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A LIGHTWEIGHT GROUND PENETRATING RADAR

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DISCLAIMER

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ABSTRACT

The detection of buried objects, particularly unexploded ordnance (UXO), has gained significant interest in the Unites States in the late 1990s. The desire to remediate the thousands of sites worldwide has become an increasing humanitarian concern. The application of radar to this problem has received renewed attention. Bechtel Nevada, Special Technologies Laboratory (STL) has developed several frequency modulated, continuous wave (FM-CW) ground penetrating radar (GPR) units for the U.S. Department of Energy since 1984. To meet these new technical requirements for high resolution data and UXO detection, STL is moving forward with advances to GPR technology, signal processing, and imaging with the development of an innovative system. The goal is to design and fabricate a lightweight, battery operated unit that does not require surface contact and can be operated by a novice user.

Key words: Ground Penetrating Radar, Unexploded Ordnance, FM-CW, UXO

INTRODUCTION

STL's original FW-CW GPR unit (Koppenjan and Bashforth, 1993) was designed to meet Naval Explosive Ordnance Division criteria for the detection of buried ordnance and has also been applied to many other areas including hazardous waste containers, site characterization (Koppenjan and Martinez, 1994), utility lines, tunnels, and fossilized dinosaur bones. The unit weighed 40 kg, required intimate ground contact for optimum performance, and needed a highly skilled operator. The most recent evolutionary development effort is toward a lightweight GPR that operates with minimal or no ground contact and provides a very simple user interface. This paper describes the advances of the latest unit called the GPR-X.

SYSTEM DESCRIPTION

The GPR-X is a portable, fully self-contained unit that weighs 10 kg. It consists of four subassemblies: the computer, the radar, the antenna, and the power supply. The unit is diagramed in Figure 1. It acquires, processes, and displays data in a real-time mode, 30 sweeps per second. The core of the system is a FM-CW radar that operates over the frequency range of

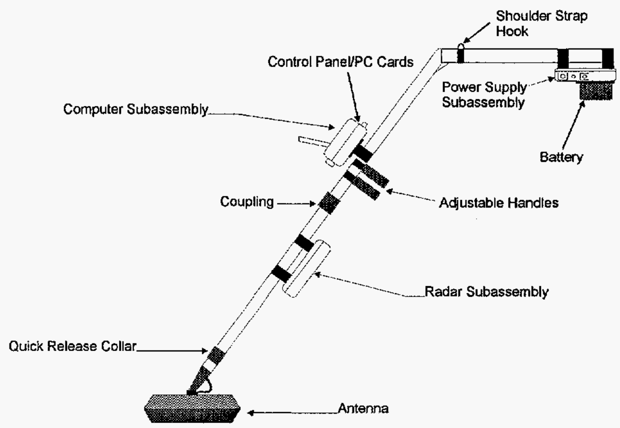

Figure 1. GPR-X system diagram.

200 - 700 MHz, with the RF carrier being modulated at 1.25 MHz. A 16-bit analog-to-digital converter (ADC) is used to sample I & Q (phase coherent) data, yielding a system dynamic range of 96 dB. It has the capability to detect targets to depths of 5 m with a range resolution of 20 cm. These parameters and the overall performance of the GPR-X are, as always, affected by soil composition, dielectric constant, E_r, and attenuation factors.

Computer Subassembly

The computer subassembly contains the signal processing and display hardware. This unit houses a PC104-bus based computer, a digital signal processing (DSP) board, a liquid crystal display (LCD), a PC (formerly PCMCIA) card interface board, a user interface board, and a digital interface module. The PC operates the GPR-X software which involves data acquisition, signal processing and depth profile display. This process is performed in parallel and greatly increases the overall system speed. The DSP is an AT&T WE32DSP which operates at 50 MHz.

The LCD is a low power, 640 x 480 resolution screen with a 0.19 dot pitch. It is a supertwisted pneumatic type with transflective backing and can be viewed in direct sunlight. The video control board uses a polynomial-based frame rate control and a dithering algorithm to produce 64 gray shades. A split screen display is implemented to allow scrolling of data at 30 Hz while maintaining a stable user interface display area. This high scroll rate is accomplished by manipulating the screen home position as opposed to shifting video memory.

The PC card sockets accept flash memory cards for saving data. The user interface contains two encoders for display adjustments and a save button. The digital interface module controls the data transfers from the radar section, programs the phase lock loop (PLL) of the RF module, interfaces to the control panel, monitors the power supply, and controls direct memory access (DMA) of the digitized radar data with the computer.

Radar Subassembly

The radar subassembly contains the microwave electronics and ADC circuitry. The microwave electronics includes the RF source, IF source, amplifiers, PLL circuitry, modulation and demodulation circuitry. Each sweep takes approximately 33 msec during which 85 data samples (85 I and 85 Q) are acquired. The sampling is performed by a Crystal CS5336 ADC. This is a 16-bit, dual channel, simultaneous sample IC that serially outputs data at 45 kHz.

Antenna Subassembly

The monostatic antenna subassembly contains a cavity-backed, bowtie element and RF and IF amplifiers. The bowtie was chosen for its good broad-band characteristics. The antenna housing is constructed with carbon fiber absorbing material that shields the antenna and attenuates the back lobes which creates a unidirectional single-lobe pattern. Through the use of the absorbing material, the usable bandwidth is increased to a multi-octave range, 200 - 1000 MHz.

Power Supply Subassembly

The power supply uses 14.4-V, 50-W, rechargeable NiCad batteries. These are high quality, commercial off-the-shelf batteries. Typical battery life is 3 hours and the recharge time is the same. External power (9-18 Vdc) may be used through the auxiliary port with any 10-W source.

Figure 2 is a picture of the GPR-X being tested. Table 1 contains a summary of technical specifications for the GPR-X. The unit's tubular section folds in the center and the antenna detaches allowing it to fit into two small carrying cases.

SYSTEM OPERATION

The GPR-X has a simple interface with only two radar adjustments: a linear "scale" and exponential "range gain." Real-time algorithms can be implemented on the data because of the system architecture and on-board

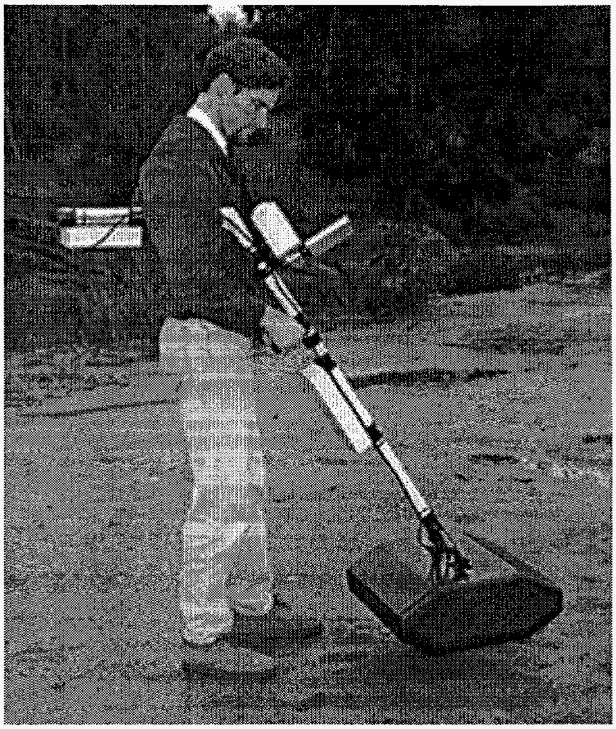

Figure 2. GPX-X being tested.

DSP. Currently a 128-point complex Fast Fourier Transform (FFT) is performed on the radar data to obtain the time-domain pulse response equivalent. A Kaiser-Bessel window is applied to the raw data before the FFT.

Other signal processing algorithms such as auto gain adjustment are being developed. This will increase the system performance and target detection capability while maintaining minimal user interface, allowing operation by the novice user.

Table 1. Summary of GPR-X system specifications.

Operating frequency	200 - 700 MHz
Bandwidth	500 MHz
Modulation frequency	1.25 MHz
Number of sampled points	85
Scan rate	30 Hz
Dynamic range	96 dB
Range resolution ($E_r = 4$)	20 cm
Depth penetration ($E_r = 4$)	5 m
Antenna type	Monostatic Bowtie
Weight	10 kg
Power source	Rechargeable NiCad (3 hr usage)

DATA and DISPLAY

Each radar sweep contains 85 data points. The individual data point is displayed as 2 pixels wide by 4 pixels high and equals 10 cm in range, assuming $E_r = 4$. The strength of the radar return is intensity mapped to a 64-level gray scale. A total of 80 channels are displayed, which equates to a total range of 8 m.

As shown in Figure 3, the GPR-X has acquired data equal to that of the original STL ground-contact GPR as previously reported (Koppenjan and Bashforth, 1993). The data were acquired with an air gap of approximately 5 to 15 cm. The data clearly show the radar returns from seven metal plates buried linearly from 0.3 to 2.2 m deep in a test pit. The target at 0.3 m appears lighter than the other targets because of the range gain setting. The multiple reflections of the two shallowest plates strongly appear at 0.6 and at 1.2 m. The plates are 0.3 x 0.3 m square and spaced 0.3 m apart.

CONCLUSIONS

A lightweight, FM-CW GPR has been built and successfully demonstrated to acquire data without intimate ground contact. Furthermore, the packaging allows the system to be quickly assembled and used by a novice operator. By reducing the complex radar adjustments, operators have been trained in less than one hour to successfully detect real-world targets.

With the modular system design, a system with a higher operating frequency can be achieved by replacing a portion of the radar subassembly and antenna. This may have applications for those with near surface/surface requirements. STL is currently researching these areas.

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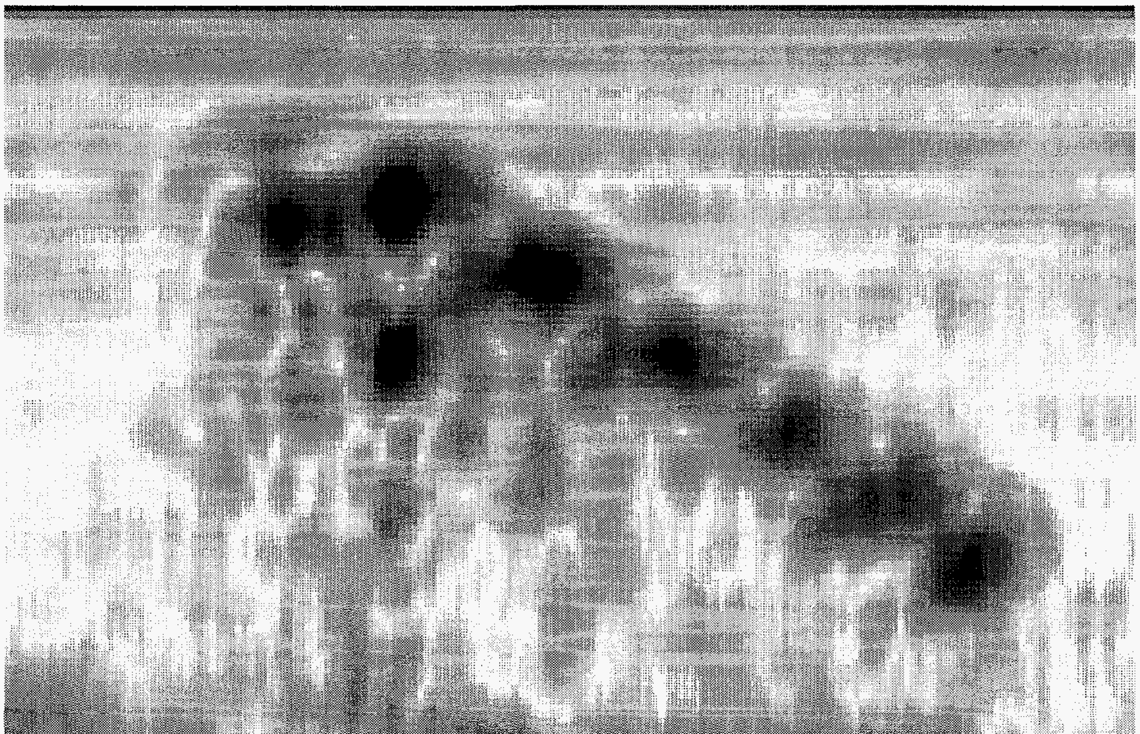

Figure 3. GPR-X depth profile of seven metal plates.