Wide band single-fed parasitically excited microstrip patch antenna for GPS

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As a part of the modernization of GPS system, a second civil signal at L2 (1227.45 MHz) and a third new civil signal at L5 (1176.45 MHz) will be added to future GPS satellites in addition to existing civil signal at L1 (1575.42 MHz) frequency. A wide band, compact, low profile, parasitically excited microstrip antenna design is presented to cover L2 and L5 frequencies. The proposed antenna design has a perfect square patch, which is parasitically excited by a nearly square patch fed at single point. Good impedance matching and circularly polarized radiation patterns have been obtained over wide frequency band by using bandwidth-enhancing techniques. The gain of the antenna is found to be more than 5.5 dB.

Keywords: GPS, Wide band microstrip antenna, Parasitic excitation, Circular polarization

1 Introduction

Global Positioning System (GPS) is a satellite based navigation system being widely used for position determination and time transfer application. The introduction of GPS has considerably increased the worldwide navigation. The single frequency GPS receiver provides less accurate range and position data due to various errors, such as ionospheric and tropospheric delays and multipath. As a result, signal reception may be poor in certain areas, such as cities or under foliage. The ionospheric delays can be eliminated, by employing dual frequency GPS receiver. Though the present civil GPS users have access to only L1 (1575.42 MHz) frequency’s C/A code; receiver manufacturers are using special techniques to access encrypted P-code signals at L2 frequency for better accuracy. As part of the modernization of civil GPS, a second civil signal at L2 (1227.45 MHz) using the same currently used C/A code of L1 and a third new frequency L5 at 1176.45 MHz with C/A code is going to be made available through block IIF GPS satellites. The signal at L5 will have four times more power than L2. The L2 and L5 signals together will provide dual frequency operation for civil use, enhancing the range accuracy significantly.

Antenna plays an important role in a GPS receiver. It should be right hand circularly polarized and should have a wide angular beam coverage to receive signals from the satellites over the horizon and sharp drop at low elevation angles for reduction in multipath errors. For airborne GPS application the antenna should have small size, light weight and low profile, as it has to be mounted on the surface of the platform which can not afford to have large projections. These requirements can be met by a microstrip antenna, which is easy to fabricate and has high repeatability for commercial exploitation as compared to other GPS antennas like helical antenna, crossed dipole antenna, conical spiral antenna, etc.

A microstrip patch antenna has inherent narrow frequency bandwidth and hence, more than one antenna may be required to cover a wide band. Stacking of parasitically coupled radiators for wide band applications are reported elsewhere. A wideband antenna is simpler than dual or triple narrow frequency band elements, which tend to get complicated and may be prone to proximity detuning in some circumstances. A single feed circularly polarized patch antenna is less complex and more attractive as it does not require any additional circuit such as 3 dB hybrid, which makes the overall size of the radiating element large and limits its usefulness in array, from spacing point of view. The single-fed circularly polarized (CP) patch antennas have been discussed extensively in literature, where they are shown to be extremely narrow band antennas. To make the antenna work over the wide frequency band,
here L2 to L5 frequencies, bandwidth enhancing techniques have to be introduced and accordingly the antenna structure should be modified.

In this paper, it is demonstrated that broadband operation can be achieved by parasitically coupling a perfectly square patch of nearly the same dimensions as that of the exciter patch as shown in Fig.1. The details of design for the proposed antenna are described. The experimental results and radiation patterns of the constructed prototype antenna over broadband are presented. The antenna seems to be very cost effective and is appropriate for use in portable GPS receivers, where typical bandwidth requirement is about 8-10%.

2 Design approach

The geometry of the proposed wide band single-fed parasitically excited patch antenna is shown in Fig.1, which consists of two square patches, stacked over a ground plane and separated with dielectric substrates. The bottom patch is nearly square and is printed along with microstrip feed line on one side of RT/Duroid 5880 copper clad dielectric substrate. The copper on the other side of the dielectric substrate acts as ground plane for the patch antenna and the microstrip feed line. The top patch is a perfect square copper plate stacked over the bottom patch with rigid foam dielectric substrate between them.

The resonant length \( L \) of a rectangular patch antenna can be easily calculated using standard analytical transmission line model\(^4\), given by

\[
L = \frac{c}{2f \sqrt{\varepsilon_r}} - 2\Delta l \quad \cdots (1)
\]

where \( \Delta l \) is the extension in patch length at each end, \( h \) the dielectric substrate thickness between the patch and the ground plane, \( W \) the width of the patch, \( f \) the resonant frequency and \( \varepsilon_r \) and \( \varepsilon_e \) respectively, the relative and effective dielectric constants. The dimension of the square patch is so chosen that it is large enough to give high efficiency but small enough for generation of higher order modes\(^5\). These design equations can also be used for square patch antennas.

Circular polarization can be obtained by combining two orthogonal modes having equal amplitude and quadrature phase difference between them. Various methods have been proposed for it\(^6\). We have employed a very simple technique for obtaining circular polarization from the square patch antenna. When a perfectly square patch of side \( a \) and area \( S \) is fed at its corner, it will generate two orthogonal modes of equal amplitude. By introducing a suitable perturbation segment \( \Delta S \) on this square patch antenna, a quadrature phase difference can be introduced between the normalized degenerate \( \text{TM}_{10} \) and \( \text{TM}_{01} \) modes to get circular polarization of the radiation pattern.

With the suitable equivalent circuit diagram, the condition for circular polarization operations is given by\(^7\)

\[
\frac{(Q_0^2 - 1)Q_0^2}{2Q_0^2 - 1} = MN \left[ 1 + \frac{(2Q_0^2 - 1)MN}{M^2 + N^2} \right] \quad \cdots (4)
\]

where, \( M = \{ 1 + m (\Delta S/S) \} \), \( N = \{ 1 + n (\Delta S/S) \} \), \( Q_0 \) is the unloaded quality factor of the patch, and \( m \) and \( n \) constants.

By simplifying Eq. (4) and taking a significant root condition for circular polarization for corner fed square patch antenna, we get
This relation is plotted in Fig. 2. From this figure the amount of perturbation needed for circular polarization can be obtained by selecting a suitable value of $Q_0$ for which the radiation efficiency of the microstrip antenna is between 80 and 90%. The radiation efficiency of a microstrip antenna is determined by the unloaded quality factor ($Q_0$) and the radiation quality factor ($Q_e$) and is given by $\eta = Q_0/Q_e$.

Among various shapes of single feed circularly polarized microstrip patches like square, circular, equilateral triangle, pentagonal, elliptical square ring, etc. the square patch is the simplest to realize. These shapes give a very narrow bandwidth of the order of 1%. By introducing metallic posts, which are a complex technique, bandwidth can be increased to 2.3%. Bandwidth enhancement techniques proposed in literature are too complex and difficult to fabricate. One method to increase the bandwidth is to excite a slot aperture by the feed line, and this slot then couples to the radiating patch. Another method is by terminating a microstrip feed line in square resonator, which is coupled to the radiating patch. These methods are complex and are not effective to get circular polarization over wide bandwidth. Hence, a combination of bandwidth enhancement techniques is used here, which is less complex and very cost effective to achieve a VSWR < 2:1 and good circular polarization bandwidth to cover the required frequencies of L2 and L5 signals with one single antenna.

This bandwidth enhancement technique consists of using low permittivity, thick substrate and parasitic elements simultaneously. This condition is maintained over a large bandwidth by stacking two square patches of nearly equal size. A thick low permittivity dielectric slab between them separates the two patches from each other. When bottom patch is excited, it parasitically couples with the upper patch. The coupling is loose or tight depending upon the properties of dielectric material present between them and its thickness. The amount of coupling can be optimized experimentally to obtain two closely spaced resonant conditions around the resonant frequency of the single patch, thus increasing the bandwidth.

As probe type of feeding is difficult to realize, less reliable and not easy to implement in array, the antenna feed is printed along with the patch, which reduces the complexity of fabrication. Also, an inset type feed in the patch will result in significant deterioration of the axial ratio. Hence, the proposed coplanar feed is simple to implement and can easily fit in array formation.

3 Experimental results and discussion

Based on the above design an antenna for dual frequency (L2 and L5) GPS signals was developed and tested. Initially, a square patch antenna was designed for center frequency 1.2 GHz, on a RT-Duroid 5880 dielectric substrate of relative dielectric constant $\varepsilon_r = 2.2$ and thickness 1.58 mm. The 50 $\Omega$ feed line was printed on the same substrate along with the patch. The perturbation for obtaining circular polarization was introduced by changing the dimension of one pair of side of the square patch, such that $\Delta S = 2.2032$ cm$^2$ and the aspect ratio $L/W$ is 1.026. The optimized dimensions of the bottom patch are 9.18 cm $\times$ 8.94 cm. This structure was printed, using photolithography method, on one side of the RT-Duroid 5880 substrate and the other side acts as ground plane of size 15 cm $\times$ 15 cm. In this antenna the equivalence conductance is mainly due to radiation conductance. Hence, it has unloaded $Q_0$ of 38 and radiation efficiency of 89%.

A coaxial to microstrip line, tab type SMA jack connector was integrated with microstrip feed input of the patch. The return loss for this structure was measured using HP-8722 D Vector Network Analyzer and its frequency response is shown as trace 1 in Fig. 3. This patch antenna resonates at 1.20 GHz having a VSWR of 1.22:1. From the plot we observe that the frequency coverage with VSWR less than 2:1 is much less than the required bandwidth. To increase the bandwidth, a perfectly square copper plate patch of size 9.18 cm $\times$ 9.18 cm and thickness 0.4 mm was stacked over the bottom patch with rigid PUF.
dielectric spacer between them. The two patches were symmetrically assembled with their centers passing through the same axis, such that the bottom patch parasitically excites the top patch.

The thickness of the foam spacer ($\varepsilon_r = 1.05$) was experimentally optimized to 25 mm for VSWR bandwidth less than 2:1, covering the required frequencies from 1100 MHz to 1233 MHz. The return loss for the parasitically excited patch antenna was measured on network analyzer and is shown as trace 2 in Fig.3. It is evident from this plot that the sharp resonance at 1.2 GHz due to lone bottom patch splits giving rise to two shallow nulls. These nulls are located on either side of the resonance of trace 1 due to presence of another patch, mounted above the first with foam dielectric in between. Thus with parasitic excitation the bandwidth of the antenna increases from 1% to about 11%.

The measurement of circularly polarized radiation patterns for the antenna was carried out in Anechoic Chamber. A linearly polarized transmitting antenna was fixed to a polarization positioner and was made to spin clockwise about its axis at 50 rpm. The test antenna was mounted on azimuth over elevation pedestal and rotated in azimuth plane at 2 rpm. The spinning linear radiation patterns for this antenna were measured over the band. Typical measured patterns at L2 and L5 frequencies are presented in Figs 4 and 5, respectively. The 3dB beam width and axial ratio derived from the measured radiation patterns over the entire frequency band of 1100-1233 MHz are shown in Figs 6 and 7, respectively. From the radiation patterns we observe that the 3 dB beam width of the antenna varies from 62° to 81° and decreases with increase in frequency. The axial ratio varies within ±3 dB. The back lobe of the antenna is better than -12 dB. From the measured radiation patterns it is also observed that the antenna can receive satellite signals over wider horizon of 120° with nominal reduction in gain. The performance of this antenna in GPS receiver will be affected minimum, due to multipath, as its radiation patterns have sharp fall in gain – more than – 12 dB over elevation angle < 20° above the horizon. The gain of the antenna was measured by gain comparison method and is plotted in Fig. 8. The antenna gain
varies from 5.5 dB to 6.6 dB. It is apparent that the gain of the proposed antenna is maximum at the center of resonant frequency, but decreases at the band edge frequencies.

4 Conclusions
A parasitically excited wide-band microstrip patch antenna suitable for GPS receiver has been designed, developed and experimentally tested. The antenna can be used for dual frequency reception of GPS civil signals at L2 and L5 frequencies. The proposed broadband circularly polarized antenna has a simple structure, and can be easily constructed at a low cost. The antenna showed a wide 2:1 VSWR impedance and circular polarisation bandwidth. The gain of the antenna is more than 5.5 dB. The 3 dB beam width is better than 62° with sharp fall at low elevation angles and hence, reduced multipath errors. The proposed antenna can also be used for mobile platforms and communication systems.

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