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PARASITIC PROBE FED MICROSTRIP ANTENNA FOR MULTI-CONSTELLATION GNSS

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Abstract—The design approach and development of a right hand circularly polarized wideband microstrip antenna for multi-constellation Global Navigation Satellite System (GNSS) is presented. The antenna is corner truncated square patch, parasitically excited by a dielectric covered straight probe. A thermacol layer of thickness $\lambda/14$ at center frequency is used to support the microstrip over the ground plane substrate. The simulated and measured results are presented. The antenna shows wide beam radiation patterns with axial ratio less than ± 1 dB. Its VSWR is better than 2.8 : 1 and the gain varies from 1.2 dBi to 3.5 dBi over the frequency band.

1. INTRODUCTION

Global Navigation Satellite Systems (GNSSs) refers to the worldwide positioning, navigation and time determination facility consisting of one or more constellations such as the Global Positioning System (GPS) of USA, Global Navigation Satellite System (GLONASS) of Russia, Galileo of European Union and other regional systems. In coming years GNSS will have multiple civil ranging signals between 1.1 GHz to 1.7 GHz frequency band, from more than 60 satellites spread over wideband of frequencies [1, 2]. The interoperability between the GNSS systems will help to overcome various shortfalls of individual navigation system such as service guarantee, integrity monitoring and improved service performance.

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For the receiver to work for entire GNSS frequency band, use of multiple single frequency antennas will be a costly proposition in addition to increased complexity of the system. Hence, it is required to develop wide frequency band antennas for simple and cost effective next generation GNSS receivers with improved performance. With the increase in bandwidth requirement it becomes difficult to design and develop an antenna that covers all the required frequency bands and meets all other requirements of the GNSS receiver. A GNSS antenna should have right hand circularly polarized (RHCP) wide angle radiation patterns covering a large frequency band. In addition it should be light in weight and easily producible. The RHCP antenna in GNSS is essential because, the transmitted GNSS signals are right hand circularly polarized. The RHCP also ensures more efficient and effective signal reception, independent of the orientation of transmitting and receiving antennas.

Studies have shown that microstrip patch antennas though very popular are somewhat band limited and are difficult to design for wideband applications [3]. Many techniques are reported for dual-frequency stacked microstrip patch antennas for GPS applications which are more expensive to develop [4]. The aperture-coupled microstrip antenna has shown some relatively larger frequency band coverage than direct fed patch but their non-contacting feed transition is complicated in fabrication [5]. Multi frequency GPS antennas have also been proposed with more complex feed networks for achieving circular polarization or covering multiple frequencies which employs either hybrids, pin diodes or MEMS switches [6, 7]. Dual frequency band coverage has been achieved in parasitically coupled stacked patch antenna where the feed probe is soldered to the top patch [8]. This probe is passed through an isolated hole in the bottom patch. In this paper, we discuss the design, simulation and development of an inexpensive wideband patch antenna and present the detailed measured results. It employs a teflon sleeve covered straight metallic probe parasitically exciting truncated corner microstrip which is separated with a layer of themacol above the FR-4 substrate having metallic ground plane printed at the bottom.

2. DESIGN APPROACH

The resonant length (L) of the proposed broadband opposite corner truncated square microstrip antenna is determined by transmission line model equations given as [1, 2, 9],

$$L = \frac{c}{2f_r\sqrt{\varepsilon_r}} - 2\Delta l \quad (1)$$

$$\Delta l = 0.412h \frac{(\varepsilon_e + 0.3)}{(\varepsilon_e - 0.258)} \frac{\left(W/h + 0.264\right)}{\left(W/h + 0.813\right)} \tag{2}$$

$$\varepsilon_e = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \frac{1}{\left(1 + 12\, h/W\right)^{1/2}} \quad \text{for } W/h \geq 1 \tag{3}$$

where Δl is the extension in patch length at its each end, h dielectric substrate thickness between the patch and the ground plane, W the width of the patch, f_r the resonant frequency, and ε_r and ε_e are the relative and effective dielectric constants, respectively. The width (W) of the square patch radiator is chosen such that it is large enough to give high efficiency but small enough for generation of higher order modes.

In microstrip antenna, circular polarization can be generated by exciting two degenerate orthogonal modes of equal amplitude and then introducing some perturbation, to remove the degeneracy of the modes. When properly designed, the phase of one mode voltage will lead the impressed current by 45°, while the other mode voltage lags by 45° producing circularly polarized radiation [10, 11]. The two modes can be treated as uncoupled parallel resonant circuits excited by a common current source having quadrature (90°) phase difference between them. For a square patch the condition for circular polarization operations is given by [11]

$$\frac{\left(Q_0^2 - 1\right) Q_0^2}{2Q_0^2 - 1} \left(M^2 + N^2\right) = MN \left\{1 + \frac{\left(2Q_0^2 - 1\right) MN}{M^2 + N^2}\right\} \tag{4}$$

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 are constants. A suitable value of Q_0 can provide the amount of perturbation needed for circular polarization. This Q_0 varies inversely with impedance bandwidth of patch antenna and is related to total area of perturbation segment ΔS introduced in the square patch and total area of patch before perturbation S as [11]

$$\frac{\Delta S}{S} = \frac{1}{2Q_0} \tag{5}$$

The bandwidth of corner truncated microstrip patch antenna on dielectric substrate is less than 3–4% [12, 13]. Usually the feed probe of the antenna is passed through the ground plane and is physically soldered to the patch at its excitation point [14]. The impedance band width of patch can be increased by employing various types of probe feeding such as an L-shaped probe, small circular disc loaded probe, straight probe or incorporating various slot geometries in patch such as ‘U’, ‘C’, ‘E’ etc. [15–20]. Most of the published literature describing such techniques deals with linearly polarized antennas or multi-layer parasitically coupled patches. However, a detailed study on use of U-slot and L-type feed probe for circular polarized patch antenna with limited band width is presented by Yang et al. [21]. A short single probe pin, concentric to a metal cylinder is reported to be used as feed to the patch with air dielectric covers 10–12% bandwidth only [22]. However, the bandwidth of microstrip patch antenna can be effectively increased by using a low dielectric constant, thick substrate between the patch and ground plane. This has been successfully implemented for the development of this antenna.

3. ANTENNA STRUCTURE SIMULATION

The geometry of the proposed antenna is shown in Fig. 1. The radiating microstrip element is positioned 15 mm above the 1.6 mm thick FR4 dielectric substrate ($\varepsilon_r = 4.4$) with a uniform air gap maintained by employing a thermocol spacer ($\varepsilon_r = 1.05$) forming a composite dielectric substrate. The metallic ground plane for the patch is printed on the bottom side of the FR4 substrate. The dimensions of

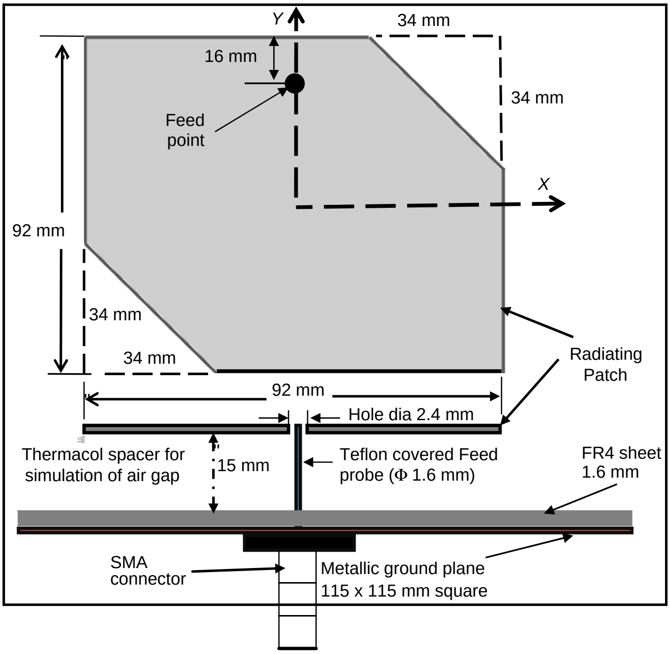

Figure 1. Schematic of the proposed broadband circularly polarized patch antenna.

the patch were calculated using Equations (1)–(3). The square patch side is 92 mm and the truncated length ΔT of the square side is 34 mm. The feed excitation point P was selected to lie on one of the central axis of the square patch where the antenna impedance is 50 ohms. A feed probe of diameter 1.6 mm was soldered to a SMA coaxial connector and passed through the ground plane, the FR4 substrate and thermocol spacer. This probe was covered with Teflon sleeve of outer diameter 2 mm and was extended up to top of the patch surface having a pass hole of diameter 2.4 mm. This provides the proximity coupling to the patch for radiation. This feed position was further experimentally optimized for better impedance matching and low axial ratio over the band of interest.

The characteristics of the antenna structure shown in Fig. 1 were modeled and analyzed using FEM based commercial HFSS (V10.1) software [23]. It was extensively investigated to arrive at the dimensions of the antenna and to gauge the fundamental requirement of low axial ratio circular polarization before realization of hardware. After iterative optimization for the radiation characteristics the current distribution on the patch surface is shown in Fig. 2. The simulation optimization was more concentrated towards obtaining excellent circularly polarized radiation pattern covering the GNSS band width. After optimizing for low axial ratio ($< \pm 1$ dB) patterns the antenna was fabricated and the feed position was further optimized experimentally for required impedance bandwidth. The simulated radiation patterns for both vertical and horizontal polarizations are shown in Figs. 3(a)–(d).

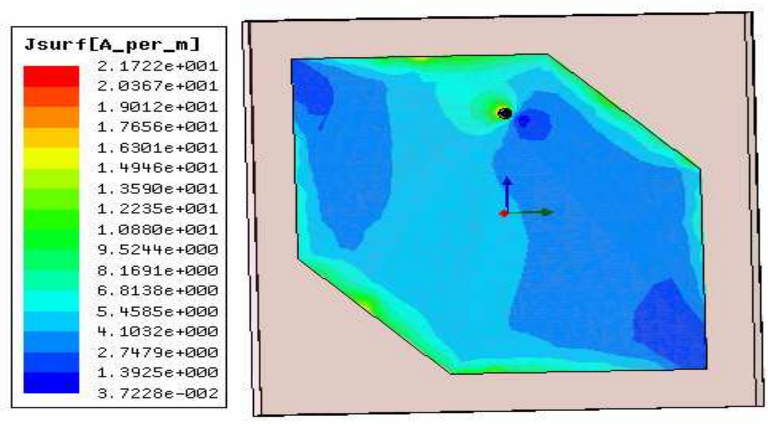

Figure 2. Surface current distribution on microstrip at 1.2 GHz.

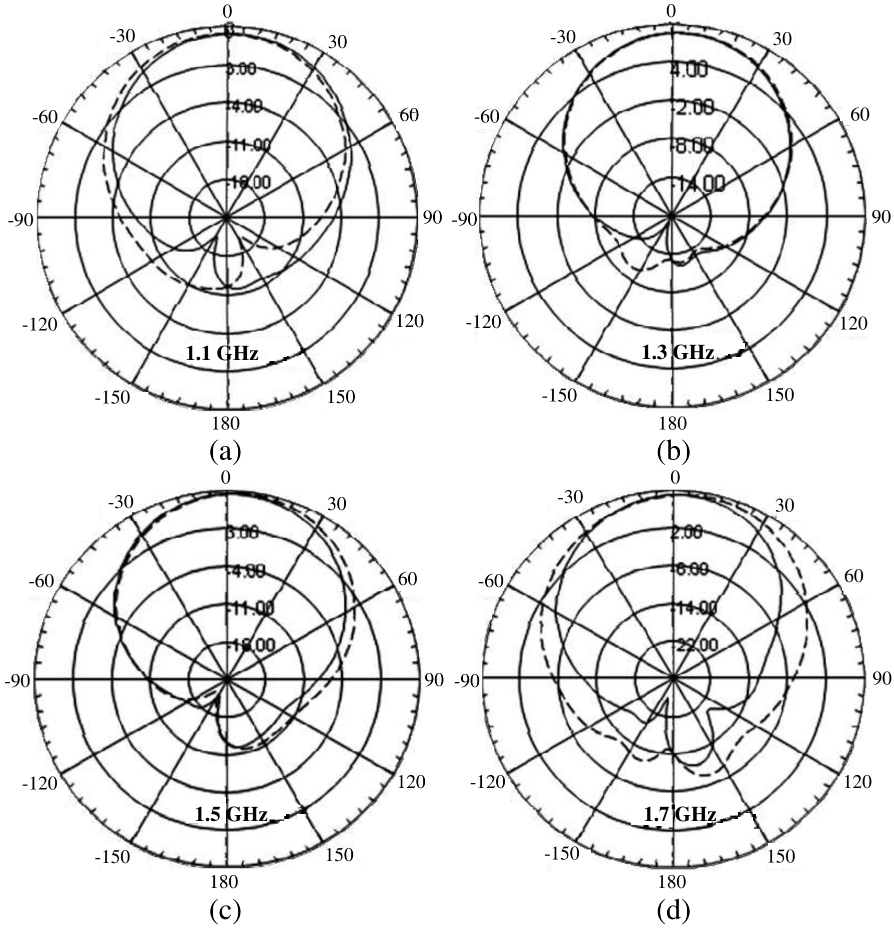

Figure 3. Simulated radiation patterns of GNSS patch antenna VP (broken line), HP (solid line).

The photograph of the developed broadband GNSS microstrip antenna is shown in Fig. 4.

4. RESULTS AND DISCUSSIONS

The antenna was evaluated for its impedance bandwidth using vector network analyzer (ZVRE-20). The plot for measured return loss along with the simulated return loss of the antenna is shown in Fig. 5. It is observed that the return loss for the antenna is better than -7 dB over the frequency band of 1.016 GHz–1.796 GHz for simulated as well as for the measured one. The antenna was evaluated

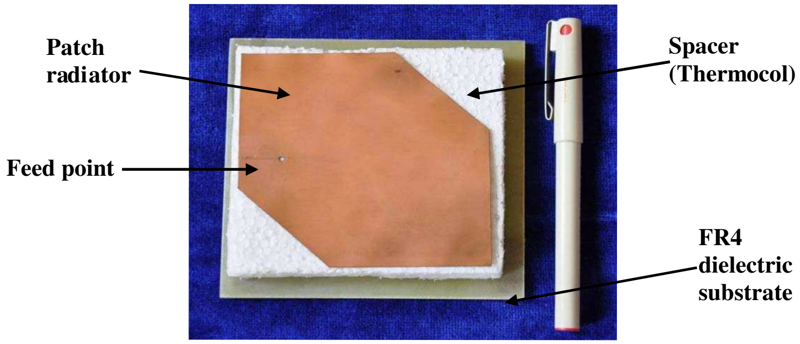

Figure 4. Broadband GNSS microstrip antenna.

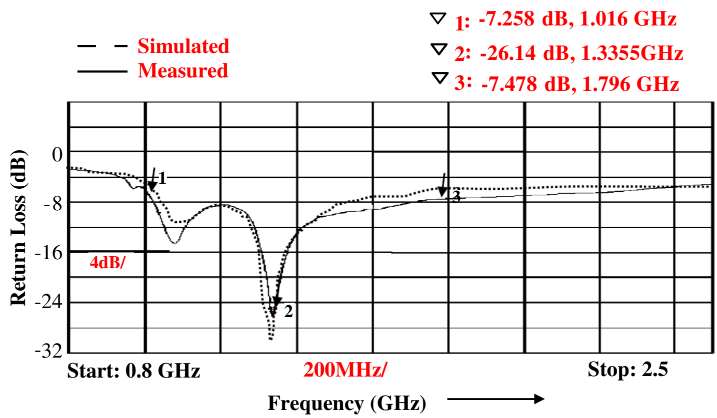

Figure 5. Comparison of Simulated and Measured return loss of the L-band patch antenna.

for its radiation characteristics in the anechoic chamber with PNA based automatic measurement system at Defence Electronics Research Laboratory (DLRL), Hyderabad. The measured radiation patterns for orthogonal horizontal and vertical polarizations were overlapped and plotted on the same graph and are shown in Figs. 6(a)–(d). From these measurements it is observed that the 3 dB beam width of the antenna varies from 70°–105° and the axial ratio is less than ±1 dB. The antenna gain was measured by gain comparison method using standard gain antennas. The measured gain varies from 1.2 dBi to 3.5 dBi. The back lobe of the antenna is better than −25 dB. It is also observed that the antenna can receive signals over wider horizon of 160° with reduction in gain by −8 to −10 dB.

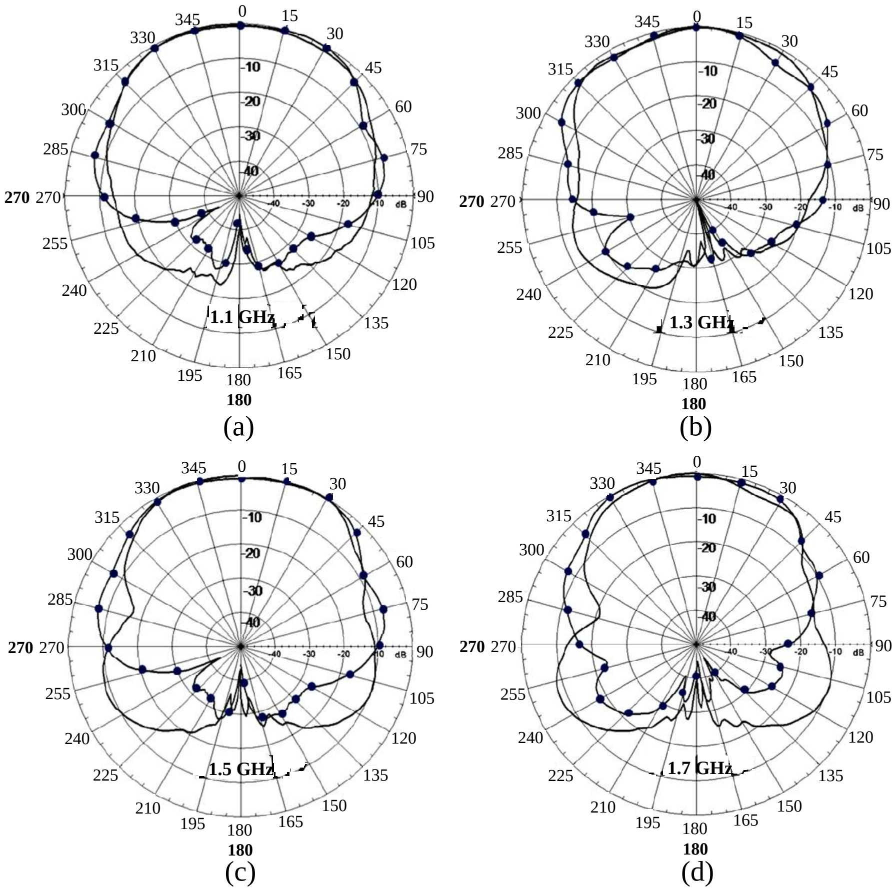

Figure 6. Measured radiation patterns of L-band patch antenna VP (dotted line), HP (solid line).

5. CONCLUSIONS

Successful design, development and realization of wideband microstrip antenna with proximity coupled straight probe feed are presented. The antenna showed a wide impedance bandwidth with VSWR less than 2.8 : 1 covering 1.016 GHz–1.796 GHz frequency band suitable for GNSS applications. The gain of the antenna varies from 1.2 dBi to 3.5 dBi, and its 3 dB beamwidth varies from 70°–105° over the band. Also, the circularly polarized radiation patterns have low axial ratio (less than ±1 dB). The measured characteristics of the antenna are in good agreement with the simulated results. The antenna is cost effective because of its simple design and construction and can provide effective reception of satellite signals from multi-constellation GNSS, over wide elevation angles (±80° from zenith). This type of antenna can also be used for mobile platforms and communication systems.

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