Low cost implementation of GPR for landmine detection

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Abstract - **This paper describes a simple and low cost hardware implementation of ground penetrating radar (GPR) that can detect landmines buried in soil. A prototype system at 920 MHz has been developed which can be easily extended to a full fledged stepped frequency GPR system. Simple and low cost microstrip antennas have been implemented. Tests have been carried out for the verification of the proposed hardware design.**

I. INTRODUCTION

Over the past two decades, ground penetrating radars (GPR) have been used extensively for sensing various buried objects, locating landmines, pipes, pavements and detecting water levels. As the cost of RF technologies reduced over the past one decade, stepped frequency radar has dominated the market, overcoming the shortcomings of the impulse GPR. Various stepped frequency GPR designs have been reported which are used for detecting landmine and other non-metallic objects [1-4]. Homodyne receiver with cavity backed spiral antennas has been discussed in [1]. An ultra-wideband radar (UWB) microwave radar sensor for pavement subsurface characterization has been reported [5]. The system uses microstrip quasi-horn antennas. All the results reported till date use a separate antenna subsystem which makes the system more costly and bulky. In this paper we discuss the implementation of a homodyne GPR with a low cost on-board antenna system. Primarily, two designs are reported. The first design implements the system with amplitude-phase detector. A novel approach has been taken to remove the phase ambiguities which occur due to the inherent phase characteristics of the IC. This approach can also be easily utilized for any transceiver design in a communication system which involves phase detection. The second design is based on an IQ demodulation scheme. Finally the test results of the radar are shown and discussed. The future improvements in the design are proposed to upgrade its performance.

II. SYSTEM DESIGN

The GPR has been initially designed for a single frequency of 920MHz. The depth of penetration of the EM waves and resolution of the system depends on the operating frequency. Taking into consideration the existing communication bands and our application, we have selected the aforementioned frequency. The system can be broadly classified in following three parts:

1) Transmitter consisting of voltage controlled oscillator and amplifier
2) Receiver section comprising of low noise amplifier, filter, demodulator, data acquisition subsystem
3) Antennas

The reflected phase and amplitude data is captured using a serial communication link onto a computer. The data acquisition system has been implemented using an Atmega AVR microcontroller and MATLAB. The radar receiver is based on the homodyne architecture. The prototype is designed at a single frequency and hence the ringing effects are also avoided, but the ambiguity due to single frequency detection may arise in many applications. Hence it is essential to extend the same design principle to a multi-frequency system. The main emphasis of our work is to design and integrate all RF modules on a single printed circuit board (PCB) along with the antennas, restoring all the specifications of a standard GPR.

III. HARDWARE IMPLEMENTATION

As stated earlier two designs have been proposed. The block diagrams of both systems have been illustrated in Fig.1. The transmitter consists of a voltage controlled oscillator (VCO) and an amplifier. A varactor diode based VCO has been designed and implemented. The VCO operates over a frequency range 850MHz-1GHz. The bias voltage to the varactors is controlled using microcontroller through an 8-bit digital-to-analog converter. This is used to change the transmitter frequency in definite steps for stepped frequency radar over the entire frequency range. This option is provided for future up-gradation to stepped frequency GPR system. The designed VCO provides an output power of 0 dBm with phase noise less than -80dBc. An amplifier has been connected at the output to provide a gain of 20dB. The amplifier operates over a wide frequency range from 100MHz to 3GHz.

Fig.1 shows the implementation of GPR with AD8302, an amplitude and phase detector IC [7]. This IC was chosen as it offers a better sensitivity of -60dBm for the radar receiver. A -30dB microstrip directional coupler has been designed at the transmitter side which couples the reference signal to the phase detector IC. The amplitude ratio and the phase difference between the reference and reflected signal can be obtained directly in terms of voltages. The phase characteristic of the IC

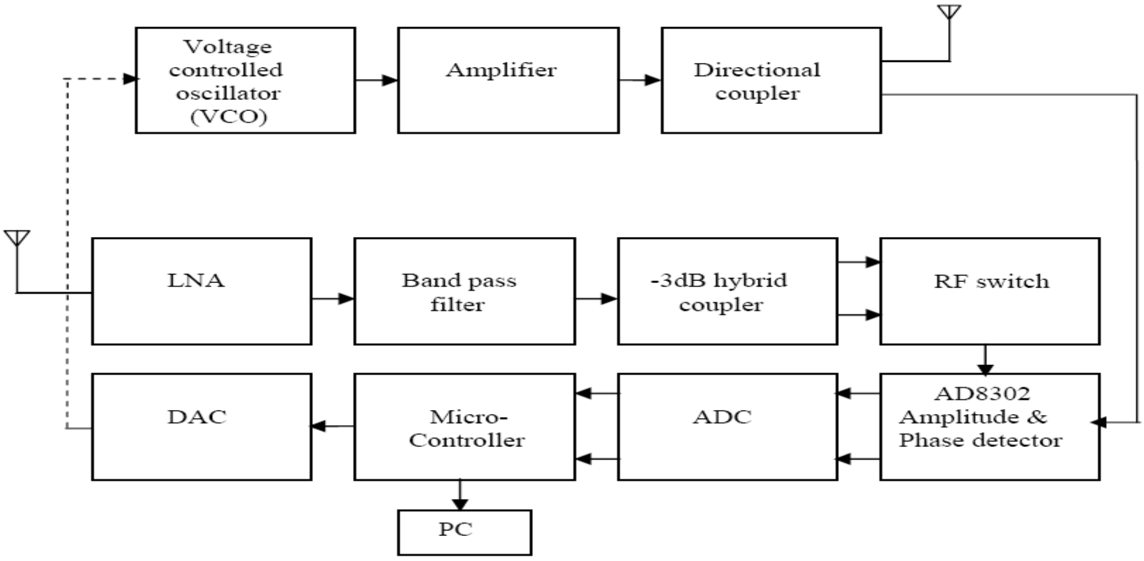


Fig.1 Block Diagram for AD8302 based GPR

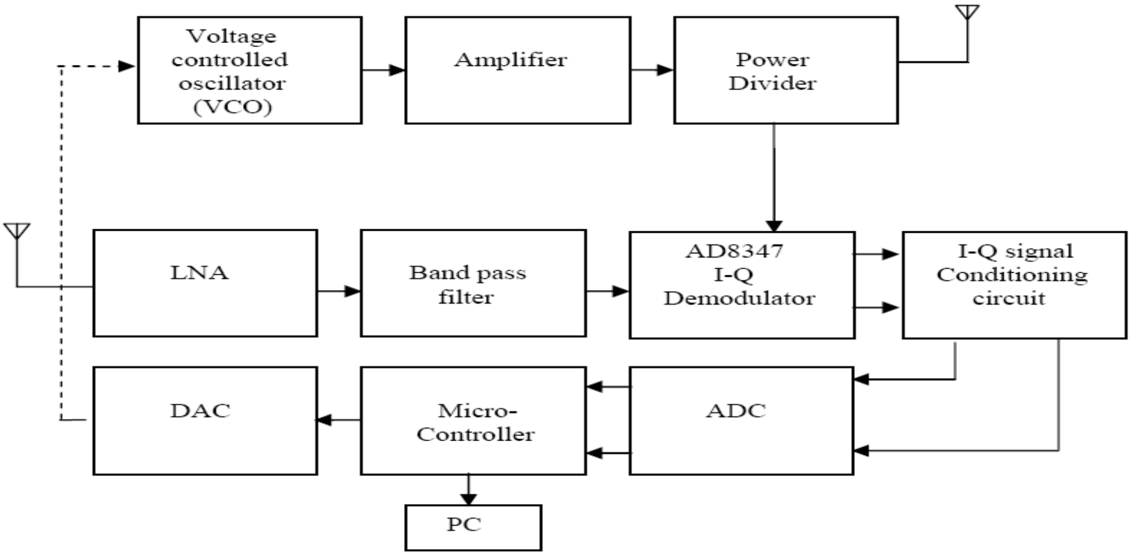


Fig.2 Block Diagram for AD8347 based GPR

is shown in Fig.3. In this IC we observe an ambiguity when measuring the phase difference between two signals. To illustrate, both 80^o and 280^o phase angles are indicated by the same value of 1volt. To avoid this problem, the received signal and its quadrature is given to the IC through a RF switch. The 90^o phase difference is obtained using a 2-branch hybrid coupler designed at 920MHz.By comparing the two phase difference readings; one can eliminate the problem and decide the exact value. All the microstrip components have been designed and simulated on IE3D software before implementing on printed circuit board (PCB).

Fig.2 shows the implementation with AD8347, an Analog Devices IQ demodulator IC [8]. This implementation is simpler but with a reduced sensitivity as compared to the previous design. The local oscillator input i.e. reference signal is fed to the IC using a simple resistive power divider at the transmitter end. The in-phase and quadrature outputs are obtained as differential voltages. The signals are further passed through an opamp amplification network for proper conditioning which are then captured by the analog-to-digital converter (ADC).

Both the designs employ a low noise amplifier (LNA) at the output of the receiving antenna which offers 30dB gain with noise figure of 1.5dB. The LNA is followed by a bandpass filter centered at 920MHz. The bandpass filter is designed using parallel coupled transmission lines as shown in Fig. 4 (a). The filter designed is a tapped combline filter. The S-parameters for the same are also shown in Fig.4 (b). For varying the transmitter frequency over a wide range, we need to use a broadband filter which can be easily done in this design by simply varying the width of separation or by adjusting the width of microstrip lines.

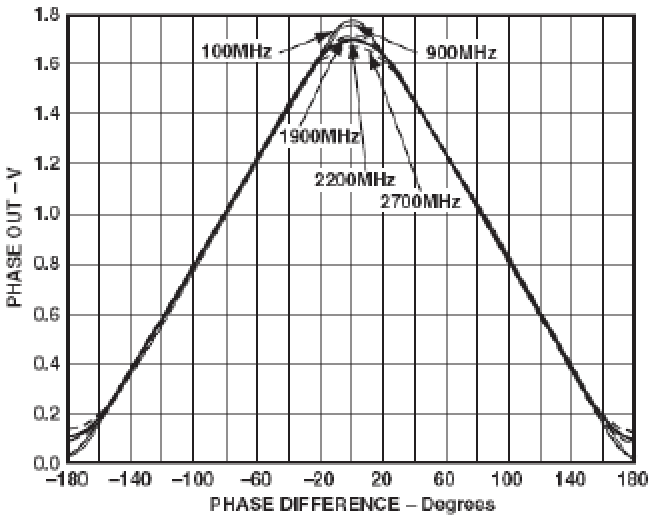
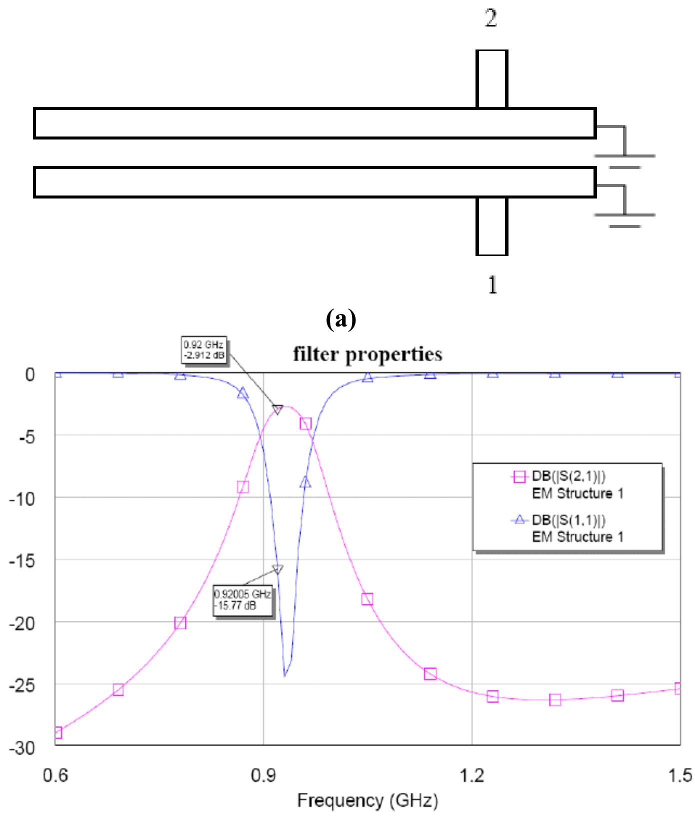


Fig.3 Phase characteristics of AD8302 [7]

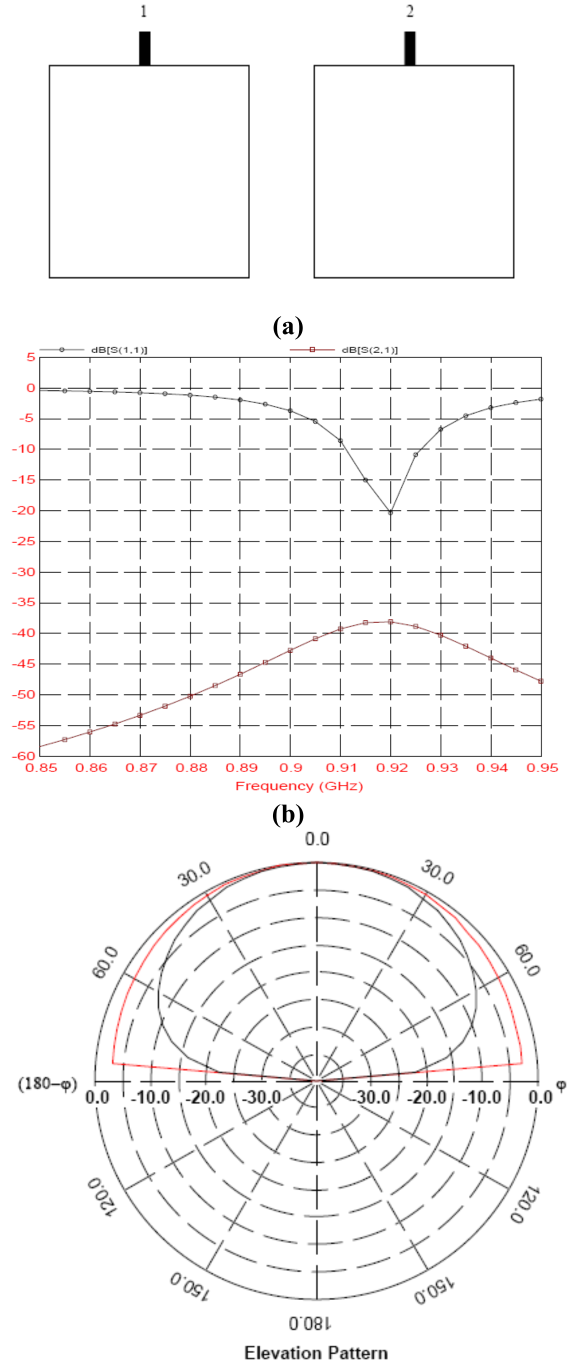


(a)

(b)

Fig.4 (a) Bandpass filter (b) Filter specifications (S_{11} and S_{21}) as simulated on Microwave Office

The antenna design is one of the most crucial design aspects in a GPR. We use a simple rectangular microstrip antenna (RMSA) with a microstrip feed, which can be easily integrated with all other RF modules on the same PCB as shown in Fig.5 (a). Port 1 is the transmitter output port while port 2 is the receiver input port. The antenna is simulated on an infinite ground plane using IE3D software. The S_{11} parameter for a 50Ω microstrip feed is shown in Fig.5 (b). The voltage standing wave ratio at 920MHz is found to be 1.2. The distance between the receiving and transmitting antenna has been kept as λ/2, to reduce the mutual coupling between the two antennas. Isolation S_{21} is observed as 38.5dB at 920MHz as shown in Fig. 5 (b). The radiation pattern for the antenna has been shown in Fig. 5 (c).



(a)

(b)

(c)

Fig.5 (a) Transmitting and receiving RMSA with microstrip feed (b) S_{11} and S_{21} curves (c) Radiation pattern (E_θ and E_φ)

IV. TEST RESULTS

Both designs have been implemented on a 0.8mm FR-4 substrate. The final PCB size is 25cm x 10cm. The GPR has been calibrated to take into account the direct radiation between the two antennas. The near field calibration techniques are discussed in [6]. The setup as shown in Fig. 6 is used for testing the AD8302 based radar. A metal plate is kept in dry soil having permittivity of approximately 2.5.

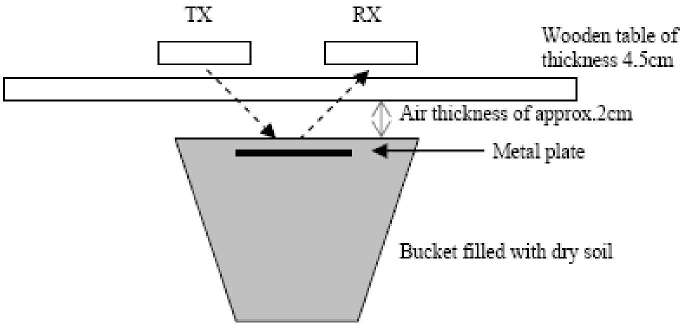


Fig.6 Experiment setup for testing GPR

In absence of metal plate, the reflected radiation from the dry soil gives an amplitude ratio of -5.33dB with a phase difference of 119.35^{o}. A circular metal plate of 8'' diameter was placed beneath the soil at a depth of 1cm as shown in Fig.6. The presence of metal increased the reflectivity resulting in change of amplitude ratio which was then observed to be -4.227dB. The phase difference was noted as -39.8^{o}. Thus even though the above measurement does not take into consideration the ground clutter and noise effects, the considerable change in phase and amplitude gives an indication of a buried object under the soil.

The IQ demodulator based system was tested by keeping a metal plate at various heights. The GPR was placed on a thick cardboard sheet having relative permittivity of approximately 3. The theoretical and practical values are noted in Table.1. The entire experiment is performed at a single frequency of 920MHz and the height '*h*' is calculated using eqn. (1)

$$\theta = \frac{4\pi h}{\lambda\sqrt{\varepsilon_e}} \quad ..\ (1)$$

where θ is the phase difference and ε_e is the effective dielectric constant. This is an approximate method of calculating height but results reveal that the practical and theoretical values match to a large extent. However the system fails when the object is brought in very close proximity of the antennas as seen in reading 4 of Table 1. This arises due to the extreme near field effects of the antenna. This situation will be avoided by properly placing the GPR at a certain height.

In another set of experiment we find that as a metal plate is moved up and down manually below the GPR with a constant velocity, we can observe the repeatability in the amplitude and phase plots as shown in Fig.7. This can assure us the correctness of the hardware implemented. One should also note that no noise or clutter rejection algorithms have been applied until this stage.

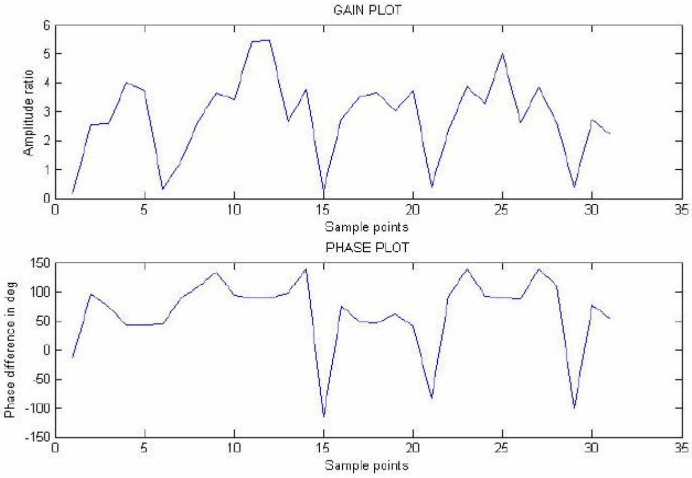


Fig.7 Amplitude and phase data as obtained by the GPR

VI. FUTURE WORK

In order to obtain a better view of the buried object, we need to take the inverse Fourier transform of the reflected phase vector which is typically done in any stepped frequency GPR. Thereafter a proper range profiling at pre-determined locations needs to be done to get the correct height. Noise and clutter rejection algorithms are necessary when working in actual field. Due to the thin lossy PCB substrate, the RMSA proves to be less efficient. Presently, we are overcoming this problem by using a broadband electromagnetically coupled patch (EMCP) antenna with air dielectric which can also be integrated on the same board and shall improve the efficiency of the system. A few other inherent disadvantages of homodyne architecture can also be mitigated by using the heterodyning concept.

VII. CONCLUSION

A low cost GPR system using two different methods have been implemented. The sensitivity of AD8302 based GPR is better than the latter design while the IQ demodulation scheme using AD8347 proves simple to implement. Both the systems can be used for detection of objects below ground, particularly landmines. The microstrip designs along with the readily available ICs have enabled us to reduce the cost considerably. The test results show that the proposed design can be further extended to a full fledged stepped frequency GPR.

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Table.1 Experimental data for AD8347 based GPR

Sr. No	*Actual height(cm)*	*Amplitude ratio*	*Phase difference*	*Obtained height (cm)*
1.	21.5	0.47	48.2°	18.6
2.	13	0.92	-97.74°	11.94
3.	9	1.10	157.3°	7.2
4.	3	0.53	225.2°	10.2 (incorrect)