UNIT-V

GROUND PENETRATING RADAR

➢ INTRODUCTION

- Also known as **MATERIAL-PENETRATING RADAR (MPR).**
- GPR uses electromagnetic radiation in the radio-frequency (RF) and microwave band of the radio spectrum and detects the reflected signals from subsurface structures.
- Ground penetrating radar (GPR) is a geophysical locating method that uses radio waves to capture images below the surface of the ground in a minimally invasive way.
- The huge advantage of GPR is that it allows crews to pinpoint the location of underground utilities without disturbing the ground.
- As you can see, ground penetrating radar can reach depths of up to 100 feet (30 meters) in low conductivity materials such as dry sand or granite.
- Moist clays, shale, and other high conductivity materials, may attenuate or absorb GPR signals, greatly decreasing the depth of penetration to 3 feet (1 meter) or less.

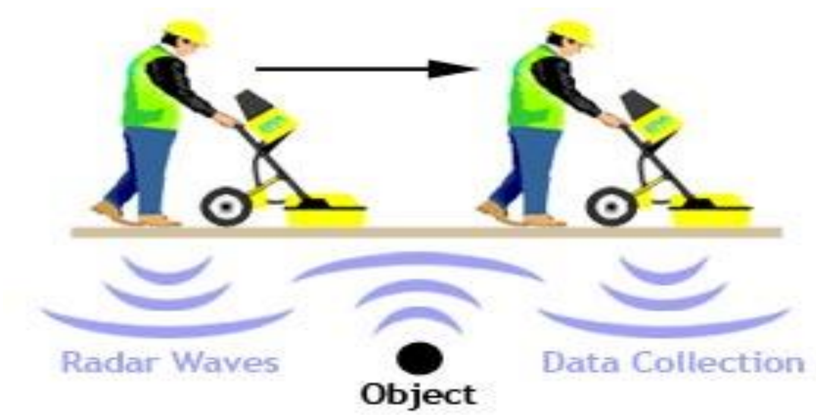
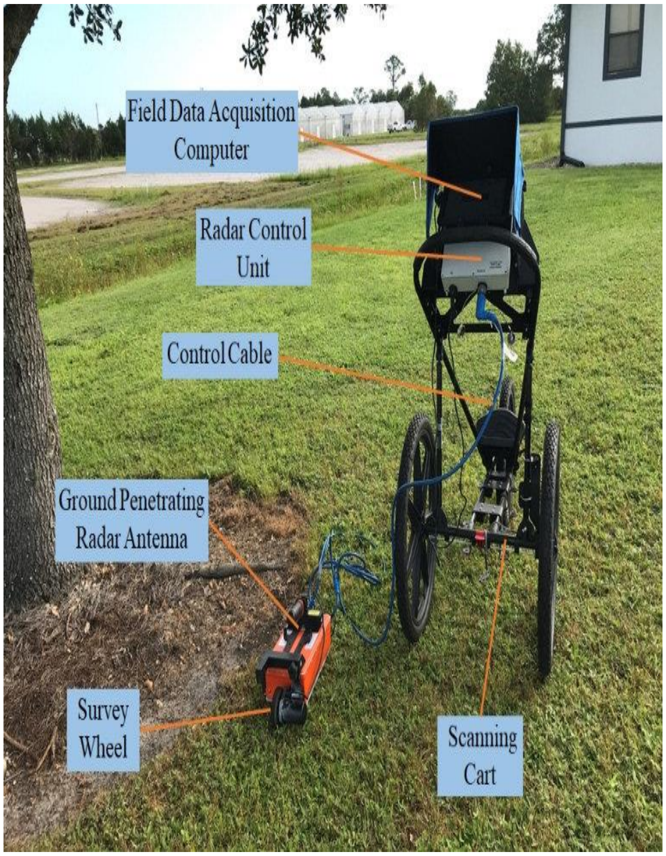
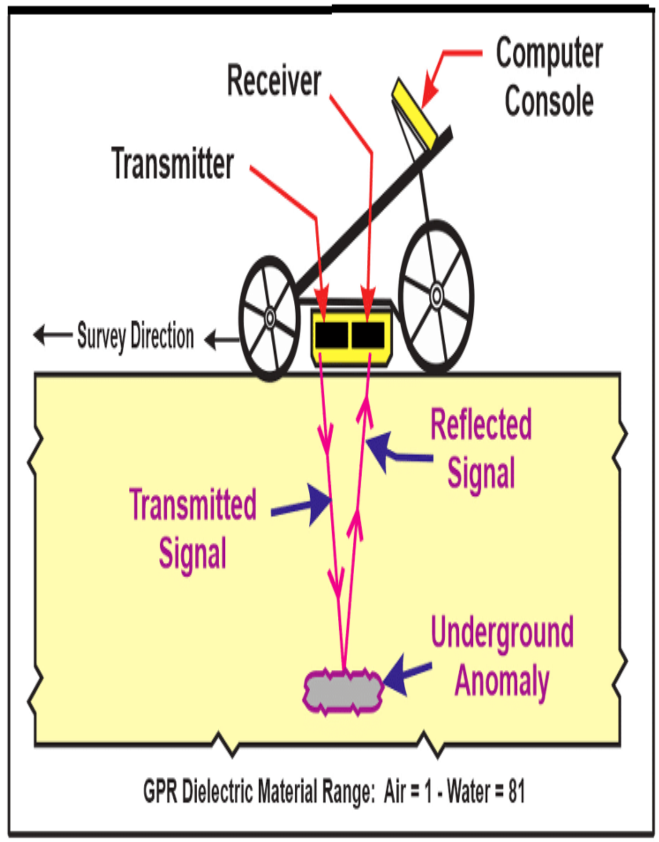


FIG::BASIC OPERATION OF GPR

➢ BASIC PRINCIPLES OF GPR





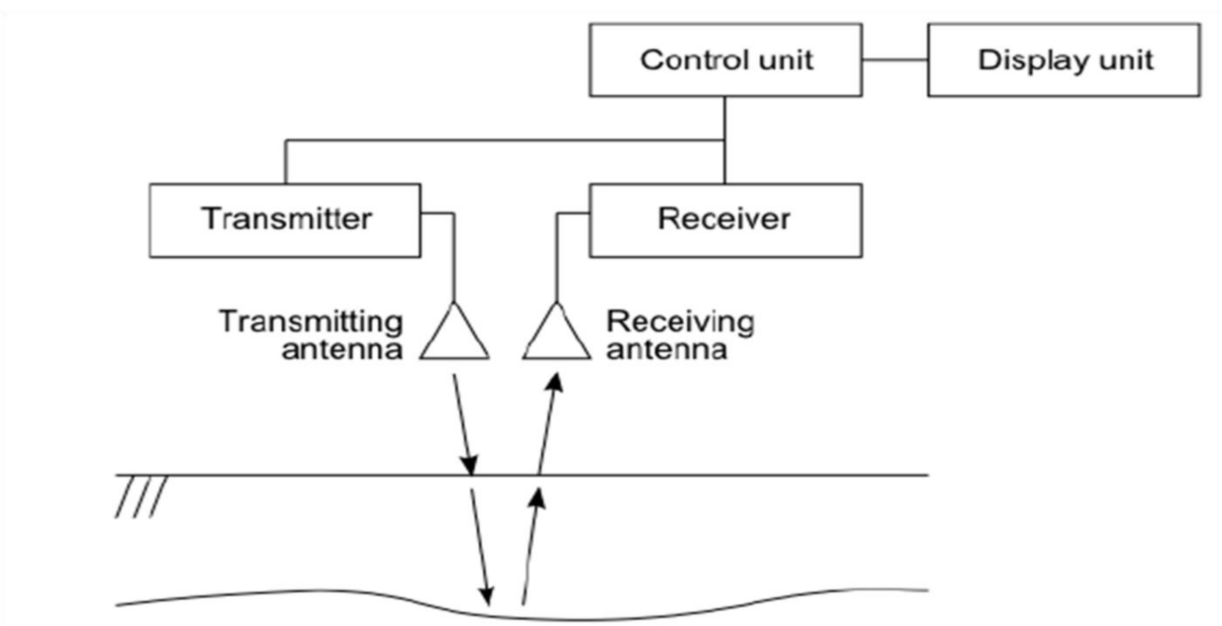


FIG-1::BASIC BLOCK DIAGRAM OF GPR

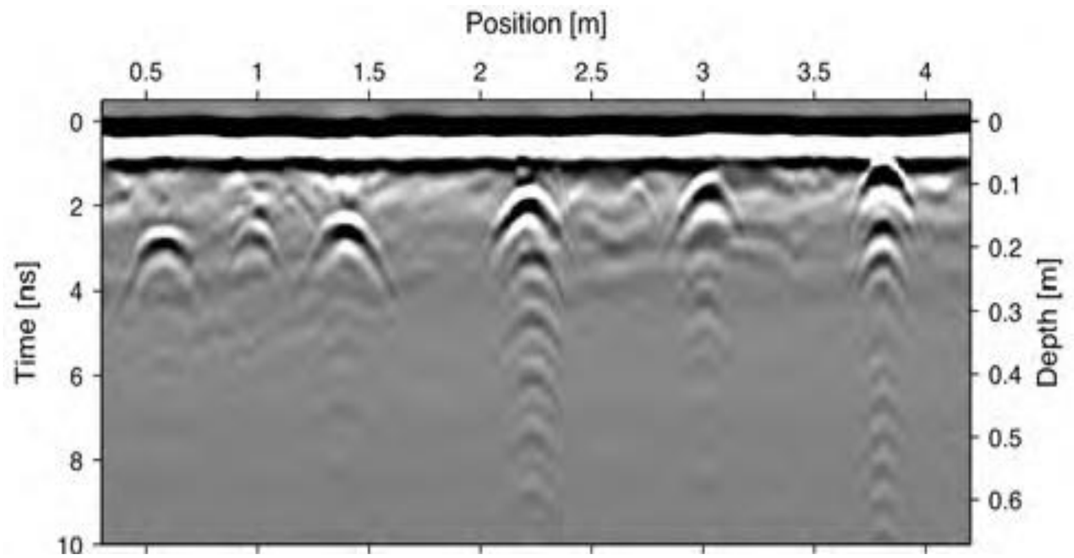


FIG-2::RESPONSE OF GPR

- A GPR system consists of a few components, as shown in Fig-1, that emit an electromagnetic wave into the ground and receive the response.
- If there is a change in electric properties in the ground or if there is an anomaly that has different electric properties than the surrounding media, a part of the electromagnetic wave is reflected back to the receiver.
- The system scans the ground to collect the data at various locations.
- Then a GPR profile can be constructed by plotting the amplitude of the received signals as a function of time and position, representing a vertical slice of the subsurface, as shown in Fig-2. .
- The time axis can be converted to depth by assuming a velocity for the electromagnetic wave in the subsurface soil.

➢ ELECTROMAGNETIC PRINCIPLES OF GPR::

Electromagnetic wave propagation in soil

The propagation velocity (v) of the electromagnetic wave in soil is characterized by the dielectric permittivity (ε)and magnetic permeability(μ)of the medium:

$$v = \frac{1}{\sqrt{\varepsilon\mu}} = \frac{1}{\sqrt{\varepsilon_0 \varepsilon_r \mu_0 \mu_r}}$$

where ε' is the dielectric polarisation term, ε'' represents the energy loss due to the polarisation lag, σ' refers to ohmic conduction, and σ'' is related to faradaic diffusion (Knight & Endres, 2005). A complex effective permittivity expresses the total loss and storage effects of the material as a whole (Cassidy, 2009):

$$\varepsilon^e = \left(\varepsilon' + \frac{\sigma''}{\omega}\right) - j\left(\varepsilon'' + \frac{\sigma'}{\omega}\right) \tag{6}$$

The ratio of the imaginary and real parts of the complex permittivity is defined as tan δ (loss tangent):

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'} \cong \frac{\sigma'}{\omega\varepsilon'} \tag{7}$$

where ε_0 = 8.854 x 10^{-12} F/m is the permittivity of free space, $\varepsilon_r = \varepsilon/\varepsilon_0$ is the relative permittivity (dielectric constant) of the medium, μ_0 = 4π x 10^{-7} H/m is the free-space magnetic permeability, and $\mu_r = \mu/\mu_0$ is the relative magnetic permeability. In most soils, magnetic properties are negligible, yielding $\mu = \mu_0$, and Eq. 1 becomes

$$v = \frac{c}{\sqrt{\varepsilon_r}} \tag{2}$$

where c = 3 x 10^8 m/s is the speed of light. The wavelength λ is defined as the distance of the wave propagation in one period of oscillation and is obtained by

$$\lambda = \frac{v}{f} = \frac{2\pi}{\omega\sqrt{\varepsilon\mu}} \tag{3}$$

where f is the frequency and $\omega = 2\pi f$ is the angular frequency.

In general, dielectric permittivity ε and electric conductivity σ are complex and can be expressed as

$$\varepsilon = \varepsilon' - j\varepsilon'' \tag{4}$$

$$\sigma = \sigma' - j\sigma'' \tag{5}$$

When ε'' and σ'' are small, it is approximated as the right most expression. In the plane-wave solution of Maxwell's equations, the electric field E of an electromagnetic wave that is travelling in z-direction is expressed as

$$E(z,t) = E_0 e^{j(\omega t - kz)} \tag{8}$$

where E_0 is the peak signal amplitude and $k = \omega\sqrt{\varepsilon\mu}$ is the wavenumber, which is complex if the medium is conductive, and it can be separated into real and imaginary parts:

$$k = \alpha + j\beta \tag{9}$$

The real part α and imaginary part β are called the attenuation constant (Np/m) and phase constant (rad/m), respectively, and given as follows:

$$\alpha = \omega\left[\frac{\varepsilon'\mu}{2}\left(\sqrt{1+\tan^2\delta} - 1\right)\right]^{1/2} \tag{10}$$

$$\beta = \omega\left[\frac{\varepsilon'\mu}{2}\left(\sqrt{1+\tan^2\delta} + 1\right)\right]^{1/2} \tag{11}$$

The attenuation constant can be expressed in dB/m by α' = 8.686α. The inverse of the attenuation constant:

$$\delta = \frac{1}{\alpha} \tag{12}$$

is called the skin depth. It gives the depth at which the amplitude of the electric field decay is $1/e$ (~ -8.7 dB, ~ 37%). It is a useful parameter to describe how lossy the medium is. Table 1 provides the typical range of permittivity, conductivity and attenuation of various materials.

Material	Relative permittivity	Conductivity [S/m]	Attenuation constant [dB/m]
Air	1	0	0
Freshwater	81	10^{-6}-10^{-2}	0.01
Clay, dry	2-6	10^{-3}-10^{-1}	10-50
Clay, wet	5-40	10^{-1}-10^{-0}	20-100
Sand, dry	2-6	10^{-7}-10^{-3}	0.01-1
Sand, wet	10-30	10^{-3}-10^{-2}	0.5-5

Table 1. Typical range of dielectric characteristics of various materials measured at 100 MHz (Daniels, 2004; Cassidy, 2009).

➢ APPLICATION::

Ground penetrating radar (GPR) is a non-destructive detection and imaging method which can be used to identify subsurface elements either underground or within a surface such as concrete.

1. **ARCHAEOLOGISTS ::**

   The ability to survey archaeological sites without having to break ground to discover the likely locations of b**uried evidence or artifacts, observe changes in soil structure,** and identify any potential damage risks.

2. **ENVIRONMENTAL STUDIES**.

   – It can play a valuable role in **Environmental Studies**.

   – It is useful for **locating buried drums and oil tanks** which could leak and contaminate the earth

3. **MILITARY**

   - Ground penetrating radar is also used by the military as a tool for **detecting unexploded items** and **detecting and mapping underground tunnels**.
   - It is often used in conjunction with other geophysical techniques along with GPS.

4. **CONSTRUCTION AND ENGINEERING**

   - GPR is used across many aspects of construction and engineering from **utility locating** to **structural assessments**.
   - As a non-destructive form of testing it is a fast, safe and efficient method for scanning.
   - It is used to **detect obstructions** in concrete such as rebar, post-tensioned cables, and conduits before cutting or coring through the concrete, meaning that engineers can identify the best location and avoid damage.
   - It can also be used to assess the damage and integrity of a structure by **detecting voids, cracks, and mapping corrosion**.
   - It also allows you to map the **depth and thickness of concrete walls or slabs**.

➢ PRINCIPLES OF MODERN RADAR:

Radar Applications is comprised of three sections:

a. **Tactical Radar,**
b. **Intelligence, Surveillance**
c. **Specialized Applications**

✓ GPR APPLICATION::

1. Detection and search:

Radar can be used in early warning systems to detect objects in the air such as surface-to-air missiles in the military.

2. Missile guidance:

Radar is used to guide missiles and other weaponry to specific targets across a long distance.

3. Biological research:

It is used to track birds and insects to trace their migration. This is also important in keeping the birds out of flight paths with an aim of preventing potential crushes by airplanes.

4. Air traffic control radar:

This is used to monitor and guide airplanes in the air and at airports.

5. Weather sensing radar:

These are used to monitor the weather patterns such as wind direction and the amount of precipitation.

6. Space probes:

They use radar signals to study the composition of the planets and objects they come across.

7. Storm forecasting:

Meteorologists use radar signals to track and forecast storms and hurricanes.

8. Radio telescope arrays:

This technology uses radar to study distant celestial bodies and to gather information regarding these bodies that help researchers to make decisions.

9. **Measuring vessel distance:**

Marine radar is also used to measure the distance between two vessels for identification and for collision avoidance

10. **Vessel traffic radar:**

These are used in ports or harbors for the purposes of monitoring and regulating ship movements in busy sea waters.

11. **Geology:**

Geologists have used specialized ground-penetrating radar to study the composition of the earth's crust.

12. **Speed radar:**

These are used by police officers on the roads to monitor the speeds of vehicles on these roads and potentially arrest over-speeding drivers

13. **Traffic radar:**

These are used by police and other traffic marshals to monitor the traffic situation on roads and advise motorists accordingly.

14. **Biological radar:**

These are mainly used to detect human body movements such as heart movements, finger gestures, and sleep patterns.

15. **Door opening:**

Some automated doors employ the use of radar signals to send instructions to the door to open or close.

16. **Light activation:**

Automated light switching use radar signals to switch the bulbs on or off.

17. **Movement detection:**

Radar signals are also used by security firms and other installments to detect movements within a building or in a room and activate alarms.

18. **Vehicle anti-Collison systems:**

Most modern vehicles have employed the use of radar signals to detect another object within a distance of 30 meters and trigger a warning to the driver of a possible collision.

19. **Vehicle parking assistance:**

Modern vehicles are designed with automatic parking assistance that gives your car the ability to self-park without instructions from the driver. This technology uses radar signals to detect objects and avoid the collision.

20. **Ground analysis:**

Radar signals are used in geophysics to study the ground and create soil profiles researchers.

21. **Radar imaging:**

Radar is also used in airports and other military installments to see through walls and other surfaces for the purposes of finding concealed weapons.

22. **Civil engineering:**

Radar is used to detect water supply lines and power cables that run through walls in the event that one needs to drill through the wall. Instead of drilling through the unseen cables and supply lines, radar devices are scanned over the area to map out where the lines run through.

23. **Surface topography**:

Radar signals are used to map out the surface topography of an area. Through radar imaging, the data sent from the surface after reflection is transferred in form of an image and this helps in creating the topography of the surface.

24. **Crustal change:**

Geologists rely on radar equipment to measure and track the change in the crustal structure and form and use this data to detect and forecast the possibility of an earthquake or the magnitude of the earthquake to be expected.

25. **Medical diagnosis:**

Radar technology is also being used in hospitals for disease diagnosis. The technology is used to scan body vitals and tell the doctors which organs have a problem in the body.

26. **Detection of meteors :**

Radar sensors are used in the detection of meteors in space and help in tracking their movements and potentially avoid any catastrophic landing on earth that would cause harm to humans.

27. **Mine inspection :**

Radar is used to carry out frequent mine inspection and in mines with an aim of preventing the collapsing of mines hence causing death and destruction. These inspections are meant to identify potential areas of weaknesses on the mine walls

28. **Navigation :**

Vessels especially sea vessels use radar signals to find direction and for navigation purposes from one place to another. Vessels especially sea vessels use radar signals to find direction and for navigation purposes from one place to another. These signals help direct the vessel towards the show or towards another vessel.

29. **Pinpointing location on earth :**

One of the most important uses of radar data is the pinpointing of positions on earth. Radar can be used to determine the exact position of an object on the surface.

30. **Population mapping :**

Radar signals are used in mapping of populations over a given geographical area. This data shows population statistics such as poverty levels and population density.

➢ ADVANTAGES

- GPR has accurate measurements
- GPR locates even small targets
- It has been well founded by the defense
- GPR operates by detecting the dielectric soils which allows it to locate even no metallic mines.
- GPR has been tested in different environmental conditions.
- Biological sensors can only operate for limited periods, but in GPR has no such limits.

➢ DISADVANTAGES

- Higher frequencies do not penetrates as far as lower frequencies(penetration is limited).
- Doesn’t work well in clay
- Terrain must be flat and even
- Interpretation of radargrams is generally complex
- Highly expensive survey method
- Cellular telephones, two-way radios, television and radio and microwave transmitters may cause noise on GPR record

➢ REFLECTION AND TRANSMISSION OF GPR WAVES

- GPR methods usually measure reflected or scattered electromagnetic signals from changes in the electric properties of materials.
- The simplest scenario is a planar boundary between two media with different electric properties as shown in Fig., which can be seen as a layered geologic structure interface between two media.

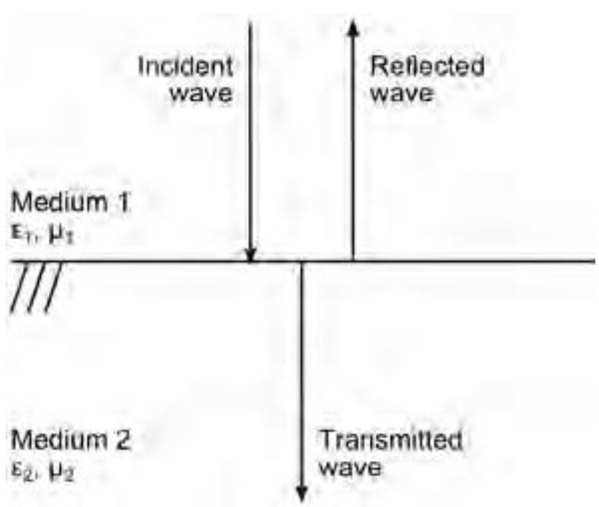


Fig. Reflection and transmission of a normally incident electromagnetic wave to a planar

- When electromagnetic waves impinge upon a planar dielectric boundary, some energy is reflected at the boundary and the remainder is transmitted into the second medium.
- The relationships of the incident, reflected, and transmitted electric field strengths are given by

$$E^i = E^r + E^t$$
$$E^r = R \cdot E^i$$
$$E^t = T \cdot E^i$$

respectively, where R is the reflection coefficient and T is the transmission coefficient. In the case of normal incidence, illustrated in Fig. 3, the reflection and transmission coefficients are given as

$$R = \frac{Z_2 - Z_1}{Z_2 + Z_1}$$

$$T = 1 - R = \frac{2Z_2}{Z_2 + Z_1}$$

where Z_1 and Z_2 are the intrinsic impedances of the first and second media, respectively, and $Z = \sqrt{\mu/\varepsilon}$. In a low-loss non-conducting medium, the reflection coefficient may be simplified as (Daniels, 2004)

$$R \cong \frac{\sqrt{\varepsilon_{r1}} - \sqrt{\varepsilon_{r2}}}{\sqrt{\varepsilon_{r1}} + \sqrt{\varepsilon_{r2}}}$$

➢ RADAR TOMOGRAPHY :

- Tomography is **imaging by sections or sectioning that uses any kind of penetrating wave**.
- The method is used in radiology, archaeology, biology, atmospheric science, geophysics, oceanography, plasma physics, materials science, astrophysics, quantum information, and other areas of science.
- A method of producing a 3D image of the internal structures of a solid object (such as the human body or the earth) by the observation and recording of the differences in the effects on the passage of waves of energy impinging on those structure.

✓ Definition of Computed Tomography(CT):

Radiography in which a 3D image of a body structure is constructed by a computer from a series of plane cross-sectional images made along an axial.

1. **INTRODUCTION TOMOGRAPHY::**

- Radar, and in particular imaging radar, has many and varied applications to security.
- Radar is a day/night all-weather sensor, and imaging radars carried by aircraft or satellites are routinely able to achieve high-resolution images of target scenes and to detect and classify stationary and moving targets at operational ranges.
- Different frequency bands may be used, for example, HF (X-band) may be used to support high bandwidths to give high range resolution, while LF is used for foliage penetration to detect targets hidden in forests, or for ground penetration to detect buried targets.
- Short-range radar techniques may be used to identify small targets, even buried in the ground or hidden behind building walls.
- Different frequency bands may be used, for example, HF (X-band) may be used to support high bandwidths to give high range resolution, while LF (HF or VHF) is used for foliage penetration to detect targets hidden in forests, or for ground penetration to detect buried targets.
- we consider the formation of high-quality radar imagery and the means by which it is possible to extract useful target information from such imagery

2. **IMAGING AND RESOLUTION TOMOGRAPHY::**

- Firstly, we can establish some of the fundamental relations for the resolution of an imaging system. In the down-range dimension resolution Δr is related to the signal bandwidth B, thus

$$\boxed{\triangle r = \frac{c}{2B}.}$$

- High resolution may be obtained either with a short-duration pulse or by a coded wide-bandwidth signal, such as a linear FM chirp or a step frequency sequence, with the appropriate pulse compression processing.

- A short-duration pulse requires a high peak transmit power and instantaneously-broadband operation; these requirements can be relaxed in the case of pulse compression. In the first instance, cross-range resolution is

$$\boxed{\triangle x = r\theta_B \approx \frac{r\lambda}{d}.}$$

➢ <u>TOMOGRAPHIC IMAGING</u>

- The techniques of tomography were developed originally for medical imaging, to provide 2D cross-sectional images of a 3D object from a set of narrow X-ray views of an object over the full 360◦ of direction.
- The results of the received signals measured from various angles are then integrated to form the image, by means of the Projection Slice Theorem.
- The Radon Transform is an equation derived from this theorem which is used by various techniques to generate tomographic images.
- Two examples of these techniques are Filtered Back projection (FBP) and Time Domain Correlation (TDC).
- In radar tomography, the observation of an object from a single radar location can be mapped into Fourier space.
- Coherently integrating the mappings from multiple viewing angles enables a three-dimensional projection in Fourier space.
- This enables a three-dimensional image of an object to be constructed using conventional tomography techniques such as wavefront reconstruction theory and back projection where the imaging parameters are determined by the occupancy in Fourier space.
- Complications can arise when target surfaces are hidden or masked at any stage in the detection process.
- This shows that intervisibility characteristics of the target scattering function are partly responsible for determining the imaging properties of moving target tomography.
- In other words, if a scatterer on an object is masked it cannot contribute to the imaging process and thus no resolution improvement is gained.
- However, if a higher number of viewing angles are employed then this can be minimized.

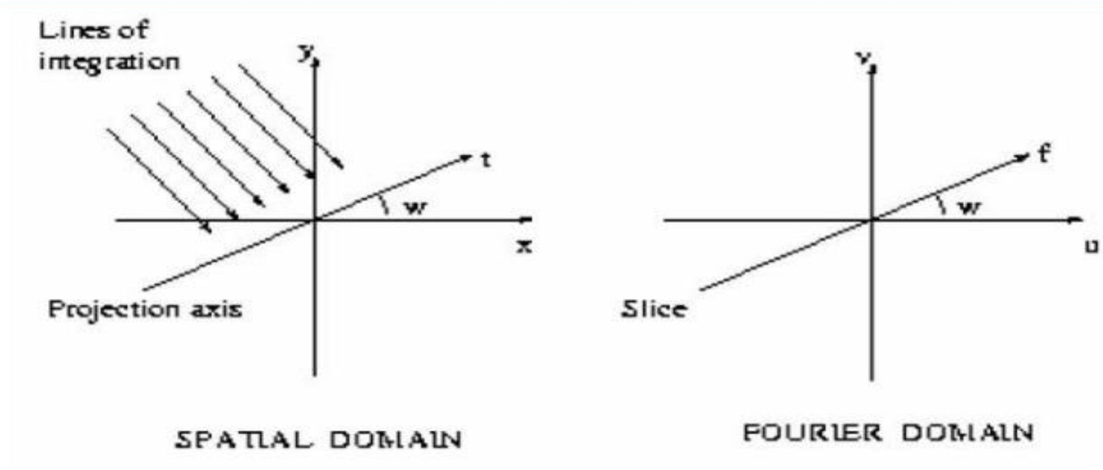


Figure 3. Tomographic reconstruction: the Projection Slice Theorem.

- Further complications may arise if (a) the point scatterer assumption used is unrealistic (as in the case of large scatterers introducing translational motion effects), (b) the small-angle imaging assumption does not apply and (c) targets with unknown motions (such as non-uniform rotational motions) create cross-product terms that cannot be resolved.

➢ THE PROJECTION SLICE THEOREM (USED TOMOGRAPHIC IMAGING)

- The Tomographic Reconstruction (TR) algorithm makes use of the Projection-Slice theorem of the Fourier transform to compute the image.
- The Projection-Slice theorem states that the 1D Fourier transform of the projection of a 2D function g (x, y), made at an angle w, is equal to a slice of the 2D Fourier transform of the function at an angle w, see Figure 3.
- Whereas some algorithms convert the outputs from many radars simultaneously into a reflectivity image using a 2D Fourier transform, TR generates an image by projecting the 1D Fourier transform of each radar projection individually back onto a 2D grid of image pixels.
- This operation gives rise to the term Back projection.
- The image can be reconstructed from the projections using the Radon transform. The equation below shows this:

$$
\begin{aligned}
g(x, y) &= \int_0^{\pi} \int_{-\infty}^{\infty} P(f) \cdot |f| \cdot e^{j2\pi f(x\cos w + y \sin w)} df\, dw \qquad (4) \\
\text{where} \quad w &= \text{projection angle} \\
P(f) &= \text{the Fourier transform of the 1-D projection } p(t).
\end{aligned}
$$

- ✓ The Filtered Back projection (FBP) method may be used to process by reconstructing the original image from its projections in two steps:
    a) Filtering projection
    b) Back projection.

✓ ***Filtering the projection:***

- The first step of FB Preconstruction is to perform the frequency integration (the inner integration) of the above equation.
- This entails filtering each of the projections using a filter with a frequency response of magnitude |f|.
- The filtering operation may be implemented by ascertaining the filter impulse response required and then performing convolution or an FFT/IFFT combination to correlate p(t) against the impulse response.

✓ ***Back projection:***

- The second step of FB Preconstruction is to perform the angle integration (the outer integration) of the above equation.
- This projects the 1D filtered projection p(t) onto the 2D image by following these steps:
- place a pixel-by-pixel rectangular grid over the XY plane, then place the 1D filtered projection p(t) in position at angle w for each pixel, then get the position of the sample needed from the projection angle and pixel position.
- Interpolate the filtered projection to obtain the sample.
- Add this back-projection value multiplied by the angled spacing. Repeat the whole process for each successive projection.

➢ TOMOGRAPHY OF MOVING TARGETS::

- The development of these concepts has been the idea of imaging moving targets using measurements from a series of multistate CW or quasi-CW transmissions, giving rise to the term ‘ultra-narrow band’ (UNB) radar.
- This may be attractive in situations of spectral congestion, in which the bandwidth necessary to achieve high resolution by conventional means (equation (1)) may not be available.
- Narrow band CW radar is also attractive as peak powers are reduced to a minimum, sidelobes are easier to control, noise is reduced and transmitters are generally low cost.
- Applications may range from surveillance of a wide region to the detection of aircraft targets, to the detection of concealed weapons carried by moving persons.
- In general, the target trajectory projection back to a given radar location will determine resolution.
- A random trajectory of constant velocity will typically generate differing resolutions in the three separate dimensions.
- However, even if there is no resolution improvement there will be an integration gain due to the time series of radar observations.
- A Hamming window or similar may be required to reduce any cross-range sidelobe distortions.
- The treatment which follows is taken from that of Bonneau, Bascom, Clancy, and Wicks Figure 4 shows the relationship between the bistatic sensor geometry and the representation in Fourier space.
- The bistatic angle is B and the bistatic bisector is the vector uB. The corresponding vector F in

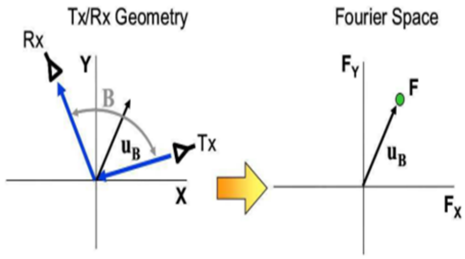


Figure 4. Relationship between bistatic sensor geometry and representation in Fourier space (after [3]).

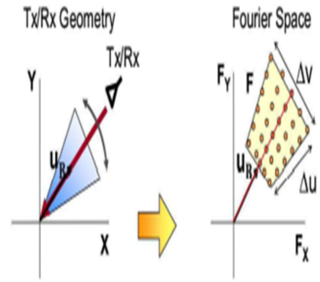


Figure 5. Fourier space sampling and scene resolution for a monostatic SAR (after

Fourier space is given by

$$F = \frac{4\pi f}{c} \cos\left(\frac{B}{2}\right) u_B \tag{5}$$

Figure 5 shows the equivalent relationship for a monostatic geometry. The resolutions are inversely proportional to the sampled extents Δu and Δv in Fourier space, thus

$$\Delta r = \frac{2\pi}{\Delta u} \qquad \Delta x = \frac{2\pi}{\Delta v} \tag{6}$$

which should be compared to equations (1),(2) and (3).

In a UNB radar, the finite bandwidth of the radar signal limits the range resolution.

However, this resolution can be recovered by multi-static measurements over a range of angles.

Fig.6 shows 4 example: and the Fourier space sampling corresponding to each.

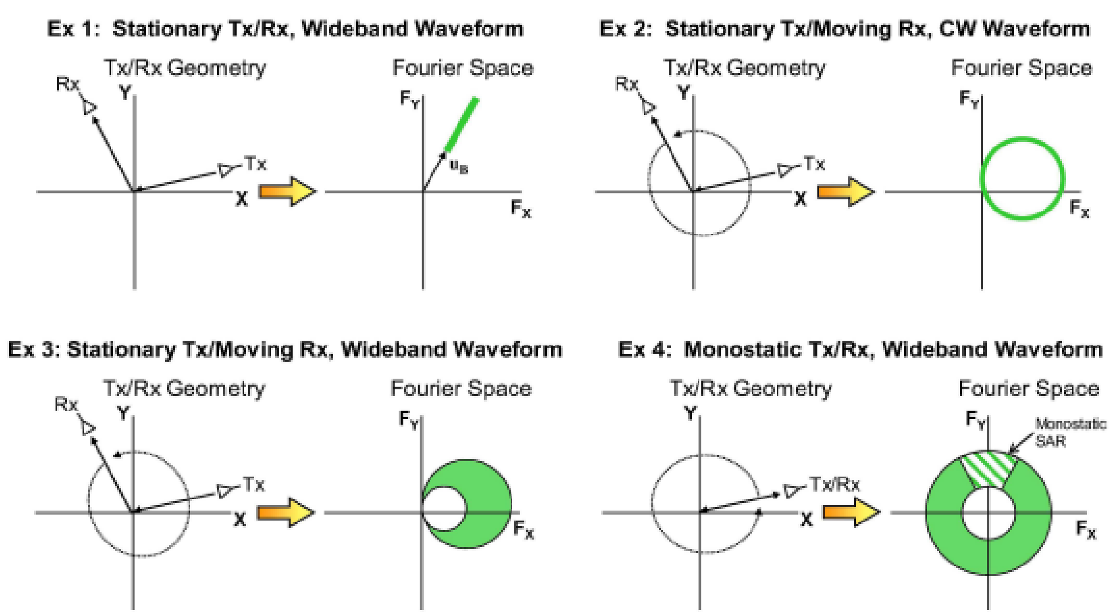
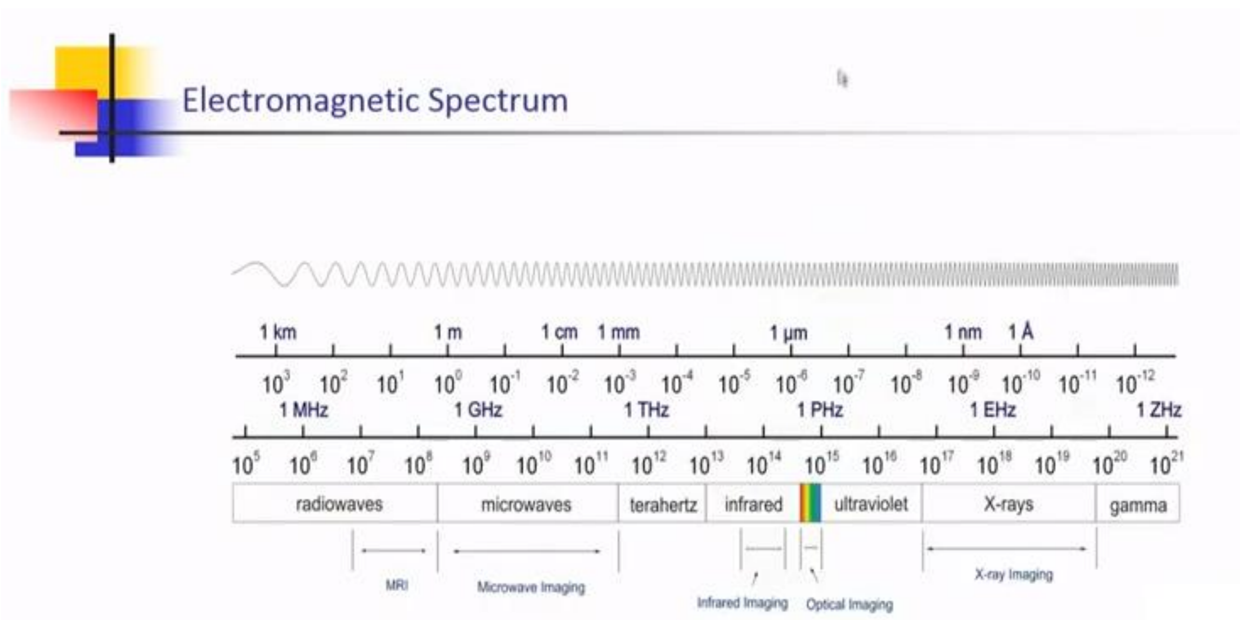


Figure 6. Fourier space sampling and scene resolution for four examples: (i) stationary tx/rx, wideband waveform; (ii) stationary tx, moving rx, CW waveform; (iii) stationary tx, moving rx, wideband waveform; (iv) monostatic tx/rx, wideband waveform (after [3]).

➢ <u>**MICROWAVE IMAGING RADAR::**</u>

- Similar to an optical flash camera but at a radio wavelength.
- A Flash camera
  - sends out a pulse of light(the flash)
  - record on film the back reflected light captured by lens
- <u>**Microwave imaging Radar::**</u> uses antenna and digital computer
- <u>**Microwave image::**</u>
  - Any image is composed of many picture elements(Pixels).Each pixel in the Radar image represents the Radar backscatter for that area on the target.
  - Back scatter depends on area
    a. Darker area in the image represents low back scatter
    b. Brighter area in the image represents high back scatter
    c. Flat surfaces appear dark in Radar images.
    d. Vegetation appears grey in radar image
    e. Wet object appears bright and dry targets appear dark
- <u>**Microwave imaging radar frequency spectrum**</u>



MICROWAVE IMAGING SETUP

- It consists of several antennas located around the body to be imaged.
- One antenna transmits at a time: it is connected to the transmitter and the scattered signal from the body is collected by the rest of the antennas that are connected to the receiver.

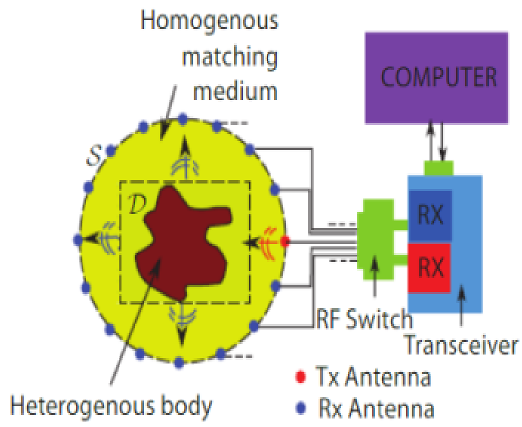


Fig 5: Basic setup of Microwave Imaging

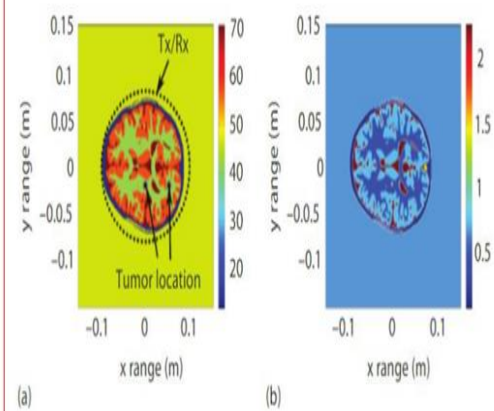
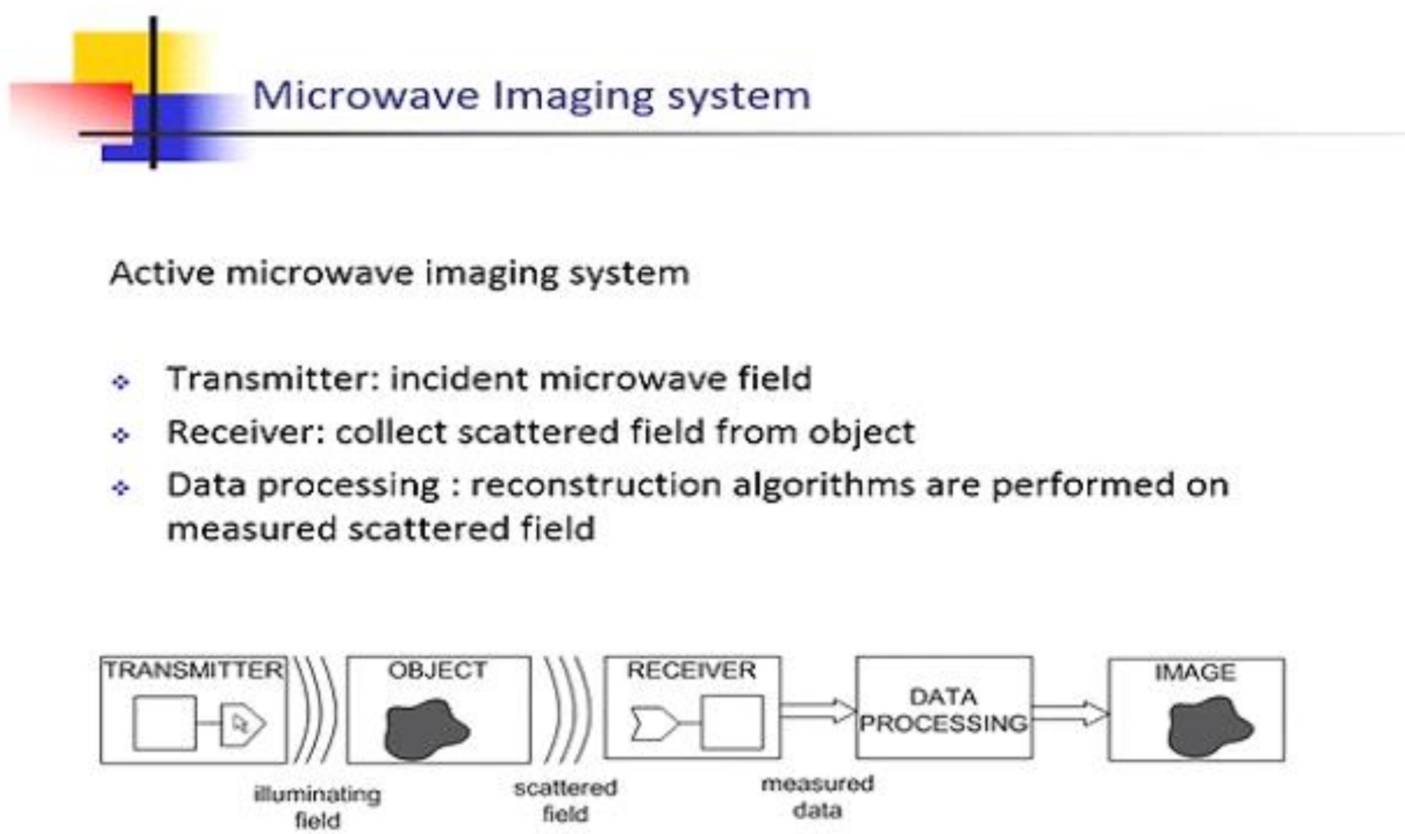


Fig 6: Example for brain tumor detection



➢ WORKING OF MICROWAVE IMAGING RADAR

- Usually, there is an RF switch that quickly switches between different antennas, such that all or some antennas act as a transmitter while the rest of the antennas are connected to the receiver.
- Between the antennas and the body, there is a homogeneous matching medium. The matching medium helps in reducing the reflections by coupling the signal to the body.
- This is because of the fact that, in the absence of the matching medium, a high reflection may occur between the tissue and the medium, which is the air in which the antenna system is kept.
- This would result in a weak signal that could penetrate the body.
- Hence, a matching medium helps in reducing this reflection, and the basic setup for microwave imaging in a two-dimensional case is when one antenna (TX) transmits the signal and all other antennas (RX) are in receiving mode.
  - D-bounded Domain
  - S-measurement Domain
- The imaging domain contains the heterogeneous body to be imaged.
- E measurement domain contain the transmit and receive antennas.
- The whole system is in a homogeneous medium that acts as a matching medium. The RF switch switches between different antennas, such that all or some antennas act as a transmitter while the rest of the antennas are connected to the receiver.
- The transceiver is connected to a computer to which the collected signal data is transferred. The computer also executes the imaging algorithm.

➢ MICROWAVE IMAGING ALGORITHMS

Microwave Imaging algorithms can be divided into 2 categories, namely,

1) Quantitative and

2) Qualitative.

Quantitative imaging algorithms

- It generate the image with the distribution of the electrical properties of the body.
- On the other hand, qualitative imaging algorithms generate the image of the intensity of the scattered signal that shows the location of the strong scatterer as the tumor.

Quantitative Imaging Algorithms

- Quantitative imaging is also called tomography.
- The microwave tomography problem is formulated in terms of electric fields.
- To formulate the problem, two domains are defined:
- bounded domain (D) and the measurement domain ().
- The bounded domain is a domain in which the body to be imaged is enclosed.
- The antennas are located in the measurement domain.

Three electric fields are defined for the purpose:

1) The incident field E_{inc} on D,
2) The total field E_{total} in D, and
3) The scattered field E_{scatt} on S.

QUALITATIVE IMAGING ALGORITHMS

- Qualitative imaging algorithms are similar to radar-based algorithms where the objective is to detect strong scattering objects.
- In case of medical microwave imaging, the malignant or the tumorous tissue is a strong scatterer due to higher dielectric properties than the surrounding tissues.
- Various radar-based imaging algorithms to focus the tumour, such as confocal microwave imaging, beam forming, and tissue sensing adaptive radar are used.
- Ultra-wideband (UWB) signal is used for qualitative imaging to have a good time resolution.
- In qualitative imaging, each antenna transmits a short pulse at a time (UWB in frequency domain), and the backscatter response is received by the same antenna.
- The backscatter response consists of the tumour response, scatter from the skin, and backscatter from other tissues.

- Signal processing is used to reduce the effect of the skin and the backscatter from other tissue, to enhance the signal backscattered by the tumour.

For example,

- In confocal microwave imaging, the processed backscattered waveform at each of the antennas is integrated over time to obtain Bt integrated waveforms,
    - ✓ Where t is the number of the transmit antennas.
- The reconstructed image is then created by time-shifting and summing data.

- **MERITS**

  i. Includes low cost
  ii. use of safer non-ionizing radiation
  iii. The ability to image bulk-electrical tissue properties.
  iv. The ability to provide functional imaging without the use of contrast agents...

- **DEMERITS**

The images obtained from Microwave Imaging are low spatial resolution images

- **APPLICATIONS**

  I. Non-destructive testing and evaluation.
  II. medical imaging (brain stroke monitoring and cancer detection).
  III. concealed weapon detection at security checkpoints.
  IV. structural health monitoring, and 5. Through-the-wall imaging.

Imaging Techniques	Frequency Range	Radiation Safety	Image Resolution	Cost
X-Ray	3*10^16 to 3*10^19 Hz	High	Low	Low
CT scanning	3*10^16 to 3*10^19 Hz	Very High	Moderate	High
MRI	10 to 300M Hz	Low	Moderate	High
Microwave Imaging	300 MHz to 300 GHz	Low	High	Low

Table 1: Comparison table for different medical Imaging techniques