EVOLUTION OF GPR ANTENNAS, PULSE GENERATORS AND SAMPLE RECORDERS

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INTRODUCTION

Different GPR applications such as detection of communication lines and pipes, road inspection, archeology and demining are associated with specific requirements for hardware – pulse generators, wide band antennas and sample recorders [1]. While in conventional GPR applications the final goal is detection of objects, some new applications such demining require identification of objects as well. The latter problem is much more difficult than simple detection and to solve it a new generation of GPR hardware is necessary. This new hardware should perform highly accurate measurements of scattered field. The optimization of different parts of GPR hardware to achieve a qualitatively new performance is presented below.

GPR ANTENNAS

Usually GPR antennas are placed on the surface of the ground or slightly elevated above it. The antenna's sensitivity to the ground parameters variation should be minimal. The antenna ringing and coupling should be minimal as well in order to avoid overlapping of target returns with ground reflection or with the coupling. We propose a new concept of antenna development. According to it the internal reflection within an antenna is allowed to occur only in one cross-section of the antenna, namely in the aperture. The field reflected from the antenna aperture exits into a feeding line which is perfectly matched to the antenna. The feeding line length is chosen to be sufficient for time gating of reflection. Additional advantage of this approach is a possibility to test and to tune the antennas in free space. Antenna measurements on the ground has proven this concept.

Several antenna types have been tested for GPR application:

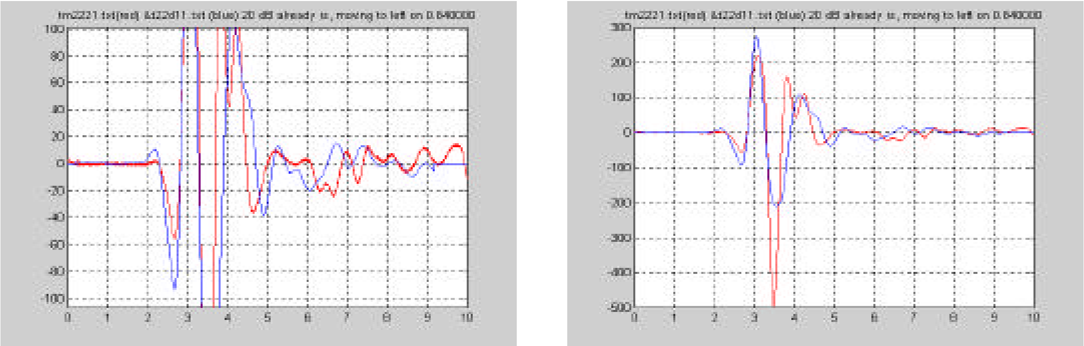
- Resistively loaded dipole. Short ringing and coupling have been achieved with this antenna, however losses may be large.
- Rigged horn. This horn effectively radiates in its working frequency band, reflection from the aperture is reasonably small. However good matching to the feeding line has not been achieved. Reflection coefficients of 0.2 have been reached causing a VSWR of about 1.5. However the trailing oscillations of the radiated signal were long.
- Shielded dipole. Dipole with elliptical arms was placed within a metal shield, which was covered with absorber. It was difficult to find suitable absorbers for low (up to 300MHz) frequencies.
- Dielectric embedded dipole (DED). The DED was a next step in the development of the shielded dipole [2]. The feedpoint in DED is matched very good to the feed line. Due to dielectric filling of the whole antenna it became possible to reduce considerably the level of internal reflections within the shield down to the level of TEM horn. However the efficiency of the antenna is smaller than that of the TEM horn, and the weight is considerably higher. The main advantage of DED as compared to TEM horn is the presence of a shield. Due to its good isolation from external EMI we have used DED as receiving antenna in the GPR system developed specially for landmine detection [3].

- TEM horn. Radiating a short pulse with small ringing air-filled TEM horn is very sensitive to the external EMI. Mutual coupling between two TEM horns in the antenna system is large and long lasting. To overcome these difficulties a dielectric filled TEM horn has been developed [4]. The reflection amplitude from feed point for the operational monocycle pulse does not exceed a single percent, and the reflection amplitude from aperture is less than -10dB. Due to this the dielectric filled TEM horn has acceptable ringing.

Using above mentioned antennas we have developed two antenna systems for impulse GPR. The first one consists of the dielectric filled TEM horn as Tx antenna and the dielectric filled dipole as a Rx antenna, the other one consists of two dielectric filled TEM horns. Transmission of the monocycle pulse with duration 0.8ns through these antenna systems is shown in Fig. 1. The antennas are placed face-to-face on the distance 180cm between apertures, elevation above the floor equals to 150 cm. The absolute level and length of the tail for TEM and DED are approximately the same, but the level of the main signal is 470mV for TEM-DED and 720mV for two TEM respectively. Thus the first antenna system has on 3.7dB worse signal-to-tail ratio. However, use of DED decreases also the level of external noise in the received signal, so the total balance can still be in favor of the first antenna system.

Spectral characteristic of the second antenna system (two TEM horns) is presented in Fig. 2. It has a bandwidth of 3.5GHz at 4dB level. With the exception of low frequencies the spectrum of the channel coincide with the spectrum of the generator output.

Quite strong mutual coupling between two TEM horns remains the main disadvantage of the second antenna system. Nevertheless the mutual coupling can be measured in free space and then subtracted from the data measured by the GPR system. The result of such subtraction is shown in Fig. 3. The signal to be subtracted starts after 7ns and ends around 10ns; a remaining amplitude of about 10mV peak-to-peak can be seen. The magnitude of the signal is 40dB less than the magnitude of the ground reflection, which starts after 11ns. Level of the cross-polarized coupling is additionally 20dB lower.



a b

Fig. 1. Transmission through the antenna system (a - main signal, b - trailing oscillations). Blue curve - TEM-DED, red curve - two TEM.

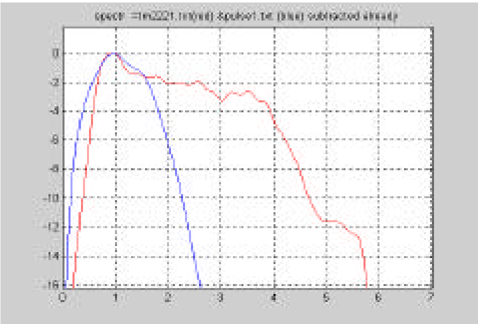


Fig. 2

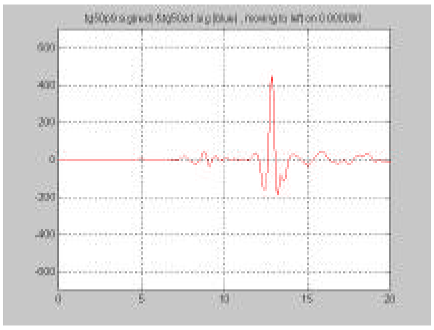


Fig. 3

Fig. 2. Spectral characteristic of the second antenna system (Red curve - channel, blue curve - spectrum of the generator).

Fig. 3. Reflection from the ground with remaining mutual coupling after subtraction.

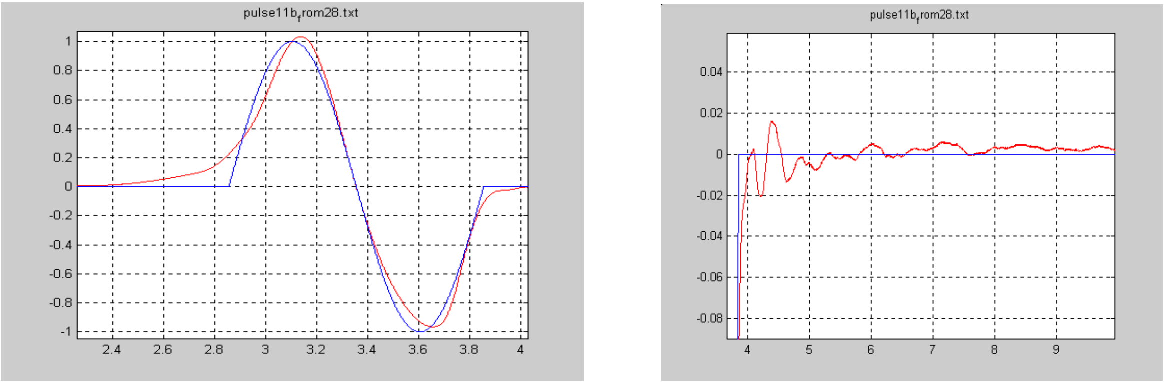
GENERATORS

The impulse generators are characterized first of all by the signal waveform. In earlier GPR systems [1] different monopulse waveforms (rectangular, triangular, gaussian, etc.) or transients (step excitation) were used. Such pulses have considerable energy at low frequencies, which are not radiated by the antenna. As a result pulses radiated by the antenna had considerable ringing, which causes degradation of the downrange resolution. Nowadays more and more systems use monocycles or even “mexican hat” wavelets.

We have developed our generators according to the following considerations:

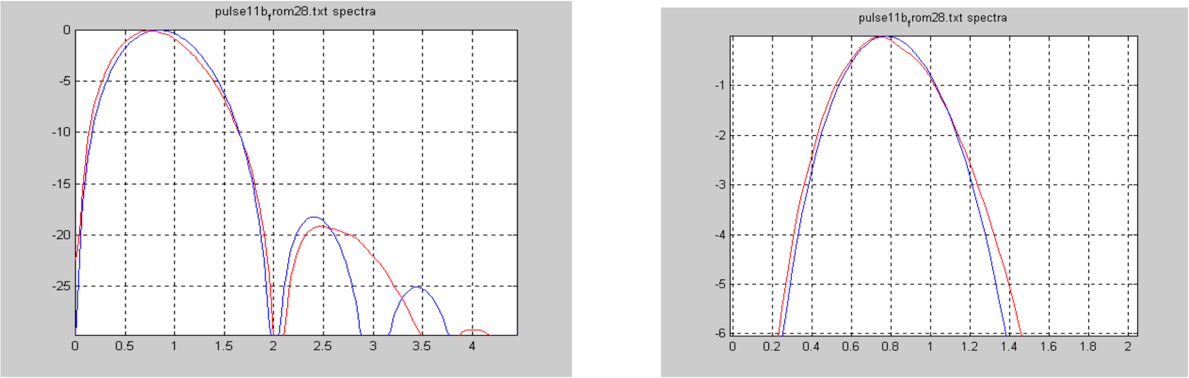
a) waveform should be close to ideal monocycle. This waveform is characterized by short duration and relatively small (in comparison with a monopulse) spectrum width. The limited bandwidth allows to keep the waveform unchanged by the propagation in a highly dispersive medium as soil.
b) Pulse duration is selected based on the desirable downrange resolution and the characteristics of the soil.
c) The spectrum of the generator should be matched to the system passband in order to avoid additional reflections.
d) Low level and small duration of trailing oscillations are necessary to provide detection of surface laid and shallow buried small targets.
e) Two generators with different pulse durations should be used in the system to provide detection of shallow buried and deeply buried objects.

As an example a waveform and a spectrum of real generator are presented in Fig. 4 and 5 correspondingly. The real pulse looks shorter than its approximation by a monocycle with 1.0ns duration. However the pulse spectrum is approximated quit good.



a b

Fig. 4. Output of the generator: a - comparison with an ideal monocycle; b - trailing oscillations. Red curve – real generator, blue curve - ideal monocycle with 1.0ns duration.



a b

Fig. 5. Generator spectrum: a - full spectrum; b - 6dB passband. Red curve – real generator, blue curve - ideal monocycle with 1.0ns duration.

At present pulse generators with following parameters are available:

- impulse amplitudes up to ±500V with durations of 3…5ns;
- impulse amplitude up to ±50V with durations of 0.8…1.0ns;
- impulse amplitude up to ±25V with durations of 0.3…0.5ns;
- impulse asymmetry in amplitude: less then 10%;
- impulse asymmetry in duration: less then 10%;
- the parasitic oscillation level after the end of impulse is less than 3%, 2%, and 1% in the first, second, and third time intervals equal to the duration of the impulse, respectively.

It is possible to manufacture generators with amplitudes up to 5000V at impulse duration 3…5 ns as well. However, the parasitic oscillation amplitude of such generators is as high as 15%. The application area for such generators is the probing of extensive deeply allocated objects, for example, for minerals search.

IMPULSE RECEIVER

An impulse receiver includes a signal conditioner, a sampling converter and a recorder. Since the noise floor of the whole receiver is determined by the sampling converter, the signal conditioner should be used to improve the signal-to-noise ratio. Besides the signal conditioner should prevent the sampling converter from saturation by large signals due to antenna coupling or air-ground reflection. In the past low noise amplifier with time-variable gain have been used in GPR signal conditioners. However a time-variable gain causes a non-linear transformation of the signal and distorts its spectrum. For object detection this distortion can be acceptable. For object recognition this distortion should be avoided. In our signal conditioners we use ultra wideband low noise amplifiers with adjustable gain (in order to adjust the system for different soil parameters) and fast limiters with extremely short recovery time to protect the sampling converter from saturation.

As far as the sampling converter is concerned we achieved the following figures:

- maximum signal level – +-1 V;
- sampling frequency: up to 300KHz per channel;
- noise level in a single measurement: 1.5mV (root-mean-square value);
- equivalent noise level after 100 averages: 0.2mV;
- number of channels: up to 12;
- irregularity of time window scale (≤20ns) after calibration: 0.1%;
- instability of time window scale (≤20ns) after calibration: 1.5ps;
- time drift after calibration: 1.5ps during the measurements.

To achieve these parameters a number of new technical solutions (such as subsystems for internal calibration and drift compensation, embedding of the AD converter in sampling heads, special digital (optical) interfaces between sampling heads and control block, thermostablization of the system, etc.) have been implemented in the device.

CONCLUSIONS

We have reached a new level of GPR hardware which combines ultrawide frequency band with a high accuracy of measured signal together with high stability of the whole system. This level of GPR hardware allows us not only to detect small shallow buried targets, but also to determine precisely its position and to approach the problem of target recognition. For the latter we can use SAR images of the objects obtained in different frequency bands, recovered value of target's dielectric permittivity as well as its polarimetric characteristics.

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