

GPR ANTENNAE CHARACTERIZATION TO IMPROVE THE DATA INTERPRETATION

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ABSTRACT:

The knowledge of the properties of the studied medium is one of the factors that are necessities in order to obtain accurate interpretations using ground-penetrating radar (GPR) data. Other important factor is the knowledge of the instrumentation used to obtain these data. Hence, it was carried out some lab experiences with four of the antennae used in our studies. These antennae are identified by their central frequency: 1 GHz, 900 MHz, 500 MHz and 200 MHz. The first one is a commutation antenna. The others have a pulse transmitter and a receiver separately. The experimental procedure consists in the analysis of the received wave arranged from the reflection in a metallic sheet, and to compare this record with the direct wave together with the internal noise. Two main anomalies are recorded in all cases: the direct wave (when the receiver and the transmitter are separated) or the internal noise from the commutation (in the commutation antenna), and the reflected wave on the metallic sheet. The obtained data in all cases is characterized by its arrival time and its amplitude. In the reflection test, both characteristics are depending on the separation between the antenna and the metallic sheet because of the short distances analysed. The objectives of those tests are:

- To analyse the minimum distance between the metallic reflector and the antenna to avoid the coupling of the reflected signal and the direct one. The direct wave and the internal noise of the antenna are obtained emitting in a direction without any reflective element. The length of the initial noise of the 1 GHz centre frequency antenna is 1.6 ns. This noise is caused by the direct signal in the 900 MHz centre frequency antenna, and its length is 2.66 ns. It is the same case of the 500 MHz and the 200 MHz centre frequency antennae. The lengths of the initial pulse in both cases are 9.9 ns and 12.5 ns respectively. The minimum separation in order to avoid coupling phenomena with this initial signal (which have the higher amplitude) is obtained from these experimental times and from the wave velocity in each medium.

- To obtain the zero of the record data (point where the time starts). This is the point of the trace that is the start of the two-way travel time of each anomaly. The aim is to convert the recorded times into depths with the minimum error. In many GPR studies the start of the direct wave is used as the start of the radar record. Because of the separation between the transmitter and the receiver, the delay could be important depending on its separation and the velocity of the wave in the medium. This effect causes an error in the conversion of the two-way travel time into depths. Also, the difference between the expected time and the recorded one is analysed. The highest differences are obtained for the smaller separations between the antenna and the reflector. This is due to the coupling of the signals. This effect difficult to recognize clearly the start of the separate waves. This difference is reduced when the distance increases. The minimum difference was achieved for a 80 cm separation. Then, the difference increases smoothly because of the difficult in to identify exactly the arrival of the reflected wave due to the decrease of the amplitude.

- It was also analysed the attenuation of the radar signal along the travel path in the medium. When this medium is the air, for the small distances considered, all the results obtained for the antennae are quite similar. The results could be fit to an equation where the amplitude depends on a constant value and on the inverse of the travelled distance. Hence, these results are used as the geometrical spreading to obtain in absorbent media the decay of the amplitude (attenuation factor) due to absorption of the energy.

1. INTRODUCTION

1.1 Introduction

Preliminary test to characterize the GPR antennas were carried out in plane media: air and water. The first one is a media considered homogeneous and non absorbent for these studies compared with the ground. Radar data will be easy to understand and interpret because the plane behaviour of the radiation in the air and also because the velocity is known. In this case this velocity could be approximate to c (Conyers and Goodman, 1997). The analysis of the radar data obtained in these test allow us to understand the basic behaviour of the equipment and, then, it is the first step to interpret radar data

from more complicated media: the ground and the constructive materials.

The results of the different test carried out are presented and discussed in this work. These test were performed using four different GSSI antennas, characterized by their central frequency: 1 GHz, 900 MHz, 500 MHz and 200 MHz. The first one is a monostatic antenna of commutation. The other three are monostatic antennas with a emitted dipole and a receiver one.

1.2 Objectives

The objective of this series of test is the calibration of the equipment. For each one of the used antennas, the next parameters are search:

Zero of the antennas. This factor is defined as the point in the radargram to begin the two-way trave time scale, to carried out a correct conversion of those times into depths. In studies in complex media, the knowledge of this factor allow us to calculate accurately the distance to the reflectors placed in a media.

Minimum distance between the antenna and the surface of the media to avoid coupling effects. It is the minimum distance that is need to separate the antenna to the medium surface to avoid coupling effects between the internal signal of the antenna and the reflection on the surface of the medium. The internal signal of the antenna is different for each one and it depends on the first arrival from the energy that is propagated from the emissor to the receiver and also to the internal noise. When the antenna is a commutative one, this signal is due to the commutation.

Geometrical spreading. An accurate approach in GPR studies is to consider the air as a non-absorbent media. Then, the cause of the attenuation during the propagation of the energy is due to the geometrical spreading. The measures of this kind of attenuation will be used in later experiences to determine the attenuation due to the absorption of the media.

2. ZERO OF THE ANTENNAS

2.1 The start of the time axis

In the GPR records a signal is introduce to indicate the beginning of them. This point indicates the beginning of a time window and it is selected from the central unit with a parameter named position record. After this signal, the other signals due to the antenna effects appear. The most important ones are the direct wave and the effects due to the commutation. The separation between the beginning of the record and those effects depends on the introduced value of the position. The waves reflected in the anomalies of the medium are recorded after these first effects (Figure 1).

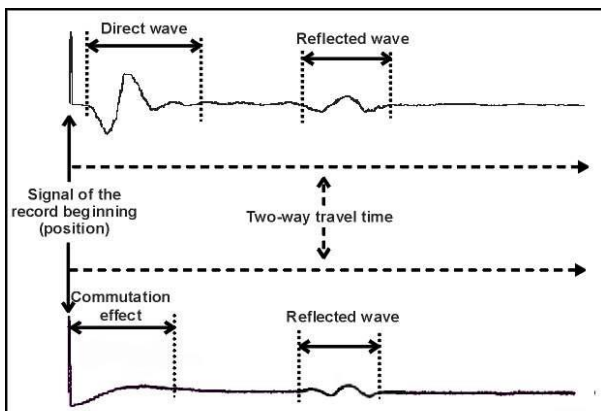


Figure 1. The above is a trace obtained with a 900 MHz antenna. The other one is a trace obtained with a 1 GHz commutation antenna.

2.2 The lab test

The antenna was placed in front of a metallic reflector, parallel to the emissor surface. The dimensions of this metallic sheet are

selected to include completely the path of the antenna. The size of the path was calculated by using the different conclusions of several authors (Conyers and Goodman, 1997; Cook, 1975). These dimensions are obtained for the most separate case between the antenna and the metallic sheet. The results are presented in table 1. Also, in this table is included the surface considered in the lab test to assure this condition (S).

Antenna	Dist. max. (cm)	λ_0 (in air) (cm)	Conyers & Goodman (cm)	Cook (cm)	S (m ²)
1 GHz	100	30	78	57	0.6m×0.6m
900 MHz	100	33.3	79	60	0.8m×0.8m
500 MHz	500	60	368.6	175.8	3.7m×3.7m
200 MHz	440	150	348.6	267.6	3.5m×3.5m

Table 1. The path of the four used antennas obtained with the conclusions of different authors. S is the size of the metallic sheet used in the lab test, and Dist. Max. is the maximum separation considered between the antenna and the sheet.

The distance between the antenna and the sheet is changed from the maximum considered (table 1) to the minimum separation (the antenna in contact with the metallic sheet). Radar data was obtained in static measurements and also with the antenna in movement. The next steps are realized to obtain the origin of time:

1. It is calculated the expected time to the wave arrival by using the known distance between the antenna and the reflector. This time is obtained for each separation distance.
2. This time is measured in the radar data from the signal due to the reflected wave. At the beginning of the radar data the end of this time is marked.
3. An average value of all this marks is obtained by using all the radar data acquired with the same antenna. This is the origin of times that will be used in other GPR studies to convert the two-way travel time into depth.

2.3 Results

In figures 2,3,4 and 5 are shown the radar data obtained with the antennas: 1 GHz and 900 MHz. It is observed that the start of the time axis is not exactly the signal of the start record or the direct wave arrival.

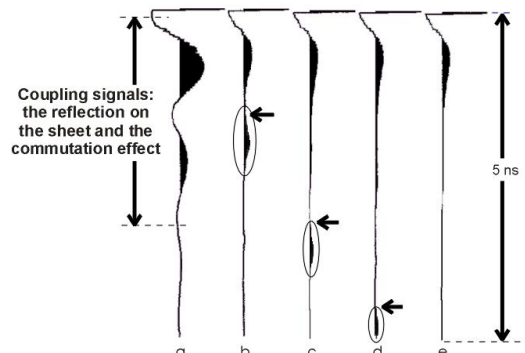


Figure 2. Radar data obtained with the 1 GHz centre frequency antenna at different sheet-antenna distances: a) 0 cm, b) 20 cm, c) 40 cm, d) 60 cm and e) 80 cm.

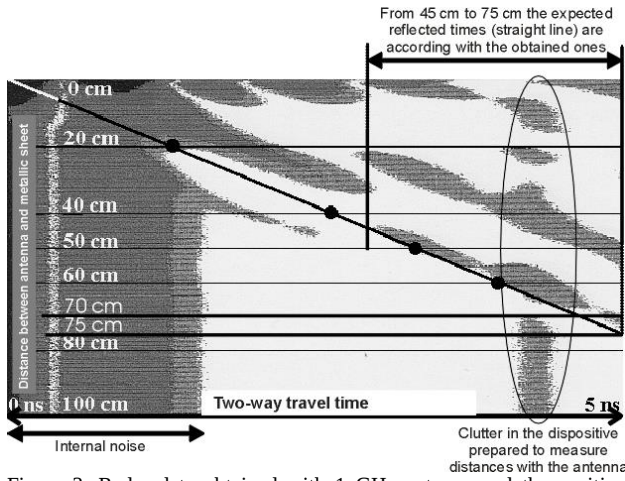


Figure 3. Radar data obtained with 1 GHz antenna and the position (straight line) of the expected times for each distance. Both times are in agreement between 45 cm to 75 cm separation distances.

The coupling effects between the internal noise of the antenna and the reflected wave is important when the separation between the antenna and the sheet is less than 20 cm. Those effects are also observed between 20 and 45 cm. Then, for these distances it is not possible to obtain the exact arrival time of the reflected wave.

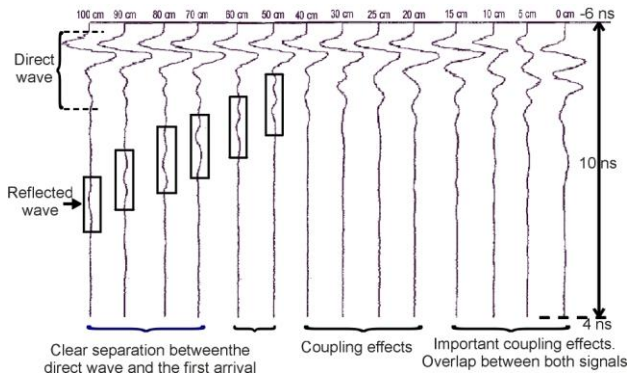


Figure 4. Radar data obtained with a 900 MHz antenna.

In table 2 the results obtained for the four studied antennas are included.

Antenna	Zero (ns)		Δx in air (cm)
1 GHz	0	Start of the first signal	0
900 MHz	-1.3	1.3 ns before the direct wave arrival	-19.5
500 MHz	0.8	In the middle of the first half-period of the direct wave. It coincides with the first amplitude maximum	12
200 MHz	1.2	In the middle of the first half-period of the direct wave. It coincides with the first amplitude maximum	18

Table 2. The position of the start in the time axis for each studied antenna.

3. DISTANCE TO AVOID THE OVERLAP

It was also determined the minimum distance between the antenna and the metallic sheet to avoid coupling effects between the direct wave and the first arrival (reflected wave). This distance depends on the length of the emitted signal and also the filter effects of the media in this signal. In these test it was assumed that the air is a non-absorptive media and, then, the first signal is not deformed. This length was measured in the time axis and it was converted into distance by using a velocity

of 30 cm/ns. To obtain this value the antenna was directed to the air and no reflectors were placed near it. It was also compared with the records obtained with a reflector in front of the antenna. In figure 3 it is observed this overlap time for the 1 GHz antenna. Figure 5 shows the results of the measures with the 500 MHz centre frequency antenna.

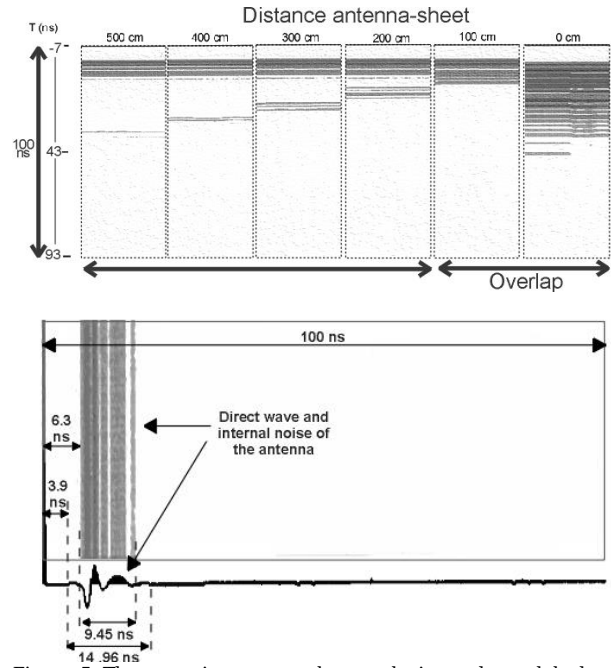


Figure 5. The separation antenna-sheet to obtain overlap and the length of the wave. This length is the minimum separation (in time) between the antenna and the sheet to avoid coupling effects. In the first image are shown the different radar data obtained at each distance and the effects of the overlap that appear in the last two records. In the second figure it is shown a record only with the direct wave recorded, to measure the length of it.

It was measured this first signal in each case. The results obtained are resumed in table 3. These times are corresponding with different distances depending on the medium. In the table are included the distance in the air and the distance in water (using the dielectric relative permittivity for the water 81).

Antenna	T_0 (ns)	x air (cm)	x water (cm)
1 GHz	1.6	24	2.7
900 MHz	2.6	39	4.3
500 MHz	9.45	141.8	15.8
200 MHz	9.5	142.5	15.8

Table 3. Length of the first signal (T_0), and the corresponding distances in air and water ($\epsilon_r=81$).

4. GEOMETRICAL SPREADING

The objective of these test were to obtain the geometrical spreading of the wave in order to separate in ground studies the attenuation due to this cause and the attenuation due to the ground absorption and to the wave dispersion.

It was measured the reflected wave on the metallic sheet for each antenna, placed at different distances. The amplitude of the recorded wave was measured in each case. The procedure with the radar data obtained in this test was:

- 1) The reflected wave was identify in the radar data for each antenna and each distance. Also it was identify the direct wave.

- 2) The amplitude of the direct wave was measured. It was a constant value for each antenna because the acquisition parameters were constants during the entire test.
- 3) The amplitudes of the reflected waves were measured.
- 4) These last amplitudes were normalized by using the value of the amplitude of the direct wave for each antenna.
- 5) The obtained values were represented in a graphic, and these points were fitting by using the next expression:

$$A_r = \frac{A_m}{A_d} = A_0 r^{-\kappa} \quad (1)$$

Where A_r is the relative amplitude, A_m is the amplitude of the reflected wave, A_d is the amplitude of the direct wave, r is the travel way (two times the distance antenna-sheet), and κ is the geometrical spreading coefficient.

The graphic representation allows us to obtain this fit expression. In figure 6 it is shown the graphic results for the 900 MHz centre frequency antenna. The obtained results for each antenna are presented in table 4.

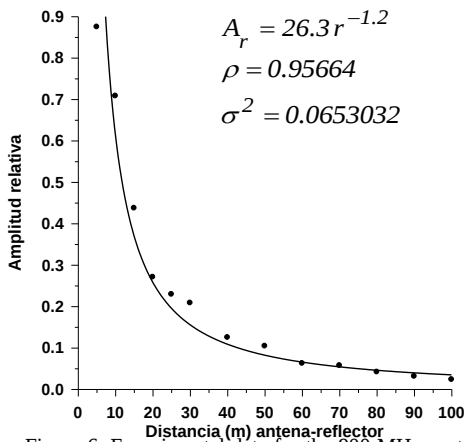


Figure 6. Experimental data for the 900 MHz centre frequency antenna and the fit results.

Antenna	R (ns)	A_0	κ	σ^2	ρ
900 MHz	10	26.3	1.2	0.065303	0.956640
500 MHz	100	48	0.93	0.005609	0.988187
200 MHz	50	1709	0.95	0.099292	0.933632
	100	131	1.2	0.011440	0.988291

Table 4. Resume of the coefficients results for three antennas.

5. DISCUSSION AND CONCLUSIONS

The simple test carried out with these antennas allows us to know their behaviour in a simple media: the air. These results will be applied in future works to determine soil properties because they allow us to separate the effects due to the antennas and the effects due to the ground.

For each antenna it was determined the start of the time axis. Although the difference in time between this point and the start of the radar record is small, this value could help in following studies to obtain an accurate two-way travel time conversion into depth. It was observed that both points are coincidental in the 1 GHz centre frequency antenna (this is a commutation antenna). But these two points are no coincidental in the antennas with a transmitter and receiver separately. This difference is not important when the medium studied is characterized by a low velocity. Also it was observed that the difference between the measured time and the expected time is

greater for smaller distances because the difficult to determine exactly the wave arrival due to the overlap effects.

The coupling between the direct wave and the reflected one produce a zone where determine arrival times is less exact. To obtain this zone, it was measured the length of the recorded direct wave. This length is 1.6 ns in the 1 GHz antenna, 2.6 ns in the 900 MHz antenna, 9.45 ns in the 500 MHz antenna and 9.5 ns in the 200 MHz antenna. This zone, measured in time, is a different length depending on the characteristic velocity of the medium.

Finally, it was calculated with the fitting measures of amplitude, the coefficient for the geometrical spreading. As it was expected, all the results for all the antennas are quite similar and, also, this kind of attenuation is proportional to the inverse of the travel way.

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REFERENCES

- Turner, G. and Siggins, A.F., 1994. Constant Q attenuation of subsurface radar pulses. *Geophysics*, 59(8), pp. 1192-1200.
- Bernabini, M., Pettinelli, E., Pierdicca, N., Piro, S. and Versino, L., 1995. Field experiments for characterization of GPR antenna and pulse propagation. *Journal of applied geophysics*, 33, pp. 63-76.
- Conyers, L.B. and Goodman, D., 1997. Ground-Penetrating Radar. An introduction for archaeologists. Altamira Press, Walnut Creek, California, pp. 232.
- Cook, J.C., 1975. Radar transparencies of mine and tunnel rocks. *Geophysics*, 40(5), pp. 865-885.
- Lorenzo Cimadevila, H., 1994. Prospección geofísica de alta resolución mediante geo-radar. Aplicación a obras civiles. Tesis doctoral, Universidad Complutense de Madrid (España), pp. 201.
- Pérez Gracia, V., 2001. Radar de subsuelo. Evaluación para aplicación a arqueología y a patrimonio histórico-artístico. Tesis doctoral, Universidad Politécnica de Cataluña (España), pp.357-507.