Design and analysis of new GPR antenna concepts

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Abstract

One of the most critical hardware components for the performance of a ground penetrating radar (GPR) is the antenna system. The antenna system must satisfy different criteria then in usual radar antennas. Most GPR systems operate in the vicinity of the ground. Thus, the important parameters determining the system performance, such as antenna beamwidth, operational frequency and transmitted wavelet, depend on the properties of the ground. The optimal antenna design must provide steady performance for different ground types and weather conditions.

In a joint research project, IRCTR and RTI are developing new GPR antenna concepts. The aim of the developments are the improvement of GPR performance. The design of GPR antennas differs from the classical approach. Therefore, this paper is started with a review on the most important design principles for GPR antennas. To verify the antenna design, a GPR antenna measurement set-up is essential. Because little information on this topic could be found in literature, we developed our own measurement set-up and procedures. The first experimental results obtained from the set-up are shown in the second part of the paper. In the last part of this paper, some new approaches in antenna design are presented and experimental results are discussed.

Keywords: GPR antenna design, GPR antenna measurements, short-pulse radiation, TEM horn, shielded dipole, spiral antenna.

1. Introduction

At the Delft University of Technology, a large program is initiated to improve the current generation of ground penetrating radar (GPR) systems. This project is financially supported by the National Technology Foundation (STW) and is entitled "*Improved Ground Penetrating Radar Technology*". Three groups of the Delft University participate, namely the Centre of Technical Geoscience, the Electromagnetic Laboratory of the faculty of Information Technology and Systems, and the International Research Centre for Telecommunications-transmission and Radar (IRCTR).

The main task for IRCTR is the development of a transportable ground penetrating radar. The radar is based on transmission and reception of short-pulse time-domain signals. The antennas are located on or just above the ground. The work is done in cooperation with GeoZondas, Vilnius, Lithuania and Academician A.L. Mints Radiotechnical Institute (RTI), Moscow, Russia. GeoZondas is responsible for the development of transmitter, receiver, controlling and processing software. RTI participates in the antenna design and manufactures the experimental antennas.

The first part of this paper reviews the important design principles of the GPR antennas. The second part describes the GPR measurement range. The last part of the article discusses our progress in the GPR antenna development.

2. Overview design principles for GPR antennas

The design of GPR antennas differs from the classical approach. It is therefore essential to formulate the relevant GPR antenna design principles. We restrict ourselves in the overview to antennas for short-pulse, time domain GPR, operating near the ground.

2.1 Time domain antenna performance

The desired antenna performance is to transmit and receive short duration, time domain waveforms (in the order of a few nanoseconds) The duration of the time domain antenna pulse is the trade-off between range resolution and penetration depth [Daniels, 1996]. The tail of the antenna signal must be minimized to prevent masking of targets by the air-ground interface or nearby object reflections.

To transmit short duration time pulses, an ultra-wideband antenna is needed. However, the bandwidth is not the only condition. A linear phase characteristic, constant phase center, constant polarization and constant gain are also required. For example, spiral and log-periodic antennas have a high operational frequency range, but the time domain antenna response have a long duration. Examples of transient antenna performance are the infinite dipole antenna and TEM horn. Note, that synthetic pulse reconstruction techniques are not attractive in time domain GPR systems due to the unknown (dispersive) propagation conditions in the ground.

To discuss the time domain antenna performance we will introduce some terms and definitions. The class of antennas with ultra-wideband and linear phase properties is called transient antennas [Foster, 1992]. The term transient is more closely related to time domain performance. We divide the time domain antenna response in two parts; the main pulse and the tail. In the main pulse we distinguish two regions (see figure 1). The transient region is resulting from the direct radiation of the excitation pulse. The resonance region is caused by reflections in the internal antenna structure (e.g. end of dipole, antenna shield). The tail is specified according some decaying law (e.g. exponential).

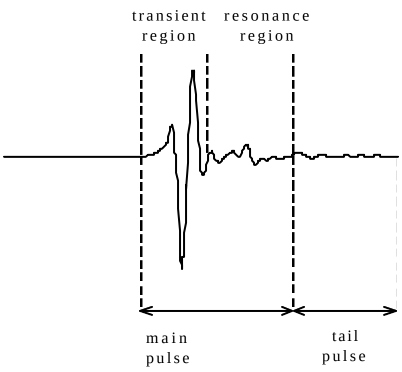

Figure 1: Time domain antenna response

The design goal for the time domain antenna performance is removal of the resonance region and minimizing the tail. Major difficulty in the practical design is the removal of the resonance region, which is cause by reflections from the ground and inside the antenna structure. The main method of reducing the tail is resistive loading [Shlager et.al., 1994].

2.2 Reduction of the ground influence

In order to couple the EM energy into the ground more efficiently, GPR systems are located on or just above the ground. As a result the current distribution on the antenna is influenced by the ground. The ground conditions change for different soil types, weather conditions (humidity) and surface roughness. Due to this, the antenna performance varies. Moreover, effects like antenna ringing due to the antenna-ground interface, can make GPR measurements less usefull. Changing conditions restrict also the interpretation of GPR data.

The design goal for the GPR antenna under development at IRCTR is to reduce the influence of the ground on the antenna performance. A method to reduce the influence is to elevate the feed point of the antenna from the ground interface [Chen, 1997]. Dielectric embedding of the feed point can lead to further improvements. The dielectric embedding reduces the contrast between the antenna and ground (thus reducing the influence) and increases the electrical length between feed point and ground interface.

2.3 Radiation characteristics

Knowledge on exact antenna radiation is important for interpretation and processing of GPR data (e.g. for migration). However, the classical characterization of antennas by its far-field radiation pattern is of little use in GPR antennas because of two reasons. First, objects can be located in the near- or intermediate region of the antenna. For processing of this data, the far-field pattern cannot be used. Second, in most cases the ground will have a layered structure. Due to the layers, the actual far-field of the antenna is depending on electrical properties, structure and thickness of the layers.

A more practical method of evaluating the radiation characteristics is to define the EM field on a planar interface just under the ground interface. Using near-to-far field transformation techniques in time domain [Yee et.al. 1991], the radiation pattern for each specific ground can be determined (for example using EM modeling). In section three of this paper our measurement method is discussed to characterize GPR antenna radiation.

2.4 Antenna shielding

The desired GPR antenna radiation is directed towards the ground. Radiation in the upper halfspace (air) must be minimized. At the same time the influence of external signals from the upper halfspace to the receive antenna must be reduced (e.g. TV, mobile phones, targets above ground).

To minimize the radiation to the upper halfspace antenna shielding can be used. Some antenna types are already shielded (like the horn antenna), while others need an additional design effort (like the dipole antenna). Major difficulty here is that the shielding must not spoil the time domain performance.

3. Antenna measurement set-up

Antenna measurements are an essential part of the design procedure. However, little information can be found in the literature on the specific topic of GPR antenna measurements. Therefore, we are developing our own measurement set-up and procedures.

3.1 Test site

For GPR antennas and systems it is essential to measure the characteristics in a well known test site. Together with TNO-FEL, the Delft University of Technology constructed a GPR test range. The dimensions of the range are 10×10×3 m. The large dimensions reduce sidewall reflections which interfere with the measurements. The test range is filled with 'homogeneous' sand. To sustain controlled conditions, the test range is shielded from external influences. The test-range is separated from the surrounding ground by wooden walls, covered with a water proof plastic coating. To protect from weather conditions, the test site is covered by a tent.

3.2 Measurement set-up

As was discussed in the previous section, the far-field pattern of the antenna is of little use. It is more practical to define a surface under the ground and use transformation algorithms to determine the radiation in the ground. From the near-field theory (in air) we know that for the determination of the antenna radiation, it is sufficient to measure on a specified surface two independent field components (out of six components). Additional research is needed to determine additional constraint for measuring the field in the ground.

To realize the near-field measurements, an EM-field probe is buried just below the ground interface. The probe measures the local time domain EM field. The antenna under test (AUT) is moved on a planar surface above the ground (see figure 2). In discrete positions, time domain waveforms are measured and stored. For the planar movement of the AUT an x-y-z scanner (1.5×1.5×0.3 m) is developed.

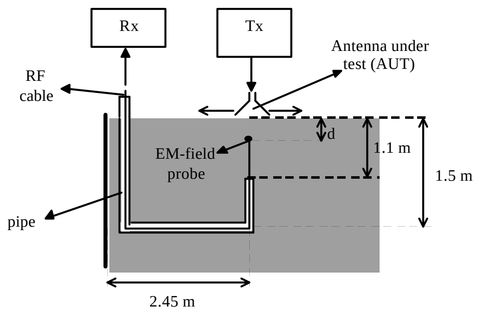

Figure 2: GPR antenna radiation measurements.

3.3 Measurement equipment

Different pulse generators can be selected to excite the AUT. In table 1 the main pulse characteristics are summarized. The time domain signals are measured with a sampling oscilloscope (K2-63, table 2).

Table 1: Pulse generator characteristics.

waveform	Duration [ns]	Amplitude [V]
monocycle	0.8 [0% level]	±25

'1ns'		
monocycle '2.5ns'	2.6 [0% level]	±100
monocycle '5ns'	5.0 [0% level]	±250
impulse 1	0.2 [50% level]	40
impulse 2	0.4 [50% level]	50

Table 2. Characteristics sampling oscilloscope

Parameter	Value
Number of channels	4
Bandwidth	2 ×(1÷6 GHz) 2 ×(1÷18 GHz)
Noise (RMS)	≤ 1.0 mV (1÷6 GHz) ≤ 4.0 mV (1÷18 GHz)
Max. input voltage	± 1.0 V
Accuracy	±(0.02 V_x + 0.002) V
A/D converter	12 bits
Number of samples	256, 512, 1024, 2048
Max. averaging	256
Min.sampling time	0.1 ps
Jitter	≤ 2.0 ps
Measurement range	10.0 ps ÷ 10 µs

3.4 EM field probe

The probe used in the first experimental antenna measurement is a home-made H-field sensor (loop antenna with inner diameter 30 mm [Goedbloed, 1991]). This simple probe antenna is used to demonstrate the feasibility of the measurement set-up. The probe is buried at depth 25 cm. The set-up is tested with two different AUT; an identical loop antenna and a TEM horn designed for 1ns monocycle transmission. Figures 3 and 4 show the measured responses.

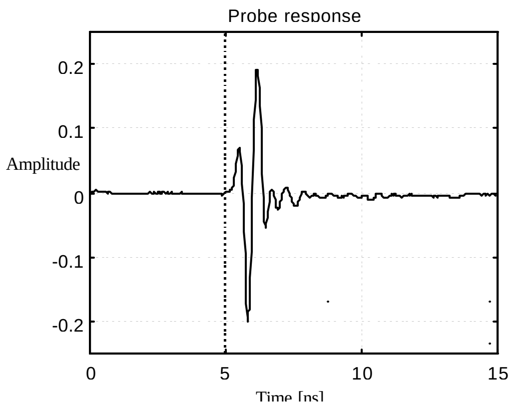

Figure 3: AUT is loop antenna.

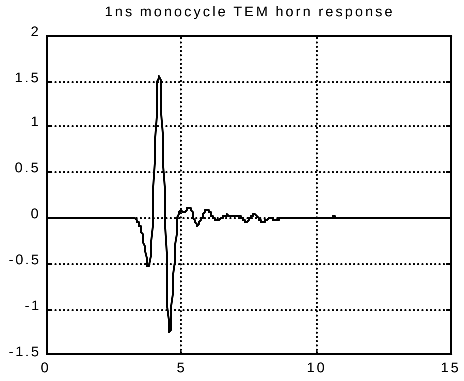

Figure 4: AUT is TEM horn

The main pulse duration and the tail for the TEM horn antenna signal is similar to the response of two identical TEM horns in the air. Furthermore, the response of the two loop antennas show no large resonance's. Additionally, the signal strength of the different antenna responses is sufficiently large. We concluded that the measurement set-up used is feasible. Further analysis of the probe characteristics is not done, because in the final measurement set-up other probe antennas will be used.

4. Analysis of different antenna concepts

Aim of the research is to develop improved GPR antenna concepts. In this paper the first experimental results are described. Three antenna types are discussed: the spiral antenna, TEM horn and dipole antenna.

4.1 The spiral antenna

As was already mentioned, the spiral antenna is ultra-wideband, but does not satisfy the requirements for transient antennas. To demonstrate the time domain performance, a spiral antenna has been measured with a 1ns monocycle excitation (see figure 5).

Due to the long time duration of the antenna response, this antenna type cannot be used for short-pulse time-domain GPR systems.

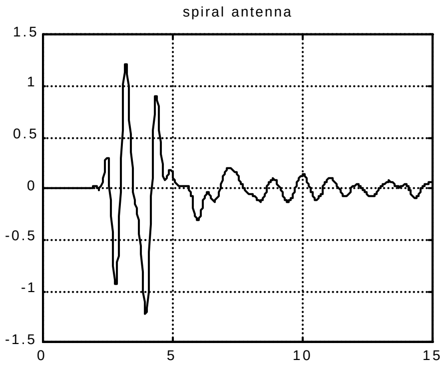

Figure 5: The spiral antenna response

4.2 TEM horn

An antenna type which is known to be good for time domain pulse radiation is the TEM horn. An air filled TEM horn is developed for the radiation of the 1 ns monocycle pulses (see figure 6).

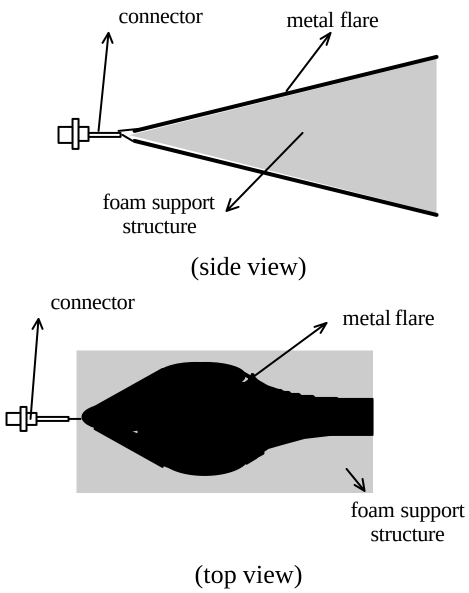

Figure 6: TEM horn antenna.

For the TEM horn response (see figure 4) the main antenna pulse is short in time and the tail is small compared to the main pulse amplitude. Note that from figure 4 the absolute antenna characteristics cannot be determined, because no probe correction is applied.

The TEM horn has also disadvantages. The TEM horn is not shielded and the crosscoupling is large. Second, the large ground interface reflection causes late time ringing. Currently we are investigating improvements to this antenna concept for use in a GPR system.

4.3 Shielded broadband dipole

The third antenna type investigated on the GPR test range is the 'shielded broadband dipole'. This concept resulted from a compromise between two GPR antenna requirements. First, a shielded antenna structure. Second, small antenna dimensions. The concept is the placement of a broadband dipole in a metal casing. The metal case acts as a waveguide and the dipole is used for the waveguide excitation. Because the propagation path in the waveguide is short, the dispersion (typical for a waveguide) is expected to be small. The dipole arms have an elliptical shape (optimized for maximum flat frequency response). In the first prototypes, no dielectric filling of the waveguide have been used and a large antenna ringing was observed (see dashed line in figure 7).

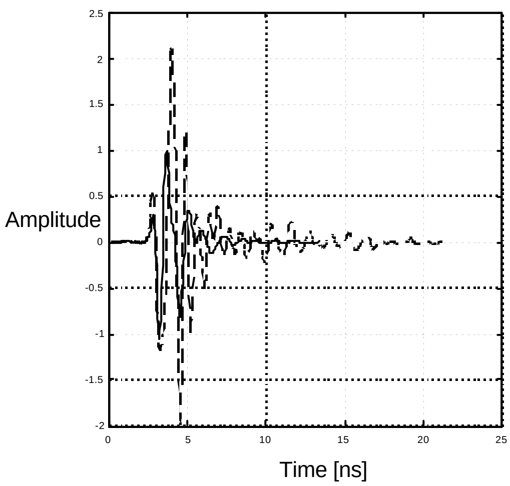

Figure 7: Shielded broadband dipole (solid line: dielectric filled; dashed line: air filled).

The time domain antenna response in figure 7 (dashed line) is not acceptable for the GPR system. By covering the sidewalls with absorbing material, the antenna ringing was reduced. The next step in the improvement was the dielectric embedding of the antenna to reduce the contrast with the ground (see figure 8). The response of the improved antenna is given by solid line in figure 7.

From figure 7 we have seen a large improvement of the radiated signal, especially for the tail. However, further improvements will be made in the main pulse.

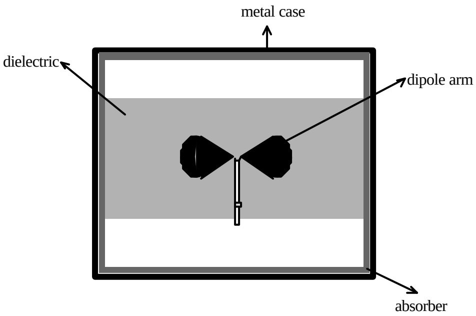

Figure 8: Top view dielectric embedded broadband dipole.

5. Conclusions

In this paper the new GPR antenna concepts are described. First, a review of the main design principles is given, because GPR antenna design differs from the classical approach. Most important principles are a good time domain performance (removal of resonance's and minimize the tail) and minimal ground influence. Second, a practical GPR antenna measurement set-up is described. Ground transmission measurements are essential in the GPR antenna design. In the test site we measure the radiated time domain field on a planar surface in the ground. The time domain antenna performance can be investigated for different excitation pulses. Third, three antenna types are discussed; the spiral antenna, TEM horn and the 'shielded broadband dipole'. The spiral antenna is not suitable for short-pulse, time domain radiation. The TEM horn has good radiation characteristics, but is sensitive for interference signals and has bad ground coupling. The 'shielded broadband dipole' is designed to have a closed structure with small antenna dimensions. Intermediate results of the first and the latest prototype are shown. However, further improvements of this antenna type are expected.

References

Daniels, D.J., *Surface Penetrating Radar*, IEE radar, navigation and avionics series 6, UK, 1996.

Chi-Chih Chen, *A New GPR Antenna design-The Horn-Fed Bowtie (HFB*), AMTA'97 proceedings, pp 67-74, Boston, USA, 1997.

Shlager, K.L. et.al., *Optimization of Bow-Tie Antennas for Pulse Radiation*, IEEE trans. Anten. & Prop.,vol. AP-42, no. 7, pp 975-982, July 1994.

Yee K.S., et.al., *Time Domain extrapolation to the far field based on FDTD calculations*, IEEE trans. Anten. & Prop.,vol. AP-39, no. 3, pp 410-413, March 1991.

Goedbloed, J.J., *Elektromagnetische Compabiliteit*, Kluwer Technische Boeken, Deventer, 1991.

Foster, P.R., *Performance of Ultrawideband Antennas*, SPIE Vol. 1631, Ultrawideband Radar, pp 134-145, 1992.