Miniaturised multiple notched omnidirectional UWB monopole antenna

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A miniaturised coplanar waveguide-fed multiple notched monopole antenna for ultra-wide bandwidth (UWB) application is presented. By introducing multiple inverted L-shaped stubs embedded within a polygonal shaped monopole antenna, multiple notches can be achieved. A prototype antenna with triple band-notched at WiMAX, WLAN, and X-band is designed and fabricated. The proposed antenna has an impedance bandwidth of 3–12 GHz with a voltage standing wave ratio of <2 except for the selected notched bands. The main advantage of the antenna is its miniaturised size (21 × 14 mm^2), as well as the straightforward design. The antenna has a unipolar configuration and good omnidirectional radiation pattern with negligible distortion which is suitable for UWB applications.

Introduction: Ultra-wide bandwidth (UWB) systems have received a lot of interests due to their low power consumption and high data rate capability. Accordingly, the UWB antennas as an essential part of these systems, which should support the allocated frequency band by Federal Communication Commission (FCC), i.e. 3.1–10.6 GHz have received attention from researchers. Features such as radiation pattern stability, compactness, unipolar configuration and simplicity make this research scope attractive for many researchers [1–4]. On the other hand, an UWB antenna with band-notch capability [5–10] to eliminate electromagnetic interference with other systems like WiMAX (3.3–3.7 GHz), WLAN (5.15–5.85 GHz), C-band (3.7–4.2 GHz), and X-band communication satellites (7.9–8.4 GHz) which have relatively narrow frequency bands, is desirable. Compromising between all of the aforementioned features together with two main characteristics of a UWB antenna, i.e. broad bandwidth and good omnidirectional radiation pattern can be a difficult task. In [5] a 30 × 45 mm^2 triple band-notched UWB antenna based on complimentary split-ring resonator (SRR) is proposed. More compact sized triple band-notched antennas can be found in [6] (35 × 35 mm^2), [7] (30 × 35 mm^2), [8] (28 × 21 mm^2), and [9] (19 × 24 mm^2) or in [10] (27 × 21 mm^2) which is based on a liquid crystal polymer substrate. However, these designs have drawbacks such as spurious radiation due to notch techniques, resulting in not so desirable omnidirectional radiation patterns. A better design of SRR-based UWB antenna with good performance and good omnidirectional pattern can be found in [11], but its size is 50 × 50 mm^2. In this Letter, we propose a multiple notched miniaturised UWB antenna fed by a coplanar waveguide (CPW) line with omnidirectional radiation pattern. The antenna has a polygonal shape with symmetric band-notched stubs printed on Rogers 4003 substrate with a size of 21 × 14 mm^2. Details of the structure and antenna performance are described below.

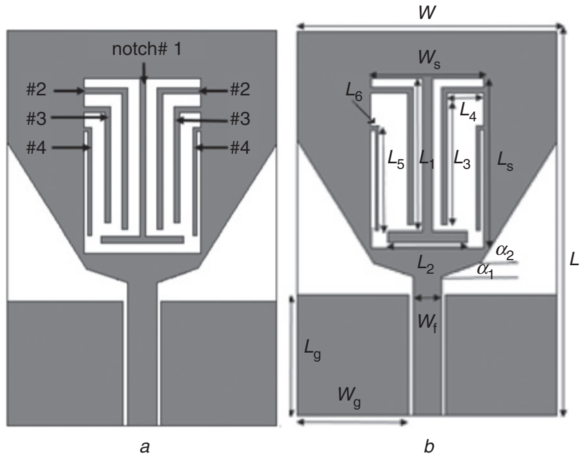

Fig. 1 *Proposed multi band-notched UWB antenna*
a Overall design
b Prototype with triple band-notch

Antenna design: The configuration of the proposed UWB antenna with multiple notches is shown in Fig. 1. The antenna dimension is 21 × 14 × 0.8 mm^3 and uses a RO4003 substrate with permittivity of 3.55. The proposed antenna is a polygonal shaped monopole which ensures a good impedance match with VSWR <2 over a broad frequency band. The parameters α_1 and α_2 in Fig. 1 can be selected appropriately to cover 3.1–10.6 GHz band, i.e. the FCC allocated spectrum for UWB application. A 50 Ω CPW transmission line fed by an SMA connector is connected to the patch antenna. This compact single-layer structure is suitable for integration with other RF circuits.

Overall an $L_s \times W_s$ slot is created in the radiating patch. The size of the slot is chosen so that it provides enough space for extra stubs to be added. To provide the desired notches, as shown in Fig. 1, multiple symmetric stubs are added in the slot. Each stub has a length of a quarter wavelength ($\lambda_g/4$) with $\lambda_g = \lambda_0/\sqrt{(\varepsilon_{\text{eff}})}$, where λ_0 is the free-space wavelength and $\varepsilon_{\text{eff}} = (\varepsilon_r + 1)/2$. The low frequency stub requires a larger length than the slot length, L_s, so an inverted T-shaped stub is used. Higher frequency stubs can be placed inside the slot and have an inverted L-shape. It is worth mentioning that the performance of the notches is strongly related to two factors: the location of the stubs and the stubs symmetry. Also, the coupling between the stubs controls the notch bandwidth which consequently is a function of stub width and location. So a compromise between these parameters should be done. It can be noted that for the slot size considered one can easily include stubs to obtain quad band notched performance.

Example and results: To examine the proposed multi-band-notch UWB antenna, a prototype antenna which has three band-notches is designed, fabricated and tested. Our goal is to have three notches at WiMAX, WLAN, and X-band communication frequency bands. The software package Ansoft HFSS is employed for the design process. The fabricated design is shown in Fig. 2. Table 1 shows the value of the parameters used. The measured and simulated VSWR are shown in Fig. 2. As seen, the simulation results are consistent with the measured result. The proposed antenna has a bandwidth ranging from 2.9 to 11 GHz and has notch bands over the 3.2–3.65 GHz (highest VSWR at 3.4 GHz), 5–5.62 GHz (highest VSWR at 5.5 GHz), and 7.85–8.45 GHz (highest VSWR at 8.2 GHz). These notches correspond to WiMAX, WLAN, and X-band communication bands, respectively. The difference between simulated and measured VSWR results can be due to the fabrication inaccuracies and substrate loss tangent.

Table 1a: Parameter values of the proposed antenna

Parameter	W	L	L_s	W_s	W_f	L_g	W_g
Value, mm	14	21	9	6	1.5	6.05	7

Table 1b

Parameter	L_1	L_2	L_3	L_4	L_5	L_6
Value, mm	8.15	4.2	7.3	2.2	5.8	0.4

Table 1c

Parameter	α_1	α_2
Value (deg)	21.25	57.5

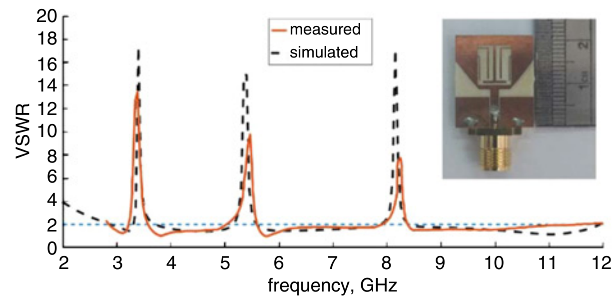

Fig. 2 *VSWR and photo of the of the proposed triple band-notched antenna*

Fig. 3 shows the surface current distribution of the patch antenna at three different frequencies. A concentrated current distribution on each individual stub, notch #1, notch #2 and notch #3, at the relevant notch frequency is seen. The current vectors on each stub are in the opposite direction with respect to the patch itself resulting in shorting out the radiating patch which introduces mismatch and hence less or no radiation at the notched band.

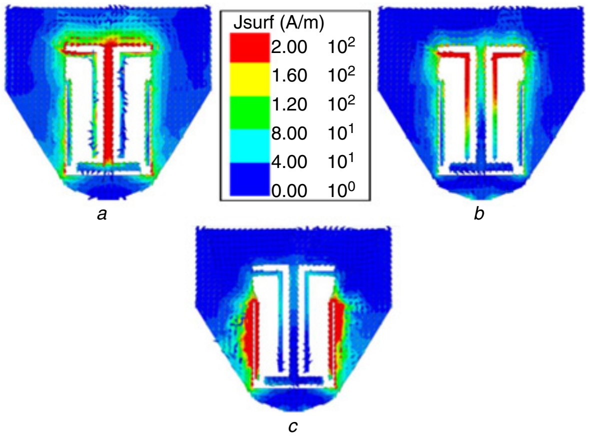

Fig. 3 *Current distribution of the patch at various frequencies*

a 3.35 GHz
b 5.40 GHz
c 8.15 GHz

The *E*- and *H*-plane radiation patterns at three frequencies of 4.5, 6.5, and 9 GHz are measured and the results are shown in Fig. 4. As shown, the patterns are omnidirectional in shape with negligible distortion which is appropriate for UWB applications. The peak gain of the proposed antenna for mentioned frequencies are 1.2, 1.5, and 2.3 dBi.

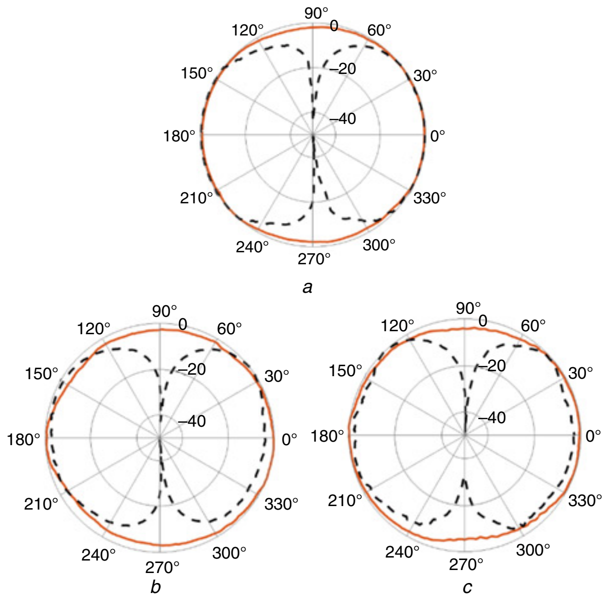

Fig. 4 *Measured radiation patterns of the proposed antenna. E-plane (black) and H-plane (red)*

a 4.5 GHz
b 6.5 GHz
c 9 GHz

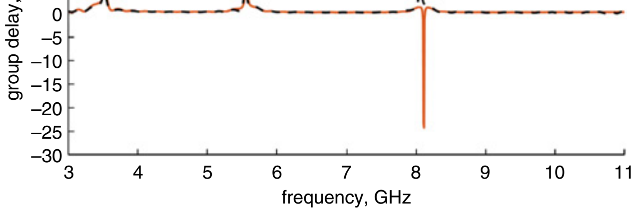

Fig. 5 *Simulated group delay for two configurations of side-by-side and face-to-face*

For the proposed UWB antenna, the time domain characteristic, the group delay, for both cases of side-by-side and face-to-face configurations are given in Fig. 5. As shown in this figure, the group delay lies within 1 ns except for the band notches, showing the non-dispersive characteristic of the proposed antenna.

Conclusion: A miniaturised UWB antenna with unipolar multiple notches is proposed. The antenna has a straightforward design which consists of multiple inverted L-shaped stubs embedded within a polygonal shaped monopole antenna. The fabricated antenna has triple band-notch at frequencies of 3.4, 5.5, and 8.2 GHz. Results show good agreement between the simulated and measured results. The stable omnidirectional radiation pattern with negligible distortion makes the proposed antenna to be suitable for UWB applications.

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One or more of the Figures in this Letter are available in colour online.

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References

1 Jung, J., Choi, W., and Choi, J.: ‘A small wideband microstrip-fed monopole antenna’, *Microw. Wirel. Comp. Lett.*, 2005, **15**, pp. 703–705
2 Zaker, R., and Abdipour, A.: ‘A very compact ultrawideband printed omnidirectional monopole antenna’, *Antennas Wirel. Propag. Lett.*, 2010, **9**, pp. 471–473
3 Fereidoony, F., Chamaani, S., and Mirtaheri, S.A.: ‘UWB monopole antenna with stable radiation pattern and low transient distortion’, *Antennas Wirel. Propag. Lett.*, 2011, **10**, pp. 302–305
4 Fereidoony, F., Chamaani, S., and Mirtaheri, S.A.: ‘Systematic design of UWB monopole antennas with stable omnidirectional radiation pattern reducing ground-plane effects on UWB monopole antennas’, *Antennas Wirel. Propag. Lett.*, 2012, **11**, pp. 752–755
5 Kim, J.-Y., Oh, B.-C., Kim, N., *et al.*: ‘Triple band-notched UWB antenna based on complementary meander line SRR’, *Electron. Lett.*, 2012, **48**, pp. 896–897
6 Sarkar, D., Srivastava, K.V., and Saurav, K.: ‘A compact microstrip-fed triple band-notched UWB monopole antenna’, *Antennas Wirel. Propag. Lett.*, 2014, **13**, pp. 396–399
7 Liu, Y., Chen, Z., and Gong, S.: ‘Triple band-notched aperture UWB antenna using hollow-cross-loop resonator’, *Electron. Lett.*, 2014, **50**, pp. 728–730
8 Zhang, C., Zhang, J., and Li, L.: ‘Triple band-notched UWB antenna based on SIR-DGS and fork-shaped stubs’, *Electron. Lett.*, 2014, **50**, pp. 67–69
9 Nguyen, D.T., Lee, D.H., and Park, H.C.: ‘Very compact printed triple band-notched UWB antenna with quarter-wavelength slots’, *Antennas Wirel. Propag. Lett.*, 2012, **11**, pp. 411–414
10 Xiao, W., Mei, T., Lan, Y., *et al.*: ‘Triple band-notched UWB monopole antenna on ultra-thin liquid crystal polymer based on ESCSRR’, *Electron. Lett.*, 2017, **53**, pp. 57–58
11 Vendik, I.B., Rusakov, A., Kanjanasit, K., *et al.*: ‘Ultra-wideband (UWB) planar antenna with single-, dual-, and triple-band notched’, *Antennas Wirel. Propag. Lett.*, 2017, **16**, pp. 1597–1600