Design and realization of a Dual Microstrip patch antenna for NavIC Applications

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Abstract

The Navigation with Indian Constellation (NavIC) is an initiative taken up by ISRO to develop and operationalize a regional navigation satellite system for Indian users. The NavIC constellation broadcasts the navigation signals in two services namely, the Standard Positioning Service (SPS) and Restricted Service (RS). Both these services are made available in two frequencies namely L5 (1176.45 MHz) and S (2492MHz).

The NavIC space segment consists of a constellation of seven satellites placed in GEO/GSO orbits. The NavIC ground segment is responsible for the maintenance of the space segment and for enabling the navigation function. As part of the NavIC applications a dual frequency timing receiver using NavIC signals has been designed by ISTRAC and is in the process of realization through Indian industry. This paper addresses the design and the realization of a dual-band dual-patch (L5 and S) antenna solution for the In-house designed NavIC timing receiver.

Keywords—In-House Dual Microstrip patch antenna, Navigation with Indian Constellation (NavIC), Microstrip Patch Antenna (MSA), NavIC timing receiver

1. Introduction

NavIC is a regional navigation satellite constellation realized by the Indian Space Research Organization consisting of 7 satellites placed in geostationary and geosynchronous orbits such that they provide navigation services over the Indian landmass and in the region extending to 1500 kilometers beyond the Indian geopolitical boundary. Three of the NavIC satellites are in geostationary orbit (32.5 E, 83E and 125.5E) while four of the satellites are in two geosynchronous orbits having an inclination of 29 degrees. While one of the geosynchronous orbit planes crosses the equator at 55 degrees’ east longitude, the other geosynchronous orbit crosses the equator at 111.75 degrees’ east longitude. The NavIC satellites provide the navigation signals in two frequency bands namely the L5 (1176.45 MHz) and S band (2492.028 MHz) and in two services namely the Standard Positioning Service (SPS) and the Restricted Service (RS). [1]

Antennas are a critical part of any GNSS receiver design. The NavIC signals are extremely weak and present unique demands on the NavIC antenna. Therefore, the choice and implementation strategy of the antenna plays a significant role in the overall performance of the NavIC Timing Receiver.

The proposed design for the NavIC antenna is a dual-band dual- microstrip patch antenna (MSA) solution. The design validation has been carried out using commercial software and the MSA fabrication has been done at ISRO PCB Facility, UR Rao Space Centre (URSC). After fabrication, the MSA (for L5 and S) underwent detailed characterization at the anechoic chamber facility of URSC. The results obtained are comparable in simulation and fabrication.

In the discussed antenna design, the substrate material used is Roger RT/Duroid 6002 substrate having a dielectric constant of 2.92. The Roger series of substrates are majorly used for the fabrication of the planar antennas, due to its low cost and easy machining capabilities. This substrate has reinforced PTFE (ceramic or glass) material giving low dielectric loss applicable for high frequency and broadband applications. The low dielectric constant of the substrate material improves the efficiency and the bandwidth performance of the antenna. The other advantage of employing a substrate with a low dielectric constant is the improvement in the fringing field. The fringing fields at the edge of MSA add up in phase and produce the required radiation. In essence, the MSA designed and developed considers having a high gain and a good return loss as the fundamental system requirements. The paper is organized as follows: Section 2 describes the principle of the antenna design; Section 3 presents the results and discussion, Section 4 provides the performance comparison of the In-house dual band dual patch antenna with an imported dual antenna being used in the NavIC ground segment, while the paper is concluded in Section 5.

2. Antenna Design

Microstrip Patch Antenna approach

The most common antenna type used for GNSS receivers is the MSA. The MSA are flat, generally have a substrate and a metal body, mounted on metallic base plates. This construction of the MSA yields a high gain in the upper half of the radiation hemisphere, which is suited for navigation applications. The MSA has a dielectric substrate, a ground plane and a thin metallic patch of aluminium, copper or gold. The patch and the ground plane are separated by the dielectric substrate. The most common shape of patch antennas used in navigation applications are the rectangle, the square and the circle. However, the
square patch MSA is best suited among all the geometry of patches available as it can obtain circular polarization that is employed by the navigation satellite system. As the NavIC signals employ circular polarization, the design of the square MSA for the NavIC timing receiver requires a reception of the circularly polarized navigation signals. In order to achieve circular polarization, pair of chamfers along the corners of the square MSA is introduced. These chamfers create perturbations so as to resonate at the required carrier frequency of NavIC (L5 and S) with RHCP characteristics. To ensure a good RHCP dominance in the received signal the MSA is designed with an axial ratio less than 2 dB. The perturbations in the MSA aids the reception of circular polarization signals by producing two orthogonally degenerate modes. The fundamental configuration of the patch and its coordinate system are shown in Figure. 1.

**Figure.1:** Fundamental configuration of Microstrip patch and its coordinate system

The electromagnetic field realized inside the MSA is derived by the dominant mode of the cavity which is enclosed by the periphery formed by the magnetic walls. This approximation is used to theoretically design the MSA using the design equations discussed in the next section. The specifications considered for the design approach are tabulated in table.1.

<table>
<thead>
<tr>
<th>Antenna parameter</th>
<th>S band</th>
<th>L5 band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frequency</td>
<td>2492.028 ± 8.25 MHz</td>
<td>1176.45 ± 12 MHz</td>
</tr>
<tr>
<td>Axial Ratio</td>
<td>&lt; 2dB</td>
<td>&lt; 2dB</td>
</tr>
<tr>
<td>Polarization</td>
<td>RHCP</td>
<td>RHCP</td>
</tr>
<tr>
<td>Peak Gain</td>
<td>+7 dBi (conical antenna)</td>
<td>+7 dBi (conical antenna)</td>
</tr>
<tr>
<td></td>
<td>+2 dBi (omnidirectional antenna)</td>
<td>+2 dBi (omnidirectional antenna)</td>
</tr>
<tr>
<td>EOC Gain</td>
<td>+1dBic</td>
<td>+1dBic</td>
</tr>
</tbody>
</table>

**Table.1:** NavIC Antenna specifications

**Design equations**

The design of the MSA involves calculation of parameters that are responsible for achieving the resonance frequency. Since, the substrate selected here has a lower dielectric constant, the impedance matching is easy. The substrate material considered here is Rogers RT Duroid 6002 with a relative permittivity of 2.92, and a loss tangent of 0.0012. The resonant frequency of the chamfered square MSA is derived from

\[ f_\text{res} = \frac{c}{a} \sqrt{\frac{1}{\epsilon_r}} \]  

(1)

Where \( f_\text{res} \): resonant frequency
\( c \): speed of light in free space
\( \epsilon_r \): relative permittivity
\( a \): effective length

\[ a = \frac{c}{2f_\text{res}\sqrt{\epsilon_{\text{reff}}}} \]  

(2)

Where \( \sqrt{\epsilon_{\text{reff}}} \) is the effective dielectric constant, given in (3)

The factor \( f_\text{ref} \) is the resonant frequency and the factor \( \sqrt{\epsilon_r} \) in (1) reflects the loading by the substrate. The effect of the fringing field along the edges is also accounted for in the calculation, while the length of the ground plane \( W \) equals the free space wavelength. To achieve circular polarization reception for RHCP, the perturbations segment \( \Delta s \) are introduced in the corners of the squared MSA. Due to the perturbations of isosceles triangles of side \( \sim 0.01*a \), the degenerate modes are resolved and thereby the structure is used as a circularly polarized antenna. It is seen that the parameters such as the dimensions of the Ground plane, the material of the patch and the dielectric thickness have a lesser influence on the MSA resonant frequency.

The coaxial feed position of the MSA is selected in its fundamental mode typically located in the direction of its resonant length. The exact position along the resonant length is determined by the electromagnetic field distribution in the patch. The square MSA is fed along the central axis with a distance of \( a/2\sqrt{\epsilon_{\text{reff}}} \). Where \( \sqrt{\epsilon_{\text{reff}}} \) is the effective dielectric constant, given in (3).

Effective dielectric constant (\( \epsilon_{\text{reff}} \)):

\[ \epsilon_{\text{reff}} = \frac{\epsilon_r+1}{2} + \frac{\epsilon_r-1}{\sqrt{4(\epsilon_r+1)}} \]  

(3)

Where, \( \epsilon_r \) is the dielectric constant of the substrate, \( h \) is the height of the substrate and \( L \) is the length of the square MSA.

It is known that the current varies along the patch in such a way that the current is a maximum at the center of the patch and is a minimum at the patch edges. The voltage that causes the electric field distribution is maximum at one end of the patch and is minimum at the other. Therefore, the current and the voltage distribution along the patch resonant length determine the location of the feed, which is selected suitably after iterative simulations in order to achieve an impedance of 50 Ohm for the square MSA.

3. Results and Discussions

The MSA design was carried out using a COTS software. The design underwent parametric variations in order to optimize its performance required for the NavIC L5 and S band ground applications. The results discussed here display the return loss, radiation pattern (RHCP & LHCP) and axial ratio for the two MSA designs for L5 and S band having center frequency as 1.176 GHz and 2.492 GHz respectively.

**Frequency response**

This section shows the HFSS simulated frequency response for the MSA for L5 and S bands.
The frequency response for the two operational frequency bands mainly S and L5 are shown in Figure 2 and Figure 3 respectively. The S parameter plots above show that the achieved return loss for S band is -25 dB and for L5 band is -45 dB.

**Radiation pattern**

The simulated radiation patterns for S and L5 bands are discussed in this section. The radiation pattern of MSA signifies the directivity in the perpendicular direction to the patch (broadside). The directivity decreases when moving away from the broadside towards lower elevation angles.

The peak gain achieved for the S band (Figure 4) patch antenna is 6.7 dB while the cross polarization isolation that is achieved is 15 dB. The peak gain achieved in case of the L5 band (Figure 5) patch antenna is 5.2 dB while the cross polarization isolation is achieved is 23 dB.

**Axial ratio**

The simulated axial ratio results are discussed in this section. The quality of the circular polarization is commonly quantified as the axial ratio (AR) and is expressed in dB. A 3 dB axial ratio is considered sufficient for most GNSS applications. The amount of variation in the axial ratio is dependent on the geometry of the MSA. The AR attained in simulation for S and L5 band are shown in Figure 6 and Figure 7 respectively. The simulation results provided confirm the circular polarization reception for RHCP, where the AR~1 dB for S and L5 bands.

The feed position was selected appropriately to impedance match and achieve 50 Ohms. These simulation results were validated and cleared for fabrication at the URSC, PCB facility.

**Fabricated Microstrip patches**

The Microstrip patches for L5 and S bands were fabricated and tested. The realized antenna was integrated with the dual band antenna subsystem to test the L5 and S band performance using the NavIC Signal in Space.

The Microstrip patches were tested in the anechoic chamber facility of Communication Systems group, URSC. The radiation pattern was achieved as per the simulation results.
Table 2: Measured radiation pattern of S and L5 bands of the fabricated MSA

<table>
<thead>
<tr>
<th>Band</th>
<th>Peak Gain</th>
<th>Cross Pol</th>
</tr>
</thead>
<tbody>
<tr>
<td>S</td>
<td>7 dBi</td>
<td>15 dB</td>
</tr>
<tr>
<td>L5</td>
<td>5.7 dB</td>
<td>10 dB</td>
</tr>
</tbody>
</table>

It is observed from the results tabulated in Table 2, that the performance of the fabricated MSA achieved is comparable w.r.t. the RHCP gain with that of the simulated design results. However, the results of cross-polarization achieved in the measured results are 15 dB cross-polarization in S band and 10 dB cross-polarization in L5 band. The patches are integrated with the antenna-subsystem to make the passive patch antenna, active antenna. The integrated antenna system functions at 5V, which is driven from the RF input port of the NavIC timing receiver.

Integration with antenna subsystem
After the patch fabrication and its characterization, the two separate patches for S band and L5 band were integrated with the antenna subsystem (Figure 9). The power required to antenna subsystem is provided from the RF port of the NavIC Timing receiver. The specifications for the antenna subsystem were worked out with respect to the imported antenna solution. The antenna along with the antenna subsystem was further enclosed in antenna housing and put up for a long term test of duration 30 days with the NavIC Signal in Space.

As shown in Figure 10, the antenna system was placed on a roof top mount where the environment of testing had variable multipath environment. This constraint has been recorded for future, to incorporate a choke ring ground plane for multipath mitigation.

4. Summary & Conclusion

The performance of the fabricated MSA was validated with respect to the RHCP gain and cross-polarization performance achieved at the upper hemisphere of the radiation pattern. The integrated dual-band dual-patch antenna results for C/N0 were compared with the imported dual band antenna and the results reflect the improved reception of C/N0 with the In-house realized dual-patch dual-band antenna. This work is currently being extended to support the new L1 (1575.42 MHz) downlink of the NavIC system.

5. References

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