GROUND PENETRATING IMPULSE RADAR FOR LANDMINE DETECTION

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ABSTRACT

The video impulse ground penetrating radar (GPR) system for detection of small and shallow buried objects has been developed. The hardware combines commercially available components with components (e.g. antennas) specially developed or modified for being used in the system. The GPR system has been designed to measure accurately electromagnetic field backscattered from subsurface targets in order to allow identification of detected targets through solution of the inverse scattering problem. The GPR has been tested in different environmental conditions and has proved its ability to detect small and shallow buried targets.

Key words: ground penetrating radar, video impulse system, landmine detection, ultra-wideband antenna system.

INTRODUCTION

Recently considerable efforts are put in development of GPR systems for detection of surface-laid and shallow buried targets such as antipersonnel landmines. Two crucial demands to any GPR system for landmine detection are 99.6% probability of detection and low false alarm rate. While detectability of the system can be improved by means of improving the resolution and the dynamic range of a system, decrease of the false alarm rate can be achieved only via localization, classification and identification of detected targets. Solution of the latter problem requires accurate measurements of the electromagnetic field scattered from the subsurface. This qualitatively new demand makes the principal difference between usual GPR and GPR for landmine detection: the first one should just detect the field scattered from a buried target (i.e. distinguish this field from all other electromagnetic fields) while the second one should measure accurately the scattered field (i.e. determine magnitude of the field as a function of time). From the measured values of the scattered field different inverse scattering methods can determine localization, size, shape and even spatial distribution of dielectric permittivity within the buried target.

Having in mind this principal difference the International Research Centre for Telecommunications-transmission and Radar (IRCTR) in the Delft University of Technology has developed two GPR systems dedicated to landmine detection: a video impulse system and a stepped-frequency continuous wave system. In this paper the main guidelines of the video impulse system design are presented. The stepped-frequency system is described elsewhere.

HARDWARE DESCRIPTION

The impulse GPR system developed in IRCTR for landmine detection comprises a pulse generator, an antenna system, a signal conditioner and a sampling converter. The pulse generator delivered by SATIS Co. produces 0.8ns monocycle. The unique feature of this generator is its small trailing oscillations, which are below 2.4% of the maximum amplitude during the first 2ns and below 0.5% afterwards (Fig. 1). The advantage of a monocycle in comparison with a monopulse is that the frequency spectrum of the first one decreases to zero at low frequencies, which cannot be efficiently transmitted via the antenna system, while the frequency spectrum of the second one has a global maximum there. As a result, the magnitude of the field radiated by an antenna system fed by a monocycle is considerably larger than the magnitude of the field radiated by the antenna system fed by a monopulse with the same magnitude. The generator spectrum covers a wide frequency band from 500MHz till 2GHz on 3dB level. At frequencies below 1GHz, attenuation losses in the ground are small (Daniels, 1996) and considerable penetration depth can be achieved. However, landmine detection requires down-range resolution (in the ground) of the order of several centimeters, which can be achieved using frequencies above 1GHz. It was found experimentally that the 0.8ns monocycle satisfies penetration and resolution requirements. The spectrum of this pulse (Fig. 2) has a maximum at frequencies where the attenuation losses in the ground start to increase. So the spectral content of the monocycle below this maximum penetrates deep into the ground and the spectral content above this maximum provides sufficient down-range resolution.

The four channel sampling converter from GeoZondas Ltd. (Lithuania) with a sampling rate 100kHz (by one channel operation) allows to measure transient signals with an accuracy of about 1% in the bandwidth from 100MHz up to 6GHz. Maximal error in time scale linearity is around 1%. The precision of the sampling converter is sufficiently high to do accurate measurements of the scattered transient field. The 12-bit A/D converter provides 66dB linear dynamic range. According to our computations this figure should be sufficient to detect both AT and AP mines in typical ground conditions.

ANTENNA SYSTEM

The antenna system is one of the most critical parts of every GPR, because its performance depends strongly on the antenna system. The antenna system should satisfy a number of (sometimes contradictory) demands. The transmit antenna should:

1. radiate short ultra-wideband (UWB) pulse with small ringing;
2. radiate electromagnetic energy within a narrow cone in order to filter out undesirable backscattering from surrounding objects;
3. produce an optimal footprint on the ground surface and below it (size of the footprint should be large enough for SAR processing but at the same time it should be small enough to reduce surface clutter);
4. the waveform of the radiated field on the surface and in the ground should be the same;
5. the waveform of the radiated field in the ground should not depend on type of the ground (i.e. its dielectric permittivity);

In order to allow successful SAR processing for the given frequency band the scattered field should be measured with a cross-range step 3cm maximum. Besides the measurement plane should be sufficiently elevated above the ground surface in order to avoid influence of evanescent fields. Together with operational demands for landmine detection it means elevation of the receive antenna at least 10cm above the ground. Thus the receive antenna should:

1. receive the field in a local point (effective aperture should not be larger than 1cm^2);
2. provide sufficient sensitivity in order to receive very weak fields;
3. be elevated at least 10cm above the ground surface;
4. allow time windowing to isolate the direct air wave from the ground reflection.

Additionally a possibility to measure simultaneously backscattered field in two orthogonal polarizations is desirable.

To satisfy demands NN.3-5 for the transmit antenna it was decided to implement the far-field approach, meaning that the transmit antenna is elevated sufficiently high above the ground. The other demands NN.1-2 can be satisfied by using a transient antenna with reasonably high directivity. Such antennas are not commercially available and design of such an antenna is extremely difficult. In close collaboration with SATIS Co. a dielectric filled TEM horn (DTEM) has been designed (Yarovoy, Schukin and Ligthart, 2000), which is ultrawideband, has linear phase characteristics over the whole operating frequency band, has constant polarization and possesses short ringing. The waveform of the electric field radiated from this antenna fed by the 0.8ns monocycle generator is presented in Fig. 3 and the antenna footprint at a distance 54cm from the antenna aperture is presented in Fig. 4. It can be seen that the footprint at 3dB level has an elliptic shape with halfaxes 21cm and 27cm. The waveform of the radiated field remains the same within the whole footprint (on 3dB level).

For the receive antenna a small loop antenna has been chosen. This antenna has an aperture of the same order as a linear dipole, but unlike the dipole the loop possesses a very small ringing. As the loop is transparent for the incident wave, the loop has been placed below the transmit antenna. As a result we have arrived at a new antenna system (Fig. 5), which has a number of advantages over usual GPR antenna systems with two (or several) identical antennas elevated to the same height above the ground. The main advantages are: a). despite of bistatic configuration the antenna system measures the backscattered field; b). this backscattered field is measured in the near zone of the target; c). it is possible to measure simultaneously two orthogonal polarization of the backscattered field in the same observation point. The developed antenna system has been patented (de Jongh et. al (1994)). Finally, the demands NN.2-4 for the receive antenna can be easily satisfied within the proposed antenna system by choosing proper elevation of the loop antenna above the ground.

The developed antenna system has an ultrawide frequency band. The waveform of the signal passed through the antenna system (perfectly conducting flat ground calibration) is presented in Fig. 6 and the spectral characteristic of the antenna channel is presented in Fig. 7.

SIGNAL CONDITIONER

An important part of the receiver chain is the signal conditioner. The signal conditioner should improve signal to noise ratio and should allow to use the whole dynamic range of the ADC. Besides, the received signal should be processed linearly otherwise the surface laid target response cannot be distinguished from the surface reflection. These demands can be satisfied if the signal conditioner will clip the high peak due to the direct wave from Tx to Rx antenna and will amplify the ground reflection signal up to the maximal level linearly acquired by the ADC. Thus the signal conditioner should combine LNAs and a limiter (with very short recovery time) for voltage clipping. Such approach differs from the usual one in which a variable gain amplifier is used. The main drawback of the conventional approach is that a variable gain amplifier changes the waveform and the spectrum of the received signal. Such changes can be acceptable if the final aim of the radar is target detection, but the task of target identification is not compatible with any nonlinear signal processing. In our approach the signal conditioner behaves linearly from the moment of arrival of the ground reflection. The performance of the signal conditioner is demonstrated in Fig. 8.

EXPERIMENTAL RESULTS

The GPR system has been tested in different environments, e.g. sand, clay, forest ground, etc. (de Jong, Lensen and Janssen, 1999). A-scans have been measured along straight lines with a step of 2.2cm, while the distance between lines equals 5cm. Sampling time in each A-scan equals 60ps. It was found that the magnitude of a typical target response is usually large enough to be detected by the system (Fig. 9). However a direct air wave from transmit to receive antenna and surface clutter create a background which often masks the response of the target. In order to remove this background pre-processing of data has been used. This pre-processing includes subtraction of the system response due to the direct air wave, averaging within the footprint of the transmit antenna and subtraction of the averaged ground reflection from each A-scan. In order to limit the magnitude of artifacts due to subtraction of time domain signals, before the subtraction the time drift is numerically compensated within each A-scan. As a reference signal for the time drift compensation the direct air wave has been used. Despite of fluctuations in the arrival time of the direct air wave due to mechanical vibration of the system and other factors, the quality of compensation was good.

After such pre-processing targets can be identified on a B-scan picture. Examples of the B-scans over shallow buried antipersonnel mines in different types of soil and a deeply buried antitank mine are presented in Fig.10 - 12. In Fig. 12 deformation of the ground surface above the mine is clearly visible.

More advanced data processing is discussed in the paper by Groenenboom and Yarovoy (2000).

CONCLUSION

The video impulse ground penetrating radar system for detection and identification of small and shallow buried objects has been developed in IRCTR. First experimental results show that the system can detect small dielectric and metal targets at a depth up to 50cm. In the next step of the program software for image processing, localization and identification of targets will be developed and implemented into the system.

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REFERENCES

Daniels, D.J., Surface-Penetrating Radar, London: The Inst. Electrical Eng., 1996, p.40.

Groenenboom J. and Yarovoy A.G., 2000. Data processing for a landmine detection dedicated GPR. *Proceedings on Ground Penetrating Radar Conference*, Gold Coast, Australia, 23-26 May 2000.

Jong, W. de, Lensen H.A. and Janssen Y.H., 1999, Sophisticated test facility to detect land mines, *Detection and Remediation Technologies for Mines and Minelike Targets IV, SPIE Proceedings*, Vol 3710, pp.1409-1418.

Jongh, R.V. de, Yarovoy A.G., Schukin A.D., Ligthart L.P., Morow I.L., *Penetrating air/medium interface microwave radar*, Patent 43107-NL, 24.11.1999.

Yarovoy, A.G., Schukin A.D. and Ligthart L.P., 2000. Development of Dielectric Filled TEM-Horn. *Proceedings on Millennium Conference on Antennas & Propagation*, Davos, Switzerland, 9-14 April 2000.

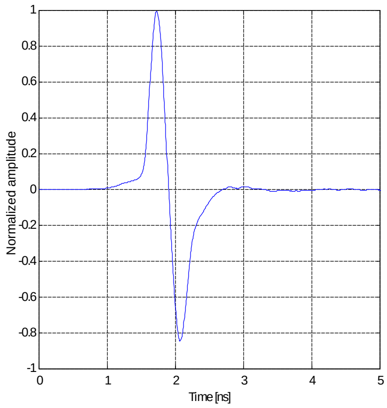

Figure 1. Output signal from the 0.8ns generator.

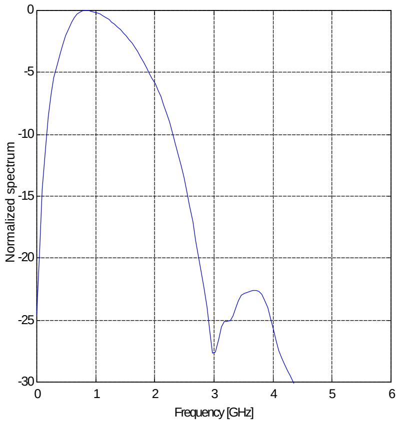

Figure 2. Spectrum of the output signal from the 0.8ns generator.

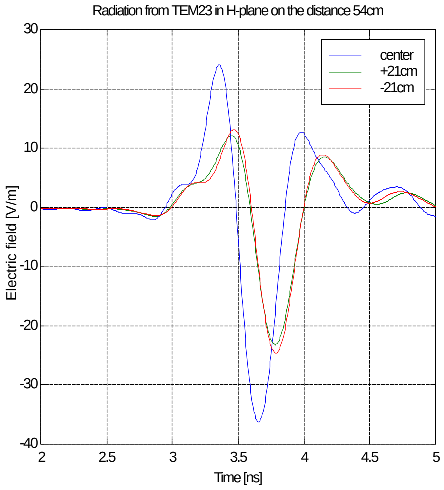

Figure 3. Waveform of the electric field radiated by the transmit antenna in the center of the footprint(blue) and at the 3dB level ellipse (green and red)

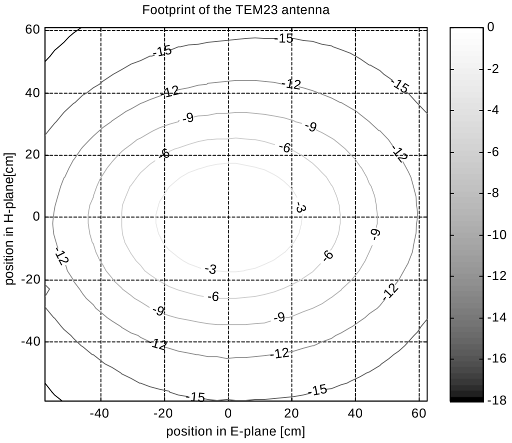

Figure 4. Footprint (in dB) of the DTEM antenna at the distance 54cm from the aperture

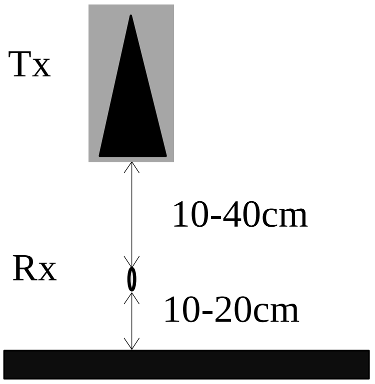

Figure 5. Antenna system geometry

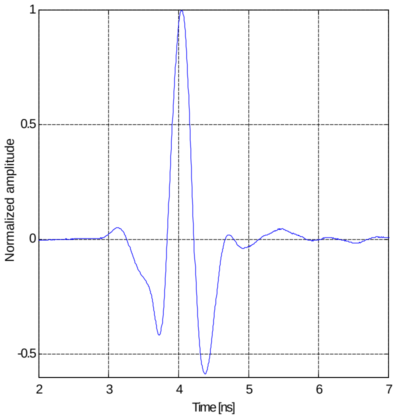

Figure 6. Waveform of the 0.8ns monocycle signal passed through the antenna system

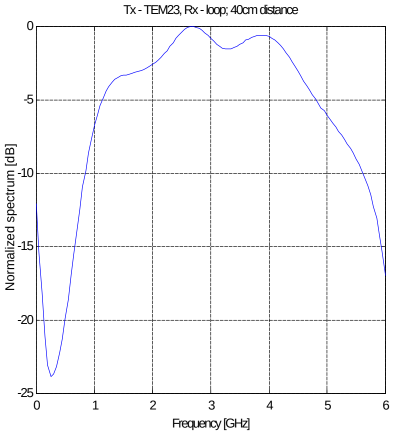

Figure 7. Frequency dependence of the channel TEM-loop

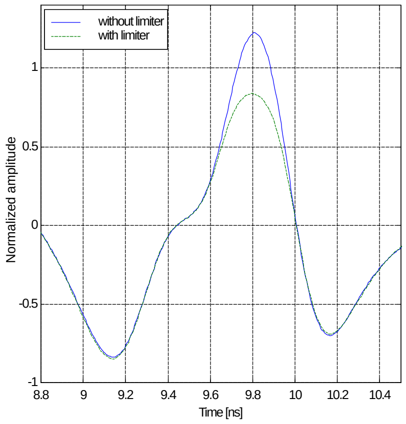

Figure 8. Clipping of the direct air wave by the signal conditioner. The output amplitude is normalized to the maximal signal level linearly acquired by the ADC

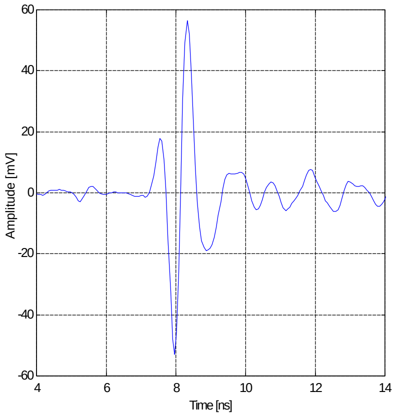

Figure 9. Target response after background subtraction

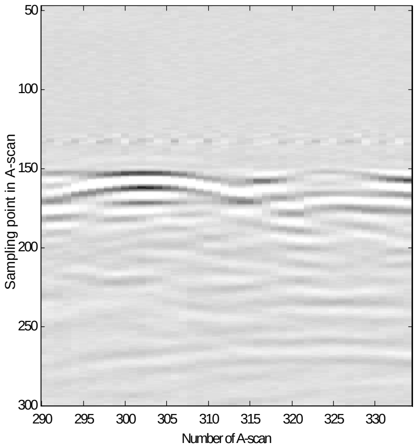

Figure 10. B-scan over a flash buried in sand AP mine

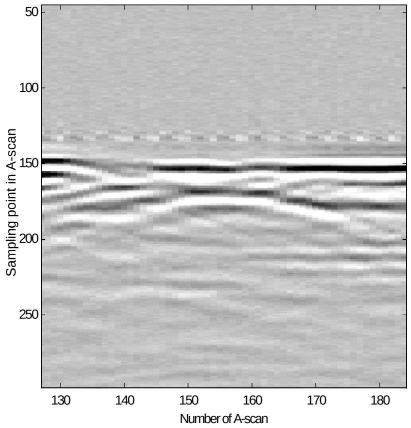

Figure 11. B-scan over a buried in a forest ground AP mine

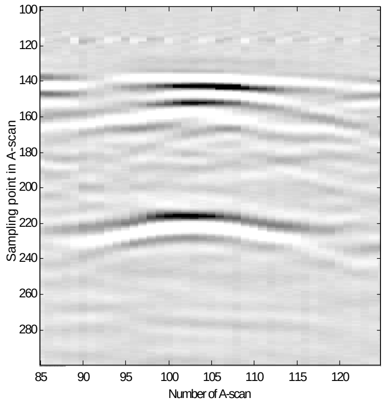

Figure 12. B-scan over a deeply buried AT mine