THE ORFEUS PROJECT (OPTIMISED RADAR FOR FINDING EVERY UTILITY IN THE STREET)

Massimiliano Pieraccini, Filippo Parrini

Department of Electronics and Telecommunications
University of Florence, via Santa Marta, 3 - 50139 Firenze, Italy

Gaetano De Pasquale
IDS SpA
via Livornese, 1019 - 56122 Pisa, Italy

Howard Scott
OSYS Technology Ltd.
Ouseburn Building, Albion Row, East Quayside, Newcastle upon Tyne, NE6 1LL, UK

ABSTRACT

The ORFEUS (Optimised Radar for Finding Every Utility in the Street) project addresses the requirement for advanced technologies for locating, maintaining and rehabilitating buried infrastructures and, in particular, it fulfils the requirement for locating buried assets, including the use of trenchless techniques for deploying pipes and cables in an urban environment. The aim of this project is to develop two radars. The first operates on the surface for planning deployment activities; the second (a bore-head GPR) will be installed in the drilling head of Horizontal Directional Drilling (HDD) equipment so that they may avoid collision and possible damage to existing cables and other infrastructure.

Index Terms GPR, CW-SF, DDS, UWB Antenna

1. INTRODUCTION

Society has grown to be dependent on services that are delivered via infrastructure buried in the ground, principally in roadways. The economic and safety implications of damages to these services can be extremely serious.

Ground Penetrating Radar (GPR), amongst the various state-of-the-art available methods, is the only non-invasive technique capable of accurately locating both metallic and non-metallic buried objects, without prior knowledge of their position. However, the performance of present state-of-the-art GPRs, in terms of confidence of the detection, penetration depth and sensitivity to small targets, should be improved to extend the GPR field of application.

Confidence of the investigation results and sensitivity to smaller targets is particularly important in trenchless excavation systems, where it is not possible to identify potential buried object, this increasing the risk of damaging buried infrastructure during the progress of the works.

For this reason the ORFEUS research project was set up in the European Commission's 6th R&D Framework Programme. The Consortium managing the project consists of 8 partners: OSYS Technology Ltd. (coordinator), the European Gas Research Group (GERG), UK Water Industry Research Ltd (UKWIR), Gaz de France, IDS S.p.A, Tracto-Technik GmbH, University of Brno, Technical University of Delft (TUDelft), and University of Florence.

2. TARGETS AND SCENARIO

The majority of buried plant is within 1.5 m of the ground surface: there is a wide variation in size, material, conductivity (metallic or non-metallic) and density (number of utilities for each meter).

These targets may be buried in a wide range of soil types. Moisture can reduce significantly the application of GPR because of high electromagnetic attenuation, while very inhomogeneous materials rise the clutter levels and locally modify the speed of electromagnetic waves.

2. THE STATE OF THE ART

The current market for GPR is dominated by pulse GPR, while CW-SF (Continuous Wave Step Frequency) and chirped radar are mainly used in experimental applications.

A careful technical analysis [1] concluded that, for state-of-the-art impulse radars, penetration depth is limited in

978-1-4244-2808-3/08/$25.00 ©2008 IEEE

about 1m when the soil is highly conductive (e.g. clay with a 50 dB/m two-way attenuation) and a detection rate of about 80% could be expected with a confidence of 90%. In such conditions detection of small (less than 20mm), non-metallic objects beyond a depth of 0.5 metres, is extremely difficult, and GPR application is strongly limited.

3. ORFEUS RADAR SYSTEMS

In order to overcome the current state of the art limitations, ORFEUS project proposes to two radar systems:

1) The ORFEUS BORE-HEAD GPR. During the pipe-laying phase, a miniaturized system installed on the drilling head of the HDD equipment will be able to locate in good time obstacles that may compromise the excavation work.

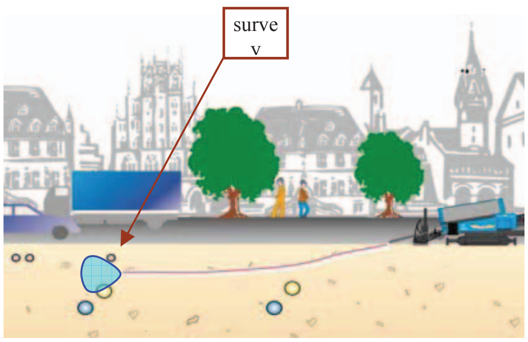

Fig. 1 The ORFEUS Bore-Head radar

Fig. 2 The ORFEUS surface radar

2) The ORFEUS SURFACE GPR. This system will operate from the road surface and will be used in planning phase of the drilling. By implementing a number of innovative technological solutions, it will be able to increase the depth performance by a factor of 1.5 with respect to current state-of-the-art GPR.

The rest of this paper is focused on the ORFEUS Surface GPR.

4. TECHNICAL AND SCIENTIFIC OBJECTIVES OF THE ORFEUS SURFACE GPR SYSTEM

The main scientific and technical objectives, relative to ORFEUS surface GPR, are as follows.

1) to develop a GPR radar system able to enhance the state-of-the art performance by a factor of 1.5;
2) to develop a very fast microwave transceiver so that rapid surveys are possible;
3) to develop an innovative “hardware active background canceller” able to cancel the effects of the soil at the microwave transceiver;
4) to develop an Ultra Wide Band (UWB) antenna with radiation characteristics that enable it to operate in most types of soil.

5. PENETRATION DEPTH

The first design choice is relative to the electronic architecture. The surface ORFEUS radar is a CW-SF system. In principle this class of radar, if compared to pulse radars, can achieve a greater dynamic range and penetration depth. Indeed the CW-SF architecture offers reduced receiver noise, as it operates step by step in very small instantaneous bandwidths (without affecting the possibility to achieve an overall large bandwidth). Consequently, an increase in dynamic range is expected, but this will be at the cost of an huge increase of the design complexity. The critical design issue is the effective exploitation of the theoretical noise rejection capabilities of a narrow-band receiver.

Generally speaking, the detection capability of a GPR system is constrained by a specific scenario. In urban environments, the medium in which plant is buried may be very inhomogeneous, thus producing a high level of clutter. This can be mitigated only by increasing the range resolution, in order to reduce the radiated energy for each single resolution cell. This approach allows an increase in the Signal-to-Clutter ratio, but it requires to increase the overall radar (and antenna) bandwidth.

A unique advantage of the CW-SF design is just its ability to manage very large bandwidth.

The majority of current GPRs have effective bandwidths of some hundreds of MHz. ORFEUS radar will operate from 100 MHz to 1GHz providing a fractional bandwidth of 1.63.

As the average permittivity of soil is about 9, this bandwidth gives a resolution of about 5cm.

6. FAST SCAN

A critical requirement for an effective GPR is the speed of the survey, especially if it requires that the street or the utility being investigated be kept out-of-service .

Unfortunately, CW-SF system is typically rather slow. Nevertheless, the in-field use requires an investigation system able to operate with a scan speed at least 1-2m/s (the speed of a walking man).

CW-SF is slow for two main reasons: the low spectral efficiency and the temporal efficiency of the synthesizer used for sweeping in steps. The first reason, is strictly related to the CW-SF modulation. Indeed, although it operates over large bandwidths, it works step by step on small bandwidths in the order of tens of kHz. Therefore, as the whole bandwidth is about 1GHz, the spectral efficiency is only about 0.005%. A possible solution is to use a number of transceivers simultaneously covering different bandwidths.

Regarding the second point (temporal efficiency of the synthesizer), it should be noted that the detection has to be carried out after the initial transient state. Unfortunately PLL (Phase Lock Loop) systems require a lock time that can be prohibitively long for this application. On the other hand, a DDS (Direct Digital Synthesizer) can change its frequency very quickly. Indeed, the literature reports several applications of DDS in this field [2]. Nevertheless, the DDS signals are affected by a high level of spurs and harmonics [3]. Therefore, DDS can be used without particular precautions only for GPR of low to medium performance in terms of bandwidth and dynamic range.

Since the ORFEUS requirement for penetration depth is particularly severe and it is combined with the need for a very large transmitted bandwidth (in order to reduce the clutter cell), the surface GPR transmitter will employ an innovative architecture based on the use of different typologies of frequency synthesizers arranged in order to accomplish the overall requirement. This system is based on joint use of a battery of PLL synthesizers and a high performance DDS, in order to exploit the very fast hopping speed of this technology. This joint architecture will allow the typical problems of DDS to be overcome: low operation frequency, harmonics and spurs.

7. HARDWARE BACKGROUND CANCELLER

Unfortunately, the penetration capability of this class of GPR is restricted not only by the receiver sensitivity (and thus its noise), but also by its effective dynamic range, because smaller targets can be hidden by artefacts generated by high amplitude signals. The CW-SF radar systems receiver operates in very difficult conditions because a very strong signal is always present due to the phenomenon of radiofrequency coupling between transmitting and receiving antennas. The receiver must be able to operate in the presence of this large coupling signal over a very large bandwidth whilst maintaining a very large dynamic range so that frequency components due to deeper targets may be recovered.

For this last reason the receiver will use two different devices for increasing the dynamic range.

The first one is an Active Background Cancellation (ABC). This subsystem will inject into the receiver chain a signal generated by a vector modulator that will cancel the strong signal caused by the antenna coupling effect. Fig. 3 shows the working principle of the clutter cancellation:

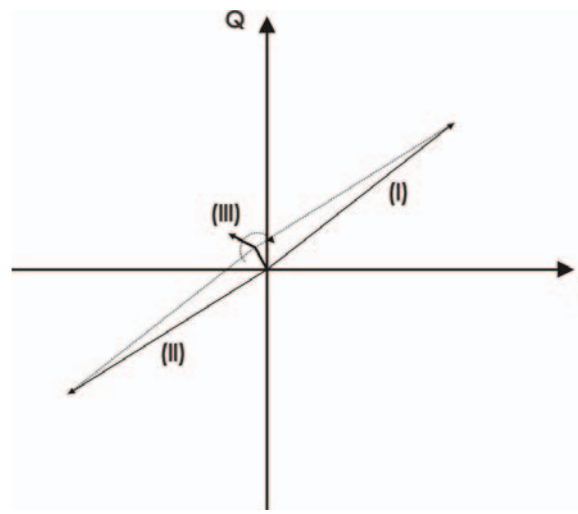

Fig. 3 – Received signal after clutter suppression

Phasor number (**I**) indicates the total signal (clutter, antenna coupling and echo from the useful targets). Phasor number (**II**) represents the signal injected by the ABC vector modulator into the receiver chain with the purpose to accomplish clutter (and antenna coupling) cancellation. The final effect is the phasor (**III**), i.e. the total signal after the cancellation; (**III**) represents the useful signal.

Due to the finite precision of the system, a complete clutter cancellation is not possible, so a small clutter signal has been represented together with phase varying signal. As can be seen, signal (**III**) needs a lower dynamic range of receiver to be correctly demodulated without risk of reaching the saturation.

Fig. 4 shows a possible implementation. As the antenna coupling depends on the *in-situ* measurement conditions, the control of the ABC has to implement some adaptivity.

Currently, we are evaluating the potential impact on performance of a running cancellation algorithm. Its effective implementation is obviously a critical point.

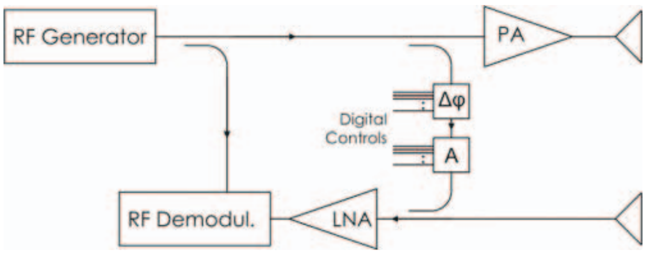

Fig. 4– Phase-Amplitude configuration for clutter canceller

The second technique under development, addressed to increasing the requirements for the receiver dynamic range, is the range gating. The basic idea of range gating is to avoid the transmitter and the receiver to be "on" at the same time. So, for each single tone, the radar transmits a "gated Continuous Wave signal" similar to a modulated pulse train, and the receiver works only in time intervals in which the transmitter is off.

The range gate subsystem will be able to increase the visibility of deep targets by performing a hardware shaping of the range profile, with an effect similar to that of and STC (Sensitive Time Control) in a pulse radar. For this reason the transmitter and receiver modules will be provided with low-jitter, hi-isolation radiofrequency switches adaptively controlled by an integrated logic in order to perform the gating task.

8. THE ANTENNA SYSTEM

The ORFEUS surface GPR antennas system has to meet severe specifications regarding low-frequency operation, broadband characteristics, small volume occupation, and sufficient sensitivity for good signal-to-noise ratio of the radar image.

In principle, CW-SF could be implemented by an antenna system optimized in electronically controlled sub-bands. Nevertheless, this very advanced solution is incompatible with the necessity for the phase response of the antenna, over the whole band, to be kept linear. The calibration of a switched antenna has proved to be a very difficult task. Therefore, the solution we are implementing, is a single bow-tie with conductivity shaped in order to keep its electromagnetic parameters as constant as possible in the presence of variable near-surface ground conditions .

9. THE TEST SITE

A suitable test site is a key factor for evaluating the effective performances of the new instrumentation. Gaz de France manages a very good site that has been widely used in previous development projects [4]. This site will be updated and customized for this specific test, aimed at comparing the ORFEUS instrumentation with commercial equipments.

10. CONCLUSIONS

This paper presents the surface GPR that will be developed within the framework of the ORFEUS project.

The objective of the work is to develop a system able to increase the penetration depth by 50% with respect to pulsed state-of-the-art equipment. This goal requires the complete revision of the current architectural solutions, in order to identify the critical aspects limiting the overall performance.

The project is due to run until November 2009.

ACKNOWLEDGMENTS

The activity described in this work has been carried out for ORFEUS (Optimised Radar to Find Every Utility in the Street) Project. The ORFEUS project is partly supported by the European Commission's 6th Framework Program-Priority (Global Change and Ecosystems), managed by Directorate General for Research under the contract N° 036856 (GOCE) and would not have been possible without the support of the Commission.

REFERENCES

[1] A.M. Thomas, C.D.F. Rogers, N. Metje, D.N. Chapman "A Stakeholder Led Accuracy Assessment System for Utility Location" Workshop on Advanced Grround Penetrating Radar, Naples 27-29 June 2007

[2] R. Ney, S. Bonaime, F. Dolon, D. Nevejans, R. Clairquin, C. Duvanaud, B. Martinat, JJ. Berthelier, VA Ciarletti, Ground penetrating radar for Mars exploration, the GPR experiment on Netlander, HF Radio Systems and Techniques, 23-26 June 2003 pp. 282 – 287

[3] Z. Pipay, Numerical distortion in single-tone DDS, Instrumentation and Measurement Technology Conference, 2001. IMTC 2001. Vol. 2, pp. 720 - 724

[4] G. Manacorda, H.F. Scott, P.D. Loach, J.J. Kazik, D. Pinchbeck, M. Rameil, J. Capdevielle, P. Fournier, The European GIGA project, Proceedings of the Tenth International Conference on Ground Penetrating Radar, GPR 2004, Delft, The Netherland, vol.1, pp.355 - 358