

Vertical and Horizontal Resolution of GPR bow-tie antennas

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Abstract— since the characteristics of the detected reflections depend on the issued signal properties, a key factor for carrying out a successful GPR survey is to know as much as possible about the transmission features of the antennas. This information is essential when deciding the antenna and which is the most appropriate parameter configuration setting for a specific study. These characteristics vary for the different available GPR equipments. Numerous experimental tests have been developed in this way. In this paper we present the first results of a set of experiments about the resolution capabilities of two commercially bow-tie antennas (1GHz and 800 MHz). The propagation media was air in this first study and the experimental results are compared with the theoretical estimations. The obtained conclusions are the first step in order to establish the real bounds for the detection capability of these antennas.

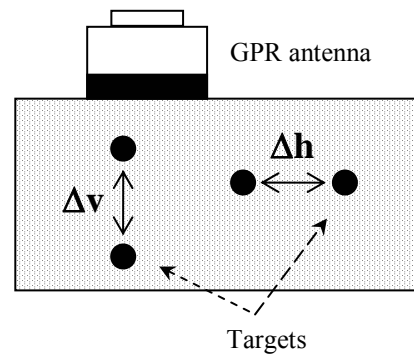
Index Terms— Ground Penetrating Radar, horizontal resolution, vertical resolution, theoretical estimation.

I. INTRODUCTION

One of the main problems related to this technology is that the technical information provided by the different companies is practically nonexistent. Commercially available antennas range from 10MHz up to 4GHz and they have its own transmitting and receiving characteristics and capabilities. In general as the frequency of the antenna increases we get better resolution but on the contrary it diminishes the capacity of penetration of the signal [1]. To perform a suitable data acquisition is indispensable in each case to select the appropriate radar antenna. 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 carrying out a GPR survey. In order to address this problem, numerous studies of different researchers have been contributing to the continuous development of the survey techniques during the last years. In this way, several antenna aspects like influence of the antenna height [2] [3], antenna beam geometry [4] [5], or the polarization scheme adopted [6] [7], have been studied by many researchers. Resolution is also an important subject of matter, and it is of particular interest in civil engineering [8]-[10], where millimetre resolution in both, vertical and horizontal planes, is sometimes required for conducting GPR surveys at an ‘audit’ level.

This paper is part of a 2-year study to characterize and calibrate the GPR equipment we use. In particular the experiments described below have been made to analyze the

resolution capacity of two different RAMAC/GPR shielded antennas characterized by the central frequency of their emission: 1GHz and 800MHz. The study centres on the detection of bars of different materials and thickness within different mediums. The first results of these tests are presented and discussed next.



II. THEORETICAL CONCEPTS

When we are talking about GPR technology, the resolution concept is essentially divided in two parts: vertical (down-range, depth or longitudinal) resolution (Δ_V) and horizontal (cross-range, angular, lateral, or plain) resolution (Δ_H), [1]. In such a way resolution is defined as the radar system capacity to discriminate individual elements in the subsoil, either in thickness or in size.

Vertical resolution allows knowing the equipment sensibility to differentiate in time two adjacent signals like different events [11]. For this type of antennas the vertical resolution mainly depends on the duration of the radar pulse, which is related to the centre frequency of the antenna. The shorter the pulse duration, the better its resolution will be. It is generally accepted that two close events can be distinguished if the targets are separated in time by a time difference of half the effective pulse duration τ_p . This τ_p is obtained from the width of the signal envelope at its -3dB level. Therefore the expected spatial vertical resolution can be calculated from the effective duration τ_p of the radar pulse and the wave propagation velocity v in the medium as follows [12],

$$\Delta_V \approx \frac{\tau_p v}{4} = \frac{\tau_p c}{4\sqrt{\epsilon_r}} \quad (1)$$

This theoretical approach doesn't take into account that the characteristics of the initial radar signal vary as it is spreading. In most of natural materials the attenuation of the electromagnetic waves it increases with the frequency. This low-pass filtered effect within the propagating materials causes an increase in the duration of the pulse and therefore a worse resolution. As the wave spreads it loses its components of high frequency. Even so, in some cases the resolution is approximately independent of this loss: earth materials with significant water content tend to have higher attenuation properties but this characteristic is balanced out with the reduction of the pulse because the wave velocity is slower in wetter materials.

Horizontal resolution indicates the minimum distance that should exist between two reflectors located one next to another at the same depth (parallel to the analyzed medium surface) so that the radar detects them as separate events [13]. The horizontal resolution of any antenna mainly depends on the number of traces/s (or traces/m), the beam width, the radar cross section of the reflector and the depth where target is located. The number of traces/s (or traces/m) is a controllable factor that operator can adjust before data acquisition. The beam geometry is different, because it depends on the characteristics of the antenna and the propagation medium [14]. A narrower beam gives a better horizontal resolution. This beam can be approximately considered as the cone of energy that intersects with the reflector surface, illuminating an area that is called antenna footprint. This zone of influence is defined as the area which can contain a second target that can not be uniquely resolved. So that horizontal resolution depends on this footprint size.

Different criteria can be considered to determine it. The area of the footprint fit in with the first Fresnel Zone. In such a way that the diameter of this area can be approximated by [14],

$$\Delta_H = d = \sqrt{\frac{\lambda^2}{4} + z\lambda} \quad (2)$$

Another expression to define the radius of this antenna footprint is proposed by [15],

$$\Delta_H = 2r \quad r = \frac{\lambda}{4} + \frac{z}{\sqrt{\epsilon_r + 1}} \quad (3)$$

In these two equations, λ is the wavelength; z is the vertical distance between the antenna and the reflector surface and ϵ_r is the relative permittivity of the medium. Other researchers define the horizontal resolution as the distance between the half power points of the spatial response of the scatterer at the plane of the surface [1].

$$\Delta_H = 4z \sqrt{\frac{\ln 2}{(2 + \alpha z)}} \quad (4)$$

This approximation takes no account of the antenna beam pattern in either x or y directions. However it indicates that horizontal resolution improves as attenuation α increases, assuming that there is sufficient signal to discriminate the prevailing clutter conditions. This characteristic focuses the radiation footprint.

These three equations are compared later to see which approaches more to the experimental results obtained in the carried out tests.

III. METHODOLOGY

The first measurements were taken with the bars in air. Two wooden structures with ladder shape were designed to be able to separate the bars in steps of 5cm. For the horizontal resolution test these structures were hanged from the ceiling, parallels with the floor, Fig. 2. For the other resolution test they were placed vertically, fixed in a wooden support, Fig. 3. In both cases the antenna was mounted on a trolley that was moved parallel to the structures and perpendicular to bars direction.

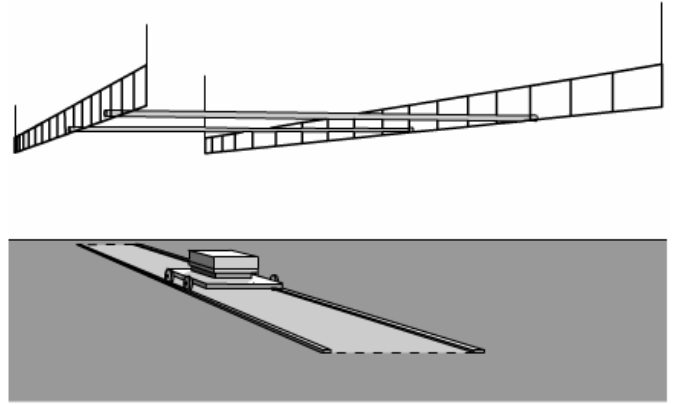


Fig. 2. Horizontal resolution test.

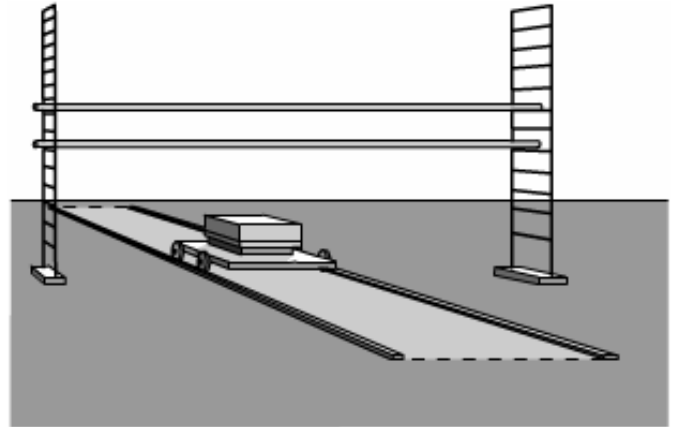


Fig. 3. Vertical resolution test.

Measurements were started with two metal bars placed together and for each new record they were separated 5cm until the bars were clearly distinguishable in the radargrams. The same tests were repeated with wooden bars. Two metal bars of 3cm in diameter and two wooden bars of 4cm width x 2.5cm height were used. These wooden bars were supported on its narrower side for the horizontal resolution study and on

its wider side for the vertical one. All these bars are much longer than wavelength λ_c corresponding to the central frequency f_c of the antennas. Measurements were made at three different heights, one in the far-field region and the other two in the near-field region. Thus the resolution variation can be analyzed as the reflectors move away from the antenna. These heights have been chosen considering the results obtained in (5) that allow us to estimate the edge of the far-field region.

$$d = \frac{2D^2}{\lambda} \approx 3\lambda \quad (5)$$

Where D is the dimension of the antenna, and λ is the wavelength of the pulse. Within the far-field region of the antenna the electric field E and magnetic field H are locally in phase and perpendicular to each other. In the near-field region around the antenna the description of the electromagnetic radiation is more complex. For all these tests (horizontal and vertical), the same stacking (8 scans averaging) and trig interval (1.1cm) configuration was used.

These experimental measurements can be compared with the results estimated with (1) for the vertical resolution and with (2), (3) and (4) for the horizontal resolution. To obtain this data set, some characteristics of the emitted signal must be calculated first. Several registers with the antenna oriented to a metal plate (180cmx180cm) have been made in [16] to be able to analyze its source wavelet. The calculated values are presented in the next table and the source wavelets of both antennas are displayed in Fig. 4.

TABLE I
EFFECTIVE PARAMETERS

| | Effective pulse duration (ns) | Central frequency (MHz) |
|----------------|-------------------------------|-------------------------|
| 1GHz Antenna | 1.2 | 936 |
| 800MHz Antenna | 1.412 | 921 |

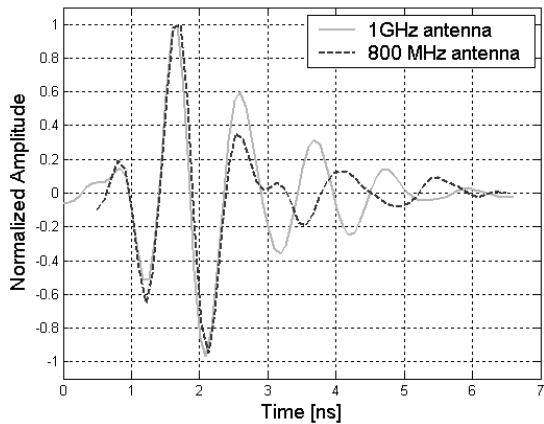


Fig.4 .Source wavelets of the antennas

IV. RESULTS

A. Vertical Resolution

The results are summarized in Table II and III for the 1GHz and 800MHz antennas respectively.

TABLE II
VERTICAL RESOLUTION FOR THE 1GHZ ANTENNA

| | | HEIGHT (CM) | | |
|--------------------------|-------------|-------------|----|-----|
| | | 16 | 63 | 143 |
| VERTICAL RESOLUTION (CM) | Wooden bars | 20 | 20 | 20 |
| | Metal bars | 35 | 30 | 30 |

TABLE III
VERTICAL RESOLUTION FOR THE 800MHZ ANTENNA

| | | HEIGHT (CM) | | |
|--------------------------|-------------|-------------|----|-----|
| | | 16 | 74 | 119 |
| VERTICAL RESOLUTION (CM) | Wooden bars | 20 | 20 | 20 |
| | Metal bars | 35 | 30 | 30 |

It can be seen that the vertical resolution is the same for both antennas and it varies depending on the reflector material. It gets worse as the conductivity of the first reflector increase. This is because the energy of the signal that reaches the upper reflector diminishes and therefore more separation is needed to be able to detect it. The B-scans in Fig. 5 and 6 show the resolution for a height of 16cm.

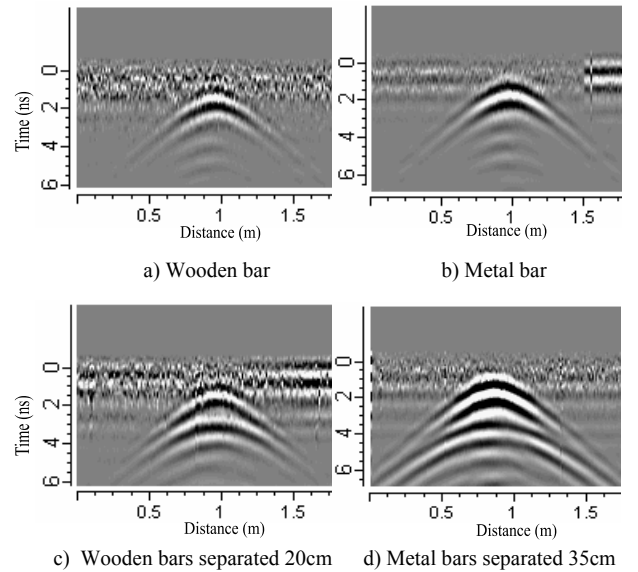


Fig.5. Radargrams of the 1GHz antenna with bars at 16cm height

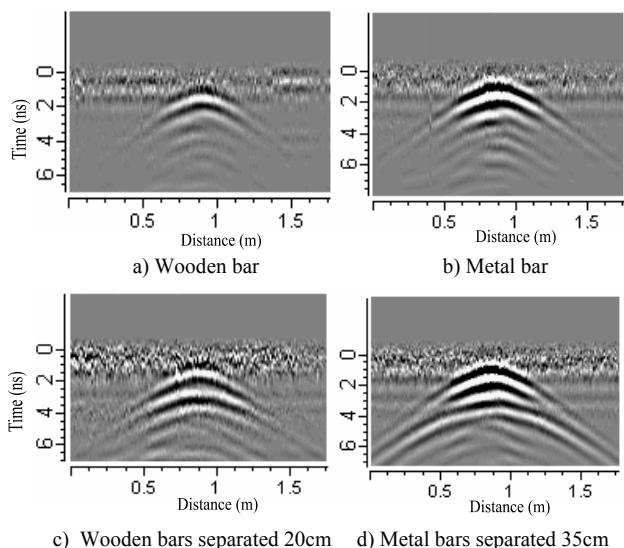


Fig.6. Radargrams of the 800MHz antenna with bars at 16cm height.

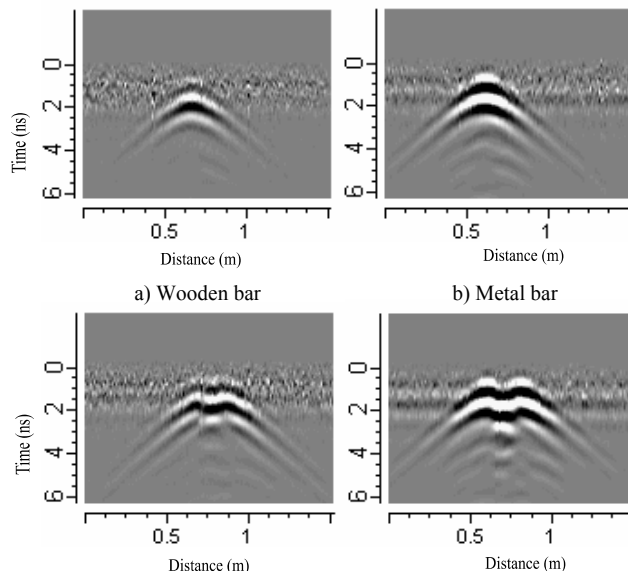


Fig.7. Radargrams of the 1GHz antenna with bars at 7cm height.

The reflected signal of the first bar is stronger in Fig. 5(d) and 6(d) because of the high conductivity of the reflector. This causes that the second reflection is weaker and, as commented previously, a greater separation is needed to recognize them as distinct events.

B. Horizontal Resolution

The capability of horizontal resolution obtained for each antenna is very similar too. The results are summarized in Table IV and V.

TABLE IV
HORIZONTAL RESOLUTION FOR THE 1GHZ ANTENNA

| | | HEIGHT (CM) | | |
|----------------------------|-------------|-------------|----|-----|
| | | 7 | 91 | 147 |
| HORIZONTAL RESOLUTION (CM) | Wooden bars | 15 | 50 | 70 |
| | Metal bars | 20 | 50 | 70 |

TABLE V
HORIZONTAL RESOLUTION FOR THE 800MHZ ANTENNA

| | | HEIGHT (CM) | | |
|----------------------------|-------------|-------------|----|-----|
| | | 7 | 91 | 147 |
| HORIZONTAL RESOLUTION (CM) | Wooden bars | 15 | 55 | 75 |
| | Metal bars | 20 | 55 | 75 |

The resolution is slightly better for the 1GHz antenna and in both cases; it gets worse as the reflectors are moved away from the antenna. In the radargrams (a) and (b) of Fig. 7 and 8, it can be seen the differences of the reflected signal from bars of different materials at 7cm height. As opposed to

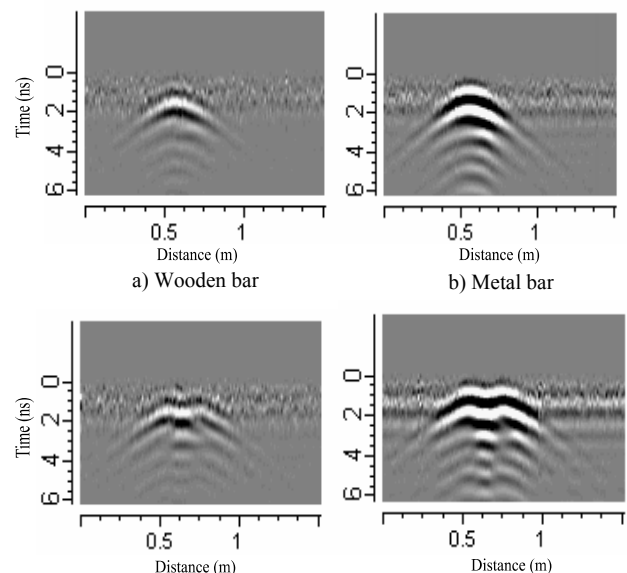


Fig.8. Radargrams of the 800MHz antenna with bars at 7cm height.

vertical resolution, the influence of the reflector material in the resolution is less, because it does not affect so much to the events overlapping. It only seems notable next to the antenna where the hyperbolas are smaller and the wooden bars are distinguished closer.

V. DISCUSSION

The theoretical vertical resolution can be estimated from (1) with the effective pulse duration for each antenna and the wave velocity in air. The results, as it can be seen in Table VI are quite less than the experimental measurements. For the best case, the experimental resolution is twice the estimation one.

TABLE VI
VERTICAL RESOLUTION ESTIMATIONS

| | | VERTICAL RESOLUTION ESTIMATIONS (CM) |
|--------|---------|--------------------------------------|
| 1GHz | Antenna | 9 |
| 800MHz | Antenna | 10.6 |

The horizontal resolution can be estimated with different expressions. Table VII and VIII summarizes the results obtained from (2), (3) and (4) for the three heights (7, 91 and 147cm) selected in these tests.

TABLE VII
HORIZONTAL RESOLUTION ESTIMATIONS FOR THE 1GHZ ANTENNA

| | | 1GHZ HORIZONTAL ESTIMATIONS (CM) | | |
|----------------|-----|----------------------------------|------------------|----------------|
| | | P. Gracia (2) | Conyers/G (3) | Daniels (4) |
| HEIGHT (CM) | 7 | 21.9 | 25.8 | 16.5 |
| | 91 | 56.2 | 144.7 | 214 |
| | 147 | 70.4 | 223.8 | 346 |

TABLE VIII
HORIZONTAL RESOLUTION ESTIMATIONS FOR THE 800MHZ ANTENNA

| | | 800MHZ HORIZONTAL ESTIMATIONS (CM) | | |
|----------------|-----|------------------------------------|-------------------|----------------|
| | | P. Gracia (2) | Conyers/G. (3) | Daniels (4) |
| HEIGHT (CM) | 7 | 22.2 | 26.2 | 16.5 |
| | 91 | 56.8 | 145 | 214 |
| | 147 | 71.1 | 224.2 | 346 |

It can be seen that the values that fits better to the experimental results are the calculated ones from the Fresnel zone expression. With the other estimations, the results are quite different. For the shorter height the results approximate to the experimental data but for the other two heights the estimated horizontal resolutions are more than the triple of the real ones.

VI. CONCLUSION

When choosing equipment for a particular application it is necessary to compromise between resolution, size of antenna, and the ability to penetrate materials. With this work we try to study in depth the characteristics of the equipment and to establish practical limits for the detection capacity of the antennas. For these first tests in air this capacity has turned out very similar for the two antennas under analysis (1GHz

and 800MHz). These results are coherent with the similarity of the effective parameters of its pulses.

The minimum vertical resolution is slightly greater to one half ($\lambda_c/2$) of the central wavelength. This value increases until a distance equivalent to the central wavelength (λ_c) for reflectors with high conductivity. So the theoretical estimation calculated with (1) and the standard practice of using a quarter of the wavelength as the minimum limit for Δv should be regarded as an optimistic recommendation.

As it was expected the horizontal resolution gets worse as the reflectors are separated from the antenna because the footprint area is getting larger. This resolution is slightly better for the 1GHz antenna. The theoretical estimations that fits better to the experimental results are the calculated ones with (2). The other estimations seem to work well when the reflector is next to the antenna but when the separation increases, they under-estimate the actual capability of the antennas to detect the targets.

At the moment, more tests of this type are being carried out in other mediums (concrete, water, sand) and with other reflectors size to compare them with these results obtained in air.

VII. ACKNOWLEDGMENT

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