ASEG2024 HOBART

MAPRad – A miniaturised magnetic antenna Ground Penetrating Radar

Matthew W Auld
Space Physics Group RMIT
s3610413@student.rmit.edu.au

James C Macnae
CD3D Pty Ltd
James.Macnae@rmit.edu.au

Gail N Iles
Space Physics Group RMIT
Gail.Iles@rmit.edu.au

SUMMARY

With increased interest in missions to the Moon and Mars aimed at permanent human presence, exploration and detection of key subsurface structures and resources is crucial. Current scientific missions to the Moon and Mars have been in the form of orbital sounding radars and surface rover-based ground penetrating radar (GPR). Orbital sounding radars often have lower resonant frequencies with lower depth resolution but higher penetration power, while rover based GPR have comparatively higher resonant frequencies which trade the better depth resolution for lower penetration depth. To date only electric field-based antennae have been used in these applications, which are restricted in their size being fractional powers of two of their resonant wavelengths.

Our project has been to design, manufacture and test a miniaturised magnetic antenna for use in a GPR system, called MAPRad. MAPRad utilizes a pair of ferromagnetic cored coil antennae designed for use at a resonant frequency of 20 MHz with a core length of 30 cm. Comparing this to an equivalent electric field half wave dipole, which would be 7.5m long, the antenna is 25 times smaller, while also possessing an increased bandwidth. The saving in space would allow for a rover mounted GPR system to operate at a significantly lower central frequency and across a wider band as compared to traditional electric field antennae, allowing for a greater depth penetration while retaining resolution.

The current MAPRad prototype has been field tested and validated using the magnetic antennae receiver and an electric transmitter. Data suggests that MAPRad has very similar detection characteristics as an equivalent electric field antenna system. The next phases of the project involve implementing the magnetic transmitter and field testing the system with both magnetic antenna on the transmitter and receiver.

Key words: GPR, Space, Magnetic Antenna, Near Surface

INTRODUCTION

The study of lava tubes offers significant benefits for advancing geological research and space exploration techniques. Basaltic lava flows, which have resistive characteristics, make excellent targets for testing electromagnetic-based exploration methods such as ground-penetrating radar (GPR). The discovery of lunar lava tubes, which studies suggest can support larger structures in the lower lunar gravity, has facilitated much interest in the Moon and other planets (Kaku, et al. 2017; Blair, et al. 2017). Lunar Lava tubes are proposed as ideal habitation areas for Astronauts on the surface of the Moon, as they provide natural protection against the harsh space radiation environment, as well as meteoroids (Horz, 1985). On other planetary bodies such as Mars with dangerous weather, natural lava tubes would also provide protection.

Several orbiters have been used around the Moon and Mars to detect geological structures, both on and under the surface (Hamran, et al. 2020; Kobayashi, et al. 2014). Orbital sounding radar techniques can utilise lower resonant frequencies, afforded by the availability of space and power, to penetrate deeper into the surface at the cost of resolution (Putzig et al., 2024). A handful of rovers equipped with GPR have been sent to the Moon, as well as Mars, to effectively detect the subsurface structure (Lai, et al. 2020). To date these rovers have only explored small regions in the Northern hemisphere of the Moon, and Mars, uncovering sedimentary layers that provide insights into the formation of the region. Rover based systems are more limited in the size of antenna they can carry, as well as the amount of power they can transmit.

Traditional GPR systems employ electric field-driven antennae, resonant at microwave frequencies (Annan, 2022). However, ferromagnetic core antennae offer a notable size reduction paired with a wider bandwidth, making them suitable for applications requiring deeper subsurface penetration in limited space. In this extended abstract we discuss our prototype MAPRad, a ferromagnetic core based magnetic antenna GPR, some of the collected data and some of the benefits of the system.

MAPRAD

MAPRad is a magnetic antenna driven GPR system, that operates at a resonant frequency of 20 MHz and is designed with the specific use case of being a rover mounted system for use on a Lunar mission. The antenna used is of the ferrite rod style, where we have used a ferromagnetic rod as the core of the antenna, based on previous work by Macnae (2013). The receiver antenna is connected to a multi-stage low noise amplifier which boosts the signal before signal capture, which is tied to an optical sync pulse. Thus far the magnetic receiver antenna has been tested with an electric transmitting antenna.

The design of MAPRad has primarily been influenced by the idea of the transmitting antenna being attached an arm that allows extension away from the rover, while the receiver would act as a tail to the rover and be pulled along behind the rover, possibly being coiled up when not in use. Simulations have been undertaken to determine if MAPRad would cause interference to, or be interfered by, a rover with the antenna mounted on an arm held out away from the main rover body (Auld, et al. 2023). These simulations have shown that there would not be significant levels of electromagnetic interference from either end to warrant a dedicated shield for this scenario.

Initial field tests using MAPRad have provided promising results in several locations, one site being the Smythesdale landfill where a previously collapsed section of an old mine shaft had been located when excavating. The mine shafts were found to be approximately 1m wide, and only a few metres beneath the surface. A simulation has been made in GPRMax to compare the data collected to what was expected to be under the surface. GPRMax is an open-source finite-difference time-domain software that is useful in simulating how EM waves generated from GPR devices will propagate through and reflect off geometry within a medium (Warren, et al. 2016).

COMPARISON TO SIMULATION

The simulation created was a basic 2D environment, consisting of a homogeneous earth layer with a 1m wide circle of free space residing 5m under the surface. The transmitter (Tx) and receiver (Rx) are placed 1m apart, just above the surface of the earth material. The Tx/Rx pair are moved horizontally across the environment in steps of 1m. This emulates the scenario of walking perpendicular over a tunnel. The results of this simulation are shown in figure 1, where a shallow hyperbolic feature can be seen at between approximately 125 – 150 ns.

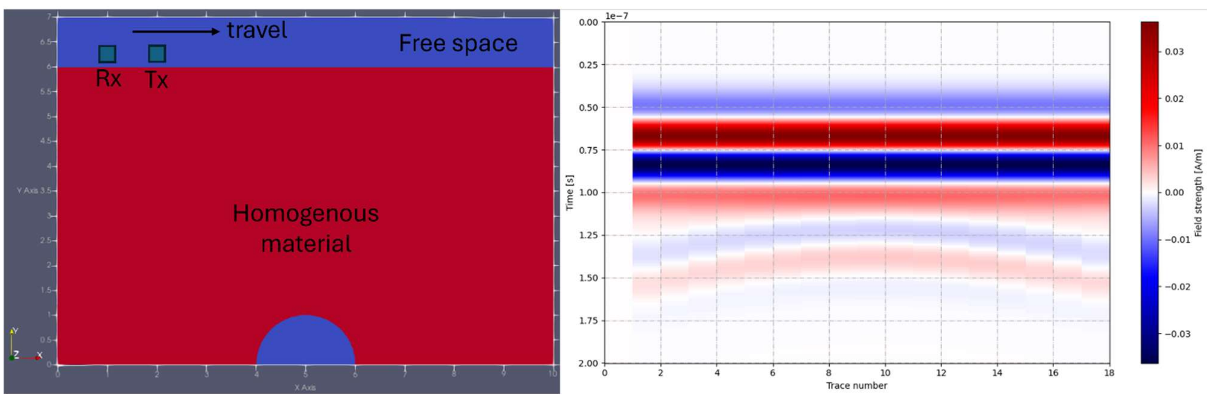

Figure 1: GPRMax simulated environment (Left) and the corresponding B-Scan of the simulated environment (Right)

We compare this to a some of the data collected at the Smythesdale site in figure 2, where with some light processing, a similar feature appears around the 100 – 125ns mark. The survey data obtained is understandably much less clear than the simulation results, due to multiple reflections and other objects nearby causing reflections.

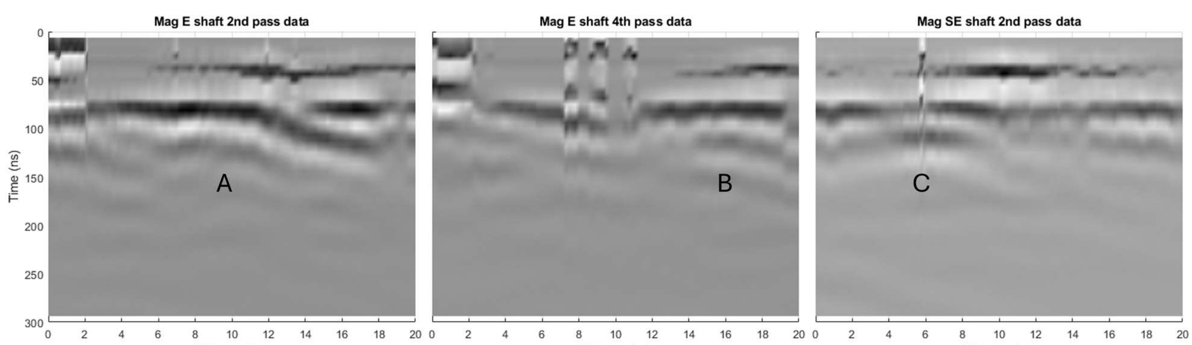

Figure 2: Suspected responses (A, B and C) from a shaft in three different passes over sections of a shaft denoted East (Left and centre) and Southeast (Right).

DISCUSSION

This data, paired with the simulation results shows that MAPRad may be capable of detecting targets as small as 1m wide, but will struggle with any smaller sized targets. This was expected as we use a relatively low resonant frequency, which comes with a lower resolvable resolution. Other survey data has shown that Maprad is capable in detecting larger targets with ease. Processing of data from a survey in the Undara Volcanic National Park is currently under review and expected to be published soon.

ACKNOWLEDGMENTS

This project is primarily funded by an Australian Government Research Training Program (RTP) Scholarship. Development of the MAPrad antenna is funded by the Australian Space Agency's Moon2Mars Demonstrator program, in conjunction with CD3D. The Australian Society of Exploration Geophysicists (ASEG) Research Foundation supports void mapping and mineral discrimination aspects of this project.

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