Circular Monopole Antenna with defected ground plane for UWB applications

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Abstract. In this paper a circular monopole antenna for Ultra Wide Band (*UWB*) applications is proposed. The structure is a simple circular shape monopole antenna designed on FR-4 substrate and fed by a 50Ω microstrip line. The ground plane of the antenna has been modified including several defects to improve its behavior in matching and wideband. A parametric study has been performed to the semicircular slots located in the ground plane area. The frequency range measured for S11<-10dB was from 1.66 - 20 GHz. The total dimensions of the antenna are 55x79mm (W x L).

Keywords: circular monopole antenna, defected ground plane, UWB.

1 Introduction

Microstrip antennas are investigated intensively due to their properties, such as low profile, low cost, conformability and ease of integration with active devices [1]. Nowadays, printed ultra wideband (UWB) antennas have been attractive for researchers due to their small size, low cost and high data rate features. The Federal Communications Commission has allocated the 3.1 GHz to 10.6 GHz frequency band for unlicensed ultra wideband applications. Most of the ultra wideband antennas are either microstrip fed or coplanar waveguide fed monopoles or slots [2]. By using different shapes for the patch and the slot, several ultra wideband antennas have been proposed [3-12]. In [4], a comparison of the different shapes such as rectangular, circular, square, elliptical and triangular shape for the patch as well as the slot was made. In [2] is shown that adding a slot to an antenna can improve the impedance bandwidth, compared to a simple patch antenna, due to the coupling between the slot and the feed line.

UWB systems have many advantages such as their wide bandwidth and low cost, being suitable to telecommunications, medical imaging and biomedical systems [13-15]. Printed monopole antennas fabricated on a substrate, offer wide impedance bandwidth that can cover the complete UWB range [16]. In [16] a circular monopole antenna is presented, which have an L-shape bended ground plane and was fabricated in FR-4 with a size of 56 x 60 mm for operation from 1.3-12 GHz having a bandwidth of 10.7 GHz. Furthermore, a circular monopole with a ground plane only below the feed line has been designed in [17] and built in a substrate with approximate dimensions of 40 x 30 mm, to work in the 3.1-11 GHz frequency range with a bandwidth of 7.9 GHz. In this paper, we propose a monopole circular antenna with a defected ground plane having a semicircular shape below the 50Ω feed line, and two quarters of a circle on the edges of the ground plane. A parametric study performed in this work, also confirm that the use of slots in the ground plane of the antenna, improve its impedance bandwidth characteristics. The proposed structure compared with the designs [16-17] shown an improvement in bandwidth, from 1.66 GHz up to 20 GHz. The advantage of the proposed antenna is the extremely wide bandwidth obtained due to the defected ground plane with semicircular slots.

2 Antenna structure

The geometry of the proposed antenna is shown in Figure 1. It is fed by a 50 Ω microstrip line and fabricated on a FR4 substrate of size W=55 mm by L=79 mm and a thickness of 1.5778 mm. The relative dielectric constant and dissipation factor of the substrate are 4.08 and 0.019 respectively.

On the top side of the substrate, there is a circular patch with radius Rp= 27.5 mm and a microstrip 50 Ω feed line with dimensions Wf=3.1 mm by Lf=24 mm as it is shown in Figure 1a.

On the bottom side of the substrate, there is a defected ground plane with sizes Wg=55mm and Lg=23.5 mm. A semicircular shape with a radius yc has been removed from the ground plane below the 50Ω feed line, and two quarters of a circle, with a radius xt from the edges of the ground plane, as it is shown in Figure 1b.

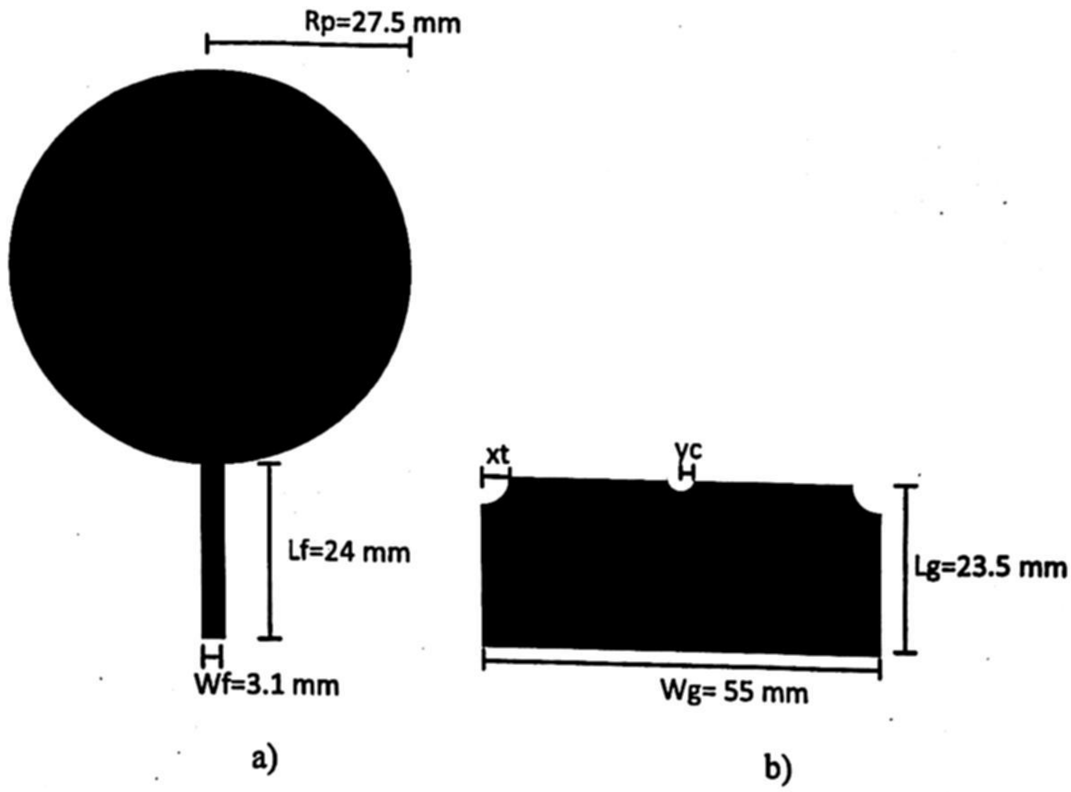


Fig. 1. Circular Monopole Antenna with defected ground plane: a) Top side, b) Bottom side.

The design expression of a simple circular microstrip antenna [13-14] to calculate the resonant frequency is

$$F_r = \frac{1.841c}{2\pi r_{eff}\sqrt{\varepsilon_{eff}}} \tag{1}$$

Where c is the velocity of light, r_{eff} is the effective radius of the patch and ε_{eff} is the effective dielectric constant. Using the equation (1), the circular patch has been designed for operation at 2 GHz, giving a radius r_{eff} of 27.5 mm.

3 Parametric study of the antenna

Before initiating the parametric study in the ground plane, the parameters Wf, Lf and Lg were optimized for a reduction of the return losses (S11<-10 dB) and to increase the frequency bandwidth. The electromagnetic analysis and optimization of the antenna was performed using the *CST Microwave Studio* software from 1 to 20 GHz. The variation effect in the slots of the ground plane is given in Figures 2 and 3, which clearly show the effect of the parameters (*yc*) and (*xt*) on the impedance bandwidth of the antenna. Figure 2 presents the return losses of the antenna in function of the variation of the radius (*yc*) of the semicircular slot, located in the center of the ground plane below the feed line. The final value of the radius (yc) was 2 mm, which reduces the return losses S11 to approximately -12dB in the frequency range. On the other hand, the S11 results in function of the variation of the radius (*xt*) of the two slots in form of a quarter of a circle, removed from the edges of the ground plane is shown in Figure 3. It can be noted clearly the improvement of S11 in the whole frequency range when the radius is increased to 4 mm, showing that the return losses are lower than -12 dB at 2 GHz and -15dB from 2.5 GHz to 20 GHz.

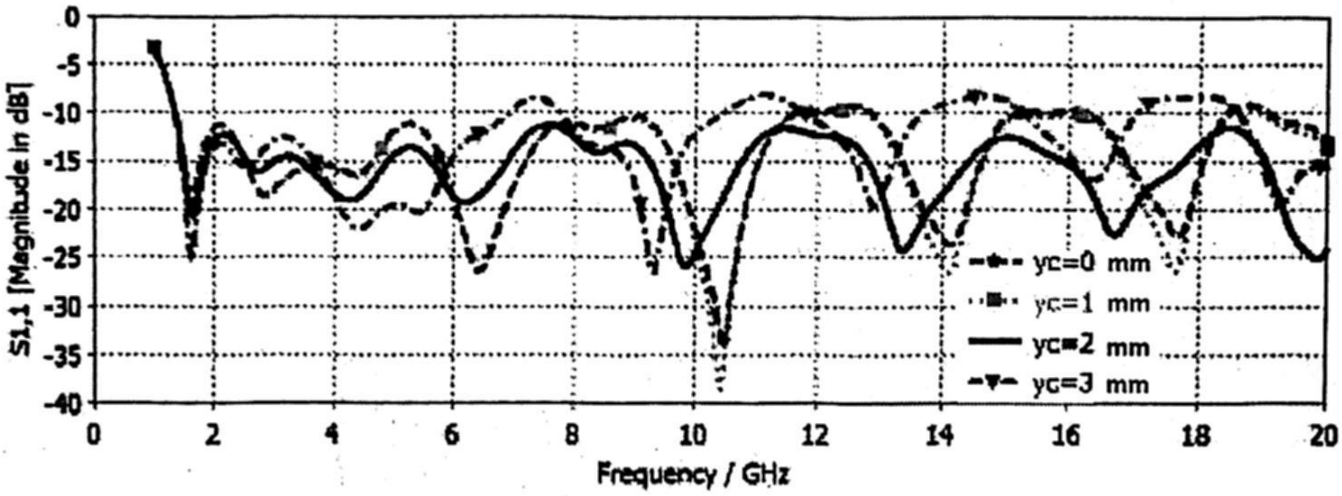


Fig. 2. Effect on the S11 due to the semicircular slot in the ground plane, below the feed line.

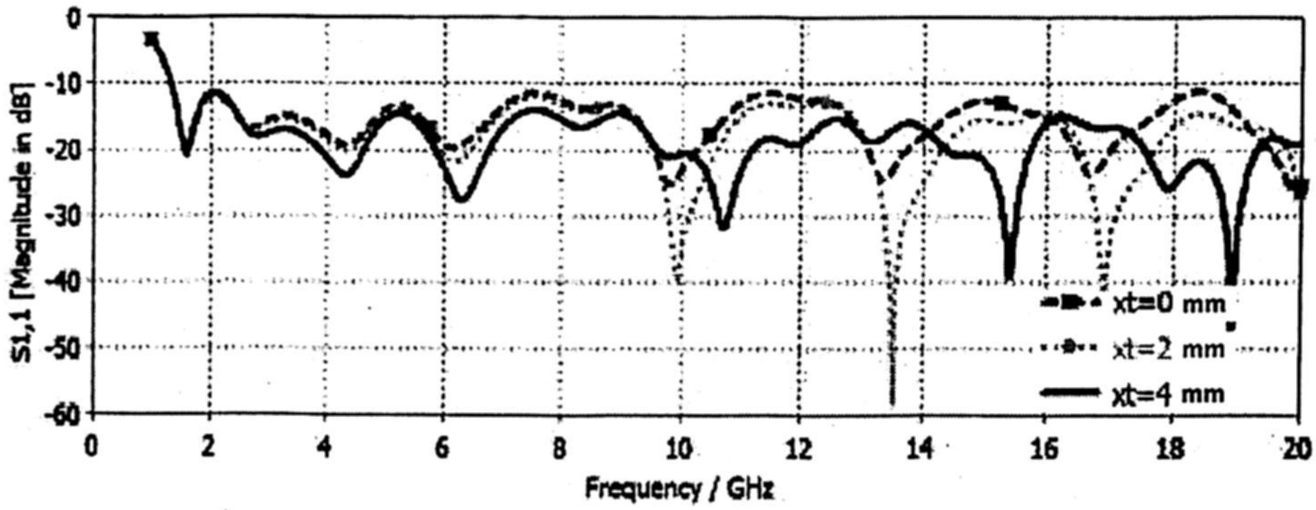


Fig. 3. Effect on the S11 caused by the two quarters of a circle removed from the edges of the ground plane.

The effect of the variation of the slots 'xt' in the gain of the antenna is given in Figure 4. It can be noted that the gain is slightly reduced when xt is increased to 4 mm. The gain varies between 0.8 to 5.6 dB from 1.66 to 20 GHz, giving the maximum from 7.5 GHz to 8 GHz.

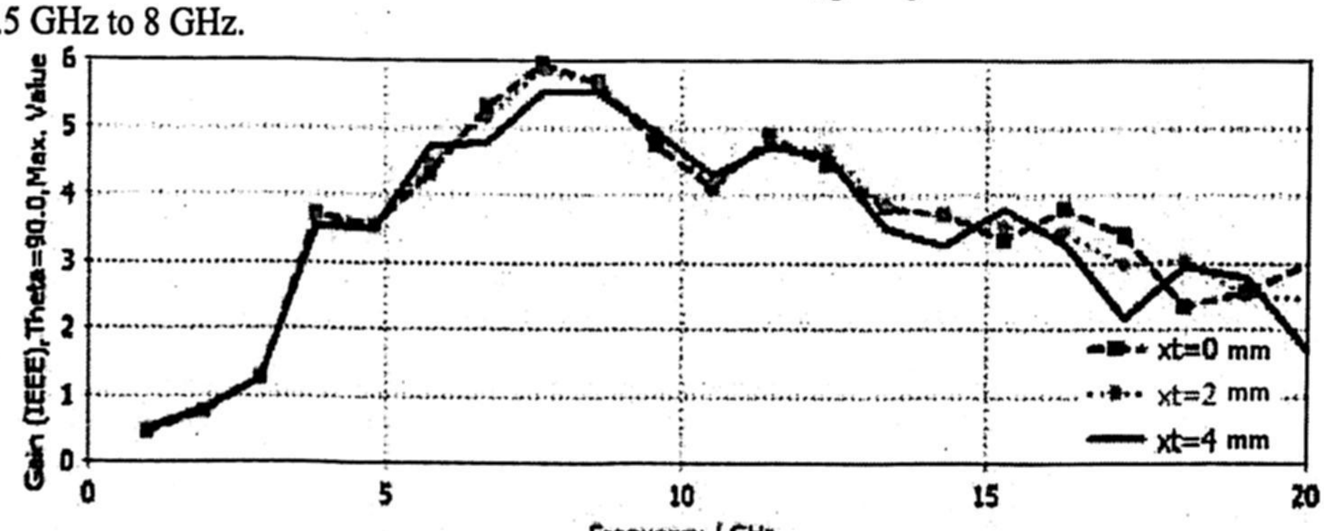
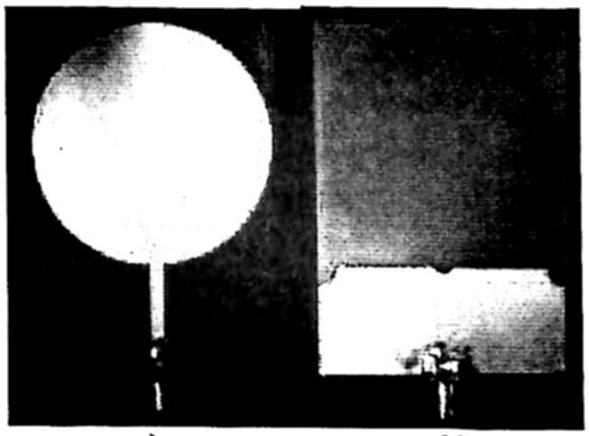


Fig. 4. Effect on the gain due to the two quarters of a circle removed in the edges of the ground plane.

Results

The circular monopole antenna was analyzed using the electromagnetic software *CST Microwave Studio*, giving the simulation results already shown in Figures 2 to 4 with dimensions shown in Figure 1 and with yc= 2 mm and xt= 4 mm. The antenna was fabricated on the two sides of a substrate FR-4 with 55 x 79 mm. In the microstrip feed line was soldered a SMA connector, as it is shown in the Figure 5. Figure 5a, present the front view showing the circular monopole, and Figure 5b the back view, where are shown the semicircular slots in the ground plane.



a) b)

Fig. 5. Fabricated antenna: a) Front, b) Back

The fabricated prototype was measured on a HP Vector Network Analyzer (8510A) calibrated from 1 to 20 GHz. The measured results are presented in Figure 6, compared to the theoretical results (Simulated) obtained with the EM software CST. In this Figure, it can be noted that the simulated parameter S11, is lower than the measured, particularly at high frequencies. Theoretical results show very good behavior in the 1.35 GHz to 20 GHz, while the measured ones provide a good performance from 1.66 GHz to 20 GHz.

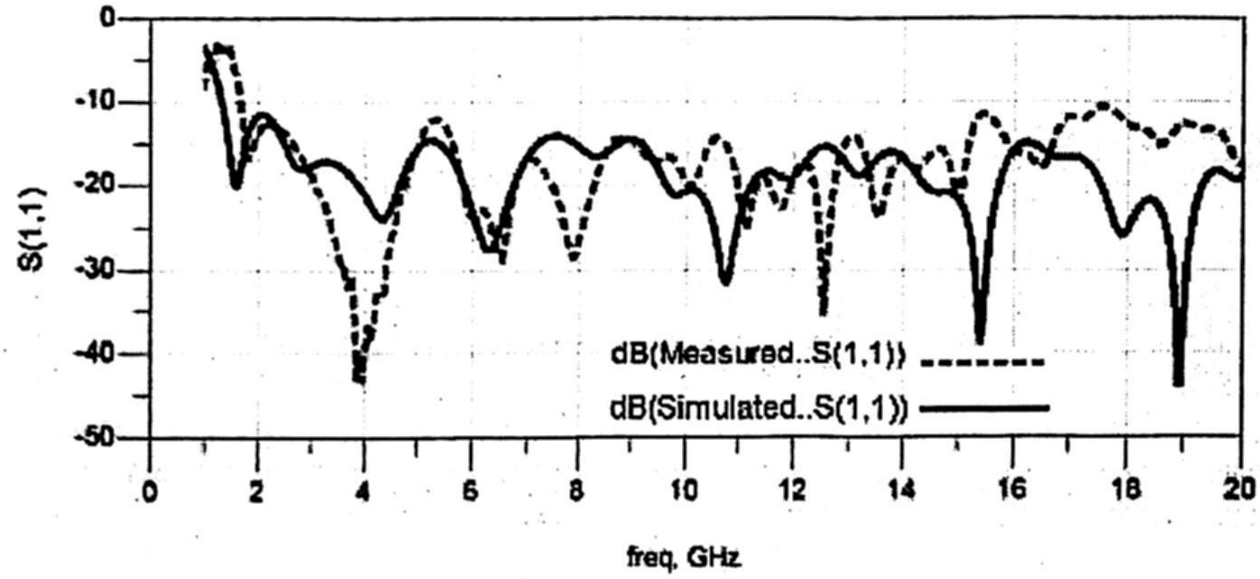


Fig. 6. Simulated and Measured Results.

As can be noted in Figure 6, the impedance bandwidth of this antenna is obtained when the S11 parameter < -10 dB.

Difference between theoretical and experimental results is attributed to fabrication errors in the construction process, where the dimensions of the antenna elements have changed slightly. The antenna dimensions were measured with a microscope, showing that two key parameters have changed, and caused a variation in the measured results respect to theoretical ones. These are yc (from 2mm to 1.6mm) and Wf (from 3.1 to 3.32mm).

It is worthy to mention that theoretical and measured results never will be exactly the same, because the electromagnetic analysis methods are only an approximation that can be more accurate when the number of cells used tends to infinity. This also can be seen in the comparison made in [2].

Figure 7 shows the theoretical and measured behavior, including a new EM analysis response using the physical dimensions measured, showing that the new results are closer to the measured ones.

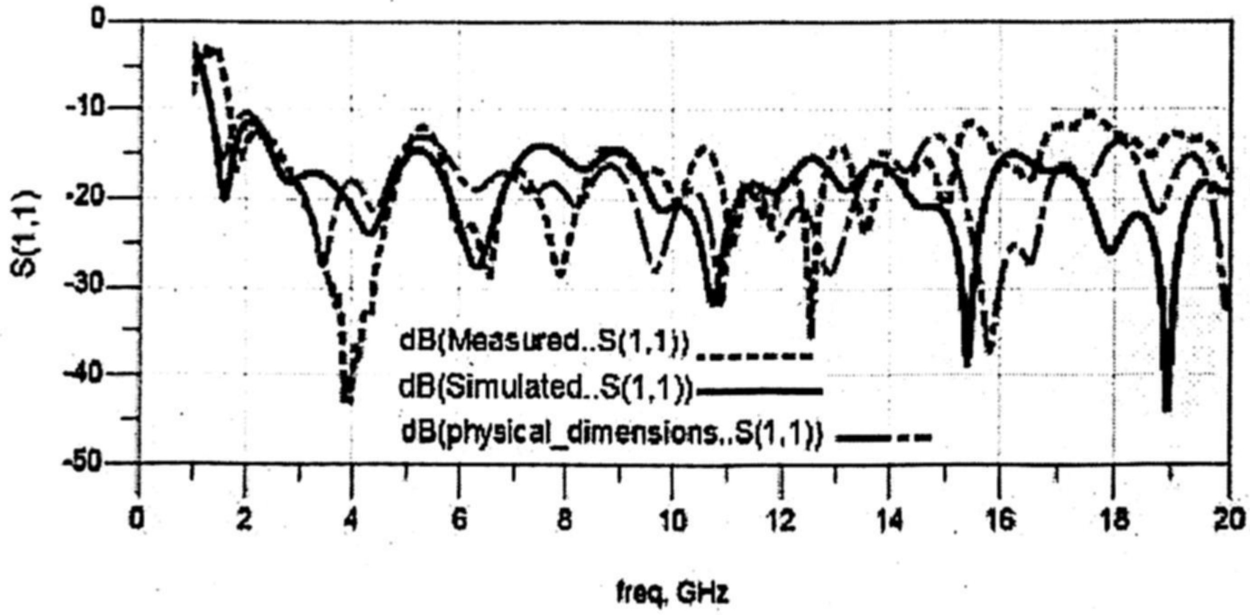


Fig. 7. Analysis of the structure with physical dimensions

Compared with previous work, in [2] an antenna design using a defected ground plane was presented, which has an impedance bandwidth of 8.2GHz. The proposed structure has the clearly advantage of a very large bandwidth behavior of 18.34 GHz compared with references [2], [16] and [17].

5 Conclusions

A circular monopole antenna was proposed and optimized for ultra wide band applications, based on a defected ground plane. To improve the impedance bandwidth and reduce the return losses, three semicircular slots in the ground plane were proposed. This antenna operates with a very good behavior from 1.66 GHz to 20 GHz, giving an extremely wide band allowing to be used in many applications, making possible its integration into mobile phones and other portable devices, due to the very small dimensions of the antenna. In addition to the presented results, the proposed antenna was analyzed to obtain other characteristics like the radiation pattern, beamwidth and efficiency at some frequencies. At 10.5 GHz the antenna shows an omnidirectional radiation pattern with a gain of 4.5 dB and 73% efficiency. The maximum efficiency was 88% at 3.1 GHz, and the minimum efficiency was 52% from 18 to 20 GHz where gain decreases to 2dBi.

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References

1. Kordzadeh, A., Hojat, F.: A new reduced size microstrip patch antenna with fractal shaped defects. In: Progress in Electromagnetics Research B, Vol. 11, 29–37 (2009)
2. Kushwaha, N., Kumar, R.: An UWB fractal antenna with defected ground structure and swastika shape electromagnetic band gap. In: Progress in Electromagnetics Research B, Vol. 52, 383-403 (2013)
3. Sadat, S., Fardis, M., Geran, F., G., Dadashzadeh, G., R.: A compact microstrip square-ring slot antenna for UWB applications. In: Progress in Electromagnetics Research, Vol. 67, 173-179 (2007)
4. Azim, R., Islam, M., T., Misran, N.: Compact tapered-shape slot antenna for UWB applications. In: IEEE Antennas and Wireless Propagation Letters, Vol. 10, 1190-1193 (2011).
5. Krishna, R., V., S., Raj, K.: Design of temple shape slot antenna for ultra wideband applications. In: Progress in Electromagnetics Research B, Vol. 47, 405-421 (2013)
6. Chen, H., D.: Broadband CPW-fed square slot antennas with a widened tuning stub. In: IEEE Transactions on Antennas and Propagation, Vol. 51, No. 8, 1982-1986 (2003)
7. Dastranj, A., Imani, A., Naser-Moghaddasi, A.: Printed wide-slot antenna for wideband applications. In: IEEE Transactions on Antennas and Propagation, Vol. 56, No. 10, 3097-3102 (2008)

8. Fallahi, R., Kalteh, A., A., Roozbahani, M., G.: A novel UWB elliptical slot antenna with band-notched characteristics. In: Progress in Electromagnetics Research, Vol. 82, 127-136 (2008)
9. Bahl, I., J., Bhartia, P.: Microstrip Antennas. Artech House, Dedham, MA (1980)
10. Kumar, G., Ray, K., P.: Broadband Microstrip Antennas. Artech House, Norwood, MA (2003)
11. Balanis, C., A.: Antenna Theory Analysis and Design. Wiley Publication, New Jersey (2005)
12. Garg, R., Bhartia, P., Bahl, I., J., Ittipiboon, A.: Microstrip Antenna Design Handbook. Artech House, Norwood, MA (2001)
13. Quintero, G., Skrivervik, A., K.: Analysis of Planar UWB Elliptical Dipoles fed by a Coplanar Stripline. In: IEEE International Conference on Ultra Wideband, Vol. 1, 113-116 (2008)
14. Powell, J., Chandrakasan, A.: Differential and Single Ended Elliptical Antennas for 3.1-10.6 GHz Ultra Wideband Communication. In: IEEE Antennas Propagation Society Int. Symp., Vol. 3, 2935–2938 (2004)
15. Liang, J., Guo, L., Chiau, C., C., Chen, X.: CPW-Fed Circular Disc monopole Antenna for UWB Applications. In: IEEE International Workshop on Antenna Technology, 505-508 (2005)
16. Shashwat, C., Sanjay, S., Shashank, C., Sachin, S., Sachin, S.: Ultra-Wide bandwidth Circular Monopole Antenna. In: International Journal of Scientific Research Engineering & Technology (IJSRET). Vol. 1, 279-282 (2012)
17. Sonar, A., F., Mishra, R., P., Mhaskar, J., Kharche, S.: UWB Circular Monopole Antenna. In: ITSI Transactions on Electrical and Electronics Engineering. Vol. 1, 2320–8945 (2013)