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Design of Ultra Wide-Band Transmit/Receive Antenna Pair for Vehicle Based Ground Penetrating RADAR

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Abstract:
This paper tries to elaborate the design of an Ultra Wide Band Antenna (single element), which is used as vehicle mounted ground penetrating Radar to identify landmines. A reflector for the antenna, transmit and receive pair, and finally array of these elements operating up to 3 GHz is subsumed in this design. Triangular micro-strip patch antenna (Idea from conical antenna, which has good Ultra Wide Band quality), focusing on the most important aspect of Miniaturization of antenna (finally 13X15 cm), providing larger perimeter for smaller frequency range and larger area for large Bandwidth, which lead to a hybrid design consisting of a triangle and ellipse, thus also removing edges but burgeoning size. Meticulously considering various parameters like Return loss, BW, VSWR, Beam angle, radiation pattern, realized gain and impedance, the final design achieves the desired requirement. Designing and simulation is performed on High Frequency Structure Simulator (HFSS) V 12.0 and loading and retesting is performed with the help of Time domain solver XFDTD V 7.1.0

Keywords*: GPR (Ground Penetrating Radar), Ultra Wideband Antenna, HFSS (High Frequency Structure Simulation), FDTD (Finite Differential Time Domain)*

1. Introduction

Around every 22 minutes somewhere in this world is somehow or the other is killed or injured by the landmine. Exorbitant amount of land go unused due to the fear of landmines. Sophisticated technology used to detect the landmines basically metal detectors, nuclear magnetic resonance, and thermal imaging and electro optical sensors. The landmine detection by ground penetrating radar (GPR) has become one of the main challenging applications for ultra-wideband (UWB) radar technology. Non-destructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. GPR can be proved useful in a variety of media, including rock, soil, ice, fresh water, pavements and structures. It can easily detect objects, changes in material, voids and cracks .Along with the metals imaging is used to ameliorate the quality of manufacturing. Higher frequencies provide better resolution to clearly discriminate between the closely buried targets (inversely proportional to wavelength), whereas the lower frequencies provide better penetration. Hence there is requirement of Ultra Wide Band Antenna.

2. Methodology

2.1. Triangular Microstrip Patch Antenna

As conventional antennas have large size, it is difficult to use them in modern day applications. Broad band feature of conical antenna gives an idea of converting it into triangular micro strip patch. Taking a triangular antenna of 15 X 20 cm, the return loss S11 degrades below 700 MHz (< -7dB), and radiation pattern has the main lobe split into two parts .The corners present in the triangle have very high current density. So it is removed by converting it into circular design leading to hybrid. As larger area/ angle provide a larger Bandwidth, there is a trade-off between area of antenna and compactness of size.

2.1.1. Requirement

- SIZE: Less Than 20cm X 20cm
- Bandwidth: 200 MHz TO 3 GHz
- Return Loss: Less Than-10dB
- VSWR: Around 1 (< 2)
- Radiation Patten: Single Main Lobe
- Mutual Coupling: < -20 dB

Complete Setup Should Be Compact So That It Can Be Easily Mounted On The Vehicle.

2.1.2. Design-1

Starting with the basic design of a triangular patch

Substrate:

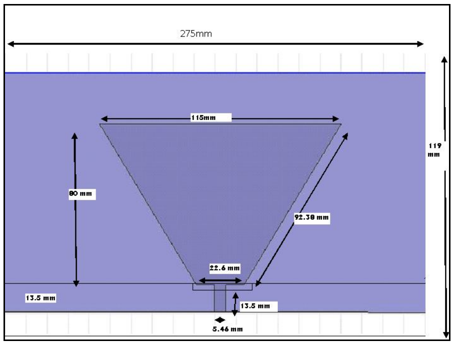
Roger 5880 (ε_r = 2.2)

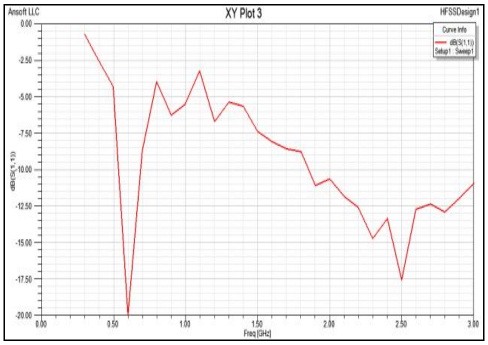
- Thickness 1.6 mm
- Length 119 mm
- Width 275 mm

Patch and ground plane are made of conducting copper with conductivity 5800000 S/m.

A rectangle is cut into the ground plane of

Dimension 19.54 mm X 2 mm behind feed at the middle of upper edge.





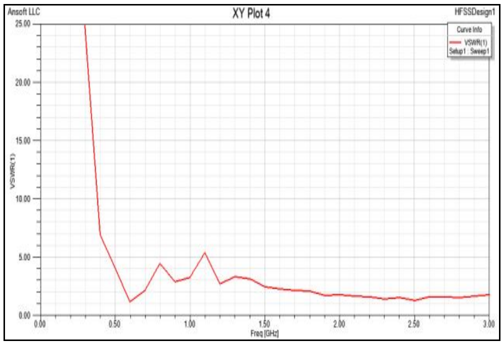
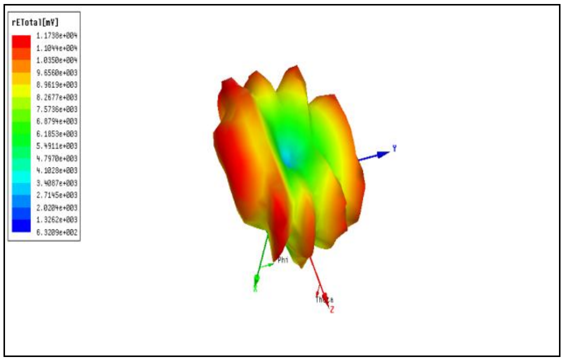


Figure 1: Design of Triangular patch Antenna
Figure 2: Return loss (dB) vs. Frequency (GHz)
Figure 3: VSWR vs. Frequency (GHz)



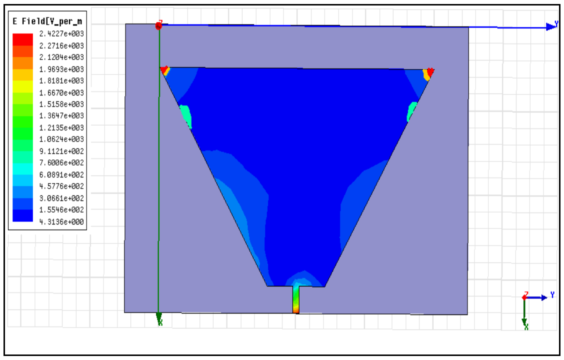


Figure 4: Radiation Pattern *Figure 5: Current Distribution*

After trying various distinct angles and altitudes, this has resulted in the best possible design at the above mentioned dimensions. Variation in return loss plot is due to variation in dimension which in turn alters the resonance frequency. Interestingly, there is no noticeable change in the lower frequency. This model shows that the S11 performs very poor below 600 MHz and between 800 MHz to 1.5 GHz. The middle region may be due to improper matching but to eliminate the lower region this design needs a slight change. It can be seen that the current density (distribution) is very high at the corners. This can be eliminated by increasing the perimeter of the design. Another drawback is the splitted radiation pattern obtained.

2.1.3. Design-2

This design overshadows the problem of current distribution of the “Hybrid” design consisting of triangular patch in the lower region and part of the ellipse in the upper region.

SUBSTRATE:

Roger 5880 ($\varepsilon_{r} = 2.2$)

- Thickness 1.6 mm
- Length 105.74 mm
- Width 80 mm

Patch and ground plane are of conducting copper with conductivity 58000000 S/m.A rectangle is cut into ground plane of dimension 20 mm X 2 mm behind feed at the middle of upper edge.

Feed:

- width = 1mm
- Length = 14.74 mm

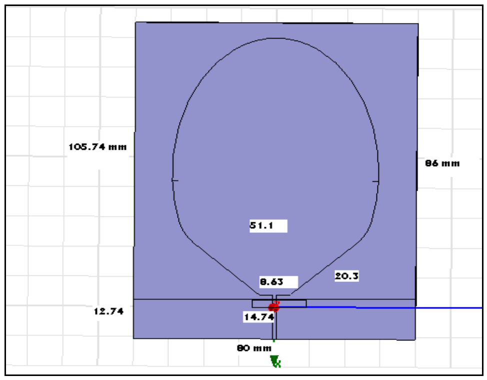
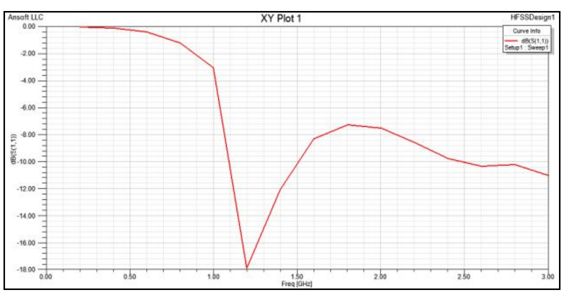


Figure 6: Design of ellipse patch antenna

Specifications of Ellipse patch *ante*nna design:

Triangle:

- major radius = 45mm
- eccentricity (e) =0.65
- Altitude = 20.38mm
- Upper edge length 55mm



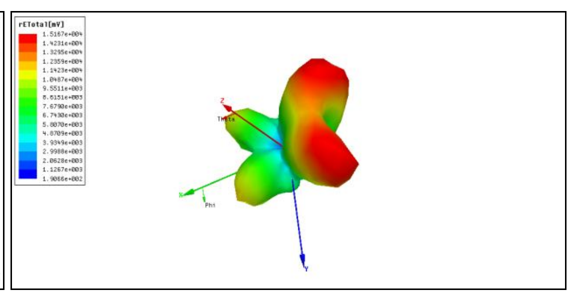


Figure 7: Return Loss vs. Frequency *Figure 8: Radiation Pattern*

This design works efficiently in higher frequency region i.e. above 1100 MHz Gain lies within the acceptable region and radiation pattern also do not possess the split in its beam.Lower frequency region i.e. below 1.1 GHz needs to be improved. This can be achieved by making slight changes in the design. Resistive loading and reflector can also be added to increase the performance of the design. Current and field magnitude distribution when animated using HFSS showed that the triangular part needs to be increased in dimensions as compared to the elliptical part. However, the curvature needs to be maintained.

2.1.4 Design-3

The design arises from the previous design. Slight changes like increase in the flat part of the triangle and maintaining the curvature results in output different that in case of DESIGN-2. This design performed well and met almost all requirements but exceeded the dimension of 20 cm X20 cm.

SUBSTRATE:
ROGER 5880 ($\varepsilon_r = 2.2$)

- Thickness 1.6mm
- Length 221mm
- Width 250mm

Patch and ground plane are made of conducting copper with conductivity 58000000 S/m.A rectangle is cut into ground plane of dimension 45 mm X 4.6 mm behind feed at the middle of upper edge.
Feed:

- Width = 4.4mm
- Length = 12 mm

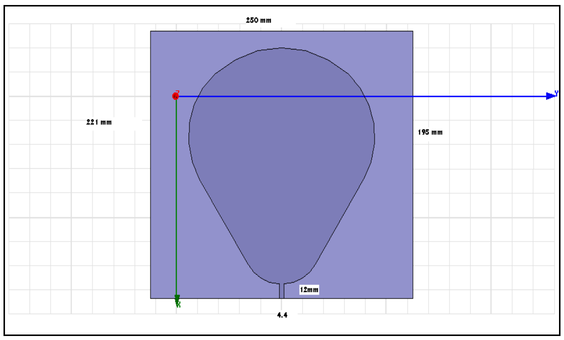


Figure 9: Design of hybrid antenna

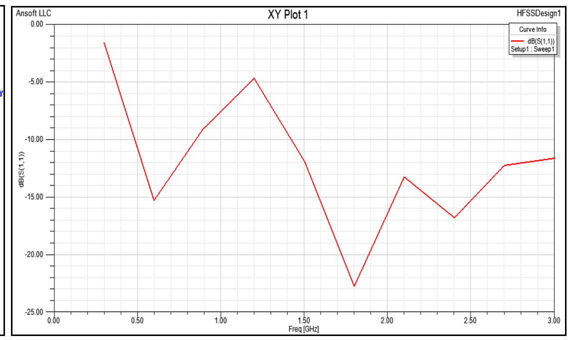


Figure 10: Return Loss vs. Frequency

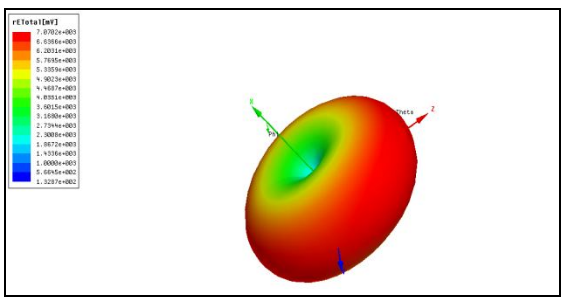


*Figure 11: Rad*iation Pattern

This design is performing as per the requirement. The Radiation pattern is good, and can be made directional by using a plane reflector. Z11 is round 50 ohms showing perfect matching. VSWR is below 2. The S11, as stated earlier, is good above 450 MHz

2.1.5. Design-4 Final Design

Previous design have encouraged us and led to this final design. Distribution of electric field in the patch efficiently allows the current to spread. Almost all the parameters are scaled down to 0.6 times of the original dimension of the design.
SUBSTRATE:
ROGER 5880 ($\varepsilon_r = 2.2$)

- Thickness 1.6mm
- Length 131mm
- Width 150 mm

Patch and ground plane are made of conducting copper with conductivity 58000000 S/m. Now the radiation pattern needs to be made directional. Reflector is implemented simultaneously. Reflector is assigned conducting material Aluminium with conductivity 38000000 S/m.
So, whole antenna element can be enclosed by a box of dimension 13.2cm X 15 cm X4.6cm.

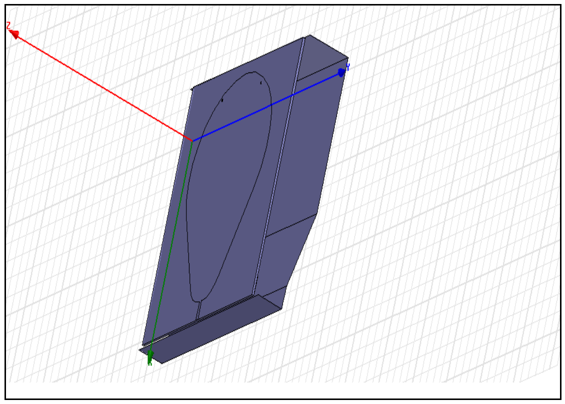


Figure 12: Design of reflector hybrid antenna

After scaling, the substrate height is again made 1.6mm and for better matching, the micro strip feed size is made 9.6mm X 2.7 mm, and width of ground plane is also kept 9.6 mm.

3. Loading

Now XFDTD V7.1.0 is used for resistive loading. We will now observe the various effect of loading on the return loss, radiation pattern and realized gain. Although loading reduces the gain but ameliorates the performance of the lower frequency and make the beam more directional. First we see the effect of loading with two resistances mounted between patch and the reflector (working as the ground plane).

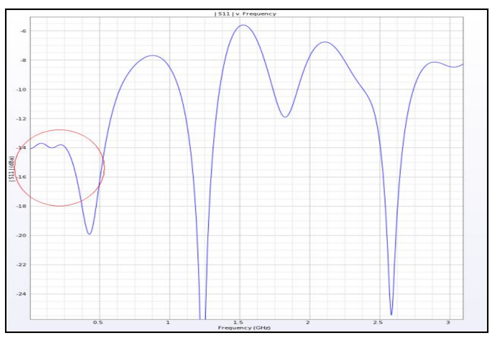


Figure 13: Return Loss vs. Frequency

We can see the drastic improvement in the lower frequency. The whole result shows that the antenna can be used from very low frequency which is required for the Ground penetration (there is less scattering in the lower frequencies). Therefore the loading of 150 ohm is used.

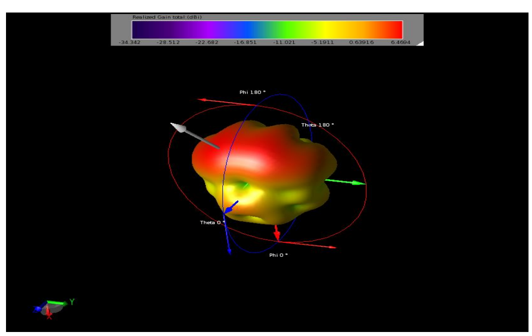


Figure 14: Radiation Pattern

4. Transmit/Receive Antenna Pair

After working on the performance of single antenna element, we move on to work on the transmit and receive antenna pair.

The two antennas are placed as shown in the *Figure 13.* The smallest distance between the feeds is 5.52 cm; largest distance between the two antennas is 285 degrees.

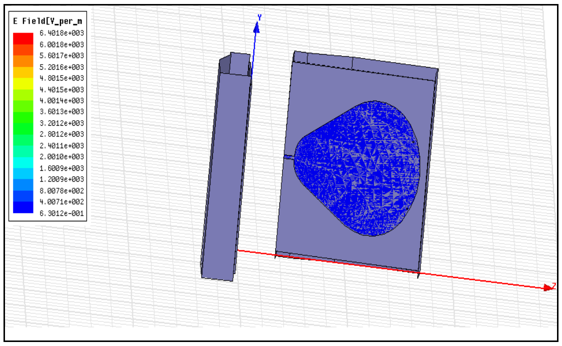


Figure 15: Design of transmit/receive antenna

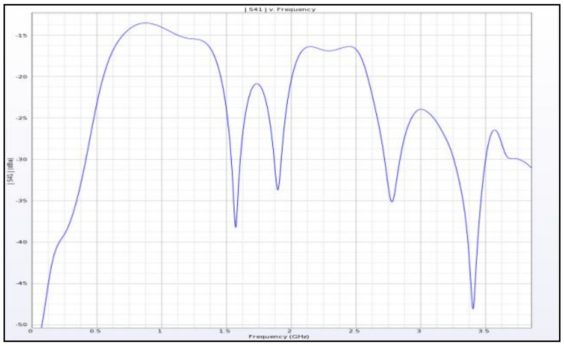


Figure 16: Return Loss vs. Frequency

5. Conclusion

In this paper we have achieved the desired design of Ultra wide band for ground penetrating Radar. This design performs well on almost all the parameters required such as Bandwidth: ~0 MHz TO 3GHZ.

- Mutual coupling: Below 17db
- Impedance: 30 to 60 ohms
- Radiation Pattern (Of Array): Do not split
- Directional: Towards Ground

The design achieves the larger parameter and provides larger surface for the current to travel and radiate simultaneously maintaining the compact size. Also, larger area gives larger bandwidth. Better lower frequency response will have lower scattering and higher penetration and the higher frequency will provide higher resolution. As the design is compact, this can be easily implemented as an array and can be mounted on vehicle. The array provides flexibility to the easy imaging and scrolling over the surface.

6. References

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