DESIGN, IMPLEMENTATION AND TESTING OF A PROTOTYPE 1.1-2.1 GHZ SFCW GPR FOR USE IN LANDMINE DETECTION

Colin Gilmore, Derek Collins, Ian Jeffrey, Scott Peters, Joe LoVetri
Department of Electrical and Computer Engineering, University of Manitoba
cgilmore@ee.umanitoba.ca, dcollins@ee.umanitoba.ca, ijeffrey@ee.umanitoba.ca, speters@ee.umanitoba.ca, lovetri@ee.umanitoba.ca

Abstract

The problem of undetected anti-personnel landmines is both of major political concern and a formidable engineering problem. Currently, no affordable, accurate method for detecting such mines exists. As a solution to the landmine problem this paper gives an account of the design, implementation and testing of an inexpensive, prototype 1.1-2.1 *GHz Stepped Frequency Continuous Wave (SFCW) Ground Penetrating Radar (GPR) for landmine detection. Initial tests performed in a laboratory based environment using a homogenous Styrofoam ground medium have shown that the design has potential to accurately detect landmines in a field test situation.*

Keywords: *GPR, RADAR, landmines*

1. INTRODUCTION

There are an estimated 100 million active landmines yet undetected in the world today. These mines pose a major concern to human safety and render land unusable for many purposes including agriculture. While major efforts, such as the negotiation of international treaties, are being undertaken to prevent the distribution and use of new landmines, the subject of finding, removing and/or disarming existing landmines is one of major engineering interest. Currently, methods for landmine detection are still unable to detect the 99.6% of landmines, to a depth of 10 cm, required to satisfy current regulations that deem a section of land suitable for human activity.

The use of GPR for landmine detection is one technique that may be able to help solve the landmine problem. GPR uses a range of frequencies chosen to optimize the balance between penetration depth and image/information resolution. In this manner that high energy, high frequency signals return optimal information for image/statistical analyses while low frequency, low energy signals have the ability to penetrate the earth. By carefully selecting an appropriate frequency range it is theoretically possible to detect landmines to a required depth while obtaining optimal resolution [1].

The design and implementation details given herein, document an attempt to produce a portable, affordable GPR system that will be able to detect landmines buried beneath the earth. While the goal of this GPR system is to produce the best possible results given the selected design, it is noted that the reliability and accuracy achieved are not sufficient for field use. The results should simply be considered as a proof of concept or a prototype for future work and innovation.

2. TARGET CONSIDERATIONS

In order to make use of a RADAR system for imaging buried objects, two fundamental criteria upon which such systems are evaluated must first be investigated. These are maximum penetration depth and depth resolution (more commonly referred to as resolving power) [1]. As indicative of its name, the maximum penetration depth of a GPR system is the maximum depth beneath a surface that a RADAR system can detect an object. The resolving power of a GPR system is defined as the minimum separation between two objects such that the presence of *both* objects can be distinguished. Thus, two objects are said to be *irresolvable* if the distance separating them is less than the resolving power of the RADAR system.

With these concepts in mind, it is clear that the design of a GPR system for detecting landmines will depend on the size, depth, and separation of the landmines in question. Two mock anti-personnel (AP) landmines were

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obtained from Canadian Department of National Defense (DND). In active mines the interior is filled with TNT, however, in these inert mines the interior cavity is air. Fig.1 depicts the two landmines next to a 15 cm ruler for perspective.

Fig. 1. Mock AP landmines

From the size of the landmines, the required resolving power of a GPR system for detecting such mines is specified as approximately 5 cm. This value was selected based on the smaller of the two mines having a diameter of 7 cm. Normally such mines are buried 5-10 cm beneath the earth's surface. Thus the maximum penetration depth of a suitable GPR system must be at least 10 cm.

Of further interest regarding the mines obtained is the fact that they are constructed almost entirely of plastics and will therefore have a much smaller RADAR cross-section (i.e., response to RADAR signals) than a metallic object.

3. SYSTEM DESIGN

3.1 Overall System Design

The system designed is a 1.1-2.1 GHz Stepped-Frequency Continuous Wave (SFCW) RADAR which measures both magnitude and phase of the received scattered signal with respect to the transmitted signal. For this frequency range the theoretical penetration depth is 1 m for practical soils as discussed in [1] and assuming a relative permittivity of $\varepsilon_r = 2$, the resolution can be shown to be approximately 10 cm [3]. For the same frequency range it is suggested in [1] that a resolution of 5 cm is possible. In order to emphasize the hardware design of the GPR and the results obtained from testing, the reader is referred to literature describing the details of SFCW [1].

In order to make the task of data acquisition and calibration possible, the system was automated by a microcontroller that samples and stores received information for later offline processing. An overall block diagram of the system is presented in Fig. 2.

Decisions regarding antenna choice and imaging techniques were made to show the feasibility of the system. The use of horn antennas was based solely on availability while images were produced as an easy verification method for mine detection. Further research into these areas, including the possibility of simple statistical analysis of data, are currently being investigated.

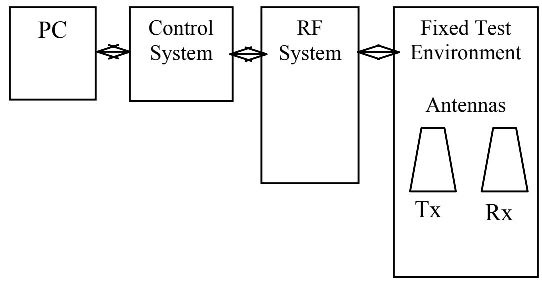

Fig. 2. GPR system block diagram.

3.2 Radio Frequency (RF) System

Since system cost needs to be kept to a minimum, and RF components are the most expensive component of the GPR, inexpensive parts were used. A block diagram of the RF system is given in Fig. 3.

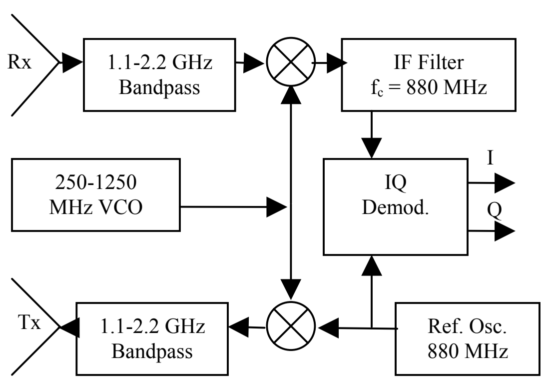

Fig. 3. RF system block diagram.

The RF system is based on a super-heterodyne receiver, with IQ demodulation.

Essentially, the output frequency will scan from 1.1 -2.2 GHz, but the received frequency will remain at a constant reference intermediate frequency, f_{RIF}. This design greatly enhances the robustness of the transceiver.

The received RF signal, f_{RF} is compared with the reference signal (f_{RIF}) and IQ demodulation performed. The resulting DC output signals can then be sampled by a microcontroller. The f_{RIF} utilized in the transceiver design is 880 MHz and was selected because of component availability (880 MHz is a common frequency in analog cell-phone systems).

In order to keep component cost to minimum, the main oscillator, with a range of 250-1250 MHz is composed of an RF switch and four Voltage Controlled Oscillators (VCOs). Control of the switch and tuning voltage for the VCOs are provided by the control system. In addition, bandpass filters were constructed by cascading inexpensive lowpass and highpass filters. While the frequency response of such filters is far from ideal and this area needs further attention, the overall performance of the system was acceptable.

An example of the transmitted frequency spectrum is given in Fig. 4. Ideally, this should be a single frequency. The spectral broadening occurs due to harmonics present in all of the frequency sources. As a result, the system needs further refinement before high-power field tests can occur (to comply with EMC regulations). This spectral broadening does not cause a problem within the system due to the super-heterodyne design.

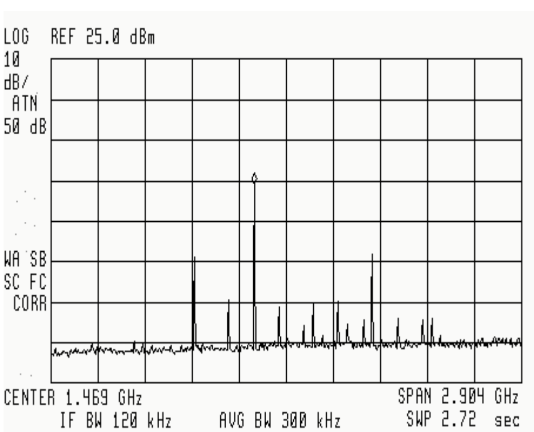

Fig. 4. Typical transmit frequency spectrum

3.2 Control System Design

To properly sequence the RF side of the design, a system was needed to sequence the RF switch and tune the VCOs. There also needed to be a way for users to interact with the RADAR system.

The main functions of the control system are as follows: to write values to a Digital-to-Analog Converter (DAC) module in order to tune the VCOs, sample I and Q values from the RF section, and assert the proper control signals for the RF switch. Figure 5 shows a diagram outlining the major components of the control system.

The PIC16C774 microcontroller chosen for this application has abundant input/output capabilities as well as an onboard 12-bit Analog-to-Digital Converter (ADC). There is 8 KB of memory in the system, which is enough space for four sets of scanned data.

Important functions of the user interface allow users to initiate a scan, reset the system, select the amount of time per frequency step and select the number of frequencies that are stepped through. In addition, software was developed to retrieve data from the system and process it.

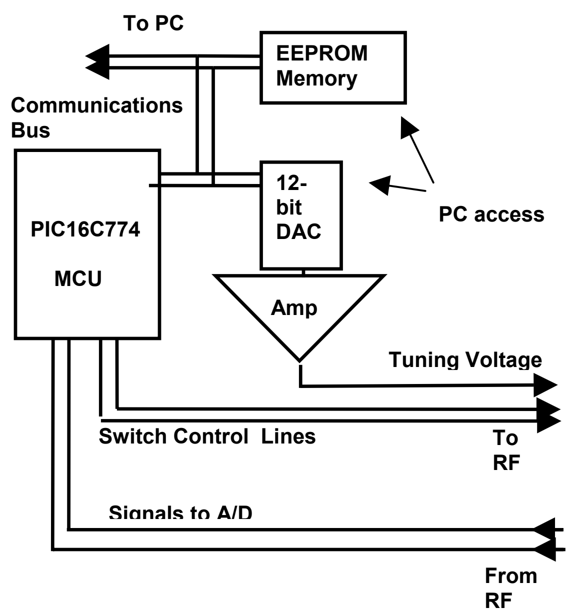

Fig. 5. Control system block diagram.

3.3 Test Environment

In order to limit the amount of variables present when testing the GPR system, a test environment was selected based on its ability to reduce these undesired variables. Testing within an anechoic chamber served to stop any RF signals from being received from outside sources, effectively limiting noise. The test structure itself, as depicted in Fig. 6, is a rigid platform constructed from wood and hard plastics to reduce reflections. This structure supported the transmit and receive antennas while also providing the lab based test environment in which the system was operated. The ground medium used for this test environment was Styrofoam. This gave a homogenous ground which served to reduce the problems a heterogeneous ground would present to the imaging requirements.

Fig. 6. Test environment and structure

4. IMAGING

To properly utilize the information acquired by the GPR transceiver system, data analysis was required. An IFFT was taken of I and Q data to transform frequency information into a spatial representation. In this manner two types of plots were produced. Firstly, the IFFT of a scan at a single point produced a range profile in which the y-axis represents the magnitude of the received signal while the x-axis represents an uncalibrated depth. Secondly, images were produced by stacking successive range profiles taken at evenly spaced intervals along the test environment. The above imaging methods are based loosely on Synthetic Aperture Radar (SAR) techniques to produce images of buried targets as discussed in [2, 3].

The adverse effects of confounding reflections, in addition to a 10 dB power variation in the transmitted frequency spectrum, made it difficult to detect the presence of a mine by performing the IFFT directly on the received I and Q data. Therefore, all testing performed made use of a 'baseline' or 'calibration' scan that contained all information regarding the environment in the absence of a mine. Thus, by taking the difference between a scan performed in the presence or absence of a mine and the aforementioned baseline data, system variations could be accounted for. It is duly noted that such test methods are unsuitable for field use. It is suggested however, that research into statistical methods of producing such calibration data based on inherent system variations and geographical location will enable landmine detection in the field.

5. RESULTS

Repeated testing in the laboratory based environment confirmed the detection of an AP landmine buried 10 cm beneath the homogeneous Styrofoam ground. Fig. 7 depicts range profiles created using calibration data and performing scans with both a mine absent and present. The distinct peak with the mine present indicates clearly the detection of the mine.

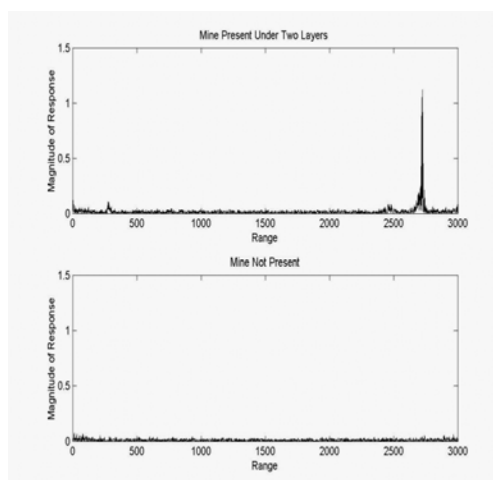

Fig. 7. Range profile of buried mine (top) and noise floor (bottom)

In order to verify that mine location within the test environment corresponds to the location of the detected peak, images were produced with the mine present in the center and at one end of the Styrofoam. Fig. 8 and Fig. 9 respectively display the results confirming the systems ability to locate the landmine. Finally, a resolution test was performed in which two mines were buried 10 cm deep and 25 cm apart. Fig. 10 displays an image of the results. While the system was designed for a theoretical resolution of 5 cm, it is obvious that even at 25 cm the mines are beginning to become irresolvable.

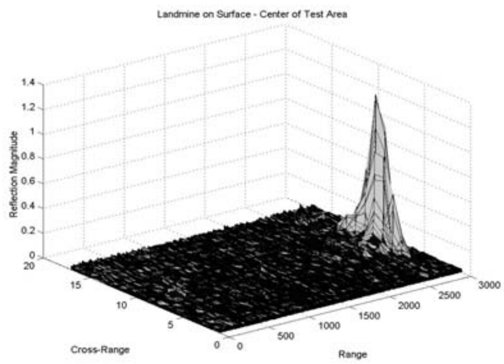

Fig. 8. Stacked cross range image of AP mine (center of test area)

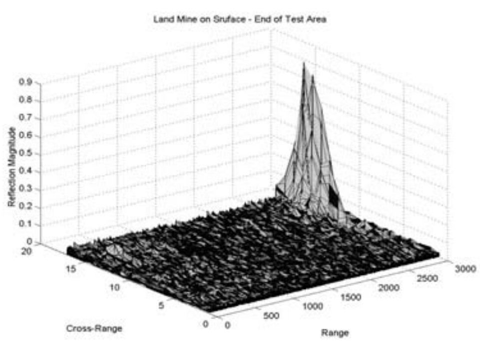

Fig. 9. Stacked cross range image of AP mine (extremity of test area)

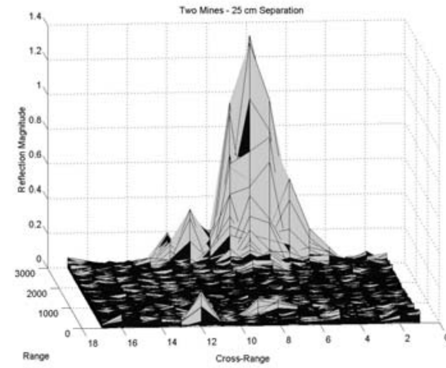

Fig. 10. Stacked cross range image of two AP mines.

6. CONCLUSIONS AND FUTURE WORK

A low cost SFCW GPR system has been successfully designed, constructed and tested. The total cost for the system is approximately $2000. The system performed better than expected, and detection of non-buried, buried and multiple AP landmines was achieved. The current calibration method is unacceptable for real applications, but further research into this area could resolve this problem.

A new prototype, with reduced cost and an advanced user interface is planned. Firstly, control can be completely shifted to the PC. This would allow a much more versatile user interface which is more in tune with the high configurability desired in a research dedicated system. Secondly, to increase the GPR resolution to the required 5 cm, the frequency range of the system will be increased. A bandwidth of 1-5 GHz is being considered, a frequency range that will give an increased resolution but maintain minimal penetration depth requirements. Lastly, the system could be constructed entirely out of surface mount components on a properly fabricated PCB. This will aid greatly in reducing system inefficiencies and expense.

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