# The Effect of Air Reflection on Ground Penetrating Radar (GPR) Data

**Ahmed Omran Abdulkareem    Firas Subhi Hameed**
*Iraqi Ministry of Science and Technology*
*Centre of Geophysics And Water Resources*

**Anas Abdulrazzaq Muhammed    Suad Mohammed Ali**
*Iraqi Ministry of Science and Technology*
*Centre of Geophysics And Water Resources*

## Abstract:
Radar surveys aim to find information about the underground bodies and structures. Some of the radar wave energy leaks out above the surface due to unwanted reflections caused by surrounding features at the survey area like buildings, columns, automobiles, trees, …etc. These unwanted reflections mask the radargram and mislead the analyst in the interpretation phase. In this research two types of air reflections were studied for both types of the GPR antennas, the shielded antenna and the unshielded antenna in order to distinguish between real GPR data from false data caused by air reflections.
**Keywords:** *GPR, Shielded Antenna, Unshielded Antenna, Radargram, Relative Permittivity*

## الخلاصة:-
ان الغاية من المسوحات الرادارية هي لإيجاد معلومات عن الأجسام والإنشاءات التي تحت سطح الأرض، غير ان تسرب بعض من الطاقة الرادارية إلى الهواء بدلا من اختراقها سطح الأرض لتنعكس عن الأجسام المحيطة مثل (البنايات، الأعمدة، السيارات، الأسلاك، الأشجار..... ) فتسبب ما يسمى بالانعكاسات الهوائية (Air reflection) والتي تشكل قناعا غير مرغوب فيه يضيف بيانات خاطئة إلى الرسوم الرادارية (Radargram) مما يربك عمل المفسرين في مرحلة التفسير لتلك الرسوم. تم في هذا البحث دراسة نوعين من الانعكاسات الهوائية والتي تظهر بشكل واضح في نوعي هوائيات الـ GPR وهي الهوائيات الغير مغلفة (Unshielded antenna) والهوائيات المغلفة (Shielded antenna)، للتمييز بين البيانات الحقيقية من البيانات الغيرحقيقية الناتجة من الانعكاسات الهوائية.

## Introduction:-
Ground Penetrating Radar is a device that transmits short pulses of electromagnetic energy with pulse duration (1-20) ns with high frequency range (10-2500) MHz to the ground by a transmitting antenna [Sushil Sheena, 2004]. The energy propagation speed through the ground depends upon dielectric constant of the medium [Sushil Sheena, 2004; Sabbar Abdullah, 2008]. When the radar waves encounter an interface between two different materials (layers) with different refraction indices, some of the transmitted wave energy is reflected back to the surface. A receiver picks up these reflections as analogue signals. The input analogue signals are digitized and quantified using an analogue-to-digital converter in order to be ready for processing in the computer to create an image called the radargram. (Fig.1, 2, 3) [Sushil Sheena, 2004; Sabbar Abdullah, 2008; Hannu Luodes,2008].

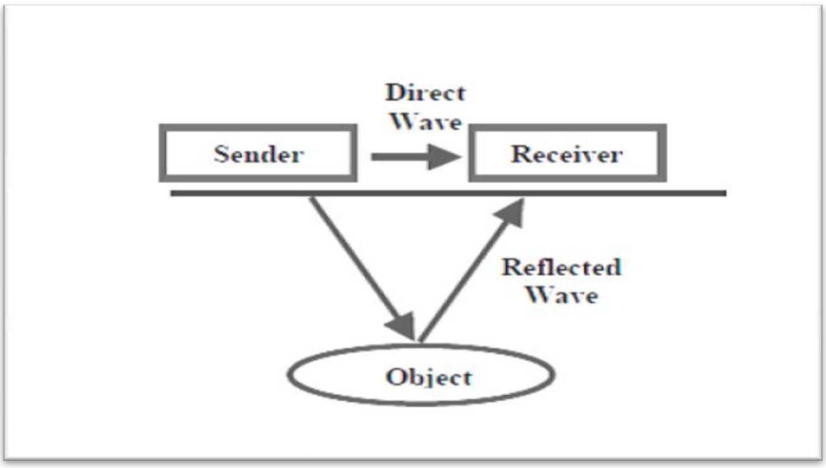


Figure 1: Illustration of different paths of reflection of radar waves

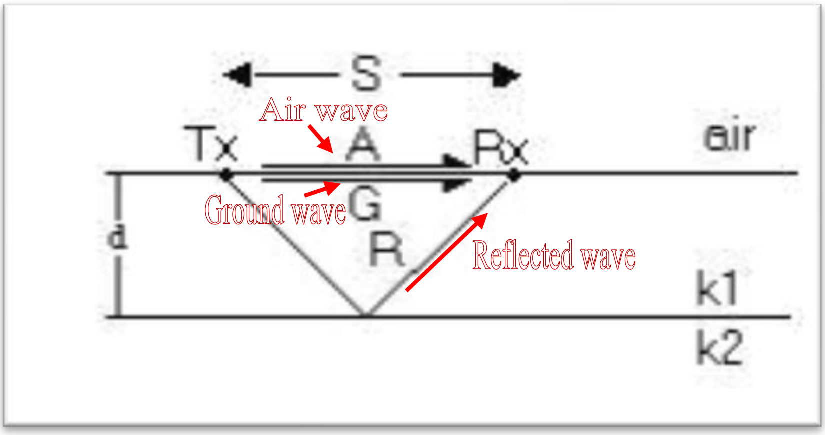


Figure 2: Illustration of the behavior of the radar waves from the beginning of transmission (Tx) until it is received by receiver antenna (Rx). Where A is an air wave, G is a ground wave, R is a reflected wave, S is the separation between the transmitter and the receiver antennas and k1, k2 are the refraction indices of the two media [ Sabbar Abdullah, 2008].

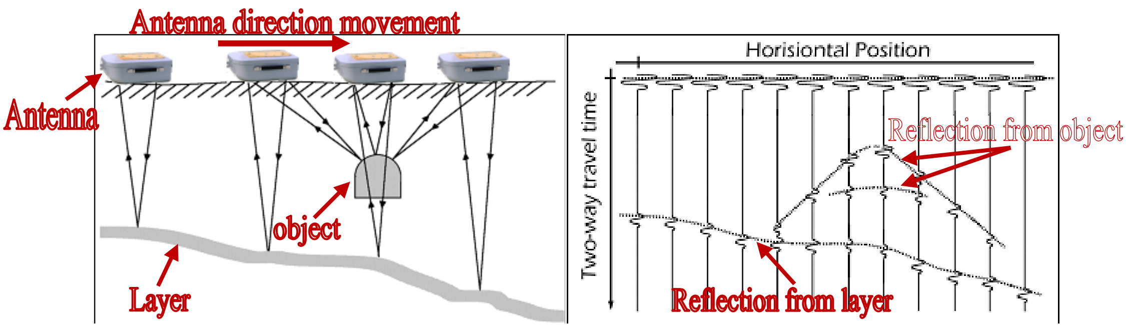


Figure 3 illustrates the principle of ground penetrating radar detection. It shows clearly that the radar wave is reflected by the buried object (on the left). The results recording are show on the right. [Hannu Luodes,2008].

The difference in media of the underground changes the phase angle and the amplitude of the radar waves which appears as sharp edges on the radargram [Sushil Sheena, 2004]. Upon receiving the reflected signals from the ground, an analog-to-digital converter is used to digitize these signals with time and store them as radar images or radargram [Bernth Johansson, 2005]. Knowing the type of the media in which the electromagnetic wave is moving is necessary to predict the depth of penetration because it is related to the dielectric constant of the media using the following relation:

$$v_m = \frac{c}{\sqrt{\varepsilon_r}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (1)$$

Where $C$ is the speed of the light in a space $\varepsilon_r$ is a dielectric constant of the medium, $v_m$ is a radar wave speed. We can determine the depth of the body using the following relation:

$$d_r = \frac{v_m t_r}{2} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where $d_r$ is the depth of the body, $v_m$ is a radar wave speed; $t_r$ is the travelling time of the radar wave [Sushil Sheena, 2004; Bernth Johansson, 2005]. The depth of penetration of the radar wave is also dependent upon both the frequency of the wave and the electrical properties of the media. The higher frequencies used, the lower depth is achieved. However, using high frequencies is usually accompanies with high resolution of the radargram and vise versa [Annan. A. P, 2004]. The best penetration is achieved in high resistivity media. Low resistivity media on the other hand attenuate the signals which results in low or shallow penetration [Bernth Johansson, 2005; Jorge Luis Porsani, 2007].

For the available frequencies (10 – 2500) MHz the penetration of the GPR signals is about (less than 1meter up to tens of meters). The most effective parameter on the depth of the GPR signals is the resistivity of the media. Even with low frequencies the signals may reach less than one meter if the medium was a low resistivity one [Sushil Sheena, 2004; Sami Eyuboglu, 2004], because only the electric component of the electromagnetic wave reacts with the medium of penetration. Hence, the electrical properties of the medium are the most important in determining the attenuation effect of the medium on the EM wave. (fig.4) [Sushil Sheena, 2004; Bernth Johansson, 2005; Kun Fa Leeabc, 2009].

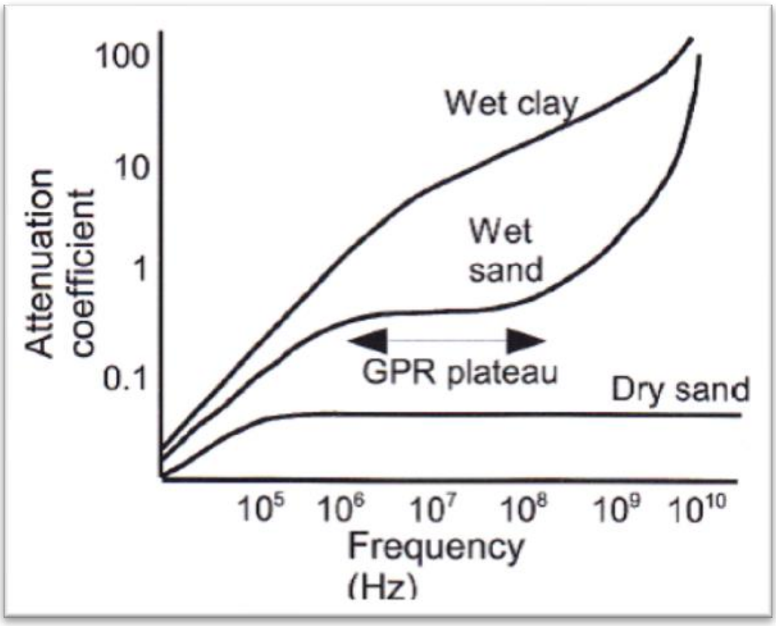


Fig.4: Illustrates the attenuation coefficient of the radar wave as a function to the frequency into the wet and dry media [Bernth Johansson, 2005; Kun Fa Leeabc, 2009].

The depth of penetration of the radar wave can be determined in different media by using the relation:

$$D = \frac{35}{\sigma} \text{ (meter)}. \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (3)$$

*D* is a penetration depth (meter); $\sigma$ is an electric conductivity of the mediums [Bernth Johansson, 2005]. See table 1.

| Material | Typical Relative Permittivity | Electrical Conductivity, mS/m | Velocity, m/ns | Attenuation, dB/m |
|---|---|---|---|---|
| Air | 1 | 0 | 0,30 | 0 |
| Distilled Water | 80 | 0,01 | 0,033 | 0,002 |
| Fresh Water | 80 | 0,5 | 0,033 | 0,1 |
| Sea Water | 80 | 3000 | 0,01 | 1000 |
| Dry Sand | 3 – 5 | 0,01 | 0,15 | 0,001 |
| Saturated Sand | 20 – 30 | 0,1 - 1,0 | 0,06 | 0,03 - 0,3 |
| Limestone | 4 – 8 | 0,5 – 2 | 0,112 | 0,4 – 1 |
| Shales | 5 – 15 | 1 – 100 | 0,09 | 1 – 100 |
| Silts | 5 – 30 | 1 – 100 | 0,07 | 1 – 100 |
| Clays | 5 – 40 | 2 – 1000 | 0,06 | 1 – 300 |
| Granite | 4 – 6 | 0,01 – 1 | 0,13 | 0,01 – 1 |
| Dry Salt | 5 – 6 | 0,01 – 1 | 0,13 | 0,01 – 1 |
| Ice | 3 - 4 | 0,01 | 0,16 | 0,01 |

Table 1: Illustrates electromagnetic wave speed, electrical conductivity, attenuation coefficient of the signal and the typical relative permittivity to the different media [Bernth Johansson, 2005; Kun Fa Leeabc,2009].

**Field Experiments:-**

We made many radar scans in different locations in Karbala city using the high frequency shielded antenna (800MHz) to detect the pipes and cables. The low frequency unshielded antenna (50MHz) is used to detect voids and fractures. It can also be used to detect the underground water table. The equipment used was the Mala Geoscience RAMAC GPR system, Sweden. The interpretation software used was *Reflexw* from Sandmeier software, Germany.

**Results and Discussion:-**

In this research, two types of air reflections were studied, the first occurs because of the reflection of the secondary electromagnetic waves that are transmitted from the transmission antenna by some bodies on the surface through the air medium only, (fig.5. No.1). The second air reflection occurs because of the reflection of the main electromagnetic waves that are transmitted from the transmission antenna by some bodies on the surface through a different media. (fig.5. No.2, 3).

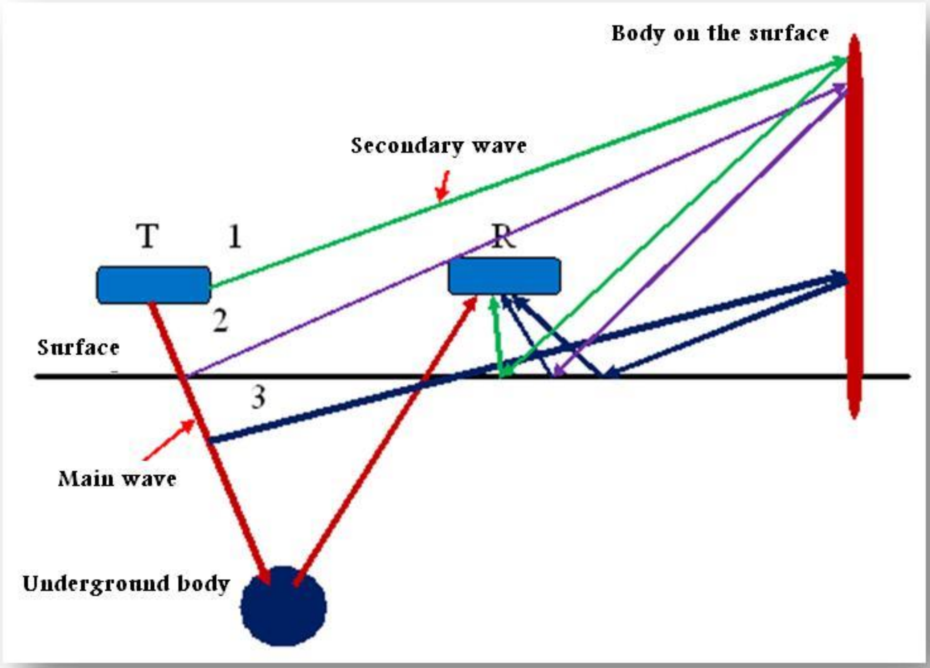


Fig.5: A schematic illustration for the path of the radar wave from the beginning of transmission until it is received by receiver antenna.

The first type of air reflection can be reduced by covering the shielded transmitting antenna by a high absorption material. But the second type of air reflection cannot be reduced this way because this radar wave is the primary one. In (fig.5) the radar wave that is transmitted into the ground was reflected by the surface through the air medium and then it was reflected by the near-body before being received by the receiving antenna. (fig.5. No.2). The radargram shown in (Fig.6) illustrates the two types of the air reflections. In this figure, a body at a depth of 3m, and two bodies at a depth of 8m were detected. In fact, this interpretation is incorrect, because when a hyperbola was fitted (by used Reflexw program) to determine the wave speed in this medium; it gave a signal speed equals to 0.3m/ns. This speed is the same as the radar wave speed through the air, see (table 1); therefore, these hyperbolic shapes are in fact air reflections from bodies above the surface and not underground bodies. The hyperbolic shape of the radargram at 3m depth is a reflection from a car stopped off-side the road while the antenna was moving in a parallel direction with the car. This means that the radar wave has travelled through the air only. This can be proved by calculating the distance between the antenna and the car using the relation (2):

$$d = v \times t$$

Where $v$ is a radar wave speed through the medium, $d$ is a distance that radar wave travelled from the beginning of transmission until it is received by receiving antenna, or twice the distance between the GPR device and the body (car), $t$ is a time of the radar wave from the beginning of transmission until it is received by receiver antenna. From the radargram (fig.6) $t$ = 40ns, $v$ = 0.3m/ns, $d$ will be 12m, therefore a distance between the GPR and the car is 6m.

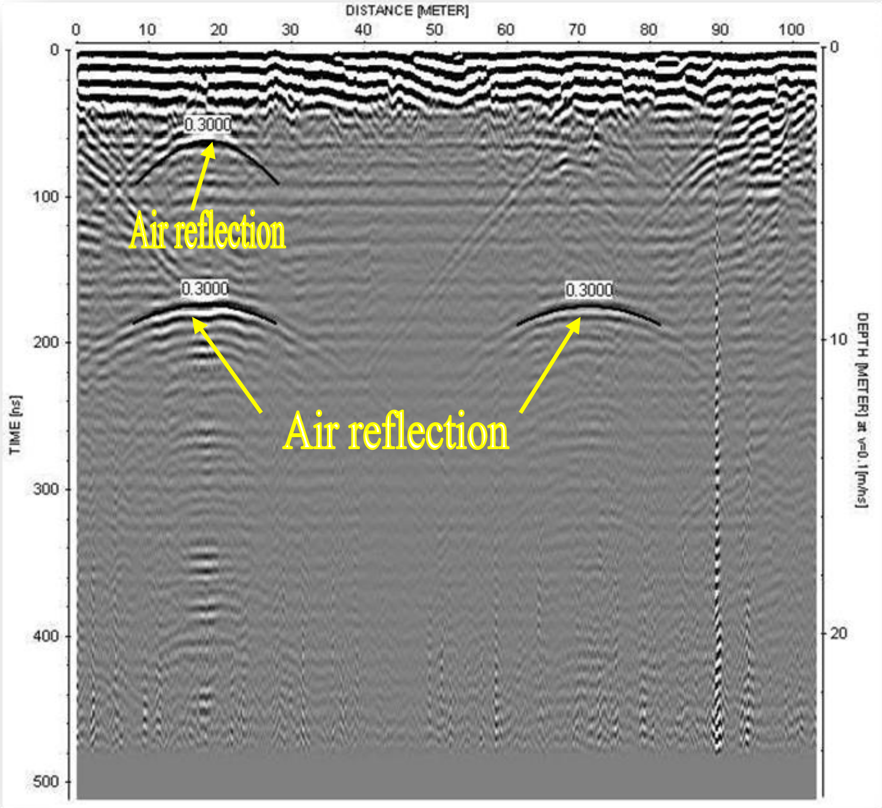


Fig.6: A radargram for one road in Karbala city (around Al-Hussain Mosque) illustrate the air reflections of the RADAR waves from the placed bodies beside the road (for example cars) by used unshielded antenna (50MHz).

The radargram illustrated in Fig.7 belongs to radar scans that were made in a location where the ground consisted of two layers, the first is an Alabaster and the second is a concrete. The scan was conducted in parallel with many metallic bars mounted above the ground and near the antenna used. These hyperbolae can be misinterpreted as 1.2m depth pipes. However, after processing this radargram with Reflexw software, these hyperbolae were in fact metallic bars mounted on the surface near the inspection site because the speed of their waves was 0.24m/ns which is the average wave speed in both the underground layer and the air. The radar signal had penetrated a few centimeters underground before it was reflected back up to the surface and hit the metallic bars. This path has led to this misinterpretation. This type of air reflection matches path No.3 in figure 5; the path of the wave was through air then ground media. We can proof this by using relation (2), which can be rewritten to the form:

$$v_{av} = v_g + d / t$$

Where $v_{av}$ is the average wave velocity through the ground and air media, $v_g$ is a wave velocity through the ground, $d$ is the distance that the radar wave has travelled from the beginning of transmission until it is received by receiving antenna, or it is twice the distance between the antenna and the body, $t$ is a time from the beginning of transmission until the reception of the radar wave by receiving antenna.

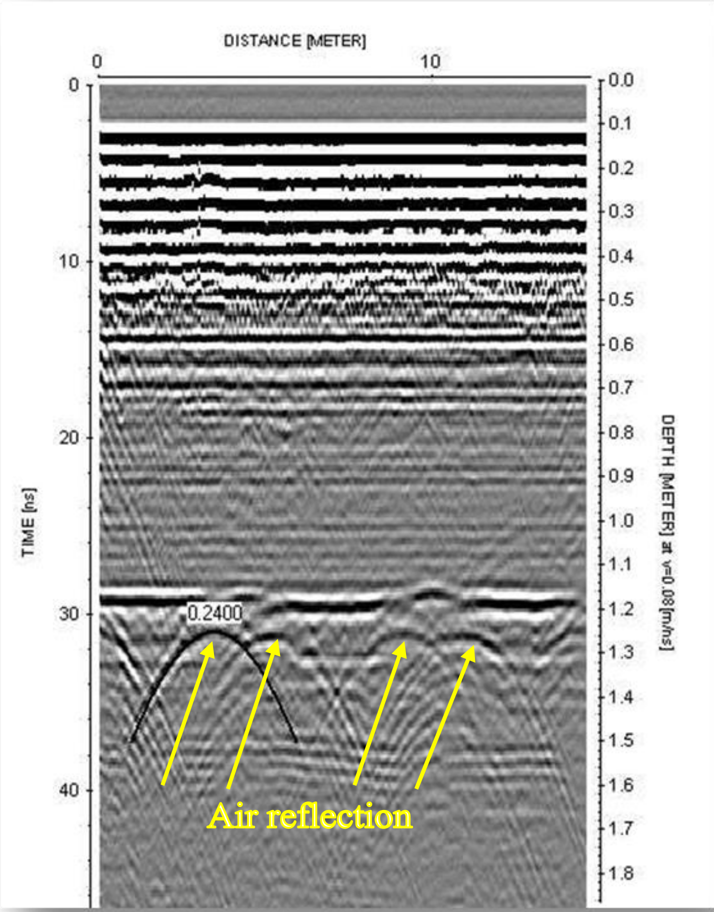


Fig.7: represents the radargram for a location in Karbala city (the ground consists of alabaster and concrete layer next). Many air reflections from bodies near the location of measurement (many of metallic poles) clearly appear. 800MHz shielded antenna was used.

From the radargram results above we find that $V_{av}$ = 0.24m/ns and $t$ = 30ns, the distance between the antenna and the nearest metallic pole is 1.5m, by using the above relation, we find that $v_g$ = 140m/ns which is a velocity of the radar wave through the concrete or granite. This gives a proof that the radar wave has penetrated the ground before reflecting back to the air.

The radargram illustrated in (fig.8**)** belongs to a radar scan conducted in a wet agricultural location. As seen there are two air reflections resulted from the surrounding buildings. The first air reflection (the upper one) is caused by moving the antenna away from the wall of the building near by. At the same time it moves towards another building wall which caused the second air reflection (the lower one). This type of air reflection matches reflection No.3 in (fig.5). The wave has travelled through the ground then the air media. The velocity was 0.17m/ns. We can proof this by using the same former method.

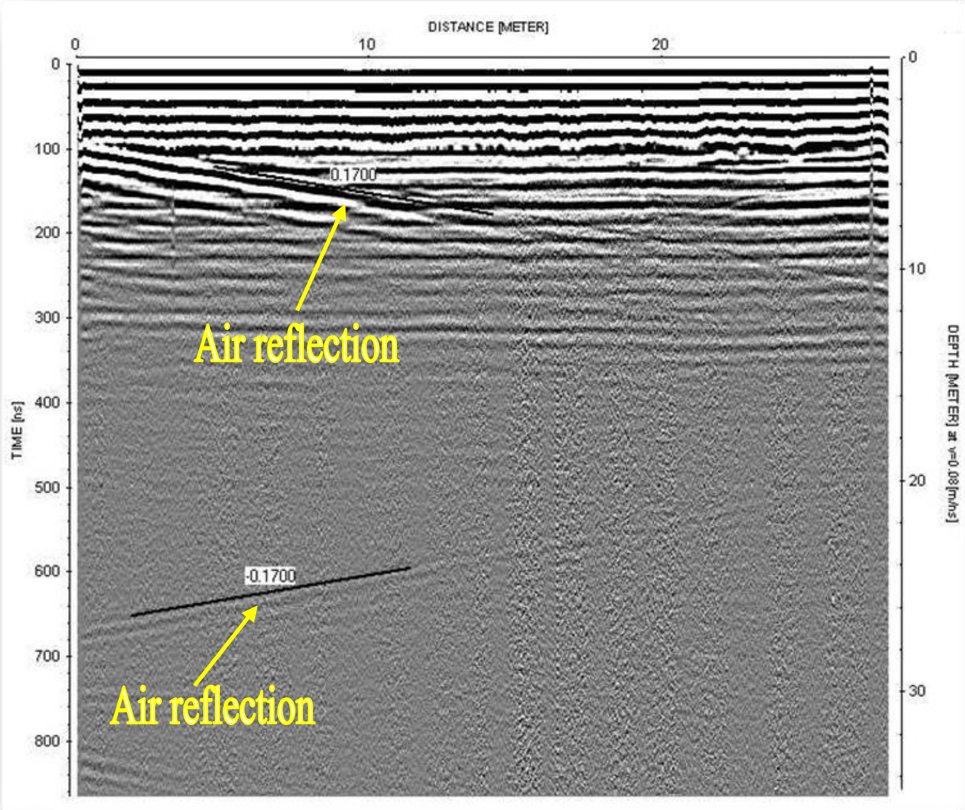


Fig.8: Is the radargram for an agricultural site. It illustrates two air reflections from surrounding bodies (buildings). The measurement was done using 50MHz unshielded antenna.

This air reflection is caused by the motion of the radar wave through a transition layer between two media which lies few centimeters down the surface. At this layer some of the radar wave energy is reflected from the interface (the dry site and the wet site of the agricultural ground) upward because of the large contrast of the radar wave velocity in the two media.

**Conclusion:**

1- The air reflections depend on two factors, the electric conductivity of ground, and the type of the antenna used (shielded or unshielded).
2- Air reflections are the source of the noise on the real data (the radargram).
3- GPR method doesn't work near residents (buildings, poles…), specially when the unshielded antenna is used.
4- Putting the antenna with touch at ground surface heavily reduces air reflection effects on the data.
5- To distinguish air reflections from real data, the interpreter should fit the suspected reflection (hyperbola or straight line) to determine the EM wave velocity through the medium. If it was calculated to be within (0.17-0.3m/ns) then it might be an air reflection.
6- The signal of air reflection is stronger than a real object reflection.

7- If the antenna moves in parallel direction with the body on the surface then the air reflection shape is a hyperbola, if otherwise the antenna moves towards (or away from) a body on the surface then the air reflection shape is a slope line.
8- Air reflections appear more often at radargrams when using an unshielded antenna than if shielded antenna is used.

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