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Recognition of Metal Objects Inside Wall using Antipodal Vivaldi Antenna

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ABSTRACT

This paper present a recognition technique of metal placed inside and between two walls. A unique scheme of recognition of metallic objects through Ultra Wide Band (UWB) Modified Antipodal Vivaldi Antenna (MAVA) frequency range of (3.1GHz to 10.6 GHz) is presented in this paper.The working mechanism of detection system based on Time Domain Reflectrometry (TDR) using through wall imaging (TWMI). A very small duration pulses generated by Vector Network Analyzer (VNA) which are used for illuminate the wall.The analysis of a system under UWB antenna probe array. The simulation results of MAVA have given an enormous potential of penetration, in order to recognize concealed metal objects with fine precision, proving a smart development in the detection system technology. The improvement of resolution in an image, special filters have been developed and implemented. The design and optimization progression is conceded out via CST simulation software for parametric performance assessment of return loss, radiation pattern and directivity.

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1. INTRODUCTION

Detection of metallic objects using UWB array detection and imaging system has been under consideration by researchers now days. It is a most popular and efficient instrument for detection and used generally. Presently various scientists are functioning on this technology for the sake of security and is being observed an improvement compared to regular electromagnetic detection systems. They have been designed and produced a consistent and economical tool for detection of concealed metal objects [1] and many other researchers still involve and try to make a detection system more efficient and effective.

In 1920, Fisher was offered a first metal detector that can be considered a very valuable and competent tool for armaments detection until today [2]. Now a day's an imaging system under UWB bandwidth, which has been showing an imperative role in the improvement of security, medical and sciences applications complemented by the expansion of latest trends of Ground-Penetrating Radar (GPR) [3].Particularly in medical application we have a need of accurate detection for clearer analysis, so this technology is giving a large contribution in a diagnosis of breast cancer, enabling premature stage detection of breast cancer [4, 5].

In recent times, it has been served for armed forces to locate and identify the presence of any targets or people behind the wall [6, 7]. Many precise calculations and examination results have been conceded for estimating through wall imaging together with ray tracking , geometrical optics (GO) [8, 9] and 2-D method for estimating moments (MoM) [10].

The Vivaldi antenna can be classified into three types: tapered slot Vivaldi antenna, antipodal Vivaldi antenna and balanced antipodal Vivaldi antenna. The basic geometrical shape of Vivaldi antenna [11] contains a feed line, which is usually micro strip or strip line, and the radiating structure. There are a number of designs of Vivaldi antenna which has been reported with difference radiating structure [12, 13]. The most suitable solution is exponentially tapered curves that can offer broad band. An Modified Antipodal Vivaldi antenna are designed simply with elliptical curves that has shown excellent potential to propose a very good return loss, higher impedance bandwidth, high gain, flat gain, minimal signal distortion, large directivity and much minimized obstruction in the UWB band pulse shape [14-16].

In this paper the projected schemes GPR and antenna sensor imaging systems are investigated and embedded with time domain reflectrometry (TDR) features [17]. UWB-Modified Antipodal Vivaldi antenna is used for the detection of metallic objects inside and between the walls. UWB –TWMI detectors both cover proposed operating principal of UWB imaging by Chang et. al. [18] based on the transport of short-interval pulses created by transmitting continuous wave (CW) signals at equidistant frequencies covering the entire UWB range. The time domain representation of the pulse can be obtained by performing inverse fast Fourier transform (IFFT) on both transmitted and reflected back signals .For image processing part of the scanned target a special filters have be applied for matching with real image. Computer simulation microwave studio (CST MWS) software is used to achieve all simulation results [19].

2. ANTENNA DESIGN AND CONFIGURATION

A low-cost FR4 substrate is used to designed an antenna includes the values of dielectric loss tangent δ=0.02, thickness h=1.5mm and dielectric constant εr=4.4 respectively. The geometry of an antipodal Vivaldi antenna is shown in Figure 1. The projected antenna contains two most important parts: feed line and the radiation flares. The shape of the flares is designed in the shape of elliptical curves. The elliptical model presents mostly good broadband characteristics because of smooth transition between the radiation flares and the feeding line. It is one of the optimum curvatures [20, 21].

Theoretically, it is derived that the upper frequency limit of a Vivaldi antenna is infinity. The lower frequency limit depends generally on the width of antenna and the effective dielectric constant *(ε_{eff})* as shown in equation (1) and (2) from [22].

$$\mathrm{fmin} = \frac{c}{2W\sqrt{\varepsilon_{\mathrm{eff}}}} \tag{1}$$

$$\varepsilon_{\mathrm{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + \frac{12h}{w})^{-1/2} \tag{2}$$

The main radii of four ellipses are selected according to the following equations.

$$a_1 = \frac{w - w_f}{2} \tag{3}$$

$$a_2 = 1.68b_2 \tag{4}$$

$$b_1 = 0.48a_1 \tag{5}$$

$$b_2 = \frac{w}{2} \tag{6}$$

The feeding line has a width of W_f contain characteristic impedance $Z_o = 50\Omega$. It can be calculated using the following equations [23].

$$z_o = \frac{60}{\sqrt{\varepsilon_{eff}}} \ln\left(\frac{8h}{w} + \frac{w}{4h}\right) \quad \text{for} \left(\frac{w}{h}\right) < 1 \tag{7}$$

$$z_o = \frac{120\pi}{\sqrt{\varepsilon_{\mathrm{eff}}}\left[\frac{w}{h} + 1.393 + \frac{2}{3}\ln\left(\frac{w}{h} + 1.444\right)\right]} \text{for} \left(\frac{w}{h}\right) \geq 1 \tag{8}$$

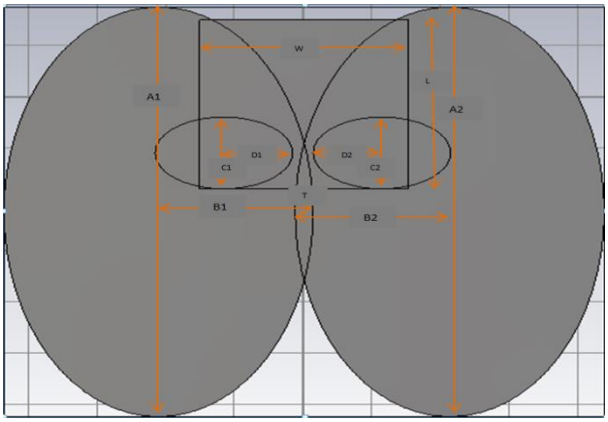


Figure 1.Geometry of the Antipodal Vivaldi Antenna

Along with the above measurement and the further transformation of antipodal Vivaldi antenna (AVA) into Modified antipodal Vivaldi antenna (MAVA) three elliptical curves are added at the edges sides for enhance the capabilities and smooth transition between the radiation flares as shown in Figure 2. The antenna has been designed for UWB usage with the input impedance $Z_o = 50\ \Omega$ and the optimal dimensions are show as adjusted in Table 1 with the support of CST simulation software

Table1. Optimized Dimensions for the UWB Antenna

Parameter	Dimension
W	60.75mm
L	66mm
A1	80mm
B1	22.5mm
A2	80mm
B2	22.5mm
C1	14mm
D1	10mm
C2	14mm
D2	10mm
T(feed width)	2.85mm
EL	3mm
EW	1.5mm
h	1.5mm
t	0.035mm

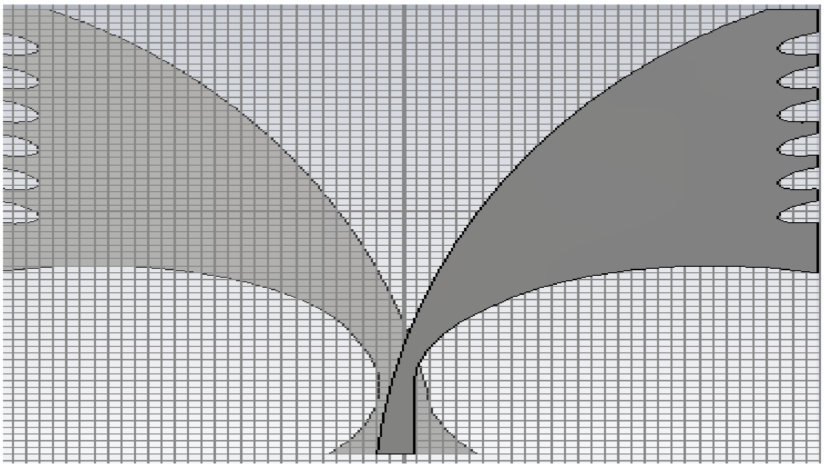


Figure 2.Modified Antipodal Vivaldi antenna

The optimized dimensions of UWB Modified antipodal Vivaldi antenna are given in Table – 1.This design shows a significant penetration in terms of the operating bandwidth frequency at 3.1GHz to 10.6GHz. It is observed that a frequency range around 3.1 GHz to10.6 GHz reflection coefficient (S11) is below -10dB see in Figure 3

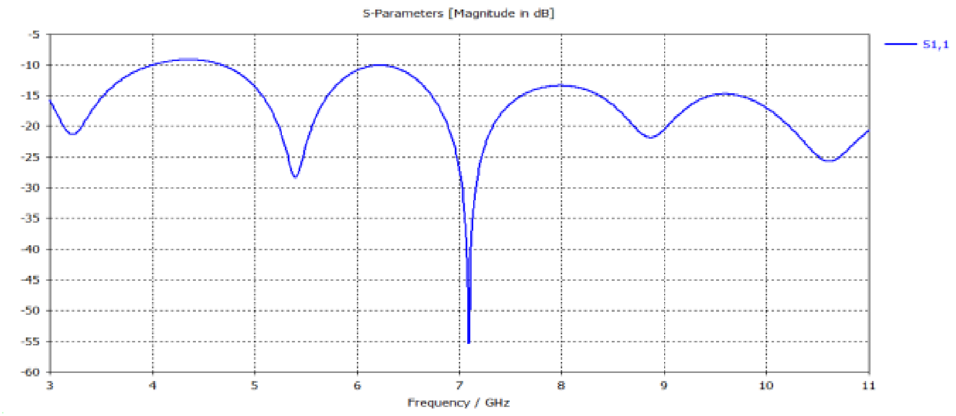


Figure 3.Variation of Reflection Coefficient (S11) with Frequency for UWB Modified Antipodal Vivaldi Antenna

3. ULTRA-WIDE BAND TWMI DETECTION SYSTEM

For the detection of buried objects UWB TWMI system is used .The target is placed in between the two walls. The channel (1) of equipment named vector network analyzer (VNA) [17] is connected to the input port of the array system and absorber is placed behind the antenna system which is vertically mounted for purpose of avoid undesired back reflections. Power amplifiers are connected with array elements for given the desire power to antennas .The antenna array system is positioned in centered to face the first wall in y-z plane. For the working in the far-field region of the antenna and ensure that the distance between the antenna and the starting wall should be choose vigilantly. One of an enormous obstacle which is faced in UWB imaging systems is undesired reflections. To overcome this issue to a synthesized pulse realized by sending continuous signals at equidistant frequencies over the required microwave band. As shown in Figure 4.

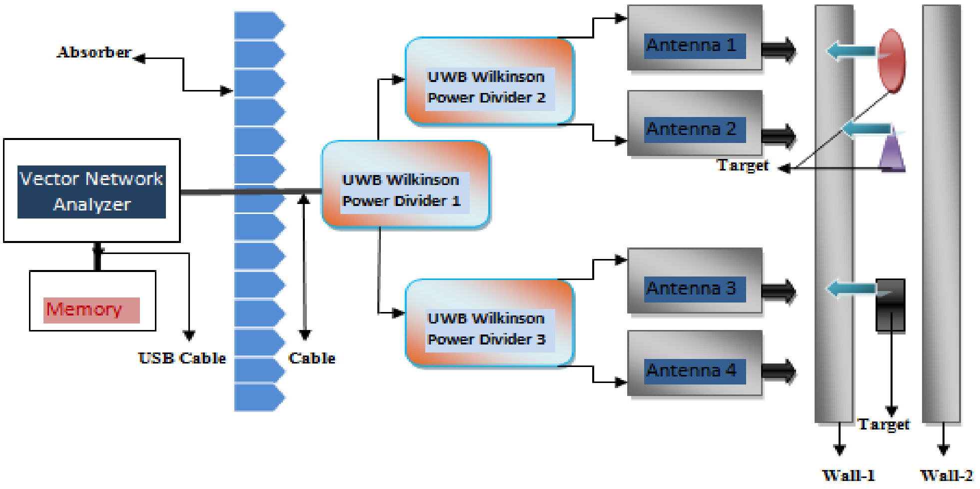


Figure 4.UWB Imaging System

4. CONCEALED OBJECT DETECTION ALGORITHM

The hidden target verdict algorithm begins by reading the reflection coefficient (S11) from the calibrated VNA. The evaluation process is carried out each point in the area under examination. The obtained data is measured as a frequency domain representation for the walls and the target reflections G(f). Using Inverse Fast Fourier Transform (IFFT) implanted code in the VNA, a time domain representation of the reflection coefficient can be obtained at each point g(t). In order to cancel the antenna system (feeding network and the antenna array), cables and connectors effects and to decrease the clutter signals from unnecessary objects, the established reflection g(t) are subtracted from the antenna system response in front of an absorber a(t). The resulted signal s(t) contains only the reflection information from the walls and the unseen target under study. By multiplying s(t) by low shape factor Kaiser window k(t) focused in the area between the two walls, only the target information can be extracted m(t). Image reconstruction can be ended by correlating the 2D data of the points locations to the area under the m(t) curve (integration of m(t))[17]. The flow chart of the unseen target detection algorithm is shown in Figure 5.

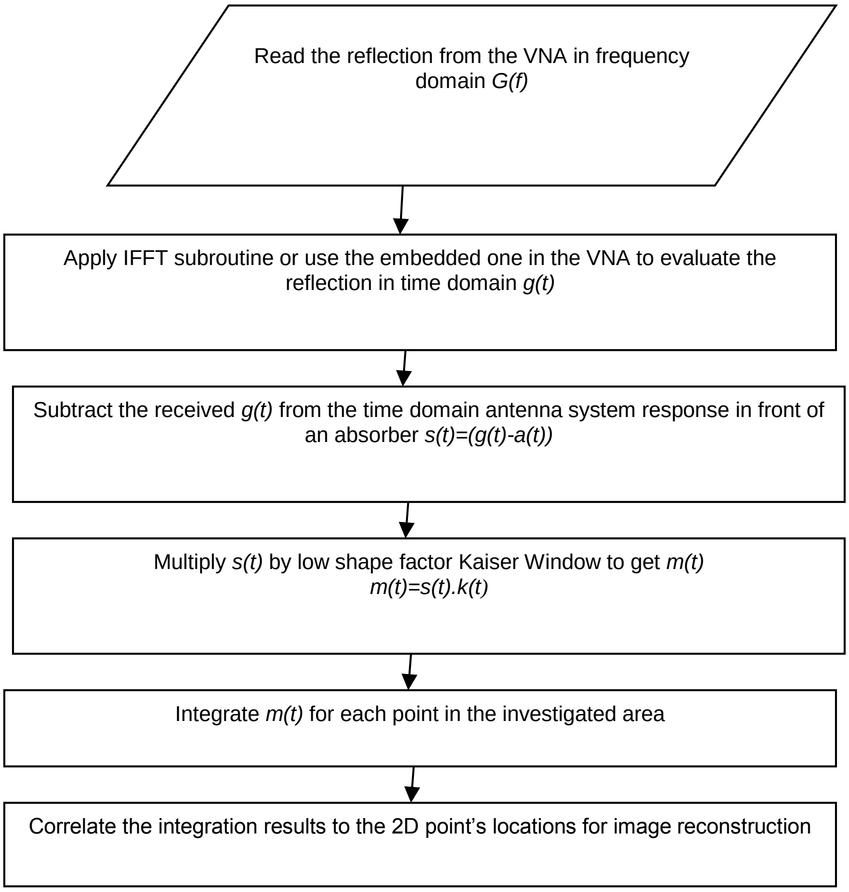


Figure 5.Algorithm of detection system

5. SIMULATION RESULTS AND DISCUSSION

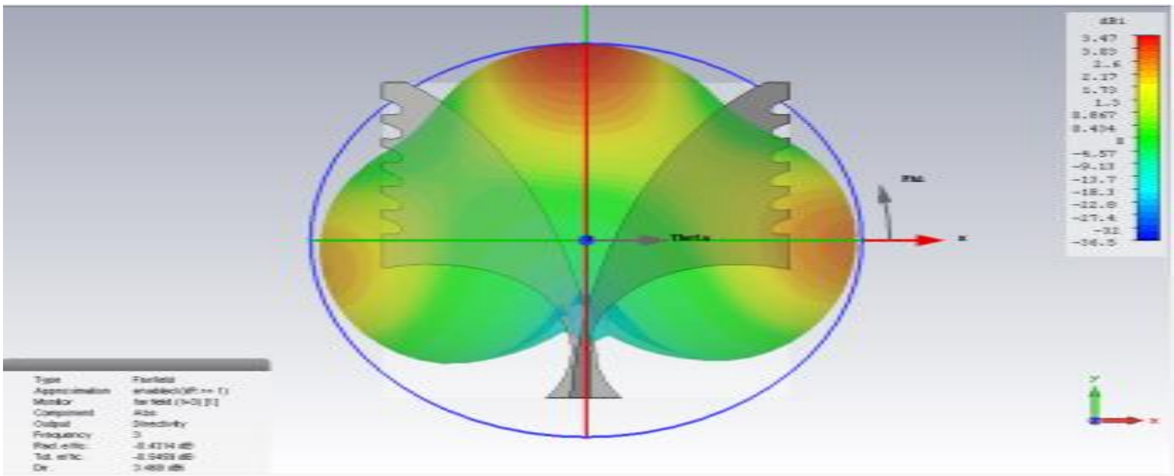
Simulation results include the following factors.

5.1. 3D Radiation Pattern

The 3D radiation patterns of the UWB Modified Antipodal Vivaldi antennas along with end fire radiation patterns at different frequency have been derived by simulation software as shown in Figure 6, with low side and back lobe levels have been observed in antenna The directivity and radiation pattern of both antennas are gradually increase with respect to frequency at certain level see in Table 2. The high gain is achieved at UWB frequencies and covered the ultra wide band channel.

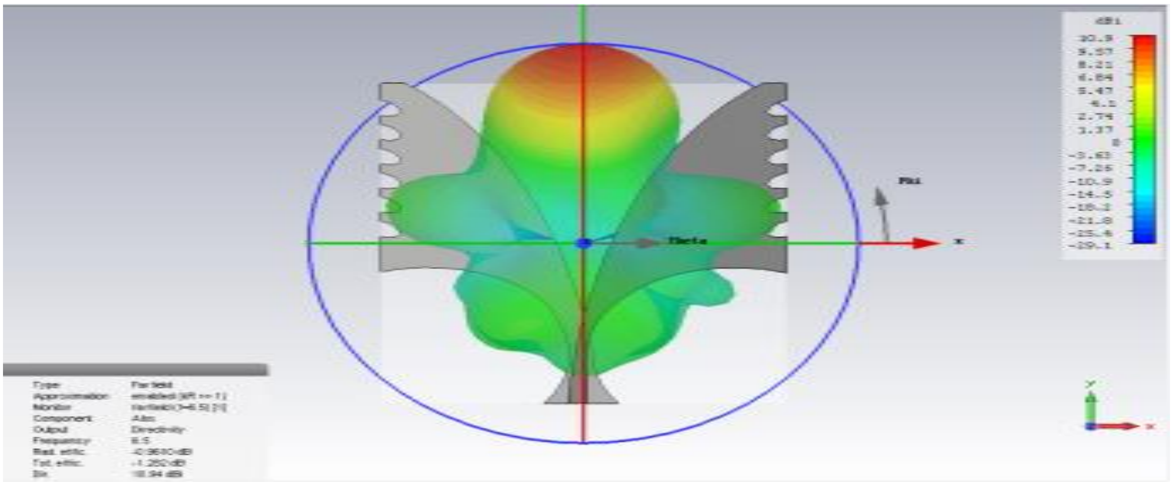
Table 2.The directivity of proposed Modified Antipodal Vivaldi antenna

Frequency (GHz)	Proposed Modified Antipodal Vivaldi Antenna Directivity (dBi)
3	3.47
3.5	5.76
4	7.09
4.5	7.89
5	8.32
5.5	9
6	9.88
6.5	10.9
7	11.1
7.5	10.9
8	10.8
8.5	10.9
9	11.5
9.5	11.6
10	10.6



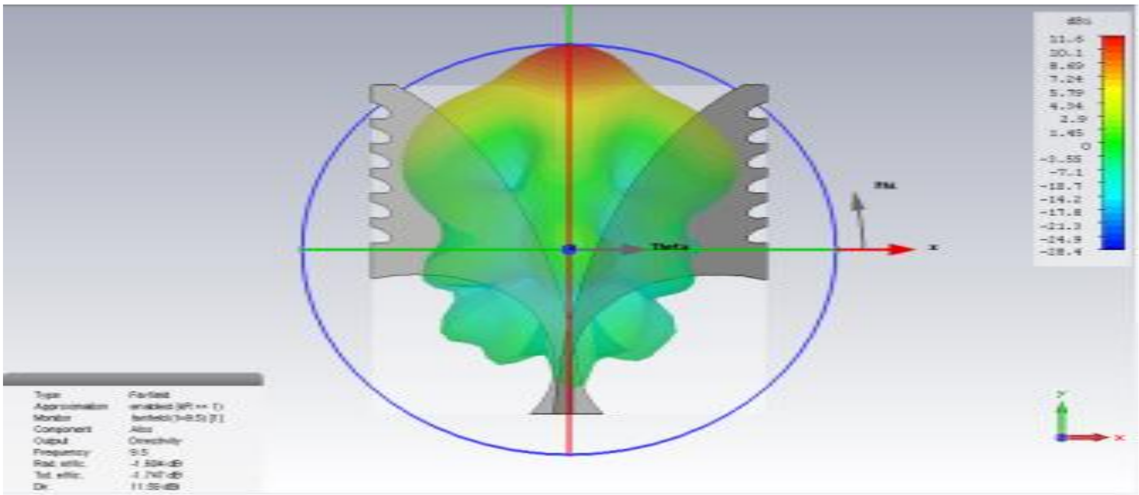
Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=3) [1]
Component Abs
Output Directivity
Frequency 3
Rad. effic. -0.4314 dB
Tot. effic. -0.5459 dB
Dir. 3.469 dBi

Frequency = 3 GHz



Type Far field
Approximation enabled (kR >> 1)
Monitor farfield (f=6.5) [1]
Component Abs
Output Directivity
Frequency 6.5
Rad. effic. -0.3610 dB
Tot. effic. -1.250 dB
Dir. 10.94 dBi

Frequency = 6.5 GHz

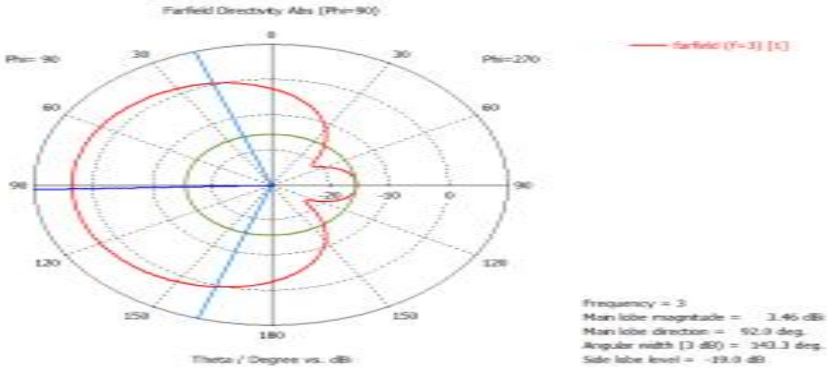


Frequency = 9.5 GHz

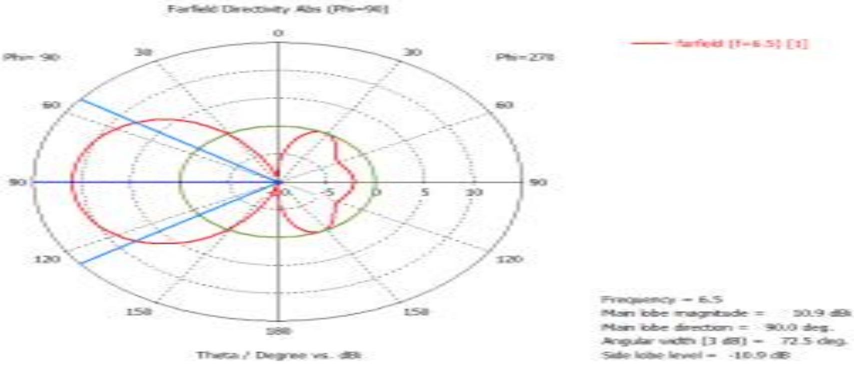
Figure 6.Far-field radiation patterns

5.2. 3D Polar Plots Representation

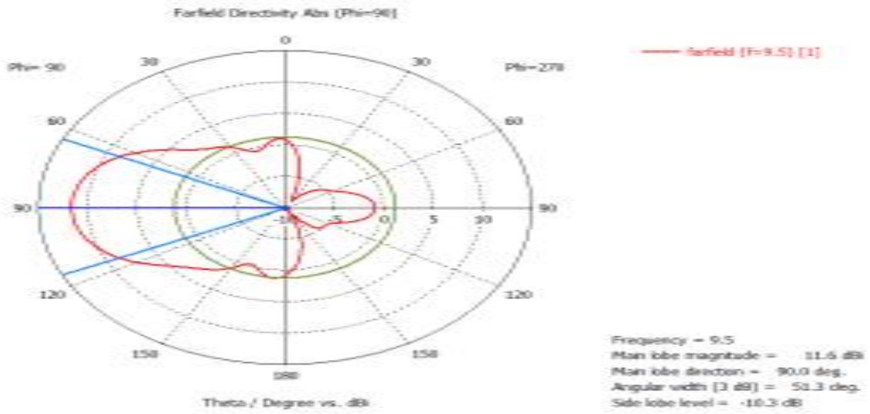
Through CST simulation software the polar plot of UWB Antipodal Vivaldi Antenna has been derived with different frequency range and it has shown a reasonable arrangement to satisfy the UWB frequency range given in Table 3. Modified antipodal antenna has offered an excellent amount of directivity and low side lobes with practical gain as shown in Figure 7. Simulation results show that modified antipodal Vivaldi antenna is more suitable of imaging application.



Frequency = 3 GHz



Frequency = 6.5 GHz



Frequency = 9.5 GHz

Figure 7.3-D polar plot pattern

Table 3: Return loss (S11) and Side lobe level (SLL)

Frequency (GHz)	Antenna	S11 (dB)	Side lobe level
3	MAVA	-15.99	-19.0
4	MAVA	-10.07	-11.3
5	MAVA	-13.63	-8.9
6	MAVA	10.84	-9.8
7	MAVA	-55.13	-11.1
8	MAVA	-13.42	-10.2
9	MAVA	-20.38	10.0
10	MAVA	-17.12	-8.6

5. CONCLUSION

In this paper modified antipodal antenna is proposed for GPR and TWI application. An antenna using a technique of step frequency synthesized pulse and TDR approach for the detection of metallic objects through wall imaging system is presented. The projected antenna covers the FCC defined UWB bandwidth. The simulation results demonstrate a very fine agreement in directivity and better rate of accuracy. An proposed array system has a vast ability in the recognition of metal placed in between two walls and some simulation results of UWB-MAVA antenna has shown a better penetration power and high gain with specified range of frequencies. The directivity of MAVA represents a good change in term of increment in values with respect to the UWB frequency and radiation pattern of the antenna have been plotted to visibly understand the antenna operating principal. Simulation results of MAVA have confirmed the validity of the design and excellent replacement of bulky or heavy antenna in system. The proposed system has shaped a good performance and suitable to be integrated into radar and imaging application. The proposed TWMI system can be validated using different UWB antenna. Circularly polarized micro strip patch antenna and horn antenna which include light in weight and reduce in size operates between frequency range 3.1-10.6GHz can also be a suitable antenna for detection. The current work is an extension of what is already reported in [24-26].

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