Bharathidasan University

Tiruchirappalli – 620 023, Tamil Nadu

6 Yr. Int. M.Tech. Geological Technology and Geoinformatics

Course Code : **MTIGT0902**

Thermal and Microwave Remote Sensing

Unit-3 : Microwave Remote Sensing-Basics

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Course Objectives

- To study the principles of thermal remote sensing
- To learn the interpretations and applications of thermal band
- To study the principles of microwave remote sensing
- To study about the space borne radar remote sensing and the sensors
- To learn about the applications of microwave remote sensing.

MTIGT0902 - Syllabus

Unit:1. Thermal Remote Sensing: Principles - Definition - Radiant temperature - Black body radiation - Thermal Emissivity of materials - Thermal energy interaction with atmosphere and terrain elements - Kinetic and radiant temperature - Thermal energy detectors - Thermal radiometers - Thermal scanners and data collection. **16 hrs.**

Unit:2. Interpretation and Application of Thermal data: Day time and night time thermal data behaviour and manifestation of objects - Thermal inertia - thermography and heat loss - geometric characteristics of thermal scanner imagery (scale distortion, relief displacement, flight parameters distortion) - Radiometric calibrations- SST and LST mapping- application of thermal remote sensing in urban climate, soil moisture and environmental studies. **12 hrs.**

Unit:3. Microwave Remote Sensing: Basic principles - RADAR systems - SLAR operations - Antennas (receivers), Spatial resolution - geometric characters of SLAR imagery (Slant Range and distortion, relief displacement, parallax) - influence of earth surface features over Radar energy (geometry, electrical property, soils, vegetation, water, etc.) - interpretation of Radar imagery. **12 hrs.**

Unit:4. Space Borne Radar Sensing: Seasat - SIR - ERS-I - Radarsat - JERS - Elements of passive microwave remote sensing (sensors) - applications of LIDAR and ALTM. **12 hrs.**

Unit:5. Applications of Microwave Remote Sensing: Applications of Microwave remote sensing in Earthquake study; Din-SAR, Surface and subsurface Lithological Mapping - Paleo channel mapping. SAR Interferometry and its applications. **12 hrs.**

Unit:6. Current Contours: (Not for Final Exam; only for Discussion): Change Detection Analysis: Urban Heat Island, Sea surface Temperature Mapping, Land Surface Temperature Mapping- Mapping of hard rock fracture system. Microwave Remote Sensing: Mapping of subsurface lithology.

References:

1. American Society of Photogrammetry, Manual of Remote Sensing (2nd Edition), ASP Falls Church, Virginia, 1983.
2. Curran, P. Principles of Remote Sensing, Longman, London.1985.
3. Barrett, E.C. and L.R. Curits, introduction To Environmental Remote Sensing, Halstged Press, Wiley, New York.1976.
4. Lillisand, T.M. and Kiefer, P.W, Remote Sensing and Image interpretation, John Wiley&Sons, New York.1986.
5. Lintz, J. and Simonett L.S. (Eds.), Remote Sensing of Environment, Addition-Wesley, Readings, Mass.1976.
6. Lo. C.P. Applied Remote Sensing, Longman, London.1986.
7. Richadson, B.F.Jr.(Ed), Introduction To Remote Sensing of The Environment, Kendall / Hunt, Dubuque, Iowa.1978.
8. Sabins, F.F.Jr., Remote Sensing Principles and interpretation, Freeman, Sanfrancisco.1978.
9. Schanda,E. (Ed), Remote Sensing for Environmental Science, Springerverlag.1976.
10. Burney, S.S Application of Thermal Imaging, Adam Hilger Publications.1988.
11. Hord R.Michel, Remote Sensing Methods and Application, John Wiley and Sons.1986.
12. Drury S.A, A Guide to Remote Sensing - interpreting Images of Earth, Oxford Science Publications, Oxford.1990.
13. Floyd M. Henderson; Principles & Applications of Imaging Radar, John Wiley & Sons, New York, 1998.
14. Alexay Bunkin& Konstantin Volia. K, - Laser Remote Sensing of the Ocean Methods & Publications. John & Wiley & Sons, New York, 2001.

Course Outcomes:

1. Students will learn about the difference among reflection, scattering and emission from earth materials.
2. Students will understand the principles of thermal and microwave remote sensing.
3. Students will come to know the applications of thermal and microwave remote sensing.
4. Students will learn about application of microwave remote sensing in earthquake field.
5. Students will understand the LIDAR and ALTM applications
6. Students will also learn about application of microwave data in subsurface lithological mapping.

UNIT - 3

Microwave Remote Sensing

Definition:

- Study of Earth’s surface, above surface and shallow subsurface features using the Electromagnetic radiation in the microwave wavelength region (1mm – 1m) through the sensors fitted in the satellites, aircrafts or any other similar platforms is known as Microwave remote sensing.

Microwave Sensors

ACTIVE & PASSIVE

Radar Altimeter sends out pulses of microwave signals and record the signal scattered back from the earth surface. The height of the surface can be measured from the time delay of the return signals.

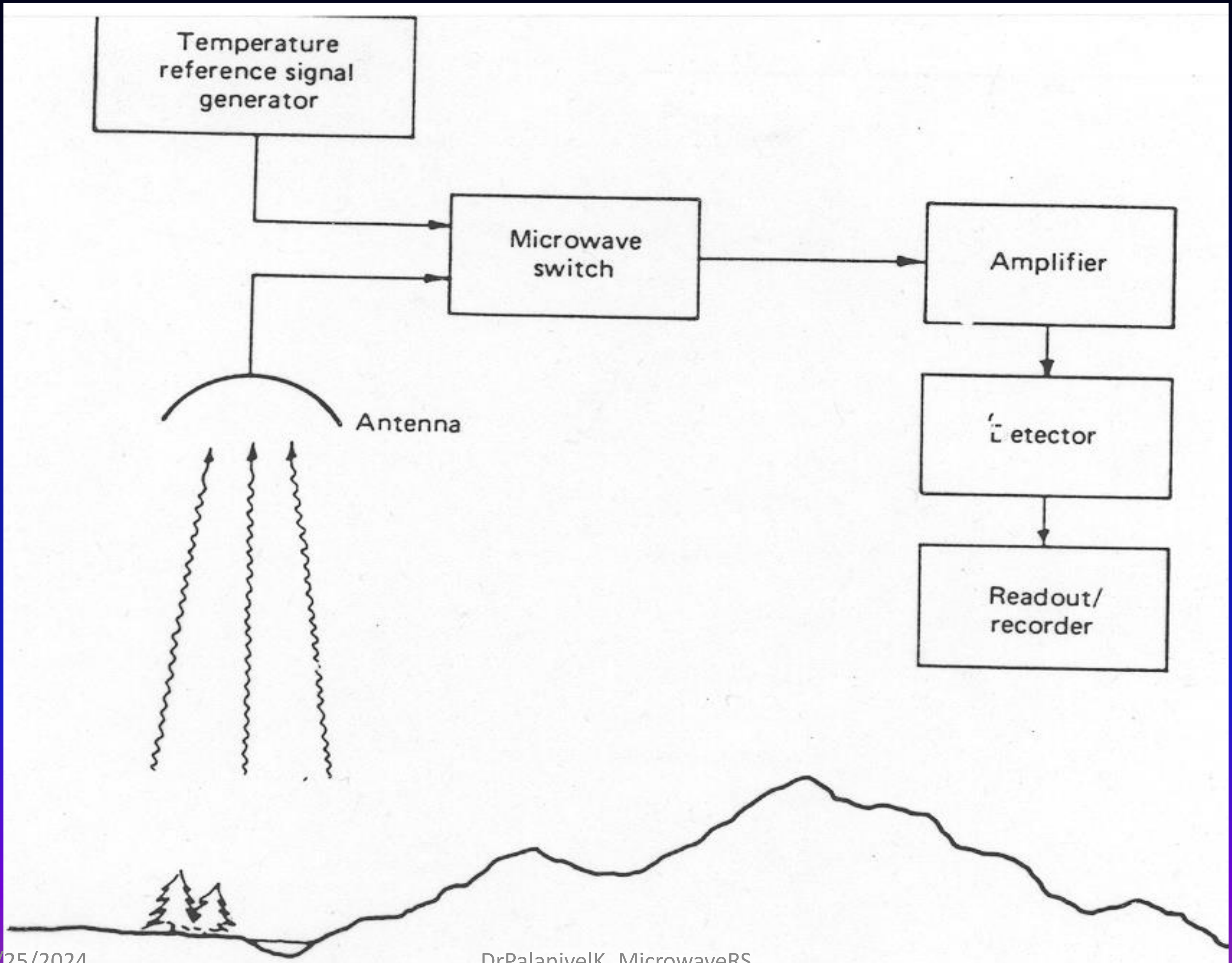
Scatterometer can be used to measure the amount of energy backscattered from the target, from that the quantum….such as, Rainfall, wind - it's speed and direction.

Microwave Radiometer

- Naturally emitted microwave energy will be sensed and recorded. Natural emission of an object depends on the **total water content** and **temperature**. The received energy may be
(1) emitted by the atmosphere, (2) reflected from the surface,
(3) emitted from the surface, or (4) transmitted from the subsurface.

NON-IMAGING & IMAGING

Mechanism – Passive Microwave Sensors

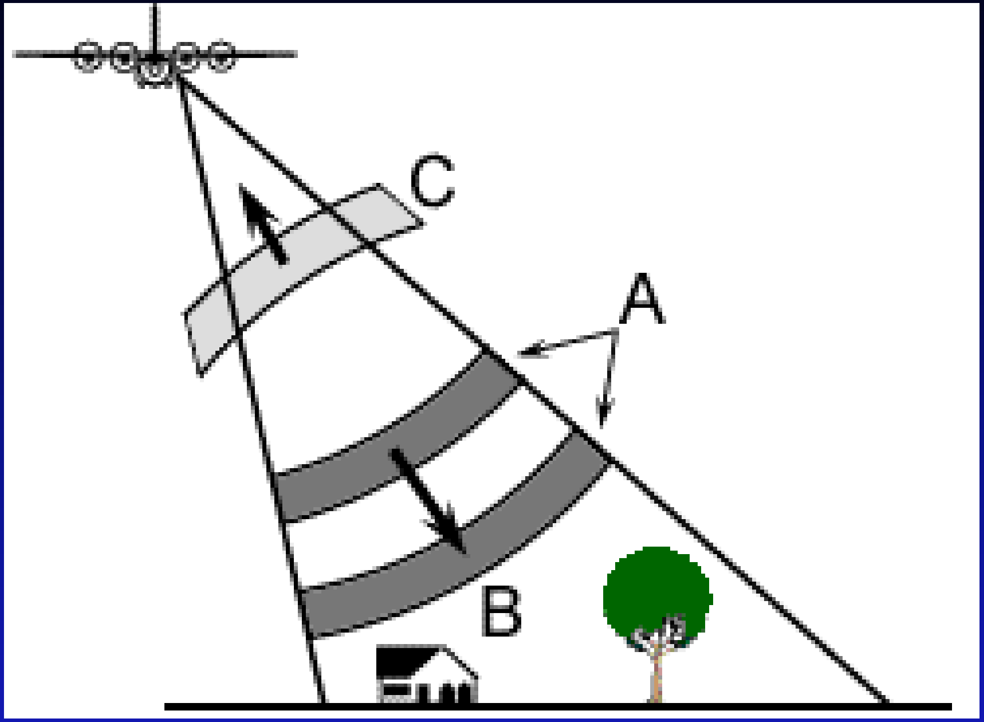


Active Sensors – Microwave R.S ...contd...

- A **wind scatterometer** sends out pulses of microwaves along several directions and records the magnitude of the signals backscattered from the ocean surface.
- The magnitude of the backscattered signal is related to the ocean surface roughness, which in turns is dependent on the sea surface wind condition, and hence the wind speed and direction can be derived.
- Space borne platforms to generate high resolution images of the earth surface using microwave energy.

RADAR (RAdio Detection And Ranging)

Radar is a Ranging & Distance measuring device

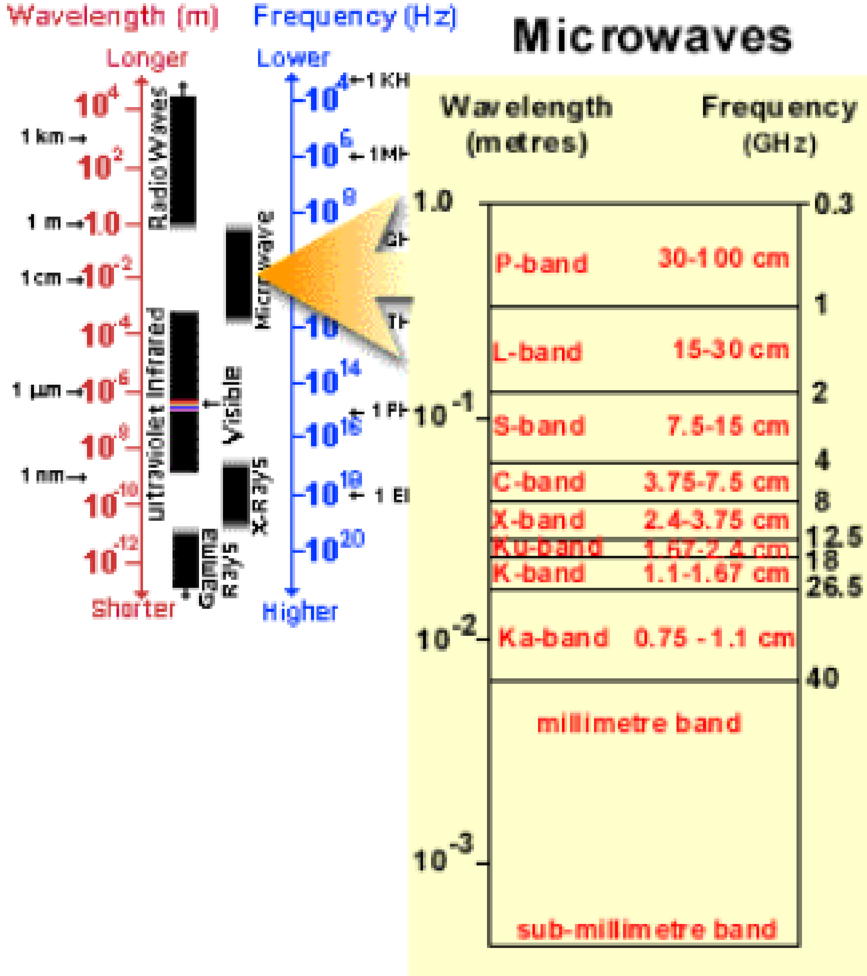


It consists of

1. Transmitter which sends successive pulses of Micro wave energy (A)
2. Antenna focuses into a beam (B)
3. This radar beam obliquely illuminates the surface perpendicular to the flight line
4. Antenna receives back scattered energy (C)

Microwave Spectrum

- The portion of the spectrum of more recent interest to remote sensing is the microwave region from about **1mm to 1m.**
- This covers the longest wavelengths used for remote sensing.
- The shorter wavelengths have properties similar to the thermal infrared region while the longer wavelengths approach the wavelengths used for radio broadcasts.
- **The remote sensing using microwave spectrum is termed as microwave sensing**



RADAR SPECTRAL RESOLUTION & FREQUENCY RANGES

S. No.	Band	Wavelength (cm)	Frequency range in GHz (10^9 cycles/second)
1	Ka-band	0.71 – 1.1	26.5 – 40.0 (old /uncommon now)
2	K-band	1.1 – 1.67	18.0 – 26.5 (-do-)
3	Ku-band	1.67 – 2.4	12.5 – 18.0 (-do-)
4	X-band	2.4 – 3.75	8.0 – 12.5 (Air Borne-army)
5	C-band	3.75 – 7.5	4.0 – 8.0 (NASA-AIRsir– ERS, RADARSAT)
6	S-band	7.5 – 15.0	2.0 – 4.0 (Russian ALMAZ)
7	L-band	15.0 – 30.0	1.0 – 2.0 (SEASAT, JERS)
8	P-band	30.0 – 100.0	0.3 – 1.0 (NASA Air Borne research)

Synthetic Aperture Radar (SAR)

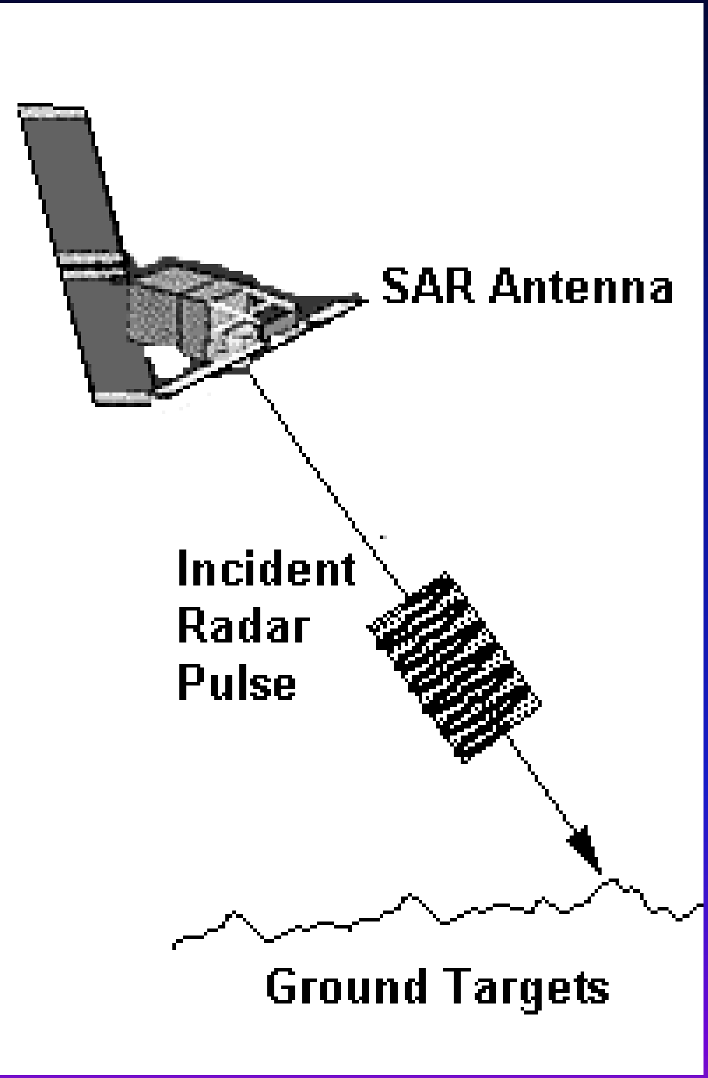
- In Synthetic Aperture Radar (SAR) imaging, microwave pulses are transmitted by an antenna towards the earth surface.
- The microwave energy scattered back to the spacecraft is measured.
- The SAR makes use of the radar principle to form an image by utilizing the time delay of the backscattered signals.

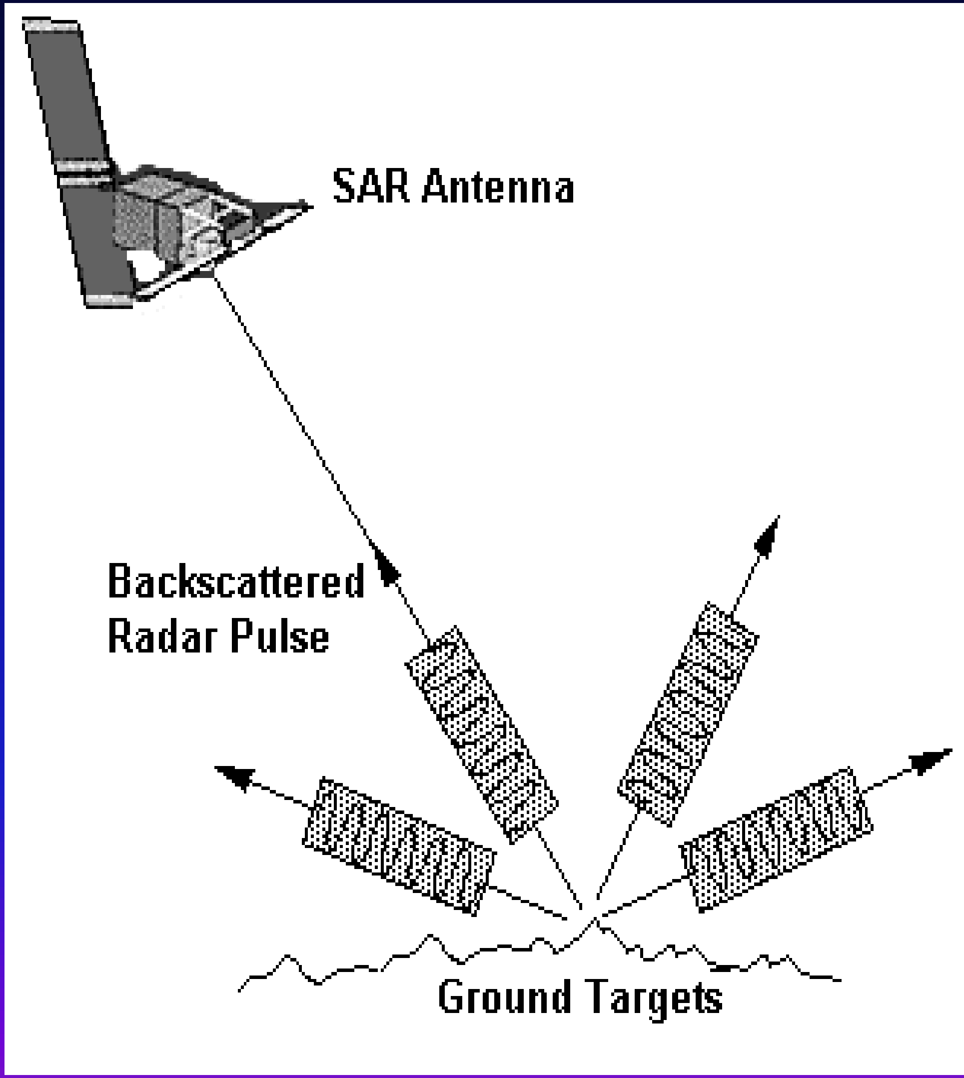
Interaction between Microwaves and Earth's Surface

When microwaves strike a surface, the proportion of energy scattered back to the sensor depends on many factors like:

- Physical factors such as the dielectric constant of the surface materials which also depends strongly on the moisture content;
- Geometric factors such as surface roughness, slopes, orientation of the objects relative to the radar beam direction;
- The types of landcover (soil, vegetation or man-made objects).
- Microwave frequency, polarisation and incident angle.

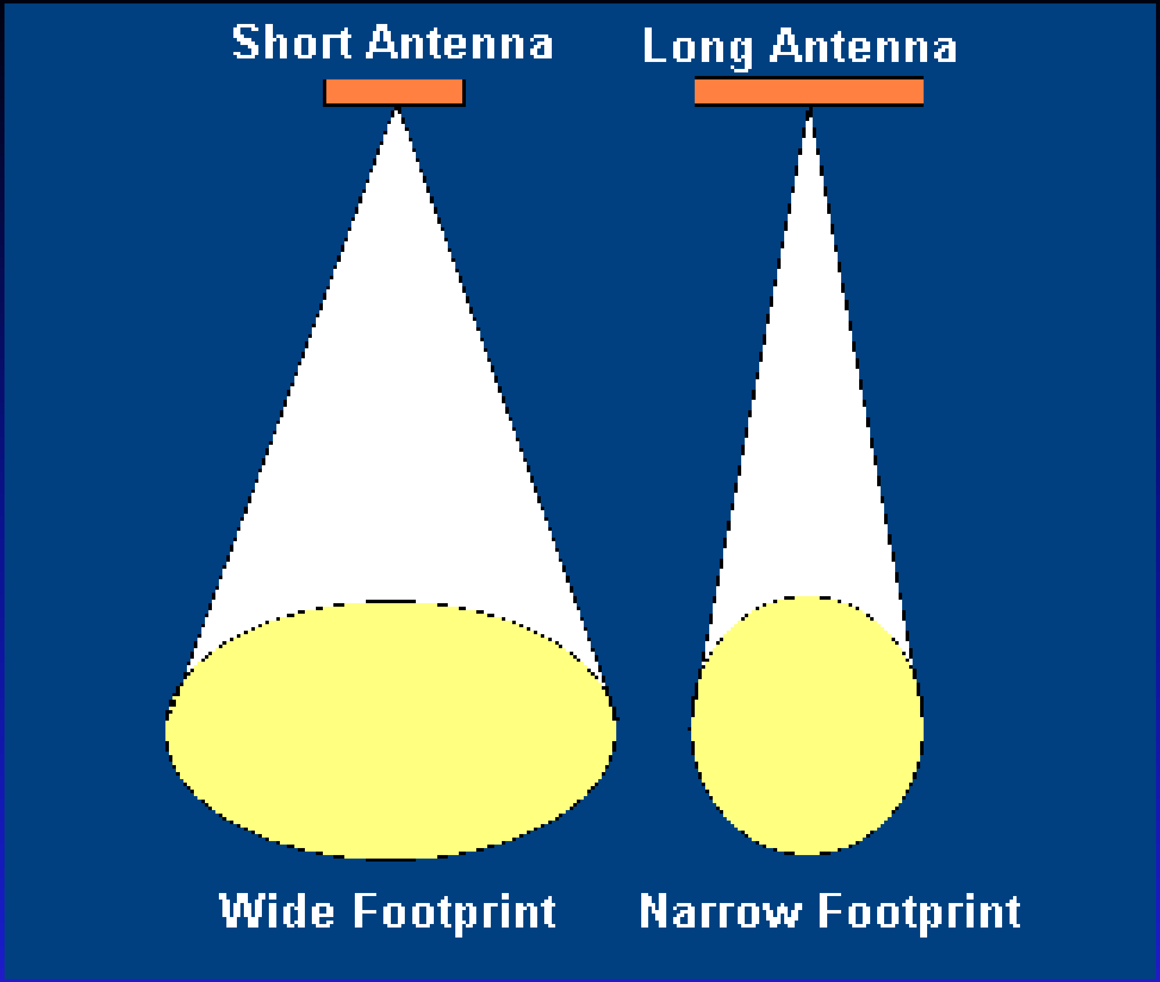
Interaction between Microwaves and Earth's Surface



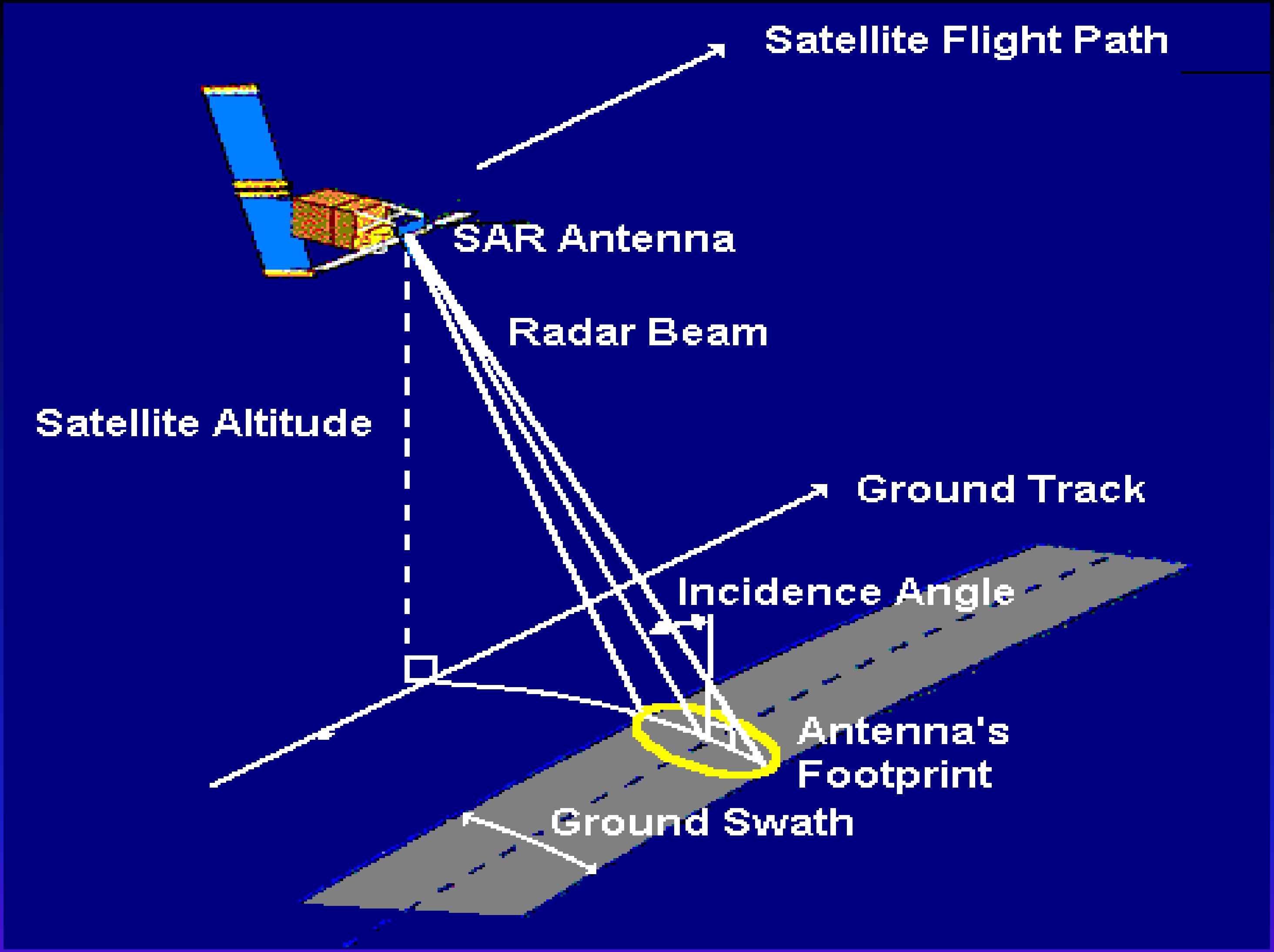


- In real aperture radar imaging, the ground resolution is limited by the size of the microwave beam sent out from the antenna.
- Finer details on the ground can be resolved by using a narrower beam.
- The beam width is inversely proportional to the size of the antenna, i.e. the longer the antenna, the narrower the beam.

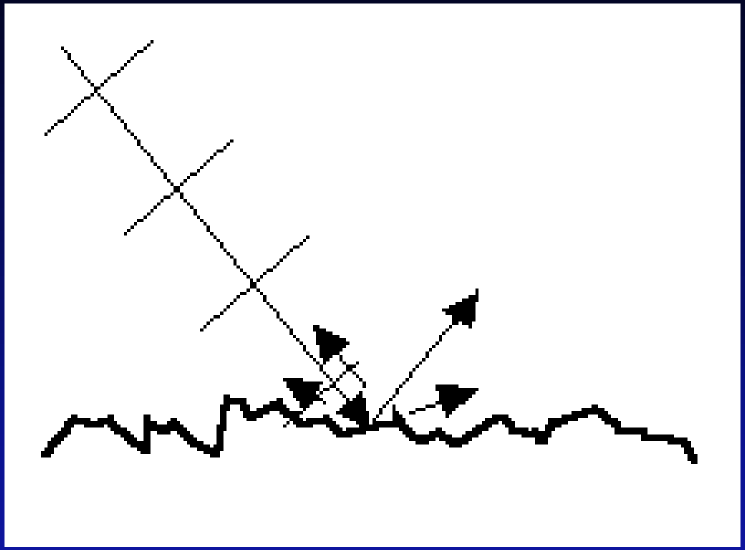
- The microwave beam sent out by the antenna illuminates an area on the ground (known as the antenna's "footprint").
- In radar imaging, the recorded signal strength depends on the microwave energy backscattered from the ground targets inside this footprint.
- Increasing the length of the antenna will decrease the width of the footprint.

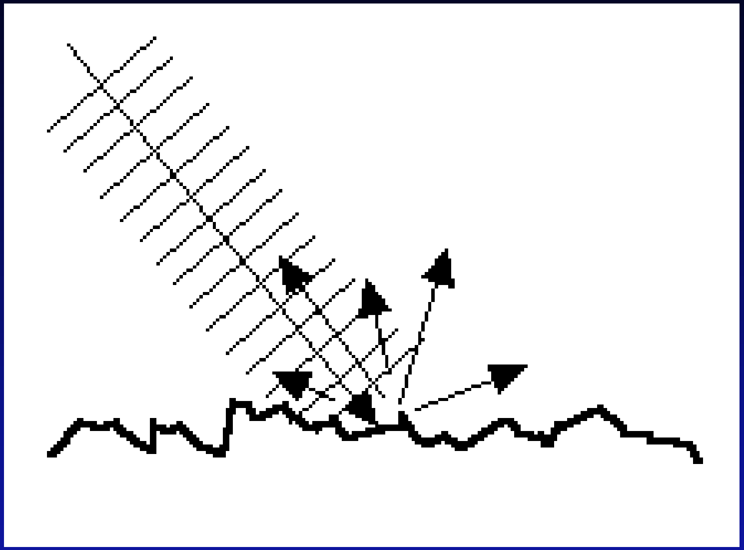


It is not feasible for a spacecraft to carry a very long antenna which is required for high resolution imaging of the earth surface. To overcome this limitation, SAR capitalises on the motion of the space craft to emulate a large antenna (about 4 km for the ERS SAR) from the small antenna (10 m on the ERS satellite) it actually carries on board



Imaging geometry for a typical strip-mapping synthetic aperture radar imaging system. The antenna's footprint sweeps out a strip parallel to the direction of the satellite's ground track.





The land surface appears smooth to a long wavelength radar. Little radiation is backscattered from the surface.

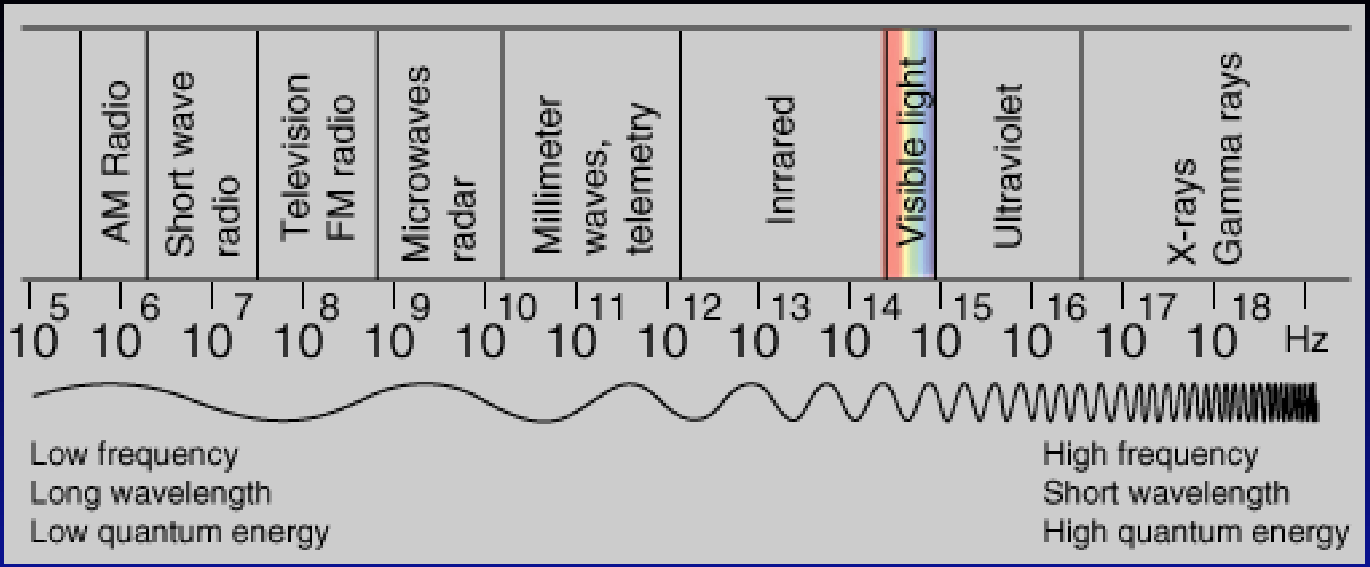
The same land surface appears rough to a short wavelength radar. The surface appears bright in the radar image due to increased backscattering from the surface.

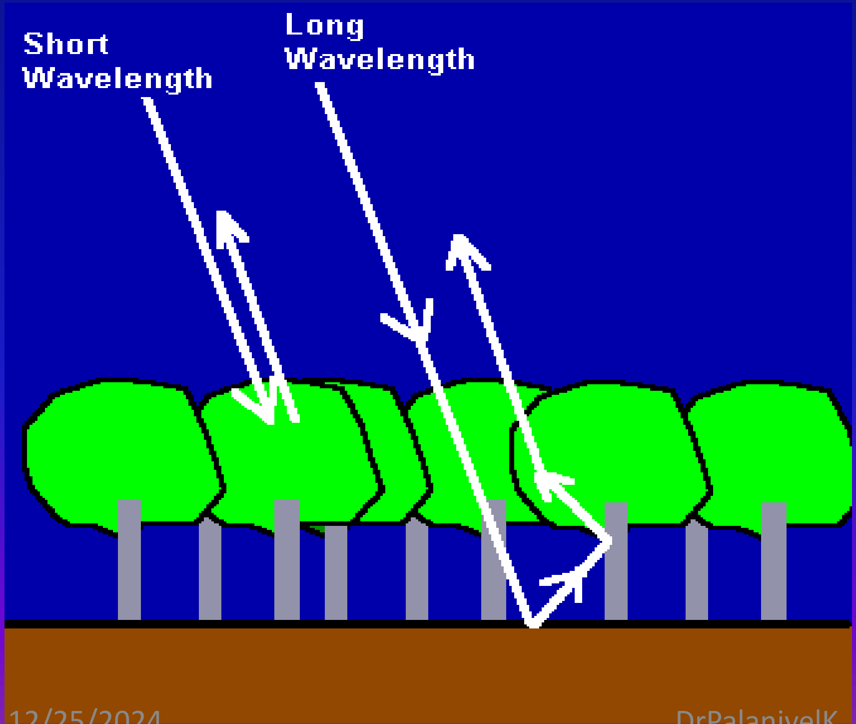
- Little radiation is backscattered from a surface with a fluctuation of the order of 5 cm if a L-band (15 to 30 cm wavelength) SAR is used and the surface will appear dark.
- However, the same surface will appear bright due to increased backscattering in a X-band (2.4 to 3.8 cm wavelength) SAR image.

- Both the ERS and RADARSAT SARs use the C band microwave(3.75-7.5 cm) while the JERS SAR uses the L band.
- The C band is useful for imaging ocean and ice features. However, it also finds numerous land applications.
- The L band has a longer wavelength and is more penetrating than the C band.
- Hence, it is more useful in forest and vegetation study as it is able to penetrate deeper into the vegetation canopy.

C – BAND
(3.75 - 7.5 cm)

L – BAND
(15 - 30 CMS)





- Microwave region
  - 300 MHz – 30 GHz.

Millimeter wave

  - 30 GHz – 300 GHz.

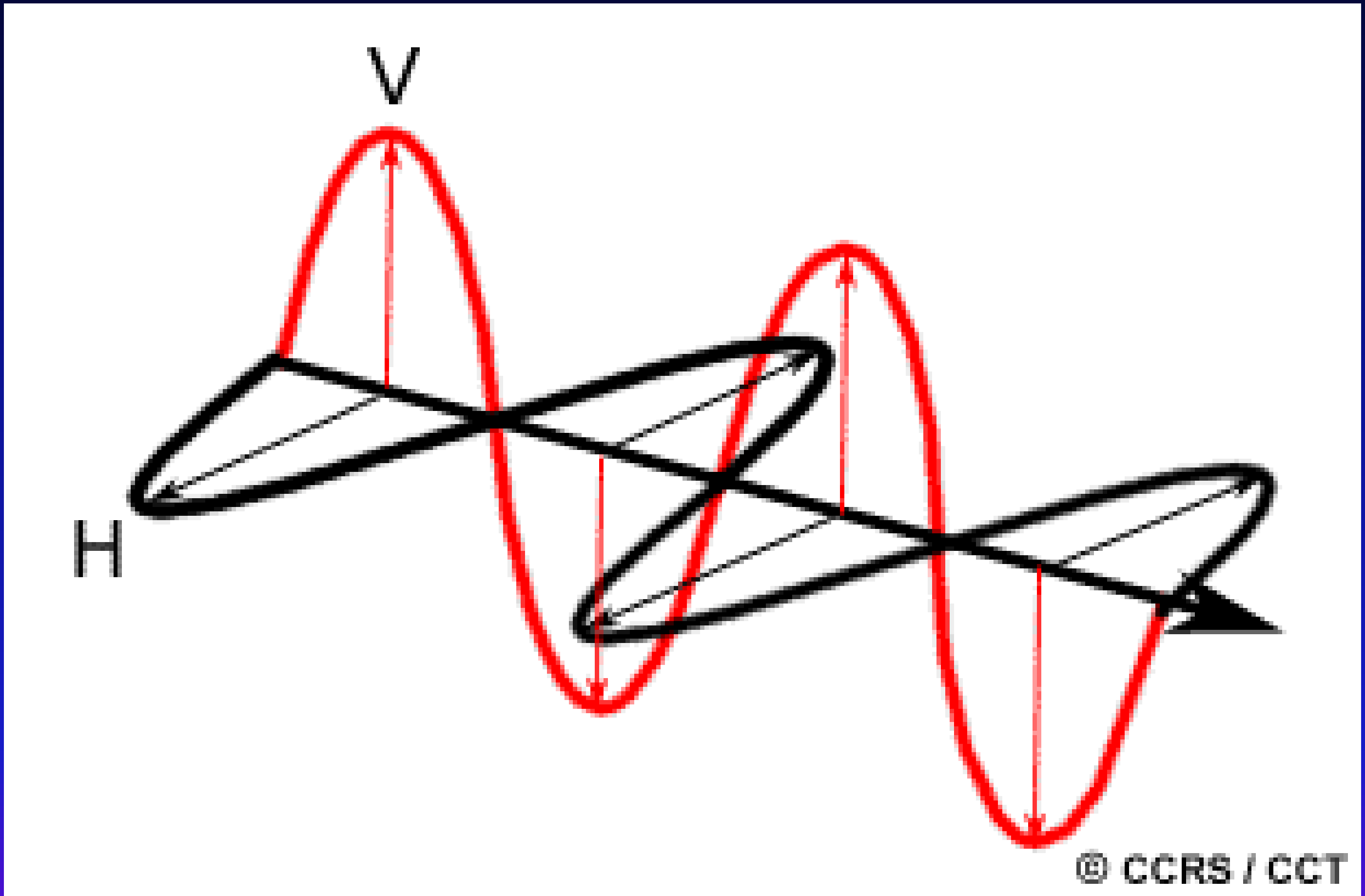
Microwave Polarisation in Synthetic Aperture Radar

- The microwave polarisation refers to the orientation of the electric field vector of the transmitted beam with respect to the horizontal direction.

- If the electric field vector oscillates along a direction parallel to the horizontal direction, the beam is said to be "**H**" polarised.

- On the other hand, if the electric field vector oscillates along a direction perpendicular to the horizontal direction, the beam is "**V**" polarised.

METHOD OF ENERGY PROPOGATION IN RADARS



V – VERTICAL

H – HORIZONTALLY POLARISED

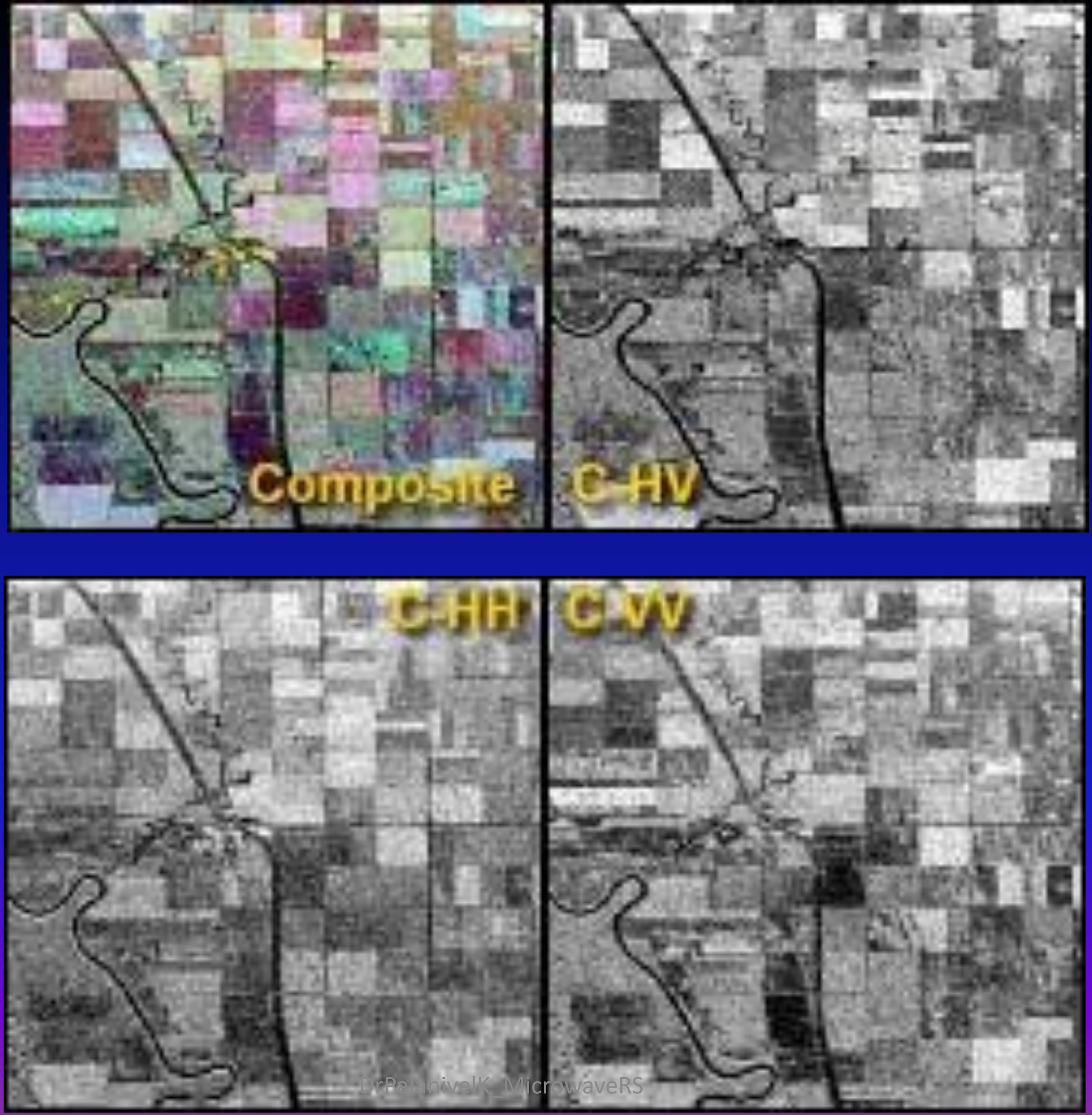
BOTH TRANSMISSION & RECEPTION

Thus, there can be four combinations of transmission & reception.

Transmission	Reception	Like Polarised	Cross Polarised
H	H	HH	HV
V	V	VV	VH

Compo-
site

HV



HH

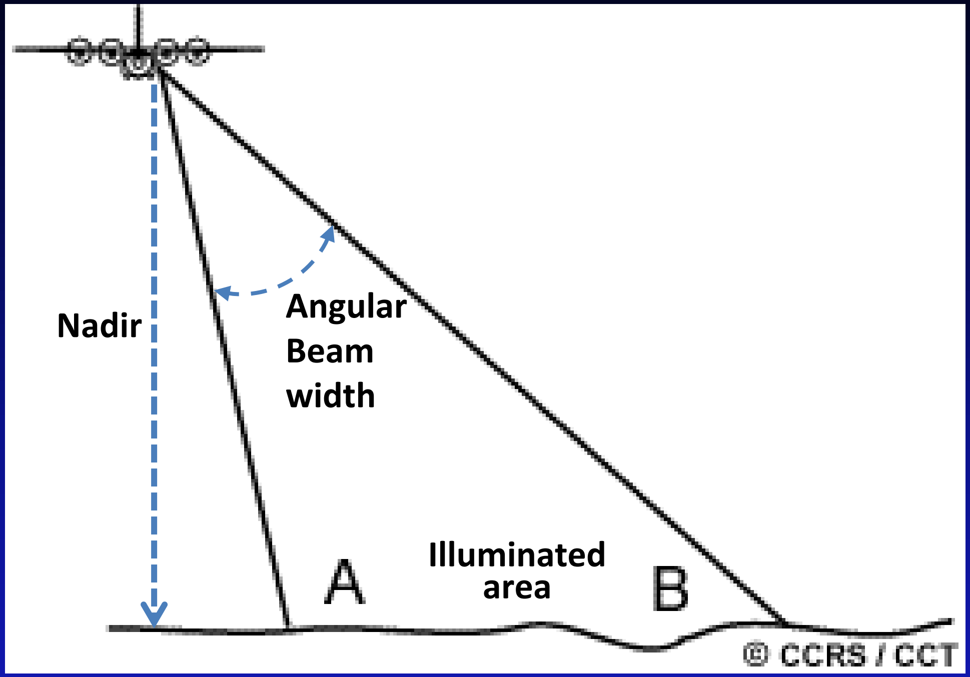
VV

SPATIAL RESOLUTION OF ‘SLAR’

- Controlled by pulse length and Antenna band width
- This cause two types of Resolution

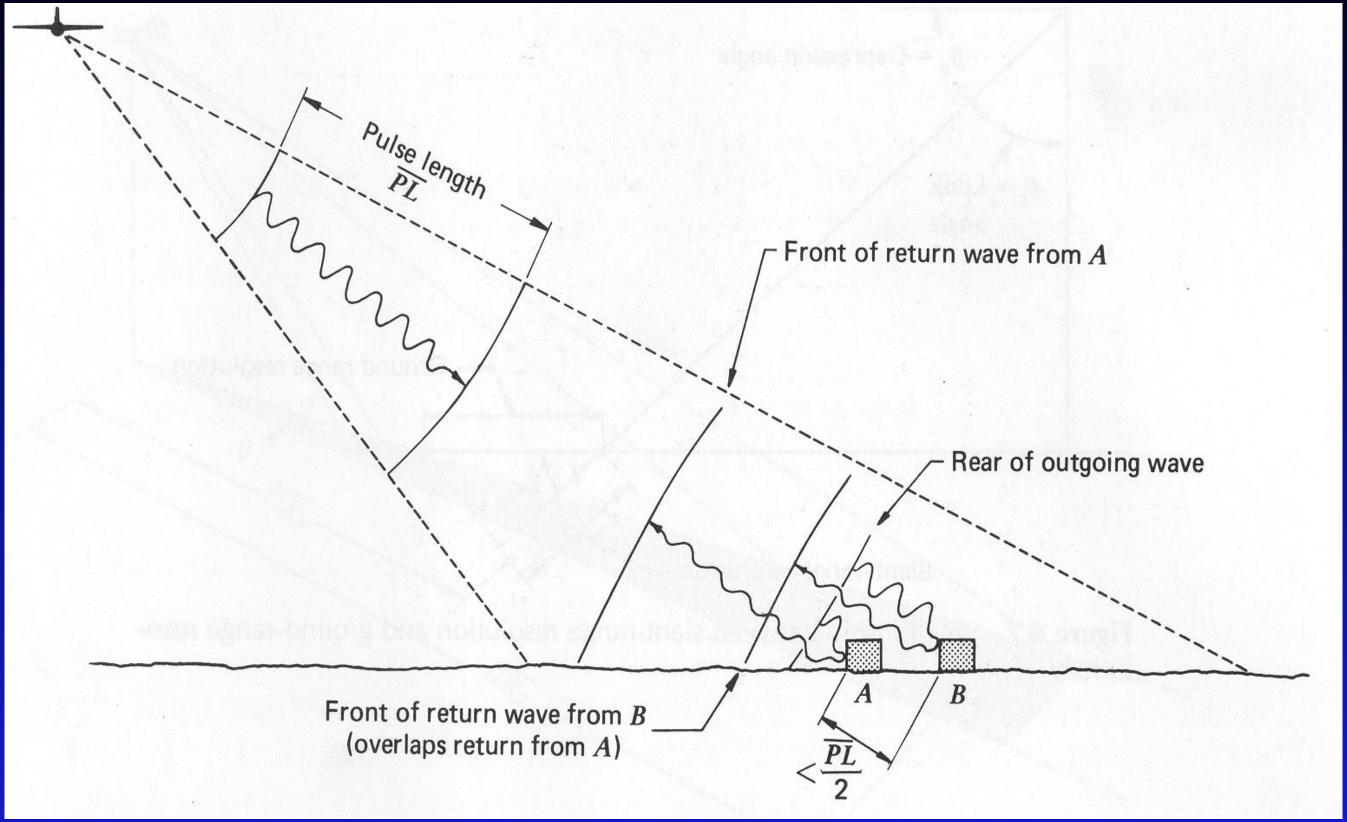
(1) Range Resolution

(2) Azimuth Resolution



The portion of the image swath closest to the nadir track of the radar platform is called the near range (A) while the portion of the swath farthest from the nadir is called the far range (B).

RANGE RESOLUTION

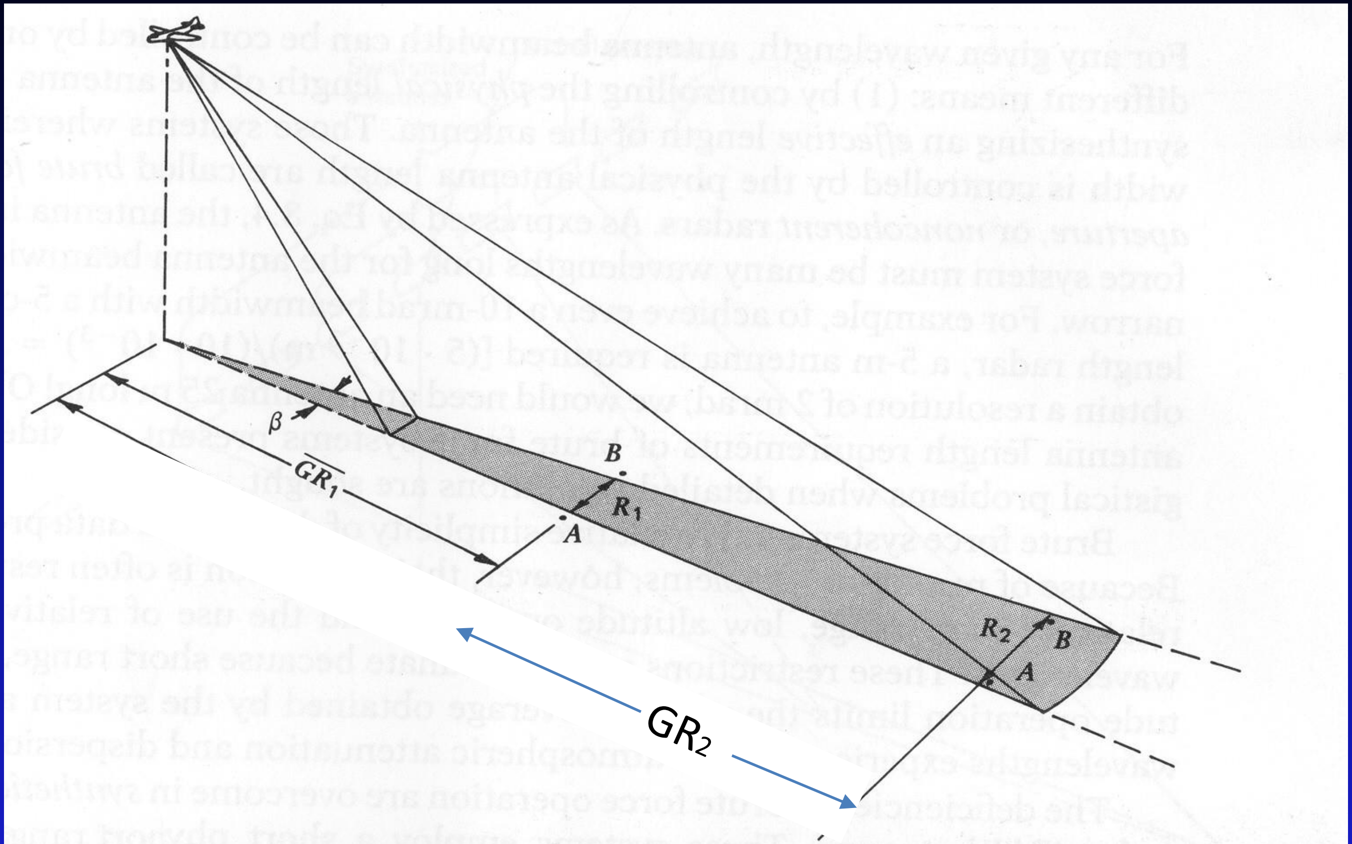


- ➔ The back scattered energy from different object should reach the antenna at different times

- ➔ If few objects are located between a distance less than the half of the Pulse Length (i.e., O_D <PL/2), then the signals will get mixed & cause blurred image.

- ➔ PL/2 is **Range or Slant Rage Resolution**

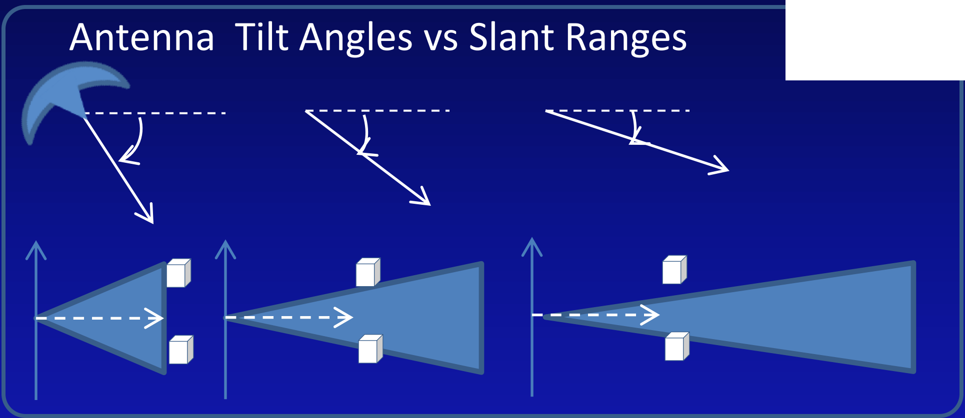
AZIMUTH RESOLUTION

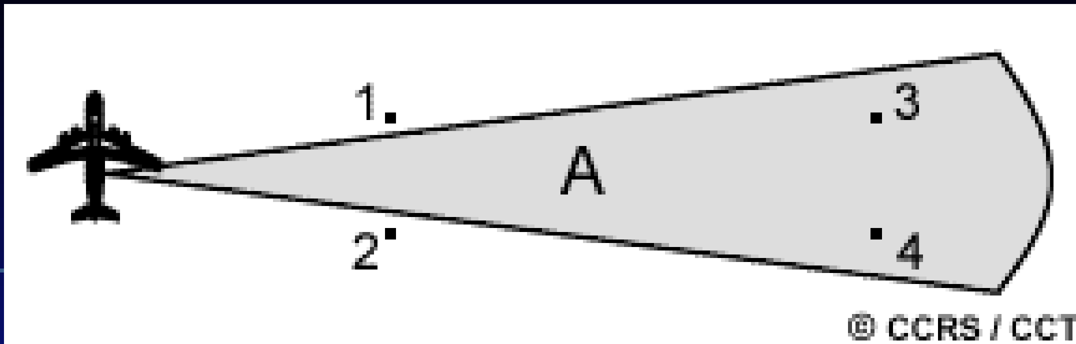


Dependence of azimuth resolution (R_a) on antenna beamwidth (β) and ground range ($\overline{GR}$).

- ➔ Depends on angular beam width (β) and Ground range (GR)
- ➔ A and B at GR_1 will be better resolved and at GR_2 not
- ➔ This is called Azimuth Resolution

The **azimuth** or **along-track resolution** is determined by the angular width of the radiated microwave beam and the slant range distance.





Foot Prints in different Slant Ranges

This **beam width (A)** is a measure of the width of the illumination pattern.

As the radar illumination propagates to increasing slant range distance from the sensor, the azimuth resolution increases (becomes coarser).

In this illustration, targets 1 and 2 in the near range would be separable, but targets 3 and 4 at further range would not.

The radar beam width is inversely proportional to the antenna length (also referred to as the aperture) which means that a longer antenna (or aperture) will produce a narrower beam and finer resolution.

6.7 RADAR IMAGE QUALITY

The Image Quality Depends on the

SYSTEM PARAMETERS

- → Polarization
- → Depression Angle
- → Wave Length

TERRAIN CHARACTERISTICS

- → Dielectric Constant
- → Surface Roughness

TYPES OF POLARISATION

LIKE POLARISATION	------	HH & VV
CROSS POLARISATON	------	HV & VH

Water and Trees → Same Sign in Both Like & Cross Polarised Images

Swamps → Bright in Like & Dark in Cross

Grass Land → Dark in Like & Bright in Cross

DEPRESSION ANGLE

LESS /VERTICAL

------- Stronger Return Energy

MORE ANGLE

------- Weak Return / Diffuse

WAVE LENGTH

LONGER ------- Stronger Specular

Reflection / No Return Energy

SHORTER ------- More Return Energy / But

Often Attenuated

TERRAIN CHARACTERISTICS

DI ELECTRIC CONSTANT

- Dielectric Constant (k) is a unitless number relating the ability of a material to carry alternating current to the ability of vacuum to carry alternating current.
- The capacitance created by the material is directly related to the Dielectric Constant of the material.

- **Depth of Penetration / Reflection is Dependent on Wave Length & DEC**
  - ✓ **LESS DEC   MORE PENETRATION**
  - ✓ **MORE DEC   LESS PENETRATION**
  - ✓ **DRY ROCK   3 - 8, WATER - 80.**
- **More the DEC, better the reflectivity.**

SURFACE ROUGHNESS

FLAT AND SMOOTH ----- Specular Reflection

RUGGED ----- Diffuse Reflection, Buildings, etc.

ANGULAR ----- Corner Reflection

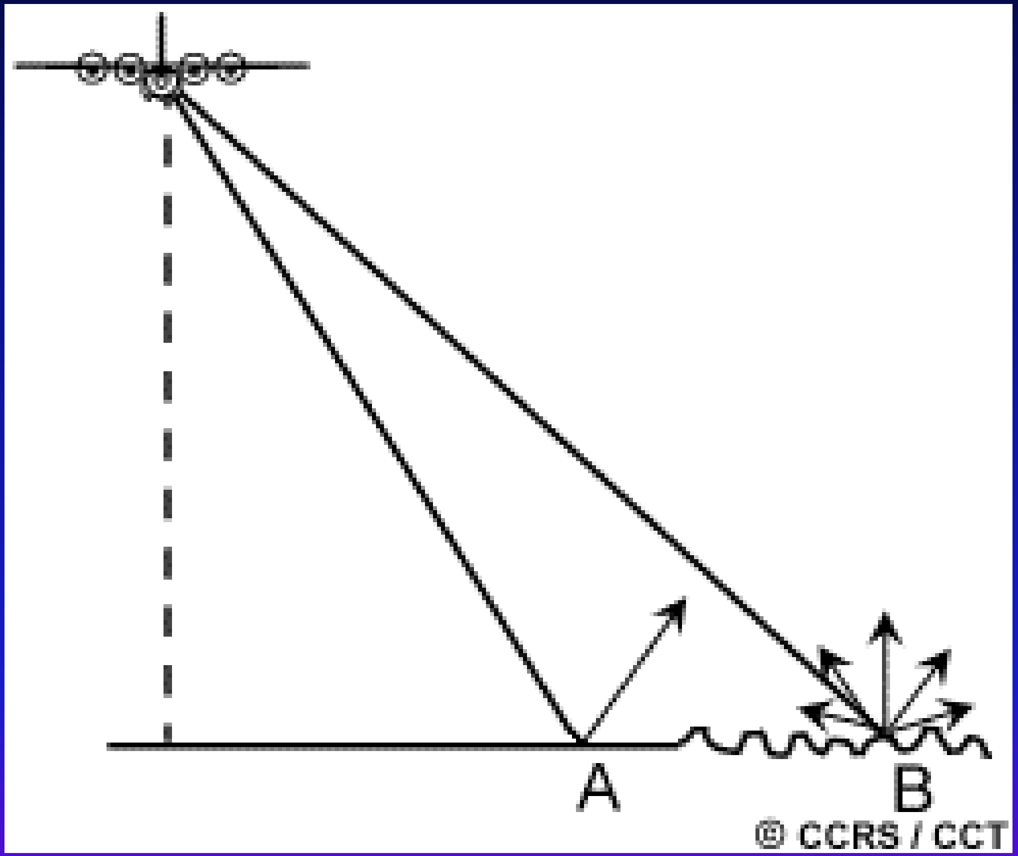
6.8.1.5 REFLECTION

FLAT AND SMOOTH

Specular Reflection – -No signal received by antenna

RUGGED

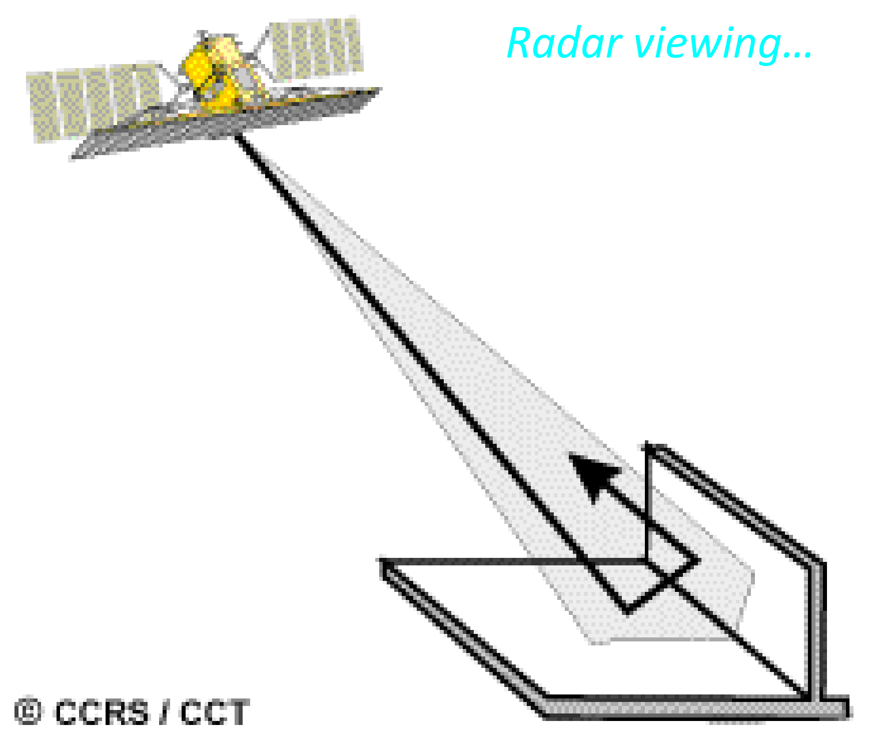
Diffuse Reflection, Tor complex, Buildings, etc.



- Features which have two (or more) surfaces (usually smooth) at right angles to one another, may cause corner reflection to occur if the 'corner' faces the general direction of the radar antenna.

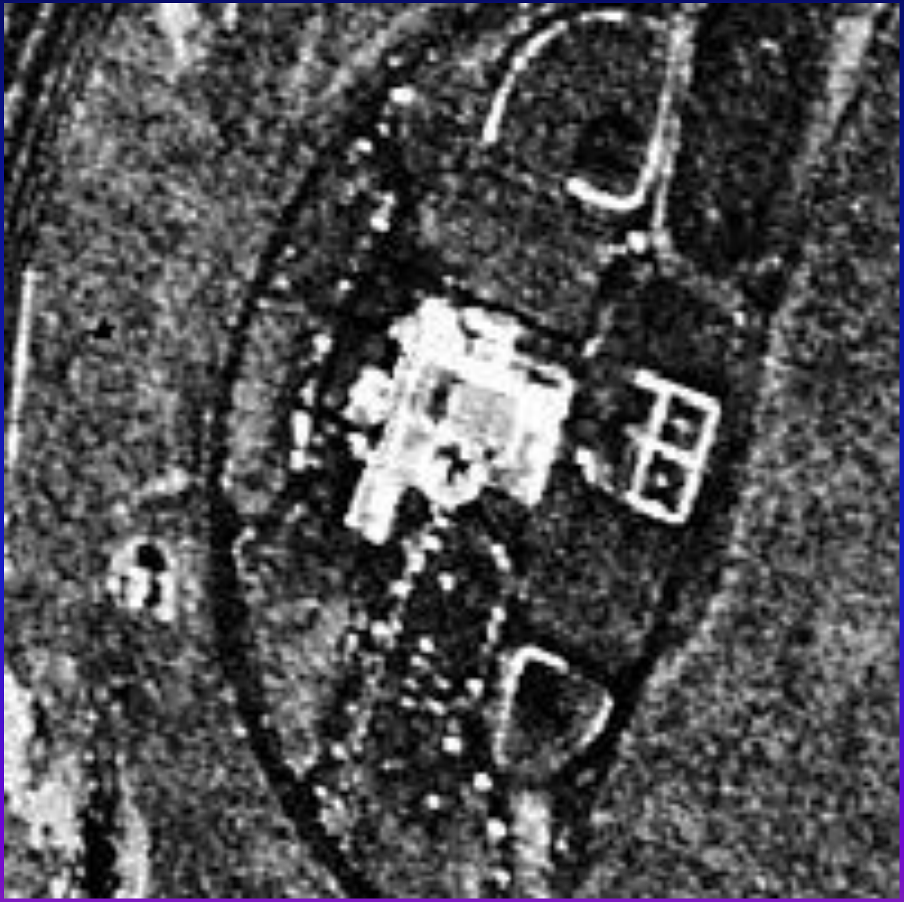
- The orientation of the surfaces at right angles causes most of the radar energy to be reflected directly back to the antenna due to the double bounce (or more) reflection.

Radar viewing…



- Corner reflectors with complex angular shapes are common in urban environments (e.g. buildings and streets, bridges, other man-made structures).
- Naturally occurring corner reflectors may include severely folded rock and cliff faces or upright vegetation standing in water.

In all cases, corner reflectors show up as very bright targets in an image, such as the buildings and other man-made structures in this radar image of a city.



RADAGRAMMETRY

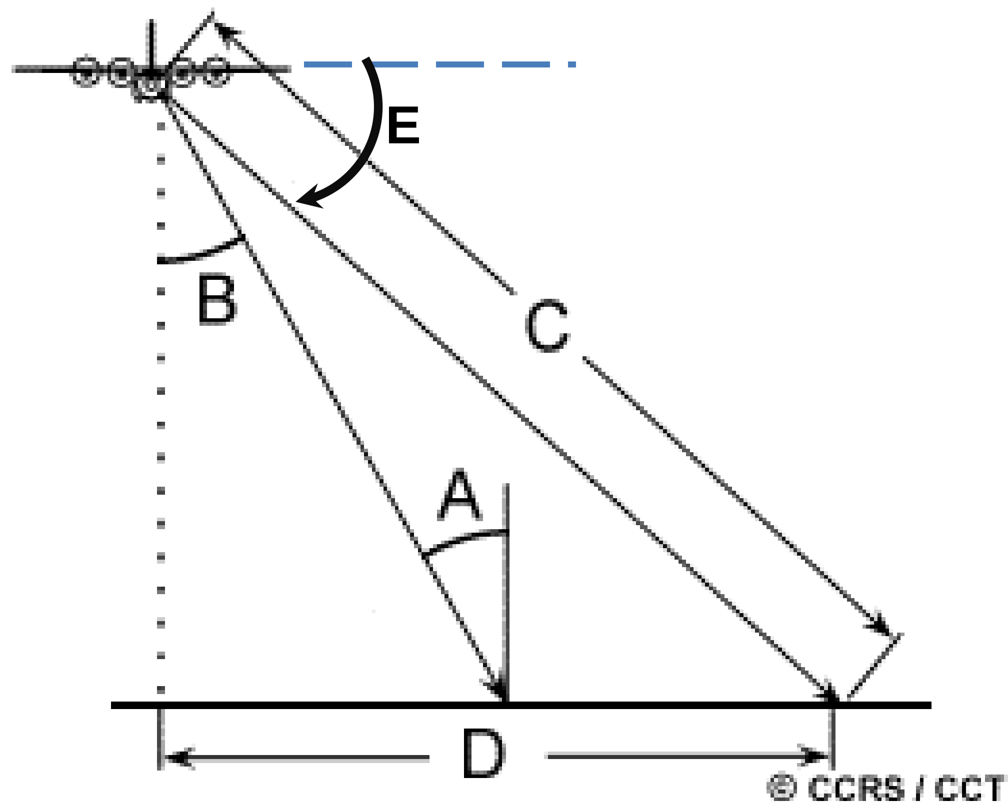
A → INCIDENT ANGLE

B → LOOK ANGLE

C → SLANT RANGE

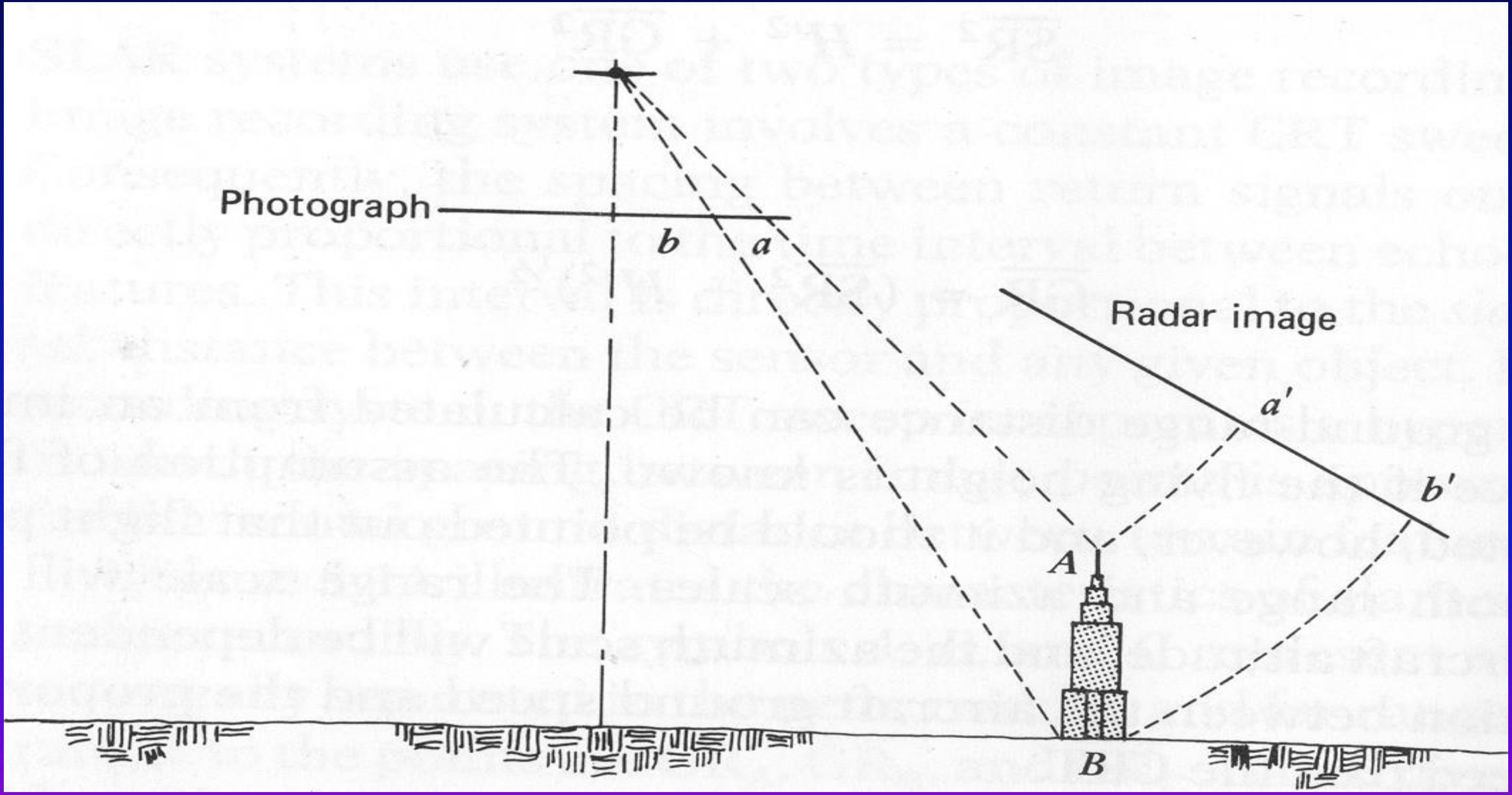
D → GROUND RANGE DISTANCE

E → DEPRESSION ANGLE

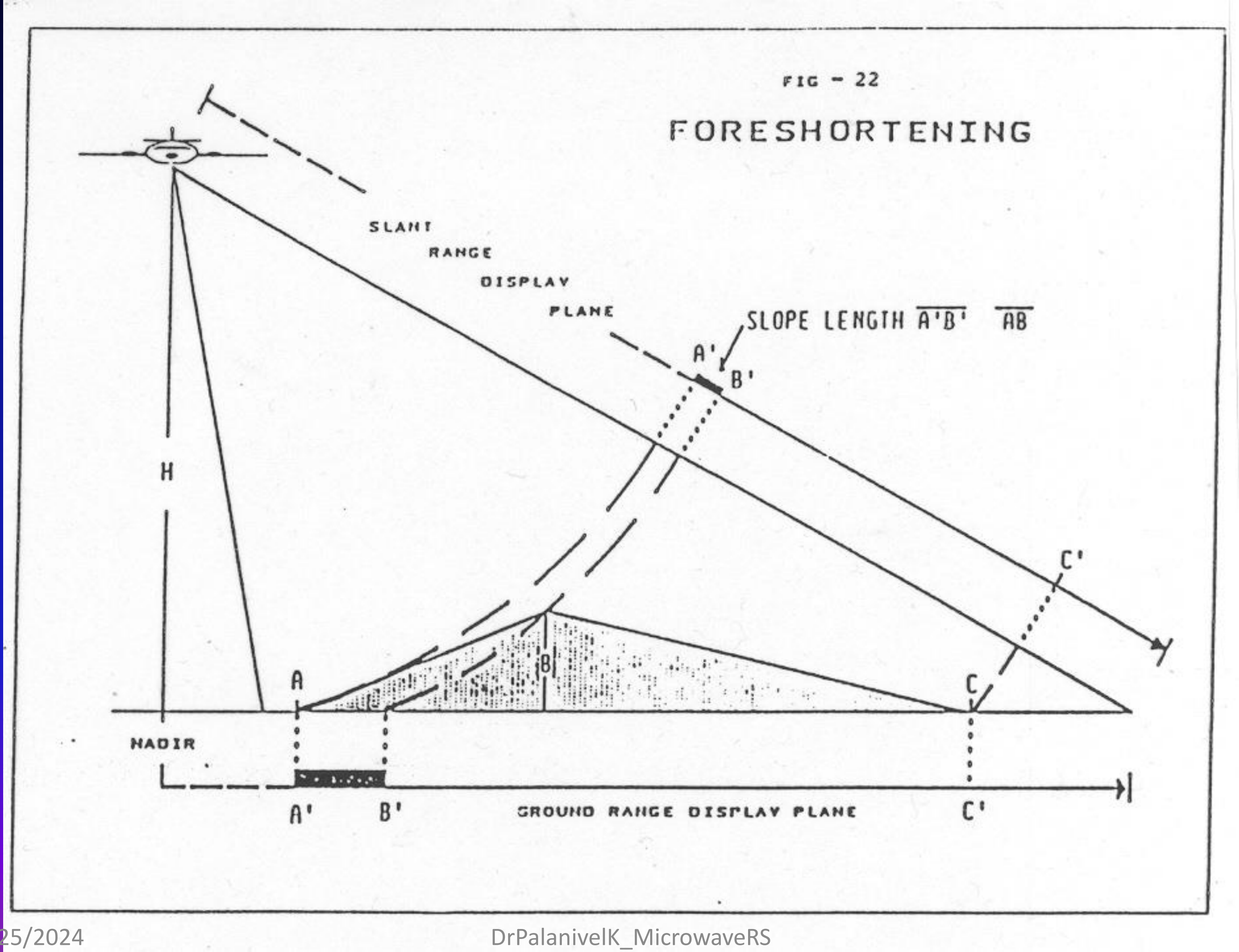


RELIEF DISPLACEMENT

ON SLAR IMAGES Vs AERIAL PHOTOGRAPHS

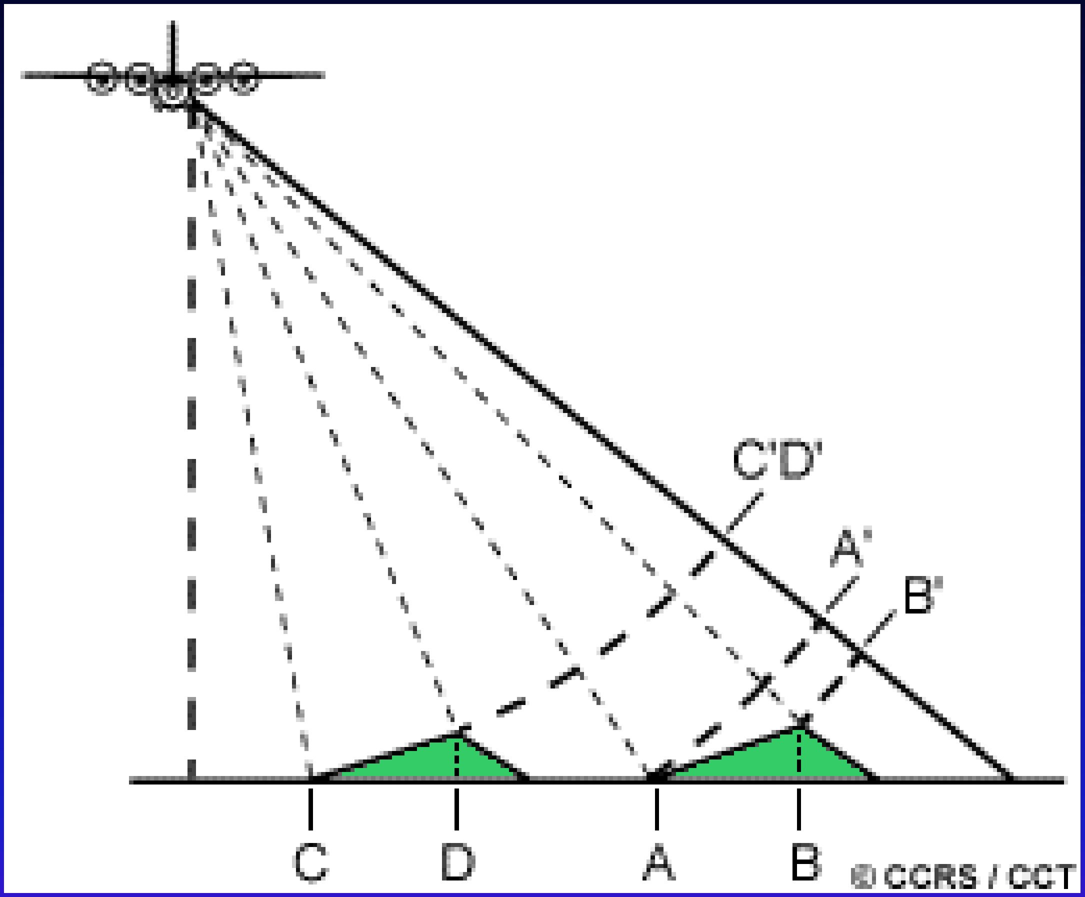


RELIEF DISPLACEMENT - <u>FORESHORTENING</u>



FORESHORTENING

Again, because the radar measures distance in slant-range, the slope (A to B) will appear compressed and the length of the slope will be represented incorrectly (A' to B').



Maximum foreshortening occurs when the radar beam is perpendicular to the slope such that the slope, the base, and the top are imaged simultaneously (C to D).

The length of the slope will be reduced to an effective length of zero in slant range (C'D').

Conversion comparison

Radar image in slant-range display, where the fields and the road in the near range on the left side of the image are compressed,

The same image converted to ground-range display with the features in their proper geometric shape.

LAY OVER

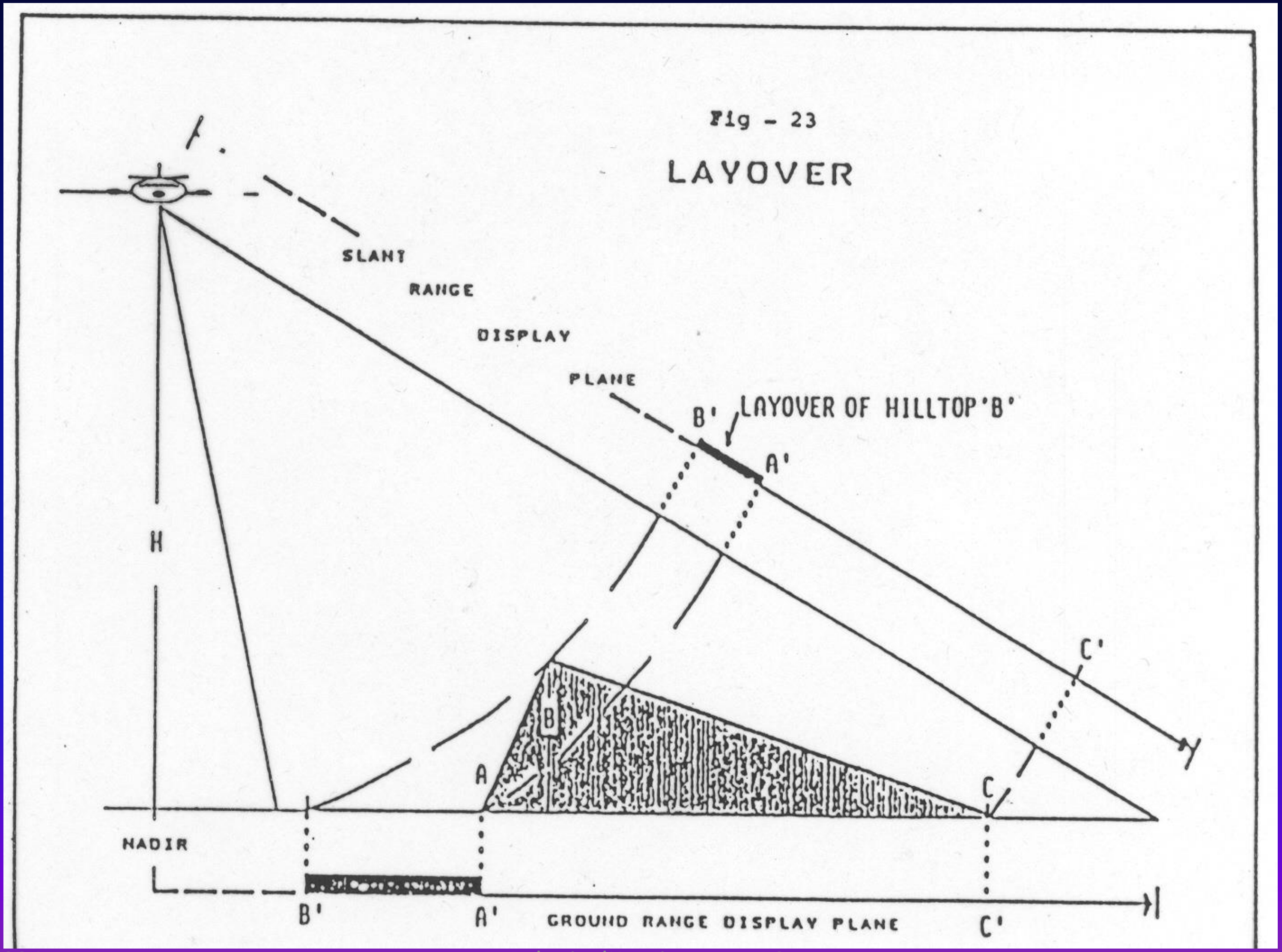
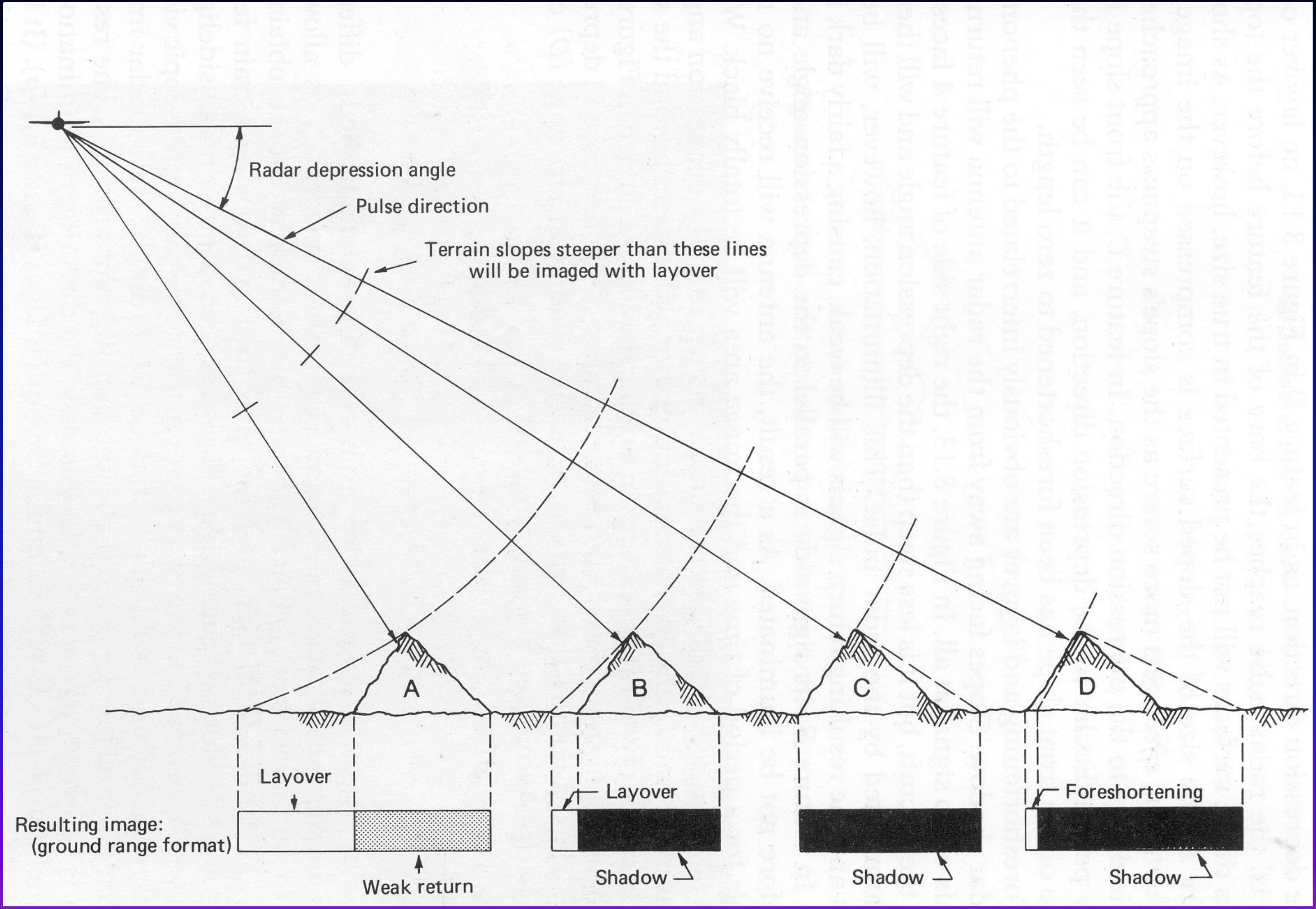


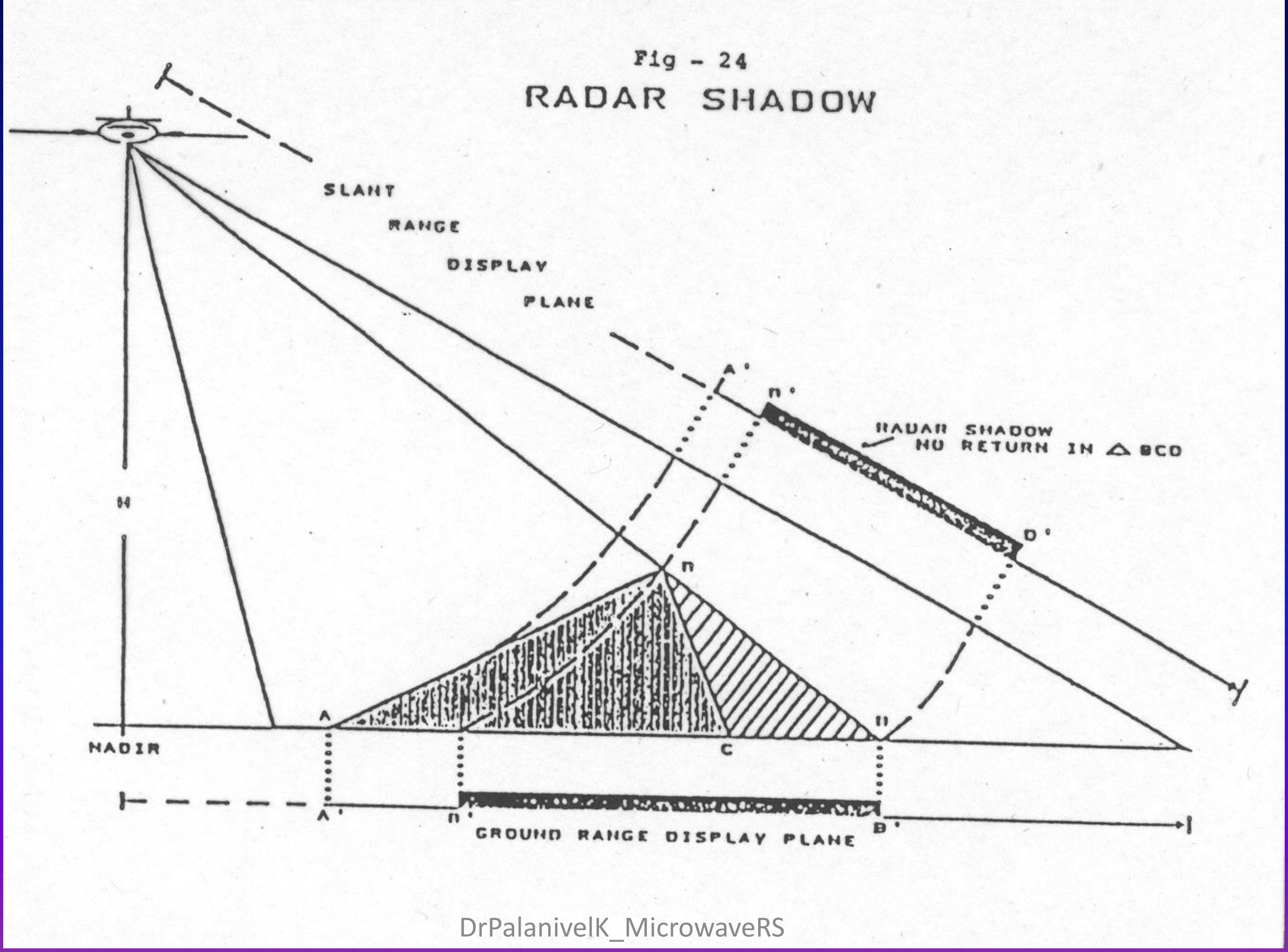
Fig - 23
LAYOVER
SLANT
RANGE
DISPLAY
PLANE
B'
LAYOVER OF HILLTOP 'B'
A'
H
B
A
C
C'
NADIR
B'
A'
GROUND RANGE DISPLAY PLANE
C'

Effects of terrain relief on SLAR images



RADAR - SHADOW

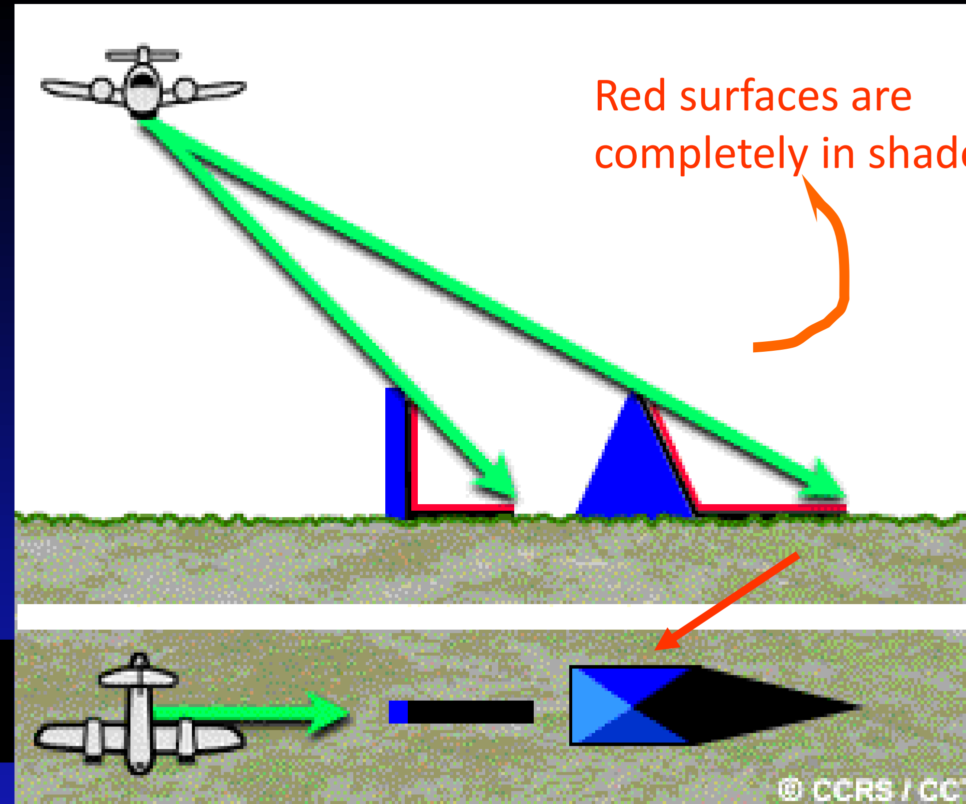
Attenuated shadow due to incident energy blow at an angle and no energy is returned to antenna



RADAR SHADOW

Both foreshortening and layover result in radar shadow.

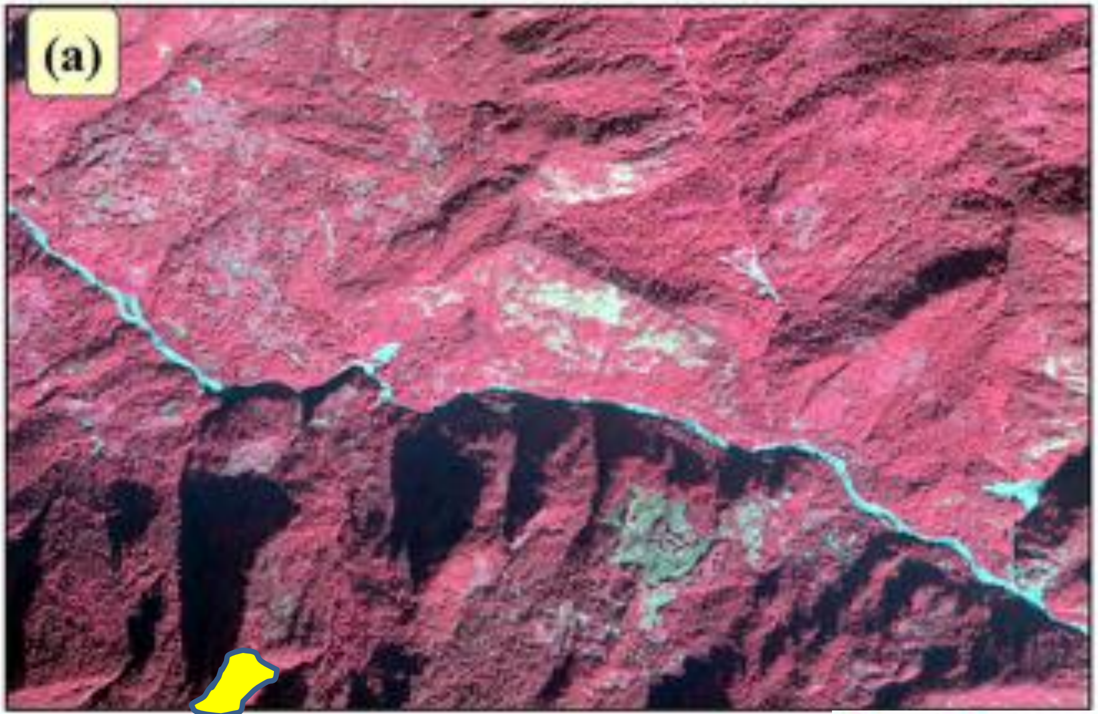
Radar shadow occurs when the radar beam is not able to illuminate the ground surface.



Black areas in image are shadowed and contain no information.

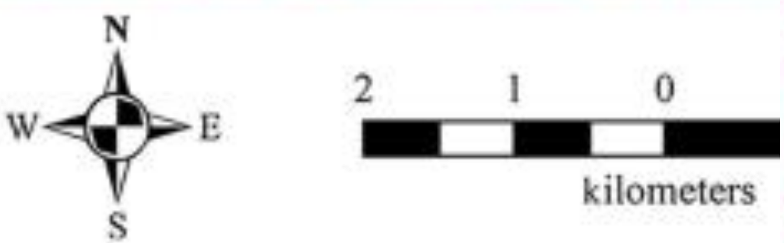
- Shadows occur in the down range dimension (i.e. towards the far range), behind vertical features or slopes with steep sides.
- Since the radar beam does not illuminate the surface, shadowed regions will appear dark on an image as no energy is available to be backscattered.
- As incidence angle increases from near to far range, so will shadow effects as the radar beam looks more and more obliquely at the surface.

Relief Displacement in Radar image - shadow effects



Sentinel-1 Synthetic Aperture Radar –SAR (a) and Sentinel-2 optical imagery (b) for identifying new landslides in vegetated and hilly areas of the north Sikkim part of India

Shadow, foreshortening (in yellow shaded slope) & layover effects

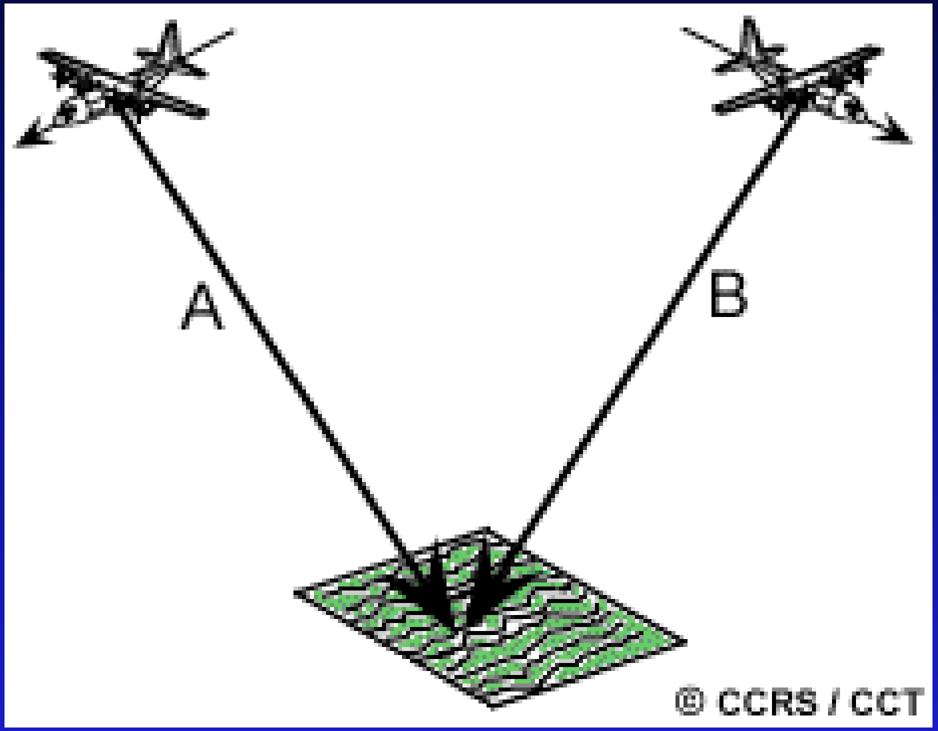


LOOK DIRECTION

- ➔ Linear feature perpendicular to Look angle more pronounced
- ➔ Parallel to Look angle less pronounced

If the **look direction** is close to **perpendicular** to the orientation of the feature (A), then a large portion of the incident energy will be reflected back to the sensor and the feature will appear as a **brighter tone**.

If the **look direction** is more **oblique** in relation to the feature orientation (B), then less energy will be returned to the radar and the feature will appear **darker** in tone.

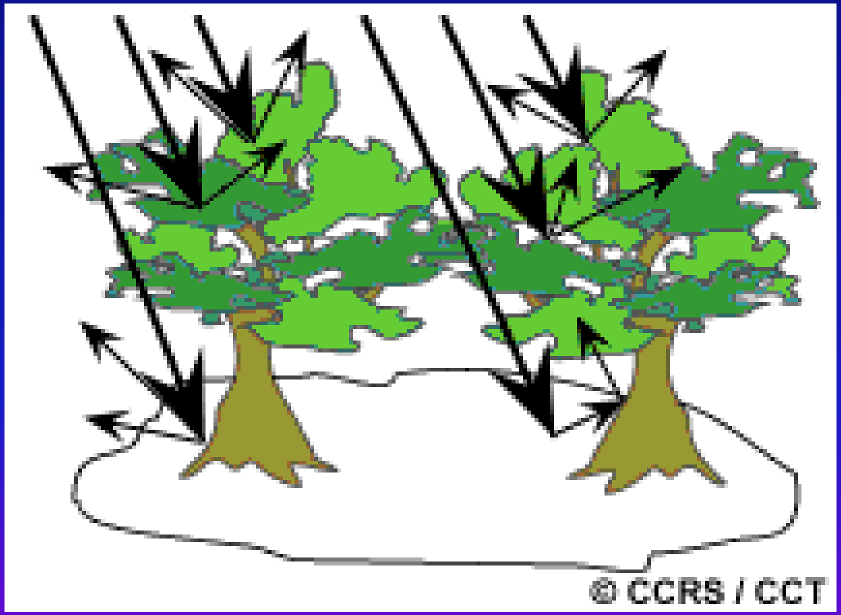


Look direction is important for enhancing the contrast between features in an image.

Volume Scattering may occur.

Volume scattering is the scattering of radar energy within a volume or medium, and usually consists of multiple bounces and reflections from different components within the volume.

For example, in a forest, scattering may come from the leaf canopy at the tops of the trees, the leaves and branches further below, and the tree trunks and soil at the ground level.

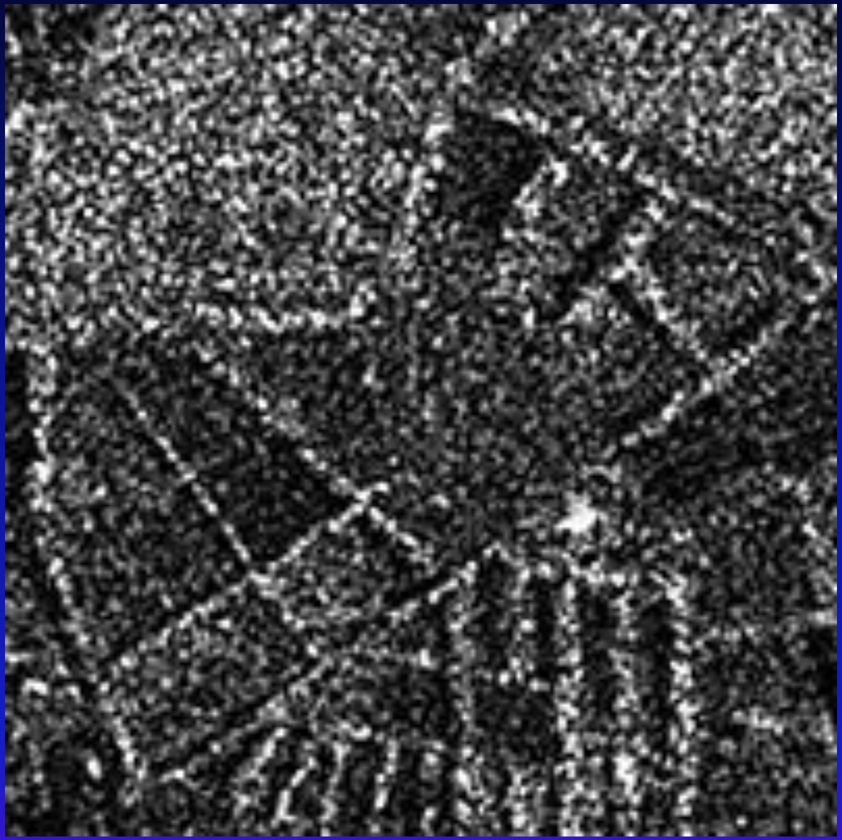


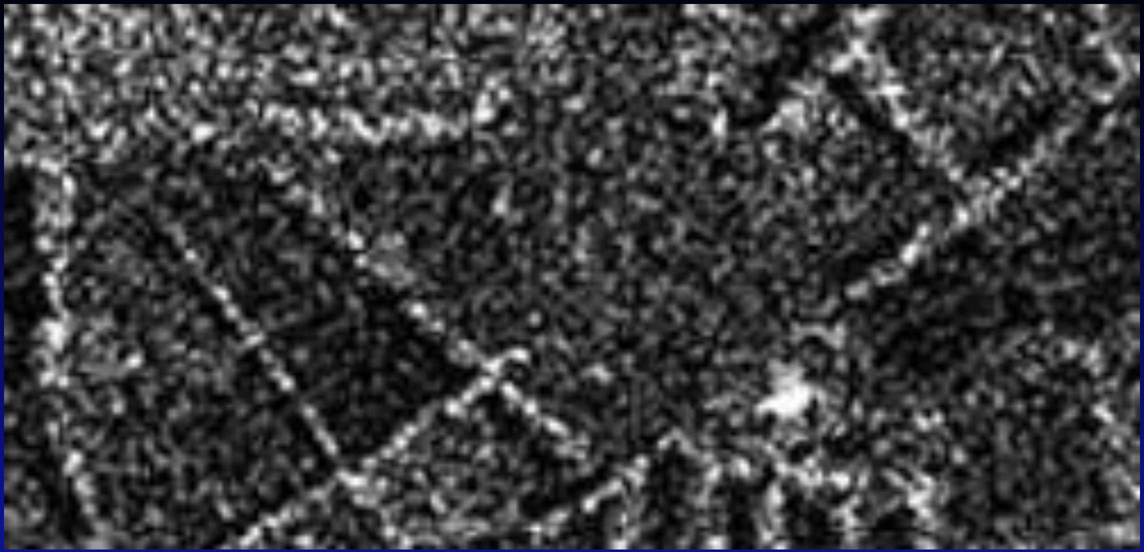
Volume scattering may serve to decrease or increase image brightness, depending on how much of the energy is scattered out of the volume and back to the radar.

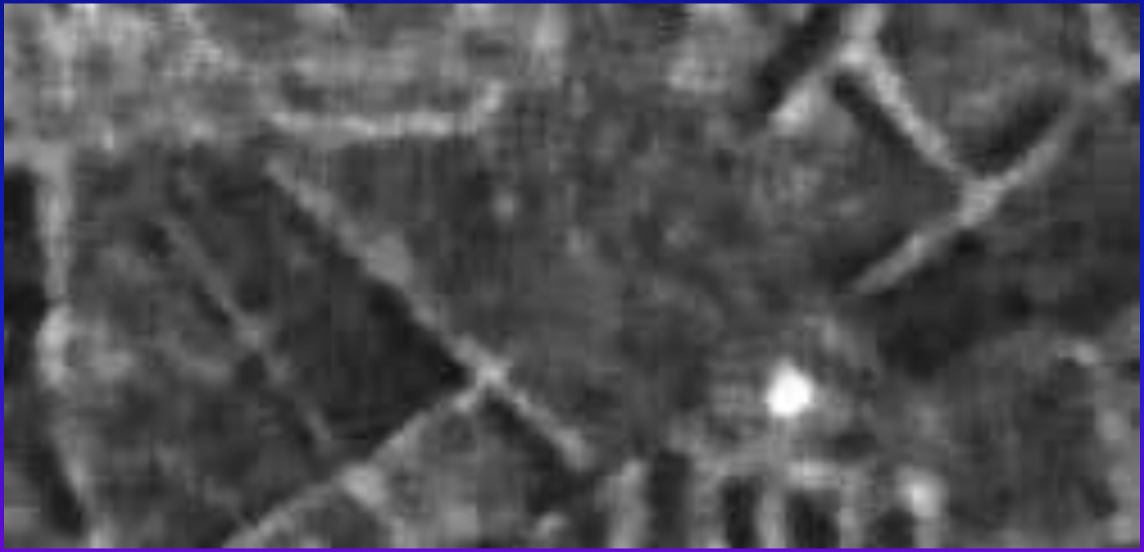
6.8.1.7. SPECKLE

SPECKLE appears as a grainy salt and pepper" texture in an image.

This is caused by random constructive and destructive interference from the multiple scattering returns that will occur within each resolution cell.



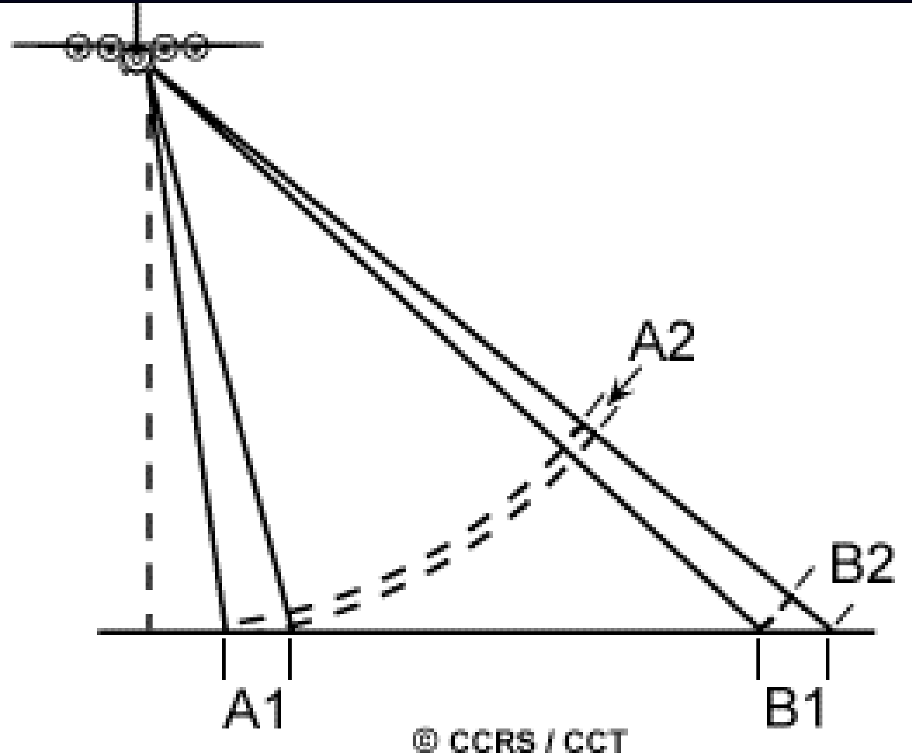




Speckle reduction using an averaging filter

Scale Difference

This results in a varying image scale, moving from near to far range. Although targets A1 and B1 are the same size on the ground, their apparent dimensions in slant range (A2 and B2) are different.



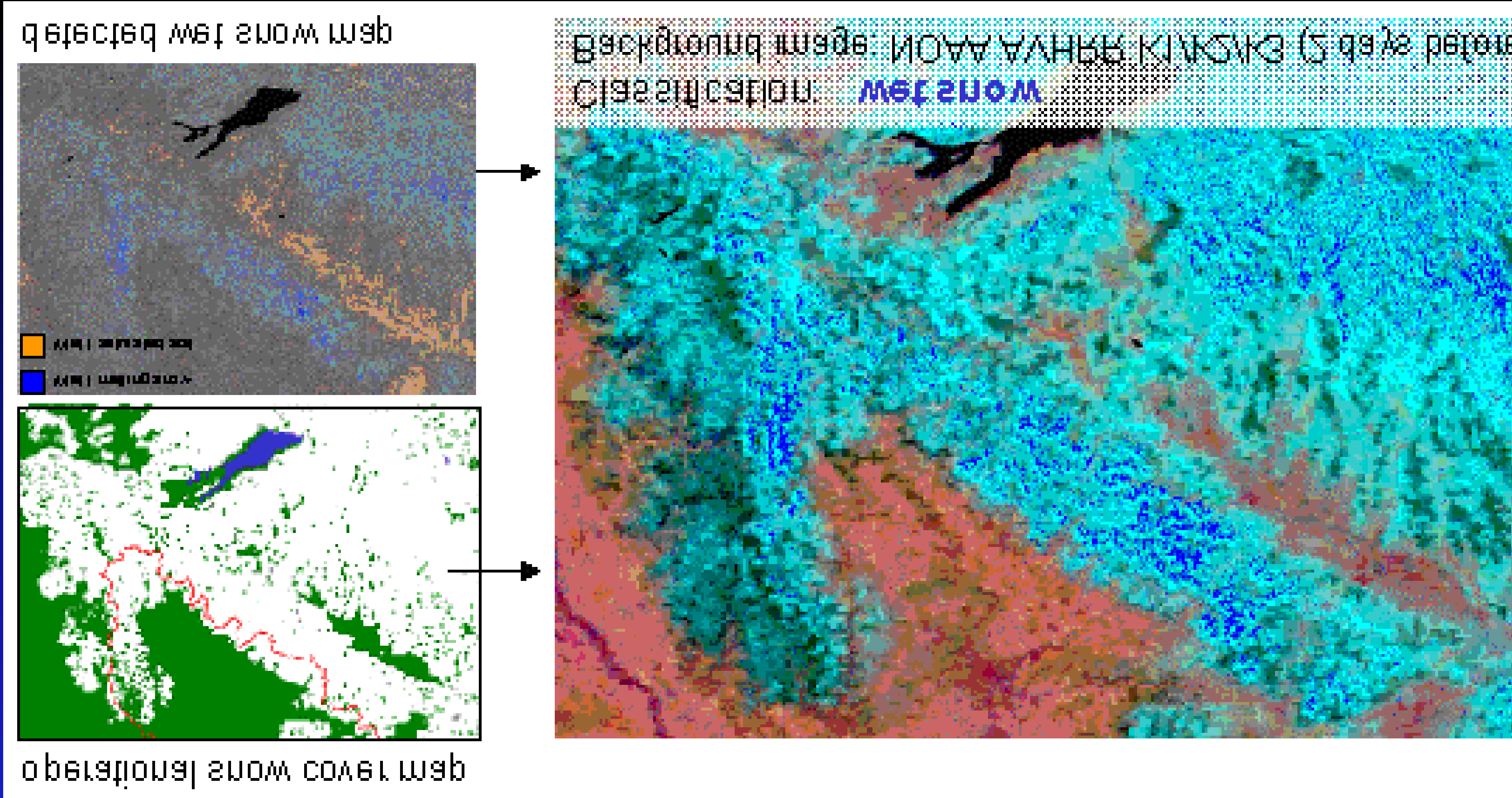
This causes targets in the near range to appear compressed relative to the far range.

Using trigonometry, the ground-range distance can be calculated from the slant-range distance and platform altitude to convert to the proper ground-range format.

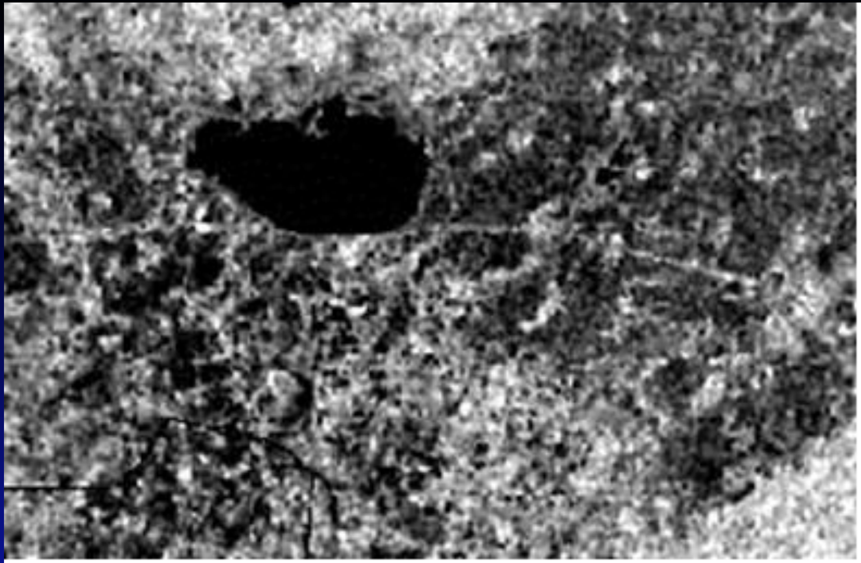
Geometric Distortions due to Relief Displacement

As with scanner imagery, this displacement is one-dimensional and occurs perpendicular to the flight path.

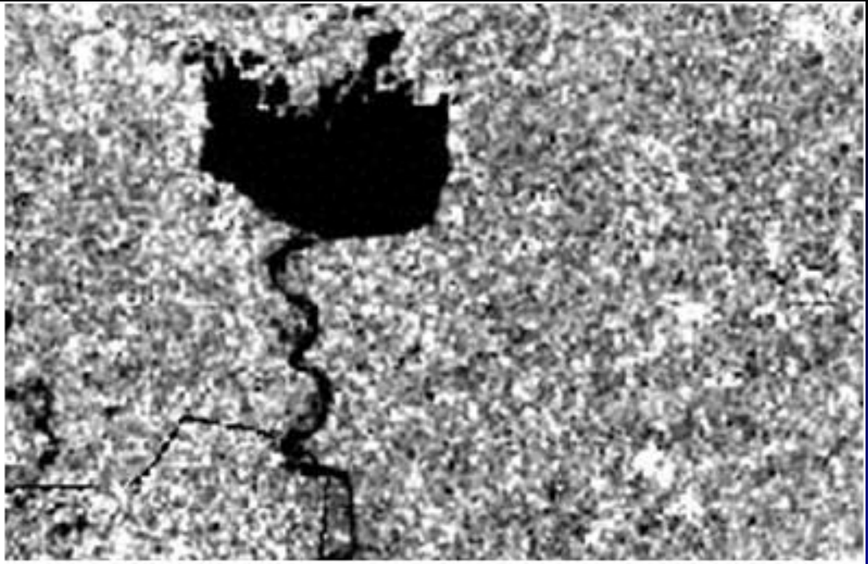
- **However, the displacement is getting reversed in radar images,**
- **i.e., with respect to the location of the targets, the displacement is towards / amongst the targets / objects / features only.**
- **But, it is away from the sensor as far as the optical remote sensing Images.**
- **Radar foreshortening and layover are two consequences resulted from relief displacement.**



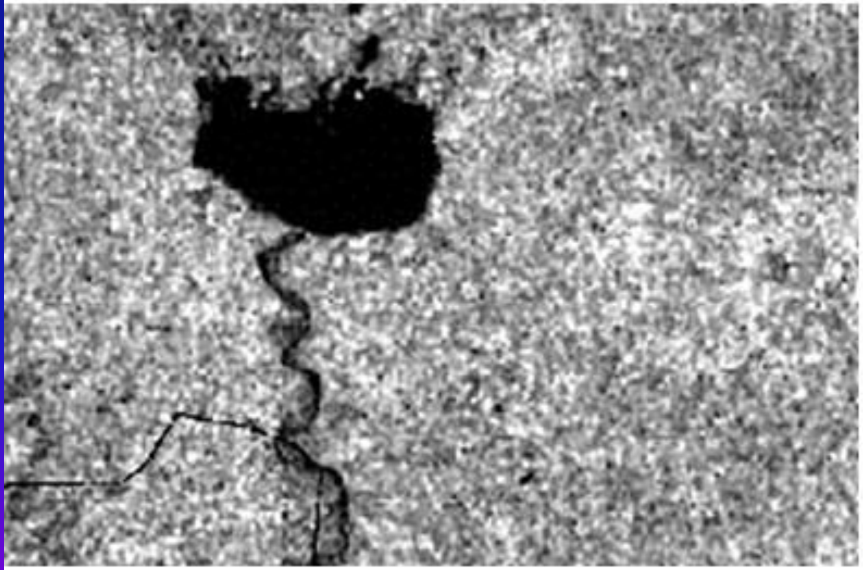
Example of wet snow and wet soil detection with ENVISAT microwave satellite imagery (lower, left) in comparison with a snow classification 2 days before the SAR acquisition (upper, left). The overlay of the melting snow pixels on the NOAA image (right image) illustrates the multi-sensoral data fusion - Florian Appel et al 2013.



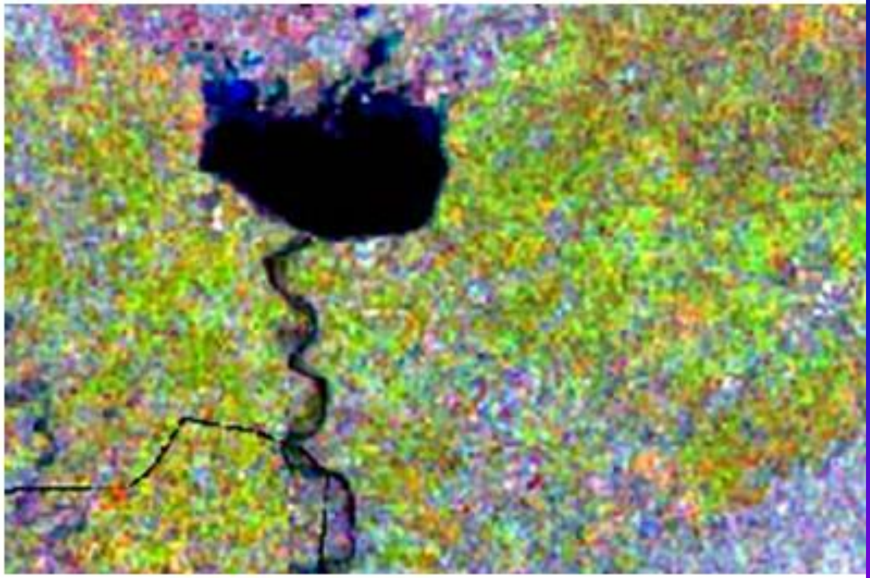
6th August



23rd September



30th August



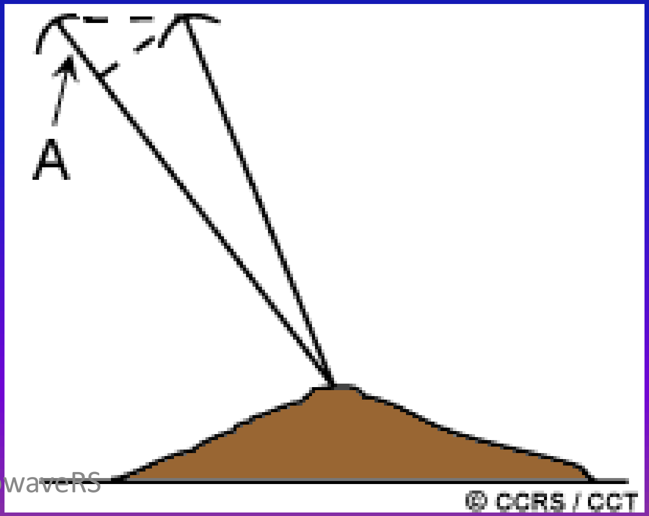
FCC image

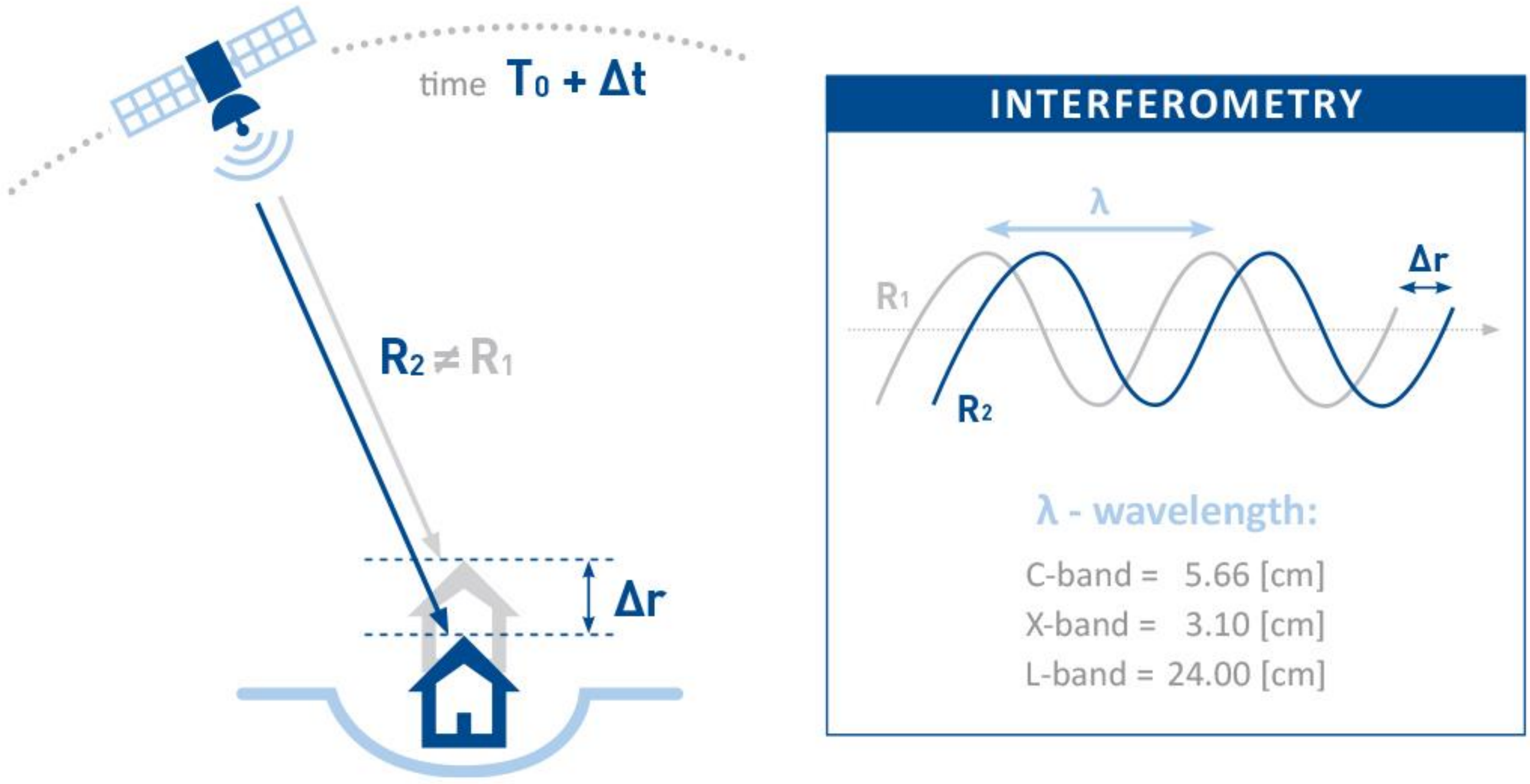
ADVANCED RADAR APPLICATIONS

Another, more advanced method is called interferometry. **INTERFEROMETRY** relies on being able to measure a property of electromagnetic waves called **phase**.

Suppose we have two waves with the exact **same wavelength and frequency** traveling along in space, but the starting point of one is offset slightly from the other.

The offset between matching points on these two waves (A) is called the **phase difference**.




time T0 + Δt
R2 ≠ R1
Δr
INTERFEROMETRY
λ
Δr
R1
R2
λ - wavelength:
C-band = 5.66 [cm]
X-band = 3.10 [cm]
L-band = 24.00 [cm]

STEREO RADAR which is similar in concept to stereo mapping using aerial photography.

Stereo radar image pairs are acquired covering the same area, but with different look/incidence angles, or opposite look directions.

Unlike aerial photos where the displacement is radially outward from the nadir point directly below the camera, radar images show displacement only in the range direction.

Stereo pairs taken from opposite look directions (i.e. one looking north and the other south) may show significant contrast and may be **difficult to interpret visually or digitally.**

Because many of these characteristics are interrelated, it is impossible to separate out each of their individual contributions to the appearance of features in a radar image.

Changes in the various parameters may have an impact on and affect the response of other parameters, which together will affect the amount of backscatter.

Thus, the brightness of features in an image is usually a combination of several of these variables.

However, for the purposes of our discussion, we can group these characteristics into three areas which fundamentally control radar energy/target interactions.

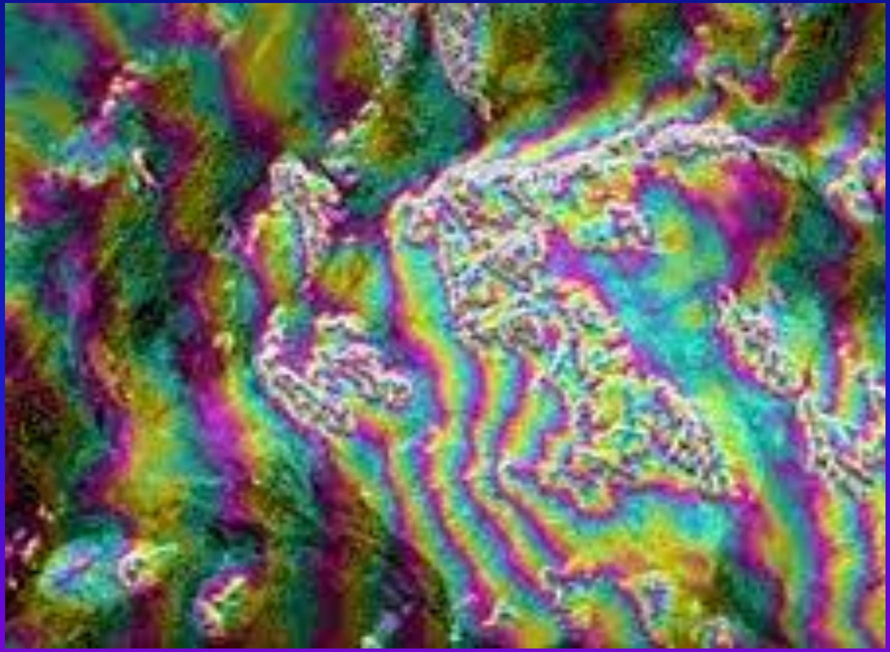
They are:

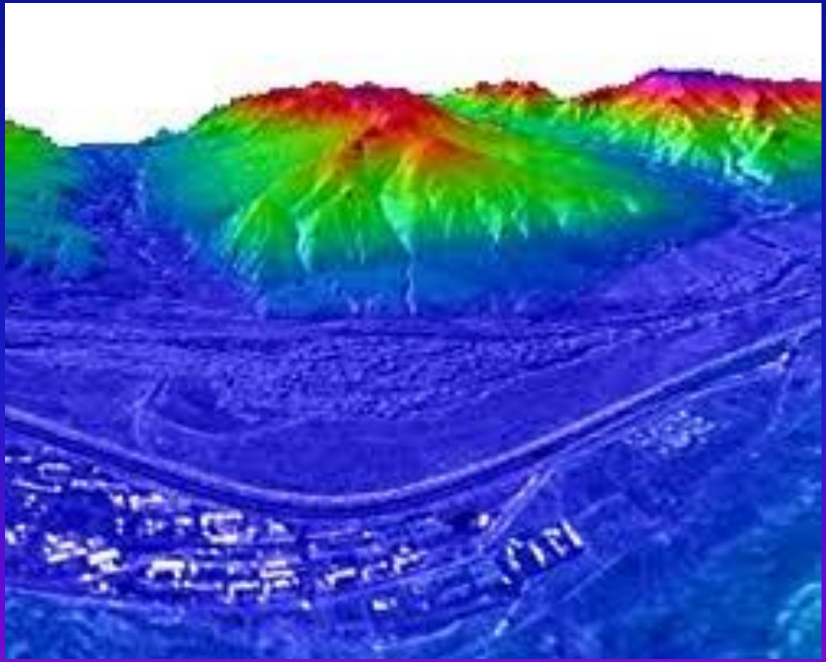
Surface roughness of the target

Radar viewing and surface geometry relationship &

Moisture content and electrical properties of the target .

INTERFEROGRAM, where colours represents the variations in height. The information contained in an interferogram can be used to derive topographic information and produce three-dimensional imagery of terrain height.





Thank you