High Precision Antenna Design with Hybrid Feeds for GPS Requirements

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Abstract: - Microstrip patch antennas provide good compatibility with communication system's printed circuitry. Here a circular microstrip patch antenna with circular configuration of ground plane and substrate has been designed for GPS using a cavity line model. RHCP is obtained by placing coaxial pins quadraturly and symmetrically along the two main axes and pins are fed through a hybrid feed arrangement. Circular ground plane effect is investigated for return loss and VSWR, which are typical parameter used to study the behavior of antennas. The results obtained provide a workable antenna design for incorporation in GPS receivers.

Key-words: - Patch Antenna, Global Positioning System (GPS), Coaxial Feed, Circular Polarization, LHCP, RHCP, and Radiation Pattern.

1 Introduction

Global Positioning System (GPS) was initially developed for the military but has since been adopted for various commercial applications. Recently, a lot of attention has been focused on smaller, low planar antenna designs without adversely effecting performance. [1, 2]

The major source of errors limiting the accuracy of communication systems is due to the multipath interference that occurs when the GPS transmitted signal is reflected or diffracted from surfaces around the antenna. The discrimination between direct and multipath signals can be made through polarization diversity. In fact, the GPS transmitted signal is right-hand circularly polarized (RHCP), thus, its odd reflections become left-hand circularly polarized (LHCP). Hence, the use of antennas with a good rejection of LHCP signals can potentially eliminate multipath effects arising from direct reflections. The inaccuracies due to double reflections remain but they are normally much weaker. In addition, the multipath rejection performance can be improved by shaping the antenna gain pattern to reject low-elevation signals while guaranteeing an adequate hemispherical coverage. [3]

Several low multipath GPS antennas have been proposed in the past including arrays [4], helix antennas [5] or patches placed on choke rings [6]. Although most of the available solutions can be designed to provide the desired radiation characteristics they are impractical in many applications due to operational requirements in terms of size and weight.

In what follows, a single element double feed circular patch antenna with circular ground and substrate operating at L1 is presented. The rest of this paper is organized as follows: Section 2 is GPS antenna requirements. Section 3 presents the antenna feed line design and circular polarization technique. Section 4 gives analysis of microtrip antenna design. The simulation results of the designed rectangular patch antenna are presented in section *5* and conclusion of the paper in section *6.*

2 GPS Antenna Requirements

A GPS antenna's critical electrical requirements are its radiation pattern, gain and polarization characteristics. A GPS antenna can be designed to operate at either one or both GPS frequencies, L1 (1575.42 MHz) and L2 (1227.6 MHz). Uniform radiation pattern over the entire upper hemisphere is required to ensure all visible satellites can maintain signal lock with a minimum signal to noise ratio. To avoid multipath effects due to reflections at the horizon, pattern cut-off must be sharp with elevation angle of above 10" and no back lobes [7].

Furthermore, as the signal received by the antenna is weak, the impedance matching is an important aspect as well as the possibility of operation at frequency, i.e. L1 (1227.6 MHz). Thus, GPS antennas are complicated enough to design as compared to various other antennas in common use.

3 Antenna Feeding & Circular Polarization

Input impedances differ mostly from 50-ohm line impedance, matching is usually required between the feed line and an antenna. The correct matching according to maximum power transfer theorem can be achieved through selecting the proper location of the feeding points; either it may affect the radiation characteristics, here coaxial feed method is used in the development of microstrip antenna. Coaxial center conductor is attached to the patch. The location of the connector is optimized for the given mode as that which yields the best match. A typical microstrip antenna using a coaxial connector is shown in Figure 1.

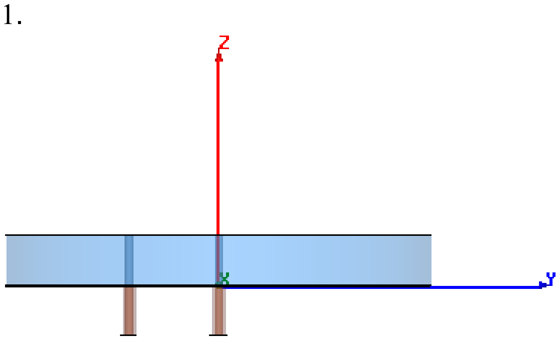

Fig.1 Side View of Coaxial Feeds at Patch Antenna

The other aspect here is that we need circular polarization for the dominant mode; it is achieved by using two coaxial feeds. By using two coax feeds separated by 90 degrees, which generate fields that are orthogonal to each other under the patch, as well as outside the patch. Also with this two-probe arrangement, each probe is positioned always at a point where the field generated by the other probe exhibits a null; therefore there is very little mutual coupling between the two probes Through the use of hybrid, 90^0 phase shift is attained for the two feeds, as shown in figure 2.

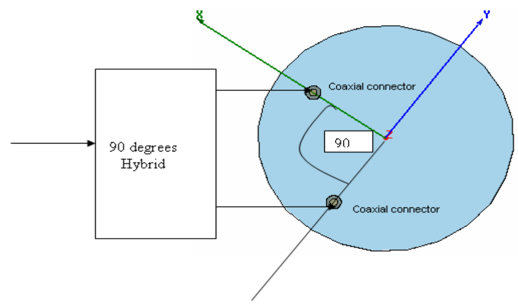

Fig.2 Hybrid Feed Arrangement

4 Antenna Design

Considering the requirement of the patch antenna, based on the cavity model formulation design procedure is followed. For starting point of the model we require the dielectric constant, the resonant frequency, and the height of the substrate material. For patch antennas the substrate height should be in rang of ($0.05\lambda \geq h \geq 0.03\lambda$), the height calculated through this formulation comes out to be 10mm. The patch antenna here is designed for the GPS L1 frequency (1.575 GHz). The substrate material used is FR-4 epoxy with the dielectric constant of 4.4. Dielectric constant at the lower end of the range provides better efficiency, larger bandwidth.

The most important parameter of antenna is the patch radius and patch effective radius. The radius of the Microstrip circular patch antenna is given by equation 1 [9] as:

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

Where, a = patch radius
h = height of substrate
ε_r = Dielectric constant
And F is the function defined by equation 2.

$$F = \frac{\left(8.791 \times 10^9\right)}{\left(fr\sqrt{\varepsilon_r}\right)} \quad \ldots\ldots\ldots\ldots\ldots\ (2)$$

Substituting $c = 3\exp 8(m/s)$, $\varepsilon_r = 4.4$ and $f_r = 1.575(Ghz)$, we get:
$F = 2.66091734$
Now substituting F = 2.66091734, ε_r = 4.4, $h = 10mm$, $\pi = 3.143$
We get the patch radius as
$a = 24.556mm$
The fringing effect makes the patch look electrically larger and therefore a remedy should be chosen for the length correction factor. So for the circular patches the correction factor is introduced by using the effective radius a*e*, to replace the actual radius [8].

$$a_{effective} = a\left\{1 + \frac{2h}{(\pi a \varepsilon_r)}\left[\ln\left(\frac{a\pi}{2h}\right) + 1.7726\right]\right\}^{1/2} \quad ..(3)$$

Substituting $a = 24.556mm$, $\varepsilon_r = 4.4$, $h = 10mm$, $\pi = 3.143$
We obtain, $a_{effective} = 26.66mm$
And for the circular ground and substrate
Radius of the ground plan(R) = 6*h* + a
This comes out to be 85mm. The coaxial probe used has a radius of 0.9mm.

5 Simulation Setup and Results

The simulating tool HFSS is used to model the microstrip patch antenna, to calculate and plot the *S* parameters, VSWR, current distributions as well as the radiation patterns. The complete model obtained is shown in the figure 3.

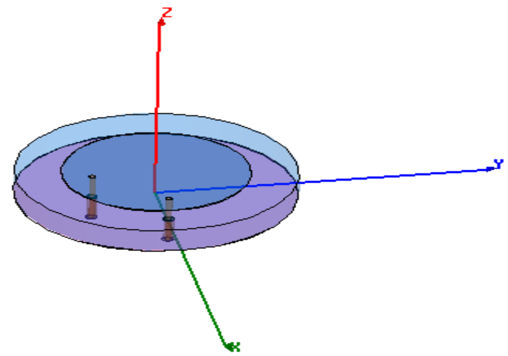

Fig.3 Model of Patch Antenna with Ground, Substrate and Feeds

When the load is mismatched, not all the available power from generator is delivered to the load. This is termed as the return loss (RL) and is given (in dB) as:

$$R_L = -20\log|\Gamma|(dB) ....(4)$$

Where, $|\Gamma|$ = reflection coefficient
The results plotted below are obtained after varying the feed location over 4 points along the radius of the patch from the origin is shown in figure 4. A frequency range of 1.075-2.075 GHz is selected to obtain accurate results.

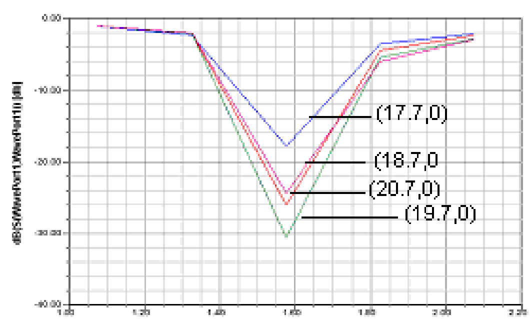

Fig.4 Return Loss against Frequency for Different Feed Locations

The bandwidth of the antenna can be said to be those range of frequencies over which the RL is greater than -9.5 dB (-9.5 dB corresponds to a VSWR of 2. From table 1, the optimum feed point is found to be at (Xf,Yf) = (19.7, 0) where a RL of -30 dB is obtained.

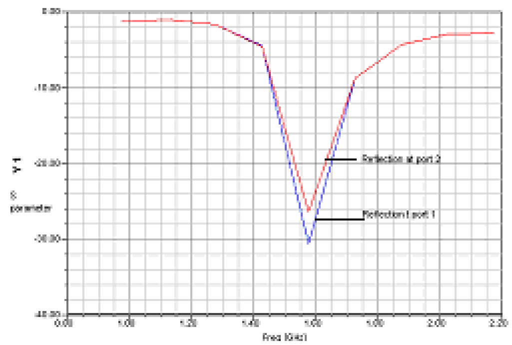

Fig.5 Return Loss Plot for Feed Point (19.7,0) at Two Ports

The higher the VSWR, the greater is the mismatch. If the condition for matching is not satisfied, then some of the power may be reflected back and this leads to the creation of standing waves. The VSWR that is acceptable is below 2.Here we have the value for VSWR as 1.2, which is in the acceptable range.

Table 1

S.No	Freq [GHz]	VSWR (WavePort12)	VSWR (WavePort2)
1	1.425000	4.025049	3.890025
2	1.575000	1.2060798	1.25100297
3	1.725000	2.143091	2.143221
4	1.875000	4.087491	4.070313

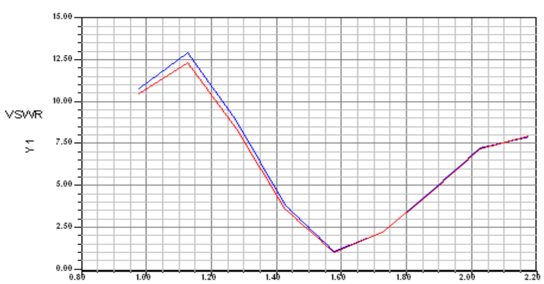

Fig.6 VSWR for Feed Locations, Port1 & Port 2

Basically gain compares the power delivered by the antenna under test (AUT) to that which would be radiated by impedance and polarization matched isotropic source. Here as shown by the plot the main component of total gain is the right hand circularly polarized gain as compared to left hand circularly polarized gain.

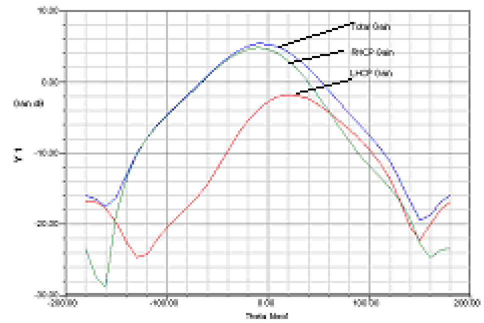

Fig.7 2D plots for total Gain 5.42dB, RHCP Gain 5.09dB, and LHCP Gain -1.79dB

The radiation property of the proposed antenna complies with the low multipath requirements for both beam shape and cross-polar rejection. Since a microstrip patch antenna radiates normal to its patch surface, the elevation pattern for θ = -90 and θ = 90 degrees would be important. Figure 8 shows the radiation pattern of the antenna at 1.575 GHz for θ = 90 and θ = 90 degrees. The maximum gain is obtained in the broadside direction with more than 120 degrees coverage and low power is radiated at low elevation angels. The back lobe radiation is sufficiently small.

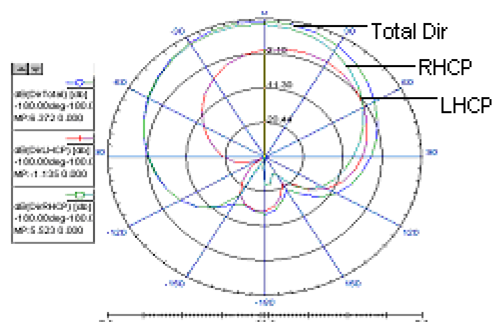

Fig.8 Radiation Pattern for Total Dir6.3dB (blue), RHCP dir 5.75dB (green), LHCP dir -2.87dB (red)

The antenna radiates its real power through the radiation resistance. Here the radiation efficiency is calculated at different frequency values, the best we attain 83% at the resonant frequency of 1.575 GHz as shown in table 2.

Table 2

NO	Frequency (GHz)	Radiation Efficiency
1	1.275	75%
2	1.425	79%
3	1.575	83%
4	1.725	82%
5	1.875	81.2%

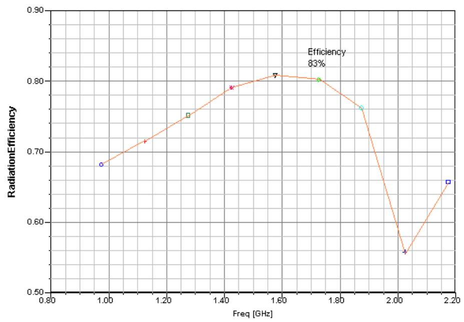

Fig.9 Radiation Efficiency vs Frequency

6 Conclusions

We have designed a circular patch antenna with circular ground plane for GPS. The proposed patch radiation pattern showed to be successful with its ability to detect satellites even at the horizon. Simulation results obtained so far are promising while considering the circular ground effect and very low return loss and VSWR is obtained. The antenna proves to be a good candidate for commercial GPS applications with high precision as from the radiation pattern of antenna, with minimum power at low elevation and thus rejecting the reflecting signals from nearby of receiver.

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