ASEC 2024 Conference

The 5th International Electronic Conference on Applied Sciences

04–06 December 2024 | Online

Design and Optimisation of an Inverted U-Shaped Patch Antenna for Ultra-wideband Ground-Penetrating Radar Applications

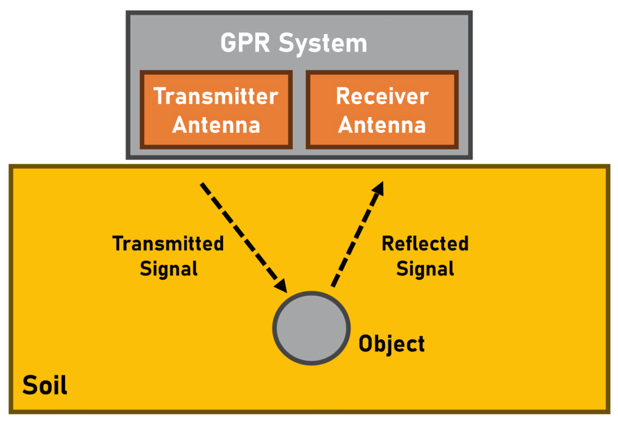
Ankur Jyoti Kalita*, Nairit Barkataki, Utpal Sarma

Department of Instrumentation & USIC, Gauhati University, Assam, India, 781014

INTRODUCTION

Ground Penetrating Radar (GPR)

- GPR sends electromagnetic waves into the ground and receives reflected signals to detect structures or objects.
- Higher frequencies provide better resolution but limited depth, while lower frequencies penetrate deeper but with lower resolution.



Importance of Antenna in GPR

- The antenna determines both resolution and penetration depth of the radar signal, crucial for accurate subsurface imaging.
- Ultra-Wideband (UWB) antennas enhance performance with their wide bandwidth, offering improved resolution and depth adaptability.
- Balancing bandwidth, gain, and resolution ensures optimal performance tailored to diverse GPR applications.

Planar Antennas for GPR

- Planar antennas offer a compact, simple design and can achieve high gain and wide bandwidth.
- However, balancing performance parameters like bandwidth, gain, and resolution remains challenging.

Aim of the Study

- The current work proposes a simple Inverted U-Shaped Patch Antenna with a Defected Ground Structure (DGS) for UWB GPR systems.
- Designed to operate at 1.5 GHz with wide bandwidth and enhanced gain.
- Validated through simulation and experimental measurements.

METHODOLOGY

Antenna Design

- The design of the proposed Inverted U-Shaped Patch Antenna builds upon previous research (Sutham et al., 2022).
- The Inverted U-Shaped Patch Antenna was designed and simulated using CST Design Studio (Student Version) on a double-sided FR4 substrate with:
  - Thickness: 1.6 mm
  - Relative permittivity (ε_r): 4.3
  - Copper thickness: 0.035 mm

Design Features

Inverted U-Shaped Patch:

- Includes a wide rectangular slot, fed with a 50 Ω Microstrip feed line and a Defected Ground Structure (DGS).
- Feed line dimensions were optimised for impedance matching and efficient power transfer across the operational band.

Parametric Optimisation:

- Slot dimensions and placement were varied to minimise return loss at 1.5 GHz while achieving a wide operational bandwidth.
- The bottom corners of the patch were rounded to further refine performance.

Defected Ground Structure (DGS):

- Ground plane dimensions were fine-tuned to improve impedance matching and expand bandwidth.
- Corner strip slots were introduced, with their size and placement optimised.

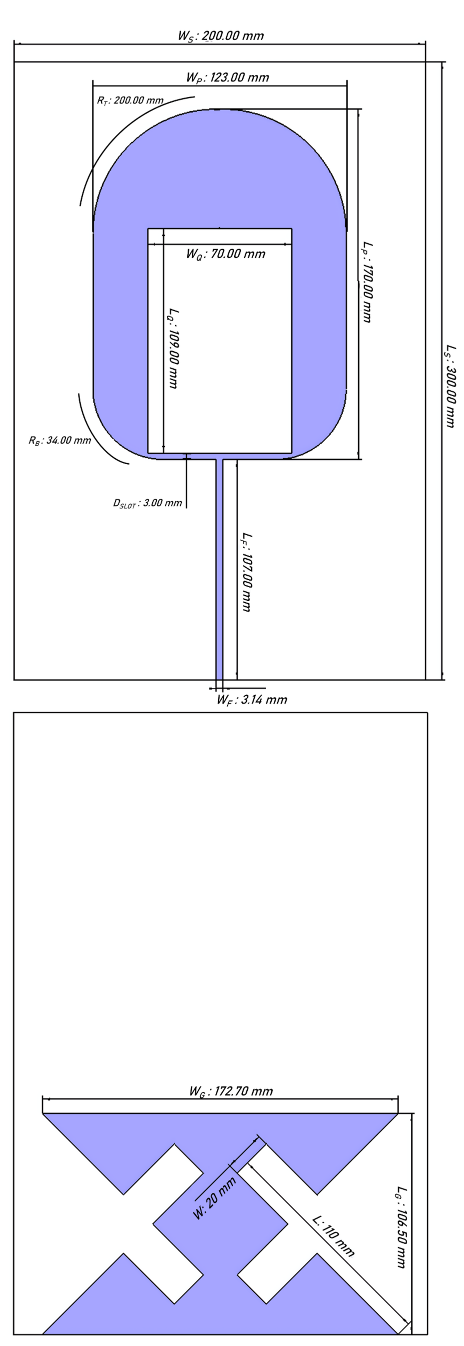


Figure 1 : Geometry of the proposed antenna

Optimised Design

- After several simulation runs in CST, the final layout (Figure 1) achieved.
- Low return loss at 1.5 GHz.
- Wide bandwidth suitable for UWB GPR applications.

RESULTS & DISCUSSION

The antenna was simulated and fabricated on an FR4 substrate as shown in Figure 2.

Wideband Performance

- Simulated Bandwidth: 1.13 GHz to 4 GHz S11 ≤ -10 dB)
- Minimum Return Loss: -32.62 dB at 1.5 GHz, -32.32 dB at 3 GHz

Experimental Validation

- Measured Bandwidth: 1.068 GHz to 4 GHz (S11 ≤ -10 dB)
- Minimum Return Loss: -32.53 dB at 2.30 GHz, -28.60 dB at 1.52 GHz

The experimental results closely match the simulated data, demonstrating the antenna's robust performance as shown in Figure 3.

Minor discrepancies arise due to fabrication tolerances and material properties.

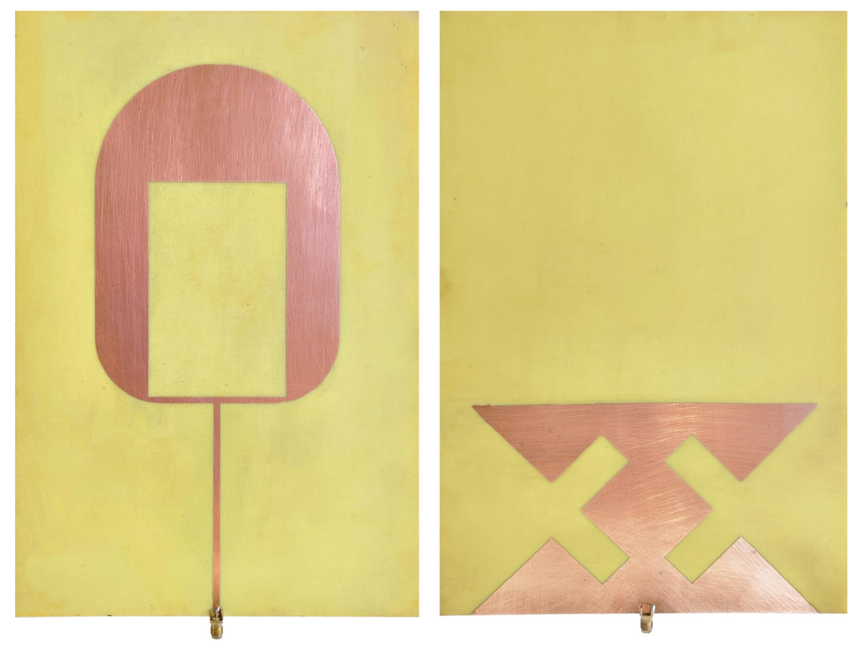


Figure 2 : Picture of the Fabricated Inverted U-Shaped Patch Antenna

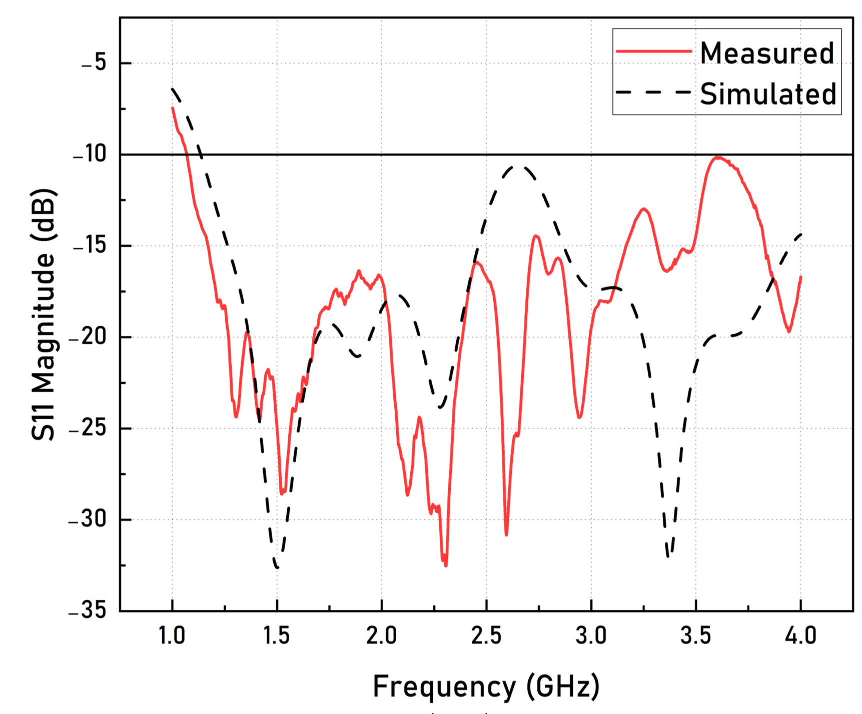


Figure 3 : S-Parameter (S11) Characteristics of the Inverted U-Shaped Patch Antenna

Simulated 3D Radiation Patterns

Gain: 5.24 dB at 1.5 GHz, 7.27 dB peak at 4 GHz

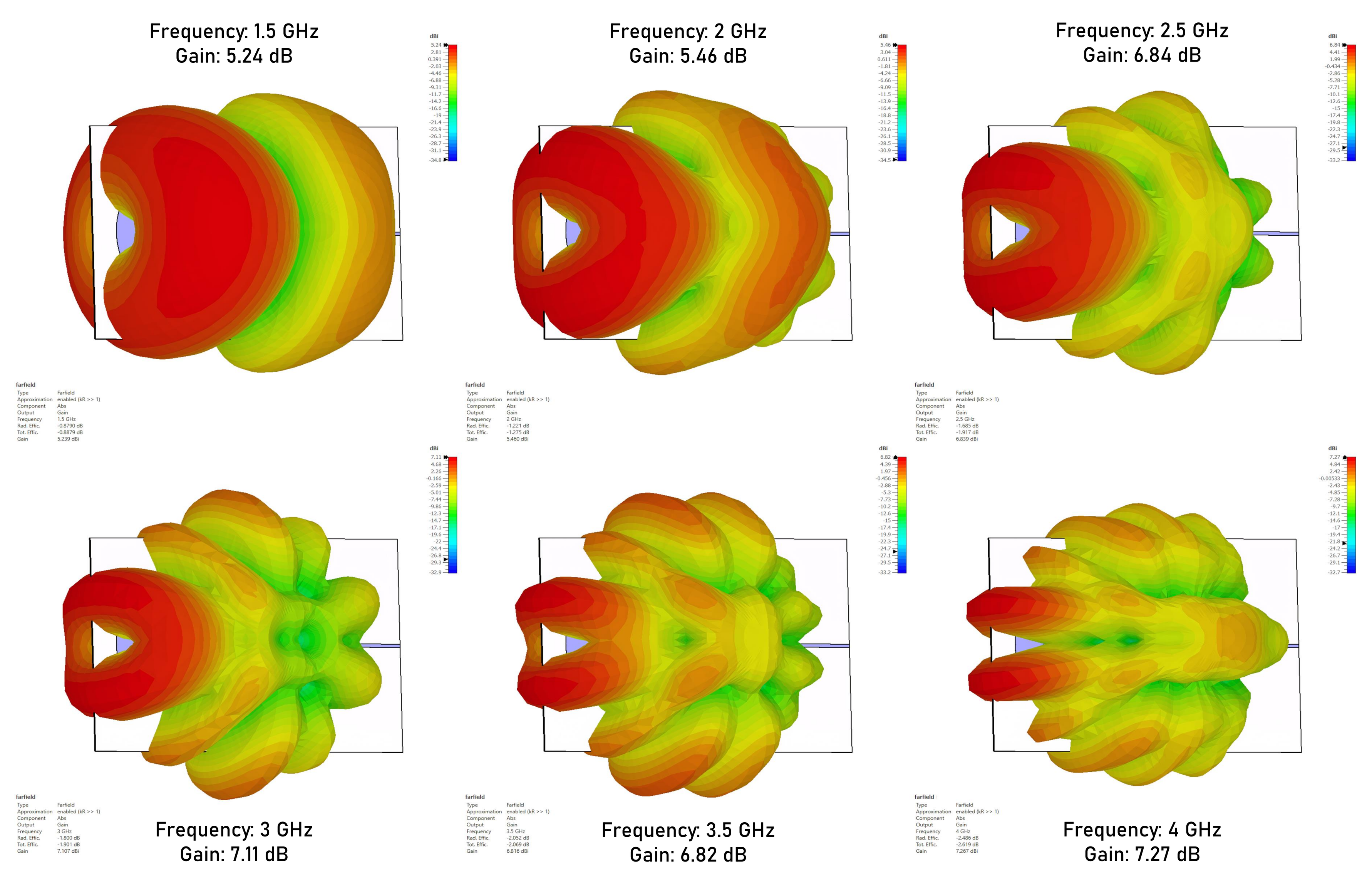


Figure 4 : Simulated 3D Radiation Patterns of the Inverted U-Shaped Patch Antenna at Various Frequencies

CONCLUSION AND FUTURE WORK

- Designed an Inverted U-Shaped Patch Antenna centered at 1.5 GHz with a wide bandwidth of 1.068–4 GHz and high gain (5.24–7.27 dB).
- The antenna exhibits wideband radiation characteristics, enabling improved resolution and deeper penetration for GPR tasks such as utility mapping and artifact detection.
- Achieves high gain without the need for a reflector, resulting in a smaller and more compact size compared to earlier designs.
- The proposed antenna introduces an improved and simplified design incorporating a DGS.
- The proposed design demonstrates scalability for further gain enhancement through reflector integration, making it highly adaptable for diverse GPR applications.

Future Work

- Reduce antenna dimensions for easier integration into compact GPR systems.
- Optimise the front-to-back (F/B) ratio to suppress side-lobe radiation and improve efficiency.

References

[1] Hertl, Ivo, and Michal Strycek. "UWB antennas for ground penetrating radar application." 2007 19th International Conference on Applied Electromagnetics and Communications. IEEE, 2007.

[2] Ali, Jawad, et al. "Ultra-wideband antenna design for GPR applications: A review." International Journal of Advanced Computer Science and Applications 8.7 (2017).

[3] Sutham, Thanakorn, Wanwisa Thaiwirot, and Prayoot Akkaraekthalin. "Design of Ultra-Wideband Inverted U-Shaped Slot Antenna with Reflector for GPR Applications." 2022 19th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON). IEEE, 2022.

[4] Ali, Jawad, et al. "Ultra-wideband antenna development to enhance gain for surface penetrating radar." Wireless Personal Communications 115 (2020): 1821-1838.

[5] Raza, Ali, et al. "A magnetic-loop based monopole antenna for GPR applications." Microwave and Optical Technology Letters 61.4 (2019): 1052-1057.

[6] Nayak, Rashmiranjan, Subrata Maiti, and Sarat Kumar Patra. "Design and simulation of compact UWB Bow-tie antenna with reduced end-fire reflections for GPR applications." 2016 International Conference on Wireless Communications, Signal Processing and Networking (WiSPNET). IEEE, 2016.

[7] Raza, A., et al. "A Wideband Reflector-Backed Antenna for Applications in GPR." International Journal of Antennas and Propagation 2021.1 (2021): 3531019.