Design of miniaturized microstrip feed antenna at 1.57 GHz for GPS applications

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***Abstract*— The miniaturization of antenna i.e., a reduction in its dimensions without significant performance degradation has been a subject of great interest for a long time. Over several decades, many papers showed a direct correlation between the size of an antenna and its bandwidth/or efficiency and it was largely believed that smaller antennas meant lesser bandwidth/ efficiency. But recent advancements have challenged this notion and enabled the design of miniaturized antennas without sacrificing performance. Some approaches for antenna miniaturization are introduction of slots, slits, short meandering and novel geometries like fractals or by using higher dielectric constant. In this paper, we propose a miniaturized microstrip patch antenna with slots which is designed for operating at a frequency of 1.57 GHz for GPS applications.**

Keywords— Microstrip patch antenna, miniaturization, dielectric constant, Voltage Standing Wave Ratio (VSWR), s-parameters, efficiency, bandwidth

I. Introduction

Antennas are basic components of any electronic system which depends on free space as a propagation medium. An antenna is a device which provides a means for radiating or receiving radio waves[1]. It is a transducer between a guided electromagnetic wave and an electromagnetic wave propagating in free space. In a communications link, the transmitter is connected through a cable or waveguide to one antenna, the signal is radiated to another antenna, and then passes through another cable or waveguide to the receiver. A transmitting antenna receives current from a transmitting device. From this current, the antenna generates EM waves at a specific frequency that radiate out through the air, where they can then be received by one or more other antennas. A receiving antenna intercepts EM waves transmitted through the air. From these waves, the antenna generates a small amount of current, which varies depending on the strength of the signal. The current is passed to the receiving device, where it is transformed for its specific environment

Some of the characteristics of an antenna which must be kept in mind while designing are: [2]

a. VSWR- The voltage standing wave ratio (VSWR) is defined as the ratio of the maximum voltage to the minimum voltage in a standing wave pattern. A standing wave is developed when power is reflected from a load. So, the VSWR is a measure of how much power is delivered to a device as opposed to the amount of power that reflected from the device. If the source and the load impedance are the same, the VSWR is 1:1 there is reflected power. If VSWR is also measure of how closely the source and load impedance are matched. For most antennas in WLAN, it is measure of how close the antenna is to a perfect 50 ohms.

b. VSWR Bandwidth- The VSWR bandwidth is defined as the frequency range over which an antenna has a specified VSWR. Often the 2:1 VSWR bandwidth is specified, but 1:5:1 is also common.

c. Radiation intensity- (RI) It is defined as the power radiates in a given direction per unit solid angle. That is,

$$RI = r^2 p\, r^2 E^2 / \eta \text{ watts/unit solid angle.}$$

Here,
η= intrinsic impedance
r= radius of the sphere
p=power radiated instantaneously
E= Electric field strength
RI= RI (θ, φ) is function of θ, φ

d. Directive gain- (g_d) It is defined as the ratio of intensity of radiation in a specified direction to the average radiation intensity. That is,
$gd = RI/RI_{av} = RI.4\pi/w_r$
w_r= radiated power

e. Power gain- (g_p) It is defined as the ratio of 4π times radiation intensity to the total input power. That is,
$g_p = 4\pi(RI)/w_t$
where $w_t = w_r + w_l$
w_l = ohmic loss in the antenna

In literature, there are a variety of antennas designed for different applications. In this paper, we propose a design for a microstrip (patch) antenna.

[3] Microstrip or patch antennas are becoming increasingly useful because they can be printed directly onto a circuit board. Microstrip antennas are becoming very widespread within the mobile phone market. Patch antennas are low cost, have a low profile and are easily fabricated. The microstrip antenna is a relatively modern invention. It was invented to allow convenient integration of an antenna and other driving circuitry of a communication system on a common printed-circuit board or a semiconductor chip (Carver and Mink, 1981; Pozar, 1992). Besides other resulting advantages, the integrated-circuit technology for the antenna fabrication allowed high dimensional accuracy, which was otherwise difficult to achieve in traditional fabrication methods. The geometry of a microstrip antenna consists of a dielectric substrate of certain thickness d, having a complete metallization on one of its surfaces and of a metal "patch" on the other side. The substrate is usually thin ($d \ll \lambda$). The metal patch on the front surface can have various shapes, although a rectangular shape. The antenna may be excited using various methods (Pozar, 1992; Pozar and Schaubert, 1995). One common approach is to feed from a microstrip line, connecting the microstrip antenna at the center of one of its edges. The microstrip line may be connected to a feeding circuitry or directly fed by connecting a signal source across the microstrip line and the ground plane.

The microstrip antenna produces maximum radiation in the broadside (perpendicular to the substrate) direction and ideally no radiation in the end-fire (along the surface of the substrate) direction. The size of the antenna is usually designed such that the antenna resonates at the operating frequency, producing a real input impedance. Despite their narrow bandwidth, the microstrip patch antennas have many advantages compared to other conventional antennas such as low manufacturing costs, low volume, weight, and thickness, simplicity of manufacturing, and the possibility of integrating discrete elements.

For several years, many studies have focused on the miniaturization of antennas. However, these techniques have been confronted with a difficult problem due to the gain and bandwidth fundamental limit that depends on the antenna size.

There are several ways of miniaturizing that have been discussed in the literature. [4]

The first method involves introduction of slots in the patch.
Slot cutting involves introducing slots or cuts in the radiating elements of the antenna, thereby modifying the current distribution and electromagnetic properties. This technique enables the reduction of the antenna's physical size while maintaining desirable radiation characteristics. By strategically placing slots in the radiating elements, it's possible to achieve resonance at desired frequencies and control the antenna's radiation pattern. Slot antennas are commonly used in various applications, including mobile communication devices, where size constraints are a critical consideration. The precise design and placement of slots contribute to the miniaturization of the antenna while ensuring efficient and reliable wireless communication. Our antenna has been designed using this method.

The second method involves use of defected ground structures. Defected Ground Structures (DGS) are periodic metallic patterns incorporated into the ground plane of printed circuit board (PCB) antennas to manipulate their electromagnetic characteristics. By introducing specific patterns or shapes in the ground plane, it's possible to create bandgaps that suppress unwanted radiation or harmonics, leading to improved antenna performance and reduced size. DGS technology allows for the miniaturization of antennas by effectively controlling the current distribution and electromagnetic waves, thus enabling the design of compact and efficient antennas for various wireless communication applications. The integration of DGS in the antenna design enhances electromagnetic properties, reduces the overall size of the antenna, and improves its performance in terms of bandwidth and radiation efficiency.

Another approach involves the use of fractal geometries. Fractal antennas are designed using intricate, self-similar geometrical patterns that allow for multiband or wideband operation within a compact form factor. By employing fractal shapes, such as the Minkowski Island or the Sierpinski gasket, it's possible to achieve miniaturization while maintaining a high level of performance. Fractal antennas are known for their space-filling properties, enabling them to operate effectively within limited physical dimensions, making them ideal for integration into small-scale electronic devices.

Moreover, the utilization of advanced fabrication techniques, such as micro-electromechanical systems (MEMS) technology, has facilitated significant advancements in antenna miniaturization. MEMS-based antennas are fabricated using microscale components and intricate manufacturing processes, enabling the creation of highly compact and customizable antenna structures. By leveraging the precision and control offered by MEMS technology, it's possible to develop miniaturized antennas with enhanced tunability, reconfigurability, and adaptability to different operating conditions, thus catering to the diverse needs of modern wireless communication systems.

These advances in miniaturization techniques have paved the way for more innovative and important applications of antennas. The above-mentioned methods enable the development of compact and efficient antennas, allowing for enhanced portability without compromising performance. By maintaining or even improving radiation efficiency and bandwidth, miniaturized antennas are well-suited for integration into small electronic devices, including smartphones, wearables, and IoT devices. Additionally, the flexibility in design customization for specific frequency bands and communication requirements ensures their adaptability across various applications, ranging from telecommunications and consumer electronics to healthcare, automotive and aerospace systems. Their space-efficient nature makes them particularly valuable in environments with limited space, enabling the efficient use of available area. These advantages collectively contribute to the seamless integration of antennas into a diverse array of technologies.

II. METHODOLOGY AND ANTENNA DESIGN

For designing the antenna, we first studied the standard patch antenna as shown in the Fig. 1. This antenna has been discussed extensively in this field. [5]

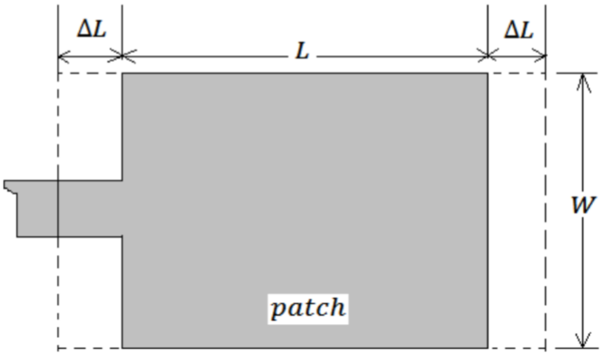

Fig. 1: Standard rectangular patch antenna with microstrip feed

For designing a standard rectangular microstrip patch antenna, there are three essential parameters: the frequency of operation f, the dielectric constant of the substrate ε_r and the height of the dielectric substrate h. Given the value of ε_r and h, we design the antenna for working at the desired resonant frequency f_r

$$W = \frac{1}{2fr\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon r+1}} \quad = \frac{\upsilon_0}{2fr}\sqrt{\frac{2}{\varepsilon r+1}}$$

Now, we determine the effective dielectric constant for the patch antenna as

$$\varepsilon_{reff} = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2\sqrt{1+\frac{12h}{W}}}$$

The extension of the antenna can be found as

$$\frac{\Delta Leff}{h} = 0.412\frac{(\varepsilon reff+0.3)(\frac{W}{h}+0.264)}{(\varepsilon reff-0.258)(\frac{W}{h}+0.8)}$$

And from this, the actual length of the antenna is given by

$$L = \frac{1}{2fr\sqrt{\varepsilon reff}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L$$

For the design, we were given design parameters as:
fr = 1.57 GHz
Substrate = FR4 with ε_r = 4.7
Thickness of substrate = 1.6mm

For miniaturization of antenna, we introduced insets into our patch layer, which reduces the effective length of the patch and also makes it possible to achieve size reduction while maintaining resonant frequencies and radiation performance. Insets help in effectively increasing the electrical length of the antenna, thereby allowing it to resonate at a lower frequency despite the physical size reduction. Moreover, the use of insets enables the fine-tuning of the antenna's impedance matching and radiation characteristics, thereby enhancing its overall performance. By strategically placing insets in specific regions of the radiating patch, we can achieve desired electrical properties, such as improved bandwidth, radiation efficiency, and gain. This approach not only facilitates miniaturization but also enables the design of antennas that can operate across multiple frequency bands The design and dimensions of our proposed antenna are as follows:

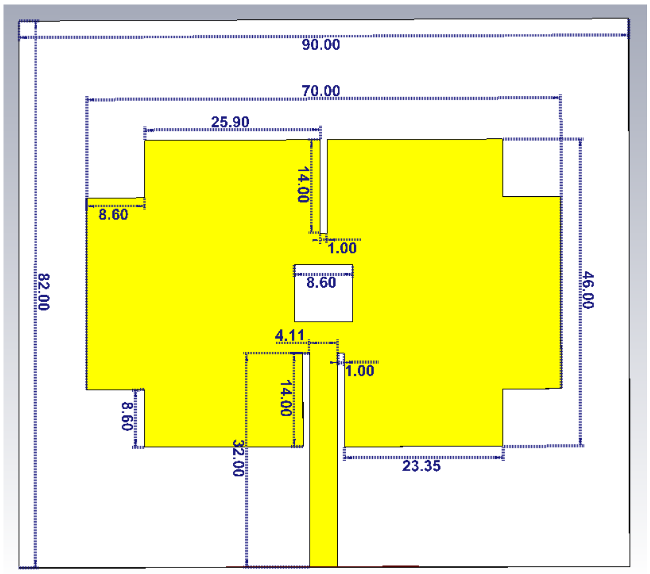

Fig. 2: Design of proposed antenna (All dimensions are in mm)

	Patch	Feed	Ground	Substrate
Material	Copper (annealed)	Copper (annealed)	Copper (annealed)	FR4
Length	46	18	82	82
Width	70	4.11	90	90
Thickness	0.035	0.035	0.035	1.6

All dimensions are in mm.

III. SIMULATION RESULTS USING CST

For designing and simulating the performance of antenna, the Computer Simulation Technology (CST) software was used, which utilizes finite integration in time domain approach.

Fig. 3 shows the scattering or s-parameter for the antenna. We can observe that the antenna is resonating for **S1,1 = -21.657 dB at 1.575 GHz.**

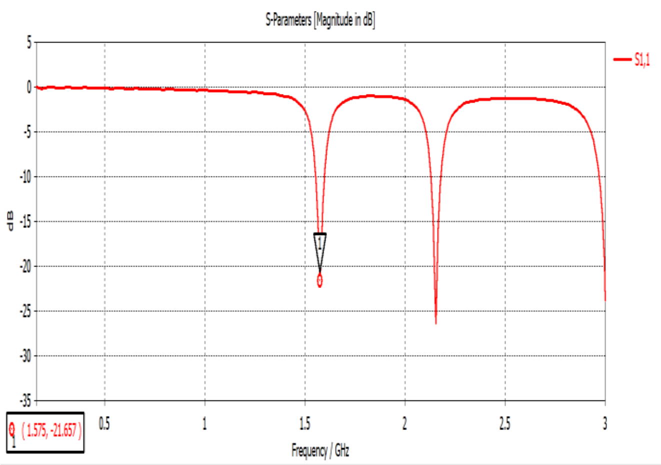

Fig. 3: s-parameter (S1,1)

Fig. 4 shows the Voltage Standing Wave Ratio (VSWR) characteristics of our antenna.
Value of VSWR is 1.1802 at 1.575 GHz.

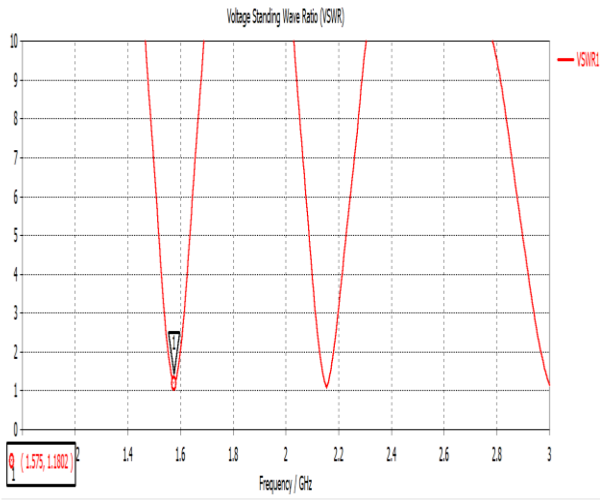

Fig. 4: VSWR values for simulated antenna

Fig. 5 and Fig. 6 show the e-field and h-field of the radiating antenna.

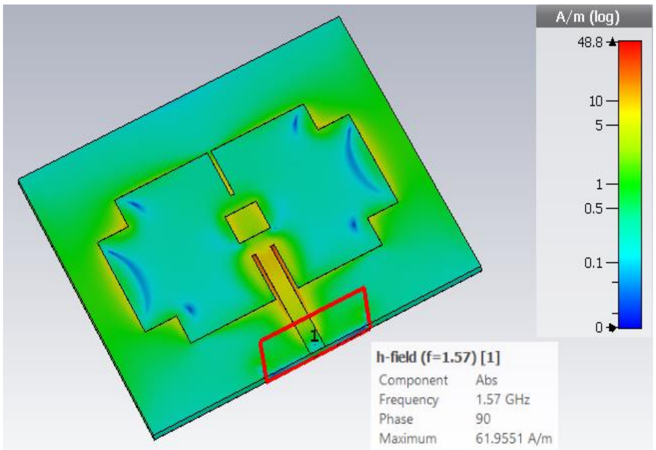

Fig. 5: Magnetic Field (h-field)

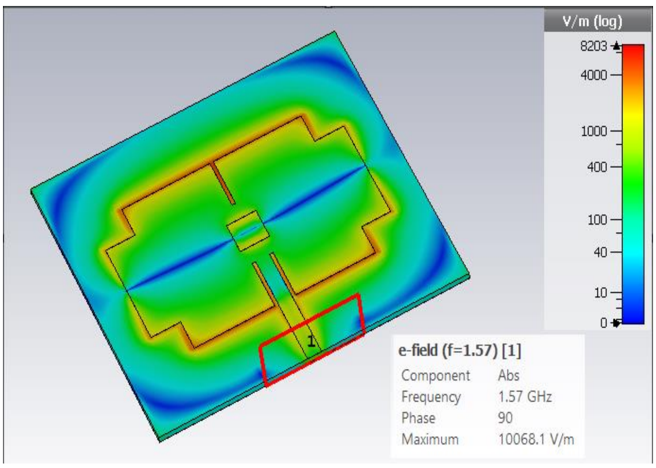

Fig. 6: Electric Field (e-field)

Fig. 7, Fig. 8 and Fig. 9 show the farfield radiation pattern and the directivity of our simulated antenna.

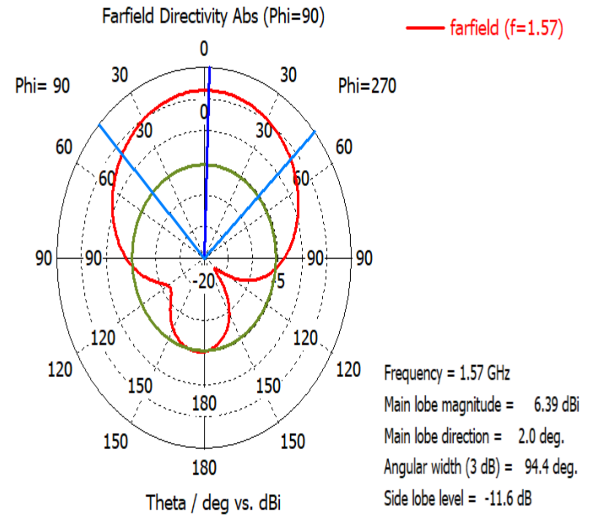

Fig. 7

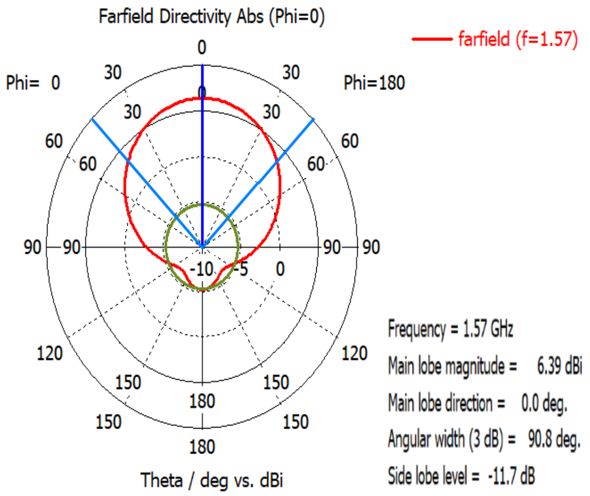

Fig. 8

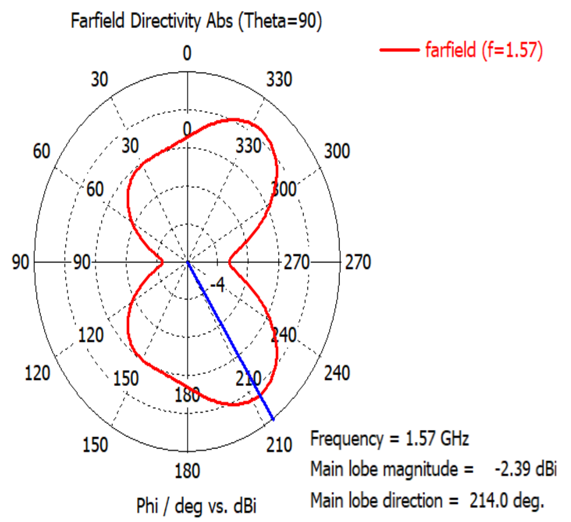

Fig. 9

CONCLUSION

Basic structure of a standard patch antenna was modified to design a miniaturized microstrip feed antenna at 1.57 GHz for GPS applications. The designed antenna resonates at multiple frequencies but here we have considered the value of our interest. The simulation results show that the antenna has resonant frequency of 1.575 GHz. Polar plots of the farfield cuts (polar plots) along with the contour form of radiation fields were also studied. It is worth noting that the proposed antenna design can be easily be exploited for designing antennas for other applications.

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