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DESIGN AND PROTOTYPE OF A COMPACT, ULTRA WIDE BAND DOUBLE RIDGED HORN ANTENNA FOR BEHIND OBSTACLE RADAR APPLICATIONS

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ABSTRACT

In this paper, we propose an ultrawide band design for the double ridged horn (DRH) antenna to be used behind the obstacle radar (BOR) applications such as ground penetrating radar (GPR) and through the wall radar (TWR) imaging. The design is developed and optimized by the help of full electromagnetic simulator code; CST. The design parameters such as frequencies of operation and the half power beam width (HPBW) are taken into account by considering the BOR application requirements. The design double ridged horn antenna provides a frequency bandwidth between 1.5 GHz and 7 GHz and HPBW around 30° around the center frequency that are very suitable for GPR and TWR applications. The final optimized design that is formed by CST is physically manufactured and measured. The prototyped DRH antenna's measurement antenna parameter results are in good agreement with the simulated ones.

Keywords: *Antenna Design, Ultra-Wide Band Antennas, Double Ridged Horn Antenna and Antenna Measurement*

1. INTRODUCTION

High gain, ultra wide band (UWB); but compact antennas have been of great interest for various microwave and radar applications; ranging from electromagnetic compatibility (EMC) measurements to behind the obstacle radar (BOR) detection and localization (Kumar and Ray, 2003; Chair *et al.*, 2004). For such applications, the most important antenna parameters are being the frequency bandwidth and the antenna beam width. The wide frequency bandwidth is usually desired to have as sharp range resolution as possible for applications such as ground penetrating radar (GPR) and through the wall radar (TWR) due to the fact that the object to be detected is in the ranges of a few centimeters (Turk, 2005; Yılmaz and Özdemir, 2016). These applications also require high gain antennas such that the propagated electromagnetic (EM) wave can penetrate opaque obstacles like wall and ground medium. Otherwise, most of the EM energy would be reflected from the air-to-wall or air-to-ground boundary. Another crucial antenna parameter is the width of the main beam along the horizontal plane. For the GPR and TWR usage, the B-scan operation and migration/focusing along the azimuth direction require to have half power beam width (HPBW) values around 30° to 60° for a successful operation of detection and imaging (Yılmaz *et al.*, 2017; Yılmaz and Özdemir, 2017). Above mentioned superior antenna parameter specifications are not possible with conventional antennas like standard gain horns or popular patches such as Vivaldi antennas (Hamid et al., 2011; Uyanik *et al.*, 2016). Horn antennas; for example, have the advantages of providing directive radiation pattern characteristics and high gain features.

On the other hand, they cannot maintain UWB operation as required in GPR and TWR applications (Hamid *et al.*, 2011; Moosazadeh *et al.*, 2016). Vivaldi patch antennas can provide very good UWB frequency usages while they suffer from the gain and the antenna radiation characteristics as in the case of usual patch antennas (Gopikrishnan *et al.*, 2016; Uyanik *et al.*, 2016). To match all these antenna parameter requirements, double ridged horn (DRH) antenna has become a typical solution. While being a type of horn antenna, DRH antenna's ridges inside the plates provide impedance transition structure that is very similar Vivaldi antennas. These translational structures; i.e. ridges, help to match waveguide mode's impedance of $50\,\Omega$ to the air's intrinsic impedance of $377\ \Omega$. Therefore, DRH antenna is best suited to be a UWB antenna together with high gain and required radiation beam with features.

In this paper, we present our study in designing and prototyping a compact, UWB DRH antenna for BOR applications such as GPR and TWR. In the next section, we share our studies in designing and optimizing the DRH antenna that was aimed to fulfill the specified antenna parameter requirements. The full EM simulation of the designed model is accomplished by the commercially available CST® software (URL 1). The designed antenna is optimized successfully to meet the requirements as explained in detail throughout this section. In Sect. 3, the designed DRH antenna is manufactured and measured to be compared with the simulated one. Comparison of the return loss characteristics demonstrates good agreement between the two. The usage of produced DRH antenna is a particular TWR imaging application is provided with an example. In the final section, the work is summarized.

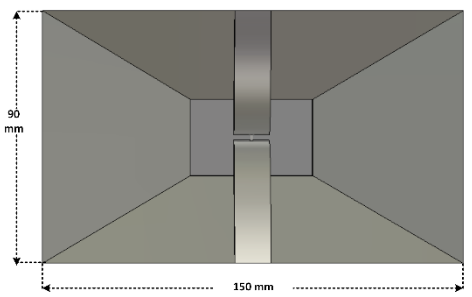
2. DESIGN AND THE CST SIMULATION OF DRH ANTENNA

2.1. The Design of DRH antenna with CST

The design and the simulation processes were carried out via full-wave EM simulator code CST. For the design criteria, the frequency of operation for the DRH antenna was chosen to be between 1 GHz and 7 GHz. Another design constraint was the beam of the main lobe and it was aimed to be around 30° to 45° at the center frequency of the bandwidth. The last design parameter was the size of the final designed antenna: Our goal was to have a design with a maximum length to be less than 15 cm.

After carrying out the EM simulations together with optimization runs, we have ended up having the final design as shown in Fig. 1 where the dimensions of the antenna DRH antenna are provided.

In Fig. 1(a), (b) and (c), front, top and perspective views of the designed DRH antenna are shown, respectively. In Fig. 1(d), side view of the inner ridge structure is given with the associated dimensions. As shown from Fig. 1, we ended up with maximum extends of 128.78 mm in length, 150 mm in width and 90 mm in height.



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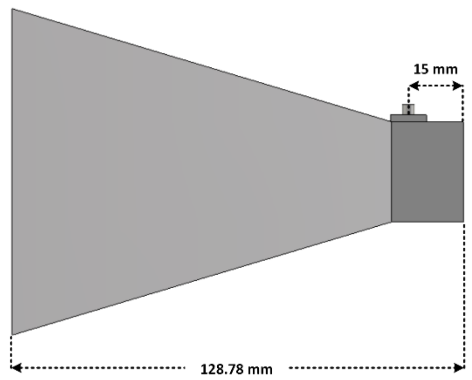

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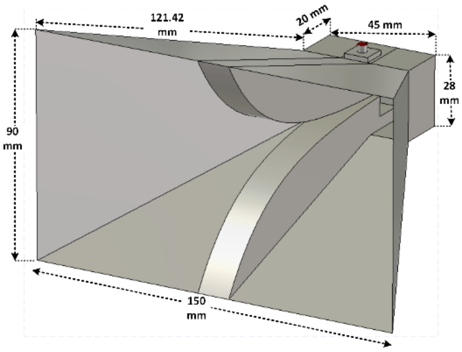

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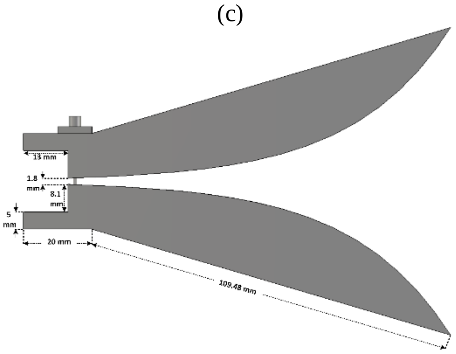


(d)

Fig. 1. Designed DRH antenna with dimensions: (a) Front view, (b) side view, (c) perspective view and (d) side view of the ridge.

2.2. The Simulation of the Antenna Parameters

Antenna parameters of the designed DRH antenna were simulated by CST simulation software. In Fig. 2, return loss (S11) characteristics of the DRH antenna is shown for frequencies. This result yields a -10 dB frequency bandwidth between 1.5 GHz and 7 GHz. Although our first goal was to have a design that can operate between 1 GHz and 7 GHz, we could achieve the about 500 MHz less bandwidth. The reason for sacrificing losing frequencies between 1 GHz and 1.5 GHz is due to size constraint of the design. If we were to include frequencies lower than 1.5 GHz, the antenna was becoming bigger that hardens our employment of antennas to be used BOR applications such as GPR and TWR. Yet, this design is really compact and provides an UWB operation with 78.5% of the total bandwidth (5.5 GHz out of 7 GHz).

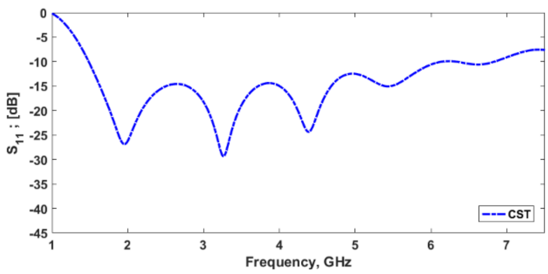
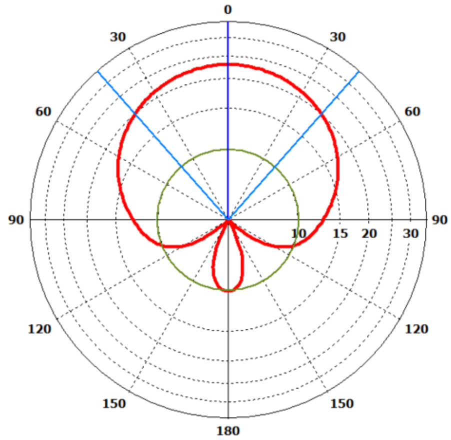
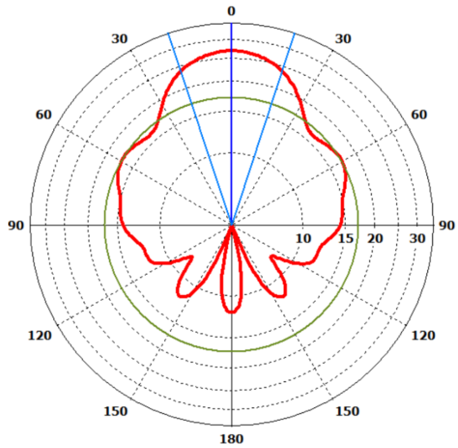


Fig. 2. Return loss plot of the designed DRH antenna

Another important antenna parameter that was considered to be crucial for our BOR applications is the width of the main beam that really affects the detection success of the target along the azimuth (cross-range) direction. For applications like GPR and TWR, the half power beam width (HPBW) values between 30° to 45° provides a good directivity with sufficient coverage of the possible targets along the azimuth direction.



(a)



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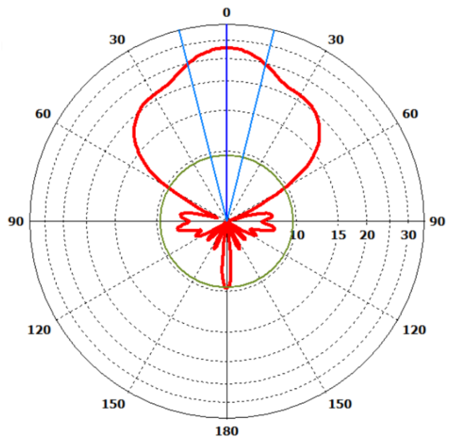


(c)

Fig. 3. Azimuth (Ø) radiation pattern at elevation angle of θ=90° for frequencies; (a) 2 GHz, (b) 4.25 GHz and (c) 7 GHz.

The CST simulation of our designed DRH antenna provides the radiation pattern plots as shown in Fig. 3. In Fig. 3(a), (b) and (c) azimuth polar radiation pattern for the constant elevation angle of 90° for the lower frequency of 2 GHz, the center frequency of 4.25 GHz and the upper frequency of 7 GHz are given, respectively. As expected, the width of the main beam is larger for lower frequencies, and it becomes narrower as the frequency is increasing. The HPBW of the designed DRH antenna is 36.5° for the mid-frequency of 4.25 GHz that pretty well matches our beam width requirement that we have set at the beginning of this study.

The Gain, HPBW and the side lobe level (SLL) for 2 GHz, 4.25 GHz and 7 GHz are listed in Table 1. As obvious from Fig.3 and Table.1, the maximum side lobe strength is always less than -10 dB for the whole bandwidth. The gain of the antenna ranges from 22.9 dBi to 27.7 dBi that is also satisfactory. Overall the frequency bandwidth results and radiation pattern characteristics of the designed antenna come out to be really suitable to be used in BOR applications.

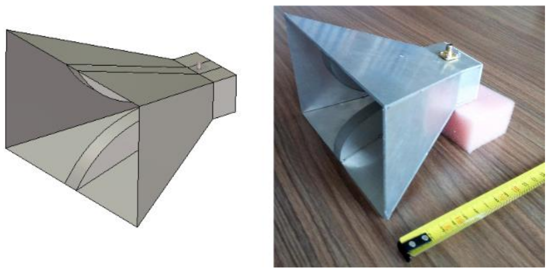
Table 1. Antenna parameters related to radiation pattern of DRH antenna

Frequency	Gain (dBi)	HPBW (°)	SLL (dB)
2	22.9	82.6	-12.9
4.25	26.8	36.5	-9.7
7	27.7	28	-18.1

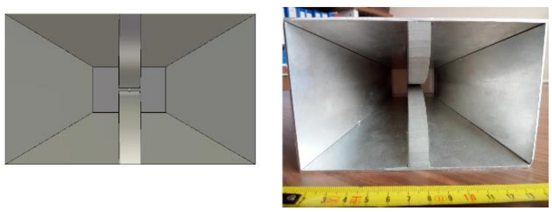
3. PRODUCTION AND MEASUREMENT OF DRH ANTENNA

3.1. Prototype of the designed DRH antenna

The designed antenna is the previous section was produced by using Aluminum plates of 1 mm thick. Production process was done by an outside company that is professional in cutting, connecting, bounding and welding Aluminum materials. The antenna is fed by an 50Ω SMA connector as considered during the design. In Fig. 4(a), (b) and (c), the perspective, front and top views of the designed and the produced DRH antenna are shown.



(a)



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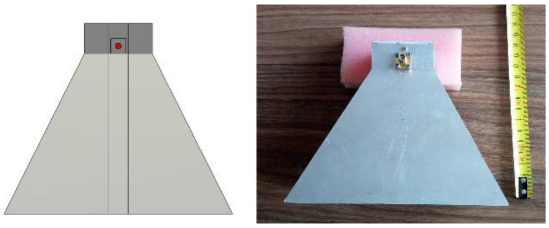


(c)

Fig. 4. The designed and produced DRH antenna: (a) perspective view, (b) front view, and (c) top view.

3.2. Measurement of the prototyped DRH antenna

The produced antenna has been put through S11 measurement process in our anechoic chamber at Mersin University's Advanced Research Center. During the measurement, Agilent 5071B ENA Vector Network Analyzer has been used for the return loss measurement for the produced DRH antenna. In Fig. 5, both the measured (shown as red, solid line) and simulated (plotted as blue, dashed line) S11 characteristics are plotted. It is clear from the figure that the agreement between the simulated and the measured return loss is satisfactory. The small discrepancies are due to imperfectness construction of the produced antenna. Overall, the S11 pattern of the prototyped antenna generally follows that of the designed one as the frequency varies within the bandwidth. The measured antenna's lower operation frequency occurred to be around 1.2 GHz that is better than the designed one. On the other hand, the return loss exceeds the lower limit of -10 dB in some frequency regions around 5 GHz and 6 GHz as obvious from the figure.

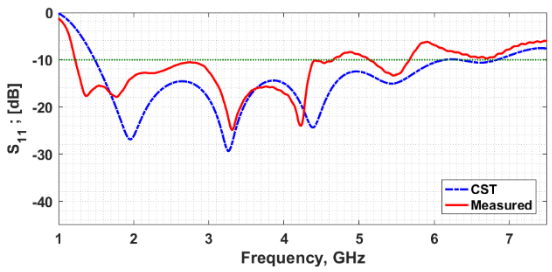


Fig. 5. The return loss results versus frequency: Simulation of designed antenna (dashed, blue) and measurement of produced antenna

3.3. Employment of produced DRH antenna in TWR usage

After completing the design and the prototype studies for our compact DRH antenna, we have produced three copies of the same antenna to be used in TWR application. To demonstrate the usage of these produced antennas, a real experimental scenario has been prepared. A picture of this experimental set-up is shown in Fig. 6. As it can be seen from the figure, three of produced DRH antennas have been connected to a RF transceiver; one being the transmitter and two being the receivers. The RF transceiver has been powered by a portable battery. The control and the automation of the whole system have been accomplished by a laptop computer. The system produces range-time signatures by two channels with two receiving DRH antennas. After two different range-time signatures are collected, the final image is constructed in range-cross range domain by applying a focusing algorithm.

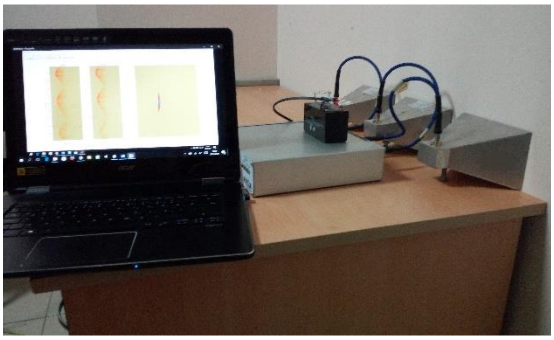
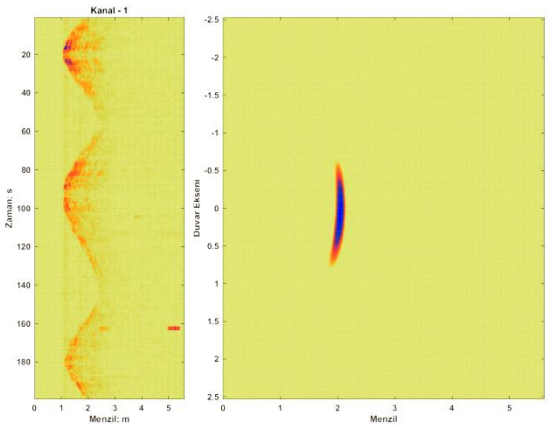


Fig. 6. Experimental set-up with produced DRH antennas for TWR imaging application

By using the set-up in Fig. 6, a measurement has been taken from a case where a man is walking on the other side of the wall while the system was collecting the scattered EM signal. For this particular scenario, the man walked towards and away from the wall for 3 times. In Fig. 7(a), range-time TWR signature histories for one-channel is given. In this image, we can see the characteristic sinusoidal behavior in TWR applications when the target is moving toward and away from the wall. After using the range-tie signatures from both channels, the image is focused in range-cross range plane as plotted in Fig. 7(b). This figure shows the real-time location of the human behind the wall in range-cross range domain.



(a) (b)

Fig. 7. TWR images obtained by produced DRH antennas: (a) Range-time image, (b) Range-cross range image

4. CONCLUSION

In this study, we have proposed a compact design of DRH antenna structure for ultra-wide band operation and large beam width to be used in behind-the-obstacle radar (BOR) applications. The design is developed in CST simulation program and optimized to match the frequency bandwidth and radiation pattern beam width requirements. Finalized design of DRH antenna is produced and the prototyped antenna is measured. Simulation and the measured results of return loss characteristics for our compact DRH antenna demonstrate the achievement of this study. Employment of the designed and produced antenna to a real BOR application has verified the successful operation of these antennas.

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