**Ground Penetrating Radar (GPR)**

**Definitions:**
- Ground Probing Radar, also known as Ground Penetrating Radar (GPR) is a high resolution, field-portable geophysical method that produces graphic sections of subsurface structure.

- Ground Probing Radar surveys are non-destructive, revealing detailed information on subsurface ground conditions without drilling or excavation.

- Ground Penetrating Radar (GPR) is also known as ground probing radar, subsurface radar, georadar and subsurface impulse radar.

- It is a new electromagnetic (EM) geophysical exploration technique that is gaining widespread use for mapping shallow subsurface geological structures and locating underground objects.

- Since the mid 1980s, GPR has become enormously popular, particular with the engineering and archaeological communities. It was applied since the 1960s

- At the same time, a receiving antenna detects the waves that
- GPR can be used from the ground surface, from the air, from inside boreholes, or in tunnels.

- In the GPR method, a short radar pulse in the frequency band 10MHz–1GHz is introduced into the ground. The reflection of electromagnetic waves is observed.

- A radar system comprises a signal generator, transmitting and receiving antennae, and a receiver that may have recording facilities.

- A typical GPR system comprises an antenna unit, control console, display monitor, and graphic printer.

- The antenna unit is in direct ground contact with the remaining equipment vehicle-mounted.

- Data is collected along accurately located survey profiles. Impulses of UHF/VHF frequency electromagnetic energy are emitted from the moving antenna and propagated into the ground.
- Reflections are generated at subsurface boundaries with an electrical contrast. Reflected signals are detected by the antenna receiver and digitally stored for post-survey processing & interpretation.
Common Uses of GPR

1- Detection of groundwater.

2- Locating underground solution cavities and tunnels.

3- Mapping stratigraphic features in shallow subsurface geological structures.

4- Archaeological investigations.

5- Location of underground oil pipeline leaks.

6- Investigate the permafrost, the thickness of sea ice and lake ice, the structure of coal seams.

7- The soil taxonomy and properties.

8- In the police investigations to detect the buried criminal objects.

9- GPR is an interesting tool to locate the landfill sites and to study the pollution from the existing ones.

10- In the detection and mapping of subsurface fluids including groundwater and contaminants such as hydrocarbons.
Typical GPR systems

A typical GPR system comprises:

1- A Control Unit for generating a short electrical pulse
2- Transmitter / Receiver Transducer (antennas with transmitting and receiving electronics) that are used for converting the electrical pulse into an EM pulse of radio-frequency (VHF and UHF band) and transmitting it into the ground or receiving it.
3- The received signals can be output to a graphic display unit and interpreted immediately in the field or digitized and stored on a magnetic tape.

4- The digital data can be transferred to a personal computer where a variety of digital signal processing procedures can be applied to enhance the signals and apply corrections.
**GPR antennas**

There are two types of antennas in the GPR systems:

1- **Monostatic mode**: a single antenna can be used as the transmitter / receiver.

2- **Bistatic mode**: one antenna can transmit while a second identical antenna placed a small distance away from the first can act as the receiver.

![Diagram of Monostatic and Bistatic antenna configurations](image-url)
Radar Section (Radargram)

1- As the receiving antenna is moved over the ground, the received signals are displayed as a function of their two way travel time (i.e. the time taken from instant of transmission to time of detection by the receiver).

2- The data along each traversed profile are shown as a radar section (radargram). The amplitude of the received signal is displayed along a trace on the vertical time axis at each horizontal position that the transmitter/receiver antenna occupies.

3- This display is analogous to a seismic section (seismogram). The main differences are that the scale of a GPR survey is about three orders of magnitude smaller than that of a reflection seismic survey and the resolution is high.
Types of Radargram

- The observed signals can be summarized as radargram.

1- A simplified output is illustrated as being signals with amplitudes greater than the set threshold are printed dark on the radar section.
2- Displays can also be output in terms of variable area wiggle or wiggle trace.

3- The more sophisticated digital recording systems display the amplitudes of the signals according to grey scale or color menu.

4- The strongest reflections can be picked out by the brightest colors.
Different displays of radargrams.
Propagation depth of radar waves

- Penetration depth for georadar signal:

\[ D \ (m) = \frac{\rho (\Omega \text{m})}{30} \]

→ small penetration depths for rocks with low resistivities
  Clay: 0.8  1m
  Saturated sand ≈ 2m
  Dry sand ≈ 5m

1- The depth of penetration of GPR can be severely limited by any increase in conductivity such as that caused by the presence of saline water, the presence of clays and shales in rocks (i.e. the attenuation of GPR signals increases as electrical conductivity increases).

2- Some materials such as polar ice are transparent to radio waves. Others such as water saturated clay and sea water are opaque to radio waves (i.e. either absorb or reflect the radio waves).

3- Such attenuation of Radar waves also depends on the frequency of radio waves.
4- Generally speaking, low frequency waves are attenuated less than high frequency waves.

5- Dry materials will have a lower signal attenuated than wet ones.

6- Thus gravel, sand, dry rock and lake water are relatively easy to probe with GPR.

7- Salt water, clay soils and conductive ores or minerals are less.
Survey design

There are three modes of surveying with radar systems which are:

1- Radar Reflection Profiling:

- In profile measurements, the transmitting and receiving antennas are moved at the same time over the ground while measurements are made.

- This procedure provides continuous record of the varying elevations of the reflection surfaces and the locations of isolated bodies.
- Commonly, antennas spacing (source-receiver offset) of one meter for the 100 MHZ and two meters for the 50 MHZ was used with a one meter step for all survey.

- The profiles are processed and plotted (wiggly trace format)

**2- Wide-angle reflection and refraction (WARR) sounding**

- In the “WARR” mode, the transmitting antenna is fixed and the measurements are made while the receiving antenna is gradually moved away.
“WARR” sounding is used to obtain an estimate of the radar signal velocity versus depth in the ground by varying the antenna spacing at a fixed location and measuring the change of the two-way travel time to the reflections.

3- Common mid-point (CMP):

- It is similar to “WARR” but both antennas are moved away from each other about a fixed location.

- The maximum antenna separation in a CMP/WARR sounding is usually 1 to 2 times the reflector depth.
- If the ground attenuation is high, the signals may die out before the maximum separation is reached.

- The reflection arrival times should have a hyperbolic dependence (to first order) on antenna separation.

- Three types of waves may be identified:

  1) **The air wave**: traveling from the transmitter to the receiver through the air at the speed of radio waves in air (0.3 m/ns).

  2) **The direct wave**: traveling directly from the transmitter through the near surface ground to the receiver at the speed of radio waves in the near surface medium (V).

  3) **The reflected wave**: traveling from the transmitter to the interface from which it is reflected to the receiver, also at the speed of radiowaves in the first layer (V1).
The travel times for both the air-wave and the direct wave plot as straight line segments on the T-X graph, but those for the reflected wave plot on a curved (hyperbolic) line.

Analysis of the move out hyperbola of time versus separation permits estimation of propagation velocity and target depth.
The basic interpretation procedure is “T2 - X2 “ analysis commonly used in early seismic reflection interpretations.

A plot of travel time squared versus antenna separation squared yield a straight line relationship whose slope gives a velocity estimate and whose time intercept yields a depth estimate and numerically can be calculated as follows:
\[ T_2 = \frac{1}{C_2} (X_2 + 4D_2) \text{ and } D = \frac{Ct_0}{2} \]

Where:
- \( T \) is the travel time of reflected waves from T to R.
- \( X \) is the antenna separation.
- \( D \) is the depth of reflector.
- \( C \) velocity of EM propagation in the ground.
- \( T_0 \) is the intercept time at \( X=0 \).

- All the segments of the travel times on the "\( T^2 - X^2 \)" graph appear as straight lines.
- The inverse gradient of each line are equal to the respective radiowave velocity squared.

- The difference in travel time between zero offset and at finite offset in the normal move out (NMO) time.

4- Transillumination sounding mode:

- It is used in locations where the transmitter and the receiver can be set up to “look” through the medium.

- In this case, the transmitter and receiver are on opposite sides of the medium under investigation.
- This method is used underground within mines, for example, where the transmitter is located in one gallery and the receiver is either in a gallery to one side of the transmitter or in a gallery above or below.

- Alternatively, one antenna is fixed to one side of a masonry pillar or concrete column while the other antenna is moved past the stationary antenna on the other side of the pillar.

**5-Borehole Radar:**
- It has been used in mining, hydrogeology, rock mechanics, dams and other construction projects.

- A transmitter is used to generate the radio waves, a separate receiver is located a short distance further down the hole (2-6m) when surveying in sedimentary rocks and 5-15m when in crystalline rocks.

- Measurements are made at fixed intervals of 0.5m or 1m. It takes about 30 seconds at each location to make the required measurements.

6- **Cross-hole configuration:**

* In which the transmitter antenna in one borehole and the receiver antenna down another. There are two forms of crosshole surveying:
1- Borehole Radar Profiling (BRP):

- This method is used for mapping geology and locating unknown objects.

- BRP is carried out simultaneously moving the transmitter and receiver to equal depths taking measurements at selected intervals.

- This method gives a quick and simple indication of material properties.
### 2- Borehole Radar Imaging (BRIM):

- This method is used for detailed definition of the area under examination.

- BRIM is achieved by moving the transmitter and receiver to as many different points as possible and taking multiple measurements through numerous paths in the materials under examination.
BRIM allows users to create tomographic images, such as those used in medical imaging. Computer processing transforms the data into an image.

Limitations of the GPR Surveying

1- The Target Depth:

- If the target depth is beyond the range of GPR in ideal conditions, then GPR can be ruled out.

2- The Target Electrical Conductivity:

- In order for the GPR to work, the target must present a contrast in electrical properties to the host environment in order that the EM signal be modified, reflected or scattered.

3- The Survey Environment:

- There are two things can prevent using of Radar:
  a) A radio transmitter located at the site. In this case, external signals may saturate the sensitive receiver electronics.
b) A tunnel lined with metal mesh to prevent loose rock from falling. In this case the radar signal would be reflected at the tunnel wall and none would penetrate into the tunnel wall.

**Applications of GPR**

**GEOLOGICAL APPLICATIONS**

1- Locate natural cavities and fissures.
2- Soil stratigraphy mapping.
3- Mapping of superfacial deposits.
4- Mineral exploration.
5- Coal seems mapping.
6- Fracture mapping.
7- Shallow geological structure mapping (Faults, dykes,…).
8- Groundwater location.

Examples:
Environmental Applications

1- Contaminant plume mapping.
2- Mapping and monitoring pollutants within groundwater.
3- Landfill investigations.
4- Locate nuclear waste disposal.
5- Locate buried fuel tanks and oil drums.
6- Locate gas leaks.
7- Detect underground storage tanks under buildings.
8- Conduct environmental site assessment.

Examples:
Utility Mapping
Accurate depth and location information
Able to rapidly map utilities in urban areas
Detect utilities as small as 2cm / deep as 10m

CONTAMINATED GROUNDWATER

Groundwater flow

Original survey

Five years after remediation.
- GPR is very sensitive to changes in groundwater chemistry.

- GPR provides a powerful means of monitoring the remediation of contaminated groundwater caused by salts or leachates, hydrocarbons or other organic materials.

- GPR is commonly used in glaciology, as ice is easily penetrated by GPR signals.
- This case study shows the recovery of the lost aircraft in Greenland during the world war two (WWII).

- The GPR system was used to map out the exact location of the aircraft in May 1992, 50 years after the aircraft disappearance.

- Following the GPR survey, the site was excavated and the aircraft has been successfully recovered.
A unique but extremely effective use of GPR is mapping the internal structures of wooden poles and trees.

GPR is a powerful mean to locate anomalies in wood, primarily associated with changes in water content (rot).

This information is very important in ascertaining the stability of poles supporting telephone and hydro-cabling.

GPR can provide accurate spatial detection of buried objects such as former buildings, foundations, tanks, pipes and barrels.
- These objects will exhibit markedly different electrical properties from the surrounding soil materials.

- Ground Penetrating Radar (GPR) offers a solution to the UST (underground storage tanks) problem.
- Subsurface Geotechnical have a wealth of experience locating buried tanks on dozens of petrol stations, transport depots, chemical works and military bases.

- GPR can detect steel, plastic and concrete tanks through most types of surfacing. A typical investigation involves surveying a grid of radar profiles at regular intervals over the site.

- Where a profile transects a cylindrical steel target such as a cylindrical tank at a high angle to its longitudinal axis, the reflections will be curved or hyperbolic in shape (below), where the GPR signal is reflected off the cylindrical surface of the tank.
Engineering & Construction Applications

1- Road pavement analysis.
2- Void detection.
3- Concrete inspection.
4- Locate reinforcement (rebars) in concrete.
5- Locate public utilities (pipes, cables,..).
6- Test integrity of building materials.
7- Tunnel lining evaluation.
The accuracy of GPR in the detection of rebar position and condition is important in determining the stability of the structures.

This study demonstrates the effectiveness of GPR for mapping rebar.

Ground Probing Radar or Ground Penetrating Radar (GPR) surveys are a useful NDT technique for structural engineering, applicable on buildings, bridges, tunnels, dams and roads.

GPR can accurately locate steelwork in concrete, find internal defects and assess the thickness of structural elements.

The method is non-destructive, revealing subsurface detail without coring, breaking out or other types of destructive testing.
Archaeological Applications

1- Locate buried structures.
2- Detection and mapping roman roads, etc..
3- Pre-excavation mapping.
4- Location of graves.
Forensic Applications
1- Location of buries targets (e.g. bodies & other materials related to police investigations).
- GPR is frequently used by police for forensic investigations.

- It has the ability to locate solid disturbances, voids, and trenching as well as both metallic and non-metallic objects.

- In this study, a GPR survey was used to find money, buried at a private premises.

- The profile shows trenching on the left side and a buried metallic object on the right.