EHB 456E - AntennasTerm Project Report

Investigated Paper:

A Novel Compact Tapered-Slot Antenna for GPR Applications [1]

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I. Introduction

Tapered slot antenna (TSA) is an ultra-wideband antenna that have applications in various fields including ground penetrating radar(GPR), medical imaging, disaster response, and communication systems. Its capability to be able to work across a wide frequency spectrum, ranging between 220 Mhz to 6 GHz, makes it the perfect fit for high-resolution sensing and imaging tasks. For ultra-wideband (UWB) systems, the most appropriate antenna types include spiral antennas, log-periodic antennas, bowtie antennas, monopole antennas, biconical antennas, and slot-based antennas. From these antennas TSA's endfire radiation pattern provides more focused energy penetration to the ground. Moreover, its small size, lightweight structure, and simple fabrication process make it ideal for portable GPR applications. [2]

In the literature, TSAs have been widely studied for their UWB capabilities, high directivity, and applications in areas such as GPR. Research includes the use of different taper profiles, such as exponential and linear tapers, as well as Vivaldi antennas. Additionally, studies have focused on improving feeding mechanisms and exploring which antenna designs are most effective for GPR applications. [2]

The design of TSA has some requirements to ensure optimal perfomance for GPR applications. One aspect is the transition design. It must match the symmetrical slotline with the asymmetrical coaxial feeing effectively. In this paper preferred aproach is a CPW to slotline transition. It is more simple and less lossy compared to its other alternatives. Another aspect is that antenna must oparete over a broad bandwith ranging from 0.64 GHz to 6 GHz. A lumped resistor is integrated between the end of the elliptical slotine and left ground plane. This resistor absorbs residual currents and guides excess energy back to the source. This resistor also helps with the integration of an additional magnetic antenna. This magnetic part works together with the electric antenna to enhance the bandwidth while keeping the size compact. Furthermore, the design focuses on reducing ringing during short pulses to ensure clear and accurate signal transmission. [1] Together, these requirements make the TSA a durable and flexible solution for modern wideband GPR antenna applications.

In this report, the antenna design is detailed in Section II, followed by the simulation results in Section III. A comparison of performance is provided in Section IV, and the conclusions are summarized in Section V.

II. Antenna design

The proposed antenna is designed for ground-penetrating radar (GPR) applications. This application has specific requirements, and the antenna's electrical and geometrical parameters are optimized to meet the demands of short-pulse radiation, wideband operation, and compact design for efficient subsurface imaging

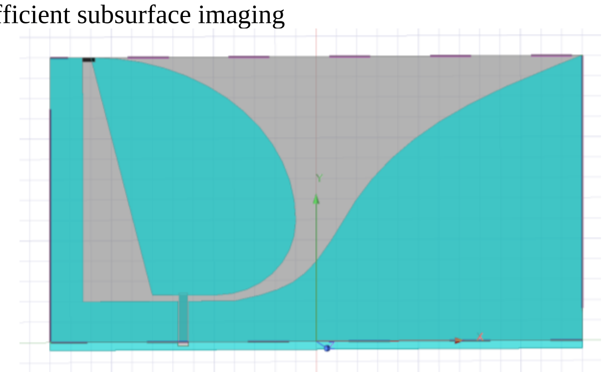


Fig. 1: The proposed antenna simulated in HFSS

A. Electrical parameters

The proposed antenna operates over a wideband frequency range of 0.64 GHz to 6 GHz, achieved with the tapered slotline design. A CPW-to-slotline transition is used to excite the antenna. The CPW feed is designed with a characteristic impedance of 50Ω. The proposed antenna uses an FR4 substrate with a relative permittivity (εr) of 4.4 and a loss tangent ($\tan\delta$) of approximately 0.02. A lumped resistor is incorporated into the design to absorb residual currents, reduce reflections and enhance bandwidth.

The material of the slot is not given in the paper so different materials are tested and copper is chosen for its low cost.

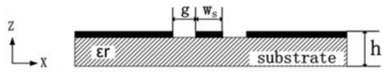
B. Geometrical Parameters

The geometrical parameters of the antenna are shown in Fig.2. The elliptical slot consists of 3 main components. a quarter of a large horizontal ellipse with a major radius of R2=50 mm, and an aspect ratio of R1/R2= 0.8, a quarter of a small vertical ellipse with a major radius of R4=19.2 mm and an aspect ratio of R3/R4=0.94, and a rectangular portion with a length of R2−R4 and a width of R3.

The parameters of the proposed antenna design are as follows: W=130 mm, H=70 mm, L=31.25 mmL = 31.25, ws=2 mm, g=0.25 mm, D=10 mm, s=1.5 mm, l=24 mm, R1=40 mm, R2=50 mm, R3=18.048 mm, R4=19.2 mm. The loaded resistor used in the design is 150 Ω. [1]

The paper does not provide a specific equation for the curve at the right ground plane. Therefore, an approximate parabola was created using the polyline tool in HFSS for simulation purposes.

Parameter	Value	Unit
W	130	mm
H	70	mm
L	31.25...	mm
w_s	2	mm
g	0.2500	mm
D	10	mm
s	1.5000	mm
l	24	mm
R1	40	mm
R2	50	mm
R3	18.04...	mm
R4	19.20...	mm
Loaded R...	150	Ω



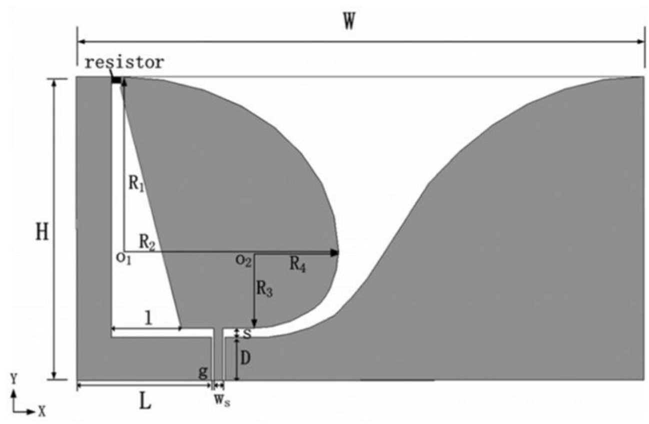


Fig. 2. Geometry of the proposed TSA: planar structure and side view of the CPW

III. SIMULATION RESULTS

In this section ANSYS HFSS is used to conduct simulations on the antenna and results of the simulations are discussed. [3]

1) *Return Loss*

S11 is defined as the reflection coefficient that represents the mismatch between the port impedance and the input impedance of the network. It is also called return loss. The S11 plot of this antenna demonstrates a wideband characteristic, with efficient operation observed across the frequency range of 0.6 GHz to 6 GHz, as illustrated in Fig. 3.

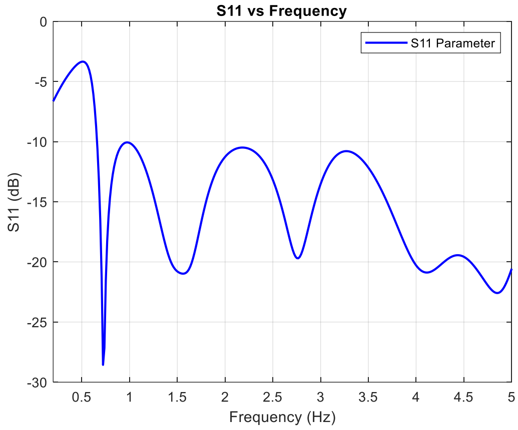


Fig. 3: S11 plot of the proposed antenna.

2) *Radiation Pattern*

An antenna radiation pattern is described as a mathematical function or graphical representation that illustrates the radiation characteristics of the antenna with respect to spatial coordinates. Generally, this pattern is evaluated in the far-field region and is expressed as a function of directional coordinates. [4] The radiation patterns are exhibited in fig. 4 and fig. 5.

The pattern exhibits a donut-like shape, which is typical for antennas with a broad, uniform radiation characteristic. As can be observed from fig.5. max gain is -1.2 and min gain is -10.8. The radiation patterns are plotted for 0.720GHz.

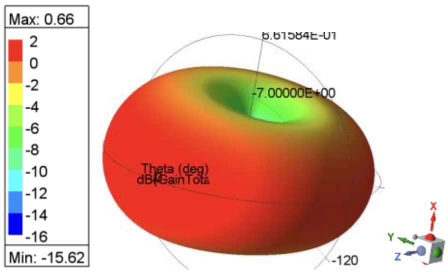


Fig. 4: 3D radiation pattern of the simulated antenna at 0.720GHz

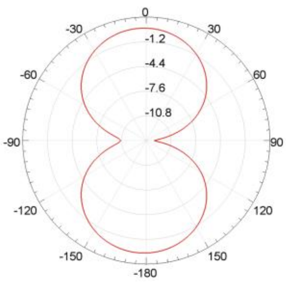


Fig. 5. 2D radiation pattern of the simulated antenna at 0.720GHz

3) *Realized Gain:*

Gain represents the ratio of the radiation intensity in a particular direction to the intensity that would happen if the power received by the antenna were distributed evenly in all directions. [4]. And realized gain represents the actual gain of the antenna, compared to gain it also takes into account of losses due to impedance mismatches and other factors.

Realized gain plot of the proposed antenna can be seen in fig.6.

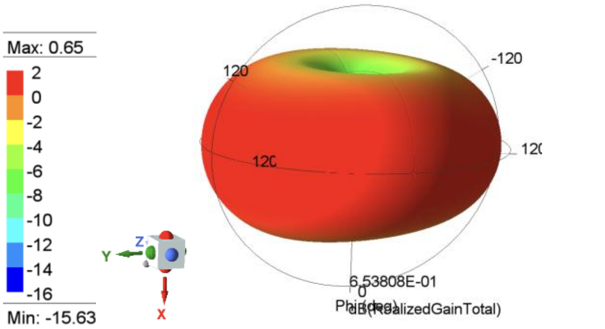


Fig. 6: 3D realized gain plot of the simulated antenna at 0.720GHz

4) Directivity:

Directivity is defined as the ratio of the radiation intensity in a specific direction to the radiation intensity of an isotropic antenna that radiates the same total power equally in all directions. Mathematically, it is expressed as:

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{\text{rad}}}$$

The antennas directivity plot can be seen from fig.7.

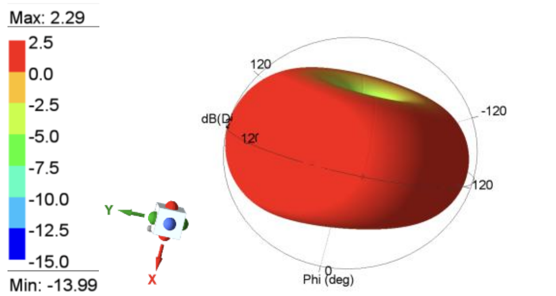


Fig. 7: 3D directivity plot of the simulated antenna at 0.720GHz

5) Current Density Plot

This field plot shows how the current is distributed in terms of magnitude. As observed, the current is significantly higher in the regions near the excitation point. Current density plot can be seen in Fig.8.

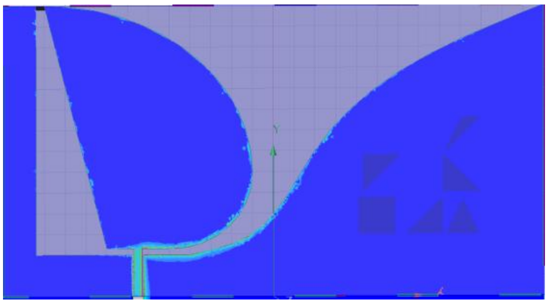


Fig. 8. Currents plotted on the proposed antenna.

IV. Parameters for Tuning Radiation Characteristics

According to the proposed antenna paper there are several parameters that effect antennas gain and performance. The first factor is the size of the triangular slot area separating the left ground plane from the magnetic antenna (elliptical section). Increasing the size of this triangular area results in improved gain. Specifically, the maximum gain increased from 0.66 to 0.77 when the parameter “l” was increased from 10 to 15.

The next parameter is the relative permittivity of the substrate material. Dielectric constant (εr) of the substrate impacts impedance matching and radiation efficiency. Lower permittivity materials generally result in higher gain.

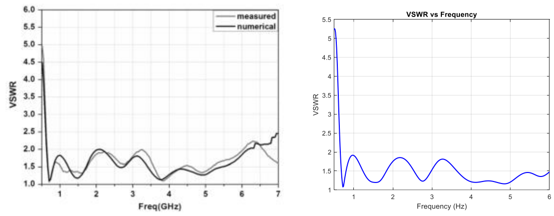
Width of the slot (s) also impacts the performance of the antenna, depending on its size mismatch reflections can ocur. And the best performance fort his parameter is observed when s=1mm.

Lastly, the value of the loaded resistor is another key parameter influencing the antenna's performance. When the resistor value was set to 50 ohms, the return loss increased, negatively affecting performance. Among the tested values of 100, 150, and 200 ohms, a resistor value of 150 ohms was determined to be optimal, providing the highest gain.

V. Comparison

In the antenna paper measured and given plots include VSWR plot and radiation pattern.

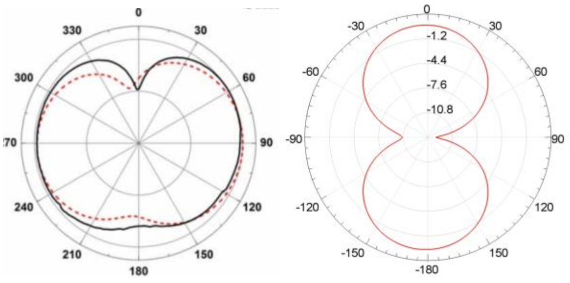
Firstly comparing VSWR resulst, both plots are very similar. Both plots demonstrate good impedance matching with a VSWR below 2 across a similar frequency range, confirming the antenna's wideband characteristics.Thus, the simulated antenna successfully meets the desired frequency range requirements. VSWR plots can be seen in fig.9.



(a) (b)

Fig. 9: VSWR plots: a) from paper b) simulated antenna

In terms of the radiation pattern, although I used the same coordinates provided in the paper, my radiation pattern appears to be rotated by 90 degrees. In terms of shape, they are somewhat similar, but the gain in the paper is significantly higher. Additionally, the pattern in the paper is more directional, whereas my design produces a more uniform pattern. Despite attempting to adjust the parameters, I was not able to reach the plot shown in the paper. The resulting plots are presented in Fig. 10.



(a) (b)

Fig. 10: 2D radiation pattern plots: a) from paper b) simulated antenna

The differences between the resulsts in paper and my design might occured because of several reasons.

In the paper the material for slot is not given so I have experimented with copper and silver which are generally used materials for these kind of designs. The effect of material losses could be the reason of difference.

Moreover, the line equation for the paraboidal shape positioned at the right side of the antenna is not given. So I tried to create a similar line using HFSS polyline tool. Even tough they look similar this can effect the size of the ground plane and therefore the functioning of the antenna. I tried my best to implement the antenna in the paper in terms of these futures.

VI. CONCLUSION

In this report, the design and performance of the tapered slot antenna for ground penetraing radar applications were analyzed using the simulation program HFSS. And than these results were compared with the original paper. While the simulated antenna met the desired frequency range there were some differences in radiation pattern and gain. The differances could stem from material losses and from approximations in the geometrical parameters, since some of these parameters are not given in the original paper. Despite the challenges, the implemented design shows the key characteristics of tapered slot antennas like wideband operation and compact structure.

REFERENCES

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