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High gain UWB Antipodal Vivaldi Antenna Design for GPR Application

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Abstract: An antipodal Vivaldi Antenna (AVA) with dielectric lens for Ground Penetrating Radar (GPR) application is proposed. Impedance bandwidth and antenna gain have been increased to 140 % (from 2.8 to 16 GHz) and 15 dBi respectively. Simulation process and related results of each step have been presented in the text. The dimension of the antenna has been reduced to 50 × 70 ×0.76 mm^3. The designed antenna is a good candidate for UWB GPR application.

Keywords: *AVA, dielectric lens, UWB and GPR.*

1. Introduction

Ground penetrating radar (GPR) is a radar which detects objects and interfaces buried beneath the earth's surface. It is considered as a very effective tool for non-destructively sensing of the subsurface environment since the radar can detect any object that has different electrical properties than the surrounding soil. Thus, it senses both metallic and nonmetallic targets as opposed to metal detectors [1]. The GPR system basically consists of a transmitter antenna connected to a source and a receiver antenna linked to the signal processing equipment [1-4].

The types of antenna and parameters of the antenna like starting frequency, bandwidth and gain of antenna are important in the detection of the target in putative depth. The antenna plays an important role in GPR systems. The antenna could be categorized in three states that are monostatic, bi-static, and multi-static. In the monostatic state, transceivers of signals are implemented on one antenna but in bi-static state, minimum two or more antennas can be utilized for transmission and reception. In multi-static state, the system uses more than one antenna for transmitting and receiving [5]. The efficiency of the antenna is also an important part of the system. The high efficiency provides more and reliable information. Having better antenna efficiency depends on the optimization works in antenna's physical features [6].

Civil and military sections are the most popular areas for the GPR applications. In military area, it is commonly used for finding unexploded bombs, underground warehouses, bomb shelters, discovering enemy communication channels or secret rooms [7]. In civil life, GPR is commonly applied for finding buried pipes and undetected voids. Together with these, GPR is also used for detecting people behind the rubble [8]. According to the application area, target details and penetration depth, GPR is used in many applications such as archeology, medicine and military from 0.01 to 10 GHz [9].

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Ultra wideband (UWB) antennas are used in GPR as in various applications. UWB GPR antenna is a good point of view and research interest for the authors [10]. Many works in the literature have been developed for wideband application including loaded bowtie antenna [11], TEM horn antenna [12], Vivaldi Antenna and so on.

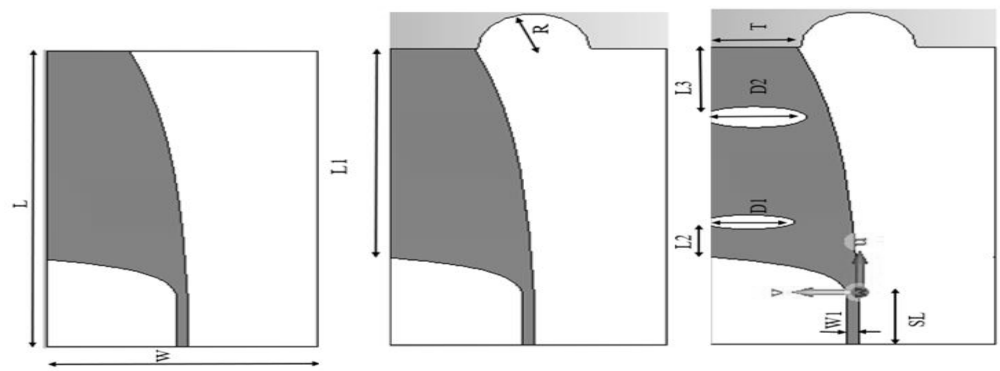
Vivaldi antenna has many advantages such as simple structure, low cost design, high stable gain air-coupled antenna, end fire direction, easy to construct and UWB properties. It also provides a smooth transition between the guided wave travelling in the transmission line and a plane wave which is radiated. Vivaldi antennas are planar antennas that work over a wide frequency range. They provide an acceptable gain depending on the length of the taper and the shape of the curvature [13].

In this article, an antipodal Vivaldi Antenna (AVA) has been developed and simulated fed by 50 Ohm coplanar waveguide. In the next sections, antenna configuration and the simulation results are presented. The simulations are done using CST studio suite 2018.

2. METHODOLOGY OF ANTENNA DESIGN AND RESULTS DISCUSSION

Figure 1(a) shows the construction of the proposed AVA with dimensions of 50 × 70 mm^2 on a substrate of Taconic with εr of 3.55 and 0.76 mm height. The antenna consists of one plate and two slots at front and back sides with the thickness of 0.035 mm.

However, this design suffers from low and inconsistent gain and directivity.

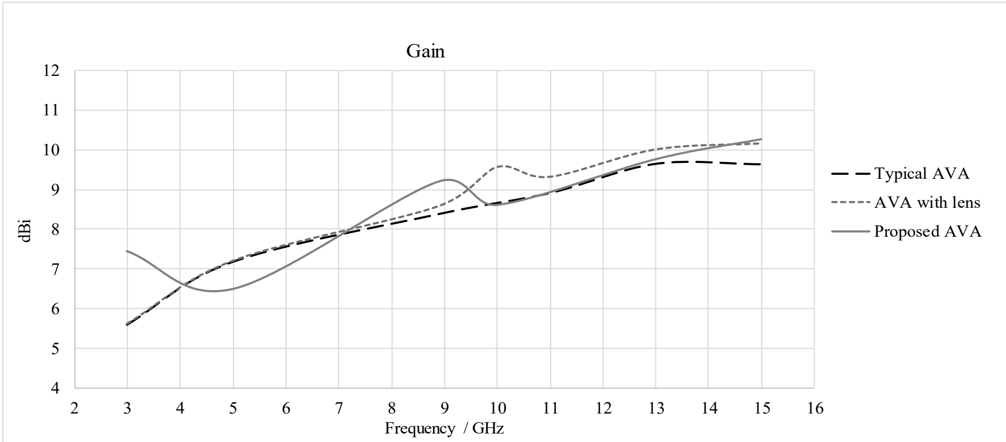


(a) (b) (c)

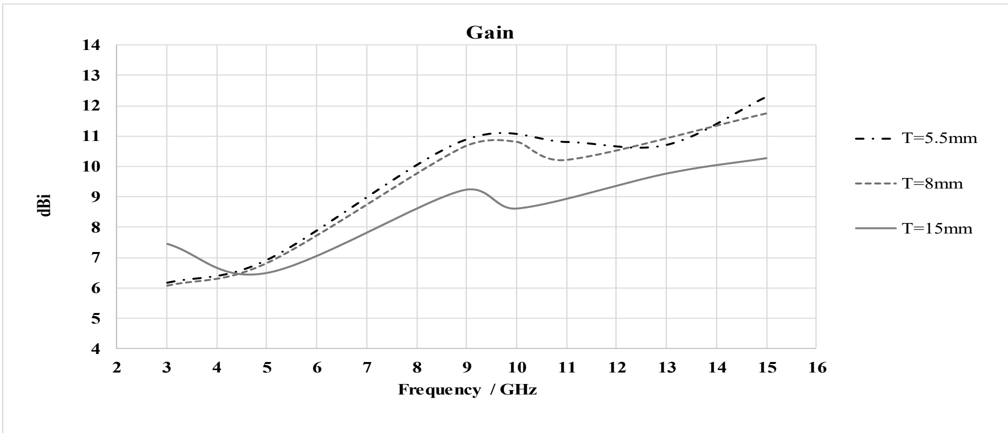
Figure 1: Structures of AVAs. (a) Typical AVA (b) AVA with lens (c) Proposed AVA.

For this, a dielectric lens is added as shown in Figure 1 (b); the lens tends to limit their wide spread utilization. They are costlier due to complex fabrication processes [14]. Also, for getting a good radiation pattern at low frequencies and to make improvement in S_{11} parameter readings an elliptical curvature edge is inserted to the slots as shown in Figure 1 (c).

According to Figure 2 (a), the maximum gain of proposed antenna was at 15 GHz (10.2dBi) whereas the highest gain at typical AVA and AVA with lens was less than this result. Moreover, at low frequencies (3 GHz) the antenna has been improved from 7.4 dBi to 5.7 dBi with elliptical curvature edge.



(a)

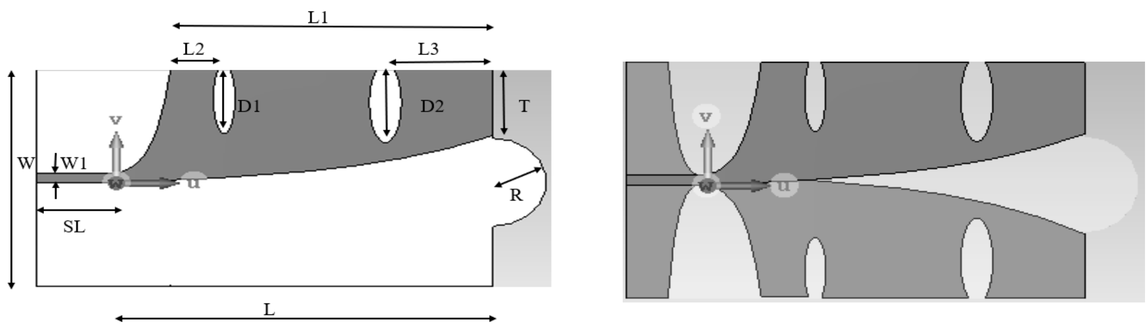


(b)

Figure 2: Antenna gain (a) Typical AVA, AVA with lens and Proposed Antenna (b) Proposed AVA with different T Distance.

On the other hand, the gain varies depending on the length of the taper and shape of the curvature [13]; according to the shape of curvature the distance between two curves at slot T have reverse relation with gain at high frequencies as shown in Figure 2 (b).

When T=5.5 mm at 15 GHz the gain is 12.2 dBi, and the gain is 11.8 dBi when T= 8 mm at the same frequency, however the proposed antenna with T=15 mm has the advantage with highest gain. At low frequency (3 GHz) the gain is 7.4 dBi whereas at the same frequency the gain was 6.1 and 6 dBi at T=5.5 and T=8mm respectively. Figure 3 represents the proposed antenna and Table 1 shows the dimensions of the antenna. The dielectric lens is used to improve the gain of Vivaldi antennas as represented in Figure 2 (a). In order to design the dielectric constant and shape of the lens the antenna parameters will be effected [15-16].



(a) (b)

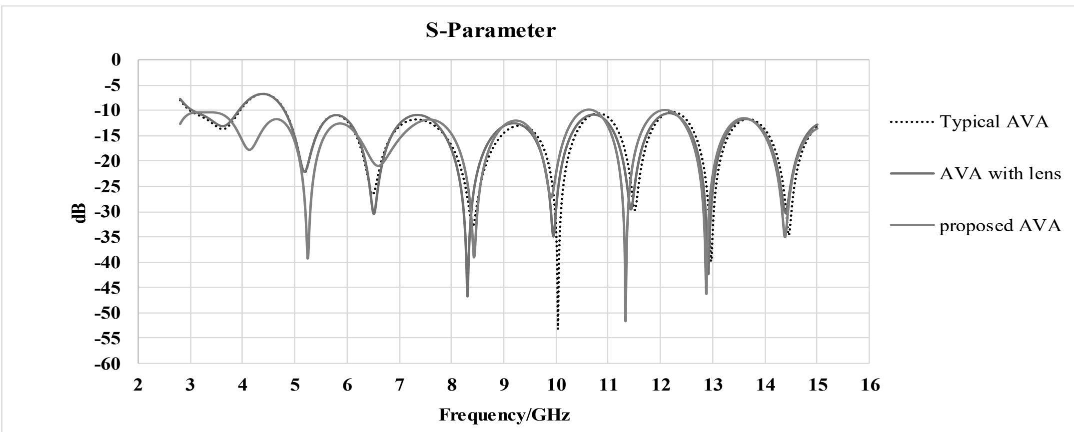
Figure 3: (a) Proposed AVA, (b) Proposed AVA two slots.

To improve the S_{11} results the elliptical curved edge is inserted to design the antenna with special dimensions.

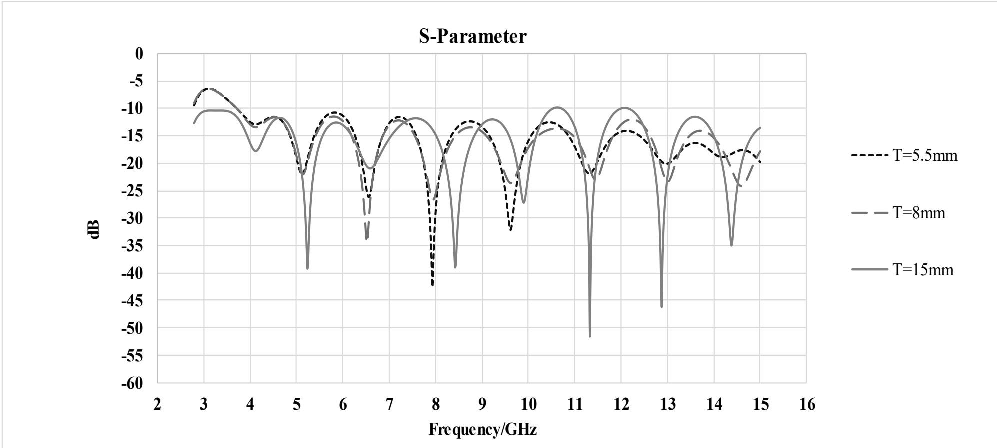
Figure 4 represents the S_{11} results of the antennas at different T distances.

Table 1: Proposed AVA Antenna Dimensions.

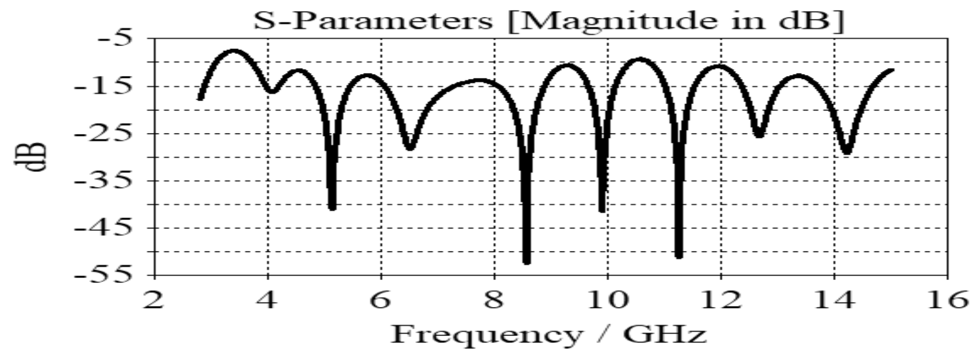
Parameters	Value (mm)	Parameters	Value(mm)
L	70	D1	14
L1	60	D2	17
L2	8.85	W1	2
L3	18.35	T	15
SL	15	R	10
W	50		



(a)



(b)



(c)

Figure 4: S_{11} results, (a) Typical AVA, AVA with lens, Proposed AVA, (b) Proposed AVA at different T Distance, (c) proposed antenna S_{11} result.

According to Figure 4 (a), S_{11} results of typical AVA and AVA with lens are started from 4.9 GHz, which means these designs do not work in good way at low frequency. According to this, the dielectric lens doesn't have a role in making improvement in S_{11} at low frequency. Because of this, proposed AVA has been designed with elliptical curvature edges. These edges improve S_{11} at low frequency and enhances the results in high frequency too. According to this, the elliptical curvature edges are the most important parameters for designing this AVA with good S_{11} at all frequencies.

As shown in Figure 4 (b), S_{11} for proposed antenna at T=15 mm is better than at T=5.5 and T=8 mm , but with using T= 15 mm the results are improved at low frequency (3 GHz).

Proposed AVA, with the dimensions of this design, has the best radiation pattern and S_{11} parameter reading.

All factors work together to apply these requirements, they depend on each other. The radiation pattern in 3D at low and high frequencies are presented in Figure 5. Figure 6 shows the gain and radiation efficiency of the proposed antenna.

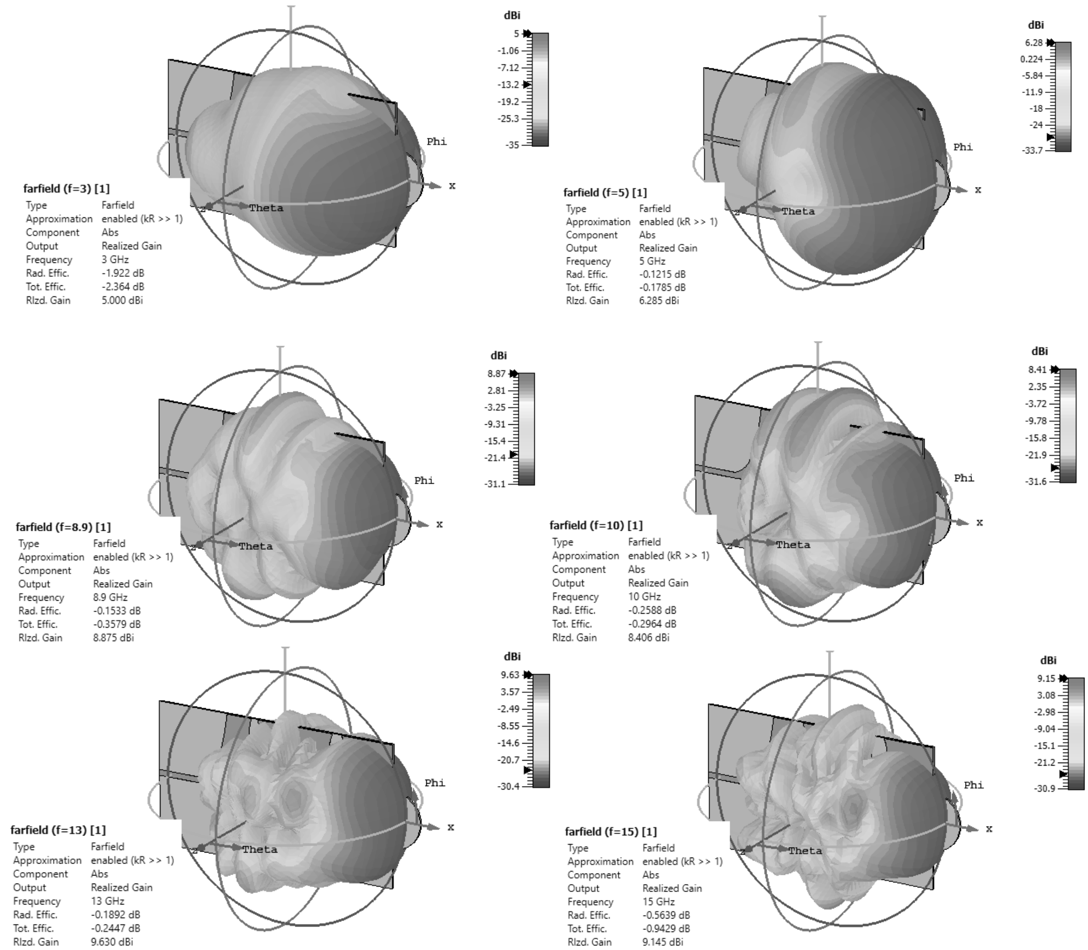
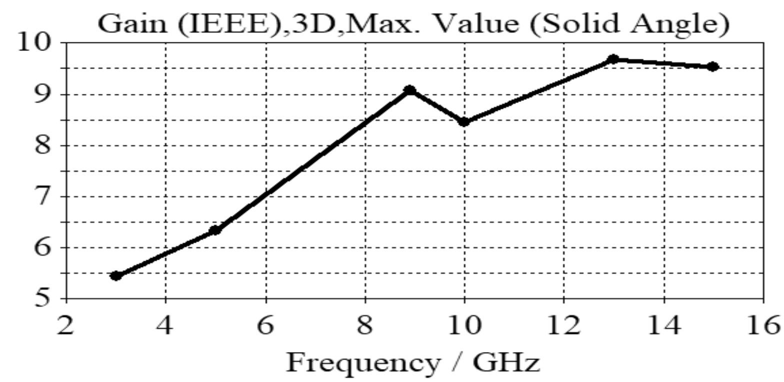
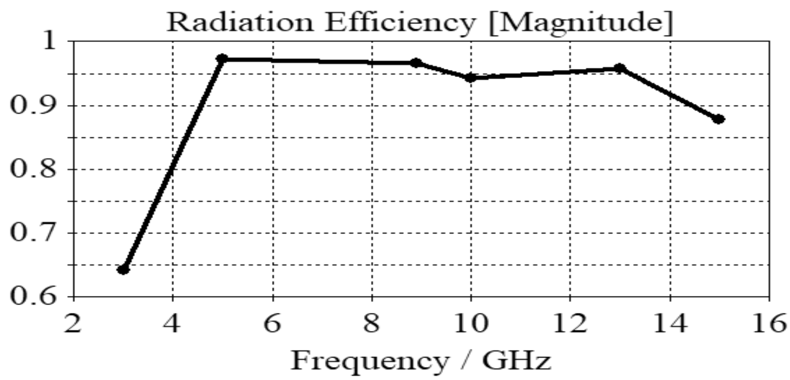


Figure 5: Simulated radiation pattern of the antenna at 3 GHz, 5 GHz, 8.9 GHz, 10GHz, 13 GHz and 15 GHz.



(a)



(b)

Figure 6: a) gain and b) radiation efficiency of proposed antenna.

Table II, illustrates the antenna parameters and dimensions in comparison with other antennas in the literature.

Table 2: Comparison of Antenna Characteristics and Literature.

REF.	Dimensions(mm3)	Frequency(GHz)	ε and material	Freq. GHz (Gain dB)
[12]	178×140×251	0.83-12.8	2.2 AN-79	0.83 (0) 12 (10)
[13]	96×50×3.15	3-18	2.55 ArlonAD255	3 (5) 18 (14)
[15]	130×76×1	3.1-14	4.2 FR4	3.1 (5.8) 10 (7.26)
[16]	90×40×0.508	3.8-40	3.3 RO4003C	3.4 (8) 19.5 (12.8)
This Paper	70×50×0.76	2.8-16	3.55 Taconic	3 (5.2) 15 (9.9)

3. Conclusion

The paper represents the Antipodal Vivaldi antenna for GPR application in frequency range from 3 to 16 GHz. The antenna is designed and simulated by CST studio software. The designed antenna has a maximum gain of 9.15 dBi at 15 GHz. The antenna is designed on Taconic substrate with εr of 3.55. The presented structure gives stable radiation characteristic, along the whole frequency band, which makes it a good candidate for GPR application.

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