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An Electrically Small All Metallic Probe-Fed Antenna for NavIC Applications

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Abstract—In this paper, a novel all-metallic probe-fed antenna is proposed for L5, L1, and S bands for Navigation with Indian Constellation (NavIC) applications, and it can be used for tracking applications. The proposed antenna dimensions are 30 mm × 80 mm × 8 mm ($0.11\lambda \times 0.31\lambda \times 0.03\lambda$) electrical size calculated at 1176.45 MHz (L5). The radiating plane has a comb like structure where there are 8 slots which are of identical size 24 mm × 1 mm and a short slot with 6 mm × 1 mm. The ground plane is 30 mm offset with respect to the radiating plane (top plane). Usually, a high dielectric substrate antenna can resonate at lower frequencies keeping the size of the antenna electrically small, but without substrate the proposed antenna resonates at lower frequencies keeping the antenna size electrically small. The proposed design is electrically compact and economical, and the dielectric loss in the antenna is zero as the antenna is designed with copper alone, which gives a strong impression that a substrate free antenna can resonate at lower frequencies. So, from this method it can also make the antenna light weight.

1. INTRODUCTION

Navigation with Indian Constellation (NavIC) is an Indian satellite navigation system, which offers accurate real time positioning and timing services over the India subcontinent and also extends its boundary up to 1500 km all over. NavIC provides navigation signals in three frequency bands: L5 band with center frequency of 1176.45 MHz, S band with center frequency of 2492.028 MHz, and L1 band with center frequency of 1575.42 MHz. So, the antenna for this application should be designed in such a way that it should be compact and operate at NavIC bands. Association of small patches in a single patch is used but resonates at L5 only [1]. A truncated patch antenna works for GPS and iridium satellite application with high dielectric constant of 10.2 which in turn increases the cost of antenna [2], and the circularly polarized annular ring-shaped planar antenna with dielectric constant of substrate 4.4 is electrically large [3]. A split rectangular slot (SRS) and stub method is used to obtain L band and S band with considerable increase in the dimension of antenna [4]. Printed Multiband Monopole Antenna which works for multiple wireless standards would unnecessarily pick up signals from adjacent bands [5]. A microstrip patch antenna with defective ground structure and a very low dielectric constant of 2.2 is used which in turn increases the size of antenna for L1 band (1.575 GHz) and L5 (1.176 GHz) band for tracking application [6]. Another approach with a cavity-backed magnetoelectric (ME) dipole antenna is used to make the antenna to work at L1 and L5 bands with a large bandwidth with a low dielectric constant of 2.26, but it does not work for S band (2.492 GHz) [7]. A dual-band and dual-polarized antenna with a low dielectric constant of 3 works at L1 band and S band with antenna height of 3.11 mm [8]. The antenna resonance is controlled using PIN diode where antennas are stacked upon each other, called as parasitic antenna, which is single fed and works for 5G/Wi-MAX/WLAN applications [9]. Five liquid metamaterial layers using the technique of distilled water split-ring resonator are stacked upon

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the reconfigurable antenna which works for X band, but for the reconfigurable antenna, an RT/Duroid 5880 substrate is used, and for reconfiguration PIN diode is used [10]. The reconfigurable antenna is made of FR4 substrate model which is like a rack. The parasitic antenna is placed inside this rack, and PIN diode is used for switching. This antenna is used for satellite, aeronautical radio navigation, and X-band synthetic aperture radar applications [11]. A dual band tapered fed antenna works for 5G and satellite band application with 80% efficiency [12]. An L-shaped radiating plane with J-shaped defected ground works for WLAN and V2X applications [13]. This paper discusses the physical dimension of the proposed antenna and working mechanism of the antenna. The results are analysed in terms of the return loss and normalized E-plane and H-plane radiations, and efficiency by comparing the simulated and measured results. Also, the proposed antenna is compared with the existing antenna designs with respect to the antenna size, bands covered, method of approach, gain, cost, and impedance bandwidth. All antenna design approaches specified [1–8] do not work for all L band and S band used for NavIC and GPS application, and some of the antennas' electrical sizes are bigger and they have high dielectric constant substrates which increases the cost of the antenna. Hence, an electrically small all metallic probe-fed antenna working at L1, L5, and S bands is proposed for NavIC, GPS, and tracking application with the overall dimension of antenna 30 mm × 80 mm × 8 mm which translates to $0.11\lambda \times 0.31\lambda \times 0.03\lambda$ at 1176.45 MHz (L5) and with gain 2 dBi, 2.1 dBi, and 3.5 dBi.

2. PROPOSED ANTENNA

The proposed antenna is an all-metallic patch antenna. The top plane has a comb like structure where each slot has a dimension of 24 mm × 1 mm except one of the slots with dimension 6 mm × 1 mm. The top plane has a dimension of 30 mm × 50 mm which translates to $0.11\lambda \times 0.19\lambda$ while the ground plane has a dimension of 30 mm × 49.5 mm which translates to $0.11\lambda \times 0.19\lambda$. The ground plane is offset with the top plane by 30 mm. The schematic of the proposed all metallic probe-fed antenna is illustrated in Figure 1.

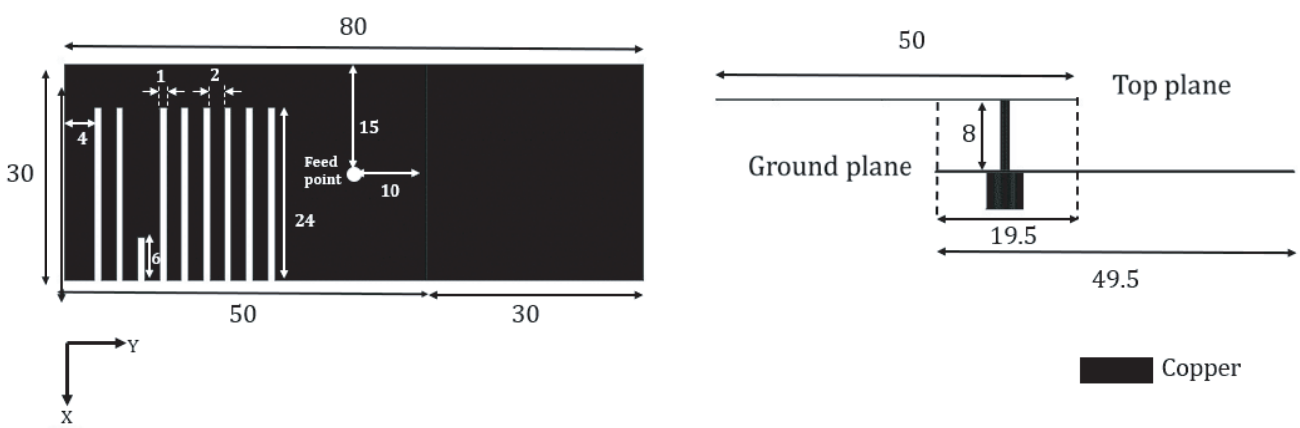
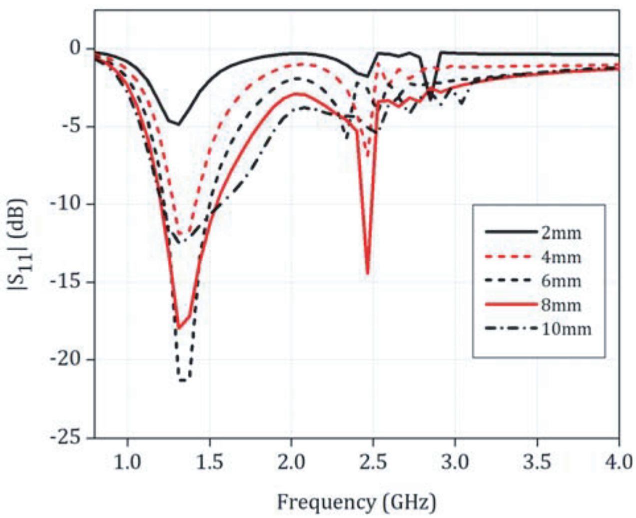
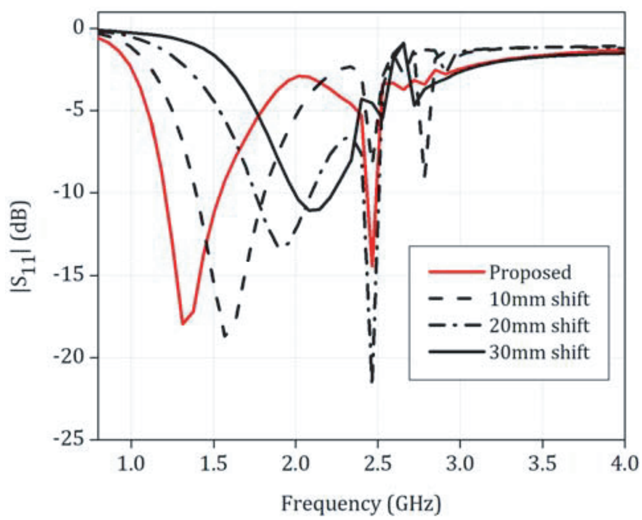


Figure 1. Proposed all metallic antenna (units in mm).

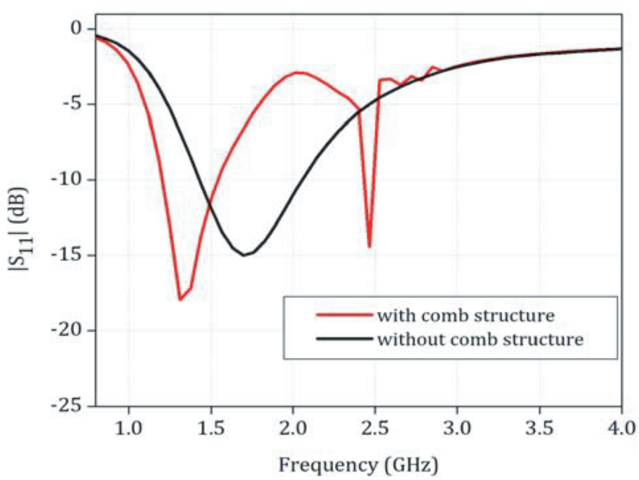
The working mechanism of proposed antenna is due to 3 key factors namely the comb structure, height between the top plane and ground plane, and the offset with the top plane and ground plane. The parametric analyses of these key features are shown in Figure 2. The comb structure is mainly responsible for the S band resonance. The height between the top plane and ground plane is responsible for less return loss. As the offset with the top plane decreases that is when the ground plane is moved towards $-Y$ direction, the resonance band of L band shifts towards the higher frequency. So, all these key parameters together resonate at L1 band, L5 band, and S band. The surface current distribution is more at the comb and is responsible for the primary radiations from the antenna as shown in Figure 3. At 1.172 GHz, the surface current ranges from 30 A/m to 40 A/m, and the radiations are more at the 8th and 9th slots of the comb structure. At 1.575 GHz, the surface current ranges from 6 A/m to 10 A/m, and the radiations are distrusted over the top radiating plane. At 2.492 GHz, the surface current ranges



(a)



(b)



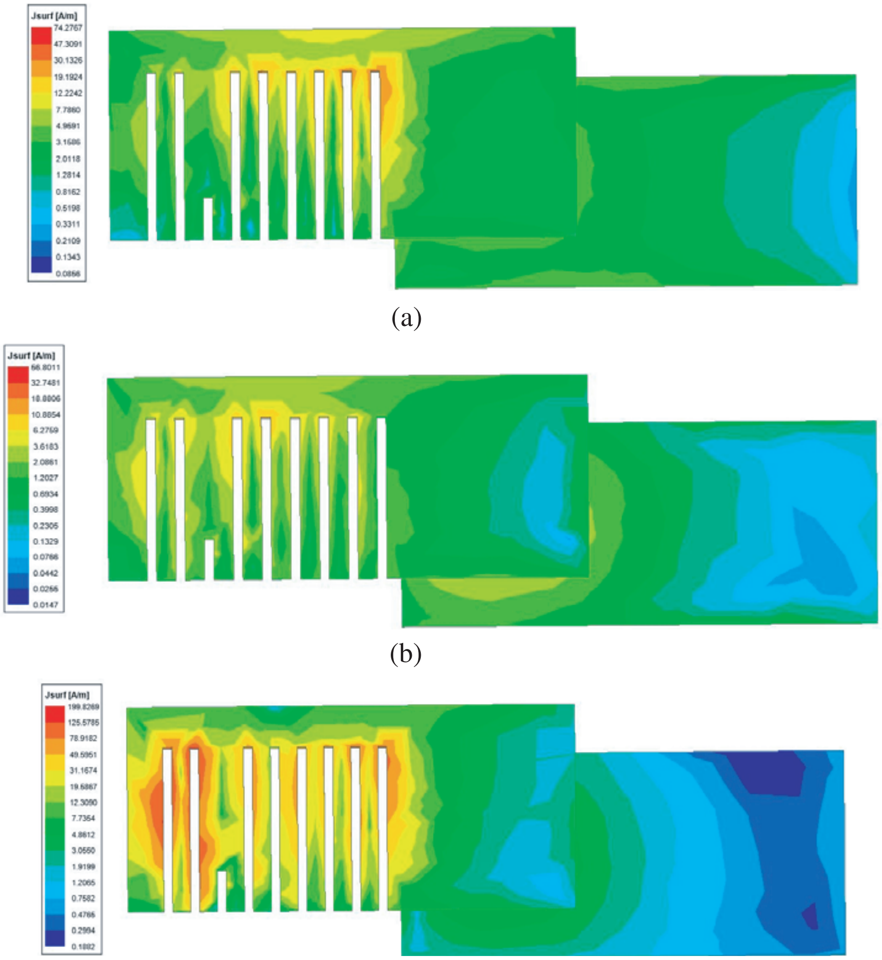
(c)

Figure 2. (a) $|S_{11}|$ of height variation of the antenna. (b) $|S_{11}|$ of ground plane shift. (c) $|S_{11}|$ of comb variation.

from 125 A/m to 195 A/m, and the radiations are more at the 1st, 2nd, and 9th slots. Overall dimension of the antenna is $30\,\text{mm} \times 8\,\text{mm} \times 8\,\text{mm}$ which translates to $0.11\lambda \times 0.31\lambda \times 0.03\lambda$, and the dimension of the radiating plane is designed keeping Equations (1)–(4) as base. The effective permittivity is calculated using Equation (5) where effective permittivity is 1. The feed point of the antenna is calculated on the basis of Equation (7) and then optimized to match 50-ohm impedance [18]. Figure 4 illustrates a photograph of the fabricated prototype antenna. The top plane and ground plane of antenna are fabricated using copper with the thickness of 0.234 mm. The method used for fabricating the antenna is chemical etching which is a industry standard low-cost fabrication method. The design of the top patch is imprinted on the top patch. So, by chemical etching process the required design is obtained, and a similar process is carried out for the ground plane. Here, an elongated Teflon SMA (subMiniature version A) connector is used to get the 8 mm height between the two planes and is soldered to the top plane.

The resonant frequency of a typical patch of a probe-fed antenna is

$$f_{mn} = k_{mn} * c / \left(2\pi\sqrt{\varepsilon_r}\right) \tag{1}$$



(a)

(b)

(c)

Figure 3. Surface current distribution at (a) 1.176 GHz, (b) 1.575 GHz, (c) 2.492 GHz.

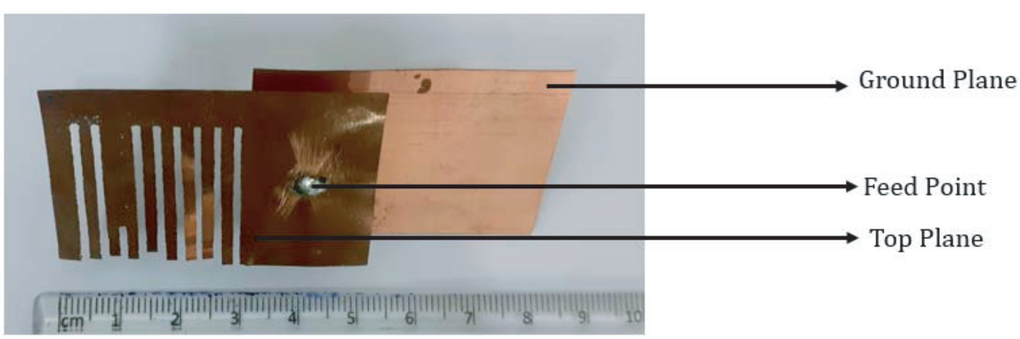


Figure 4. Photograph of the fabricated prototype.

where value of k_{mn} is given by the equation below

$$k_{mn}^2 = \frac{m\pi}{a^2} + \frac{n\pi}{b^2} \tag{2}$$

where a is length of the patch and b is breadth of the patch.

$$a_e = a + t/2 \tag{3}$$

$$b_e = b + t/2 \tag{4}$$

Also, a_e gives the effective length of the patch, and b_e gives effective breadth of the patch.

The effective permittivity is given by the equation below:

$$\varepsilon_{eff} = (\varepsilon_r + 1)/2 + (\varepsilon_r - 1)/2 * \left[1 + \frac{10t}{b}\right]^{-\frac{1}{2}} \tag{5}$$

The location of the probe feeding is given by the equation:

$$X_f = a/\sqrt{\varepsilon_{eff}} \tag{6}$$
$$Y_f = b/2 \tag{7}$$

where (X_f, Y_f) determines the position of the feed point.

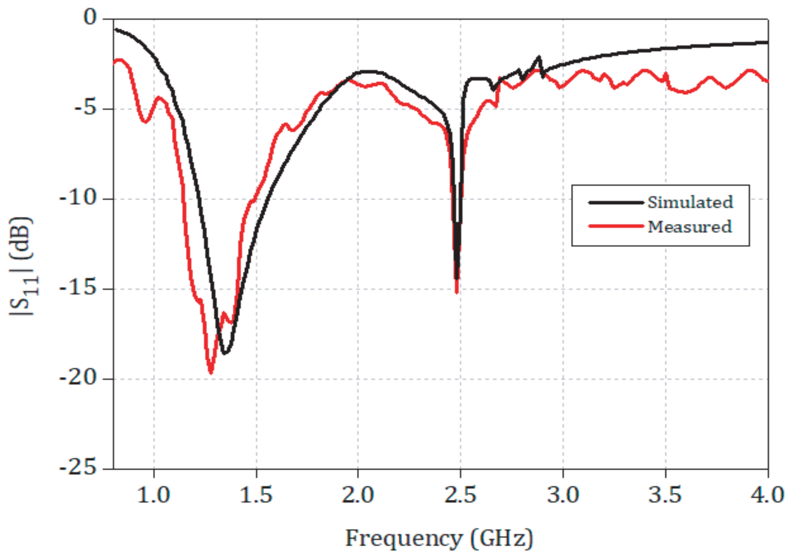


Figure 5. $|S_{11}|$ of Proposed all metallic patch antenna.

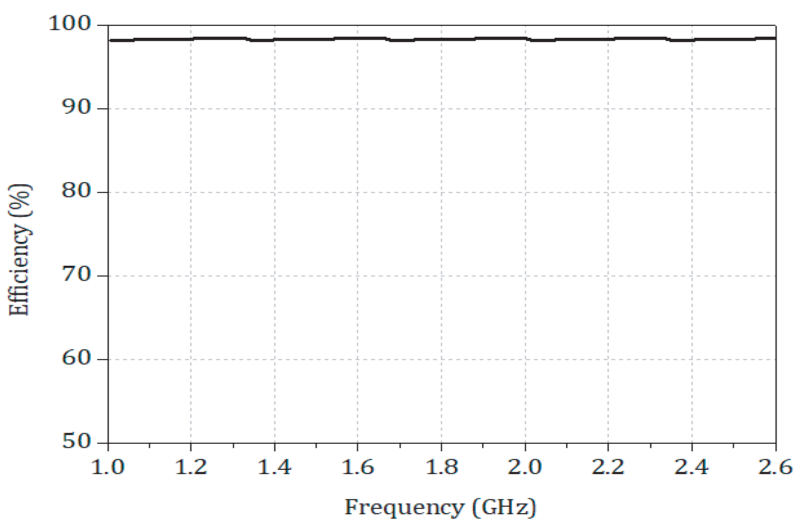


Figure 6. Efficiency of proposed antenna.

3. RESULTS AND DISCUSSIONS

Figure 5 shows the simulated and measured reflection coefficients of the proposed all metallic probe-fed antenna. The antenna resonates at L1 band, L5 band, and S band. Here, −6 dB reflection coefficient value is taken as reference because for an electrically small antenna −6 dB reflection coefficient value is

Table 1. Comparison of Proposed antenna with other antenna designs.

Ref.	Antenna size in mm (electrical size)	Substrate (ε_r)	Bands covered (GHz)	Method of approach	Gain (dBic/dBi)	Cost	IBW (%)
[1]	$65 \times 65 \times 1.6$ (0.25λ)	FR4 (4.4)	1.176, 2.335	Association of small patches and coaxial fed	4.2, 6.6	Moderate	3, 3
[2]	$110 \times 60 \times 6.35$ (0.57λ)	AD 1000 (10.2)	1.564, 1.632	Coaxial fed antenna with truncated patch corner	5, 5.1	High	4, 4
[3]	$107.5 \times 96 \times 1.6$ (0.42λ)	FR4 (4.4)	1.5754, 1.2276, 1.1764	circularly polarized annular ring-shaped planar antenna	3.45, 2.5, 2.85	Moderate	4, 10, 10
[4]	$127.5 \times 127.5 \times 1.6$ (0.48λ)	FR4 (4.4)	1.129, 1.208, 1.575	split rectangular slot (SRS) and stub	4.03, 5.6, 2.31	Moderate	1.107, 1.603, 0.394
[5]	$50 \times 200 \times 1.6$ (1.6λ)	FR4 (4.4)	2.4, 2.59, 2.95, 3.7, 4.12, 4.5, 5.5	Printed Multiband Monopole Antenna	1.89, 1.61, 0.97, 0.98, 1.72, 1.92	Moderate	14.16, 6.78, 6.78, 6.78, 6.21, 3.15, 7.77, 8.18
[6]	$172.37 \times 96.38 \times 3.175$ (0.65λ)	RTDuroid 5880 (2.2)	1.1237–1.2546 1.5653–1.5855	Microstrip patch with Defected ground structure (DGS)	4.39, 5.94	High	10, 1.2
[7]	$90 \times 90 \times 40$ (0.34λ)	Polypropylene (2.26)	1.14–1.72	cavity-backed ME dipole antenna	5.1	High	40
[8]	$70.4 \times 76.14 \times 3.11$ (0.37λ)	RO3003C (3)	1.575, 2.451	dual-band and dual-polarized antenna	5.03, 5.07	High	1.837, 0.735
Proposed	$30 \times 80 \times 8$ (0.31λ)	Air (1)	1.176, 1.575, 2.492	All Metallic patch Antenna	2.0, 2.1, 3.5	Low	41, 41, 4

valid as a good reflection coefficient [14–17]. The L band resonance is from 1136 MHz to 1728 MHz which translates to 41% bandwidth while the S band resonance supports from 2432 MHz to 2520 MHz which translates to 3% bandwidth. The simulated and measured normalized radiation patterns for various frequencies in both the orthogonal planes are depicted in Figure 7. These are similar to omnidirectional radiators as the size of antenna is electrically small. The gain of antenna at L1 band is 2.0 dBi; the gain at L5 band is 2.1 dBi; and the gain at S band is 3.5 dBi.

The efficiency of the antenna is about 98% throughout from the range 1 GHz to 2.6 GHz for the simulation is shown in Figure 6.

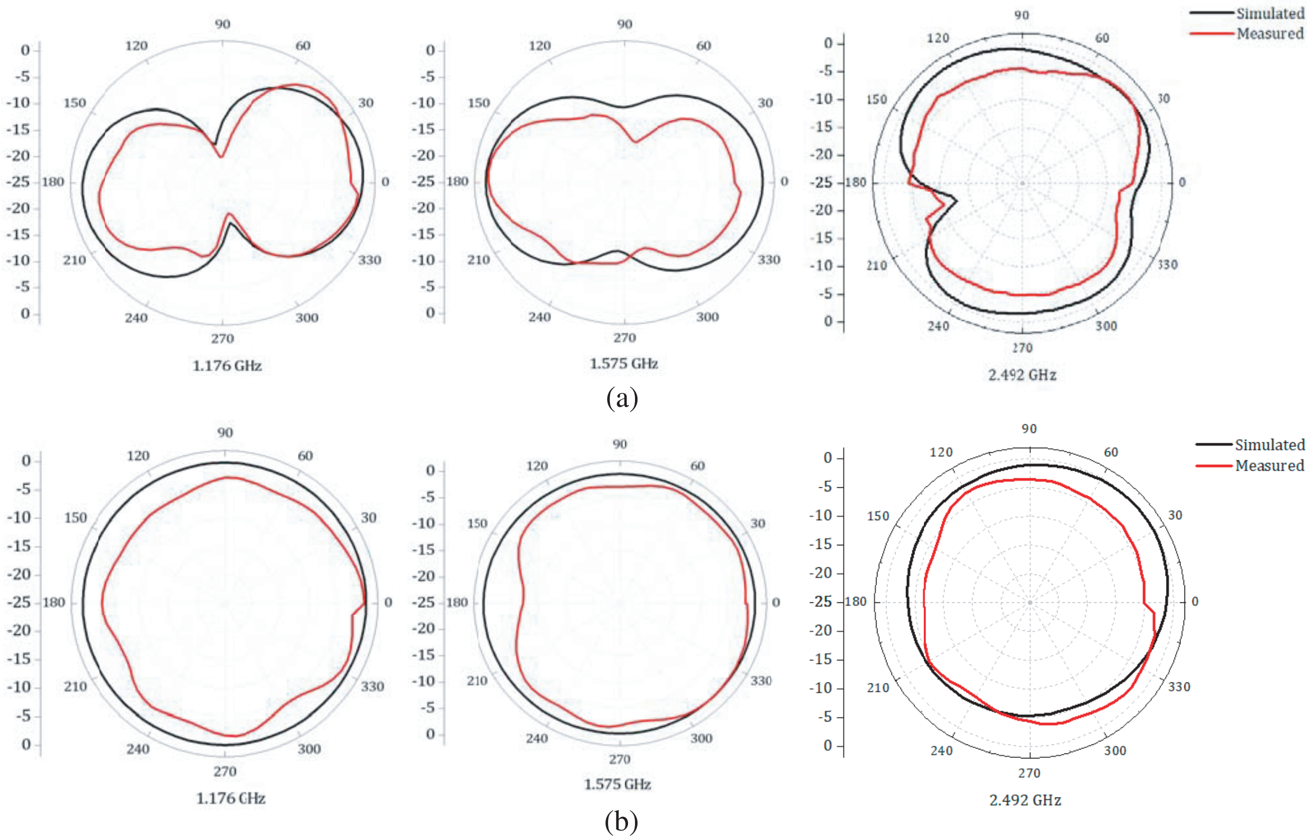


Figure 7. (a) and (b) represent the Radiation patterns at 1.176 GHz, 1.575 GHz and 2.492 GHz. (a) E plane. (b) H Plane.

Table 1 depicts the comparison of proposed antenna with other designs with respect to the substrate, band covered, method of approach, gain, cost, and impedance bandwidth (IBW).

4. CONCLUSION

An electrically small all metallic probe-fed antenna is designed for NavIC applications. The proposed design is electrically compact and economical, and the dielectric loss in the antenna is zero as the antenna is designed with copper alone and could be a potential candidate for NavIC receivers. The performances of the antenna are measured, and the radiation patterns are omnidirectional.

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