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Analysing the Impact of Substrate Thickness on Antenna Performance for GPS Application

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ABSTRACT- A microstrip patch antenna is a popular choice of antenna for use in the L band frequency range. They also have good radiation characteristics, making them ideal for receiving and transmitting low-power radio frequency signals. The proposed compact antenna is meant for GPS applications covering the L1 band. The antenna is designed involving the Rogers's substrate having a dielectric constant of 2.2. The design is based on circular microstrip patch structure with inset feed technique. The selection of the dielectric material and its thickness is very crucial in designing microstrip patch antenna. This paper also explains how antenna performance is improved by varying the thickness of the substrate. The radiation pattern, return loss, gain, directivity, VSWR and efficiency are obtained using EM Simulation and the results are compared for various designs structures. It is inferred that as the thickness of the substrate increases, the performance of the antenna also gets better.

KEYWORDS- GPS, Microstrip Patch Antenna, Radiation pattern, S Parameter, VSWR

I. INTRODUCTION

Antennas have become an indispensable part of our connected world, serving as the backbone of modern communication systems. Their impact can be felt in almost every aspect of our lives, from our daily interactions to the global infrastructure that keeps us connected. As we delve deeper into the realm of wireless connectivity, antennas will continue to play a crucial role, shaping the future of communication and connecting us in ways we never thought possible. With rapid advancements in antenna engineering, microstrip patch antennas are playing a vital role in application of mobile radio, wireless communication, satellite, missile, high-performance aircraft and spacecraft because of their light weight, low profile, simplicity and low cost. Rectangular, circular, elliptical are some common patch shapes that are widely sought after due to their versatility in terms of feeding options, adaptability to different frequencies and flexibility in operation.

With the progress of electronic communication, the GPS application spreads into all aspects of national economic production and people's daily lives. Such few and vital applications are search and rescue operation, path finding, military and civilian aircraft control, missiles or rocket missions etc. The two most popular types of the antennas used in GPS receivers are patch and quad helix. Among them microstrip patch antennas are suitable as GPS receiver antennas due to their light weight, ease of installation, and having less air-drag.

A microstrip patch antenna (MPA) consists of a conducting patch of any planar or non-planar geometry on one side of the dielectric substrate with a ground plane present on the other side. Feeding can be done by using any one of the methods such as co-axial feed, line feed, inset feed, proximity coupling or aperture coupling.

Microstrip patch antennas are typically used for GPS applications because they are lightweight, compact, and cost-effective. They also have good radiation characteristics, making them ideal for receiving and transmitting low-power radio frequency signals. Additionally, they are easy to design and integrate into electronic equipment.

II. ANTENNA GEOMETRY

The schematic diagram of the patch (i.e., front view) and the ground plane (i.e., back view) of proposed Circular Microstrip Patch Antenna (CMPA) are shown in Fig. 1(a) and Fig. 1(b), respectively [1]. The patch antenna is designed on Rogers substrate whose dielectric constant is 2.2 and thickness is 1.6 mm.

The ground plane is designed using Copper Annealed with dimension of Wg and Lg and is depicted in Fig. 2. The length and width of the FR-4 (Flame Retardant) substrate are represented by L and W, respectively as depicted in Fig.3. The radius of circular patch is denoted by Rp and the signal is fed through an inset feed transmission line having width Wf.

The inset distance of the feedline is denoted by Fi. Various slots are cut at equal intervals on the ground. Patch is also incorporated with a notch at the top of the circular structure and small circular slots as shown in Fig.4.

The impedance of inset feed transmission line at the input port is assumed to be 50 Ω. The antenna design is optimized by strategically incorporating slots both on ground and the patch. The integration enhances the radiation pattern facilitate frequency tuning and improves impedance matching. For the microstrip patch antenna, the height of the dielectric substrate is critical because with increase in frequency, height of the substrate (thickness) decreases. But to ensure good radiation, the height of the substrate should be large and its dielectric constant should be low. However, after a certain point if the height is increased, the radiation decreases for the design structure.

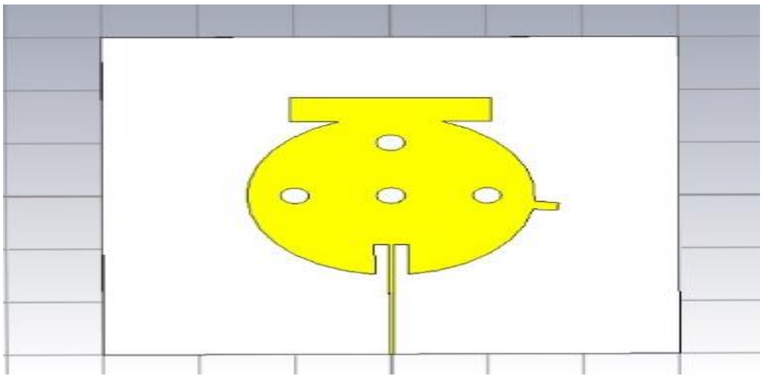


Figure 1(a): Front View

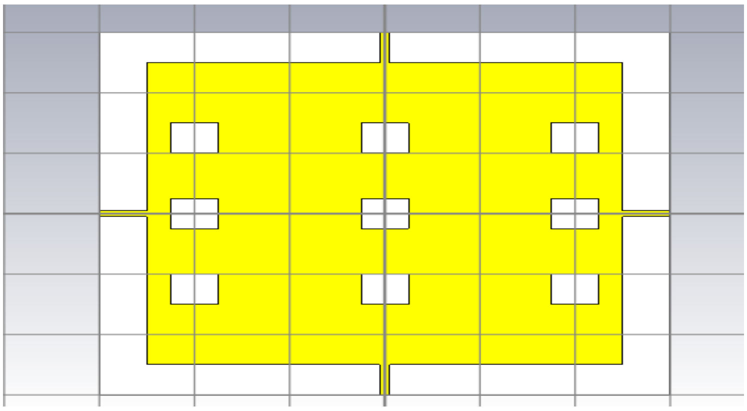


Figure 1(b): Back View

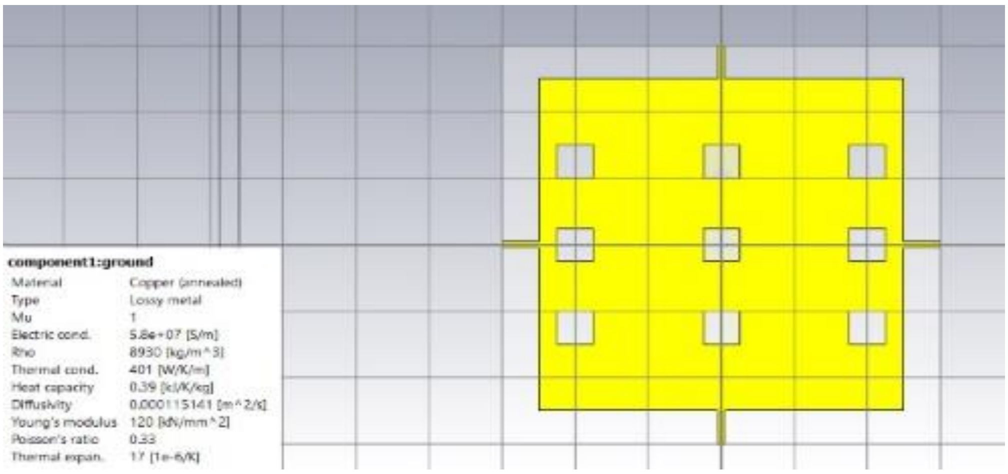


Figure 2: Ground Plane

Ground Length L_g = 110mm
Ground Width W_g = 110mm

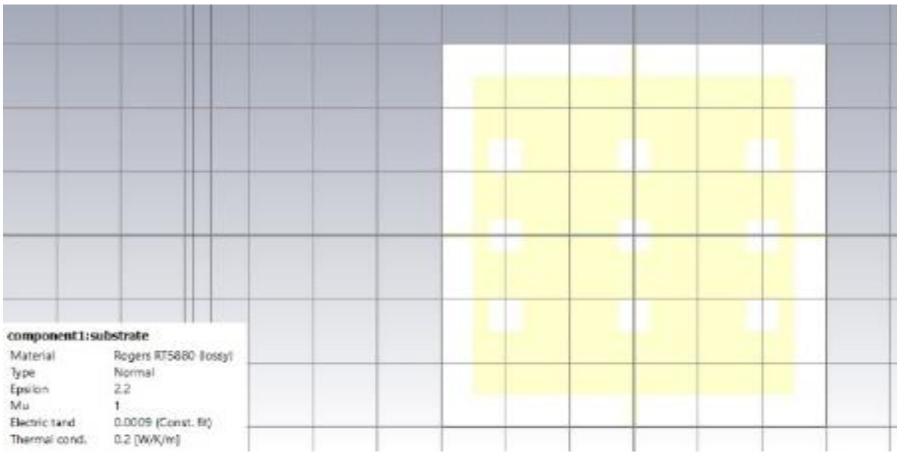


Figure 3: Substrate

Substrate Length L_s = 120mm
Substrate Width W_s = 120mm

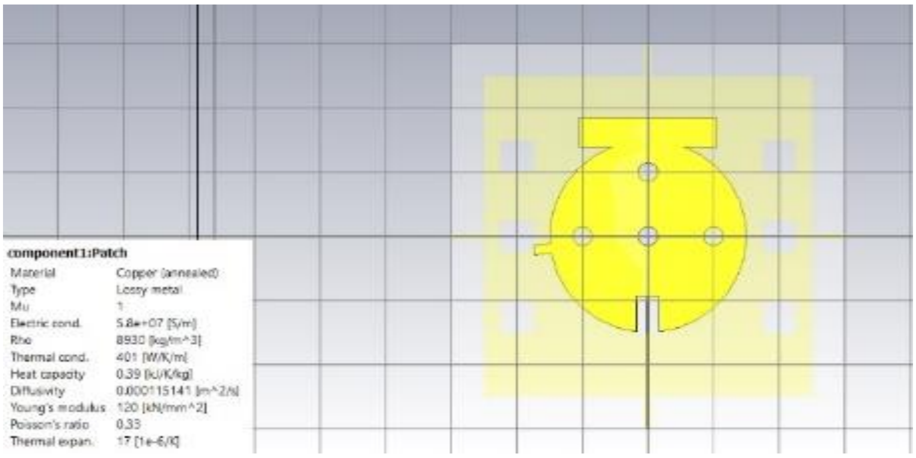


Figure 4: Patch

R_p = 30mm
W_f = 1mm
F_l = 41.5mm
L_f = 11.5mm

III. DESIGN EQUATIONS

Necessary formulas for designing the antennas are provided in [5]. The patch is in the form of circle, where the radius of the
radiating elements can be obtained through the equation (1.1)

$$a = \frac{F}{\left\{1+\frac{2h}{\pi\varepsilon_r F}\left[ln\left(\frac{\pi F}{2h}\right)+1.7726\right]\right\}^{1/2}} \quad \text{....... (1.1)}$$

Where,
a = circular radius dimension (cm)
h = Thick of substrate (m)
ε_r= Relative dielectric permittivity of substrate (F/m)
F = logarithmic function (F) of radiating element

While the logarithmic function (F) of the radiating element is determined by the equation (1.2)

$$F = \frac{8.719 \times 10^9}{f_r\sqrt{\varepsilon_r}} \quad \text{......... (1.2)}$$

Where,
fr = Resonating Frequency (MHz)
ε_r= Relative dielectric permittivity of substrate (F/m)

As for the width and length of the slot is obtained by using the equation (1.3) & (1.4)

$$W = \frac{c}{2\,f_o} \quad \text{......... (1.3)}$$

$$L = \frac{c}{2f_0\cdot\sqrt{\varepsilon_r}} - 2\Delta l \quad \text{............. (1.4)}$$

Where,
L = Length of slot
W = Width of slot

The patch length is selected from the resonant condition and the fringing field consideration and fringing field length is given by equation (1.5)

$$\frac{\Delta L}{h} = 0.412 \frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)} \quad \text{……….} \; (1.5)$$

The effective dielectric constant of the propagation medium (air + solid dielectric substrate) is calculated by equation (1.6)

IV. ANALYSIS AND SIMULATION RESULTS

The antenna is sketched and simulated using CST. Each layer of the design is assigned with corresponding physical and electrical properties and impedance matching is done. The result of the return loss, voltage standing wave ratio (VSWR), gain and the directivity are measured. The S11

$$\varepsilon_{eff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}\left[1+12\frac{h}{W}\right]^{\frac{1}{2}} \quad \text{………..} \; (1.6)$$

The length and width of the ground and substrate calculated to be twice the length and width of the slot for better performance.

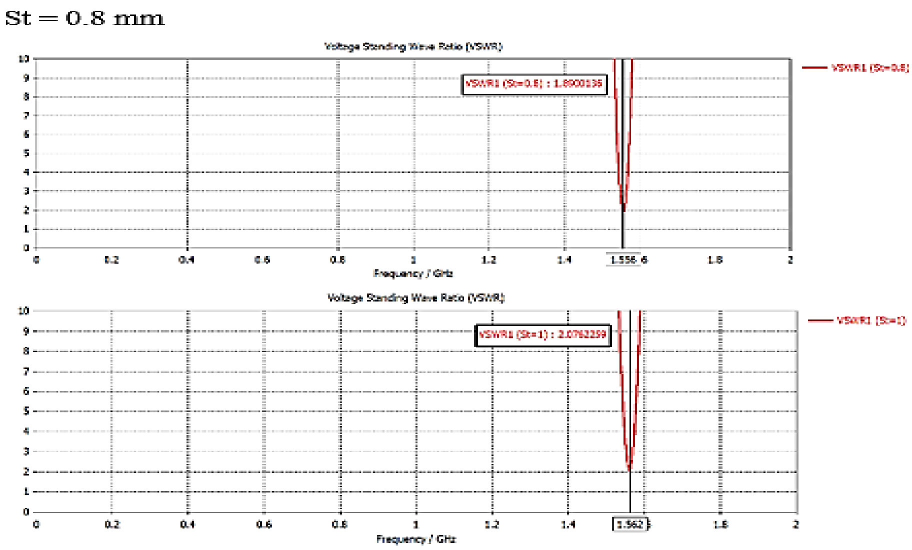
$$L_g = L_s = 2 \times L$$
$$W_g = W_s = 2 \times W$$

parameters are calculated using wave guide port configuration.

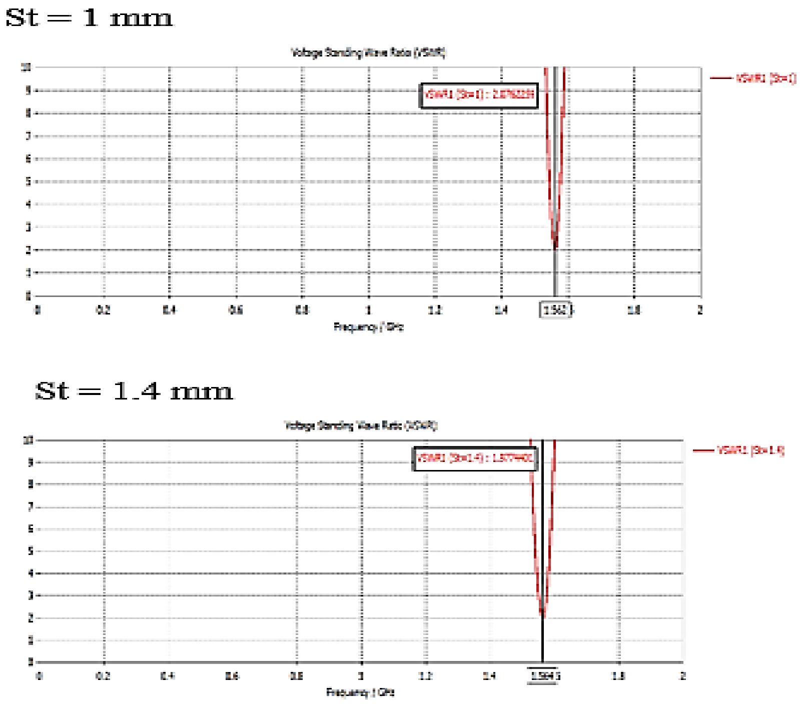
A) Effects of Varying Height of the Substrate

The results of S parameter, VSWR, radiation efficiency is compared with varying the height of the substrate by a step width on 0.2mm (i.e.) from 0.8mm to 1mm

a) S Parameter Results

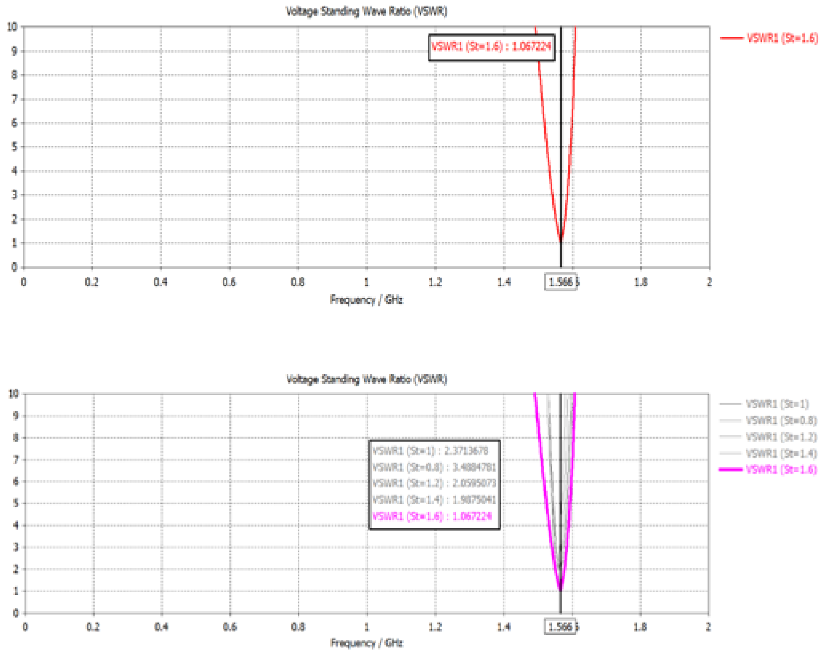


(a)



(b)

St = 1.6 mm



(c)

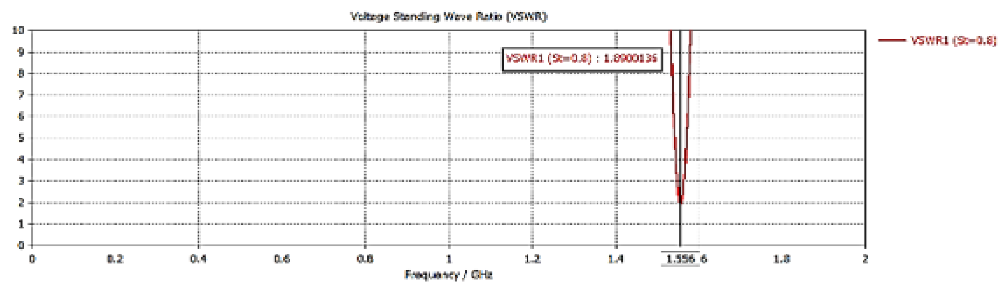
Figure 5: S Parameter Results

- **Inference of S Result**

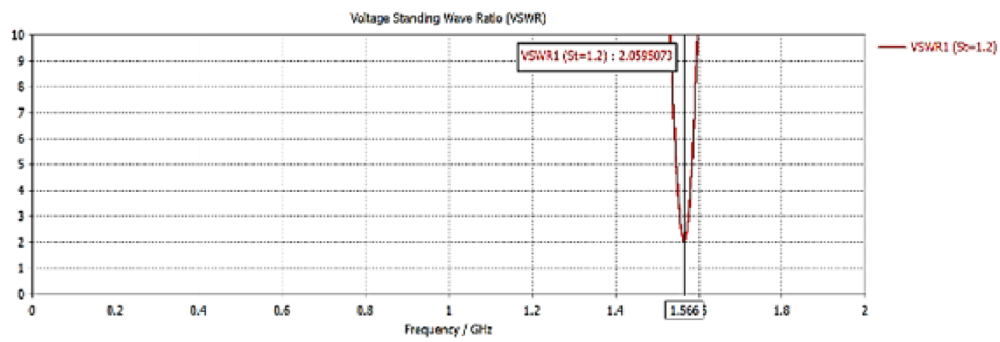
The S parameter refers to the reflection coefficient which indicates how much of the incident power is reflected back from the antenna(figure 5). From the results it can be inferred that increasing the substrate thickness enhances the performance of the antenna by reducing the power reflected back.

b) VSWR Results

St = 0.8 mm

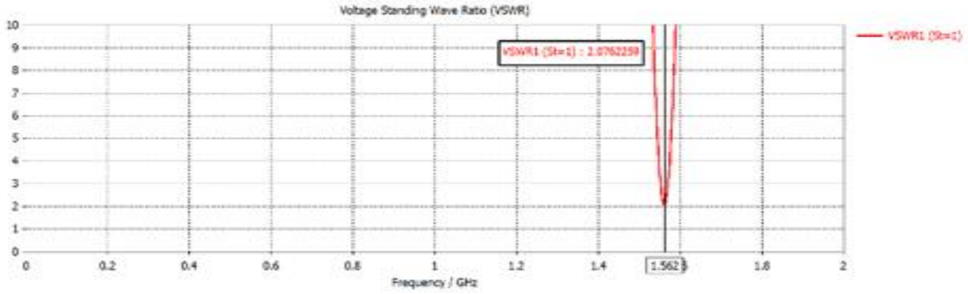


St = 1.2 mm

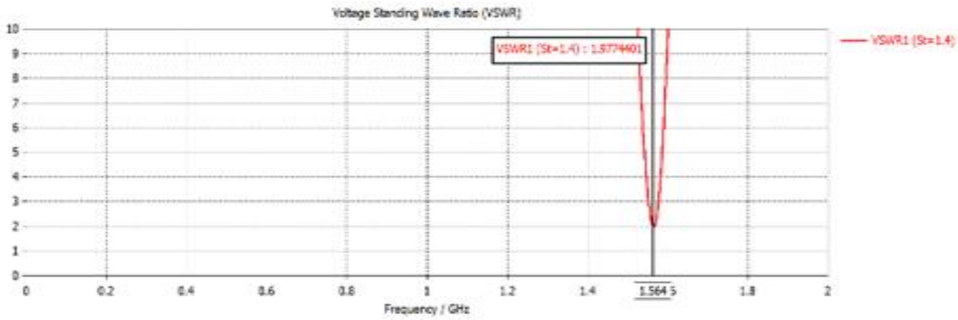


(a)

St = 1 mm

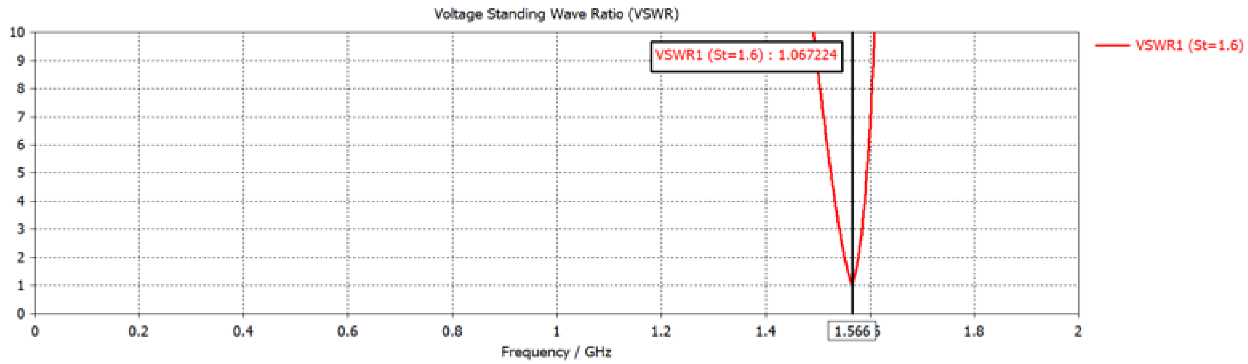


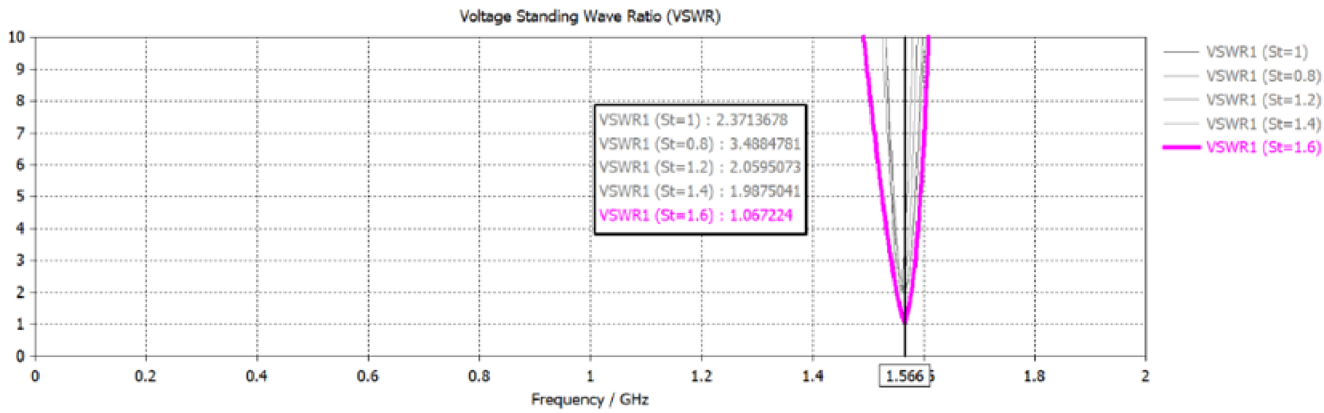
St = 1.4 mm



(b)

St = 1.6 mm





(c)

Figure 6: VSWR Results

- **Inference of VSWR result**

The VSWR (Voltage Standing Wave Ratio) is a measure of how well an antenna is matched to the transmission line or the source impendence (figure 6). A VSWR value closer to 1 indicates a better match and less power being reflected back from the antenna. From the results, it can be inferred that increasing the substrate thickness enhances the matching between the antenna and the transmission line.

c) Radiation Pattern and Gain Parameters

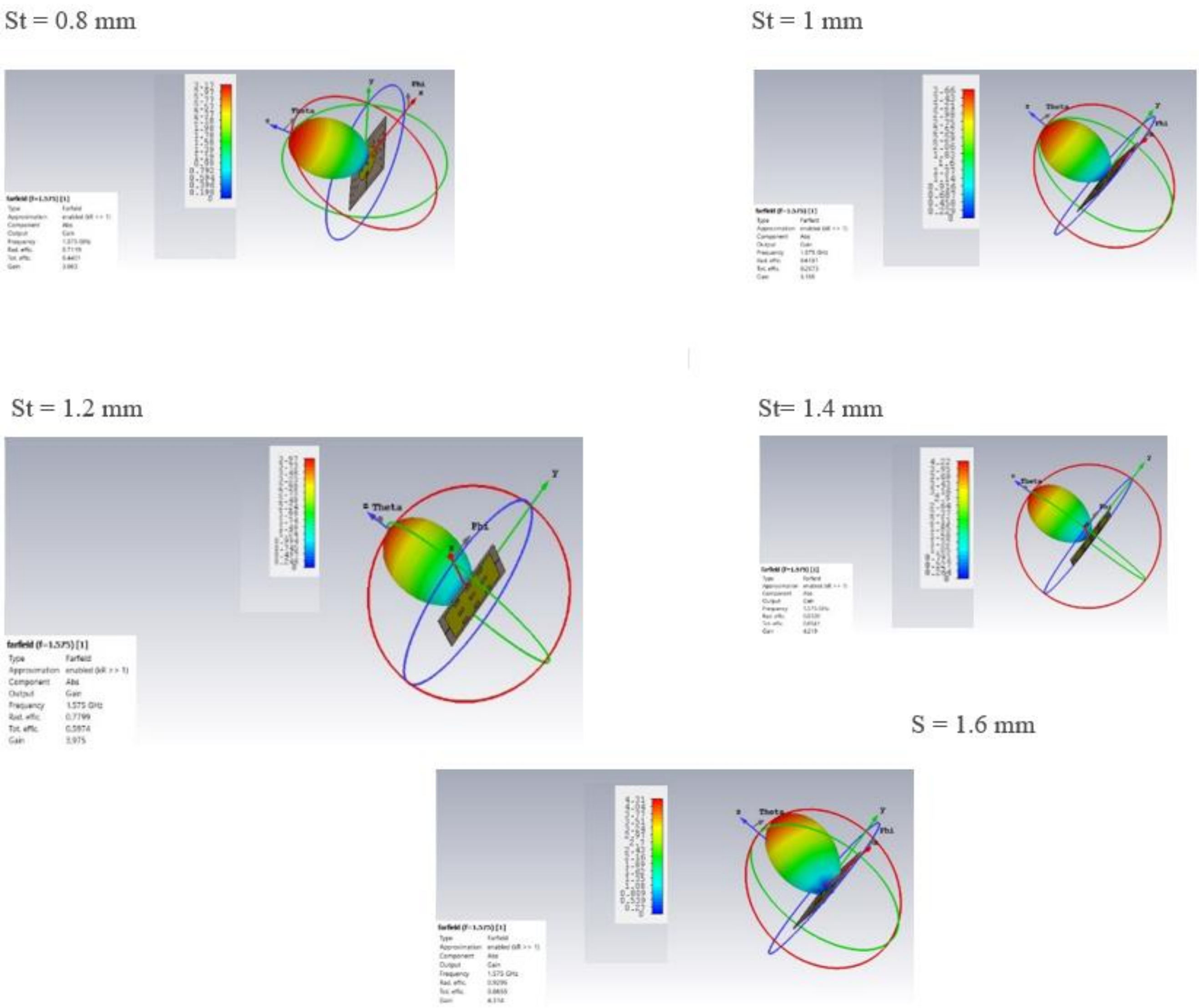


Figure 7: Radiation Pattern and Gain Parameters

- ***Inference of* Radiation Pattern and Gain Parameters**

From the results, it can be inferred that increasing the substrate thickness enhances the performances of the antenna in terms of its radiating efficiency and total efficiency (figure 7 and table 1).
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Table 1: Tabulation of the Comparison

Substrate Thickness H_s (mm)	Return Loss S11 (dB)	VSWR	Radiation Efficiency (%)	Gain	Directivity	Frequency GHz
0.8	-10.23	1.890	62	3.166	5.123	1.556
1	-9.122	2.076	71	3.663	5.146	1.562
1.2	-9.210	2.059	77	3.975	5.097	1.566
1.4	-9.615	1.987	83	4.219	5.071	1.566
1.6	-29.757	1.0672	94	4.314	4.626	1.575

There are several important points to note regarding the reasons behind the observed improvement in the performance of the antenna.

• Increasing the substrate thickness alters the electromagnetic field distribution within the antenna structure, leading to a better impedance matching between the antenna and the feeding network. This improved impedance matching reduces the reflected power and results in lower VSWR.

• A thicker substrate provides more space for the electromagnetic waves to propagate, reducing the standing wave effects. Standing waves occur when there is a mismatch between the antenna and the transmission line, causing reflections. By increasing the substrate thickness, the occurrence of standing waves is minimized.

For the micro strip patch antenna, the height of the dielectric substrate is critical because with increase in frequency, height of the substrate decreases. But for better radiation height should be large and the dielectric constant should be low. However, after certain point, increases in height decreases the radiation. Therefore, careful consideration and analysis are necessary to determine the optimal substrate thickness for a circular microstrip antenna, based on the specific requirements and constraints of the application.

To tune the frequency of this circular microstrip patch, a notch structure is introduced. A notch is a narrow slot or gap in the circular conductor pattern. The location and dimensions of the notch can be adjusted to modify the antenna's resonance characteristics. By incorporating slots, the effective size of the antenna can be reduced without sacrificing performance. This miniaturization effect is particularly advantageous when space constraints are a concern, allowing for compact and efficient antenna designs.

The slots cut on the ground and patch provides additional benefits. Slots can be strategically placed to modify the radiation pattern of the antenna. By adjusting the size, shape, and position of the slots, the antenna's radiation pattern can be tailored to meet specific requirements. This control over the radiation pattern enables better coverage, increased gain in desired directions, and reduced unwanted radiation in other directions.

By incorporating slots, the effective size of the antenna can be reduced without sacrificing performance. This miniaturization effect is particularly advantageous when space constraints are a concern, allowing for compact and efficient antenna designs. Below is the tabulation of the antenna parameters that produced the desired results(table 2).

Table 2: Tabulation of the antenna parameters

Parameter list	Symbol	Value (mm)
Ground Length	Lg	110
Ground Width	Wg	110
Ground Thickness	Hg	0.035
Substrate Length	Ls	120
Substrate Width	Ws	120
Substrate Thickness	Hs	1.6
Patch Radius	Rp	30
Feedline Width	Wf	1.6
Feedline Length	Lf	41.5
Inset Length	Li	11.5
Slots Length	Ls	10
Slots Width	Ws	10

V. CONCLUSION

A compact antenna for civilian GPS application was designed and optimized. The performance of the antenna was fully characterized through simulation and measurement at the L1 frequency band. It is inferred from the simulation that as the height of the antenna is increased the return loss and the efficiency increases. It is also noted that the slots incorporated in equal intervals on the ground provides better antenna performance.

The results recorded for the optimized antenna is given below:

Frequency: 1.56 GHz

Return loss (S11): -29.75db

VSWR: 1.067

Radiation efficiency: 92%

Total efficiency: 86%

Directivity: 4.314

Gain: 4.628

CONFLICTS OF INTEREST

The authors declare that they have no conflicts of interest.

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