Improvement and Optimization of Thin Dipole for UWB Applications

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ABSTRACT:
In this paper, thin dipole is investigated in the 3.1-10.6 GHz Ultra-Wide Band frequency range. The study includes the design of half wave dipole antenna with different dipole radii to improve the antenna characteristics. Antenna parameters including return loss, Voltage Standing Wave Ratio, -10 dB bandwidth and radiation pattern are examined according to Federal Communication Commission regulations and Ultra-Wide Band system requirements in this frequency range. Additionally, two optimization techniques, Genetic Algorithm and Particle Swarm Optimization are applied to obtain the best dipole radius. CST Microwave Studio, an electromagnetic simulation program, is used for the design of the antenna structure and the simulation purposes. The simulation is performed in transient mode. The results show that the antenna performance can be improved by selecting the suitable antenna dimensions. Additionally, Genetic Algorithm and Particle Swarm Optimization techniques are compared in terms of time consumption to obtain the best VSWR and return loss values. The results also depict that Genetic Algorithm yields better results for the proposed structure.

KEYWORDS: Antenna Design, CST MWS, GA, PSO, Thin Dipole, UWB.

1. INTRODUCTION

The Ultra-Wide Band (UWB) systems have expanded rapidly after the Federal Communications Commission (FCC) allowed the unlicensed use of frequency spectrum by ultra-short pulse signals. There has been a flourishing prospect of UWB technology in recent years for both communication and other purposes such as microwave imaging and radar applications. The design of the UWB antennas is vigorous and rigorous issue which needs considerable research effort in order to adapt to UWB requirements. Federal Communications Commission limited the frequency band between 3.1 GHz and 10.6 GHz due to the extremely wide operating bandwidth for UWB applications [1]. Thus, according to FCC rules, -10 dB bandwidth should be between 3.1 and 10.6 GHz for UWB requirements. In other words, Return Loss should be below -10 dB along that frequency range. Similarly, VSWR should be below 2 in the UWB frequency band of interest. Numerous parameters such as radiation pattern, return loss, VSWR, gain and directivity are required so as to design the UWB antenna effectively.

Half wave dipole has a simpler structure as compared to other antenna types and it has some advantageous features such as reasonable size, radiation pattern uniformity, manageable input impedance, and gain consistency. Many UWB half wavelength antennas have been discussed in the literature to investigate the antenna characteristics over the frequency range of interest [2-7].

In this study, a half wave dipole antenna is designed and simulated via CST Microwave Studio. Additionally, theoretical and practical aspects are presented. The antenna is simulated in transient mode in order to observe antenna characteristics while the radius of the dipole arm is changed. Taking everything into account, simulation results show that possible improvements of the antenna parameters can be achieved by selecting the optimal antenna dimensions.

2. HALF WAVE DIPOLE ANTENNA DESIGN

The center frequency of proposed antenna is calculated in the UWB frequency range (3.1 GHz-10.6 GHz) by using relation in Equation (1). According to calculation, the center frequency is obtained as 6.85 GHz. Thus, all antenna dimension parameters are calculated at the resonant frequency, 6.85 GHz, in order to observe antenna behavior for UWB applications [2]. Length, feeding gap, wavelength and radius of the antenna are calculated through equations (2-5) respectively as follows:

$$f_{center} = \frac{f_{upper} + f_{lower}}{2} = \frac{10.6\ GHz + 3.1\ GHz}{2} = 6.85\ GHz \quad (1)$$

$$L = 143/f_{center} = 143/6.85\ GHz = 20.9\ mm \quad (2)$$

$$g = L/200 = 0.1045\ mm \quad (3)$$

$$\lambda = c/f_{center} = 3x10^8/6.85\ GHz = 43.8\ mm \quad (4)$$

$$r = \lambda/1000 = 0.0438\ mm \quad (5)$$

Table 1 presents dimensions of the proposed half wave dipole. Besides, Fig. 1 presents the designed half wave dipole with front view and top views. The antenna is simulated in transient mode by using CST Microwave Studio. Gaussian pulse is applied as the excitation signal which is shown in Fig. 2. Global mesh properties are adjusted for obtaining more accurate results.

Table 1. Calculated antenna dimensions.

Parameter	Value
f_{center}	6.85 GHz
Wavelength (λ)	43.8 mm
Feeding gap (g)	0.1045 mm
Radius (r)	0.0438 mm

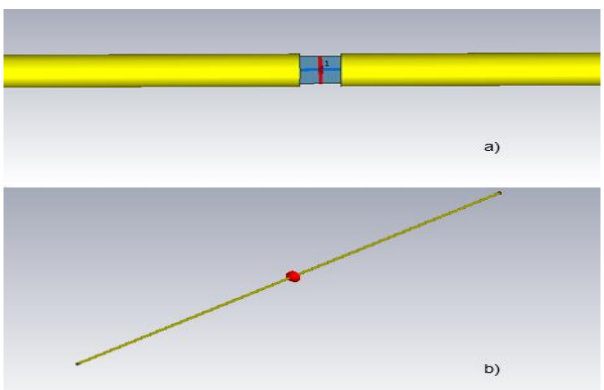


Fig. 1. Half Wave Dipole Antenna Geometry
a) Front View b) Top View.

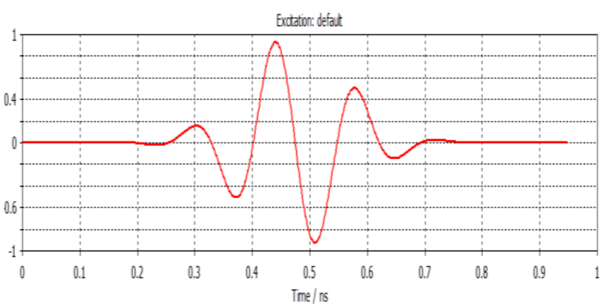


Fig. 2. Excitation Signal-Gaussian Pulse.

Fig. 3 illustrates the impedance characteristics of the simulated antenna. The proposed antenna impedance is around 74 Ω, which is compatible with theoretical approach.

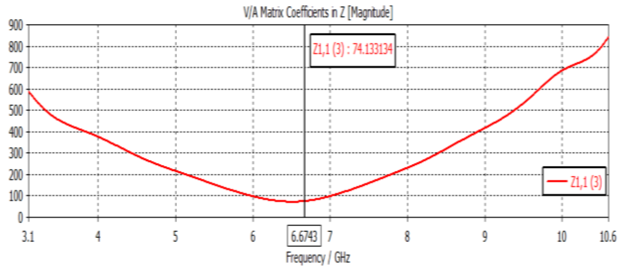


Fig. 3. Impedance characteristic of the proposed half wave dipole antenna.

Return loss and VSWR characteristics for the half wave dipole antenna are shown in figures of 4 and 5, respectively. In Fig. 4, antenna is resonating at 6.6743 GHz. The -10 dB impedance bandwidth of the proposed antenna extends in the 6.3088-7.1065 GHz range. Corresponding bandwidth is calculated as 798 MHz. Furthermore; minimum return loss is equal to approximately -40.49 dB. As Fig. 5 indicates, VSWR is smaller than 2 (VSWR≤ 2) and S_{11} is smaller than -10 dB (S_{11}≤ -10 dB) throughout the 6.3088 GHz - 7.1065 GHz frequency range. Nevertheless, this frequency range (6.3088 GHz-7.1065 GHz) is narrow for UWB applications. Thus, various enhancement techniques need to be applied in order to have better antenna characteristics such as larger bandwidth, lower VSWR and return loss values over the desired frequency range.

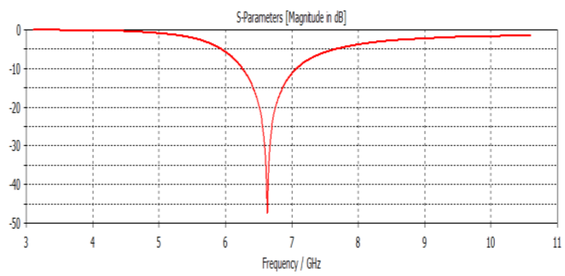


Fig. 4. Return loss characteristic of the half wave dipole antenna.

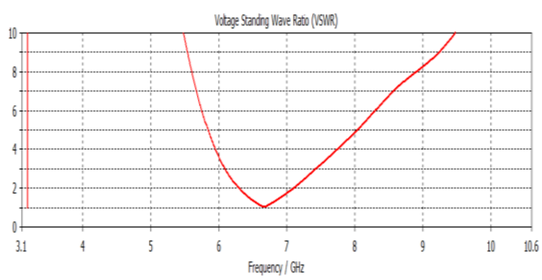


Fig. 5. VSWR versus frequency plot for the proposed half wave dipole antenna.

The simulated radiation patterns for the dipole are sketched in Figures 6 a, b and c at 4, 5, and 6 GHz, respectively. It is apparent from these figures that proposed antenna has omnidirectional radiation pattern at all three frequencies. In the figures, as the frequency increases, main lobe magnitude increases while 3 dB beamwidth decreases.

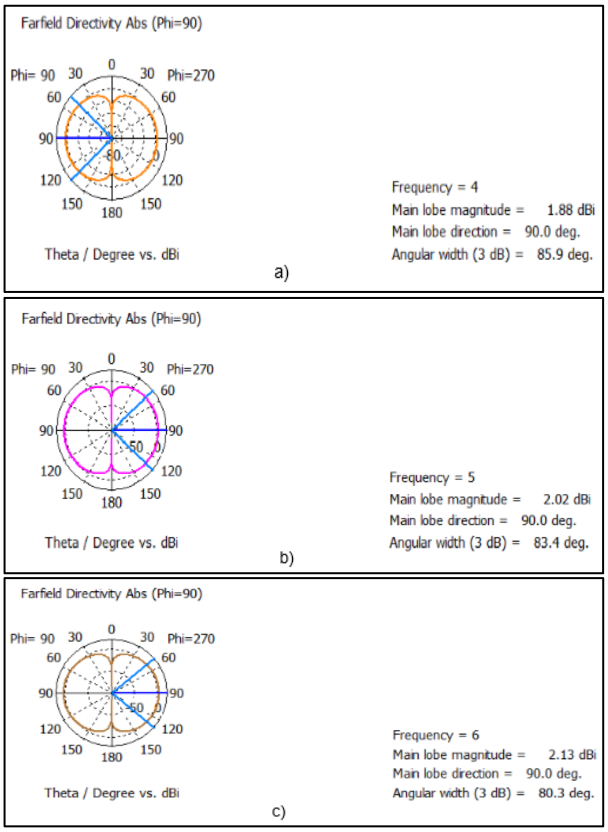
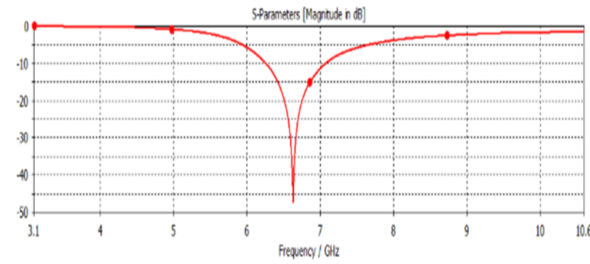


Fig. 6. Radiation Pattern for half wave dipole antenna with frequency a) 4 GHz b) 5 GHz c) 6 GHz, respectively.

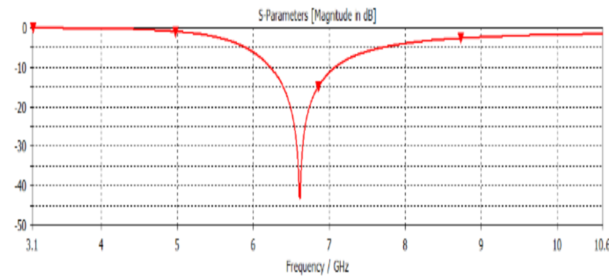
2.1. Radius Effect

Dipole antenna is one of the significant antenna structures in antenna design problems. While thin dipole is considered, the radius of the dipole is assumed to be very small as compared to the antenna length. When thin dipoles are examined, the bandwidth of the proposed antenna reduces or increases slightly depending on the value of the dipole radius. Various mathematical approaches are used to figure out how the radius affects the bandwidth characteristics. One method is to change the length to radius ratio (L/r) in order to improve the bandwidth.

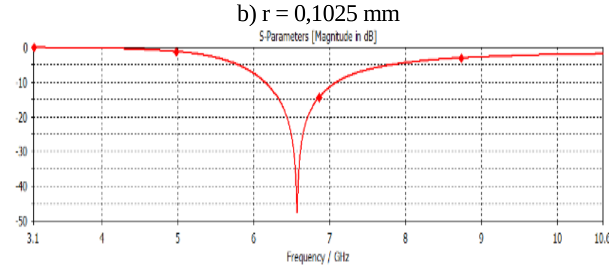
Fig. 7 illustrates the return loss characteristics of the half wave length dipole with different radii (r = 0.07, 0.1025, 0.135, 0.1675, 0.2 mm, respectively) when the other dimensions are fixed as given in Table 1. As seen from Fig. 7, when radius (r) increases, the bandwidth of the proposed antenna also increases. The bandwidth for each case has been calculated as 814.4 MHz, 844 MHz, 940.3 MHz, 984.7 MHz, and 1.0217 GHz, respectively.



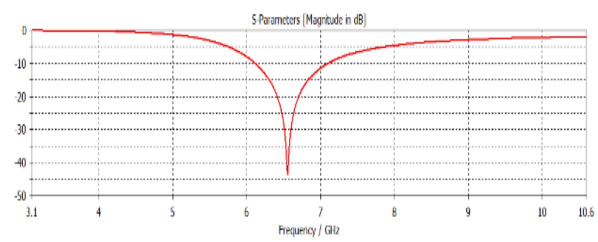
a) r = 0.07 mm



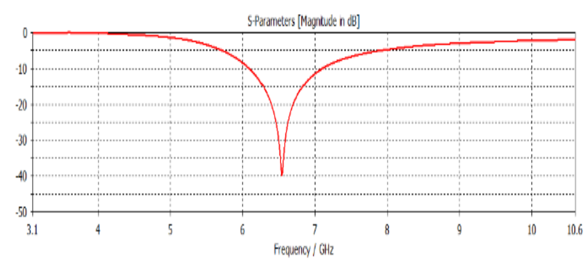
b) r = 0,1025 mm



c) r = 0,135 mm



d) r = 0,1675 mm



e) r = 0,2 mm

Fig. 7. Simulated return loss curve of half wave dipole for different radius r with a) 0.07 b) 0.1025 c) 0.135 d) 0.1675 e) 0.2 mm, L=20.9 mm and g =0.1045 mm.

The radius of the proposed antenna is increased slightly in order to observe the changes in bandwidth by using CST Microwave Studio. In Table 2, as the radius increases from 0.3 mm to 0.5 mm, while dipole length is fixed, that is, as L/r ratio decreases, the bandwidth increases. On the other hand, as the radius increases even further from 0.5 mm to 1 mm, bandwidth decreases and becomes unacceptable for UWB applications. Then it would not be reasonable to increase the radius anymore.

Table 2. Bandwidth values with respect to the different radius.

Radius	Bandwidth	S_{11}	VSWR
0.3 mm	1.1476 GHz	-31.349847 dB	1.0556489
0.4 mm	1.2291 GHz	-26.072863 dB	1.1045987
0.5 mm	1.2587 GHz	-20.772655 dB	1.2014034
0.6 mm	1.194 GHz	-17.229804 dB	1.3190169
0.7 mm	1.0365 GHz	-14.18651 dB	1.4853598
0.8 mm	746.4 MHz	-11.782886 dB	1.6937714
0.9 mm	Not acceptable for UWB	-9.4497215 dB	2.0104937
1.0 mm	Not acceptable for UWB	-7.8714976 dB	2.3559339

3. THE RADIUS OPTIMIZATION THROUGH CONVENTIONAL METHODS INCLUDING PARTICLE SWARM OPTIMIZATION AND GENETIC ALGORITHM

Designing a half wave dipole antenna is not so tedious when compared to other antenna structures namely bowtie, micro-strip, Yagi-Uda, horn, log-periodic dipole array, metamaterial based antennas etc. However, there are some restrictions during the design of half wavelength dipole antenna such as defining the arm radius, material of the arm and overall length of the antenna. In this section, radius of the arm length is optimized by two conventional optimization techniques, namely genetic algorithm (GA) and particle swarm optimization (PSO) in order to obtain the best antenna structure.

Optimization in radius by using genetic algorithm and particle swarm optimization is initially performed with 25 iterations. Basic antenna parameters including return loss (S_{11}) and VSWR are analyzed to define the best structures. Additionally, computational time is observed according to two conventional methods. Table 3 provides the correlations among the antenna parameters and computational time. It is apparent from this table that very few differences occur between GA and PSO. There is slightly difference in radius values. The better return loss and VSWR values are obtained through genetic algorithm methods. Conversely, particle swarm optimization process runs 8 minutes while the computational time of genetic algorithm is 9 minutes. Thus, there is a trade-off between antenna parameters and computational time.

Table 3. Optimization results with 25 iterations.

Optimization result with 25 iterations					
Opt. Tech.	Radius (R)	S_{11} (dB)	VSWR	Resn. Freq (GHz)	Comp. Time
PSO	0.4982 mm	-20.87 dB	1.1990	6.505 GHz	8 minutes
GA	0.4969 mm	-20.92 dB	1.1977	6.505 GHz	9 minutes

One criticism of the optimization methods is the number of iterations. Therefore, the number of iterations is increased from 25 to 261 so as to observe the enhancement of the antenna parameters more clearly. As seen from Table 4, the best antenna parameters are again obtained via genetic algorithm with more computational time.

Table 4. Optimization results with 261 iterations.

Optimization result with 261 iterations					
Opt. Tech.	Radii (R)	S_{11} (dB)	VSWR	Resn. Freq (GHz)	Comp. Time
PSO	0.4997 mm	-20.79 dB	1.2011	6.505 GHz	93 minutes
GA	0.4956 mm	-20.97 dB	1.1964	6.505 GHz	95 minutes

Fig. 8 illustrates the return loss characteristics of the half wave dipole antenna with respect to conventional GA and PSO optimization methods with 25 iterations. Similarly, Fig. 9 presents the VSWR characteristics of the proposed antenna obtained according to optimization methods. As a result, Figures 8 and 9 also support the results presented in Table 3.

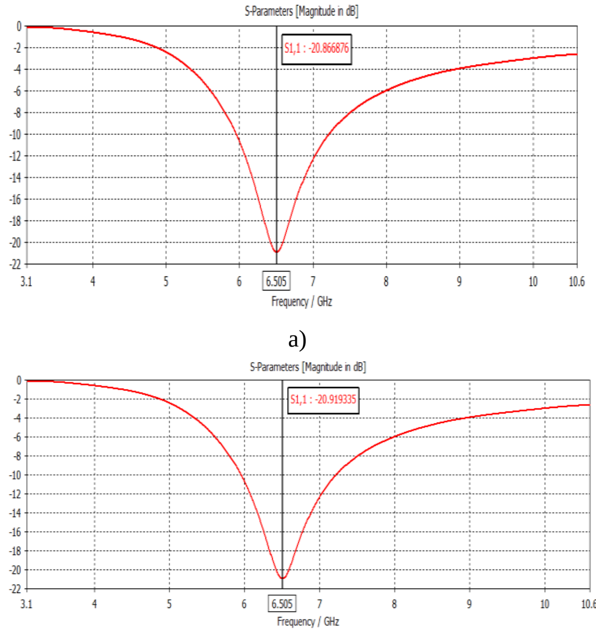


Fig. 8. Return Loss Characteristics of the half wave dipole antenna by using a) PSO b) GA with 25 iterations.

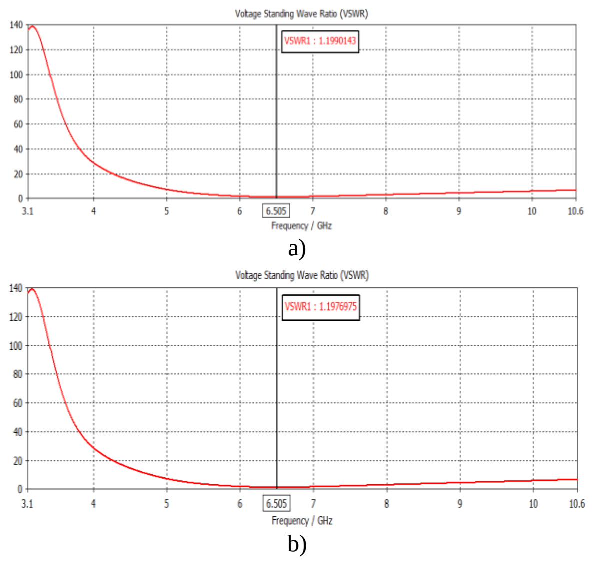


Fig. 9. VSWR Characteristics of the half wave dipole antenna by using a) PSO b) GA with 25 iterations.

Fig. 10 illustrates the return loss characteristics of the half wave dipole with respect to those optimization methods with 261 iterations. Additionally, Fig. 11 presents the VSWR characteristics of the proposed antenna according to optimization methods. As a result, Figures 10 and 11 depict that the simulation results are compatible with the optimization results which have been declared in Table 4.

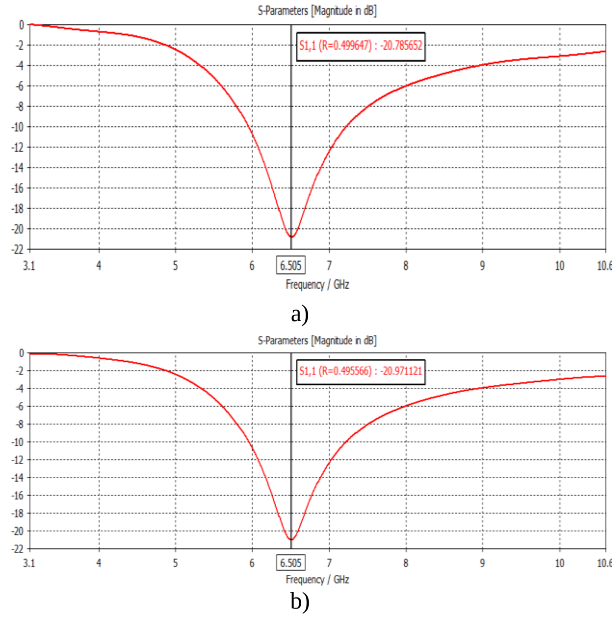


Fig. 10. Return Loss Characteristics of the half wave dipole antenna by using a) PSO b) GA with 261 iterations.

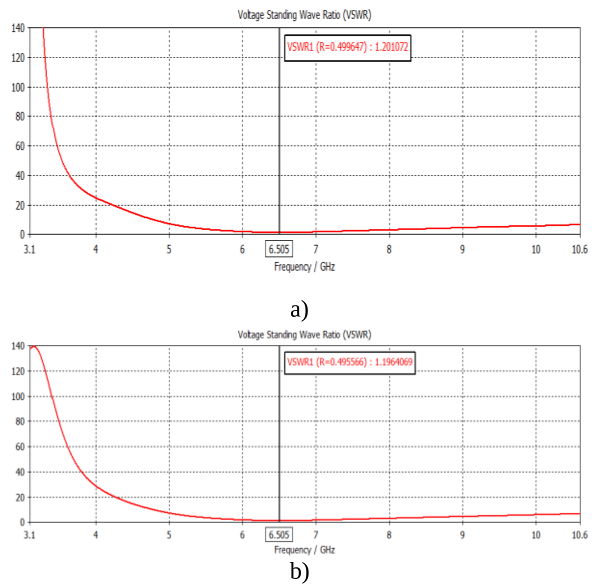


Fig. 11. VSWR Characteristics of the half wave dipole antenna by using a) PSO b) GA with 261 iterations.

4. CONCLUSIONS

This paper implies the design of the half wave dipole antenna to improve the antenna characteristics including return loss, VSWR and bandwidth in the UWB frequency range, i.e. from 3.1 GHz to 10.6 GHz. The main purpose in the improvement process is to change the radius of the antenna arms. Basically, the parameter sweep and two conventional optimization methods namely GA and PSO are employed as a tool in the design of the half wave dipole antenna. The physical antenna parameters such as dipole length, radius of the dipole arm, feeding gap of the antenna are calculated according to UWB communication system requirements. Additionally, the centre frequency is selected as 6.85 GHz which is calculated through the boundary frequency values of the UWB systems. Initially, the proposed antenna is simulated via CST MWS commercial electromagnetic simulation program. The antenna parameters are analysed in order to define the antenna characteristic, i.e. broadband or narrowband. Secondly, the radius of the dipole arm is swept from 0.07 mm to 0.2 mm to obtain best antenna structures. The simulation results of the swept radius values are compared so as to observe the enhancement of the antenna performance. The initial value of the radius is decided as 0.2 mm during the increment of the radius. After that the increment of the radius is handled from 0.3 mm to 1.0 mm by the increment scale of 0.1 mm to define the optimal radius value. Simultaneously, the antenna parameters are also investigated whether the proposed antennas are acceptable antenna structures for UWB communications systems. Thirdly, the GA and PSO are applied to select the best radius value of antenna arms. The number of iterations is set up similar with each other in order to compare explicitly. GA and PSO with 25 and 261 iterations are applied and simulated in accordance with FCC restrictions. From the results, it is observed that the best optimization technique is defined as Genetic Algorithm to predict one of the design parameters, namely radius of antenna arms in the frequency of interest. Conversely, it is also depicted from the compared results that, PSO technique has lower time demands than GA method.

5. ACKNOWLEDGMENT

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