An Italian experience on stepped frequency GPR

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Abstract

In the framework of ARCHEO, a national research project funded by the Italian Ministry for Universities and Scientific and Technological Research (M.I.U.R.), a ground penetrating radar (GPR) has been developed by the Italian Consortium for Research on Advanced Remote Sensing Systems (CO.RI.S.T.A.). The system has been designed to meet archaeological requirements and it has been conceived and realized as a stepped frequency UWB radar working both in gated and ungated mode. This paper either underlines and summarizes new aspects related to this system and shows the main results obtained during data acquisition campaigns.

Introduction

It is well known that the capability of electromagnetic waves to propagate beyond the physical discontinuities of propagation media makes it possible to exploit them to investigate internal features of dielectric bodies. From this property, an endless number of practical applications have been arisen, ranging from medical prospecting to detection of mines, nondestructive testing of industrial items and GPR applications. In this paper we are concerned with archaeological prospecting by making use of the GPR system realized by CO.RI.S.T.A. in the framework of a research project (ARCHEO) funded by the Italian Ministry M.I.U.R. [1].

The choice of a stepped frequency GPR (SFGPR) has been adopted for this system, because the several advantages with respect to the traditional impulsive GPR systems, that have been witnessed since the seventies and up to now [2]. The realized GPR system can work both in ungated and gated mode [5]. This is in order to have at disposal both the possibility to reduce the coupling between the transmitting and receiving antennas offered by the gated mode and, if needed, the greater dynamic range of the ungated mode. The radar is equipped with a positioning system [3-4] able to move independently the antennas without any human effort: this can someway decrease the relevance of the weight and of the compactness of the system. The movement of the antennas is fully programmable in order to gather data automatically in several configurations.

The system realized was a prototype devised to experiment new possibilities in GPR prospecting rather than to be itself a new commercial system. In other words, the emphasis of the project ARCHEO has been on the combination of a plurality of techniques for discovering and recognizing archaeological finds rather than on the implementation of a particularly compact device.

Description of the system

The circuital scheme of the SFGPR is given in Figure 1 and the main system parameters are shown in Table 1. Basically the system uses a conventional heterodyne receiving scheme where the key point is the use of a synchronization chain derived by the transmitted and received signals itself. In this way we solve the problem of having a precise time reference for sampling the received signal that is, in addition, independent of instrument paths and errors.

The main body of the system includes two commercial synthesizers that generate RF tones with a "spectral distance" of 1 MHz in ungated mode and of 101 MHz in gated mode. The intermediate frequency (IF) signal is at 1 MHz and, therefore, a 100 MHz coherent oscillator (COHO) oscillator is required along the receiving chain in gated mode. This choice reduces the effects of flicker noise [6] at low frequencies. The digital attenuator along the transmitting chain (see Figure 1) allows to compensate the fluctuation of amplitude vs. the frequency introduced by the system within the band of interest, and allows to shape the synthetic pulse within the frequency domain according to a "mask" programmed by the user. A power amplifier provides a high power signal (up to about 10 W) to the antenna feed point. The 3 MHz clock of the analog to digital-converter (ADC) is obtained from the 1 MHz signal at the output of S2 filter (see Figure 1) by means of harmonic distortion and filtering performed within the timing block of Figure 1. An HP E1437A ADC performs the sampling with a resolution of 23 bits. The converter also demodulates the signal providing the in-phase and in-quadrature components. When the system works in gated mode, the transmitted and received signals are gated "on" and "off" by means of fast GaAs FET switches driven by an Altera's gate array. The minimum length and the repetition time of the pulses depend on the frequency of COHO that drives the Tx and Rx switches (see Figure 1). The gate array allows setting any duty cycle matching the constraints mentioned above.

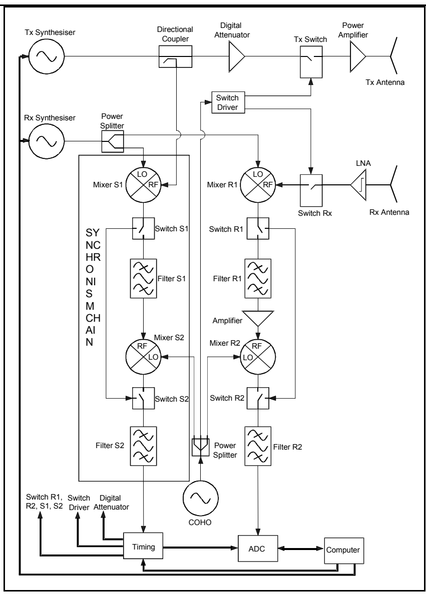

Figure 1. Block diagram of the system

Table 1. Main system parameters

Transmitted frequency range	100-900 MHz
Synthesizers frequency range	10kHz-1 GHz
Synthesizers frequency resolution	0.2 Hz
Synthesizers output power level	-137-13 dBm
Synthesizers power resolution	0.1 dB
Synthesizers max. switching time	15 μs
Synthesizers max. number of steps	8192
Length of a single step	10 μs up to 10 s
Intermediate frequency	1 MHz
COHO frequency	100 MHz
Resolution of the ADC	23 bit
Dynamic range of the ADC	> 100 dB
Max. sapling ratio of the ADC	20 MHz
Power at the antenna feed point	Up to 10 W
Band of the filter R1	2 MHz
Band of the filter R2	25 kHz
Band of the Filter S1	12 MHz
Band of the Filter S2	140 kHz

The antennas consist of two-arm log-spiral radiating elements. They are nominally circularly polarized in the “broadside” direction [7]. Therefore, in order to detect a wider class of targets, the GPR system can be easily configured to work with two antennas with either the same or opposite polarization.

The positioning system has a size of 320x320 cm and a highness of 1 meter, but it is reducible in case of particular conditions during the measurement campaign. Its main structure is similar to a mobile bridge with two sliding points. Each antenna can move along an axle by a rack. The axle itself can move within a horizontal plane by two further racks. A pulley can move up and down the antennas. All these movements are driven by stepped motors, via LABVIEW. The precision in the placement is of the order of 1 cm (the dimension of the teeth of the racks) that is an order of magnitude littler than the minimum wavelength expected in the soil (in correspondence of the frequency of 800 MHz).

Outdoor tests in a controlled site

Outdoor tests on the GPR in a controlled site, have been performed after laboratory tests [4]. In order to calibrate the system and assess its performances, a dedicated outdoor test facility has been realized. In the framework of an agreement with the Italian Aerospace Research Centre (C.I.R.A.) located in Capua (southern Italy), within its establishment, a 25x25 m2 pool with a depth of 5 m has been build up and filled with river sand. Several objects, such as metallic sheets, plastic pipes, and tanks at different depth have been buried as reference targets.

As example, in **Errore. L'origine riferimento non è stata trovata.** the obtained image of a metallic sheet (1x2 m2 wide) placed at 50 cm of depth is shown. In **Errore. L'origine riferimento non è stata trovata.** and in the successive figures, the vertical axis represents the return time, in seconds, with respect to the equivalent synthetic pulse, whereas the horizontal axis is the spatial co-ordinate expressed in index of the consequent positions. In this case, the transmitting and receiving antennas have been moved in linear common offset along the direction orthogonal to the shorter side of the sheet, by keeping a distance of 55 cm between the antennas. This distance has been kept unchanged for all the measurements described in the present paper and it is the result of a trade-off between the levels of the direct antenna leakage and of the received signal. The used frequency band was from 200 up to 800 MHz with a frequency step of 2 MHz. The GPR has worked in ungated mode. No particular signal processing (Conyers et al., 1997) has been applied to the GPR data, apart the mandatory IFFT to get the synthetic pulses from the data gathered in the frequency domain. In spite of this, we can appreciate a very good resolution.

In **Errore. L'origine riferimento non è stata trovata.** the image of the same metallic sheet, but deeper (1.2 m), is shown. Actually, this time the sheet (evidenced by a rectangular frame) appears as a weaker signal with respect to the direct coupling signal between the antennas. This coupling evidences a sort of false layer at the temporal depth of 10 ns wherein a ghost target toward the right hand side is particularly evident. This had not happened with the shallower sheet because the stronger returns from the target covered the coupling signal (the map of colors refers always to a normalized graph). A B-scan in gated mode on the same target has been performed. The result is exposed in Figure 4, wherein the false target due to the coupling disappears. The gated mode has been implemented by considering 10 non-overlapping layers of 10 ns and then by retaining the comprehensive response of the seven deeper layers. This result shows the usefulness of having at disposal both the ungated and gated modes: if the image obtained in ungated mode “generates some doubts” a different image in gated mode might “clarify” these doubts.

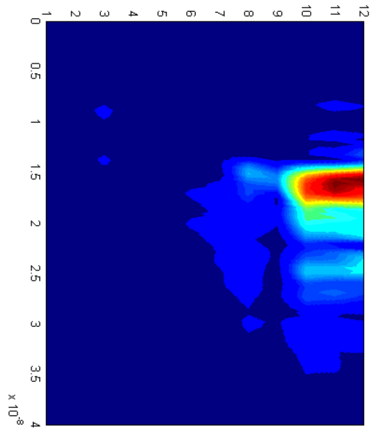

Figure 2. Metal sheet at 50 cm of depth in ungated mode.

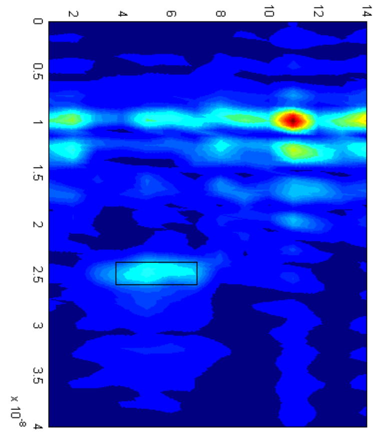

Figure 3. Metal sheet at 120 cm of depth in ungated mode.

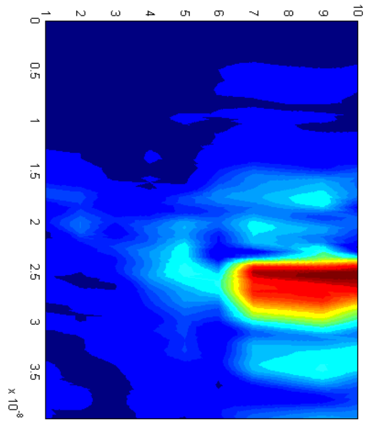

Figure 4. Metal sheet at 120 cm of depth in gated mode.

The archaeological site of Cales

External tests on a real archaeological site, authorized by the Soprintendenza Archeologica di Napoli e Caserta, have been performed with the assistance of archaeologists. The site at hand is constituted by the ruins of the ancient Roman town of Cales, placed in a tufaceous plateau at about 50 Km at north of Naples (Southern Italy). The area of Cales is currently exploited for agricultural purposes and this makes it difficult the enforcement of a proper protection program. Some of the buildings of the ancient town are only partially covered and their structures are partially hidden at a shallow depth.

The GPR has been tested in the neighbors of a theater, whose plant is given in

Figure 5. Excavations performed by the Soprintendenza Archeologica di Napoli e Caserta in the year 1999 brought to light, on the southwest side of this monument, part of a road made with flagstones. This road is labeled with an "S" in

Figure 5. The road has been never thoroughly excavated and, at the moment, we do not know the whole of its path. We have performed some prospecting toward northwest and south along the known part of the path, in order to investigate about the possible directions of its prosecution.

Figure 6 represents one of the B-scans (square A of

Figure 5) performed such as the final positions were in correspondence of the ancient road (depth of about 40 cm). From the intensity of colors, it can be noted how this feature results. An analogous scan has been performed in correspondence of the square B, wherein the other side of the road has been investigated. The results (not reported for brevity) have confirmed the evidences shown for the square A.

Let us now show some results obtained in correspondence of the square C, which is aligned with a hypothetical continuation of the road S along a straight path (prolonged hypothetically beyond the lane S1). A planar scan constituted of 4 parallel B-scans distant 60 cm to each other has been performed. In each B-scan, the data have been gathered in 10 positions, spaced of 25 cm. In

Figure 7 a horizontal slice at the depth of 15 ns is shown: a meaningful signal can be noted on the lower and left side of the image. This makes us to think of a localized reflection. It seems likely that we are not in presence of a planar reflecting structure. In fact, the answer of the instrument is quite different from that obtained in the squares A and B. In other words, the road S does not seem to prosecute along a straight line beyond the current lane S1. In the end, it is likely that also the lane S1, analogously to the cardo maximus, is a current path superposed to an ancient Roman road. However, the veridicality of such a conjecture, and in particular the nature of the reflection put into evidence by

Figure 7, can be clarified only by archaeological excavation.

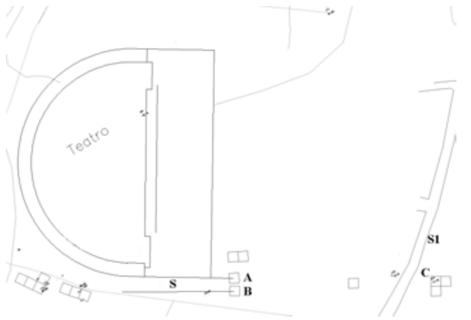

Figure 5. Plant of the area of the Roman theater of Cales.

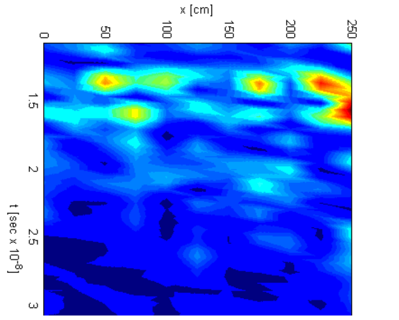

Figure 6. Prospecting in linear common offset on a buried Roman road.

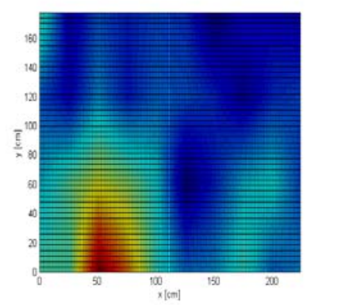

Figure 7. Horizontal slice at 15 nsec outside the theatre area.

Conclusions

In this paper the main outdoor tests performed with a SFGPR system realized by CO.RI.S.T.A. have been summarized. As new aspects, the system can work both in ungated and gated mode and it is equipped with a positioning system able to move automatically and independently the antennas.

The tests have been performed first in a controlled site and then in a real archaeological. The prospecting in the real archaeological site has been performed with the assistance of two archaeologists, and in particular real archaeological questions have been addressed.

Acknowledgments

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