Design of Compact Printed Monopole Antenna with Enhanced Bandwidth and Controllable Filtering Notch for UWB Applications

Issa Elfergani[1(✉)], Mina Alrawi[2], Abdelgader M. Abdalla[1], Jonathan Rodriguez[1,3], Atta Ullah[4], and Raed Abd-Alhameed[4]

[1] Instituto de Telecomunicações, Aveiro, Portugal
{i.t.e.elfergani,a.m.abdalla,jonathan}@av.it.pt
[2] Universidade de Aveiro, Aveiro, Portugal
mina.alrawi@ua.pt
[3] University of South Wales, Pontypridd CF37 1DL, UK
[4] Faculty of Engineering and Informatics,
Bradford University, Bradford BD7 1DP, UK
{A.Ullah5,R.A.A.Abd}@bradford.ac.uk

Abstract. Compact printed monopole antenna suitable for UWB applications has been studied and analyzed. The design procedure of the proposed antenna has been elaborated into five stages, Firstly, the antenna with full ground plane was built, in which shows a narrow band of around 10 GHz. Secondly, the ground plane was optimally cut in order to enhance the antenna bandwidth, this version demonstrates a wide bandwidth from 3.15 GHz to 7.20 GHz. Thirdly, to cover the whole range of the UWB spectrum, a rectangle slot was generated on the micro strip line, this version shows a broad frequency range from 3.15 GHz up to 11 GHz, in which meet the UWB system. However, an electromagnetic interference (EMI) may exist in the UWB spectrum, thus, a simple and effective approach of U-slot was used. The U-slot was printed over the radiating element, in which created a notched band around 6.5 GHz. However, this fixed filtering notch cannot be tuned, therefore, a lumped capacitor was positioned on the best place over the generated U-slot, this makes the introduced rejected band tuned over a broad frequency range from 6.5 GHz up to 5.2 GHz. The results exhibit that the antenna structure may be deemed as an attractive candidate for todays' smart applications.

Keywords: Printed monopole antenna · Tunable notched-band
Defected ground plane

1 Introduction

There has been a tremendous interest in exploiting the Ultra-Wideband (UWB) technology since the Federal Communication Commission (FCC) released the 3.1–10.6 GHz frequency spectrum for unlicensed usage [1]. A broad attention has been given to UWB systems, in which within the UWB system; the antenna has an indispensable effect in UWB signal quality. Thus, a significant amount of research activity

V. Sucasas et al. (Eds.): BROADNETS 2018, LNICST 263, pp. 299–306, 2019.
https://doi.org/10.1007/978-3-030-05195-2_29

has been carried out in the area of the design and implementation of UWB antennas. The most imperative factors in the design of UWB antenna are good matching over the UWB frequency band and low transient distortion [2]. However, depending on the application, the requirements for UWB antenna design may vary significantly, for example, in the case of the mobile handheld devices, the small size, acceptable gain, high efficiency and the omni-directional radiation pattern are highly demanded.

Therefore, to develop a compact antenna that operates in a broadband or ultrawideband (UWB) range for contemporary wireless communication devices has become of a great challenge for the antenna designers and engineers. The printed antenna structures have been largely used for the UWB systems due to their low compact volume, reasonable cost, less complexity and easy integration with the device's circuit board. This kind of antennas include, the antenna with probe-fed [3], the antenna with microstrip feeding line [4], the planar inverted-F antennas (PIFAs) [5], and the antenna with coplanar waveguide (CPW)-feeding method [6].

However, on the other hand, the above-mentioned antennas [3–6] suffer from some limitations, for example, the antenna with a probe feeding approach needs to be done through a hole to connect and feed the radiating element, in which may lead size increasing and design complexity. The microstrip feeding line antenna usually comes up with a larger size of ground plane, which may affect the antenna radiation, gain and efficiency. The PIFA has such a great advantages of compact volume, easy fabrication, but it suffers from insufficient impedance bandwidth for use in broadband or multiband operation.

In fact, in short-range UWB communications, the trade-off between size, radiation efficiency, gain, bandwidth, and low cost should be optimized to accomplish a suitable antenna design. To meet these requirements, the printed monopole antenna designs have been rolled out. Several printed monopole antenna structures with different techniques have been recently reported for UWB applications [7–10]. The printed monopole antennas have several advantages such low cost, size reduction, broad bandwidth, improved gain and high efficiency. However, despite all the aforementioned of the printed monopole antennas, these antennas still may face some constraints as they are very sensitive to the electromagnetic interferences with existing narrowband wireless communication systems that work below 10 GHz, such as the wireless local area network (WLAN) for IEEE802.11a operating at 5.15–5.825 GHz band and IEEE 802.16 WiMAX system operating at 3.3–3.7 GHz, which may cause severe interference to the UWB system.

Such envisaged interferences caused by these narrow bands can be mitigated by using spatial filters but this approach will lead to several drawbacks such as complexity increase cost, size and weight of the system. Therefore, it is required to design UWB antennas with band-rejection feature in those narrow bands spectrum in order avoid feasible interference, while still keeping the other performance metrics such as the UWB characteristics of an impedance matching and radiation stability, the size compactness of the antenna geometry, and the low fabrication cost for consumer electronics applications. Numerous UWB antennas with single notched-band were proposed in [11, 12], with dual-notched bands in [13, 14] and with triple rejected bands as in [15, 16]. However, these designs have come up with fixed rejected bands, which cannot be shifted to cover other channels. Thus, this paper documents printed monopole UWB antenna design with controllable notched bands.

2 Antenna Design and Procedure

The layout and the full dimensions of the proposed antennas are depicted in Fig. 1. The radiating element with size of 12 mm^2 × 12 mm^2, is printed over 0.8 mm FR4 substrate, dielectric constant $\varepsilon r = 4.4$ and loss tangent $\tan \delta = 0.017$. The dimensions of the substrate are 30 mm^3 × 30 mm^3 × 0.8 mm^3. The other side of the substrate has a rectangular defected ground plane (DGP) copper ground plane with dimensions 30 mm^2 × 9 mm^2, as illustrated in Fig. 1,b. The proposed structures were feed by using a 50-Ω microstrip line size of 10 mm^2 × 1.5 mm^2. The antenna designs are constructed and assembled with the help of the CST EM simulator [17].

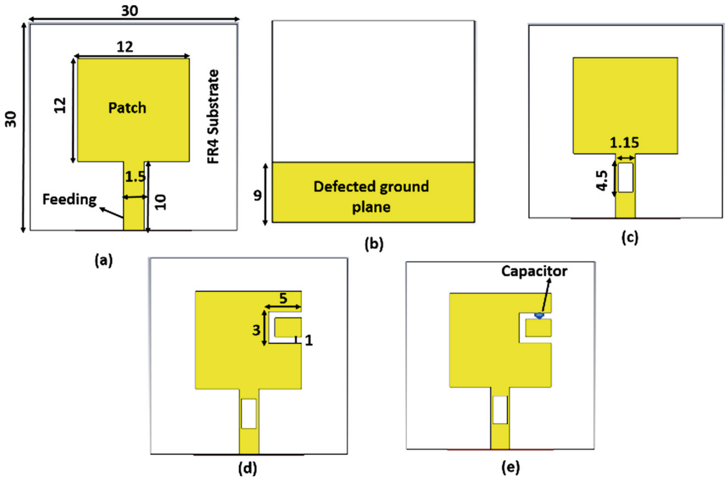

Fig. 1. The proposed antenna designs, (a) top view, (b) bottom view/DGP, (c) with DGP & slotted feed, (d) DGP& slotted feed & U-slot feeding, (e) loaded antenna.

3 Results and Discussions

3.1 The Reflections Coefficients (S_{11})

The reflection coefficients (S_{11}) of the proposed antennas are shown in Figs. 2 and 3. As should be noted that the first version of the antenna (full ground plane) exhibits a narrow bandwidth at 10 GHz. However, as the main goal of this work is to develop a compact antenna design for use in UWB applications, thus, the defected ground plane (DGP) approach was employed as seen in Fig. 1b, this antenna version demonstrates a wide bandwidth from 3.15 GHz to 7.20 GHz as illustrated in Fig. 2.

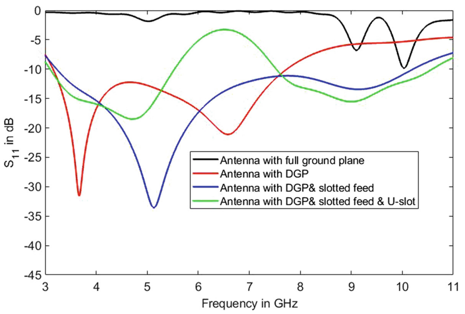

Fig. 2. The S11 variations of the antenna with full ground, with DGP, with DGP & slotted-feed and with DGP & slotted-feed & U-slot

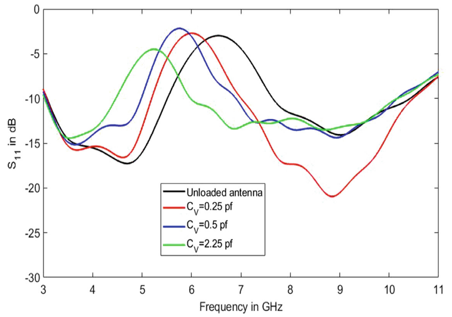

Fig. 3. The S11 variations of the antenna with loaded capacitor

However, this does not cover the higher UWB range that is defined by the FCC (up to 10.3 GHz). Therefore, an optimized rectangular slot was inserted over the microstrip feeding line as depicted in Fig. 1c. This makes the third version able to cover the whole UWB spectrum from 3.15 GHz up to 11 GHz as shown in Fig. 2. The wide spectrum of the UWB system may be subjected to an electromagnetic interference (EMI) with other adjacent narrow systems. Hence it is better to have UWB antenna with built in notch characteristics. Thus, desired notched frequency band at 6.5 GHz is achieved by producing U- shaped slot over the radiating patch as shown in Fig. 1d. By properly selecting the best position of the U-slot, it is feasible to create the desired bandwidth and center frequency of notched band. This forth antenna version design is capable of producing a steeper rise in S11 curve at the notch frequency as indicated in Fig. 2.

Though the forth version of the proposed antennas have advantages of avoiding the interference with the existing systems. However, this is such a fixed rejected band, which is not possible to be tuned to cover several bands of existing systems. Moreover, hence the key issue is the design of a compact volume with good wideband characteristics, including a tunable filtering notched frequency that is able to cover a wide continuous rejected band range, As a result, a lumped capacitor was attached over the proposer location of the U-shaped slot (See Fig. 1e). By varying the capacitance of the capacitor from 0.25pf, 0.5pf and 2.25pf, the created rejected band was smoothly tuned from 6 GHz, 5.7 GHz and 5.2 GHz respectively as shown in Fig. 3. This enables the proposed design to avoid the foreseen interferences such as lower WLAN5.2 GHz, higher WLAN5.8 GHz and band C around 6.5 GHz.

3.2 The Power Gain and Efficiency

The power gains of the proposed antennas are investigated as in Fig. 4. The UWB antenna without notched band shows a smooth gain values vary from 2.2 dBi up to 4.3 dBi over the entire UWB range. The antenna design with fixed rejected band, displays also a smooth gain from 2.1 dBi to around 4 dBi, except at the 6.5 GHz, where the gain was significantly dropped to around −3.9 dBi. In the scenario of the loaded antenna with 0.25pf capacitor, the proposed antenna shows power gains values from 2.1 dBi to 4 dBi, except at the notched band of 6 GHz, where the gain dropped to around −3.1 dBi. When the antenna loaded with 0.5pf capacitor, gain values from 2.2 dBi up to 4.3 dBi were accomplished over the all UWB spectrum, however, a sharp decrease of the 3.6 dBi occurred at the notched band of 5.8 GHz. Also, a smooth gain vary from 2.3 dBi to 4.3 dBi over the frequency range from 3.15 GHz to 11 GHz, with the exception of the lower WLAN5.2 GHz, where the gain was hugely dropped to −2.8 dBi as the rejected band created.

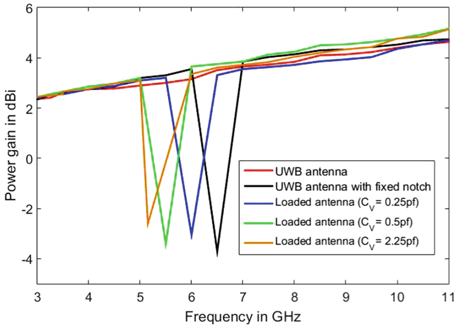

Fig. 4. Power gains of the proposed antennas

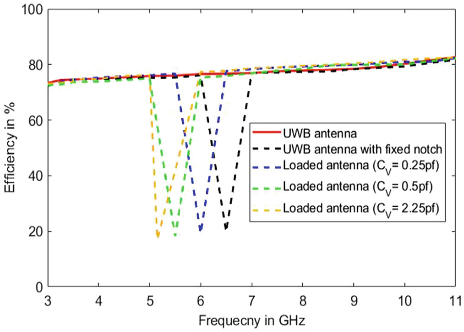

Fig. 5. Radiation efficiency of the proposed antenna

The radiation efficiency of the proposed antennas are analyzed in Fig. 5. The UWB antenna demonstrates flat efficiency values from 78% to 83% over the UWB range from 3.15 GHz up to 11 GHz, while the version of the UWB antenna with fixed rejected band shows efficiency from 77% to 82%, except at the produced notch where the efficiency goes down to 21%. In the paradigm of the loaded antenna, the three loaded versions with 0.25pf, 0.5pf and 2.25pf display smooth efficiency vary from 77.5% to 82.5%, however, the efficiency show significant drop to 21%, 19.5% and 20%, where the filtering notches were generated respectively.

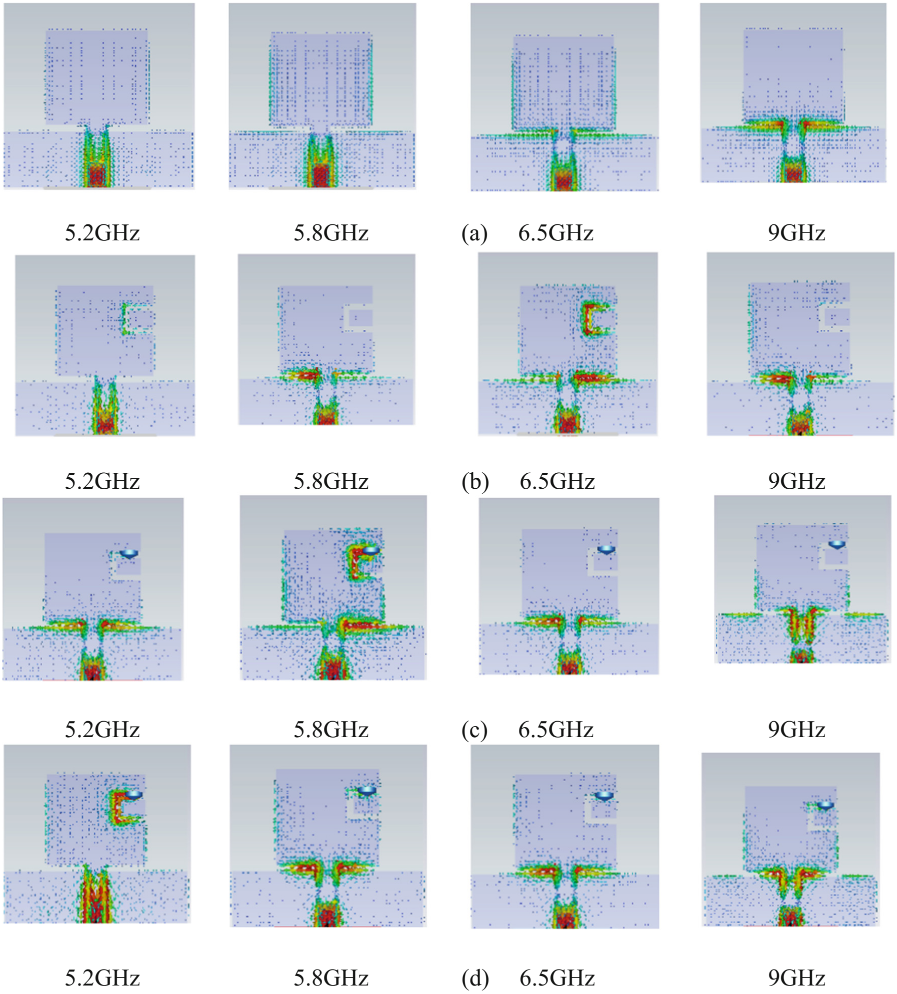

Fig. 6. The current surfaces for the proposed antennas, (a) UWB antenna, (b) antenna with fixed notch, (c) antenna with 0.5pf loaded capacitor, (c) antenna with 2.25pf loaded capacitor, at 5.2 GHz, 5.8 GHz, 6.5 GHz and 9 GHz.

3.3 The Current Surfaces

In order to prove the outcomes in Figs. 2, 3, 4 and 5, the current surfaces of the proposed antenna versions, namely the UWB antenna, antenna with fixed notched band and the antenna with tunable rejected band were studied and analyzed as presented in Fig. 6. Four frequencies were selected, i.e. 5.2 GHz, 5.8 GHz, 6.5 GHz and 9 GHz, which cover the aggregate bandwidth. Most of the currents induce on the feeding line in the case of the UWB antenna over the four targeted frequency bands since there no notched bands created as indicated in Fig. 6a. In the second scenario (antenna with U-slot) most of the currents flow around the feeding line, except at the 6.5 GHz as the current concentrate on both the feeding strip as well as the U-slot as shown in Fig. 6b. This indicates that the U-slot approach acts as an effective stop-band filter and confirms the objective of the U-slot technique in Fig. 2. When the antenna loaded with 0.5pf and 2.25pf, the current mainly concentrate on the feeding line, except at the WLAN5.8 GHz and WLAN5.2 GHz, where the both rejected bands were introduced as depicted in Fig. 6c and d. These findings prove the statement in previous sections for the antenna to simultaneously function as a radiator and stop-band filter within a single system device.

4 Conclusion

A compact volume of UWB printed monopole antenna, including band-notched function for UWB systems has been developed and analysed. Five antenna versions have been designed. The proposed design occupies a compact volume of 30 x 30 x 0.8 mm^3. For bandwidth improvement, a defected ground plane (DGP) was initially used. To further meet the spectrum of the UWB released by the FCC (3.1 GHz to 10.6 GHz), a rectangular slot has been inserted on the proper location over the feeding line. Moreover, a U-shaped slot was added over the radiating patch to obtain the filtering notch feature, while keeping the same UWB spectrum range. Finally, a lumped capacitor has been placed over the U-slot, in which by varying its capacitance values the created rejected band was easily shifted downwards to cover the range from 6.5 GHz up to 5.2 GHz. The proposed antennas indicated stable performances in terms of reflection coefficients, current distributions, gains and efficiency. The proposed final design was able to accomplish the desired band-notched characteristics, making the design as a smart candidate for the UWB applications.

Acknowledgment. This work is carried out under the grant of the Fundacão para a Ciência e a Tecnologia (FCT - Portugal), with the reference number: SFRH/BPD/95110/2013. This work is supported by the European Union's Horizon 2020 Research and Innovation program under grant agreement H2020-MSCA-ITN-2016-SECRET-722424.

References

1. FCC 1st report and order on ultra-wideband technology. FCC, Washington, DC, February 2002
2. Chamaani, S., Mirtaheri, S.A.: Planar UWB monopole antenna optimization to enhance time-domain characteristics using PSO. Int. J. Electron. Commun. **64**, 351–359 (2010)
3. Al-Zoubi, A., Yang, F., Kishk, A.: A broadband center-fed circular patch-ring antenna with a monopole like radiation pattern. IEEE Trans. Antennas Propag. **57**, 789–792 (2009)
4. Sarin, V.P., Deepu, V., Aanandan, C.K., Mohanan, P., Vasudevan, K.: Wideband printed microstrip antenna for wireless communications. IEEE Antennas Wireless Propag. Lett. **8**, 779–781 (2009)
5. Oh, S.K., Yoon, H.S., Park, S.O.: A PIFA-type varactor-tunable slim antenna with a PIL patch feed for multiband applications. IEEE Antennas Wireless Propag. Lett. **6**, 103–105 (2007)
6. Nasimuddin, N., Chen, Z.N.: Wideband multilayered microstrip antennas fed by coplanar waveguide-loop with and without via combinations. IET Microw. Antennas Propag. **3**, 85–91 (2009)
7. Elfergani, I., Hussaini, A.S., Rodriguez, J., Abd-Alhameed, R.A.: Antenna Fundamentals for Legacy Mobile Applications and Beyond. Springer, Cham (2017). https://doi.org/10.1007/978-3-319-63967-3. ISBN 978-3-319-63967-3
8. Ray, K.P., Thakur, S.S., Deshmkh, A.A.: Compact slotted printed monopole UWB antenna. In: International Conference on Communication Technology, pp. 16–18 (2013)
9. Khan, M.K., Khan, M.I., Ahmad, I., Saleem, M.: Design of a printed monopole antenna with ridged ground for ultra wideband applications. In: 2016 Progress In Electromagnetic Research Symposium (PIERS), Shanghai, China, 8–11 August, pp. 4394–4396 (2016)
10. Abid, M., Kazim, J., Owais, O.: Ultra-wideband circular printed monopole antenna for cognitive radio applications. Int. J. Microw. Opt. Technol. **10**(3), 184–189 (2015)
11. Ebadzadeh, S.R., Zehforoosh, Y.: A compact UWB monopole antenna with rejected WLAN band using split-ring resonator and assessed by analytic hierarchy process method. J. Microwaves Optoelectron. Electromagn. Appl. **16**(2), 592–601 (2017)
12. Jangid, K.G., et al.: Circular patch antenna with defected ground for UWB communication with WLAN band rejection. Defence Sci. J. **66**(2), 162–167 (2016). https://doi.org/10.14429/dsj.66.9329
13. Yadav, A., Sethi, D., Khanna, R.K.: Slot loaded UWB antenna: dual band notched characteristics. Int. J. Electron. Commun. (AEÜ) **70**, 331–335 (2016)
14. Elfergani, I., Lopes, P., Rodriguez, J., Lo Hine Tong, D.: Simple and compact planar ultra-wideband antenna with band-notched characteristics. In: Elfergani, I., Hussaini, A.S., Rodriguez, J., Abd-Alhameed, R. (eds.) Antenna Fundamentals for Legacy Mobile Applications and Beyond, pp. 119–134. Springer, Cham (2018). https://doi.org/10.1007/978-3-319-63967-3_6
15. Hamad, E.K.I., Mahmoud, N.: Compact tri-band notched characteristics UWB antenna for WiMAX, WLAN and X-band applications. Adv. Electromagnetics **6**(2), 53–58 (2017)
16. Chen, X., Xu, F., Tan, X.: Design of a compact UWB antenna with triple notched bands using nonuniform width slots. Journal of Sensors **2017**, 1–9 (2017). Article ID 7673168
17. CST-Computer Simulation Technology AG (2014)