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A new wideband planar antenna with band-notch functionality at GPS, Bluetooth and WiFi bands for integration in portable wireless systems

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ABSTRACT

Empirical results are presented for a novel miniature planar antenna that operates over a wide bandwidth (500 MHz to 3.05G Hz). The antenna consists of dual-square radiating patches separated by two narrow vertical stubs to reject interferences from GPS, Bluetooth and WiFi bands. Radiating patches and stubs are surrounded by a ground-plane conductor, and the antenna is fed through a common coplanar waveguide transmission line (CPW-TL). The two vertical stubs generate pass-band resonances enabling wideband operation across the following communications standards: cellular, APMS, JCDMA, GSM, DCS, PCS, KPCS, IMT-2000, WCDMA, UMTS and WiMAX. Embedded in the ground-plane conductor is an H-shaped dielectric slit, which has been rotated by 90°, whose function is to reject interferences from GPS, Bluetooth and WiFi bands. Measurements results confirm the antenna exhibits notched characteristics at frequency bands of GPS (1574.4–1576.4 MHz), Bluetooth (2402–2480 MHz) and WiFi (2412–2483.5 MHz). The impedance bandwidth of the antenna is 2.55G Hz for VSWR < 2, which corresponds to a fractional bandwidth of 143.66%. Measured results also confirm that the antenna radiates omnidirectionally in the E-plane with appreciable gain performance over its operating frequency range. The antenna has dimensions of $15 \times 15 \times 0.8\ mm^3$.

1. Introduction

Recently, broadband technology has attracted great attention for wireless applications as it offers advantages of high speed data rate, low power consumption, high capacity, low cost, and low complexity [1–3]. Broadband systems necessitate the use of broadband antennas with desirable features including small physical size, ease of manufacture using conventional fabrication technologies, gain and omnidirectional radiation characteristics. Several broadband antenna designs have been recently developed [4–16]; such designs include planar monopole antennas that promise wideband performance for wireless communication systems. Wideband systems however will need to operate and coexist with narrowband communication systems such as Global Position System (GPS) (1574.4–1576.4 MHz), Bluetooth (2402–2480 MHz) and WiFi (2412–2483.5 MHz). The abovementioned narrowband systems are a source of severe electromagnetic interference to the operation of wideband systems. It is therefore highly desirable to design the broadband antenna with integral band-notched functionality in order to mitigate any interference. Extensive investigations have been carried out to design wideband antennas with notch bands without using stop band filters [17–19]. Various techniques have been adopted to incorporate band-notched functionality in wideband antennas, including embedding in the radiator and ground-plane the use of slits of different shapes and sizes [20–23]. Hence, a common way to create single or dual notch bands in wideband systems is to add resonant elements to the antenna that includes loading the antenna with slots of various shapes, i.e. L-shaped slots [24], U-shaped slots [25], C-shaped slot [26], W-shaped slot [27] and H-shaped slot [28]. In [29,30], the authors have used split-ring resonators (SRR) in the antenna structure to create notch bands. It is shown in [31] that rejection bands can also be created by adding multiple U-shaped slots in a log periodic dipole antenna. In [32,33] the authors have placed a modified a U-slot on a planar plate monopole antenna to create notch bands.

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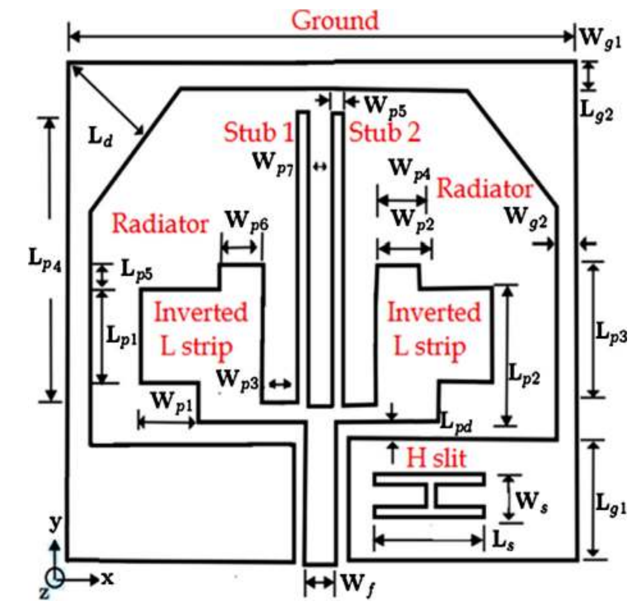
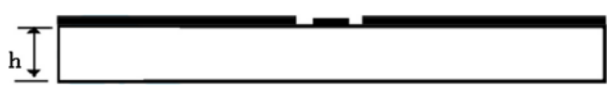


(a) Top view



(b) Side view

(c) Photograph of the fabricated antenna

Fig. 1. Geometry and photograph of the proposed wideband antenna.

In the above techniques the design of notch bands in antennas is not easy and furthermore the overall size of the resulting antenna is considered to be large to include in wireless transceivers.

In this article we have proposed a novel miniature wideband microstrip antenna design to overcome the above cited limitations in reported wideband antennas, in particular, (i) the proposed antenna design is simple; (ii) it can be fabricated on a single layer of the dielectric substrate; (iii) it avoids the use of via-holes; (iv) is cheaper to fabricate; and (v) it is relatively smaller in size. The proposed antenna includes band-notched functionality that is capable of eliminating interferences from GPS, Bluetooth and WiFi systems. This is achieved by embedding an H-shaped slit, which has been rotated by 90°, in the ground-plane conductor. The function of the slit is to reject interferences between 1574.4 MHz–1576.4 MHz, 2402 MHz–2480 MHz, and 2412 MHz–2483.5 MHz. Two vertical stubs in close proximity are deployed between the radiation patches to create resonances that extend the antenna's bandwidth for wideband operation from 500 MHz to 3.05 GHz with good radiation performance.

2. Antenna design with notched bands

The geometry of the proposed antenna is shown in Fig. 1. The rectangular antenna includes two vertical narrow stubs that are in close proximity located on either side of the square patches. The square radiators and stubs are surrounded by the ground-plane conductor. The patches are fed through a common coplanar waveguide (CPW) transmission line. Etched in the ground-plane conductor and located next to the CPW feed-line is an H-shaped slit, which is rotated by 90°. The purpose of the H-shaped slit is to reject the unwanted frequencies at the GPS, Bluetooth and WiFi bands. The bandwidth of the rejection bands can be controlled by simply adjusting the length and width of the H-shaped slit. The two vertical stubs in the antenna are used to create resonances to provide wideband operation from 500 MHz to 3.05 GHz with good radiation performances.

The equivalent circuit of the proposed band-notched wideband antenna is depicted in Fig. 2, where the radiating element is approximately represented by several RLC parallel cells in series. The equivalent circuit input impedance can be expressed as [34]

$$Z_n = \sum_{k=1}^{n} \frac{j\omega R_k L_k}{R_k(1 - \omega^2 C_k L_k) + j\omega L_k} \tag{1}$$

The antenna was designed and fabricated on a 0.8 mm-thick Rogers RT/Duroid5880 substrate with dielectric constant ε_r of 2.2 and loss tangent of 9×10^{-4}. The overall dimensions of the antenna are $15 \times 15 \times 0.8$ mm^3. The antenna's performance was optimized using Ansoft's HFSS [35], a commercial electromagnetic simulator based on finite element method (FEM). The optimized parameters of the antenna are given in Table 1.

The effect of the length and width of H-shaped slit on the antenna's performance was studied. The simulated reflection coefficient response with different values of slit width (W_s) is shown in Fig. 3.

It is evident from Fig. 3 that when W_s is increased from 0.5 to 1.5 mm, the first rejection band moves marginally toward the lower frequency, while second rejection band, which is located at the Bluetooth and WiFi frequency range, remains unchanged. The optimum value of W_s = 1 mm was found to provide a notch rejection centered at 1575.4 MHz (GPS band). Fig. 4 shows the simulated reflection coefficient response of the antenna as a function of slit length (L_s) when it's varied from 3.3 to 5.3 mm. The change in slit length causes a marginal change in the second stop-band while the first notch-band at the GPS frequency range remains unaffected. An increase in L_s causes the second notch-band to shift towards the higher frequency and increases the magnitude of the rejection level. The slit length selected in the design was 3.3 mm to provide a notch rejection centered at 2.443 GHz (Bluetooth and WiFi bands).

The current distribution over the antenna without and with the H-shaped slit is shown in Fig. 5. It is observed that the current density is strongly concentrated at the edges of the H-shaped slit corresponding to the center frequency of the first and second notch bands, i.e. 1575.4 MHz and 2443 MHz, respectively. At the pass-band frequency of 1700 MHz (outside the notched bands), the distribution of the surface current is uniform over the entire antenna. Clearly the H-shaped slit provides an effective current path to ground for frequencies centered around 1575.4 MHz and

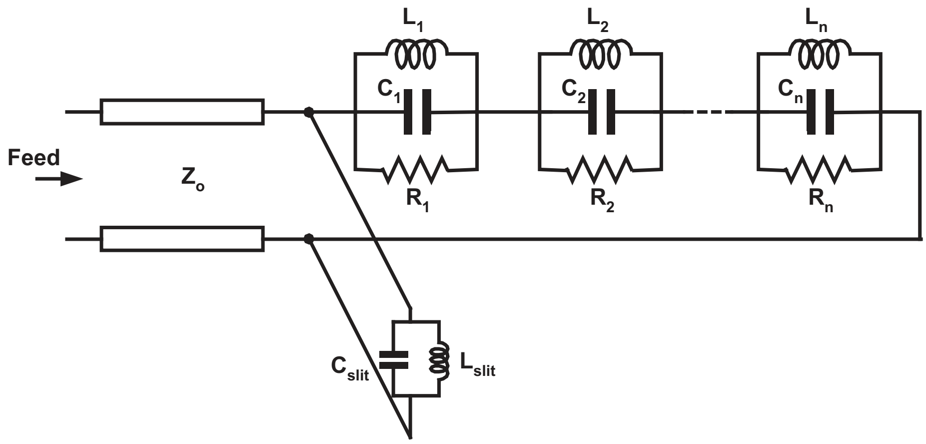


Fig. 2. Impedance model for radiating element of the proposed wideband antenna.

Table 1
Antenna design parameters (units in mm).

L_{p1}: 3	L_{p2}: 4.5	L_{p3}: 4.6	L_{p4}: 9	L_{p5}: 1	L_{pd}: 0.35
L_s: 3.3	W_{p1}: 2.15	W_{p2}: 1.9	W_{p3}: 1.3	W_{p4}: 1.3	W_{p5}: 0.5
W_{p6}: 1.3	W_{p7}: 1	W_s: 1	L_{g1}: 3.8	L_{g2}: 0.8	L_d: 2.4
W_{g1}: 15	W_{g2}: 0.9	W_f: 1.5	h: 0.8		

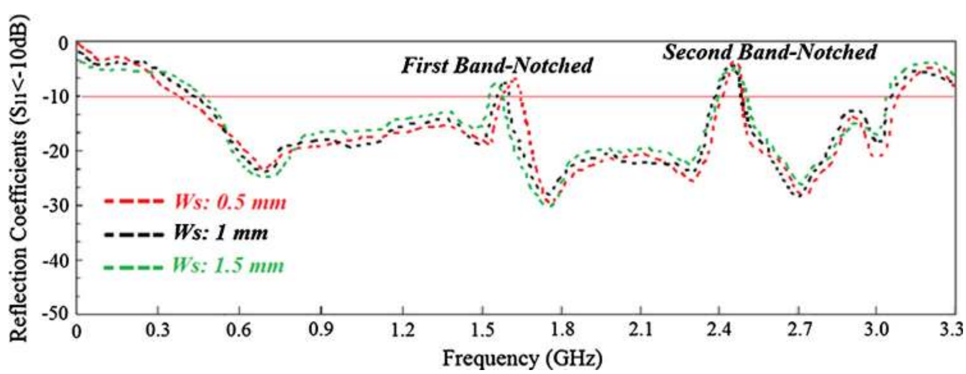


Fig. 3. Simulated reflection coefficient response of the proposed antenna as a function of W_s. All other parameters are the same as listed in Table 1.

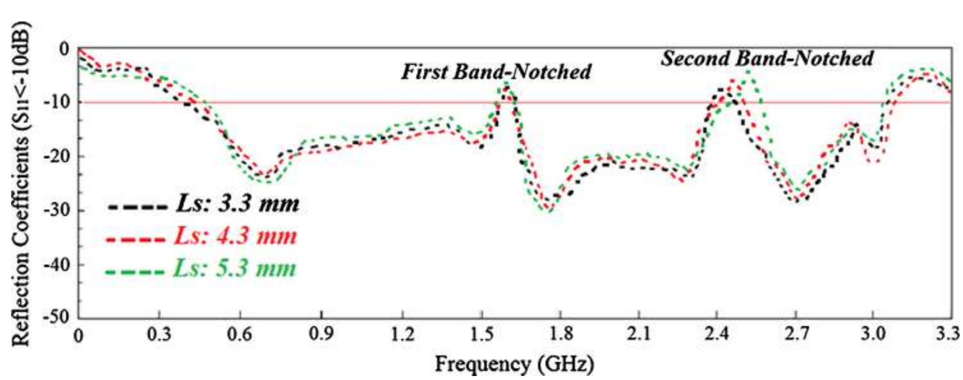


Fig. 4. Simulated reflection coefficient response of the proposed antenna as a function of L_s. All other parameters are the same as listed in Table 1.

2443 MHz, which is necessary to eliminate interference from GPS, Bluetooth and WiFi systems.

3. Results and discussions

Fig. 6 shows simulated and measured reflection coefficient of the proposed antenna. Measurement was performed with an Agilent N5230A vector network analyzer. There is good agreement between the simulated and measured results, which show that the antenna operates across 0.5–3.05 GHz for a VSWR less than 2, exhibiting two distinct notch bands between 1574.4 MHz–1576.4 MHz and 2402 MHz–2484 MHz.

The simulated and measured radiation patterns of proposed antenna without and with H-shaped slit in the E-plane (x-y) and

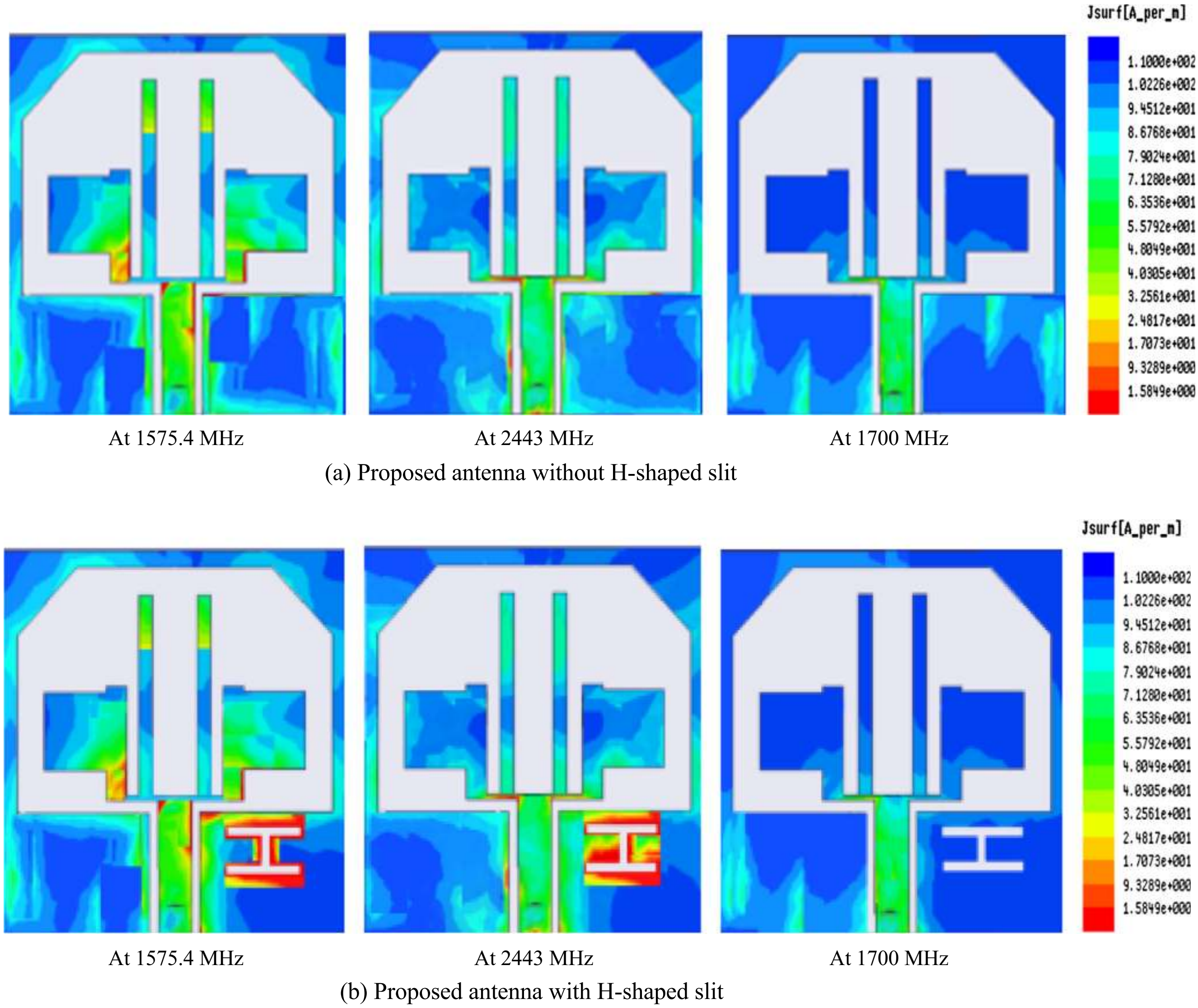


Fig. 5. Surface current densities over the proposed antenna at various frequencies, (a) without H-shaped slit, and (b) with H-shaped slit.

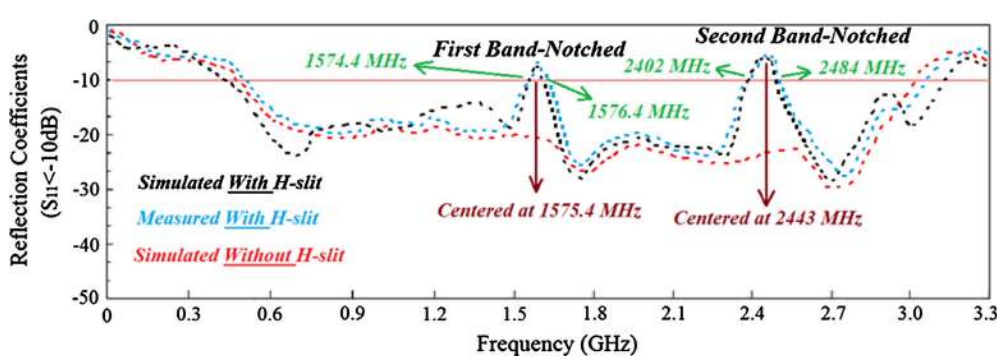


Fig. 6. Simulated and measured reflection coefficient of the proposed wideband antenna with two notch bands.

H-plane (*x-z*) at 1575.4 MHz, 2443 MHz, and 1700 MHz are shown in Figs. 7 and 8. The co- and cross-polarizations in the E-plane of the antenna excluding the H-shaped slit are shown by the red and green lines, respectively, in Fig. 7; and the co- and cross-polarizations in the H-plane are shown by blue and black lines, respectively. At the two notched band frequencies centered at 1575.4 MHz and 2443 MHz the antenna radiation is omnidirectional; however at 1700 MHz the antenna's radiation patterns in E- and H-planes are dipole-like.

The antenna with H-shaped slit, shown in Fig. 8, radiates omnidirectionally in the E-plane and has dipole-like radiation pattern in the H-plane at frequencies outside the notched bands. The

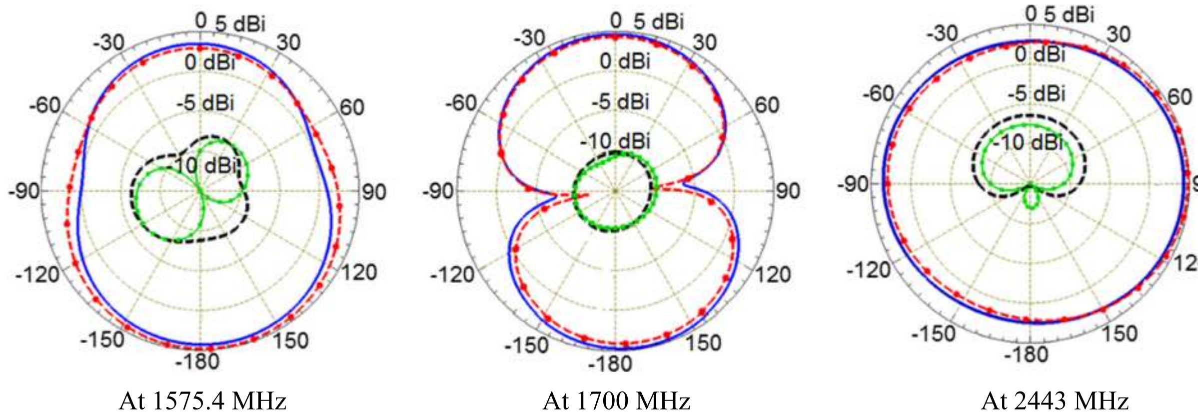


Fig. 7. Radiation patterns of the proposed antenna without H-shaped slit at various resonance frequencies. Please note that, Co- and Cross-polarizations in the E-plane are shown by Red and Green lines, and also Co- and Cross-polarizations in the H-plane are shown by Blue and Black lines, respectively. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

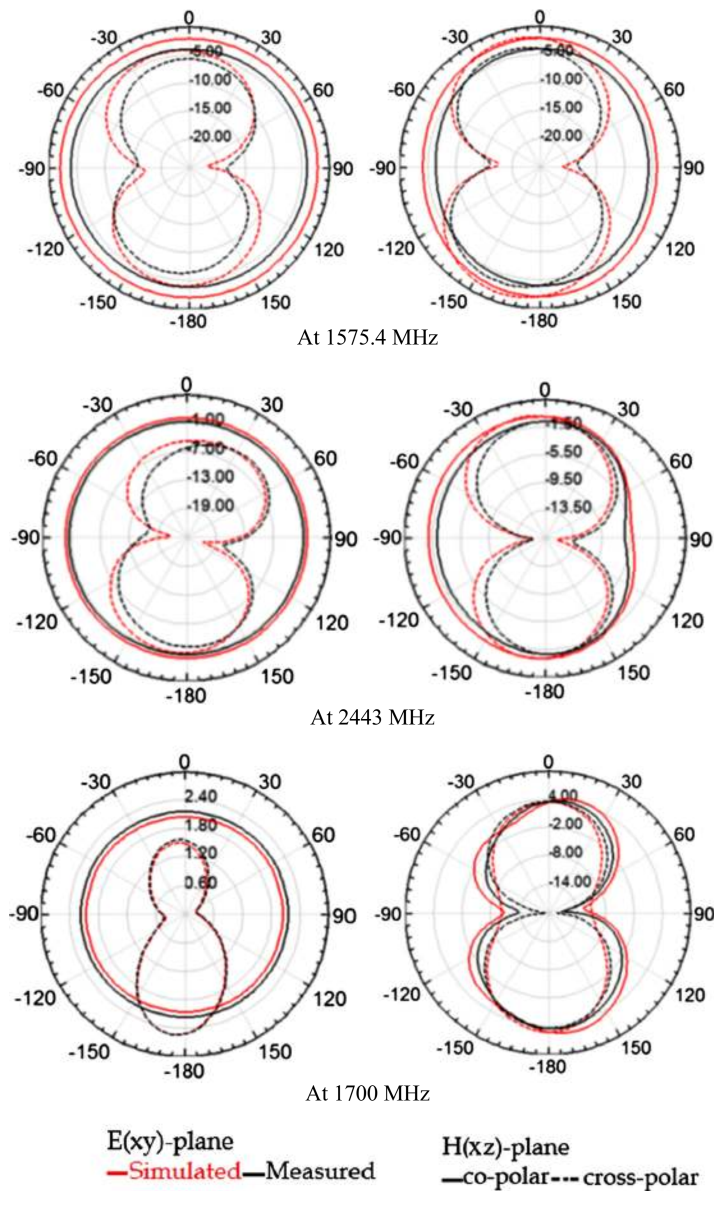


Fig. 8. Radiation patterns of the proposed antenna at various resonance frequencies.

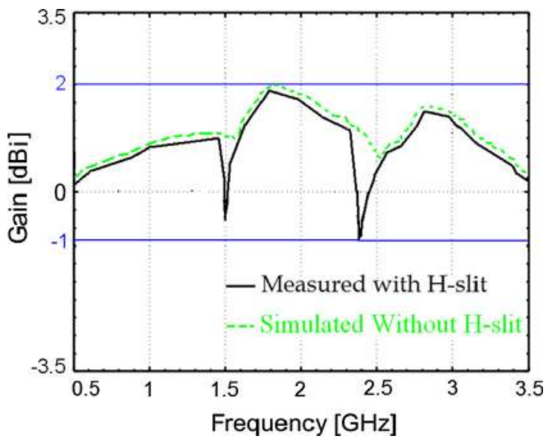


Fig. 9. The simulated and measured gain response of the proposed antenna with and without band-notches.

Table 2
Antenna characteristics.

Dimension (mm^3)	15 × 15 × 0.8
Bandwidth (GHz)	2.55 GHz (from 0.5 GHz to 3.05 GHz) band-notches between 1574.4 GHz–1576.4 GHz and 2402 GHz–2484 GHz
Gain (dBi) @ freq. (GHz): 0.5, 1, 1.5754, 1.7, 2.443, 2.8 and 3.05	0.1, 0.8, −0.5, 1.9, −1.0, 1.2 and 0.9
Efficiency (%) @ same frequencies	15, 28, 10, 52, 13, 48 and 36

antenna's radiation patterns are stable at the notched band frequencies centered at 1575.4 MHz and 2443 MHz, shown in Fig. 8 (a) and (b). At these two frequencies the antenna gain drops significantly, as depicted in Fig. 9. The resulting antenna characteristics are summarized in Table 2.

The antenna efficiency was measured in an anechoic chamber by feeding power to the antenna feed and measuring the strength of the radiated electromagnetic field in the surrounding space. The efficiency was calculated by taking the ratio of the radiated power to the input power of the antenna. The gain of the antenna was measured using the standard gain comparison technique where pre-calibrated standard gain antenna was used to determine the absolute gain of the antenna under test.

4. Conclusions

Results of a novel miniature wideband printed microstrip antenna are presented that exhibits dual notched band property enabling mitigation of interference from GPS, Bluetooth and WiFi bands. The antenna employs two radiating patches separated with two vertical open-circuited stubs to provide wideband operation from 500 MHz to 3.05 GHz. Also included is an H-shaped slit, rotated by 90°, etched in the ground-plane conductor whose function is to reject interferences between bands 1574.4 MHz–1576.4 MHz, 2402 MHz–2480 MHz, and 2412 MHz–2483.5 MHz. The antenna performance is stable over its operating frequency range and it radiates omnidirectionally in the E-plane. The proposed antenna is suitable for integration in portable wireless systems.

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