Ground penetrating radar Innovative research for highly reliable robustness/accuracy GAs pipe detection/location

Guido Manacorda
IDS Georadar Division
Equipment Engineering Manager

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STATEMENT OF THE PROBLEM

Reliable utility locating technologies are needed

- ✓ **for better planning routes of new installations**
- ✓ **for choosing the most suitable digging method (excavation, directional drilling, micro-trench)**
- ✓ **for avoiding incidents/damages when digging**

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THE NEED FOR UTILITY LOCATING TECHNOLOGIES

✓ **The cause of many accidents during excavations/DD installations is a lack of knowledge of the subsoil conditions**

✓ **A 36-fiber optic cable can carry up to 870,912 circuits and generate more than $175,000 per minute in revenue**

✓ **In 1993, there were in the U.S. more than 104,000 hits or third-party damage to gas pipelines**

From:

“Utility Locating Technologies: summary of responses to a Statement of Need”

FLCTT Washington, DC

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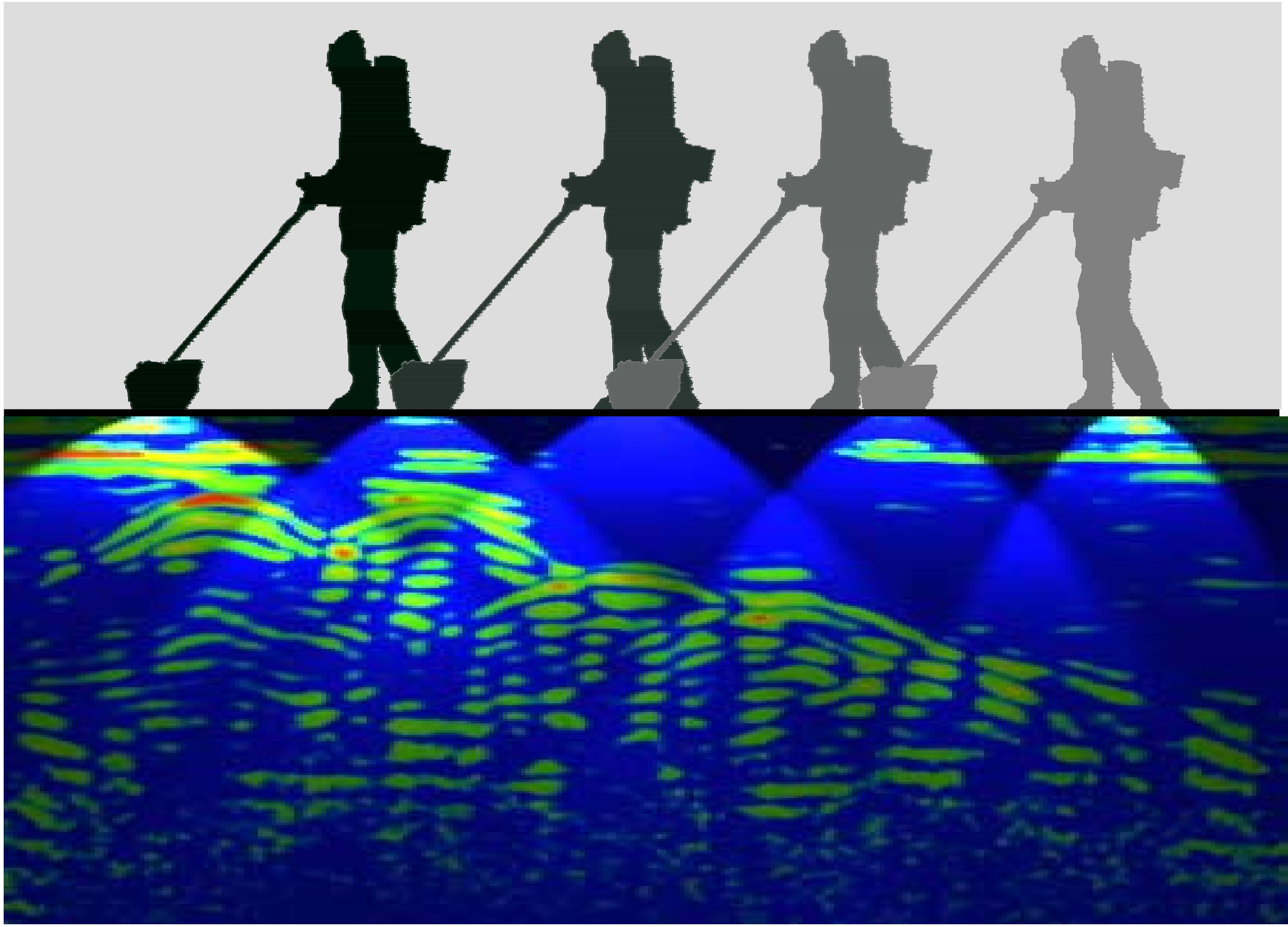
GROUND PENETRATING RADAR (G.P.R)

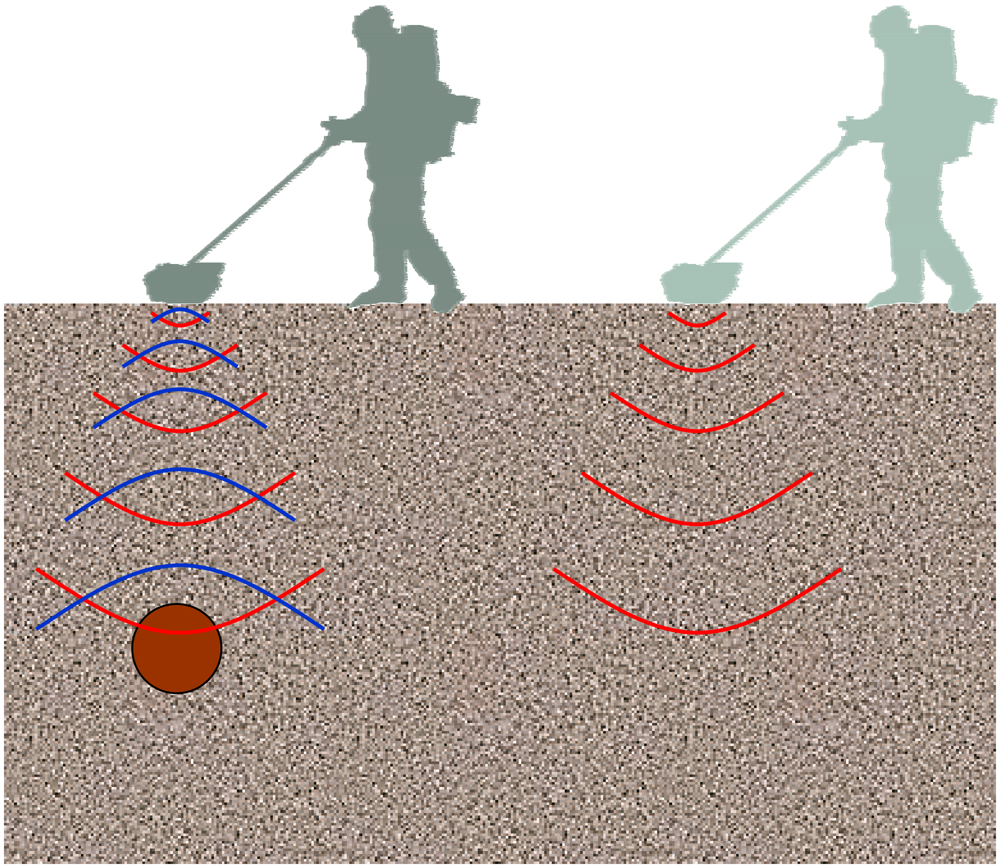
The **G.P.R.** systems are non-destructive survey instruments.

Thanks to the use of electromagnetic waves those systems are able to detect objects and anomalies within materials without interfering with their physical, mechanical and chemical properties.



GROUND PENETRATING RADAR (G.P.R.)

- ✓ The GPR transmits a very short pulse of e.m. energy into the material by a transmitting antenna
- ✓ Energy reflected by discontinuities is captured by a receiving antenna.
- ✓ Depth range & resolution are related to the radar frequency, transmitted power, host material e.m. properties and to the shape and characteristics of the targets.



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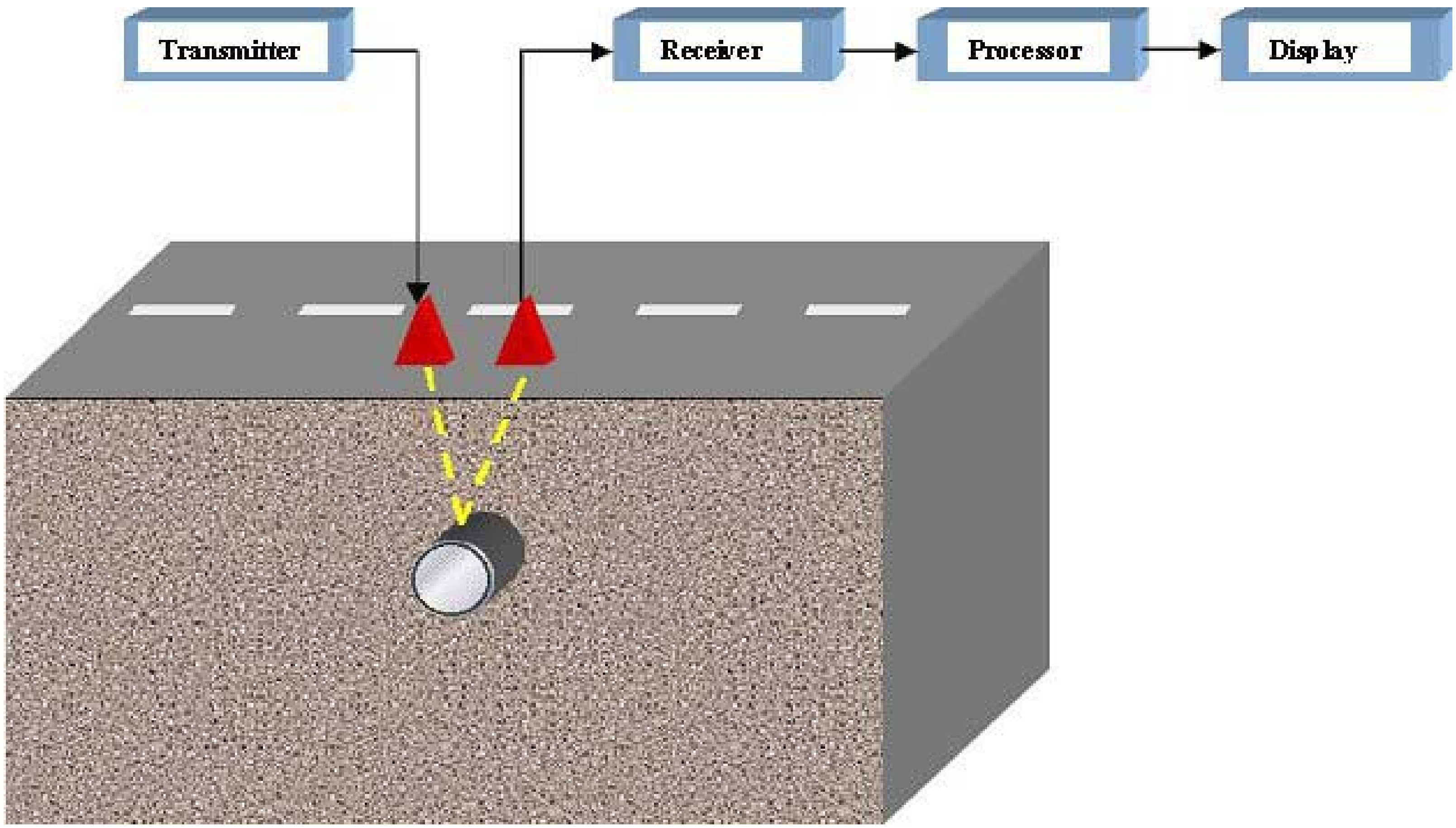
BASIC GPR WORKING SCHEME



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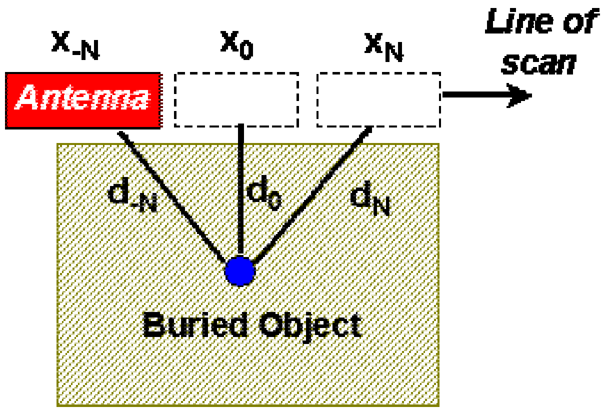
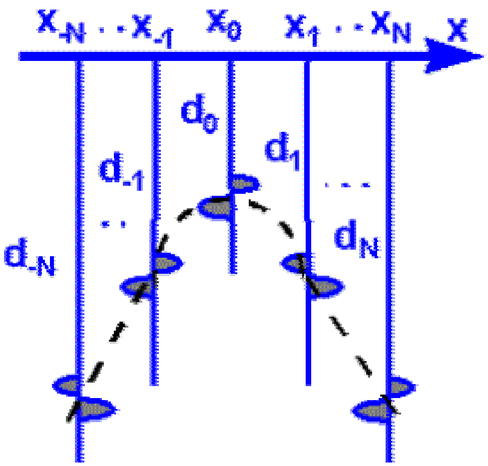
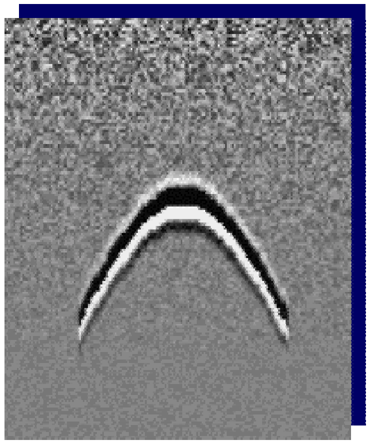
GROUND PENETRATING RADAR (G.P.R.)

GPR is capable of accurately locating both metallic and non-metallic buried objects, without prior knowledge of their position



Acquisition





Radar map

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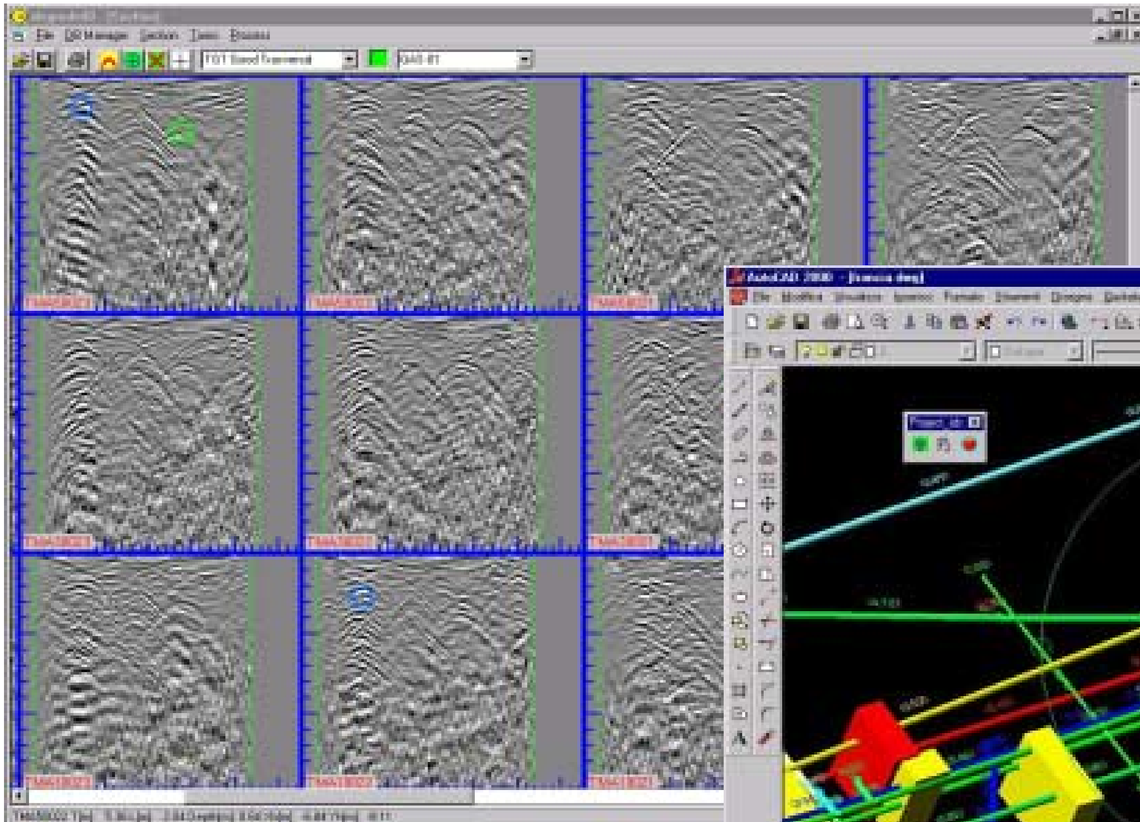
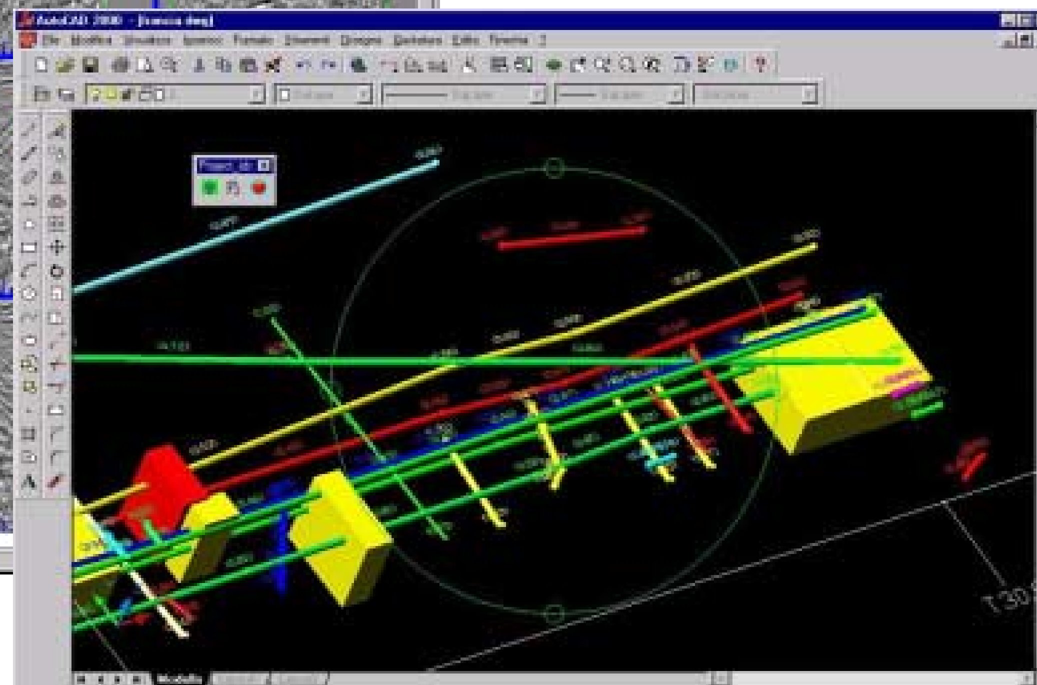
DATA ANALYSIS TOOLS



Multi-channel data visualisation

3D CAD map



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GPR for locating utilities

✓ GPR has proved very attractive, mainly because it is capable of accurately locating both metallic and non-metallic buried objects, without prior knowledge of their position

✓ Poor results due to the limited performance achieved by unsuitable equipment and/or unskilled GPR operators, have made drilling contractors unable to rely totally upon GPR

✓ Surprisingly, current developments in GPR are mainly oriented towards visualization improvement, such as 3-dimensional plots, and GPS positioning, **with no attention paid to addressing the basic radar signal detection problem**

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GIGA PROJECT

- ✓ **GIGA is a research study with the main objective of enabling the design of a novel Ground Penetrating Radar specifically designed to provide the precision and high resolution required for no-dig installation of gas pipelines by means of Horizontal Directional Drilling (HDD)**
- ✓ **The GIGA project is partly supported by the European Commission within the:**

5th Framework Programme for Community Research, Energy, Environment and Sustainable Development Programme

- ✓ **GIGA Value: 3 M€**
- ✓ **Completion date: end of 2003**

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THE GIGA CONSORTIUM

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Gaz de France

GAS

END

USERS

IDS
INGEGNERIA DEI SISTEMI SpA

THALES
AIR DEFENCE

TRACTO-TECHNIK GmbH
SPEZIALMASCHINEN

INDUSTRIES

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GPR EXPERTS

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GIGA Work Plan

Three steps

1. Requirements specification of GPR end-users, also due to a survey of European utilities (gas, water, telecom, electricity, etc.) and European directional drilling companies
2. Gathering and understanding data from the physical phenomena involved, especially in complex situations, for addressing the design of an enhanced GPR system
3. End-user analysis of the new technical solutions

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End-users Requirements

Requirements have been stated in terms of

- ✓ Performances
- ✓ Presentation of results
- ✓ Functionality
- ✓ Construction
- ✓ Environmental
- ✓ Safety
- ✓ Documentation and Training
- ✓ Costs

for the short and the medium-long term developments

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Design of an enhanced GPR

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Current G.P.R. Technology

End User requirements

Design of the short-term GPR

Bottom-up approach

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Study of the physical phoenomena

End User requirements

Long-term research

Top-down approach

The reference test site

- Gaz de France has established a unique trial area for buried network detection, in order to be able to conduct methodical tests of all of the relevant existing sub-surface imagery devices

- This area includes five different grounds and a selection of metal and plastic pipes of various diameters, are buried at various depths and in various configurations: it allows to evaluate performances in terms of
  - ✓ detection
  - ✓ accuracy of location in the Horizontal plane
  - ✓ accuracy of location in the Vertical plane
  - ✓ penetration depth
  - ✓ resolution of multiple objects in the Horizontal plane

The reference test site

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Reference measurements executed by IDS

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Reference measurements performed by Thales AD

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Assessment of the state of the art

- ✓ Trial performed in the Gaz de France test site allowed an assessment of the performances nowadays achievable
- ✓ IDS GPR performed as follows:
  - Detection rate: 83%
  - False alarm rate: 0%
  - Penetration depth (best case): 4 mt
  - Penetration depth (worst case): 1 mt
  - Vertical acccuracy: 28.7 mm (rms)
  - Horizontal accuracy: 25.4 mm (rms)
  - Resolution in the horizontal plane: 280 mm (at 1 mt depth)

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Performance analysis summary

- ✓ By analysing these results, it follows that two important issues need to be addressed
  - ➢ penetration depth (when the soil is highly conductive)
  - ➢ detection of small diameter plastic pipes (∅ ≤ 20 mm), particularly where the ground consists of high-conductive material and when deeper than 0.5 mt
- ✓ Other performances are very close to meeting the requirements

Design of the short-term GPR

Basing on the analysis of performances shown by current systems, the design of a new GPR was executed for allowing:

- ✓ **Bandwidth extension to cover the frequency range 150MHz to 2GHz (multi-frequency approach)**
- ✓ **Improvement of the dynamic range and coupling of energy into the ground due to a suitable design of the antenna/receiver**
- ✓ **Reduction of the dependence upon operator skill and knowledge thanks to advanced data processing tools (3D migration and automatic detection)**
- ✓ **Link to a GIS**

Moreover, polarisation techniques will be investigated for "extracting the features" from GPR data.

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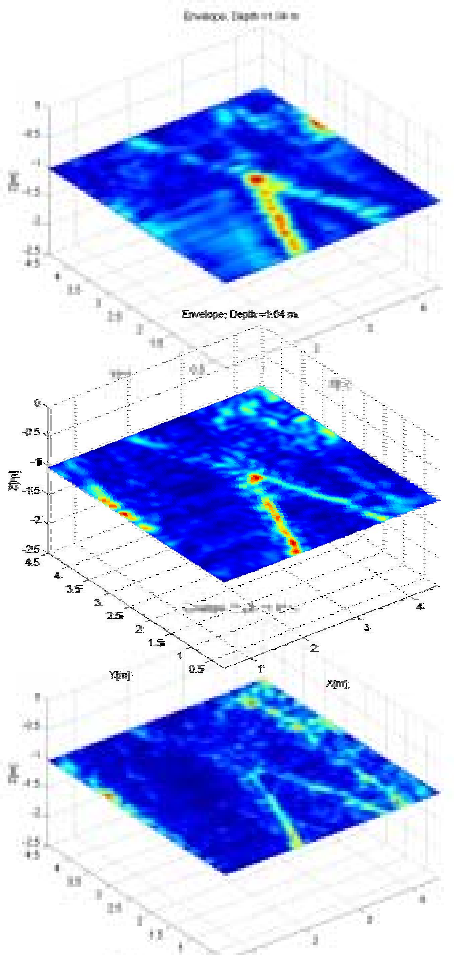

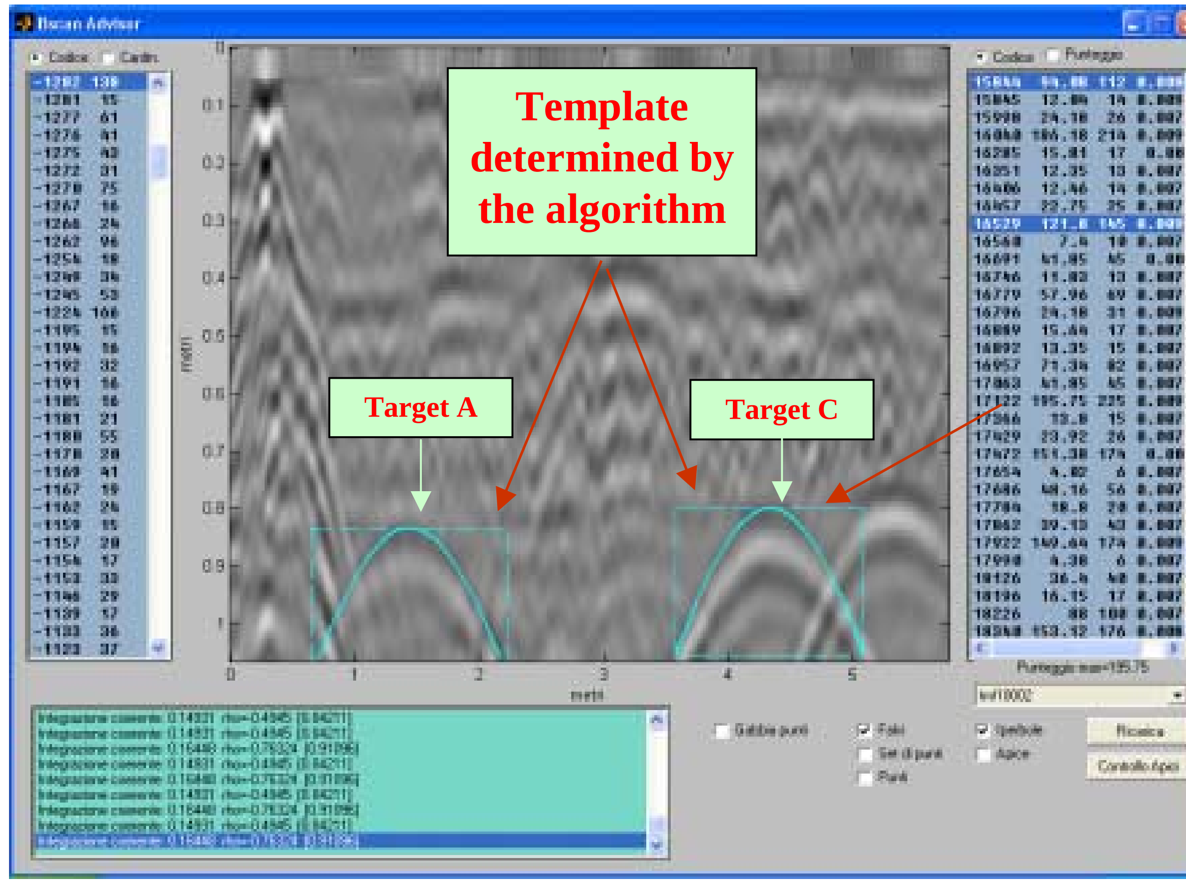

IDS data analysis: example of 3-D migration and automatic detection of targets

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Long term research and development

The top-down approach evaluated techniques that, although not immediately applicable because of cost or incomplete knowledge, may offer performance advantages for future systems. In detail:

- ✓ **System design (Stepped Frequency Continuous Wave - SFCW)**
- ✓ **Antenna design (Vivaldi wide band antenna system)**
- ✓ **Data processing (Fast Fourier Transform – FFT)**
- ✓ **Image processing (Declivity Filter for suppressing the clutter)**
- ✓ **Modelling tools (TLM and Behavioural simulation)**

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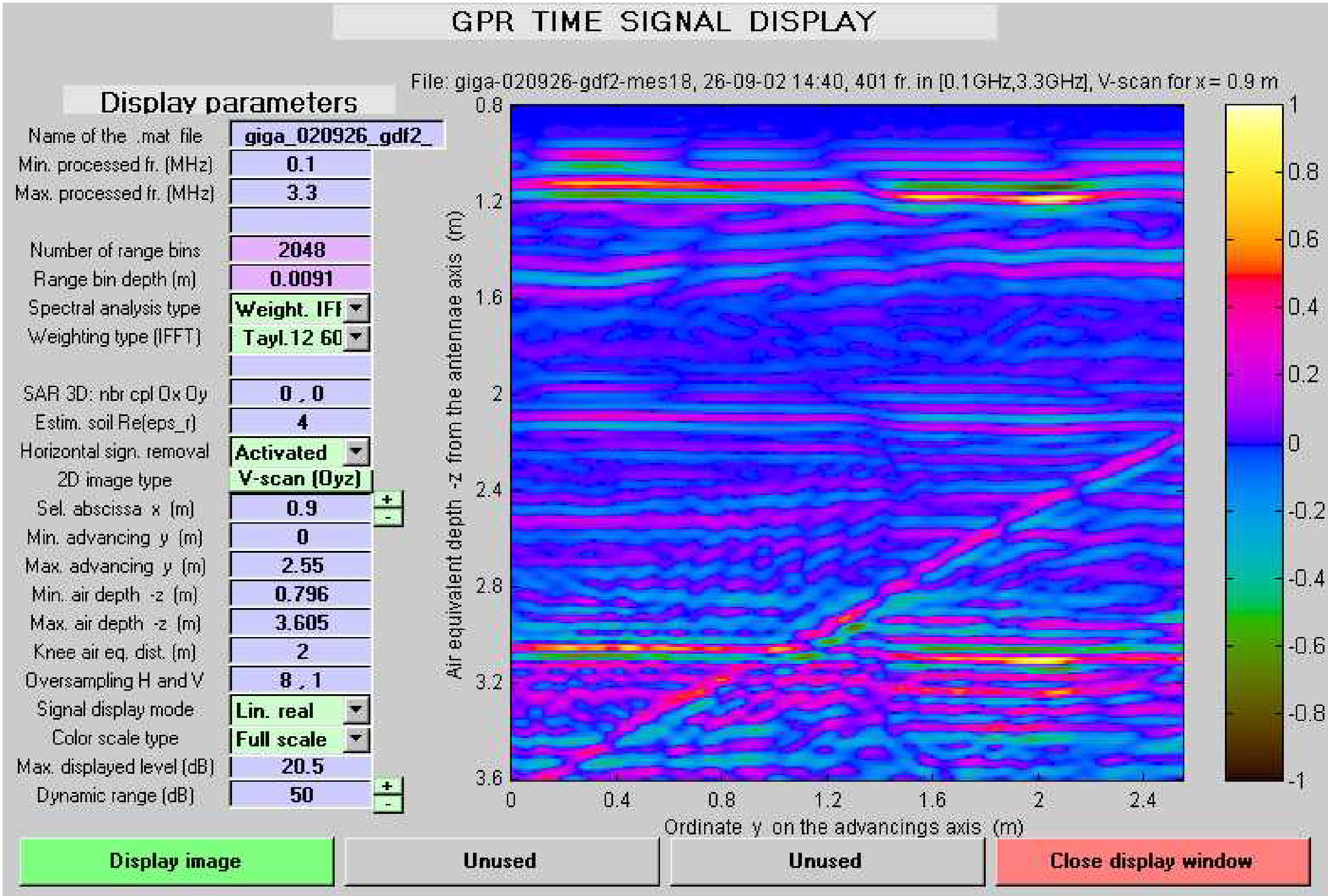

Thales AD data analysis: steel, sloping pipe

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Simulation tools

- Development of software tools capable of accurately simulating both the propagation of the electromagnetic signal through the ground and the scattering produced by buried targets
- It can help to address next GPR developments
- Two approaches
  - ✓ Accurate simulation (by solving Maxwell's equations)
  - ✓ Behavioural simulations (by using the optical propagation laws and then the Descartes and Huygens laws)

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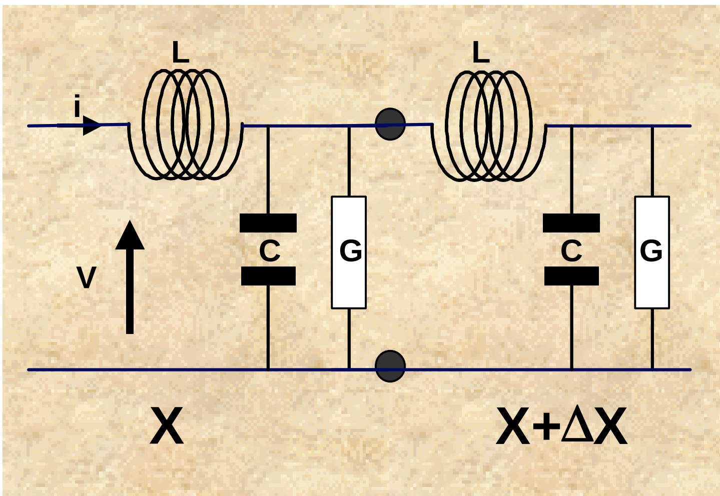
Accurate simulation (led by IDS)

Transmission Line and EM Field Equivalencies



Transmission Line		EM Field
i	$\Leftrightarrow$	H
$\dfrac{L}{\Delta x}$	$\Leftrightarrow$	μ
$\dfrac{C}{\Delta x}$	$\Leftrightarrow$	ε
$\dfrac{1}{G\Delta x}$	$\Leftrightarrow$	σ

$$\frac{\partial^2 i}{\partial x^2} = \frac{LC}{(\Delta x)^2}\frac{\partial^2 i}{\partial t^2} + \frac{L}{(\Delta x)^2 G}\frac{\partial i}{\partial t}$$

$$\frac{\partial^2 H}{\partial x^2} = \mu\varepsilon\frac{\partial^2 H}{\partial t^2} + \mu\sigma\frac{\partial H}{\partial t}$$

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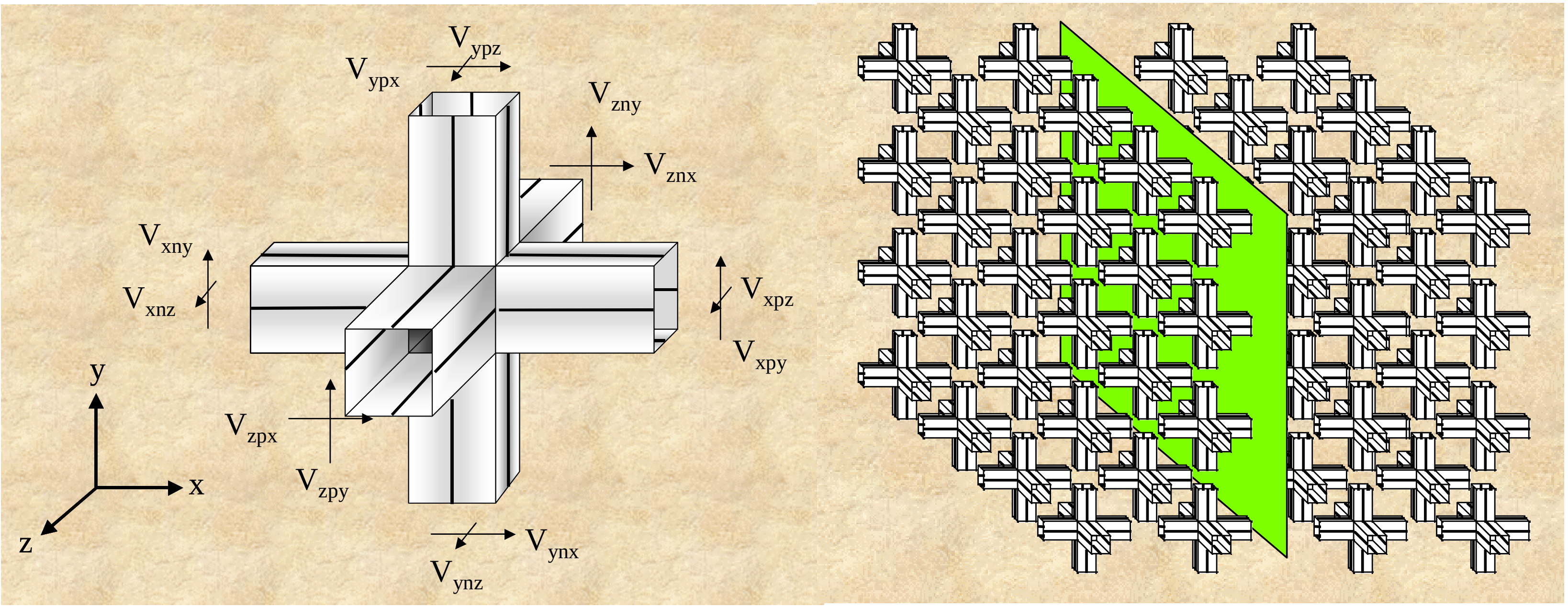
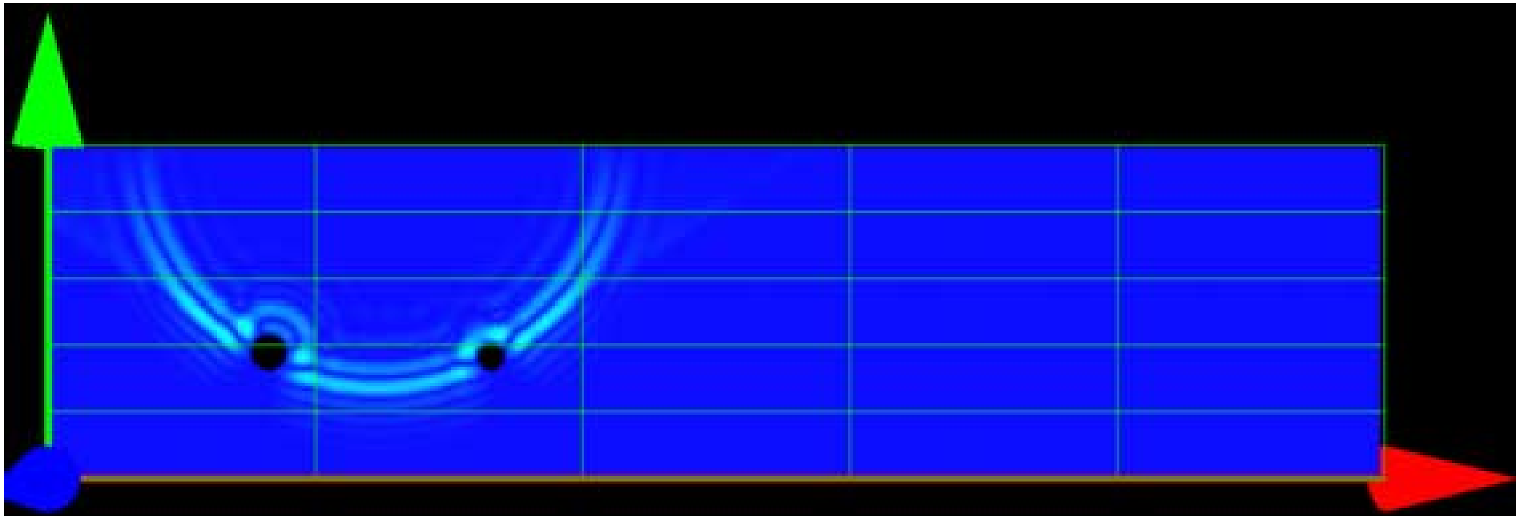
TLM Node and Spatial Discretisation



TLM Capabilities and example of an output

1. Wire and cable modelling
2. Material modelling (Metals, Lossy dielectrics, Frequency dependent materials)
3. 2D and 3D models
4. Absorbing boundaries



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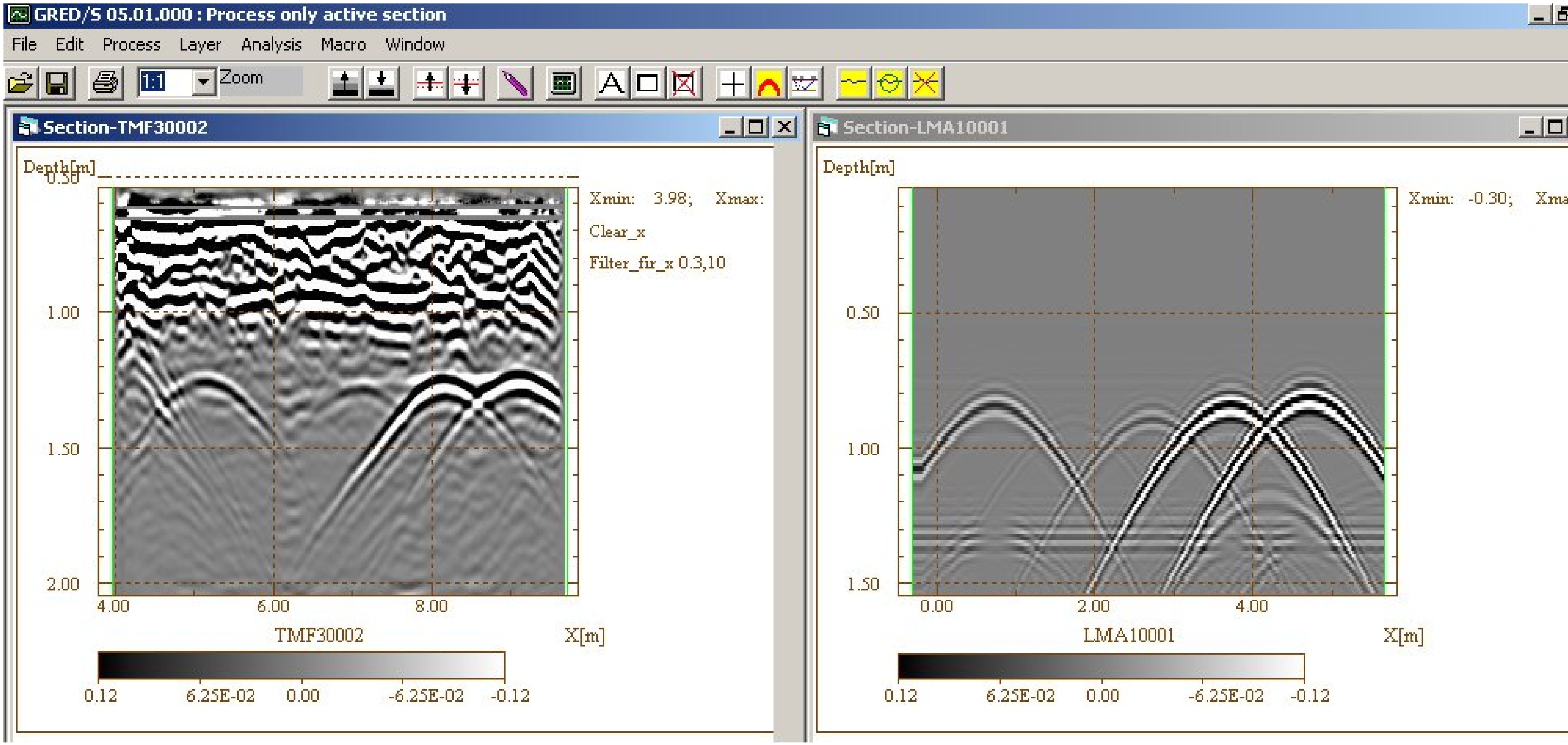
Measurements vs. TLM Predictions



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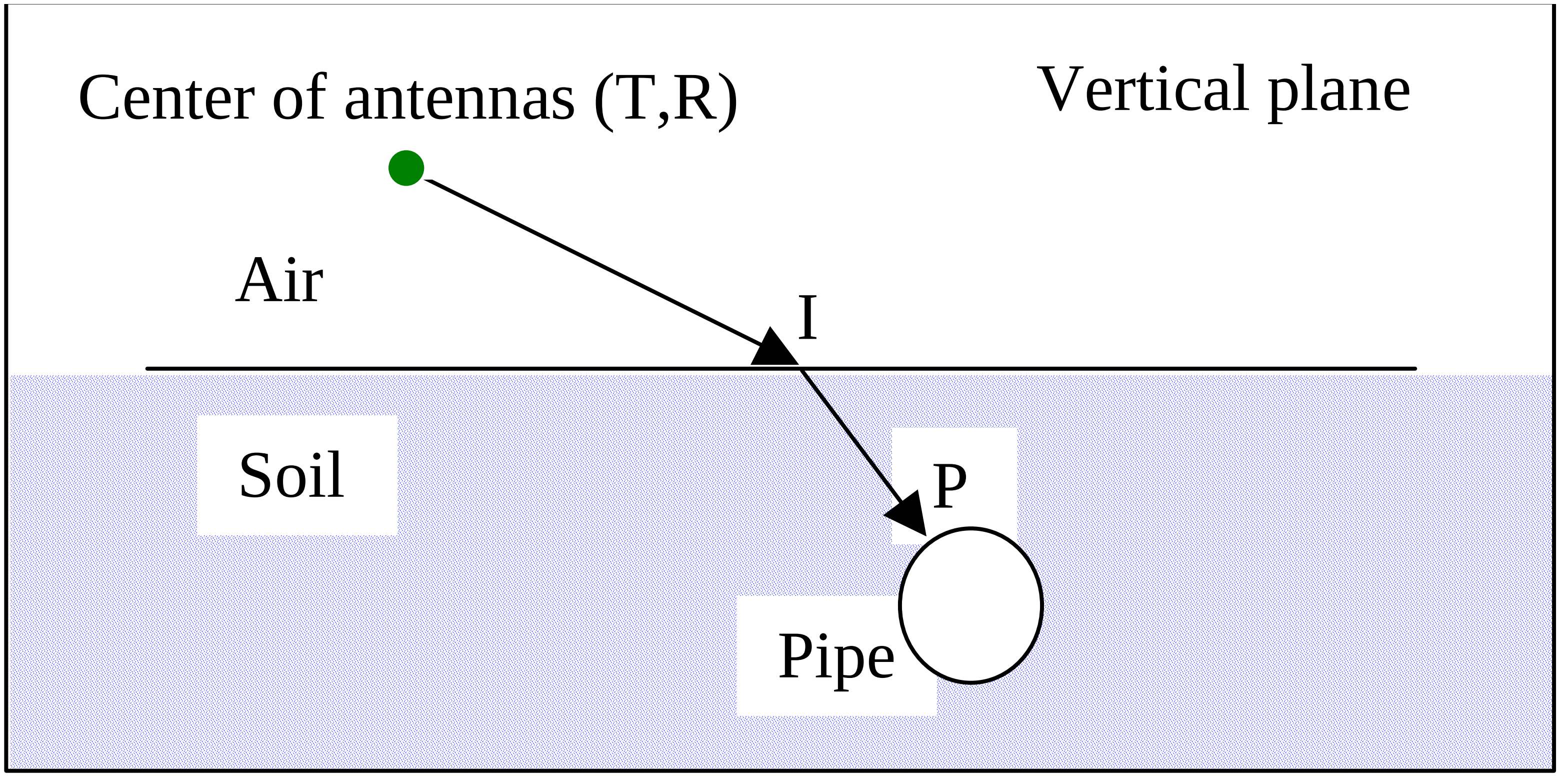
Behavioural simulation (led by Thales-AD)

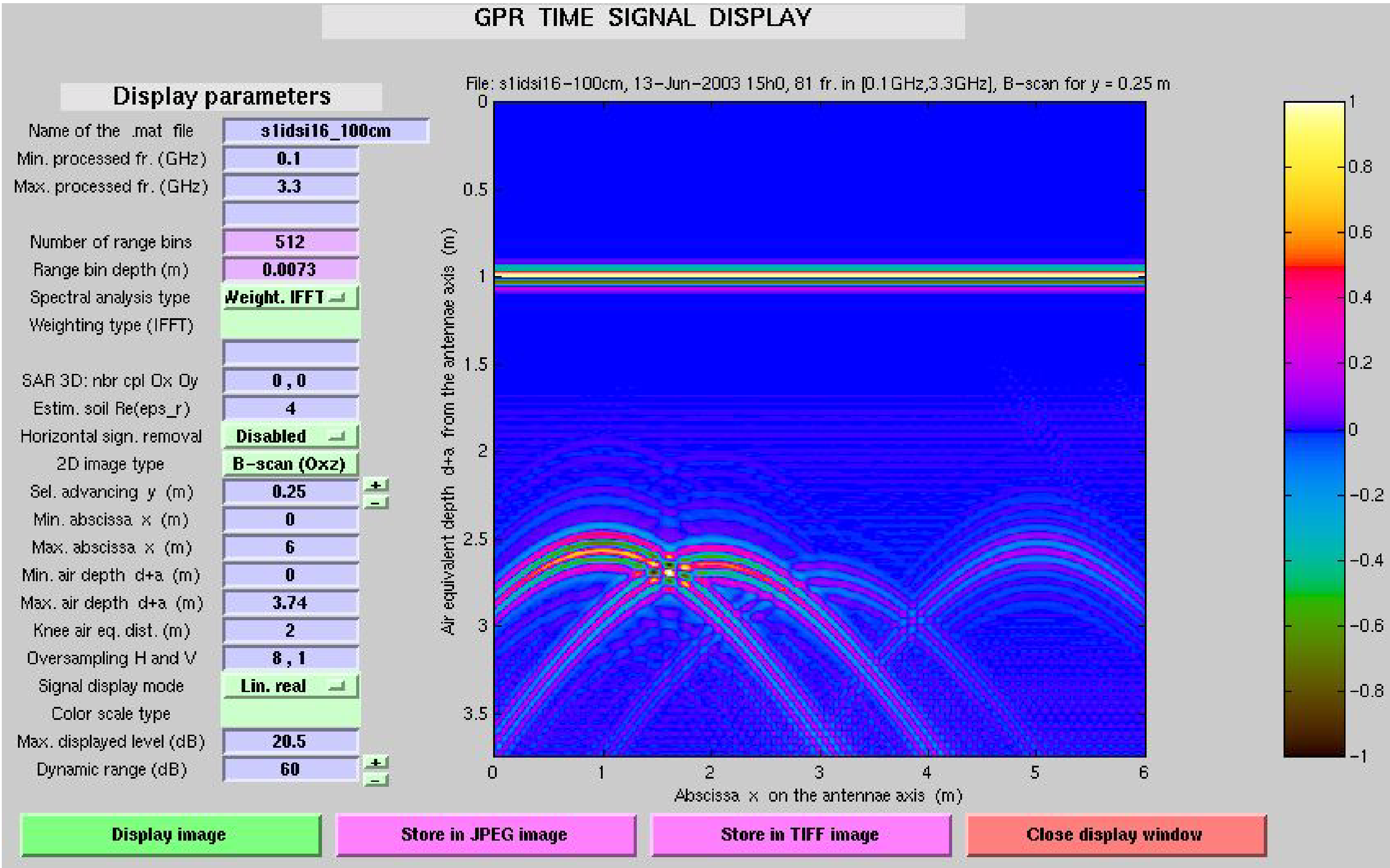
- Antenna modelization
- Modelization of the soil
- Modelization of the object
- Calculus of the electromagnetic scene
- Display of the simulation results

Behavioural simulation



Ray drawing in the perpendicular plane of the pipe

Behavioural simulation



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Conclusions/1

- GIGA's innovative approach comes from the analysis of requirements as stated by HDD operators and utility companies, and from research activities by following a top-down and a bottom-up methodology.
- The design of an innovative GPR system, to be implemented in the short-term, has been proposed. It should fulfil most of the requirements.
- Next research phases shall address the limitations of the technology due to penetration depth and the detection of small diameter, deep, plastic pipes.

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Conclusions/2

- **The quality of the information obtained using the GPR technique has strongly depended upon the *know-how of the operator*. The GIGA project has addressed this aspect of the technology and software techniques have been developed to reduce the need for data analysis by a highly trained operator.**
- **The simulation tools developed during the project enable a theoretical view of the radar problem. Use of these tools to investigate the problem of small dielectric targets will provide a useful guide for equipment design decisions.**
- **Moreover, an innovative GPR solution is currently under study in order to allow an accurate survey at shallow depth (within 70cm) to be used during the installation of gas pipes by means of mini-trench digging machines.**

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