*Journal of Harbin Engineering University*
*ISSN: 1006-7043*

Vol 46 No. 10
October 2025

# Simulation study of ground penetrating radar operation with an antenna array

**Aye Mint Mohamed Mostapha, Ould Mohamed Yeslem Ahmed El Mouna**

Department of Physics, University of Nouakchott

**Abstract**

Ground Penetrating Radar (GPR) is a geophysical technique based on the emission and reception of high-frequency electromagnetic waves, used to explore and map underground structures. The effectiveness of GPR is directly conditioned by the choice of the antenna, each offering specific properties that impact the accuracy of the information obtained. This work presents a simulation study of the operation of GPR radar with an antenna array as in the Reflexw software. Different models were carried out to evaluate the detection of objects of various shapes, sizes and natures, buried in various mediums. The results obtained showed the effectiveness of the antenna in most of the cases studied. However, in certain mediums with high conductivity, the rapid attenuation of GPR waves led to non-detection of objects.

**Keywords**: GPR, Antenna Array, Reflexw software, FDTD method.

## 1. Introduction

Ground Penetrating Radar (GPR) is a non-destructive geophysical prospecting technique based on the analysis of propagation phenomena (refraction, reflection and diffraction) of high-frequency electromagnetic waves in the subsoil [1-2]. It is used in several research fields such as geology, archaeology, civil engineering, etc. [3-4].

A GPR system consists of a transmitting antenna that sends short pulses of high-frequency radio waves into the ground. When these waves encounter different underground materials or structures, they are reflected back to the surface. The degree of reflection depends on the dielectric properties of the materials. A receiving antenna then picks up the reflected signals, which are recorded and processed by the GPR system [5-7].

The penetration depth of waves is limited both by their frequency and by the conductivity of the materials they pass through. Thus, higher frequencies provide better resolution but shallower penetration, while lower frequencies penetrate deeper but with lower resolution [8-10].

Regardless of the GPR operating mode or application area, the antenna must have a wide bandwidth, ensuring the stability of its impedance, directivity and polarization properties over a wide frequency range. Choosing the antenna best suited to a given application is Therefore a determining factor for the efficiency of the system [11-12].

This work presents a simulation study of the operation of GPR with the antenna array (as in Reflexw software), for the detection of objects of various shapes, sizes and natures, buried in different mediums. The simulations were performed using Reflexw software, which is based on the FDTD (Finite Difference Time Domain) method.

## 2. Antenna array

An antenna array is a group of antennas connected and arranged in a regular structure to form a single antenna that can be used in GPR systems to enable faster data collection by increasing the extent of the surveyed area per unit time [13-14].

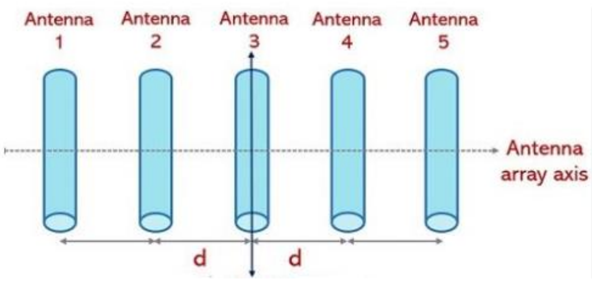



Fig.1. Example of an antenna array

This can be a significant advantage in archaeological prospecting, road and bridge inspection, mine detection, as well as in several other civil engineering and geoscience applications where data collection requires the execution of a large number of additional profiles, Antenna arrays allow the simultaneous collection of multi-offset measurements, thus providing additional information for more efficient imaging and characterization of the natural or artificial scenario under test [15].

## 3. Results and discussion

### 3.1 Detection of two circular objects: conductor and dielectric

In this part, we simulated the detection of two objects, one conductive and the other dielectric, buried in different mediums (dry sand, wet sand, concrete, snow and clay). Figures 2, 3, 4, 5 and 6 show the radargrams of object detection and the evolution of GPR waves in the studied mediums over time. On the radargrams, we note the presence of hyperbolas which indicate the presence of objects. However, the visibility of these hyperbolas varies depending on the medium, due to the differences in physical properties (permittivity, conductivity) of each of them. It can be seen that the presence of the conductive object is always marked by clearer and better defined hyperbolas than those associated with the dielectric object. This is explained by the high conductivity of the conductive material, which leads to a more intense reflection of the GPR signal. In the particular case of the clay medium (Figure 6a), the detection of objects is not possible. Indeed, the high conductivity of the clay causes a rapid attenuation of the GPR waves (Figure 6b), which prevents the detection of objects.

- **Dry sand medium**

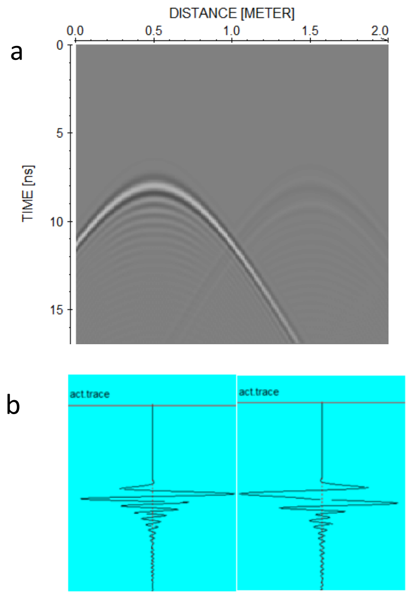



Fig.2. (a) radargram of the detection of two objects buried in a dry sand medium (b) evolution of GPR waves over time.

- **Wet sand medium**

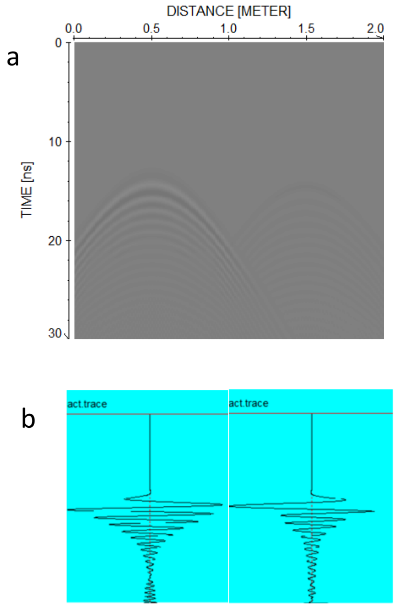



Fig.3. (a) radargram of the detection of two objects buried in a wet sand medium (b) evolution of GPR waves over time.

- **Concrete medium**

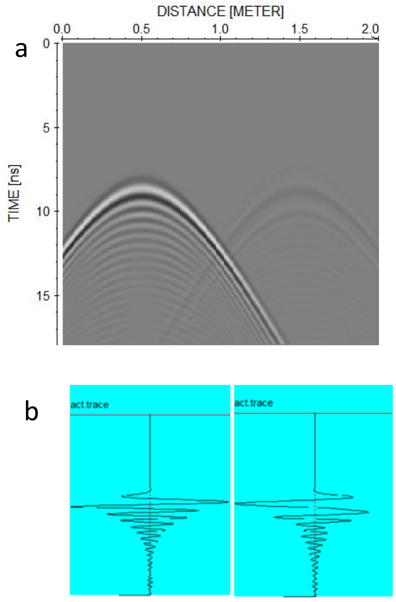



Fig.4. (a) radargram of the detection of two objects buried in a concrete medium (b) evolution of GPR waves over time.

- **Snow medium**

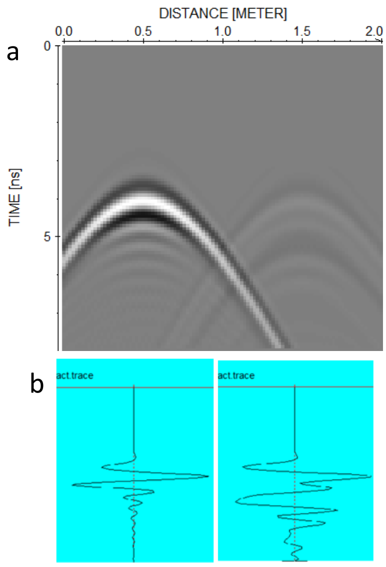



Fig.5. (a) radargram of the detection of two objects buried in a snow medium (b) evolution of GPR waves over time.

- **Clay medium**

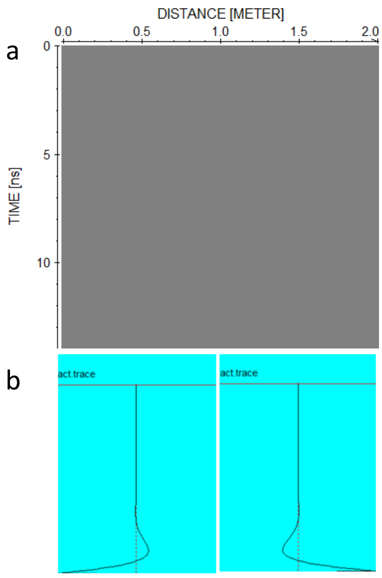



Fig.6. (a) radargram of the detection of two objects buried in a clay medium (b) evolution of GPR waves over time.

### 3.2 Detection of conductive objects of different shapes and sizes

In this section, we simulated the detection of conductive objects of different shapes and sizes, buried in the same mediums studied previously. The figures below present the models of the objects as well as the radargrams obtained. In dry sand (Figure 7 b), hyperbolas indicating the presence of objects are very visible. However, their contrast varies depending on the shape, size and depth of the objects. These parameters directly influence the strength of GPR wave reflection, and therefore the visibility of hyperbolas. In wet sand (Figure 8 b), hyperbolas appear less distinctly, especially for objects located at depth. This reduction in visibility is due to the greater attenuation of electromagnetic waves in a humid environment. In concrete and snow (Figure 9 b and 10 b), hyperbolas are clearly observed, but there are still some differences between the results obtained in these two mediums, linked to their distinct electromagnetic properties (permittivity, conductivity). Finally, in the clay medium (Figure 11 b), the objects are not detected. As in the previous section, the high conductivity of clay causes a rapid attenuation of the GPR signal, which prevents the appearance of the characteristic hyperbolas.

- **Dry sand medium**

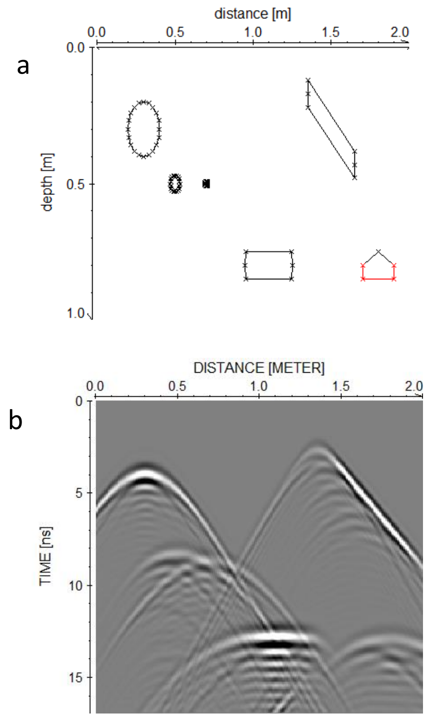



Fig. 7. (a) Model of some conductive objects buried in a dry sand medium (b) radargram of object detection.

- **Wet sand medium**

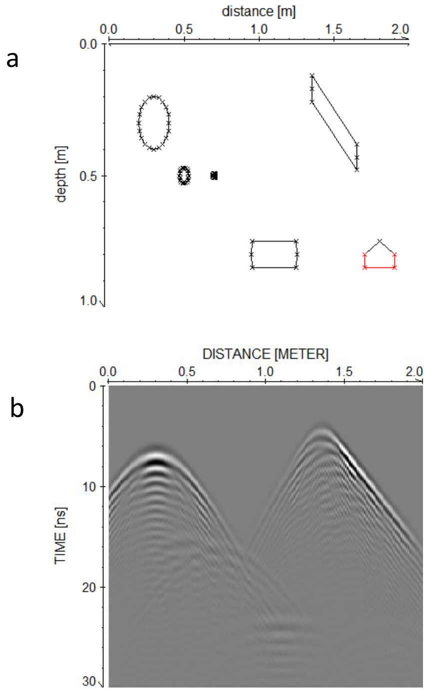



Fig.8. (a) Model of some conductive objects buried in a wet sand medium (b) radargram of object detection.

- **Concrete medium**

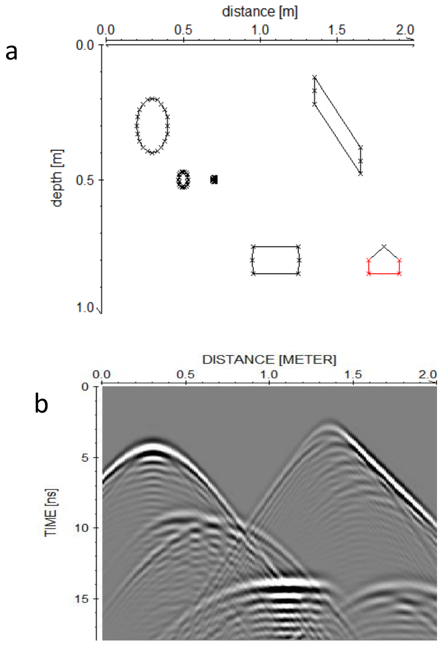



Fig.9. (a) Model of some conductive objects buried in a concrete medium (b) radargram of object detection.

- **Snow medium**

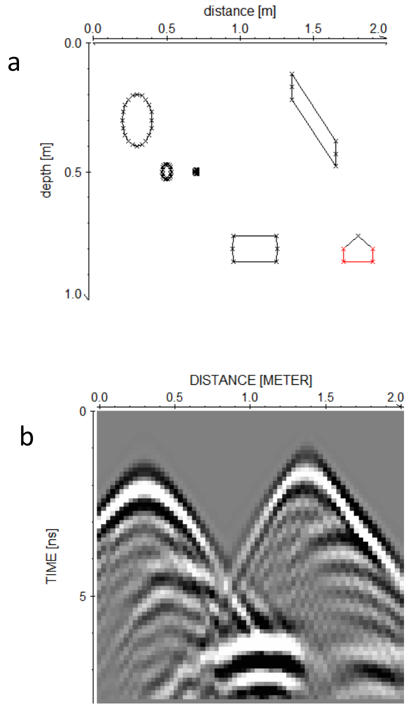



Fig.10. (a) Model of some conductive objects buried in a snow medium (b) radargram of object detection

- **Clay medium**

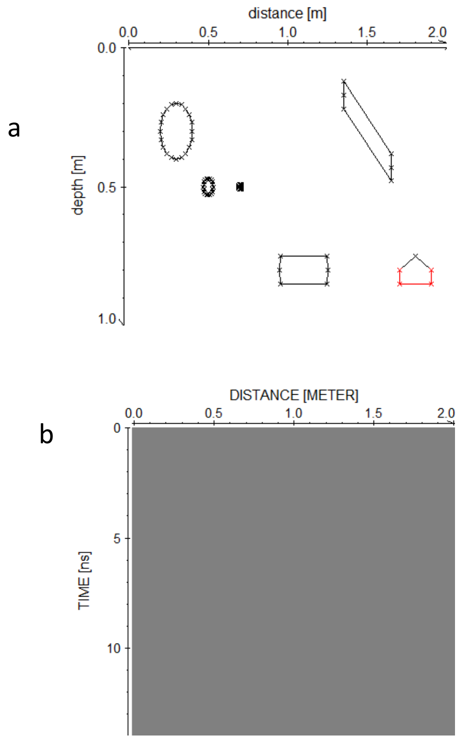


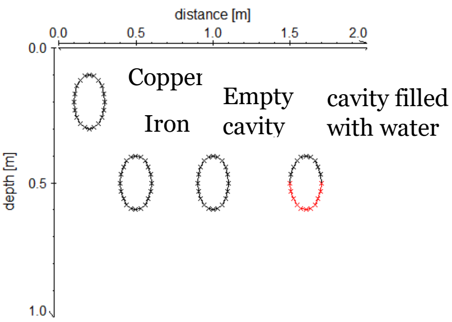

Fig.11. (a) Model of some conductive objects buried in a clay medium (b) radargram of object detection.

### 3.3 Detection of objects of different natures

In this section, we simulated the detection of objects of different natures: iron, copper, empty cavity and cavity filled with water, buried in the same mediums considered previously. The figures below present the models of the objects as well as the radargrams obtained. In dry sand (Figure 12 b), detection is generally satisfactory. Hyperbolas associated with iron and copper objects appear sharper and more contrasted than those corresponding to cavities. This difference is explained by the high electrical conductivity of metals, which causes a more intense reflection of the GPR signal. In wet sand (Figure 13 b), the hyperbola associated with the iron object remains clearly visible, mainly due to its high conductivity and its reduced depth, close to the surface. On the other hand, the hyperbolas associated with other objects appear much less distinct, or even almost invisible, due to the increased attenuation of GPR waves in this medium. In concrete and snow (Figure 14 b and figure 15 b), objects are detected, but differences in the visibility and clarity of hyperbolas are still observed. These variations are linked to the electromagnetic properties specific to each material, which influence the propagation and reflection of GPR waves differently. Finally, in the clay medium (Figure 16 b), the detection of objects remains impossible, including those located near the surface. The high conductivity of clay leads to rapid absorption of the radar signal, which considerably limits the penetration of waves and prevents the appearance of characteristic hyperbolas.

- **Dry sand medium**

a




b

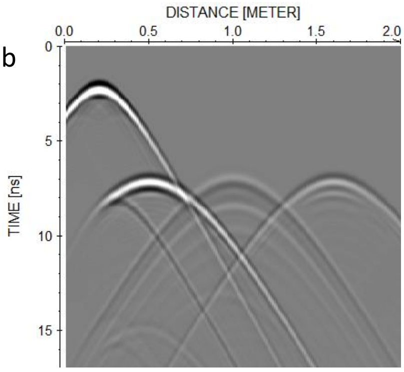
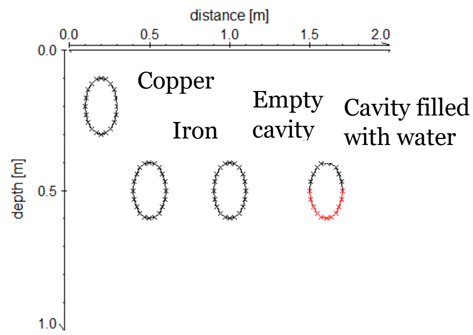



Fig.12. (a) Model of objects of different natures buried in a dry sand medium(b) Radargram of object detection

- **wet sand medium**

a




b

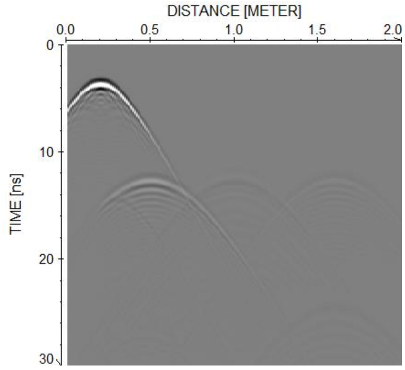



Fig.13. (a) Model of objects of different natures buried in a wet sand medium(b) Radargram of object detection.

- **Concrete medium**

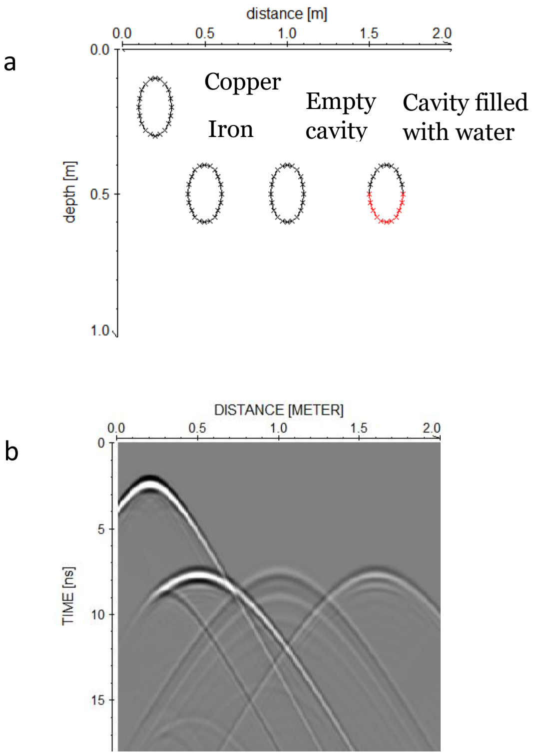



Fig.14. (a) Model of objects of different natures buried in a concrete medium(b) Radargram of object detection.

- **Snow medium**

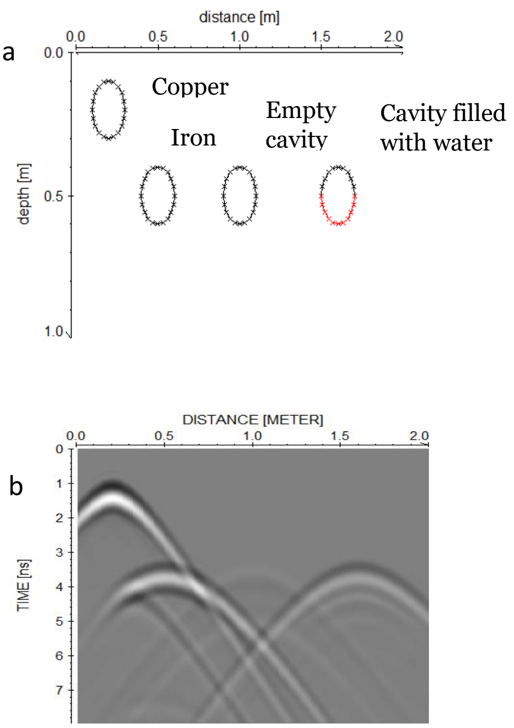



Fig.15. (a) Model of objects of different natures buried in a snow medium(b) Radargram of object detection.

- **Clay medium**

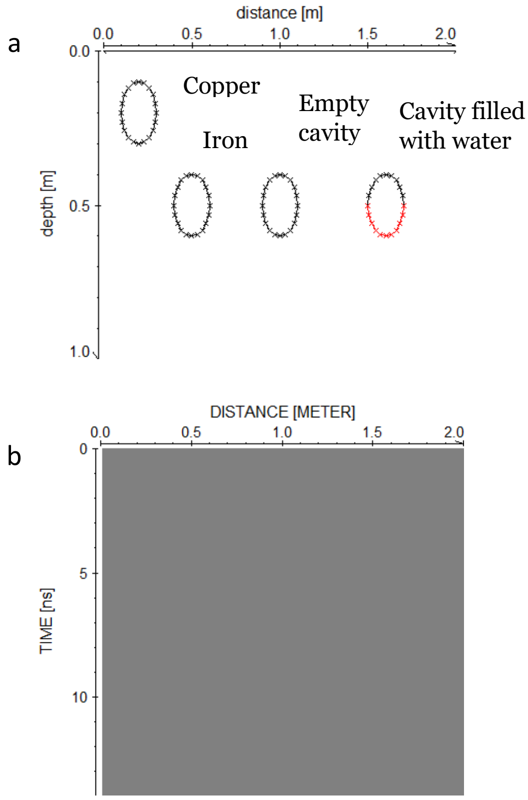



Fig.16. (a) Model of objects of different natures buried in a clay medium(b) Radargram of object detection.

## 4. Conclusion

In this work, we simulated the operation of GPR radar with an antenna array. Different models have been created to detect objects of various sizes, shapes and natures buried in different mediums. The results obtained showed the effectiveness of this antenna for GPR applications, except in certain cases where the conductivity of the medium is high. In these situations, the rapid attenuation of GPR waves prevents the detection of objects.

**Refrences**

[1] Alsharahi, G., et al. "2D FDTD simulation to Study response of GPR Signals in homogeneous and inhomogeneous mediums." International Journal on Communications Antenna and Propagation (IRECAP) 20 (2016).

[2] Serma, Awangku Iswandy Awangku, and Halim Setan. "Ground penetrating radar (gpr) for subsurface mapping: preliminary result." Geoinf Sci J 9 (2009): 45-62.

[3] Knight, Rosemary. "Ground penetrating radar for environmental applications." Annual Review of Earth and Planetary Sciences 29.1 (2001): 229-255.

[4] Ortega-Ramírez, J., et al. "Application of non-invasive geophysical methods (GPR and ERT) to locate the ancient foundations of the first cathedral of Puebla, Mexico. A case study." Journal of Applied Geophysics 174 (2020): 103958.

[5] Varevac, Damir, et al. "Challenges in Ground-Penetrating Radar Application in Structural Elements: Determination of the Dielectric Constant of Glued Laminated Timber Case Study." Electronics 13.18 (2024): 3718.

[6] Alsharahi, Gamil, et al. "Contribution of analysis and detection the risks appearing in roads using GPR method: A case study in Morocco." Ain Shams Engineering Journal 12.2 (2021): 1435-1450.

[7] Mostapha, A., et al. "Effect of the Variation in Humidity of the Medium on the GPR Radar Response." Proceedings. Vol. 63. No. 1. MDPI, 2020.

[8] Venkateswarlu, B., and Vinod C. Tewari. "Geotechnical applications of ground penetrating radar (GPR)." Jour. Ind. Geol. Cong 6.1 (2014): 35-46.

[9] Quinn, James A., et al. "Novel application of ground penetrating radar for damage detection in thick FRP composites." Composites Part B: Engineering 284 (2024): 111716.

[10] Song, P., et al. "Feasibility study of a high-resolution shallow surface penetration radar for space application." Radio Science 56.2 (2021): 1-20.

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

[12] Sun, Hai-Han, et al. "Compact dual-polarized vivaldi antenna with high gain and high polarization purity for GPR applications." Sensors 21.2 (2021): 503.

[13] Vescovo, Roberto, and Lara Pajewski. "Multiple-ring Circular Array for Ground-Penetrating Radar Applications: Basic Ideas and Preliminary Results." Journal of Telecommunications and Information Technology (2017).

[14] Liu, Hai, and Motoyuki Sato. "Design of a GPR antenna array for asphalt pavement inspection." Conference Proceedings of 2013 Asia-Pacific Conference on Synthetic Aperture Radar (APSAR). IEEE, 2013.

[15] Benedetto, Andrea, and Lara Pajewski, eds. "Civil engineering applications of ground penetrating radar."Book. Springer, 2015.