Realization of Ground Penetrating Radar System for Environmental Explorations

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***Abstract*—Ground penetrating radar(GPR) is a geophysical method that employs an electromagnetic technique for environmental purposes.Ituses the latest ground penetrating technology to provide critical information on utilities, concrete, water content, metals, landmines, and other potential problem areas within existing structures or underground. In this paper, the hardware implementation of a proposed GPR system is introduced. The antennas utilized in the system are fabricated using microstrip technology. The antenna element is fabricated on an FR4 (lossy) substrate with dielectric constant $\varepsilon_r = 4.5$, loss tangent of 0.025, and height$h = 1.5\ mm$. The proposed system is marked by simplicity, flexibility, and cheapness. It can detect wide varieties of hidden objects or materials beneath the ground surface. The system is supplied with two main elements which greatly contribute to enhance its performance and functionality. These two elements are the wide band (WB) antenna element and the wide band RF voltage controlled oscillator. These elements allow the device to work over wide range of frequencies, which indeed enables the system to discover a lot of materials with different characteristics. In addition, the proposed system will operate at large range of variable penetrating depths and variable resolution which are easily controlled by the adjustment of the operating frequency.**

Keywords: Ground penetrating radar (GPR), Environmental Exploration, Microstrip antennas.

I. INTRODUCTION

Environmental engineering technology is one of the most important fieldsin recent decades.Ithas been a topic of interest amongst engineering educators due to the increasing number of global environmental problems. Engineers develop solutions to environmental problemsusing the principles of communication and electronics. Environmental technologies are involved in water and airpollution control, recycling, waste disposal, method of detection, and public health issues. Using those techniques we can conducthazardous-environmental management, studies in which theyevaluate the significance of the hazard, offer analysis andtreatment, and develop regulations to prevent mishaps. By using the GPR technology,designing or simulating a layout municipal for any systems become easier. Itprovides legal and financial consulting on matters related to the environment. Environmental engineering technologyis concerned with local and worldwide environmental issues. The researcher can also study and attempt to minimize the effects of acid rain, global warming, automobile emissions,and ozone depletion as well as the protection of wildlife. Many environmental engineers work as consultants, helping their clients to abide by regulations and to clean up unsafe sites.

One of the most practical techniques for environmental exploration is GPR which isa geophysical method that employs an electromagnetic technique for environmental purposes; theGPR method is useful for rapid and nondestructive site investigations. It is considered to be economically feasible for other routine applications. This technique is also used in a broad range of applications and becoming easier to use with the newly developed portable GPR systems

One of the initial successful applications was measuring ice thickness on polar ice sheets. It was a primitive method depending on Time Domain Reflectometry (TDR) [1]. Since then,there have been rapid developments in the hardware, measurement and analysis technique. The application has become more broadly used in fields such as archaeology, civil engineering, forensic, geology, water supply, and metal and mine detection[2]. There is a variety of useful practical applications, some of which will be studied.

One of the most important applications of GPR is calculating the amount of water content in different kinds of soil.The estimation of soil water content is not only bound tohydrological methods, but also can be realized bygeophysical measurements, especially when anondestructive method is required [3]. The GPRis used to estimate the soil water content during irrigation and drainagedepending on the fact that measurement of wave propagation velocity can be used to determine soil water content based on various relationships between water content and dielectricconstancy.(e.g.Topp et al., 1980; Topp and Ferre, 2002)comparedtheir results using GPR with TDR [4].The temporal patterns of soil watercontent change measured with the GPR method werevery similar to the TDR method. During irrigation anddrainage, the GPR direct ground wave sampling depthwas from 0.2 to 0.5 m, based on the fact that the GPRestimates of cumulative irrigation and drainage weremost similar with the TDR-based measurements for the same lengths.

Another study to measure the water content in landfill, estimating water content from GPR data was based on determining the dielectric permittivity (ε), of the landfill waste was presented in [5]. Thedielectric permittivity was calculated through a relationship between velocities of an electromagnetic (EM) wave in a medium (v). GPR is also employed to detect the void inside dikes and dams [6] and [7].Results of experiments received by towing of 900 MHz and 1000 MHzantenna units over cylindrical void targets of differentdiameters and heights, excavated into the clay base ofthe test site.

There is also another issue that GPR would be helpful. And one of the biggest environmental issues is landmines;Landmines are small explosive objects that are buried under theearth surface. They are classified as Antipersonnel (AP) landmines,which are used to target persons, and Antitank (AT) landmines. Many obstacles are faced in removing these buriedlandmines, such as the loss or absence of maps or informationabout them or even the areas where they were laid in, the changeof their locations due to climatic and physical factors[8]. GPR can detect and provide critical information about landmines, landmines also classified as a metallic and non- metallic, the non-metallic landmines is a challenging taskthat cannot be performed using traditional techniques. But with the rapid developments in GPR techniques it became easier.

(Zakarya Zyada et al)[9]presents the advances in surface-adaptive groundpenetrating radar (GPR)-based anti-personnel landmine detection project in Nagoya University.Thepaperproposed landmine detection system which has the followingfeatures based on the problems encountered in previous demining systems: (1) can entermine field; (2) uses compound sensor; (3) sensing with adaptation to landform andvegetation; (4) records sensing result to information management system and uses it forprodding or other mine action.

Another study has been made by (Mahmoud A. Mohanaa et al)[10]. Depending on GPR sensitivity to detect discontinuities in the electric permittivity of the ground has long been recognized asmaking it useful for finding landmines with little or no metalcontent.

In this paper, the hardware implementation of a proposed GPR system is introduced. The proposed GPR system consists of four subsystems; the GPR measurement subsystem, the monitoring subsystem, the remote control subsystem, and wireless camera module. All these subsystems are connected together through Bluetooth and Xbee wireless modules that provide the ability to remote control and monitoring the operation without being nearby. The antennas utilized in theGPR measurement subsystem are fabricated using microstrip technology. The antenna element is fabricated on an FR4 (lossy) substrate with dielectric constant $\varepsilon_r = 4.5$, loss tangent of 0.025, and height$h = 1.5\ mm$. The proposed system is marked by simplicity, flexibility, and cheapness. It can detect wide varieties of hidden objects or materials beneath the ground surface.And one of main and important application of GPR has been studied, metal and mine detection. The functionality of this device can be improved by using a higher gain antennas and power amplifiers. Furthermore, the capabilities of the device can be extended from target detection only to detection and identification by simply modifying the system software without any changes in hardware.

II.PROPOSED GPR SYSTEM

In this section, the hardware implementation of a proposed GPR system is introduced. The block diagram of the proposed system is shown in figure (1) while the hardware implementation of the system is shown in figure (2).The proposed GPR system consists of four subsystems; the GPR measurement subsystem, the monitoring subsystem, the remote control subsystem, and wireless camera module. All these subsystems are connected together through Bluetooth and Xbee wireless modules that provide the ability to remote control and monitoring the operation without being nearby. The system is supplied with two main elements which greatly contribute to enhance its performance and functionality. These two elements are the wide band (WB) antenna element and the wide band RF voltage controlled oscillator. These elements allow the device to work over wide range of frequencies, which indeed enables the system to discover a lot of materials with different characteristics. In addition, the proposed system will operate at large range of variable penetrating depths and variable range resolution which are easily controlled by the adjustment of the operating frequency.

The basic building blocks and components of the proposed GPR system are described in the next sections.

A. GPR Measurement Subsystem

The GPR measurement subsystem is the main subsystem. It consists of the following building blocks; (1) two semi-circle-like slot antennas, (2) RF voltage controlled oscillator, (3) RF power amplifier, (4) RF power detector, (5) Arduino microcontroller, (6) XBee TX module, (7) camera module, and (8) TREX board.

A. (1) Implementation of the Antenna Elements

Antennas are the most important hardware components of GPR system since they control the electromagnetic signal generated and detected. Optimum GPR performance requires antennas that transmit and receive broad frequency content with minimal phase shift when using short duration electromagnetic pulses. In this section, the implementation of a wideband Semi- Circle- Like slot antenna element is introduced. The antenna element is fabricated on an FR4 (lossy) substrate with dielectric constant $\varepsilon_r = 4.5$, loss tangent of 0.025, and height $h = 1.5\ mm$.

The development of wireless technologies like an ultra-wideband antenna technology, have increased demand for wideband (WB) antennas. In these systems, printed wide slot antennas have received much attention owing to their wideband matching characteristics and Omni directional radiation patterns .In this section, a design of a wideband antenna with microstrip line feed is presented. The total bandwidth of the antenna is controlled by optimizing the width D and the length H of the fork-shaped tuning stub. Figure (3) shows the geometry and dimensions of the proposed slot antenna with a (R=19mm) radius semi-circle-like aperture. The circle radius is at the center of the substrate.

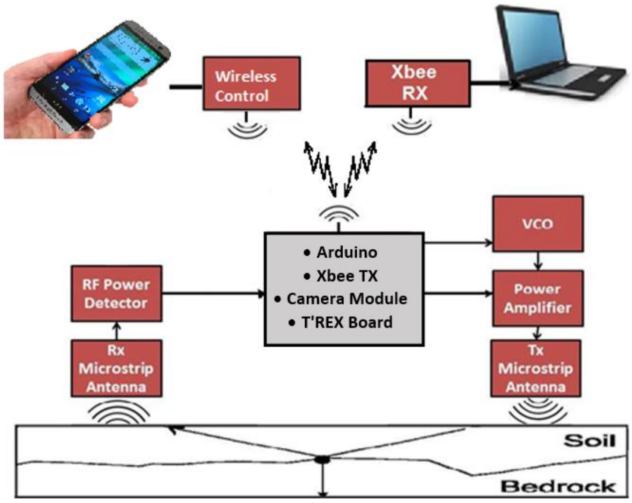


Fig.1. The block diagram of the proposed GPR system.

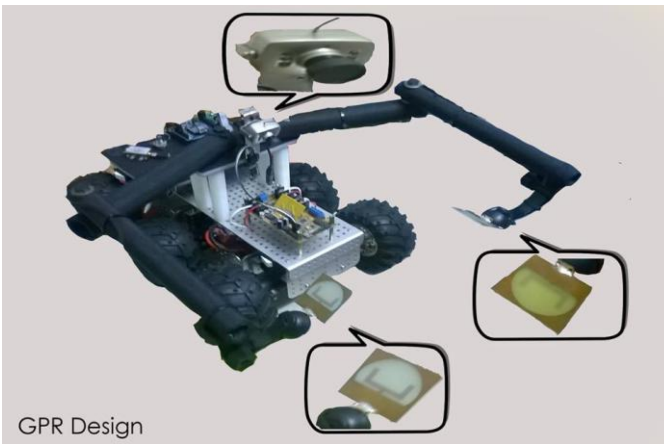


Fig. 2. Hardware implementation of the proposed GPR system.

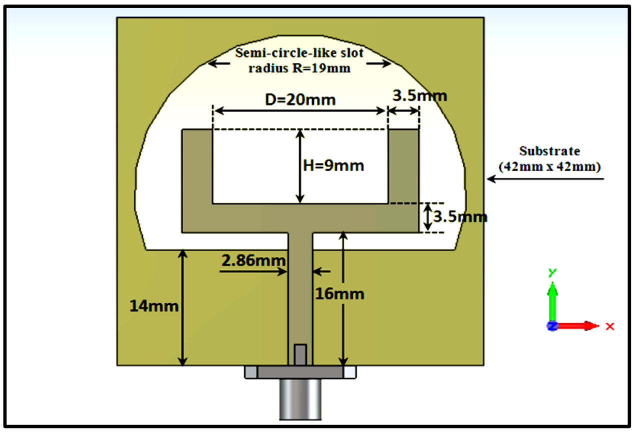


Fig.3.Configuration of the proposed semi-circle-like slot antenna designed using the CST software using FR4 (lossy) substrate with $\varepsilon_r = 4.5$ and $h = 1.5\ mm$.

Figure(4) shows the fabricated semi-circle-like slot antenna. Figure(5) shows the scattering parameter of the antenna element obtained using CST software compared to the experimental measurements of the fabricated antenna element using the VNA (HP8719Es). The simulation results indicate that the designed antenna element has wideband frequency range (1.86 GHz- 4.43 GHz). The measurements indicate that the fabricated antenna element has wideband frequency range (2.1 GHz to more than6 GHz).

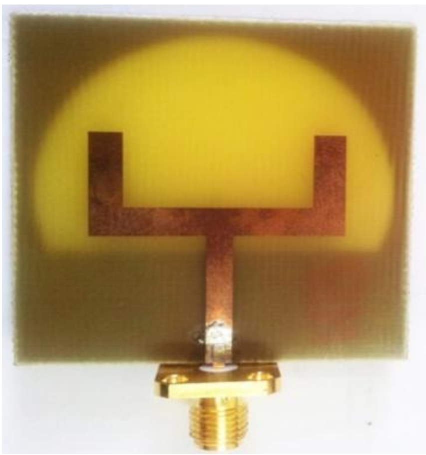


Fig. 4.The fabricated semi-circle-like slot antenna element.

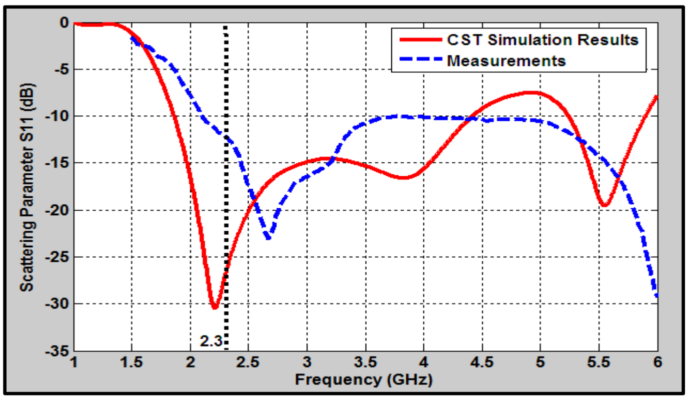
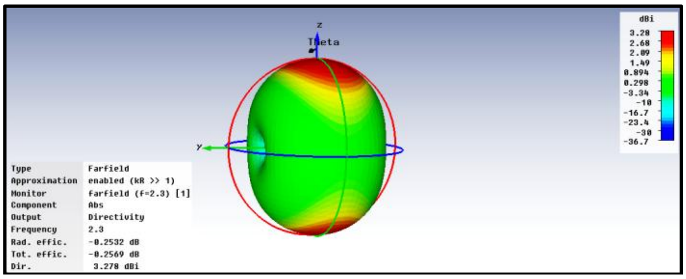
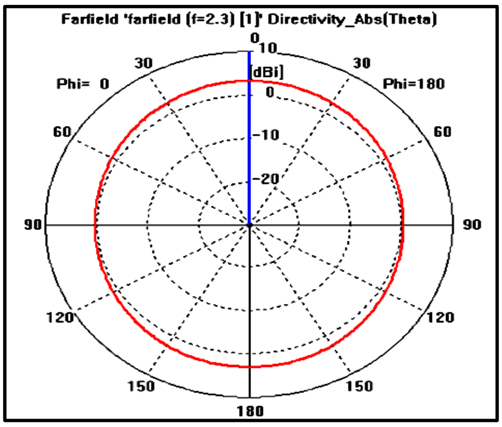


Fig.5.The scattering parameter S_{11} of the semi-circle-like slot antenna element using the CST simulation compared to the experimental measurements.

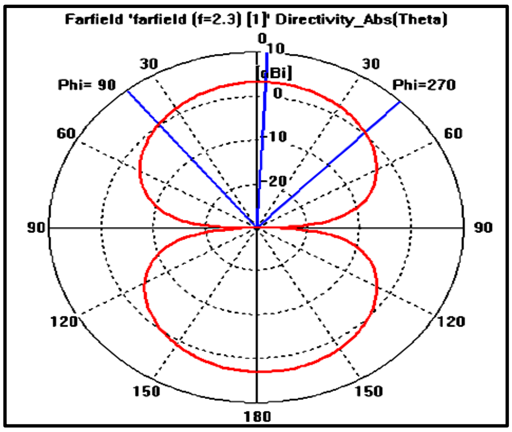
Figure6. (a), (b), and (c) show the simulated far field radiation pattern of the proposed antenna element at the frequency $f_o = 2.3\ GHz$. The antenna gives a nearly omnidirectional radiation pattern in the H-plane and a dipole-like radiation pattern in the E-plane as shown.



(a)



(b)



(c)

Fig.6.The simulated radiation pattern of the proposed antenna element at the power divider resonance frequency 2.3 GHz (a) 3D plot of the pattern, (b) Polar plot of the pattern in the H-plane, and (c) Polar plot of the pattern in the E- plane.

A. (2)RF Voltage Controlled Oscillator

An (ZX95-2500+) voltage controlled oscillator is used as a source or generator for the RF signal.The VCO provides operating frequency band from 1600 to 2500 MHz, output power 7.5 dBm, supply voltage 12 V, supply current 28 mA, and tuning voltage 0.5 V to 14 V.

A. (3)RF Power Amplifier

A (UM10480- BGA7210) MMIC variable gain power amplifier is used to amplify the RF signal received from the RF voltage controlled oscillator. The BGA7210 MMICis an extremely linear Variable Gain Amplifier (VGA), operating from0.7 GHz to 3.8 GHz. The maximum gain is 30dB. It has an attenuation range from 0 dB to63 dB.At its minimum attenuation setting it has a maximum output power of 21 dBm, an IP3O of39 dBm and a noise figure of 6.5 dB.The current consumption can be optimized per attenuation setting allowing for optimized overall system performance. The current consumption and attenuation level are controlledthrough a digital serial interface (SPI). The current can be reduced to 120 mA. Optimallinearity performance is obtained at 185 mA. The BGA7210 has a fast switchingpower-down pin to further reduce current consumption during idle time.

A. (4)RF Power Detector

Thetransmitting antennaconverts the amplifiedRF signal into an electromagnetic wave that penetrates the ground.If there is a buriedtarget beneath the ground, the impinging wave will be reflected by the target back to the receivingantenna which converts it into an electrical RF signal which is fed to the power detector.The RF power detector, (ZX47- 40LN+), converts the receivedRF signal into DC voltage.Two50Ω SMA connectors are used, input power range from $-40dBm$ to $+20dBm$, and operating frequency range from$10Hz$ to $8GHz$.

A. (5)Arduino Microcontroller

The main unit or themain brain of the GPR system is Arduino Uno. Arduino board is based on the ATmega328 which has all features of microcontrollers. It is simply connected to the computer using a USB cable which provides the required power to start the device operation and a mean for data transfer.The Atmega16U2 is easily programmed using the USB cable and there is no need for a separate burner.The Arduino supplies the control voltages to the RF voltage controlled oscillator and the power amplifier to adjust the operating frequency and the amplifier gain respectively. It takes the DC signal from the power detector and supplies it to the XBee wireless transmitter module to be transmitted to the monitoring system.

A. (6) XBee Wireless Module

XBee RF modules are embedded solutions providing wireless end-point connectivity to devices. These modules use the IEEE 802.15.4 networking protocol for fast point-to-multipoint or peer-to-peer networking. They are designed for high-throughput applications requiring low latency and predictable communication timing.

A. (7) Wireless Camera Module

A wireless camera is mounted at the front of the moving GPR to display the area to be covered during detection process.The live video of the camera will be displayed on the screen of the monitoring systemto facilitate the remote control process without being nearby for risk reduction.

A. (8)T'REX board

TheT'REX boardis used toremote control the system motion using Bluetooth technique.It is a wireless interface board that simply connects the motors driverswith any mobile using android software.

B. Monitoring Subsystem

Xbee receiver module takes up the received signal from the Xbee wireless transmitter and supplies it to the monitoring system. The received signal will be displayed on laptop screen using open source project "GUINO". The GUINO main function is to open serial port, listening for instruction from Arduino to generate Graphical User Interface "GUI". Figure(7) shows the GUINO interface.

III.EXPERIMENTALRESULTS

In this section, we examine the ability of system to detect the metals. The measurements have been divided into two subcategories. First, the GPR system has been examined on a clear and dry soil area.The detected DClevel was between (500 and 600 mV) as shown in figure (7). Second, a metallic disc of 10cm radius was buried at 25cm beneath the ground surface ofthe same area. The system frequency is adjusted to $f = 2.19\ GHz$. The detectedDC levelwas above 800 mVas shown in figure (7). The system shows a promising ability to detect the metallic objects at small depths. To increase the penetrating depth, it requires a design of high gain antennas and higher gain power amplifiers.

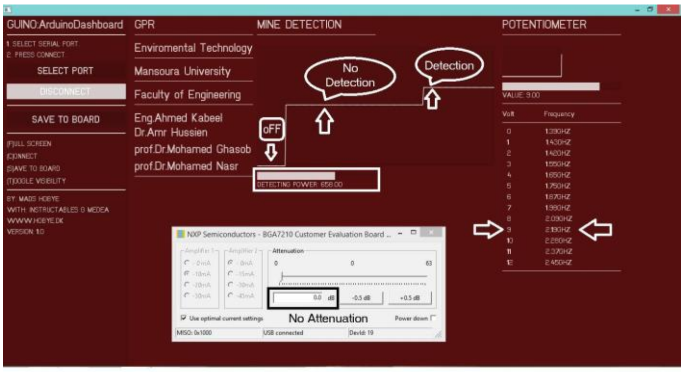


Fig.7.The GUINO interface.

IV.CONCLUSIONS

In this paper, a hardwareimplementation of ground penetrating radar (GPR) systems is introduced.The proposed system is marked by simplicity, flexibility, and cheapness. It can detect wide varieties of hidden objects or materials beneath the ground surface. The system is supplied with two main elements which greatly contributed to enhance its performance and functionality. These two elements are the wide band (WB) antenna element and the wide band RF voltage controlled oscillator. These elements allow the device to work over wide range of frequencies, which indeed enables the GPR system to discover a lot of materials with different characteristics. In addition, theproposed GPR system will operate at large range ofvariable penetrating depthsand variable range resolution whichare easily controlled by the adjustment of the operating frequency. The functionality of this device can be improved by using a higher gain antennas and power amplifiers. Furthermore, the capabilities of the device can be extended from target detection only to detection and identification by simply modifying the system software without any changes in hardware.

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