ANALYSIS OF CHARACTERISTICS OF GROUND PENETRATING RADAR ANTENNAS

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KEY WORDS: Ground penetrating radar, spherical spread attenuation, stacking, time aliasing, time base drift, trace time zero.

ABSTRACT:

A key factor for the accurate interpretation of surface-penetrating radar records is to know as much as possible about the transmission features of our antennas. The characteristics of the detected reflections (trace time zero, duration and shape of the reflected pulse, minimum overlap distance between direct signal and first reflection, etc) depend on the issued signal properties. Since these characteristics can vary for the different GPR equipments available, in this paper we present the results of various experiments to analyze and calibrate 500, 800 and 1000 MHz shielded antennas.

1. INTRODUCTION

The continuous development of the survey techniques has extended the applications of the Ground Penetrating Radar (GPR), opening new areas of study and applications. As the technology matures, the sophistication of signal recovery techniques, hardware designs and operating practices increases [1]. The numerous contributions made in this field lead to its spectacular advance. There are many examples of these contributions; case studies, computer simulations, experimental tests and computing. In spite of this considerable evolution, there are not that many companies associated with the development, manufacture and supply of GPR equipment.

One of the main problems related to this technology is that the technical information provided by the different companies is practically inexistent, except for certain details about the processing capacity of the equipment. The lack of knowledge of the different parameters of emission of the antennas as well as other characteristics of the emitted signal constitutes an added difficulty for accurate interpretation of GPR data. In order to address this problem, a set of experiments have been made to analyze the characteristics of the signal emitted by the antennas and to calibrate them.

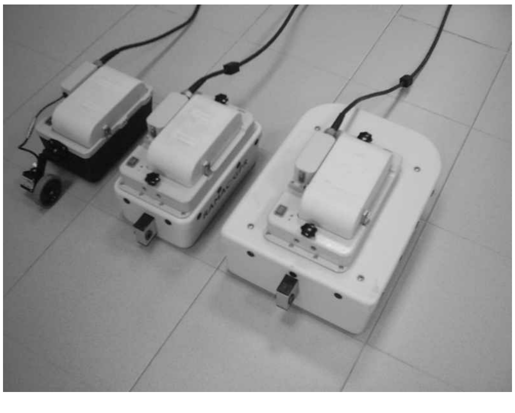

Fig.1.Shielded antennas under test.

The propagation media in the first tests was air. For the purpose of this study, we can consider it homogenous, non-absorbent and having a well-known speed [2]. The simplicity of the propagation media should provide a simple propagation pattern, making the obtained records easy and readily to interpret. The information given by these records will allow, as commented previously, to calibrate the equipment and, therefore, to lay the foundations to interpret the radargrams obtained in more complicated media (inhomogeneous and/or absorbent). In addition, it will help in optimizing the disposition of the antennas with respect to the concrete objectives of the region under study, as well as in recognizing the antennas reaction in the presence of possible interferences of internal/external nature and temporary instabilities of the emitted signal.

The results of the different tests are presented and discussed in this paper. We used three different RAMAC/GPR shielded antennas (Fig 1) characterized by the central frequency of their emission: 1 GHz, 800 MHz and 500 MHz.

2. METHODOLOGY

In a first group of experiments the antennas under test (AUT) connected to the control unit (CU II), were placed at different distances from a surface (S) which provided a clear reflection on GPR records. Data obtained in different measurements relative to amplitudes and double travel times (TWT) were analyzed.

In a first study, each AUT was suspended on wood crosspieces above S, which was covered with aluminium paper to strengthen the reflected signal. Since aluminium is highly conductive (σ =$3.54 \cdot 10^7$ S/m), it has a high reflection coefficient in air (0.99996) and could be approximated as a near-perfect radar reflector.

The measurements were made at a height of 1.6 m above S. This height, allows to clearly differentiate between the direct air wave and the reflected wave. AUT and control unit were turned on and immediately began collecting data for a minimum of 60 min. On one hand, we determine the stabilization intervals of the signal emitted by the antennas. This would allow to quantify the effects of the signal drift, as well as the warm-up time necessary to provide a stable operation for each antenna, and that must be considered before starting the first measurements.

On the other, we determine the real starting point in GPR records for the antennas used. We set this zero position choosing a relatively stable and easily identified location in the trace.

In a second study, each AUT elevated on trestles, is located initially in contact with a wall covered by aluminium paper and it is separated successively in equidistant intervals. With this test we obtained the minimum distance at which the antenna must be placed with respect to the surface of the medium under study in order to avoid the overlap between the direct signal of the antenna and the first reflection produced in this surface.

We also studied the spherical spread of the wavefront. We analyzed the attenuation of the propagating signal to determine the dependency of the amplitude of the emitted impulse with respect to the whole range.

In another group of experiments, profiles in different test sites were registered. The dimensions and composition of the buried objects of the different test sites were known. This allow us to check the obtained results considering the following objectives: to analyze the influence of collecting GPR data using different stacking values, and to determine the difference in resolution and depth of record between antennas of different frequencies under the same study conditions.

3. RESULTS

Prior to comment the results obtained, some of the characteristics of the impulse emitted by the AUT are shown in Table I. To determine the impulse characteristics, each AUT was oriented towards the sky in a reflector free surrounding, in order to isolate the direct signal between dipoles.

AUT (MHz)	Main Pulse (ns)	Transient Region (ns)	Bandwidth 3dB (MHz)
500	10.40	5.74	361
800	6.26	2.36	425
1000	4.50	2.59	525

Table 1. Pulse characteristics

Table 1 shows the time duration for the different transmitted pulses associated with bandwidth. The initial section is also specified within the main pulse where most of the energy is concentrated (Transient Region) Fig.2, as sets out in [3].

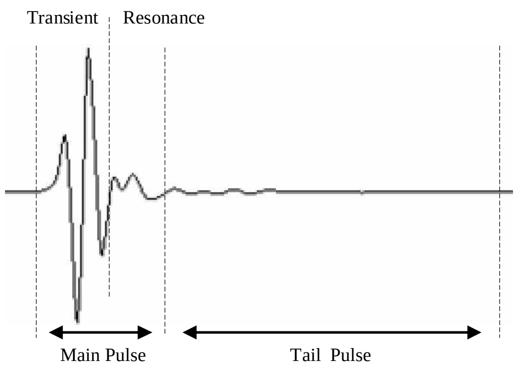

Fig. 2. Time domain 500 Mhz antenna response

3.1 Time Base Drift

Fig. 3 represents the relative travel times of the direct signal and reflected pulse for the different AUT, according to the results obtained for the time base drift evaluation. A-scans were collected each 5 s with an internal 128-fold stack per trace for a minimum of 60 min. As in [4], the median travel time of both reflections was removed to emphasize their relative drift, in such a way that demedianed data virtually overlie each other. Resulting travel times drift have values between 0.2 and -0.6 ns.

As it can be observed, the rate of drift of the signal is not exactly the same for the three antennas. Therefore, in order to diminish the possible committed errors and to establish a valid criterion for all antennas during the field work, a warming-up time of 10min will be enough to provide accurate results. If the initial stabilization period of the signal is not considered, traces deviations could cause time differences and therefore, wrong depth estimations.

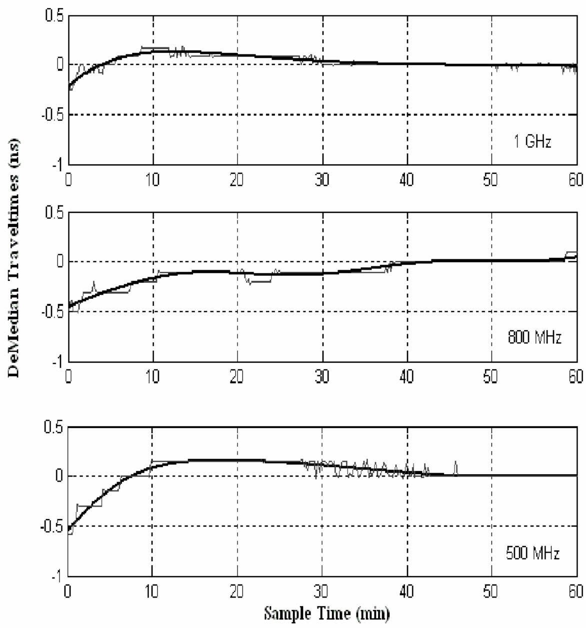

Fig. 3. Time base drift

This drift error will be more important in mediums with a low dielectric permittivity. As it can be observed, the rate of drift of the signal is not the same one for the three antennas.

3.2 Time Zero

The a-priori knowledge of the distance between the antenna and the reflector, allows to establish the origin of the two-way travel times scale for the A-scans obtained in this study.

As we can see in Fig.4, starting off at the greatest amplitude value from the first semiperiod of the reflected pulse and considering the separation with respect to the antenna (1.60m), we can fix the origin. This origin corresponds to the greatest amplitude value of the first semiperiod of the direct signal in the case of the 800 and 500 MHz antennas. For the 1GHz antenna, it coincides with the start of this first semiperiod.

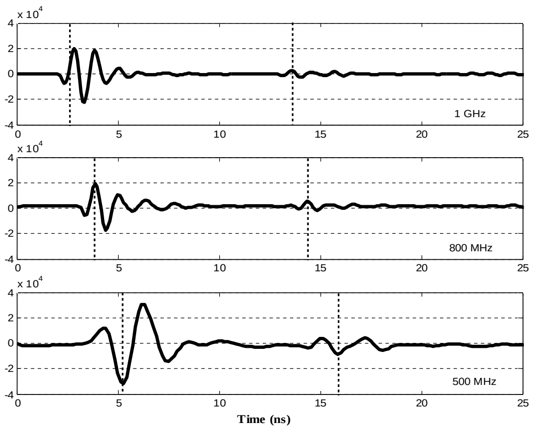

Fig. 4. Data time zero

3.3 Time Aliasing and Spherical Spread Attenuation

For each AUT, the minimum separation distance between the antenna and the surface, at which the direct signal and the reflected one overlap, is different. This is due to the longer pulse emitted by the lower frequency antennas (Table 1).

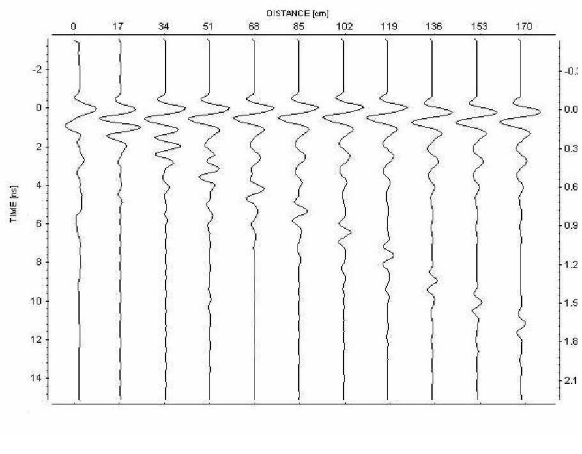

Fig. 5. Sequence of stacked traces for different distances with the 800 MHz antenna

Similar as in [5], a sequence of consecutive A-scans gathered with the 800 MHz antenna is displayed in Fig.5. In each position an interpolation of 20 traces, with an internal 128-fold stack per trace has been made. For the 800MHz antenna the overlap of the reflected signal in the transient region starts with a separation of 38cm, but already for a separation of 25cm the signals are no clearly differentiated. The equivalent distances for the rest of the AUTs are: 69cm-46cm for the 500MHz antenna and 37cm-21cm for the 1 GHz antenna.

We also analysed the attenuation caused by the spherical spread of the wavefront, as done in [6]. Fig 6 shows the results obtained with the 500 MHz antenna. For each A-scan the direct signal between transmitter and receiver was subtracted and the relative amplitude values (divided by the amplitude of its direct signal) were used to adjust a decay function.

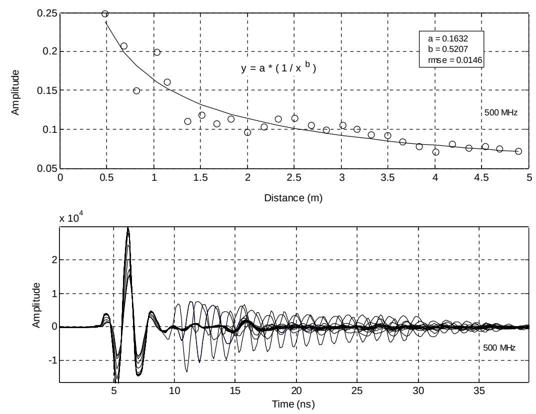

Fig. 6. Results obtained for the 500 MHz antenna.

This result could be applied to other mediums, with the intention to separate this effect with regard to attenuation determined mainly by the conductivity of the ground and scattering effects.

3.4 Stacking and Differences in Antenna Resolution

A set of B-scans with an internal stacking of 1, 8, 16 and 32 traces were recorded for the different AUTs. This system can stack up to 32 traces (even an internal 32768-fold stack per trace is possible), but these are unviable in studies that demand some kind of continuous movement. Fig. 7 shows the same trace with different stacking values (1, 8 and 32 respectively) gathered with the 1GHz antenna.

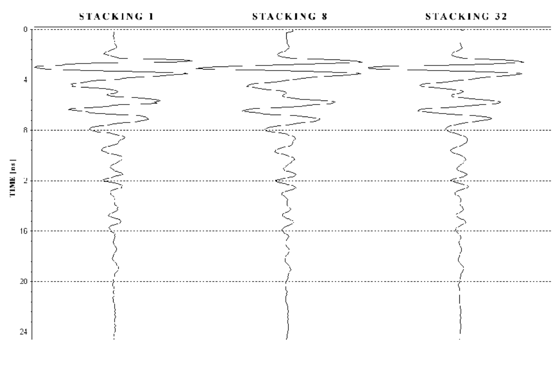

Fig. 7. 1GHz A-scans with different stacking values.

As it was expected, a high stacking produces a smoothed signal shape improving the signal-to-noise ratio.

For the records obtained with the antenna of 500 MHz these differences are less notable due to pulses of greater duration and amplitude. In any case, for every AUTs the difference between 16 and 32 does not seem to be appreciable.

Finally, to compare the different antenna resolutions, a set of B-scans were gathered for each AUT under the same conditions (test site, stacking and trace interval). An example of this is showed in the Fig 8. In these B-scans the same filter configuration (dewow, gain function and trace average removal) has been applied in order to enhance the desired targets and to reduce clutter. As we can see, shallow reflectors are easier to identify in the 800 and 1 GHz records, than in the 500 MHz one. Furthermore, in the 500 MHz B-scan, the registered events closer to the surface overlap with the direct signal between transmitter and receiver.

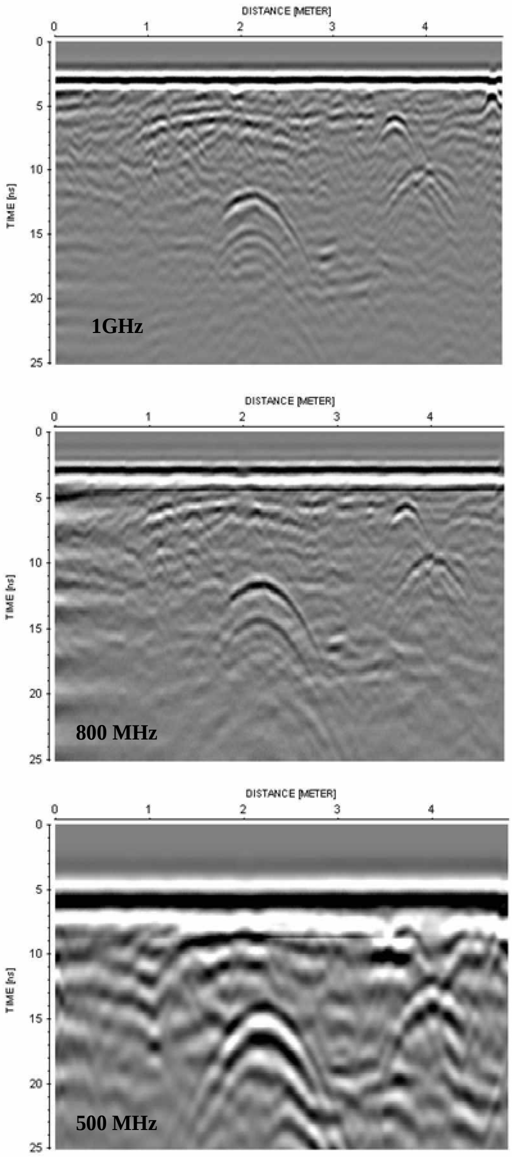

Fig. 8. Example of GPR data obtained on a test site where PVC and concrete pipes of different sizes were present.

4. CONCLUSIONS

The results obtained in the different tests presented in this paper contribute in our knowledge of certain characteristics of the signal transmitted by our equipment. The greater knowledge of the signal allow us to establish guidelines to be considered in future applications. These guidelines provide an efficient calibration, minimizing the possible errors produced in the calculation of depths and elements discrimination.

4.1 Warm-up time

To make sure that the signal emitted by the antenna is stable, the antenna should be allowed a warm-up time. It reduces the vertical signal deflection of the data. Although the manufacturer recommends waiting between 3-5min, the results obtained in this study suggest a greater delay (10min). With this delay, we are sure to avoid the errors in depth calculations due to the time deviations of the traces in this initial period. These errors will logically have more relevance for those mediums where the propagation velocity of the wave is greater. In any case the time drift effect for our antennas seems less significant than the ones quantified in similar studies with other equipment [2].

4.2 Properly fitting the two-way travel time scale

The study of the time origin allows us to establish the criterion to fit the two way travel time scale properly. With this procedure we are able to diminish the errors related to the zero misalignment. It has been observed that for certain separation distances the interference of the first reflected signal is very destructive and the main pulse is dramatically altered. This effect is being exhaustively quantified for GPR applications on road evaluation.

4.3 Aliasing and Spherical spread attenuation

The calculations of the minimum no-overlap distances allow us to know how far must we separate the antenna from the surface for a clear first reflection. Otherwise, if the study will need the antenna to be closer, knowing the medium where we are going to survey and before data acquisition, we can estimate the zone of the medium that will be unclear because of this overlap. The minimum no-overlap distances are directly related to the internal signal size of each AUT. This signal is determined by the direct wave, the internal reverberations and the electronic noise. In some antennas of this type, between the receiver and the emitter there is an absorbent element to diminish the amplitude of this signal and to make sure that the greater percentage of energy reaches the receiver from the external reflection.

Spherical spread attenuation is one of the easier attenuation effects to offset, because it is computable from the distance between the antenna and the reflector. When carrying out field studies the signal can be amplified applying gains to diminish the signal attenuation due to this effect. This provides a better radargram interpretation.

4.4 Stacking

Its effect is more evident with the high frecuency antennas. The suitable value depends on the precision with which we want to detect and the optimum survey velocity of recording. A stacking value of 1 allows a high prospection speed but the noise level can become considerable. As we increase the number of traces stacked, the noise level decreases, but the prospection speed is slower too. Generally a value of 8 seems to be a good commitment, but for certain GPR applications where the velocity of survey is an important factor, the suitable value could be lower.

ACKNOWLEDGMENTS

This project is the result of a collaborative effort between the Environmental Engineering & Natural Resources Department of the University of Vigo and the companies Panatec S.L. (Spain) and Roadscanners Oy. (Finland).

We are grateful to A.G. Gorriti of Delft University of Technology, Department of Applied Earth Sciences CITG, for her helpful suggestions and review of the text.

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