ISSN : 2231-0711
Samer N. Naji et al | International Journal of Computer Science Engineering and Technology(IJCSET) | Dec 2014 | Vol 4, Issue 12,404-411

Design and Simulation of UWB Monopole Disk Antenna

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***Abstract*— Because of their broadband characteristics ultra-wideband (UWB) antennas continue to capture the interest of many researchers and developers worldwide especially those involved in areas such as high data rate wireless communications, indoor positioning, and through-the-wall imaging. However, these systems are required to work side by side with other narrowband applications such as WiMAX and WLAN systems without causing any performance degradation. For this reason, a monopole disk antenna is presented here to cover the whole IEEE 802.15.4a UWB designation with two band notches at 3.5 and 5/6 GHz for interference-free operation with WiMAX and WLAN systems, respectively. The presented design incorporates a C-slot and a hairpin slot in the radiating disk and microstrip feed line, respectively, to allow for the two band notches. It also incorporates a set of circular cuts in the truncated ground plane on the backside of the substrate to allow for extended freedom in setting out the design parameters for achieving the desired performance.**

I. Introduction

Ultra Wideband Radio (UWB) is a potentially revolutionary approach to wireless communication in that it transmits and receives pulse based waveforms compressed in time rather than sinusoidal waveforms compressed in frequency. This is contrary to the traditional convention of transmitting over a very narrow bandwidth of frequency, typical of standard narrowband systems such as 802.11a, b, and Bluetooth. This enables transmission over a wide swath of frequencies such that a very low power spectral density can be successfully received [1].

In addition, with the release of the 3.1 - 10.6 GHz band for ultra-wideband (UWB) operation, a variety of typical UWB applications evolved; examples are indoor/outdoor communication systems, ground-penetrating and vehicular radars, wall and through-wall imaging, medical imaging and surveillance [2].

For communication applications, high data rates are possible due to the large number of pulses that can be created in short time duration. Due to its low power spectral density, UWB can be used in military applications that require low probability of detection. Other common uses of UWB are in radar and imaging technologies, where the ability to resolve multipath delay is in the nanosecond range, allowing for finer resolution whether it be from a target or from an image. After recognizing the potential advantages of UWB, FCC developed a report to allow UWB as a communications and imaging technology. A UWB definition was created as a signal with a fractional bandwidth greater than 0.2, or which reserve more than 500 MHz of spectrum [3].

The rapid development of components and systems for future ultra-wideband (UWB) technology has significantly increased measurement efforts within the electromagnetic compatibility community. Therefore, frequency- and time-domain testing capability for UWB compliance is at the forefront of research and development in this area. Within such testing systems, the UWB antenna is a specific component whose transmitting and receiving properties differ from those for conventional narrowband operation. Several antennas have been developed [2].

It is a well-known fact that planar monopole antennas present appealing physical features, such as simple structure, small size and low cost. Additionally, planar monopoles are compact broadband omnidirectional antennas, and are non-dispersive. Due to all these interesting characteristics, planar monopoles are extremely attractive to be used in emerging UWB applications, and growing research activity is being focused on them. An important effort has been made to find the planar shape, which provides the wider input bandwidth. Consequently, a number of planar monopoles with different geometries have been experimentally characterized and automatic design methods have been developed to achieve the optimum planar shape [4].

Monopole antennas have several advantages but for their narrow bandwidth. Broadband planar monopole antennas have all the advantages of the monopole in terms of their cost, and ease of fabrication besides, yielding very large bandwidths. For many applications, large bandwidth is required. Recently, many techniques to tailor and optimize the impedance BW of these antennas have been investigated. These include the use of bevels, slots and shorting posts. These antennas are becoming popular, and have been proposed for modern and future wideband wireless applications [5].

The problem of achieving a wide impedance bandwidth (e.g., greater than or about 10% suitable for present-day cellular communication systems) for a compact microstrip antenna is becoming an important topic in microstrip antenna design. Recently, for a compact design using a shorted patch with a thick air substrate, the obtained impedance bandwidth (10-dB return loss) has been reported to be 10% or much greater. This kind of broadband-shorted patch antenna is conventionally fed by using a probe feed [6].

Broadband techniques suitable for applications for compact microstrip antennas with a thin dielectric substrate are available in the open literature. One of these compact broadband techniques uses a chip resistor of low resistance (usually approximately 1 Ω) connected between the antenna's radiating patch and ground plane. In this case, with the chip-resistor loading technique, similar antenna size reduction to the compact design using shorting-pin loading can be obtained. Moreover, owing to the introduced small ohmic loss of the chip resistor, the quality factor of the microstrip antenna is greatly lowered. When an inexpensive FR4 substrate of thickness 1.6 mm and relative permittivity 4.3 is used, such a chip-resistor-loaded microstrip antenna can have an impedance bandwidth of about 10% or greater [6].

II. REFERENCE MONOPOLE ANTENNA

The geometry of the monopole disk antenna is shown in Fig. 1. To determine the initial parameters of the monopole disk antenna, we should first understand their operation mechanism. It has been shown that disc monopoles with a finite ground plane are capable of supporting multiple resonant modes instead of only one resonant mode (as in a conventional circular patch antenna) over a complete ground plane.

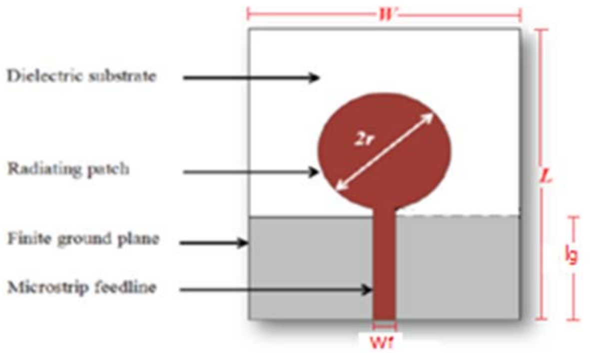


Figure 1: The configuration of the monopole disk antenna showing the necessary antenna parameters.

Overlapping closely spaced multiple resonance modes (f_1, f_2, f_3… f_N) as shown in Fig. 2 can achieve a wide bandwidth and this is the idea behind the UWB bandwidth of circular disc monopole antennas. The frequency of the first resonant mode can be determined by the size of the circular disc. At the first resonance f_1, the disc antenna tends to behave like a quarter-wavelength monopole antenna, i.e. $\lambda/4$.

That means the diameter of the circular disc is $2r = \lambda/4$ at the first resonant frequency. Then the higher order modes, f_2, f_3… f_N will be the harmonics of the first or fundamental mode of the disc. Unlike the conventional patch antennas with a complete ground plane, the ground plane of disc monopole antennas should be of a finite length lg to support multiple resonances and hence achieve wideband operation. The width of the ground plane W is found to be approximately twice the diameter of the disc or $W=\lambda/2$ at the first resonance frequency [7].

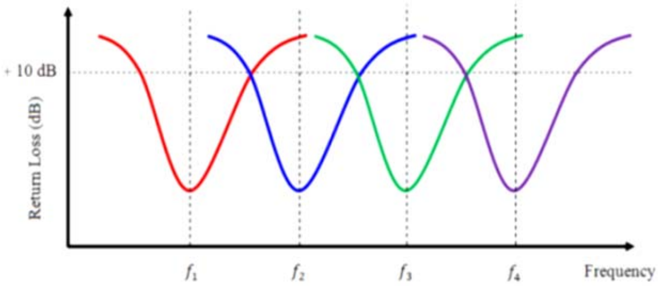


Figure 2: The concept of overlapping closely spaced multiple resonance modes for the monopole disk antenna [7].

Fig. 3 shows the geometry of the UWB monopole disk antenna. The antenna is to be modelled using an FR4 substrate with thickness of 1.6 mm and relative permittivity of 4.2. On the front surface of the substrate, a rectangular radiating patch with initial dimensions of 28 mm × 35 mm, has been etched.

For design convenience, a 50 Ohm microstrip line printed on the radiator side of the substrate feeds the proposed antenna. The feed line width is of about 3 mm, and is symmetrically located with respect to both the radiating element and the ground plane. On the other side of the substrate, a conducting ground plane of 28 mm × 13 mm is placed and Table 1 shows the dimensions of the antenna.

Table 1: Reference Antenna Parameter and Dimensions.

Parameter	Description	Value
H	Thickness of substrate	1.6 mm
L	Length of substrate	35 mm
Mt	Thickness of patch	0.1 mm
W	Width of substrate	28 mm
lf	Length of feed line	13 mm
lg	Length of ground	11 mm
r1	Radius of circular patch	10 mm
wf	Width of feed line	3 mm
εr	Dielectric Constant	4.3 mm

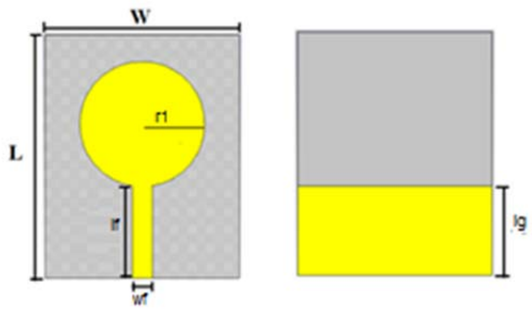


Figure 3: The proposed antenna.

A- *Effect of the Ground Length on the Bandwidth*

The return loss responses of the modelled antenna, shown in Fig. 4, have been carried out for different lengths of the ground plane lg. It is clearly shown that the variation of the ground plane has little effect on the lower frequency F_L position, while its effect on the higher frequencies becomes clearer.

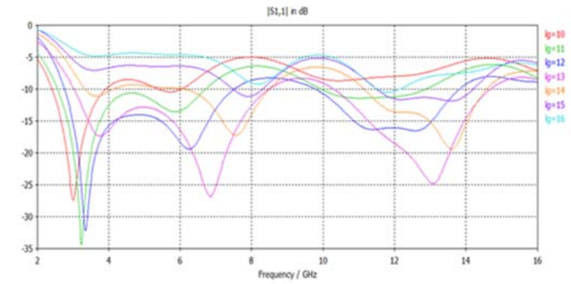


Figure 4: The return loss responses of antenna structure with variable lg

Fig. 4 illustrates that the variation of the ground length has an effect on the bandwidth of the design, as it will change the number of pass band frequencies and the high and low cut-off frequencies. Also, it can be noticed that when the length of ground is almost the same as the length of the feed line (13 mm) gives the broadest bandwidth while increasing the difference between the feed line and ground length will decrease the bandwidth.

B- The Effect of Radius of Circular Patch on the Bandwidth

The return loss responses of the modelled antenna, shown in Fig. 5, have been carried out for different radius of the disk patch r1. It is clearly shown that the variation of the diameter has little effect on the lower frequency F_L position, and improve the BW for the range of frequencies 9-11 GHz as r1 increased.

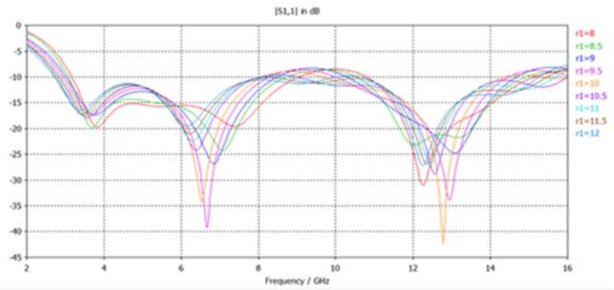


Figure 5: The return loss responses of antenna structure with variable r1

Fig. 5 shows that by increasing the radius of the disk patch the more bandwidth can be obtained as the larger the radius is the higher the bandwidth is, as it will affect the higher and lower cut-off frequencies as well as the resonance frequency, the lower $S_{1,1}$ at the resonance frequency it will be granted more bandwidth.

C- The Effect of Feed Line Length on the Bandwidth

Fig. 6 represents the return loss responses of the modelled antenna that have been carried out for different lengths of the feed line lf. It is clearly shown that the variation of the feed length has little effect on the lower frequency F_L position, and improves the BW for the range of frequencies 7-12 GHz.

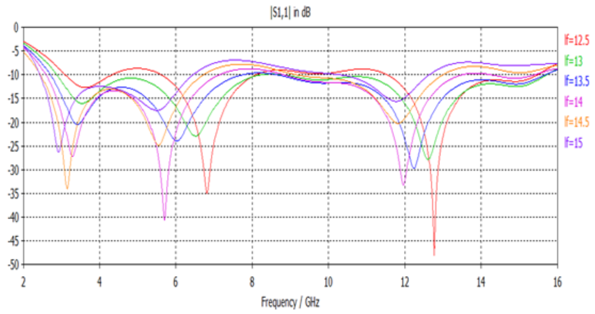


Figure 6: The return loss responses of antenna structure with variable lf

From Fig. 6 it can be observed that as the variation of the length of feed line will affect the higher and lower cut-off frequencies hence it will affect the bandwidth of the design. Also the best bandwidth can be obtained when the length of the feed line is almost the same as the length of the ground plane while when the difference is large we get lower bandwidth.

D- The Effect of Feed Line Width on Bandwidth

The return loss responses of the modelled antenna for different width of the feed line wf is shown in Fig. 7. It is clearly shown that the variation of the feed width improved the BW for the range of frequencies 7-9 GHz.

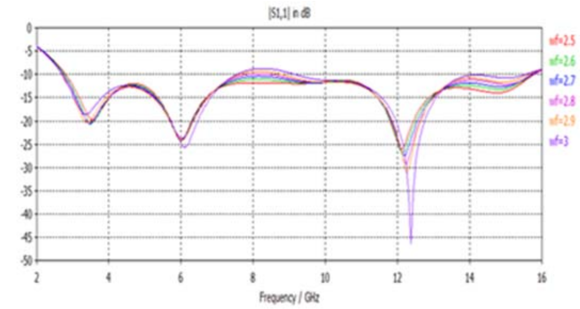


Figure 7: The return loss responses of antenna structure with variable wf

III. IMPROVING ANTENNA BANDWIDTH WITH GROUND SLOT TECHNIQUE

The techniques of ground-cut slots and miniaturization are applied in the design of microstrip antenna which reduces the resonance frequency and enhances the bandwidth. In the following subsections a half circle ground slots has been implemented in order to enhance the bandwidth.

A- Single Ground Slot

Fig. 8 represent the geometry of the ground plane with a half circle slot. The slot has a radius of r_g. The slot radius has an effect on the upper cut off frequencies and the range of frequencies 5-8 GHz.

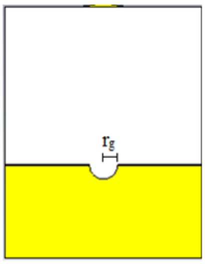


Figure 8: The ground of the antenna with one slot.

Fig. 9 shows the effect of ground slot radius on the return loss.

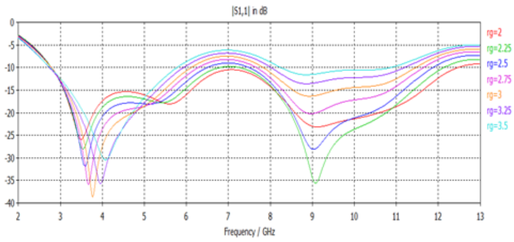


Figure 9: The return loss response of one slot.

It can be observed that, the radius of the slot variation has an effect on the upper cut off frequencies only. An enhancement in the frequency range 5-8 GHz can be obtained by decreasing the slot radius.

B- Three Ground Slot

Now, after examining one slot performance we triplicate it to both side of the ground plan, with half size of the radius of the middle slot is shown in Fig. 10 which represent the geometry of ground plan.

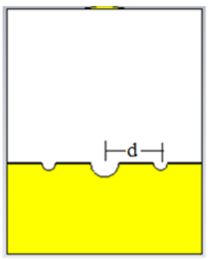


Figure 10: The ground of the antenna with three slots.

Fig. 11 shows the return loss response of the modelled antenna for a sweep of the parameter (d) depicted in Fig. 10.

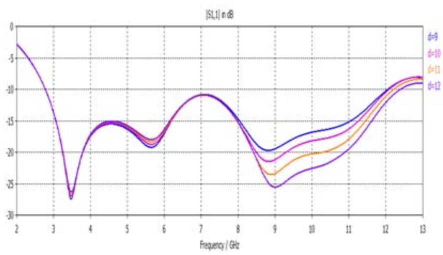


Figure 11: Return loss response of three ground slots with deferent d values.

As increasing the distance between the slots will get better performance in the range of frequencies 8-12 GHz and it will slightly effect the upper cut off frequencies.

IV. Monopole Disk Antenna with C-Slot for 3.5 GHz Notch Response

In this section, we have investigated and proposed a modified circular disc with C - slot to obtain a notch frequency response at 3.5 GHz. Fig. 12 shows the proposed geometry. The slot have a radius of 6 mm, and width of 0.45 mm, while Q represent the half angle subtended by C slot, and r2 the radius of the C – circle and r2c represents the width of C-slot.

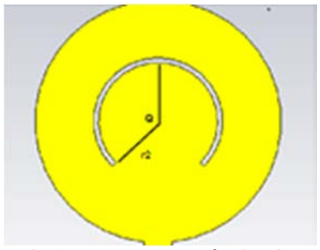


Figure 12: Antenna structure for 3.5 GHz notch

A- *Variation of Q angle*

The modelling of this geometry for different values of Q shows that the centre frequency of the notch can be controlled by changing the angle subtended by C slot as shown in Fig. 13

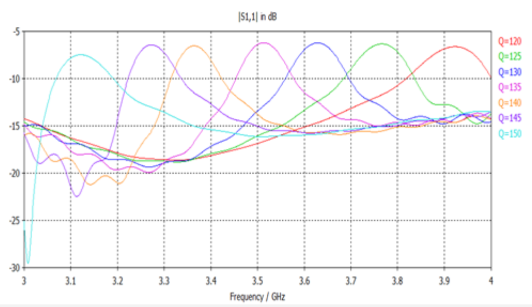


Figure 13: The return loss response of 3.5 GHZ notch for different Q values.

The angle of C slot had inverse relation with the centre frequency of the notch and has a slight effect on the notch bandwidth.

B- *Variation of r2*

Fig. 14 represents the return loss response of the notch structure for different values of r2. It is found that the effect of r2 variation is similar to the effect of C slot angle.

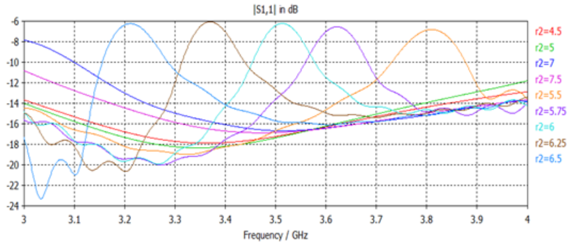


Figure 14: The return loss response of 3.5 GHZ notch for different r2 values.

C- Variation of r_{2C}

The return loss response of the notch structure are shown in Fig. 15 for different values of r2c, which is clearly seen to control the centre frequency of notch.

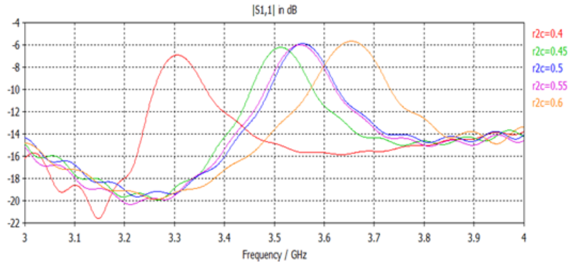


Figure 15: The return loss response of 3.5 GHZ notch for different r2C values.

As it can be seen that the width of C-slot are linearly related with the centre frequency of the notch.

V. Monopole Disk Antenna with Hairpin Slot for 5/6 GHz Notch Response References

In this section, we have investigated and proposed a modified feeding with hairpin slot to obtain a notch frequency response at 5.5 GHz. Fig. 16 shows the proposed geometry.

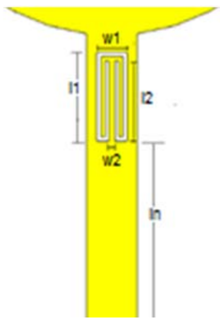


Figure 16: Antenna feed structure with 5.5 notches

The hairpin slot has the following parameters as shown in Table 2.

Table 2: 5.5 GHz Notch parameters

Parameter	Description	Value
w1	Width of the hairpin	1.4 mm
w2	Distance between the two pins	0.3 mm
l1	Length of the hairpin	4.2 mm
l2	Length of the inner pin	3.8 mm
ln	The distance from the feed line edge to the hair pin	8 mm
S	Slot width	0.2 mm

A- l1 Effect:

Fig. 17 shows the return loss response of the antenna for different values of l1.

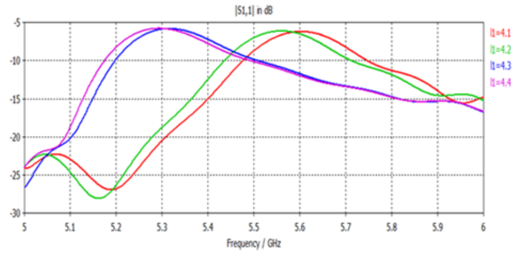


Figure 17: Notch response for different values of l1.

It can be seen that by increasing l1 the centre frequency of the notch will be decrease.

B- ln Effect:

Fig. 18 shows the return loss response of the antenna for different values of ln.

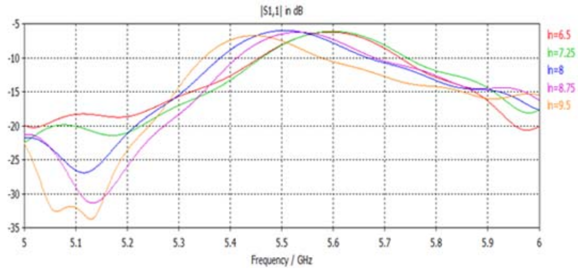


Figure 18: Notch response for different values of ln.

It is found that the effect of ln variation is similar to the effect of l1.

C- w1 Effect:

Fig. 19 shows the return loss response of the antenna for different values of w1.

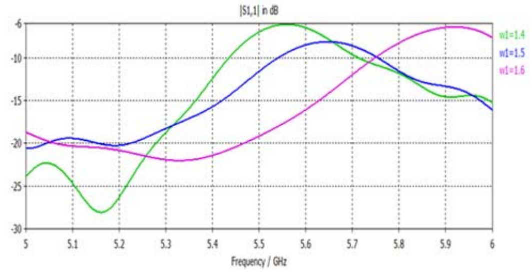
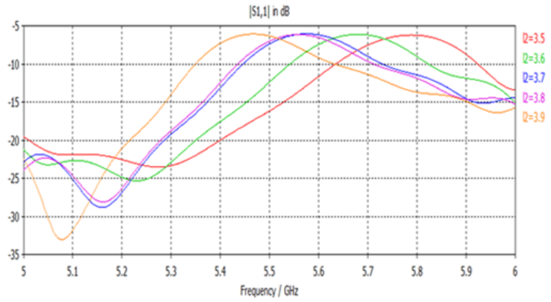


Figure 19: Notch response for different values of w1

It can be seen that by increasing w1 the centre frequency of the notch will be increase.

D- l2 Effect:

Fig. 20 shows the return loss response of the antenna for



different values of l2.

Figure 20: Notch response for different values of l2.

Increasing l2 has an effect of decreasing the notch centre frequency.

VI. Optimization, Simulation and Implementation

PSO is a computational method that optimizes a problem by iteratively trying to improve a candidate solution with regard to a given measure of quality. PSO optimizes a problem by having a population of candidate solutions, here dubbed particles, and moving these particles around in the search-space according to simple mathematical formulae over the particle's position and velocity. Each particle's movement is influenced by its local best-known position but is also guided toward the best-known positions in the search-space, which are updated as better positions are found by other particles.

As expected, the parallel PSO algorithm optimizes the return loss (S_{11}) of the designed antennas and improves antenna bandwidth and notch selection. The PSO tries to find the optimum performance for the design that has below the threshold value given in the fitness function which is the return loss should be less than -10 dB.

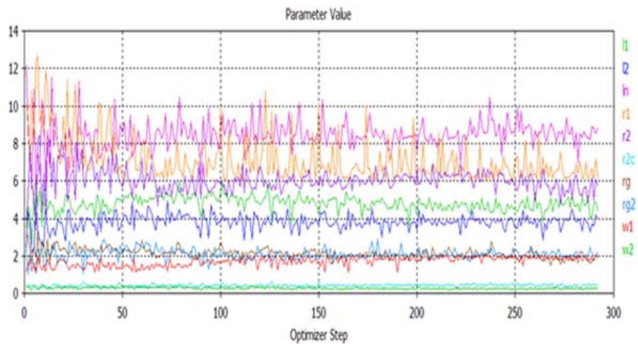


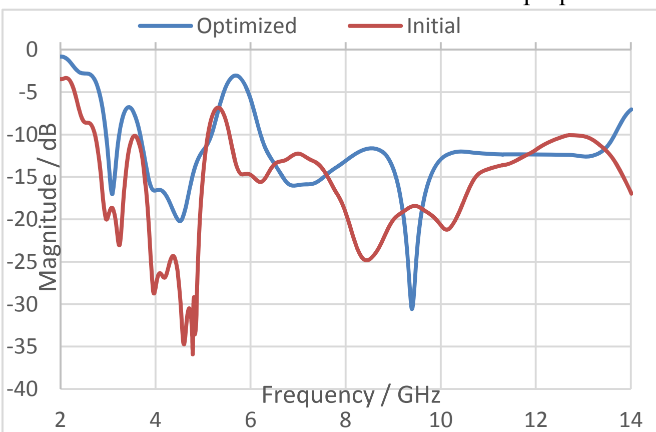
Fig. 21 shows the optimizer steps, while Table 3 represent the optimum values for the design.

Figure 21: Optimizer steps.

Table 3: Optimum value of the design.

Parameter name	Value (mm)
Q	159.61448107918
l1	4.3702460207262
l2	3.9789111303329
ln	8.8624393631625
r1	6.1181578189376
r2	5.6831193991463
r_{g1}	1.884324306533
r_{g2}	2.2706023538993
w1	2.0127849441502
w2	0.26395930718313

The electromagnetic performance of the optimized antenna is simulated using the electromagnetic CST MWS simulator. The return loss characteristics for the optimized antennas are shown in Fig. 22. The return loss for the reference antenna is also shown for the purpose of



comparison.

Figure 22: The return loss responses of the optimized and initial design.

Fig. 23 and 24 represent the VSWR and gain response, as it shows clearly the antenna bandwidth with the notch in (3.5

& 5.5) GHz as both bands are rejected from the desired bandwidth to eliminate the WiMAX and WLAN applications.

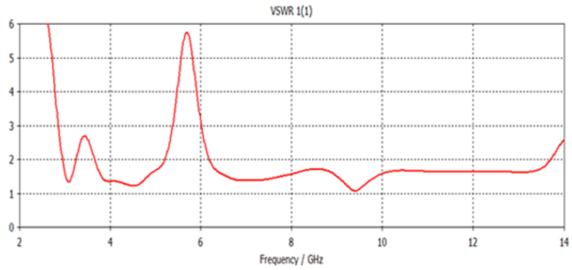


Figure 23: VSWR response of the Optimized Design

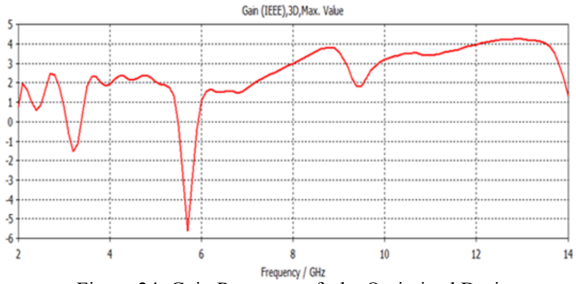


Figure 24: Gain Response of- the Optimized Design

Implementation had been carried using LPKF ProtoMat S100 rapid PCB prototyping machine for the fabrication of the optimized antennas. The photographs of the first fabricated antenna prototype are shown in Fig. 25.

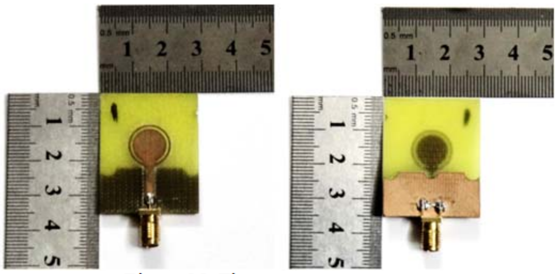


Figure 25: The prototype antenna.

After the construction, the characteristic measurements were performed using Vector Network Analyzer (VNA-MS4642A). The return loss and input impedance versus frequency were measured for the first fabricated antenna and are shown in Fig. 26.

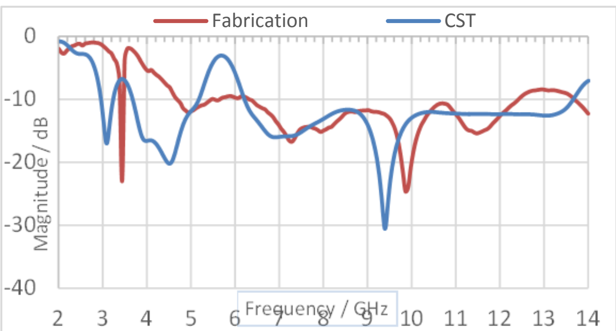


Figure 26: the measured and simulated return loss response.

Group delay is an important characteristic because it helps to indicate how well a UWB pulse will be transmitted and to what degree it may be distorted or dispersed. If the phase is linear throughout the frequency range, the group delay will be constant for the frequency range. This Linear phase and low dispersion ensure low values of group delay, which is imperative for transmitting and receiving a pulse with minimal distortion.

From the Fig. 27, it can be seen that the group delay is less than 0.8 in almost all the range of frequencies.

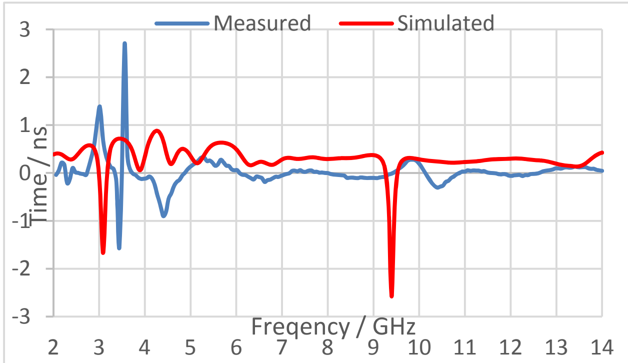


Figure 27: Group delay for simulated and measured results.

VII. CONCLUSION

In this work an UWB monopole disk antenna had been designed, optimized and implemented for the UWB range of frequency from 2.95 GHz to 13.66 GHz, as it is simply constructed on a 35 mm × 28 mm substrate. It can easily integrated in any device.

The conventional UWB monopole antenna is modified for producing dual band-notched frequency to avoid the interference signals of WLAN IEEE 802.11a/h/n and WiMAX systems. The combining of the C-shaped slot on radiating circular patch and hairpin slot on microstrip transmission line causes the rejection bands with centre frequencies of 3.5 and 5.5 GHz.

The group delay of the antenna has acceptable range, which is less than 0.8 ns, which satisfy the UWB applications. With these features, the proposed antenna seems to be attractive for the UWB communication applications. As the low values of group delay will ensure low distortion and low dispersion.

ACKNOWLEDGEMENTS

The authors gratefully acknowledge the support from Ghaleb N. Radad, Ahmed Jafar and Mahmood R. Muhsen from Ministry of science and technology for their excellent technical assistance and providing laboratory facilities for practical implementation and testing of the fabricated antenna.

REFERENCES

[1] Johnna Powell, "Antenna Design for Ultra Wideband Radio", New Mexico State University, 2001.

[2] Hung-Jui Lam, "Ultra-Wideband Antenna in Coplanar Technology", University of Victoria, 2005.

[3] Malay Yadav, "Coplanar Waveguide Fed UWB Antenna with Dual Band Notch Characteristics", Thapar University, 2012.

[4] M. Ferrando Bataller, M. Cabedo Fabrés, E. Antonino Daviu and A. Valero Nogueira, "Overview of Planar Monopole Antennas for UWB Applications", Proc. 'EuCAP 2006', Nice, France, November 2006.

[5] Rajender Singh, "Broadband Planar Monopole Antennas", M. Tech credit seminar report, Electronic Systems group, EE Dept., IIT Bombay, November 2003.

[6] Kin-Lu Wong, "Compact and Broadband Microstrip Antennas", John Wiley & Sons Ltd, 2002.

[7] Osama Haraz and Abdel-Razik Sebak, "UWB Antennas for Wireless Applications", Concordia University, Canada, 2013.