



## An Equivalent Circuit Modeling of UWB Patch Antenna with Band Notched Characteristics

Shilpa Jangid<sup>1</sup> and V Siva Brahmaiah Rama<sup>2</sup>

<sup>1</sup>Department of Electronics Engineering, Rajasthan Technical University, Kota, Rajasthan, India

<sup>2</sup>Department of Electrical Engineering, Mewar University, Chittorgarh, Rajasthan, India  
shilpa.jangid08@gmail.com

### ABSTRACT

In this paper, a band notched ultra-wideband (UWB) patch antenna is presented with its circuit modelling. The rectangular patch antenna is designed on dielectric substrate and fed with  $50 \Omega$  microstrip by optimizing the width of partial ground, the width of the feed line to operate in UWB. This antenna consists of a radiating element with a strip, and a partial ground plane and feeding line has been demonstrated. With the design, the return loss is lower than 10 dB in 3.1-10.6 GHz frequency range and show the band-notch characteristic in the UWB band to avoid interferences, which is caused by WLAN (5.15–5.825 GHz) and WIMAX (5.25–5.85 GHz) systems. In addition, band-notched filtering properties in the 5.15- 5.825 GHz are achieved by cutting a circular slot on the radiating patch. The antenna design is simulated on electromagnetic (EM) simulation software using FR-4 substrate with dielectric constant of 4.4 and thickness of 1.6 mm. The proposed antenna has a compact structure and the total size is  $15 \times 14.5 \text{ mm}^2$ . Simplified lumped element circuit model of band notched UWB patch antenna had been derived. The circuit model had been simulated in Serenade simulator and the S- parameters is compared with the obtained scattering parameter from simulating in EM simulator.

**Key words:** Band notched, partial ground plane, patch antenna, and UWB antenna

### INTRODUCTION

With the development of modern wireless and mobile communication, ultra-wideband (UWB) systems have recently attracted attention owing to several advantages, including high-speed data rate, small size, and low power consumption [1]. According to the Federal Communications Commission (FCC) document, the frequency band of the UWB (category of communications and measurement systems) should be between 3.1 and 10.6 GHz in 2002 for the use of indoor and hand-held systems [2]. UWB antennas have enormous attention in both academia and industry for applications in wireless transmission systems [3]. Impulse-Ultra wideband (I-UWB) is a carrier less short range communications technology in which its transmission occupies a bandwidth of more than 20% of its center frequency ( $>500 \text{ MHz}$ ) [4]. Wireless communication systems have developed rapidly in recent years, an antenna as a front component is required to have a wide band, good radiation performances and sometimes switchable ability [5-6]. To obtain the switchable ability of the antenna, the concept of a reconfigurable antenna was proposed a few years ago [7-10]. To undertake the effect caused by the frequency interference from WLAN (5.15–5.825 GHz) and WiMax (5.25–5.85 GHz) systems, some UWB antennas with band-notched feature have been designed [11-13] like w-shaped slots on the radiating patch [14]. Equivalent circuit of the patch antenna had been also derived by using lumped elements [15-16].

In this paper, an UWB patch antenna is presented. The planar UWB patch antenna is designed with circular slot of desired operating frequency range with band-notch characteristic. The antenna consists of a rectangular patch, a circular slot, a partial ground plane and feeding line. This antenna is easy to integrate with microwave circuitry for low manufacturing cost. Optimum dimension of the antenna is obtained by simulating the design. In the Section II

of this paper describes the. The antenna design, computer simulation and circuit modelling of UWB antenna results are presented in this paper.

**ANTENNA DESIGN**

The proposed design of UWB antenna is simple and compact. This planar UWB antenna has the capability to notch frequencies within the 5.15–5.85 GHz band. Fig. 1 illustrated the configuration of the proposed antenna, which consists of a rectangular patch with two steps, a circular slot, a partial ground plane, and a feed-line. The antenna structure was designed on FR-4 substrate having dielectric constant of 4.4 and thickness of 1.6 mm. The design was simulated using EM Simulation software. The substrate dimension is 30×30 mm<sup>2</sup>. The design antenna has the following optimized parameters:  $A_w = 15\text{mm}$ ,  $A_p = 12\text{mm}$ ,  $A_h = 14.5\text{mm}$ ,  $S_{1h} = 1.5\text{mm}$ ,  $S_{2h} = 1\text{mm}$ ,  $d = 1\text{mm}$ ,  $G_h = 10.8\text{mm}$ ,  $G_g = 9.4\text{mm}$ ,  $G_w = 2.8\text{mm}$ ,  $F_w = 2.4\text{mm}$ ,  $F_h = 12.5\text{mm}$  that is shown in Fig. 1. The antenna is fed using a 50Ω microstrip line whose width is calculated using the well-known microstrip line design equations. The circular slot placed at the center of the patch can be devoted to generating desirable resonance for the stopband operation. The rectangular radiating patch antenna with steps, a partial ground plane, feed line and circular slot parameters was optimized to get desired response. Therefore, the geometric parameters of the proposed structure can be adjusted to tune the return loss and bandwidth over wide range of frequency.

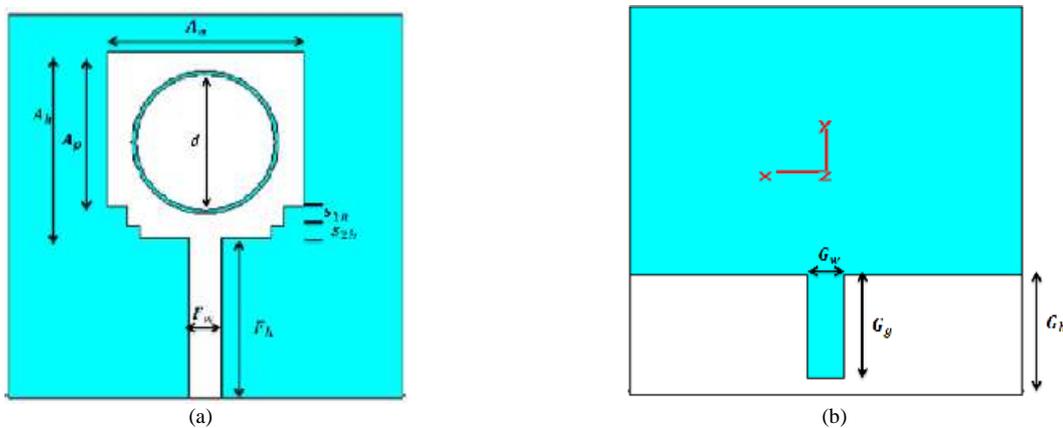


Fig.1 Antenna configuration (a) front (b) back view

**RESULTS AND DISCUSSION**

The proposed antenna is optimized by using electromagnetic (EM) simulator software. A planar antenna was designed and the return loss was measured. Fig. 2 shows the simulated results for return loss of this antenna with and without circular slot. The overall goal of the proposed antenna design is to achieve good performance in the return loss below -10dB. Suitable antenna geometry is needed for this reason. The proposed UWB antenna shows the simulated operating frequency band 2.99-12GHz. The circular slot rejects the frequency band of about 5.07–5.89GHz, so the effects due to the frequency interference can be avoided well.

Fig. 3 shows the simulated result of VSWR against frequency (GHz). The VSWR of the antenna is closely related to the return loss. VSWR values from 1 to 2 throughout the frequency region except from 5.07GHz to 5.89GHz. Since UWB characteristic requires the VSWR to range from 1 to 2, the frequency region from 5.07GHz to 5.89GHz for the measured result does not agree with the UWB characteristic. Based on the simulated results, the proposed antenna exhibits good UWB characteristics and operates from 2.99-12GHz. It complies with the VSWR range from 1 to 2 throughout the impedance bandwidth.

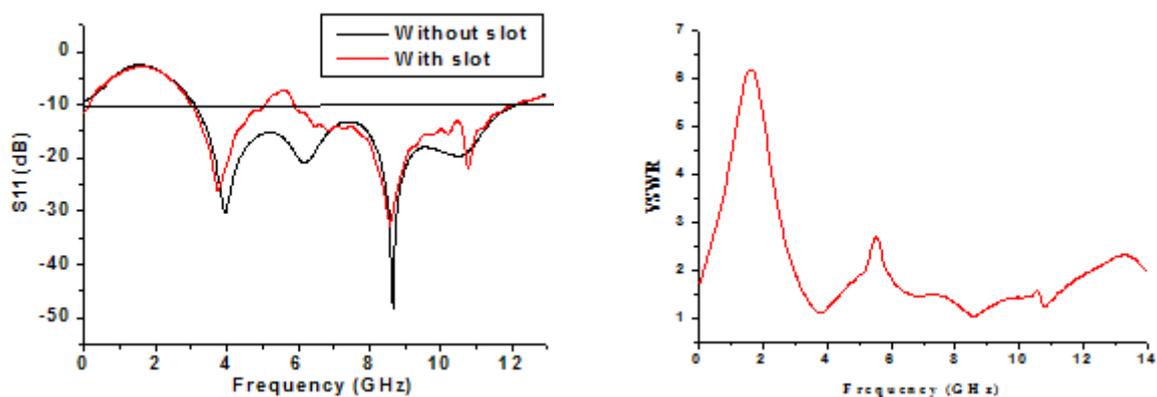


Fig.2 Simulated return loss of the antenna with notched band behaviour

Fig.3 Simulated VSWR of the antenna with band notched behaviour

Simplified lumped element circuit model of the UWB patch antenna had been derived. This model was obtained by studying the scattering parameter ( $S_{11}$ ) of the antenna structure by simulating the antenna in EM simulator. By obtaining this S-parameter the overall structure of the circuit model had been transformed to imply the characteristics of the antenna. The equivalent circuit of patch antenna is shown in fig. 4 where patch cavity is modelled as a parallel RLC circuit, while the probe inductance is modelled as a series inductor. Fig. 5 shows the structure of step discontinuity. The equivalent circuit of step discontinuity is modelled as in fig. 6. When a notch is incorporated into the patch, the resonance features change. An equivalent circuit for a switch branch is modelled as a parallel LC circuit.

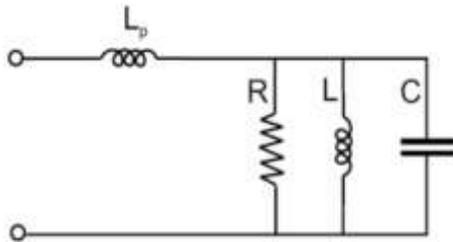


Fig.4 Equivalent circuit of patch antenna

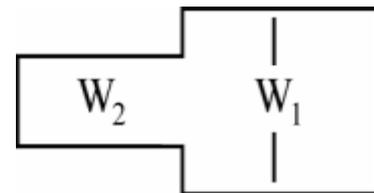


Fig.5 Structure of step discontinuity

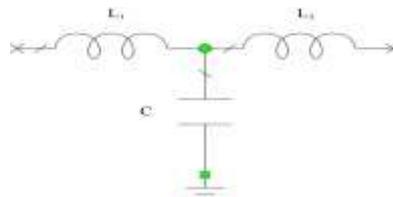


Fig.6 Equivalent circuit of step discontinuity

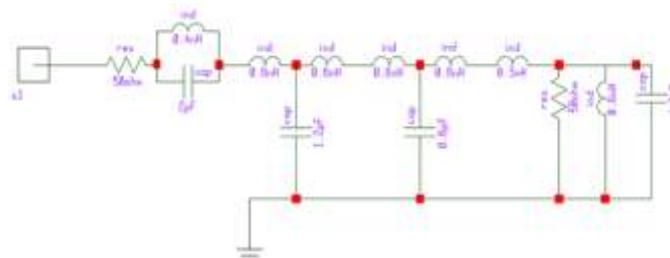


Fig.7 Equivalent circuit of proposed antenna

Fig. 7 shows the equivalent circuit of UWB patch antenna with circular slot. The proposed antenna is designed by using equivalent circuit of step discontinuity, rectangular patch antenna and circular slot for notch. In the proposed antenna two steps are used. In this model the patch cavity is modelled as a parallel RLC circuit, while the probe inductance is modelled as a series inductor. A parallel LC circuit shows the notch characteristic. When a notch is incorporated into the patch, the resonance features change. An equivalent circuit for a switch branch is modelled as a parallel LC circuit. The circuit model had been simulated in Serenade simulator and the S- parameter is compared with the obtained scattering parameter from simulating the EM structure in EM simulator. Fig. 8 shows simulated return loss of the UWB patch antenna with circular slot. For theoretical analysis code this circuit on MATLAB. Fig.9 shows the simulated return loss of the UWB patch antenna with circular slot on MATLAB.

The reflection coefficient and return loss can be computed.

Reflection Coefficient

$$\Gamma = \frac{Z_0 - Z_{in}}{Z_0 + Z_{in}} \tag{1}$$

Return Loss

$$20 \log |\Gamma| \tag{2}$$

For the calculation of input impedance we have to solve the complete circuit in simplified way. The calculation is-

$$P_1 = j\omega(L_2 + L_3) + \frac{(R_1)(1/j\omega C_1)(j\omega L_1)}{(R_1)(1/j\omega C_1) + (1/j\omega C_1)(j\omega L_1) + (R_1)(j\omega L_1)} \tag{3}$$

$$P_2 = j\omega(L_3 + L_3) + \frac{(1/j\omega C_2)(1/P_1)}{(1/j\omega C_2) + (1/P_1)} \tag{4}$$

$$Z_{in} = R_1 + \frac{(1/j\omega C_4) \cdot j\omega L_4}{(1/j\omega C_4) + j\omega L_4} + j\omega L_3 + \frac{(1/j\omega C_3) \cdot (1/P_2)}{(1/j\omega C_3) + (1/P_2)} \quad (5)$$

For theoretical analysis we can calculate input impedance by putting the value of  $L_1, L_2, L_3, L_4, C_1, C_2, C_3, C_4$  and  $R_1$  in above equations. In the equivalent circuit of band notched UWB patch antenna  $L_1=0.8\text{nH}, L_2=0.3\text{nH}, L_3=0.6\text{nH}, L_4=0.4\text{nH}, C_1=1.2\text{pF}, C_2=0.6\text{pF}, C_3=1.2\text{pF}, C_4=2\text{pF}$  and  $R_1=50\text{ohm}$ . From equation (1) and (2), we can calculate reflection coefficient by putting value of  $Z_{in}$  and  $Z_o=50\text{ ohm}$ .

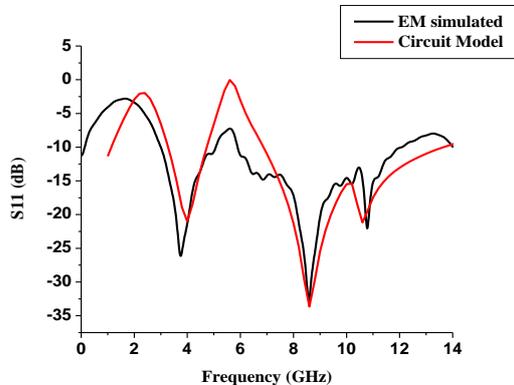


Fig. 8 Simulated return loss of the proposed antenna

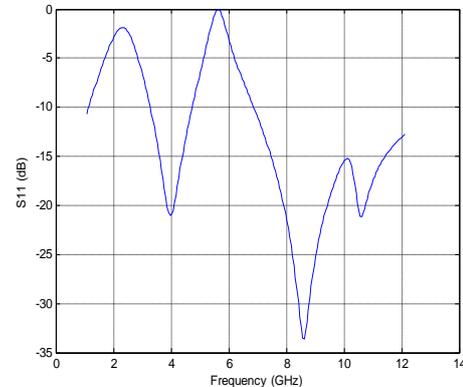


Fig.9 Simulated return loss of the proposed antenna on MATLAB

## CONCLUSION

In this paper, circuit modelling of band notched rectangular patch antennas with partial ground for UWB communication systems has been modelled. An ultra-wideband patch antenna is presented with 2.99-12GHz frequency range, and rejecting the frequency band of about 5.07–5.89GHz. The simulated results of the proposed antenna satisfy the 10-dB return loss requirement for UWB as defined by the FCC. The proposed UWB antenna structure can be used in future UWB systems. It can tackle the frequency interference from WLAN and WIMAX. The antenna structure is flat, and its design is simple and straight forward geometrically small, hence embedded easily in wireless communication systems.

With the help of this tuneable stop band, frequency interference issues may be better addressed as well. Furthermore, properties such as good omni directional coverage, stable transmission characteristics indicate that the proposed compact antenna is well suitable for integration into UWB portable devices.

## REFERENCES

- [1] G Brzezina, Q Ye, L Roy, Development of a Practical Ultra- Wideband Antenna With Planar Circuit Integration Possibilities, *IEEE Antenna and Propagation Soc Int Symp*, **2005**, pp 504- 507.
- [2] Ching-Fang Tseng, Planar UWB Dipole Antenna with Band-Notched Characteristic, *IEEE*, **2009**.
- [3] M K A Rahim, M N A Karim, T Masri, A Asrokin, Comparison between Straight and U shape of Ultra-wide Band Microstrip Antenna using Log Periodic Technique, *IEEE International Conference on Ultra-Wideband*, **2007**, pp 696 – 699.
- [4] Mohammad Hadi Badjian, Chandan Kumar Chakrabarty, Goh Chin Hock, and Sanjay Devkumar, An Impulse UWB Patch Antenna with Integrated Bandpass Filter, *IEEE Conference on Photonics*, Putrajaya, Malaysia, **2008**, pp 166 – 169.
- [5] TA Denidni, L Lim and Q Rao, Wide Band High Efficiency Printed Loop Antenna Design for Wireless Communication Systems, *IEEE Trans Veh Technol*, **2005**, 54, (3), pp 873-878.
- [6] TP Wong and KM Luk, A Wide Bandwidth and Wide Beamwidth CDMA/GSM Base Station Antenna Array with Low Backlobe Radiation, *IEEE Trans Veh Technol*, **2005**, 54, (3), pp 903-909.
- [7] SQ Xiao, ZH Shao, M Fujise, and BZ Wang, Pattern Reconfigurable Leaky-Wave Antenna design by FDTD Method and Floquet's Theorem, *IEEE Trans Antenna Propagation*, **2005**, 53, (5), pp 1845-1848.
- [8] F Yang and Y Rahmat-amii, Patch Antennas with Switchable Slots (PASS) in Wireless Communications: Concepts, Designs and Applications, *IEEE Antenna Propag Mag*, **2005**, 47, (2) pp645-654.
- [9] D Peroulis, K Sarabi and LPB Katehi, Design of Reconfigurable Slot Antenna, *IEEE Trans Antennas Propag*, **2005**, 53, (2), pp 645-654.
- [10] JL Freeman, BJ Lamberty and GS Rews, , Optoelectronically Reconfigurable Monopole Antenna, *Electron Letters*, **1992**, 28, (16), pp 1502-1503.

- [11] KG Jangid, VS Kulhar, V Sharma, A Tiwari, BR Sharma and D Bhatnagar, Compact Circular Microstrip Patch Antenna with Modified Ground Plane for Broadband Performance, IEEE International Conference on Signal Propagation and Computer Technology (ICSPCT), **2014**, pp.25-28.
- [12] Hsien-Wen Liu, Chia-Hao Ku, Te-Shun Wang, and Chang-Fa Yang, Compact Monopole Antenna with Band-Notched Characteristic for UWB Applications, *IEEE Antenna and Wireless Propag. Letters*, **2010**, Vol 9.
- [13] Nader Behdad and Kamal Sarabandi, Dual-Band Reconfigurable Antenna with a Very Wide Tunability Range, *IEEE Antenna and Wireless Propagation Letters*, **2006**, Vol 54, No 2.
- [14] Vijay Sharma, S Yadav, KG Jangid, D Bhatnagar and MM Sharma, A Compact CPW Fed Modified Circular Patch Antenna with Stub for UWB Applications, IEEE International Conference on Signal Propagation and Computer Technology (ICSPCT), **2014**, pp.214-217.
- [15] Mohammad Hadi Badjian and Chandan Kumar Chakrabarty, Circuit Modeling of an UWB Patch Antenna, *IEEE International RF and Microwave Conference*, Kuala Lumpur, Malaysia, **2008**.
- [16] Y Wang, J Z Li and L X Ran, An Equivalent Circuit Modeling Method for Ultra-Wideband Antenna, *Progress In Electromagnetics Research*, 2008, 82, 433-445.