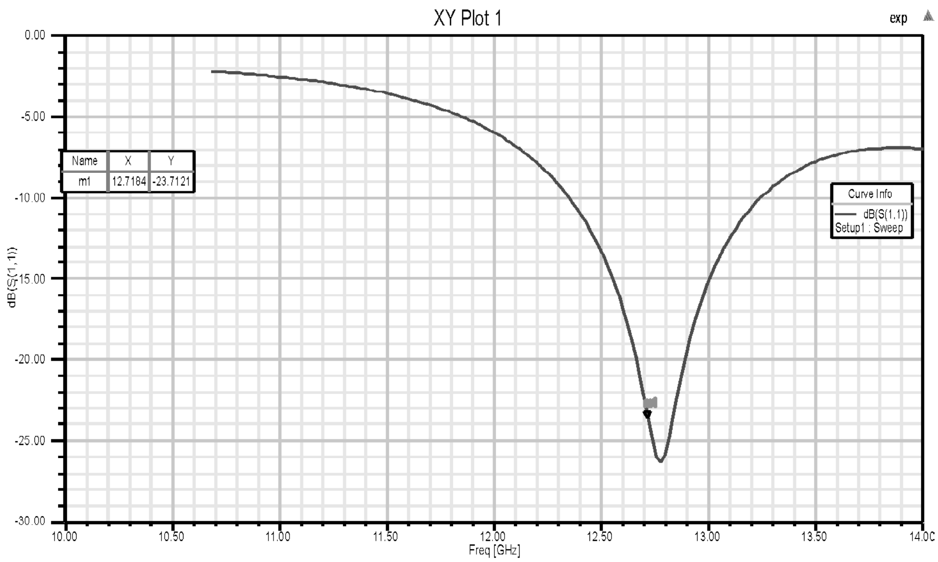


**Figure 5: The rectangular patch antenna's return loss**

## B. VSWR

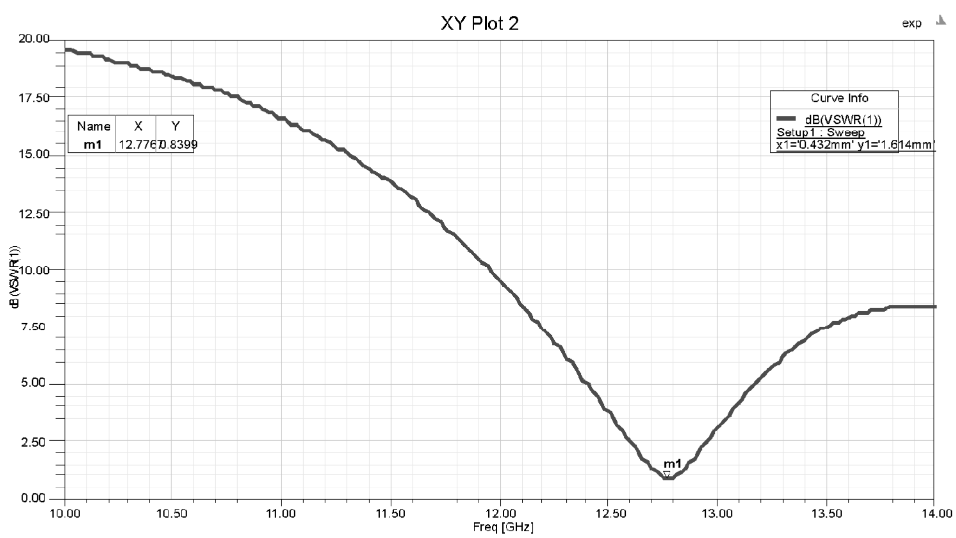


**Figure 6: The rectangular patch antenna's VSWR**

## C. Electric field


**Figure 7: The rectangular patch antenna's electric field pattern**

## D. Gain


**Figure 8: The rectangular patch antenna's gain**

## E. Directivity


**Figure 9: The rectangular patch antenna's directivity**

From the figures 5-9, the rectangular patch antenna's return loss is 23.71dB, VSWR is 0.83, Electric Field is 21.3dB, Gain is 4.86dB and directivity is 6.17dB at the operating frequency is 12 GHz, substrate height 1.5mm (constant) and dielectric constant 4.4.

The complete details are tabulated below:

**Table 1**
**Height of substrate (H) is constant with input frequency, x0 and y0 defined with designed rules**

| *S. No* | *f0 (GHz)* | *H (mm)* | *x0 (mm)* | *y0 (mm)* | *S11 (dB)* | *VSWR* | *E (dB)* | *GAIN (dB)* | *DIR (dB)* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 1.5 | 1.6 | 7.20 | -13.11 | 3.9 | 20.58 | 3.08 | 5.54 |
| 2 | 6 | 1.5 | 0.8 | 3.49 | -41.09 | 0.15 | 22.66 | 5.0671 | 6.99 |
| 3 | 9 | 1.5 | 0.5 | 2.24 | -24.03 | 1.09 | 22.19 | 5.132 | 6.73 |
| 4 | 12 | 1.5 | 0.4 | 1.61 | -26.32 | 0.83 | 21.4 | 4.86 | 6.17 |
| 5 | 15 | 1.5 | 0.3 | 1.23 | -33.81 | 0.35 | 22.64 | 6.217 | 7.31 |

## *Case II: Constant Height of substrate for all frequencies with proposed formulas for depth and gap*

### A. Return Loss

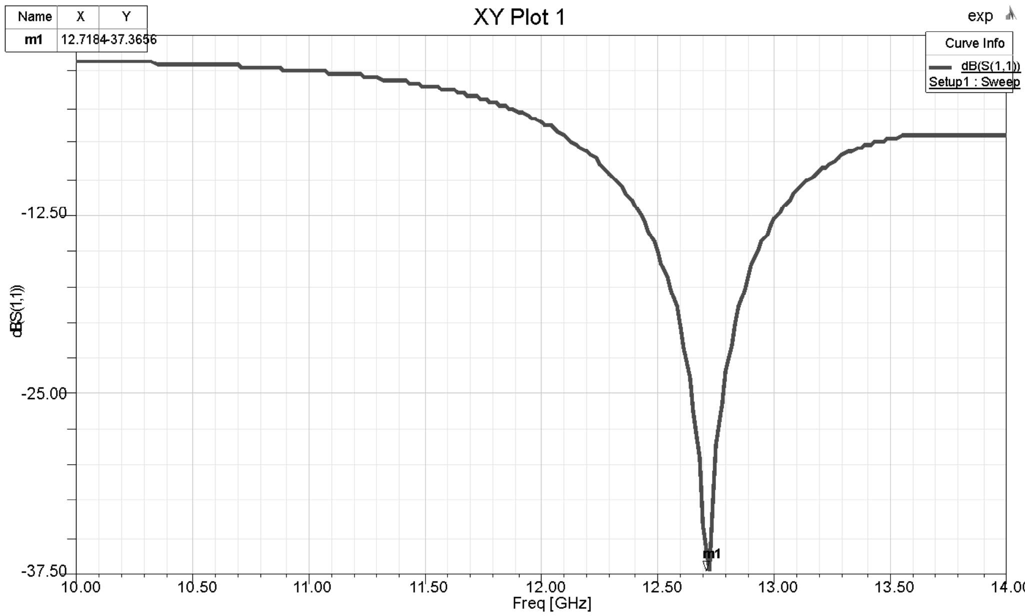


**Figure 10: The rectangular patch antenna's return loss**

### B. VSWR

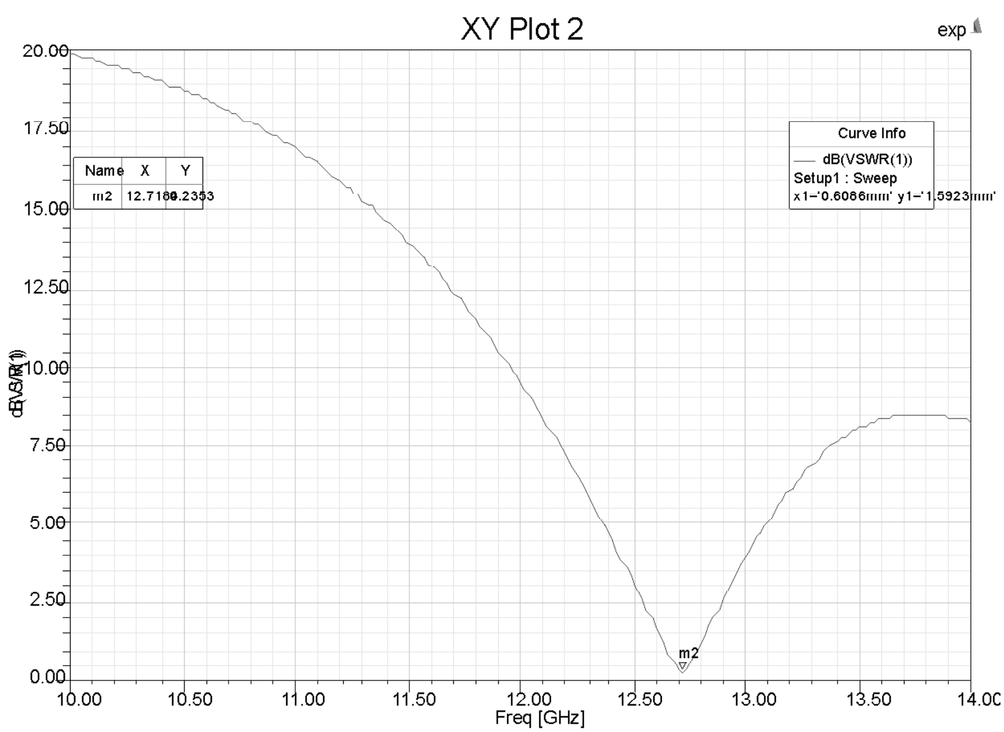


**Figure 11: The rectangular patch antenna's VSWR**

## C. Electric Filed


**Figure 12: The rectangular patch antenna's electric field pattern**

## D. Gain


**Figure 13: The rectangular patch antenna's gain**

## E. Directivity


**Figure 14: The rectangular patch antenna's directivity**

From figures 10-14, The rectangular patch antenna's return loss is 37.36dB, VSWR is 0.23, Electric Field is 21.43dB, Gain is 4.88dB and directivity is 6.20 dB at the operating frequency is 12 GHz, substrate height 1.5mm (constant) and dielectric constant 4.4 with this paper proposed formulas . From case I and case II, we are getting better gain and return loss for case II. The complete details are tabulated below:

**Table 2**
**Height of substrate (H) is constant with input frequency, x0 and y0 defined with this proposed formula**

| *S. No* | *f0 (GHz)* | *H (mm)* | *x0 (mm)* | *y0 (mm)* | *S11 (dB)* | *VSWR* | *E (dB)* | *GAIN (dB)* | *DIR (dB)* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 1.5 | 2.43 | 7.11 | -9.9 | 5.71 | 20.27 | 2.95 | 5.50 |
| 2 | 6 | 1.5 | 1.21 | 3.44 | -19 | 1.75 | 22.68 | 5.10 | 7.02 |
| 3 | 9 | 1.5 | 0.81 | 2.21 | -31 | 0.44 | 22.24 | 5.14 | 6.72 |
| 4 | 12 | 1.5 | 0.60 | 1.59 | -37 | 0.23 | 21.44 | 4.88 | 6.2 |
| 5 | 15 | 1.5 | 0.48 | 1.21 | -24 | 1.16 | 22.63 | 6.24 | 7.32 |

### *Case III: Variable Height of substrate for all frequencies (Height changes w r t input frequency) with predefined formulas for depth and gap*

### A. Return Loss

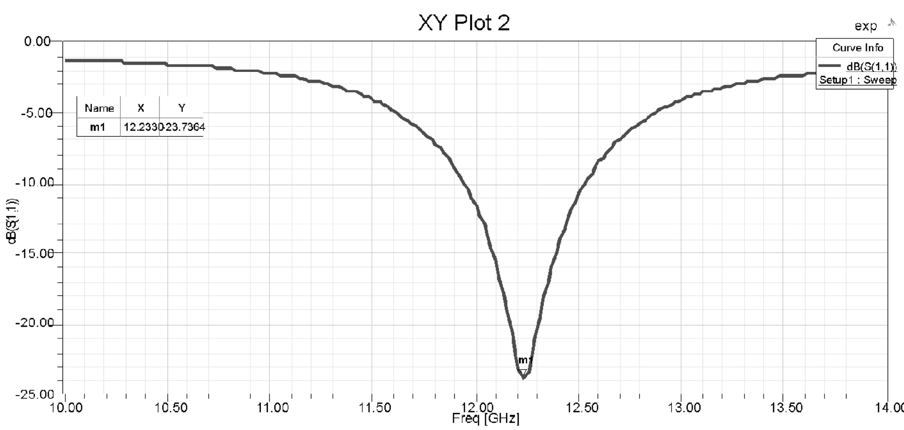


**Figure 15: The rectangular patch antenna's return loss**

### B. VSWR

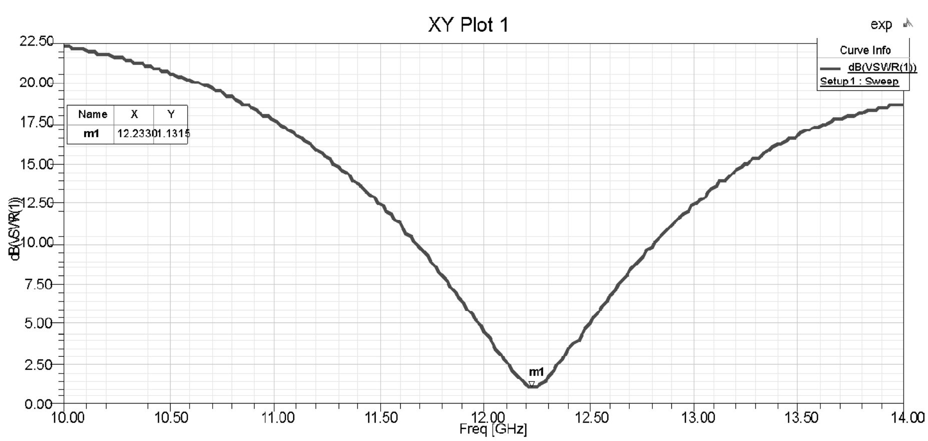


**Figure 16: The rectangular patch antenna's VSWR.**

## C. Electric Filed


**Figure 17: The rectangular patch antenna's electric field pattern**

## D. Gain


**Figure 18: The rectangular patch antenna's gain**

## E. Directivity

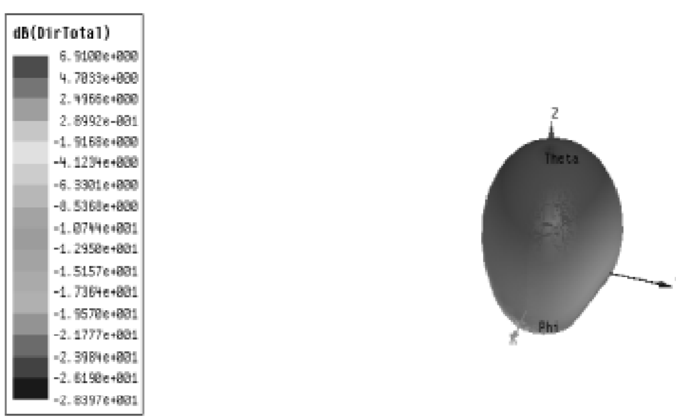


**Figure 19: The rectangular patch antenna's directivity**

From figures 15-19, The rectangular patch antenna's return loss is 23.73dB, VSWR is 1.14, Electric Field is 22.65dB, Gain is 5.16 dB and directivity is 6.92 dB at the operating frequency is 12 GHz, substrate height 0.94mm (not constant) and dielectric constant 4.4 with previous paper proposed formulas .From case I, case II and case III, we are getting better gain and return loss for case III.

The complete details are tabulated below:

**Table 3**
**Height of substrate (H) is not constant with input frequency, x0 and y0 defined with predefine proposed formulas**

| *S. No* | *f0 (GHz)* | *H (mm)* | *x0 (mm)* | *y0 (mm)* | *S11 (dB)* | *VSWR* | *E (dB)* | *GAIN (dB)* | *DIR (dB)* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 3.79 | 1.69 | 6.85 | -31.78 | 0.44 | 22.48 | 5.26 | 7.02 |
| 2 | 6 | 1.89 | 0.84 | 3.42 | -30.81 | 0.5 | 22.62 | 5.31 | 7.03 |
| 3 | 9 | 1.26 | 0.56 | 2.28 | -26.73 | 0.8 | 22.58 | 5.17 | 6.91 |
| 4 | 12 | 0.94 | 0.42 | 1.71 | -23.73 | 1.13 | 22.65 | 5.18 | 6.91 |
| 5 | 15 | 0.75 | 0.33 | 1.37 | -21.67 | 1.44 | 22.73 | 5.25 | 6.95 |

***Case IV: Variable Height of substrate for all frequencies (Height changes w r t input frequency) with proposed formulas for depth and gap***

**A. Return Loss**

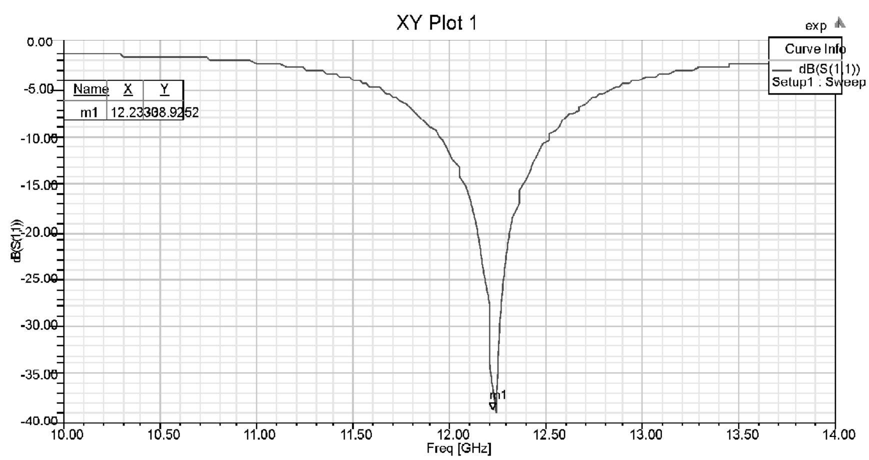


**Figure 20: The rectangular patch antenna's return loss**

**B. VSWR**

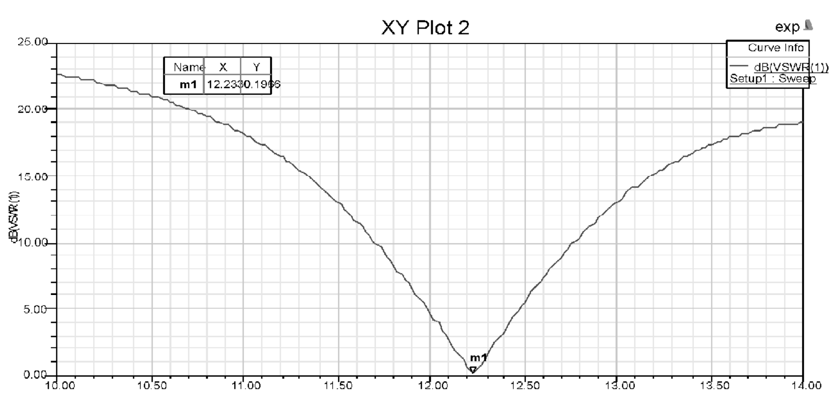


**Figure 21: The rectangular patch antenna's VSWR**

## C. Electric Filed


**Figure 22: The rectangular patch antenna's Electric field pattern**

## D. Gain


**Figure 23: The rectangular patch antenna's gain**

## E. Directivity


**Figure 24: The rectangular patch antenna's directivity**

From figures 15-19, The rectangular patch antenna's return loss is 38.92dB, VSWR is 0.19, Electric Field is 22.72 dB, Gain is 5.25 dB and directivity is 6.95 dB at the operating frequency is 12 GHz, substrate height 0.94mm (not constant) and dielectric constant 4.4 with this paper proposed formulas . From the four cases, we are getting better gain and return loss for case IV, constant gain for all frequencies.

The complete details are tabulated below:

**Table 4**
**Height of substrate (H) varies with input frequency, x0 and y0 defined with this proposed formulas.**

| *S. No.* | *f0 (GHz)* | *H (mm)* | *x0 (mm)* | *y0 (mm)* | *S11 (dB)* | *VSWR* | *E (dB)* | *GAIN (dB)* | *DIR (dB)* |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 3 | 3.79 | 2.02 | 6.76 | -33.53 | 0.37 | 22.46 | 5.25 | 7.02 |
| 2 | 6 | 1.89 | 1.01 | 3.38 | -32.5 | 0.41 | 22.46 | 5.25 | 7.02 |
| 3 | 9 | 1.26 | 0.81 | 2.25 | -30.46 | 0.52 | 22.61 | 5.23 | 6.95 |
| 4 | 12 | 0.94 | 0.55 | 1.69 | -38.92 | 0.19 | 22.72 | 5.25 | 6.95 |
| 5 | 15 | 0.75 | 0.535 | 1.35 | -31.58 | 0.46 | 22.81 | 5.24 | 6.95 |

## 4. CONCLUSIONS

By the experimental analysis, the impedance mismatched of radiating patch and feed line play a very big important role as it will be decided the performance of the MSA. The impedance mismatch between patch and feed line can be decreased by a slight change in notch depth and gap can change the overall capacitance of the patch antenna, which can compensate the inductive load of the patch. Here by changing height of substrate with operating frequency and defined new formulas for notch depth and gap could be given better results. We can easily analyze that increases return loss, gain as well as directivity of the patch. The resonant frequency could be changed above 6% in pre-proposed formulas, with newly proposed formulas this could be up to 2%. We can get constant gain at any frequency for variable substrate height and this paper proposed formulas. It can be easily concluded that the effect of varying height of substrate, notch depth and gap have more pronounced effect on performance of antenna parameters.

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