Design of Linearly Polarized Rectangular Microstrip Patch Antenna for GPS Applications at 1575.42MHz

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Abstract —**The antennas are the eyes and ears of GPS system. These are used for transmitting and receiving purpose. There are different types of antennas like bi-conical, log periodic dipole, microstrip antenna etc. In recent year's microstrip antenna have gained considerable popularity for GPS applications. These are low profile, easily conformable to planar surfaces, inexpensive to manufacture in large quantities using printed circuit techniques, flexible to produce a wide variety of pattern and polarization and easy to integrate with active components.**

A microstrip antenna consists of conducting patch of any particular geometry on one side of dielectric substrate backed by a ground plane on other side. A patch conductor can assume virtually any shape but conventional shapes are generally used to simplify the analysis and performance prediction. The radiating patch may be square, rectangular, circular, elliptical and triangular or any other configuration.

This paper aimed on Design and Development of printed circuit microstrip patch antenna at 1575.42 MHz which is applicable for GPS applications.

Keywords—Microstrip; GPS; return loss; gain

I. INTRODUCTION

The Global Positioning System (GPS) is a satellite-based navigation system that was developed by the U.S. Department of Defense (DoD) in the early 1970s. Initially, GPS was developed as a military system to fulfill U.S. military needs. However, it was later made available to civilians, and is now a dual-use system that can be accessed by both military and civilian users. GPS provides continuous positioning and timing information, anywhere in the world under any weather conditions. Each GPS satellite transmits a microwave radio signal composed of two carrier frequencies (or sine waves) modulated by two digital codes and a navigation message. The two carrier frequencies are generated at 1,575.42 MHz (referred to as the L1 carrier) and 1,227.60 MHz (referred to as the L2 carrier). The corresponding carrier wavelengths are approximately 19 cm and 24.4 cm, respectively. All of the GPS satellites transmit the same L1 and L2 carrier frequencies. The code modulation, however, is different for each satellite, which significantly minimizes the signal interference[1].

Antennas are essential parts in GPS communication systems. These are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device (e.g. waveguide, transmission line) and free space.

In the recent years, Micro strip antennas have been receiving much attention owing to their low profile, light weight, low cost, small size, design flexibility, and ease of installation. Micro strip antenna technology continues for designing low profile antennas from microwave to millimeter wave lengths. These antennas are ideally suited in many modern applications like GPS, vehicle and man portable systems, and commercial applications.

Depending upon the geometry and feed method, antennas can produce different polarizations. Some antennas are very simple while other exhibit complex shapes. For a particular application, signals that have linear or circular polarizations are desired. For GPS applications, probably linear polarization will be used.

II. ANTENNAS

Electromagnetic waves are often referred to as radio waves. Antennas are fundamental components of all radio systems and use free space as the carrying medium. They are used to interface the transmitter or receiver to free space.

An antenna must be tuned or matched to the same frequency band, as the radio system to which it is connected otherwise reception or transmission will be impaired. An antenna transmits a stronger signal if it is resonant on the frequency band.

A. Antennas Classification

J D Kraus has suggested a basic classification [2] for antenna types depending on their design peculiarities, mode of operation and applications in which they can be employed. Antenna can be classified on the basis of:

- Frequency -VLF, LF, HF, VHF, UHF, Microwave, Millimeter wave antenna etc.
- Aperture - Wire, Parabolic Dish, Micro strip patch antenna etc.

- Polarization - Linear (Vertical/Horizontal), Circular polarization antenna etc.
- Radiation - Isotropic, Omni directional, Directional, Hemispherical antenna etc.

B. Antenna Parameters

There are important parameters[3] need to be considered that characterize all antenna designs. Some of them are

1) Radiation Pattern: Radiation pattern is defined as the power radiated or received by an antenna in an angular position and at radial distance from the antenna. It describes how the antenna directs the energy it radiates. The graphical representation of radiation of an antenna as a function of direction is known as Radiation pattern. fig. 1. shows the radiation pattern of directional antenna

2) Return Loss: The Return loss (RL) is a parameter which indicates the amount of power that is lost to the load and does not return as a reflection. When the transmitter and antenna impedance do not match reflection of waves takes place leading to the formation of standing waves. Hence the RL is a parameter similar to the VSWR to indicate how well the matching between the transmitter and antenna had taken place. The RL is given as:

$$RL(dB) = 10\log_{10}\frac{P_i}{P_r} \quad (1)$$

Where *RL* (dB) is the return loss in dB, P_i is the incident power and P_r is the reflected power.

3) Half Power Beamwidth: An antenna's beam width is usually understood to mean the half-power beam width. The peak radiation intensity is found, and then the points on either side of the peak which represent half the power of peak intensity are located. The angular distance between the half power points is defined as the beam width. Half the power expressed in decibels is -3dB, so the half power beam width is sometimes referred to as 3dB beam width, shown in fig.1 .

4) Bandwidth: The bandwidth (BW) of an antenna is defined as range of usable frequencies within which the performance of the antenna, with respect to some characteristics, conforms to a specified standard. The bandwidth can be the range of frequencies on either side of centre frequency(f_C) where the antenna characteristics like input impedance, radiation pattern, beamwidth, polarization, side love level gain, are close to those values which have been obtained at the centre frequency.

$$BW_{broadband} = \frac{f_H}{f_L} \quad (2)$$

$$BW_{narrowband} = \frac{f_H - f_L}{f_C} \quad (3)$$

Where f_H = Upper Frequency, f_L = Lower Frequency

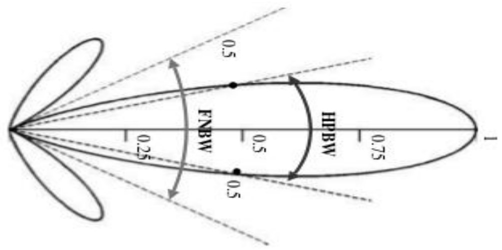

Fig. 1. Radiation pattern of a Generic Directional Antenna

5) Directivity: The directivity of an antenna is Radiation intensity of antenna in one direction to the mean Radiation intensity in all directions.

6) Polarization : Polarization of an antenna is defined as the polarization of the wave transmitted by the antenna, whereas polarization of radiated wave is defined as property of an electromagnetic wave describing the time varying direction and relative magnitude of the electric field vector; specifically, the figure traced as a function of time by the extremity of the vector at fixed location in the space, and the sense in which it is traced, as observed along the direction of propagation. Polarization may be classified as linear , circular and elliptical.

III. MICROSTRIP PATCH ANTENNAS

A microstrip patch antenna (MPA)[3] is a popular resonant antenna for narrow band microwave wireless links that require semi-hemispherical coverage. It consists of a conducting patch of any planar or non-planar geometry on one side of dielectric substrate with a ground plane on other side. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and feed lines are usually photo etched on the dielectric substrate. Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground place. In order to achieve good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable as this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth, Hence a compromise must be reached between antenna dimensions and antenna performance.

Microstrip antenna in its basic form consists of four parts-Metallic patch, Dielectric substrate, Ground plane and Feeding structure as shown in Fig.2. Where L is the length of the patch, W is the width of the patch, h is the dielectric substrate height and ε_r is substrate relative permittivity.

1) Metallic Patch: It consists of a very thin metallic sheet mounted on dielectric substrate. The antenna patch shape as shown in fig.2 can be square, rectangular, strip, circular, triangular, elliptical, or any combination of these shapes.

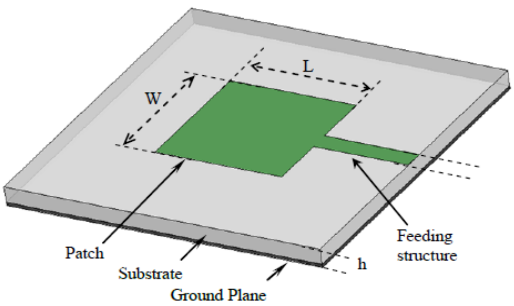

Fig .2. Microstrip Antenna

Every shape has its own characteristics and is chosen to meet certain requirements. The square, rectangular, and circular are the most popular shapes because they are the easiest in analysis and fabrication.

2) Dielectric Substrate: It is the dielectric layer between the patch and the ground. There are a lot of substrate material and specifications to choose from according to the antenna requirements. The most two factors specifying dielectric substrate is substrate height ($0.003\lambda_0 \leq h \leq 0.02\lambda_0$) and dielectric constant ($2.2 \leq \varepsilon_r \leq 12$) as ε_r gets higher in value the antenna size gets smaller. Substrates that are thick with low dielectric constant are preferable for enhancing efficiency, bandwidth and radiation in space. On the other hand substrates that are thin with high dielectric constant are preferable for microwave circuits.

3) Ground Plane : It is the metallic part found on the other side of the substrate. There are some perturbations that can be done to the ground to enhance the antenna performance towards certain specifications, like inserting shapes or slots in the ground plane.

In microstrip antenna, the electromagnetic (EM) wave fringe off the top patch into the substrate, reflecting off the ground plane and radiates out into the air. Radiation occurs mostly due to fringing field between the patch and ground. Fringe field of patch antenna is show in fig.3.

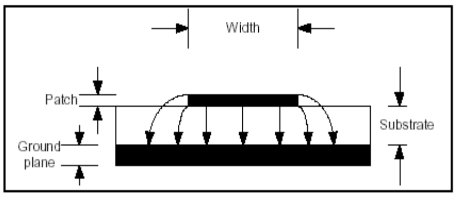

Fig. 3. Fringe field of Microstrip Patch Antenna

The radiation efficiency of the patch antenna depends largely on the permittivity (ε_r) of the dielectric. Ideally, a thick dielectric, low ε_r, and low insertion loss is preferred for broadband purposes and increased efficiency.

4) Feeding Structure: Microstrip patch antennas can be fed by a variety of methods[2]. These methods can be classified into two categories:

- Contacting
- Non-Contacting

In the **contacting method**, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line.

In the **non-contacting scheme**, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch.

The four most popular feed techniques used are as Follows

- The microstrip feed
- Coaxial probe
- Aperture coupling
- Proximity coupling

Among these coaxial feed is most suitable for microstrip antenna and the advantages of the same are given below.

a) Coaxial Feed: The Coaxial feed or probe feed is a very common technique used for feeding microstrip patch antennas. As seen from Fig.4. the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

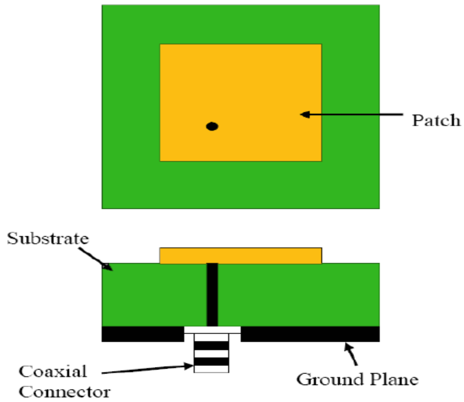

Fig. 4. Probe Fed Rectangular Microstrip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, a major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems.

IV. Design of Microstrip Patch Antenna

A. Design Specifications

The essential parameters for the design of a square microstrip patch antenna are

- The resonant frequency (f_o) selected for the design must be
  1575.42MHz
- The return loss should be less than – 20dB.
- The gain of patch antenna should be more than 5dB

B. Design parameters of the patch

- Dielectric constant (ε_r) of substrate

- Height(h) of the dielectric substrate
- Width of the patch(W)
- Length of patch(L)
- Feed position for co-axial feed

Here the patch is rectangular patch. Therefore width of the patch is equals to length of the patch.

C. Design Procedure

Design of patch antenna[5-6] involves selection of suitable dielectric material, calculation of height of dielectric, calculation of length and width of patch and finally calculation of feed position. Detailed procedure is given below.

a) *Selection of Substrate material:* The substrate plays a double role: electrically, it is an integral part of the transmission line circuits, and antennas; mechanically, it is the support of the structure. The electrical properties are the relative permittivity ε_r, the substrate thickness 'h' and the dielectric loss factor tanδ.

The ones that are most desirable for antenna performance are thick substrates whose dielectric constant is in the lower end of the range because they provide better efficiency, larger bandwidth, loosely bound fields for radiation into space, but at the expense of larger element size. In the present design RT/Duroid5880 is taken as dielectric that accounts for high efficiency and lightweight of the antenna. Table 1 gives comparison between different dielectric materials.

TABLE 1: Dielectric constants of different materials

Material	Dielectric constant	Dissipation Factor
RT/Duroid5880	2.20±0.02	0.0009 typical
RT/Duroid5870	2.33±0.02	0.0012 typical
RT/Duroid5500	2.50±0.04	0.0015 typical
RT/Duroid6006	6.00±0.25	0.0020 typical
RT/Duroid6010.2	10.2±0.25	0.0020 typical
RT/Duroid6010.5	10.5±0.25	0.0020 typical

b) *Calculation of Width (W):* The width of the micro strip patch antenna is given by the equation

$$W = \frac{c}{2 f_0 \sqrt{\frac{(\varepsilon_r + 1)}{2}}} \qquad (4)$$

On substituting , $C = 3 \times 10^8$ m/sec, f_0=1575.42MHz, ε_r=2.2, width of the patch is

W=75.3mm

c) *Calculation of Effective Dielectric Constant (ε_{reff}):* The calculation of effective dielectric constant of the micro strip patch antenna is given by the equation

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{\frac{-1}{2}} \qquad (5)$$

On substituting h=1.6mm, W and ε_r, we get ε_{reff} = 2.13.

d) *Calculation of Effective Length (L_{eff}):* The calculation of effective length of the micro strip patch antenna is given by the equation

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \qquad (6)$$

By substituting all, we get L_{eff} = 65.2mm

e) *Calculation of Length Extension (ΔL):* The calculation of effective length[6] of the micro strip patch antenna is given by the equation

$$\Delta L = \frac{0.412h(\varepsilon_{reff} + 0.3)\left(\frac{W}{h} + 0.264\right)}{(\varepsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.813\right)} \qquad (7)$$

On substituting h=1.6mm, W = 65.2mm, ε_{reff} = 2.13we get ΔL = 1.096mm

f) *Calculation of Actual Length of Square Patch (L):* The actual length of the micro strip patch antenna is given by the equation

$$L = L_{eff} - 2\Delta L \qquad (8)$$

On substituting L_{eff} = 65.2mm, ΔL = 1.096mm we get L=63.1mm

g) *Calculation of the Feed Point:* Feed location of the patch antenna can be calculated using following procedure

$$G_1 = \frac{W}{120\lambda_0}\left[1 - \frac{1}{24}(k_0 h)^2\right] \qquad (9)$$

Where G_1 is slot conductance, $K_o = 2\pi/\lambda_0$ = .033, h is height of the patch (1.6mm), on substituting we get G_1 = 2.44 m/Ω

Input slot resistance R_{in}, at edge of antenna is given by

R_{in} = 196.92 Ω, $R_{in}(y=y_0) = R_{in} \cos^2(\pi/W * y_0)$

Where $R_{in}(y=y_0)$ = 50 Ω, y_0 is the desired feed offset

The distance from the centre d could be calculated with equation

$$d = \frac{W}{2} - y_0 \qquad (10)$$

After calculation we get d=24.78mm

V. Simulation & Results

A. Technical Approach

Using the calculated dimensions of the microstrip antenna as initial values, geometry and dimensions of the antenna were optimized using the CADFEKO. The expected performance of the antenna in the terms of return loss, radiation pattern in rectangular, polar and 3D was plotted.

The antenna was supposed to be practically realized on RT/Duroid5880 substrate using the optimized dimensions of the antenna. The simulated result is to be compared with measured results and a close agreement should be obtained.

B. Return Loss Graph (dB)

The return loss is obtained from the graph dB vs Frequency which is shown in the fig.5. As the return Loss is very good, impedance matching is obtained between the feed and printed antenna. Form the fig. 5. It is clear that the designed antenna has -23dB return loss at required frequency of operation.

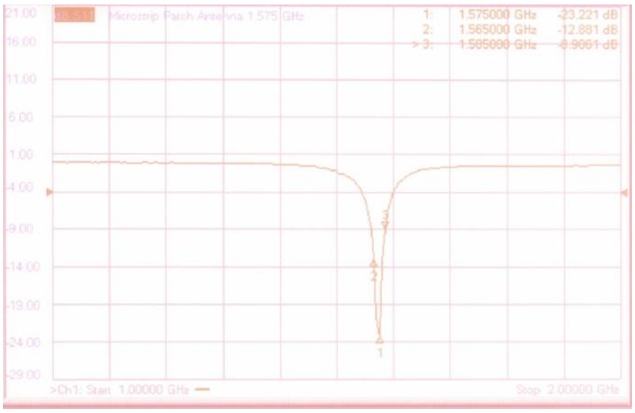

Fig.5. Measured input return loss against frequency

C. Measured Radiation Patterns

The radiation pattern for designed antenna are drawn in E-plane and H-plane for different angles and is shown in fig.6. The corresponding gain is also calculated at different frequencies and is tabulated in table 2.

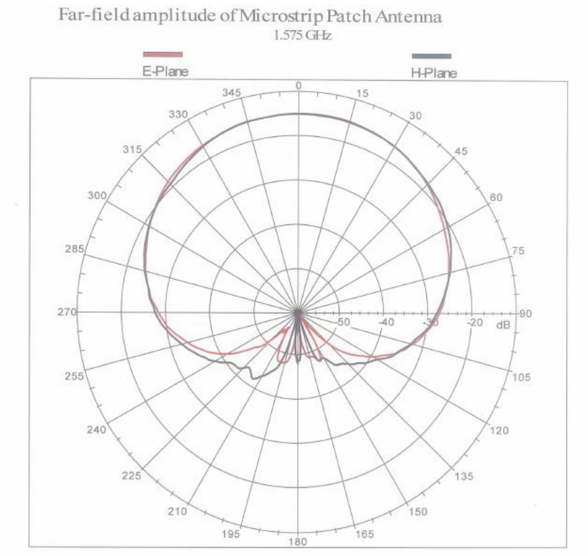

Fig.6. Measured Radiation Pattern of patch antenna at 1575.42MHz

TABLE 2: Parameters obtained at Different Frequencies

S.No	Frequency (MHz)	3dB Beam width(deg)		Gain (dB)
		E-Plane	H-Plane	
1	1565.42	83.84	78.69	5.15
2	1575.42	85.25	79.48	5.2
3	1585.42	85.7	77.65	5

CONCLUSION

Analysis, design of a linearly polarized microstrip patch antenna with wide impedance bandwidths at the center frequency of 1575.42MHz is presented in this paper. For the operation of the design coaxial probe feed technique is used.

For the given specifications, a single band linearly polarized microstrip patch antenna with coaxial probe feed is designed. Initial design of the patch antenna is performed using the closed-form expressions of the transmission line model and later the design is optimized using CADFEKO software for best performance.

According to the designed parameters, the antenna has been simulated for return loss, radiation pattern and gain measurements. These results have been compared with the required results and both are in good agreement over the entire frequency range of operation. The patch antenna can be further iterated and the different resonant frequencies obtained can be used for many applications.

REFERENCES

[1] El-Rabbany, Ahmed, "Introduction to GPS: the global positioning system", ARTECH HOUSE.INC, Norwood , 2002.

[2] J.D Kraus, R.J Marhefka, "Antenna for all applications" 3rd Ed., Mc Graw-Hill, 2002.

[3] C.A Balanis, "Antenna theory: analysis & design", 2nd ed., John Willey & Son, Inc., 1997.

[4] IEEE Standard Test Procedures for Antennas, IEEE Std. 149-1979, Institute of Electrical & Electronics Engineers, New York, 1979, sec. 11.

[5] Rakhesh Singh Kshetrimayum, "Printed Monopole Antennas for Multiband Applications", International Journal of Microwave and Optical Technology, Vol. 3, No. 4, September 2008,pp. 474-480

[6] Ashwani kumar, A D Sarma, "Wide band single- fed parasitically excited microstrip patch antenna for GPS", IJRSP, Vol.34, June 2005, pp.179-183.