POLITECNICO MILANO 1863

GPR Acquisition Experiment

Course: **Geophysical Imaging**
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1. Introduction

Ground-penetrating radar (GPR) is a geophysical method that uses radar pulses to image the subsurface. It is a non-intrusive method of surveying the sub-surface to investigate underground utilities such as concrete, asphalt, metals, pipes, cables or masonry.[1] This nondestructive method uses electromagnetic radiation in the microwave band (UHF/VHF frequencies) of the radio spectrum, and detects the reflected signals from subsurface structures. GPR can have applications in a variety of media, including rock, soil, ice, fresh water, pavements and structures. In the right conditions, practitioners can use GPR to detect subsurface objects, changes in material properties, and voids and cracks.

GPR uses high-frequency (usually polarized) radio waves, usually in the range 10 MHz to 2.6 GHz. A GPR transmitter and antenna emits electromagnetic energy into the ground. When the energy encounters a buried object or a boundary between materials having different permittivities, it may be reflected or refracted or scattered back to the surface. A receiving antenna can then record the variations in the return signal. The principles involved are similar to seismology, except GPR methods implement electromagnetic energy rather than acoustic energy, and energy may be reflected at boundaries where subsurface electrical properties change rather than subsurface mechanical properties as is the case with seismic energy.

The electrical conductivity of the ground, the transmitted center frequency, and the radiated power all may limit the effective depth range of GPR investigation. Increases in electrical conductivity attenuate the introduced electromagnetic wave, and thus the penetration depth decreases. Because of frequency-dependent attenuation mechanisms, higher frequencies do not penetrate as far as lower frequencies. However, higher frequencies may provide improved resolution. Thus operating frequency is always a trade-off between resolution and penetration. Optimal depth of subsurface penetration is achieved in ice where the depth of penetration can achieve several thousand metres (to bedrock in Greenland) at low GPR frequencies. Dry sandy soils or massive dry materials such as granite, limestone, and concrete tend to be resistive rather than conductive, and the depth of penetration could be up to 15 metres (49 ft). However, in moist or clay-laden soils and materials with high electrical conductivity, penetration may be as little as a few centimetres.

2. Experiment

On December 6th we performed a GPR acquisition on the area located on Via Clericetti, 20133 MILAN, Italy, illustrated in the Figure 1, to identify subsurface service lines (pipes, cables, tunnels). We collected 17 X-profiles, 10 m long, with a distance between the lines of 0.25m, and 21 Y profiles, 4 m long, with a distance between the lines of 0.5m. We used a Detector Duo from Ingegneria dei Sistemi (IDS). It is a dual antenna system, one at 250MHz, the other at 700Mhz. The image and properties of this device is displayed in the Table 1.

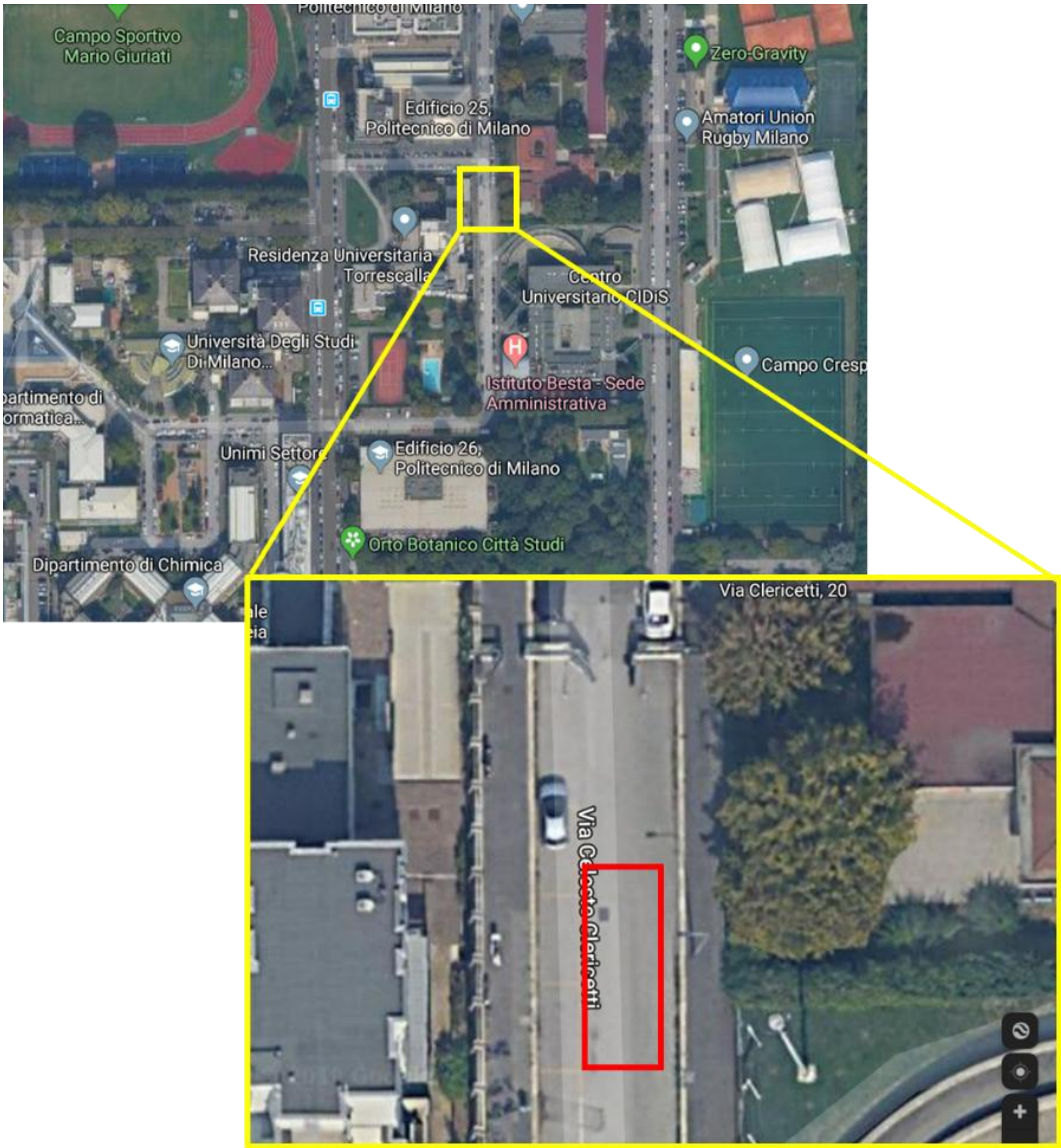
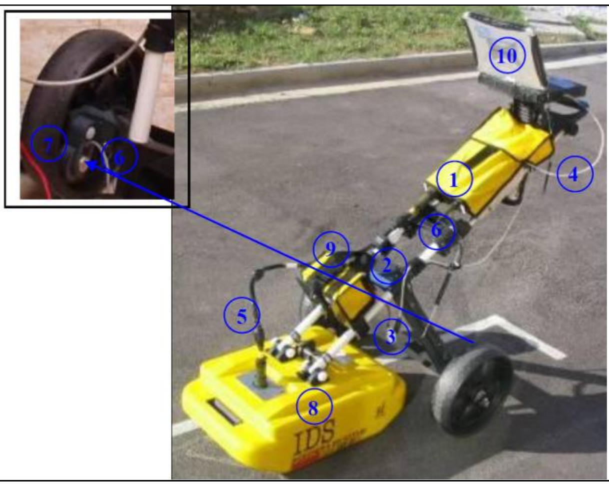


Figure 1: Location of GPR acquisition experiment

Table 1: Properties of Detector Duo utilized to the GPR acquisition experiment

	• DAD DECT DUO Control unit(1). • Two wheeled trolley used to move the system (2). • Power cable (3). • Inverted network cable (4). • Antenna Box - Control Unit connection cable (5). • Position sensor connection cable (6). • Position sensor (7). • Detector Duo Antenna (8). • 12V lead battery (9) . • Notebook computer (10).

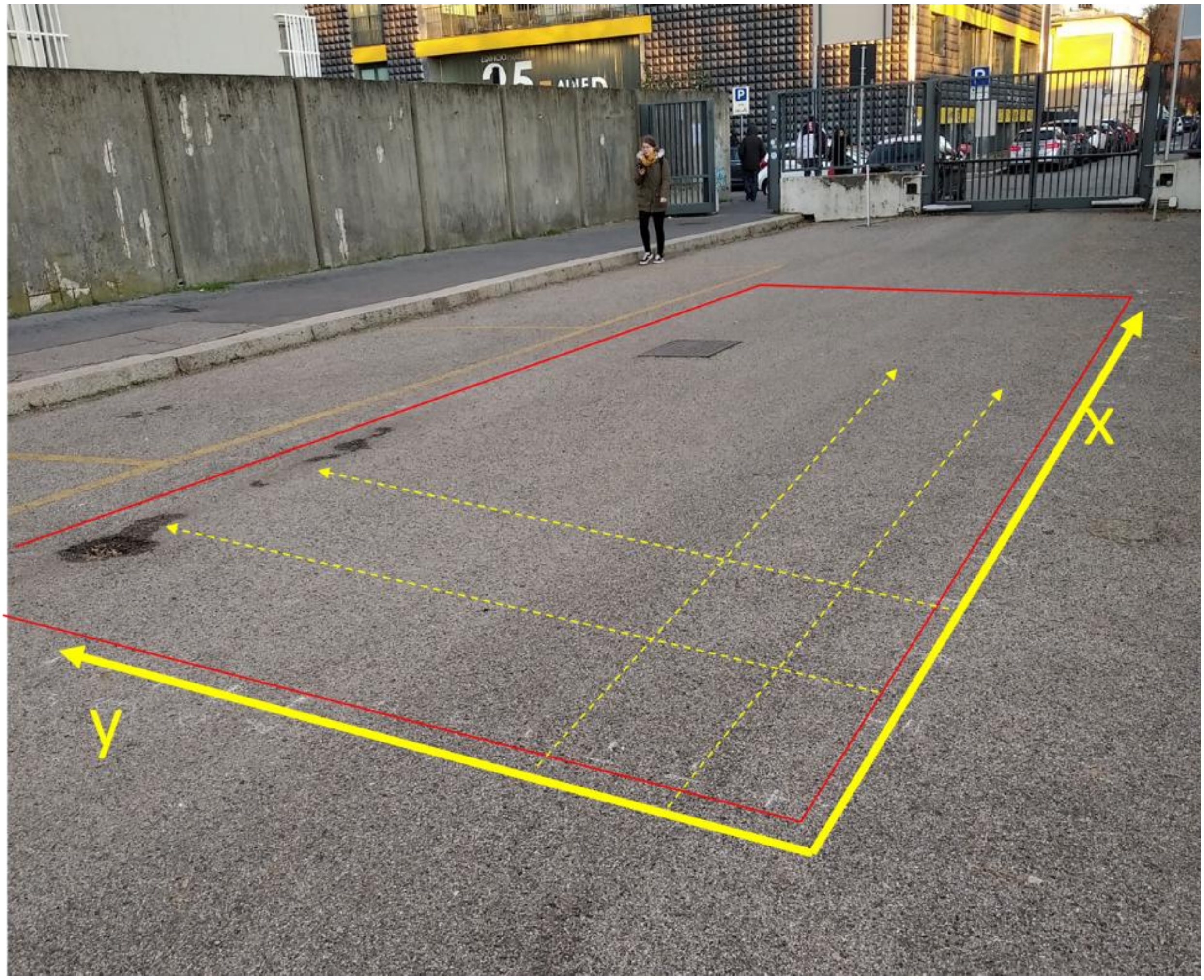


Figure 2: Considered area for GPR acquisition experiment

Looking at the Figure 2, we can see that there is a metallic object on the surface that will be used as “marker” in the final result. Moreover, there are some holes in the asphalt where water can penetrate in the soil.

When Ground Penetrating Radar (GPR) is used over a metal surface, the metal reflects almost all the electromagnetic energy transmitted by the GPR. This strong reflection is due to the high electrical conductivity and impermeability of metal to electromagnetic waves. Here are the key points of what happens:

1. Strong Reflection: The metal surface reflects the transmitted EM pulse very strongly. This results in a significant echo or reflection that appears prominently in the GPR data.

2. Minimal Penetration: The EM waves do not penetrate the metal. As a result, the GPR cannot provide information about what is beneath the metal surface.

3. Saturated Signal: The receiver antenna records a saturated signal due to the strong reflection, which can obscure or mask other signals or reflections from deeper layers or objects.

The presence of water in a Ground Penetrating Radar (GPR) acquisition has several significant effects due to water's high dielectric constant and electrical conductivity:

1. Increased Dielectric Constant: Water has a high relative dielectric constant (approximately 81), which greatly slows down the velocity of the electromagnetic waves. This causes the travel time of the waves to increase, which can affect the interpretation of depth and distance.

2. Decreased Penetration Depth: Water increases the conductivity of the material, which in turn decreases the penetration depth of the electromagnetic waves. This means that the GPR's ability to detect and image objects at greater depths is reduced in wet conditions.

3. Attenuation and Absorption: Water absorbs and attenuates the GPR signals, leading to a weaker return signal. This makes it more difficult to distinguish between different subsurface features and can reduce the overall quality and clarity of the GPR data.

4. Reflection and Scattering: Water can create additional reflections and scattering of the GPR signal. These reflections can complicate the data by introducing noise and making it more challenging to identify and interpret true subsurface features.

Having two pairs of antennas at different frequencies in GPR systems provides several key advantages:

1. Improved Resolution and Penetration: Different frequencies offer a trade-off between resolution and penetration depth. Higher frequencies provide better resolution but shallower penetration, while lower frequencies penetrate deeper but with lower resolution. By using two pairs of antennas at different frequencies, a GPR system can achieve both high-resolution imaging of shallow targets and deep penetration for detecting deeper objects.

2. Comprehensive Subsurface Imaging: Combining data from different frequencies allows for a more comprehensive understanding of the subsurface. High-frequency antennas can detect small, shallow features, while low-frequency antennas can reveal larger, deeper structures. This combination provides a fuller picture of the subsurface conditions.

3. Enhanced Data Interpretation: Multiple frequencies enable cross-verification and more accurate interpretation of subsurface features. Discrepancies between the data sets from different frequencies can highlight variations in material properties and help differentiate between different types of targets.

4. Versatility in Different Environments: Different environments and subsurface conditions can affect GPR performance. By using antennas with different frequencies, a GPR system can adapt to varying conditions, such as different soil types, moisture levels, and presence of conductive materials, ensuring reliable data acquisition across diverse scenarios.

5. Detection of a Wider Range of Targets: Some subsurface features may only be detectable at specific frequencies. For example, fine details in shallow layers may be visible only at higher frequencies, while larger, deeper anomalies may require lower frequencies. Utilizing multiple frequencies increases the likelihood of detecting a broader range of targets.

3. Processing Steps

3. 1 Background Noise Removal

Background noise refers to unwanted signals or interference that obscure or distort the actual reflections from subsurface features. This noise can originate from various sources and can significantly impact the quality and interpretability of GPR data. The key aspects of background noise in GPR are:

1. Environmental Electromagnetic Interference (EMI): External sources of electromagnetic fields, such as power lines, radio transmitters, and other electronic devices, can introduce noise into the GPR system. This interference can create false signals or increase the baseline noise level.

2. System Noise: The GPR equipment itself can generate noise due to the inherent electronic components and circuitry. This system noise is usually constant and can be minimized through calibration and proper system maintenance.

3. Surface Clutter: Objects on or near the surface, such as vegetation, debris, or uneven terrain, can create reflections that interfere with the detection of deeper targets. These surface reflections can be particularly problematic in cluttered environments.

4. Multipath Reflections: EM waves can bounce off multiple surfaces before reaching the receiver antenna, creating complex, overlapping signals. These multipath reflections can complicate the data and make it challenging to identify the true subsurface features.

5. Antenna Coupling: Interference between the transmitting and receiving antennas can generate noise. Proper antenna design and placement can help reduce this type of noise.

6. Scattering: Irregularities in the subsurface, such as rocks, voids, or heterogeneous materials, can scatter the EM waves, producing noise that can mask or distort the desired reflections.

7. Thermal Noise: All electronic systems produce thermal noise due to the random motion of electrons. While typically small, this noise can still affect the overall signal quality.

There are some Mitigation Techniques that can be used to decrease the negative impact of background noise:

- **Background Removal:** Techniques such as subtracting an average background signal from the data can help eliminate consistent noise patterns.
- **Filtering:** Applying band-pass filters to isolate the frequency range of interest can help reduce noise from other sources.
- **Signal Processing:** Advanced signal processing techniques, including deconvolution and migration, can enhance signal clarity and reduce noise effects.
- **Proper Setup and Calibration:** Ensuring that the GPR system is correctly set up, calibrated, and maintained can minimize system noise and optimize performance.

The following figures show the processing steps for an x-profile with the low frequency antenna (250MHz). Left is initial data, right after processing.

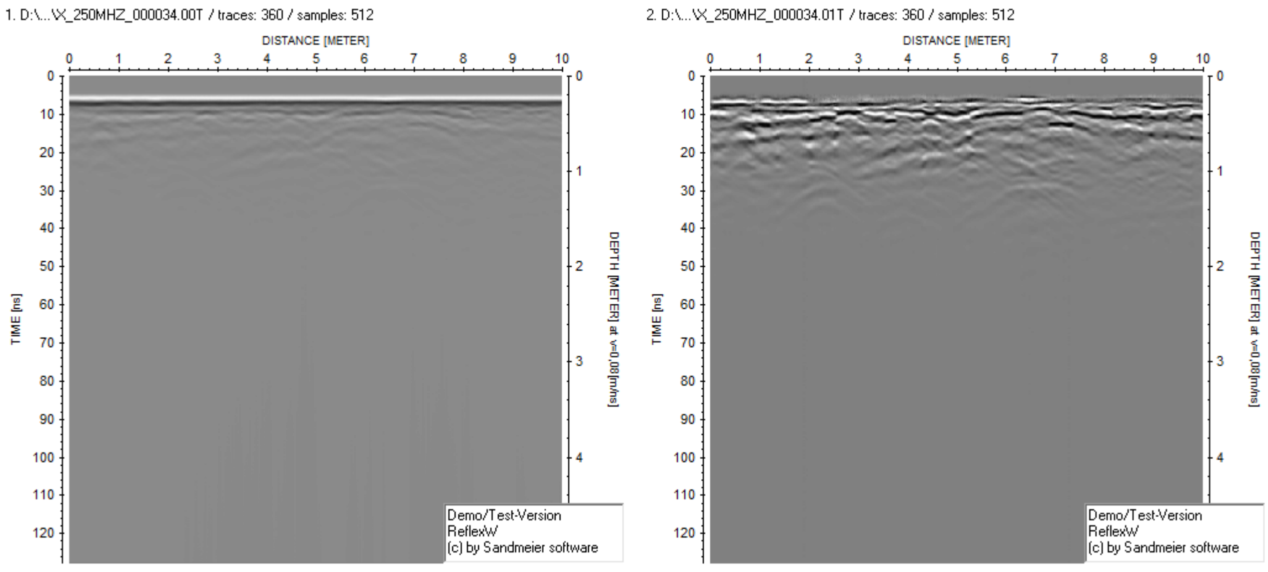


Figure 3: Background removal through trace average and subtraction

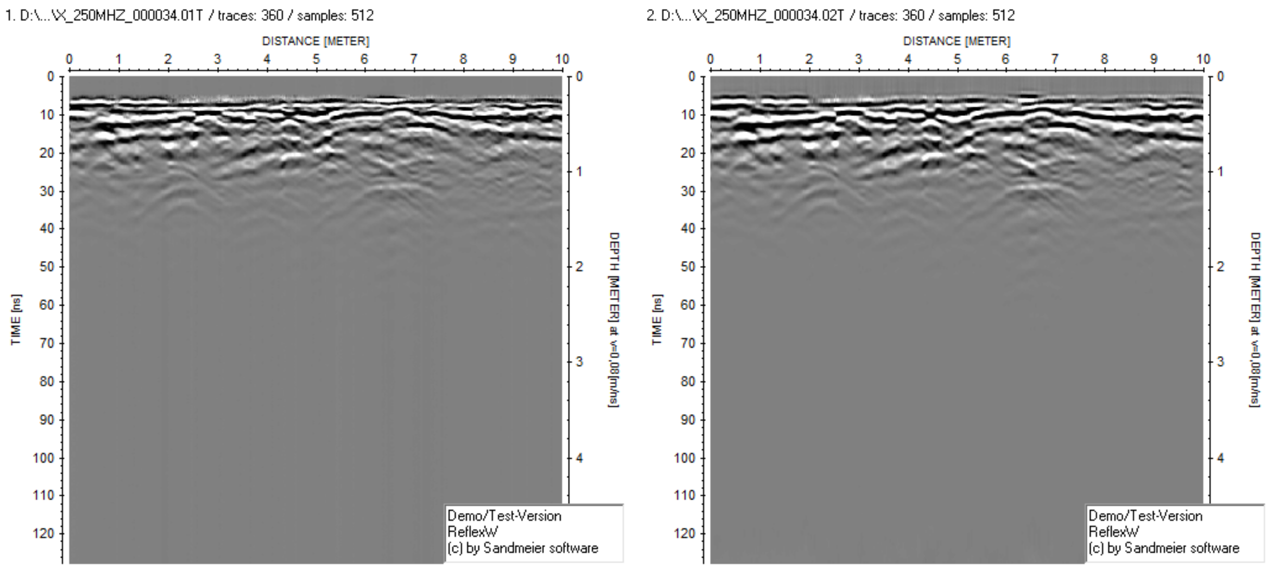


Figure 4: Bandpass filtering

3.2 Gain Recovery

Gain recovery in GPR is a crucial step in the data processing workflow to ensure the quality and interpretability of the acquired data. Here are the primary reasons for performing gain recovery:

1. Compensate for Signal Attenuation: As the electromagnetic waves travel through the subsurface, they experience attenuation, which means the signal strength decreases with depth. Gain recovery compensates for this loss by amplifying the weaker signals from deeper reflections, making them more comparable to the stronger signals from shallower depths.

2. Improve Signal-to-Noise Ratio (SNR): Over time and depth, the GPR signal weakens, and the background noise becomes more prominent. Gain recovery helps to enhance the actual subsurface reflections while suppressing the background noise, thereby improving the overall SNR.

3. Enhance Data Visibility: Without gain recovery, deeper features may be difficult to discern in the raw GPR data due to their weaker signal strength. By applying gain recovery, these deeper features become more visible and easier to interpret, leading to more accurate subsurface mapping.

4. Ensure Uniformity: Gain recovery ensures that the amplitude of reflections from various depths appears more uniform in the GPR data. This uniformity is essential for accurate interpretation and comparison of subsurface features across different depths.

5. Facilitate Data Analysis: Enhanced signals make it easier to apply further data processing techniques, such as migration and velocity analysis, which rely on clear and strong reflections to accurately locate and characterize subsurface features.

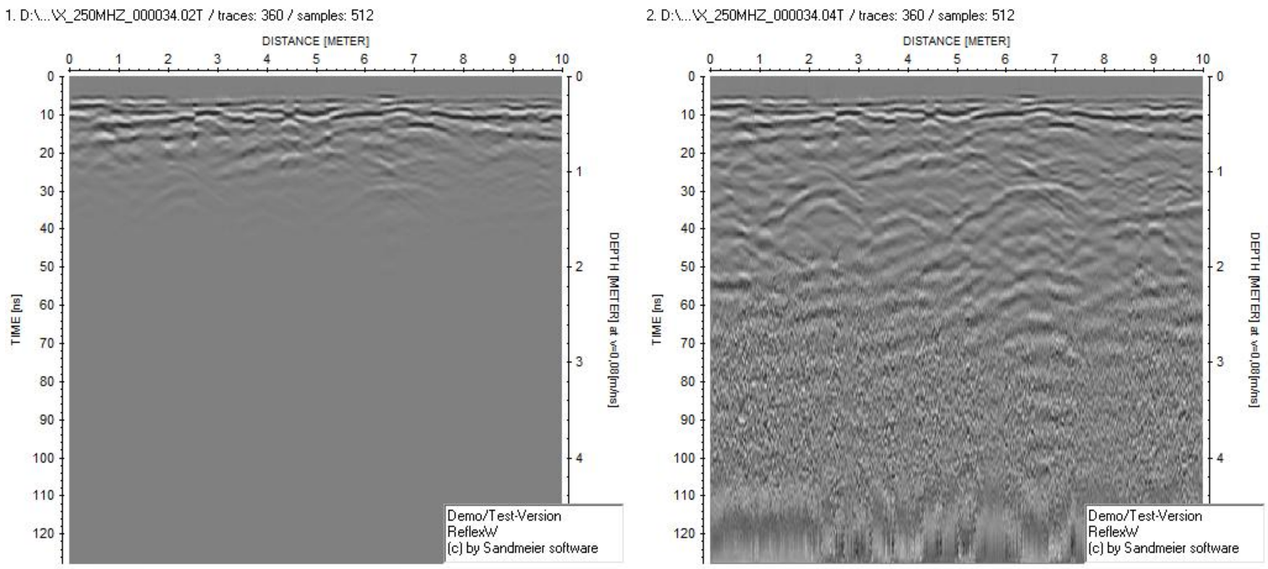


Figure 5: Gain recovery (energy compensation)

3D Image Reconstruction

The 17 x-profiles for the 250Mhz antennas have been processed with the same processing flow. The migrated gather for each line has been merged in a 3D volume.

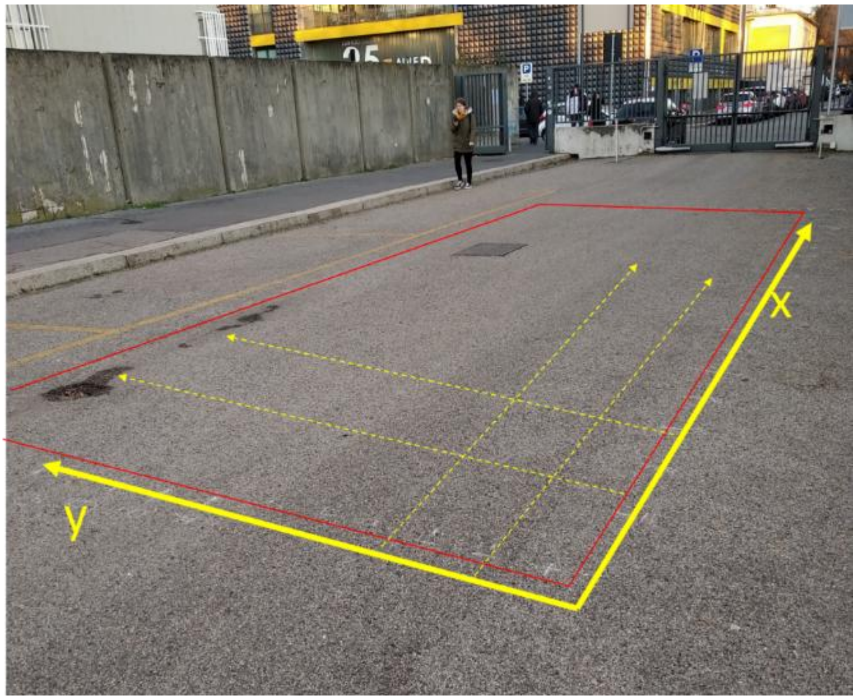


Figure 6: Considered area of the experiment.

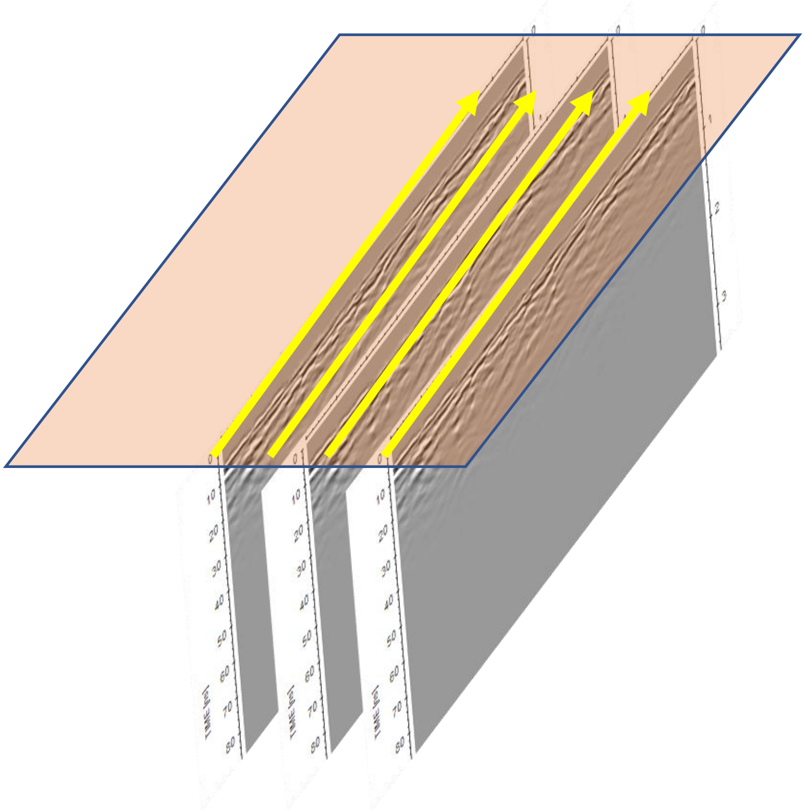


Figure 7: Some "slices" of the volume

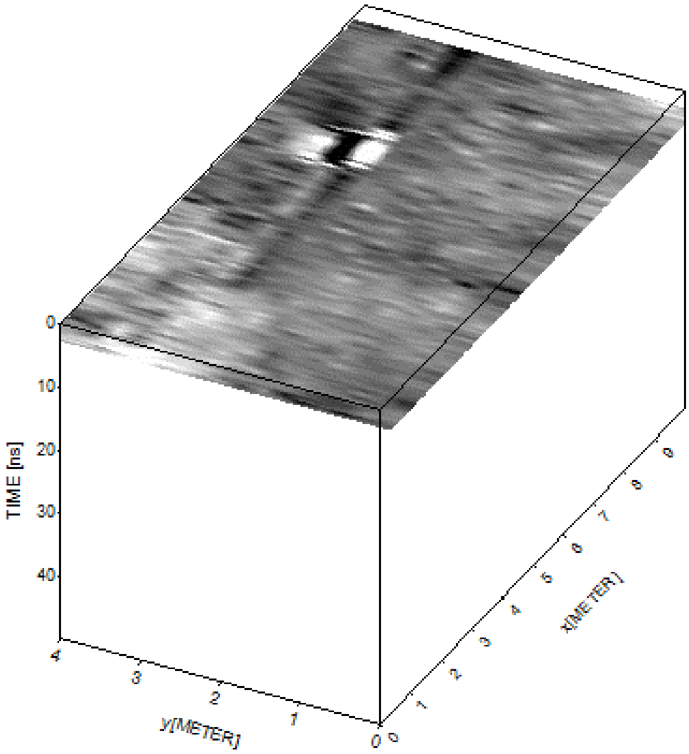


Figure 8: Slice at 20cm from the surface (gray scale).

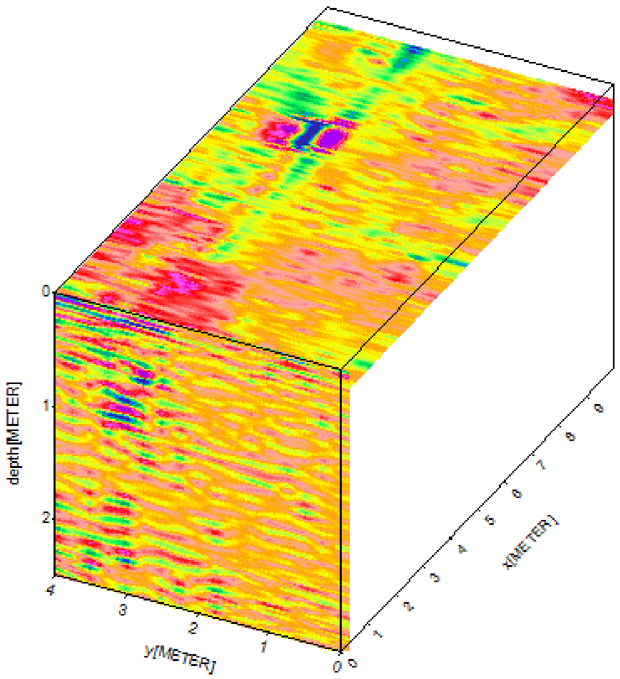


Figure 9: Slice at Slice at 20cm from the surface (colors).

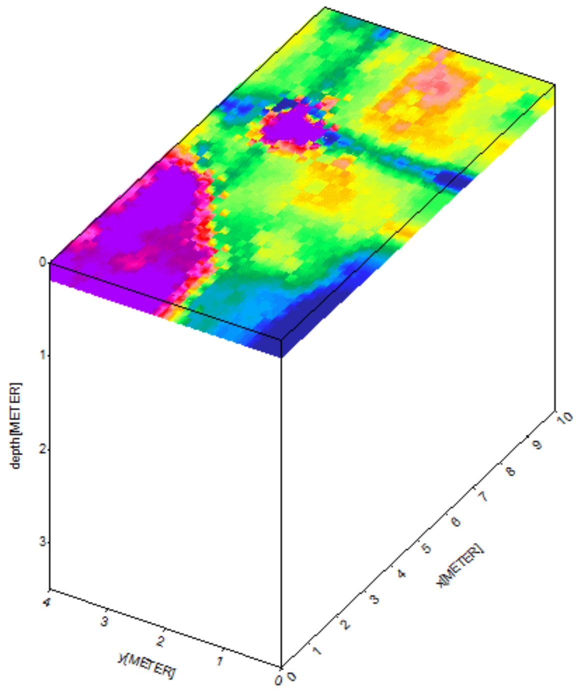


Figure 10: X and Y profiles processed together. Slice at 20cm from the surface (colors).