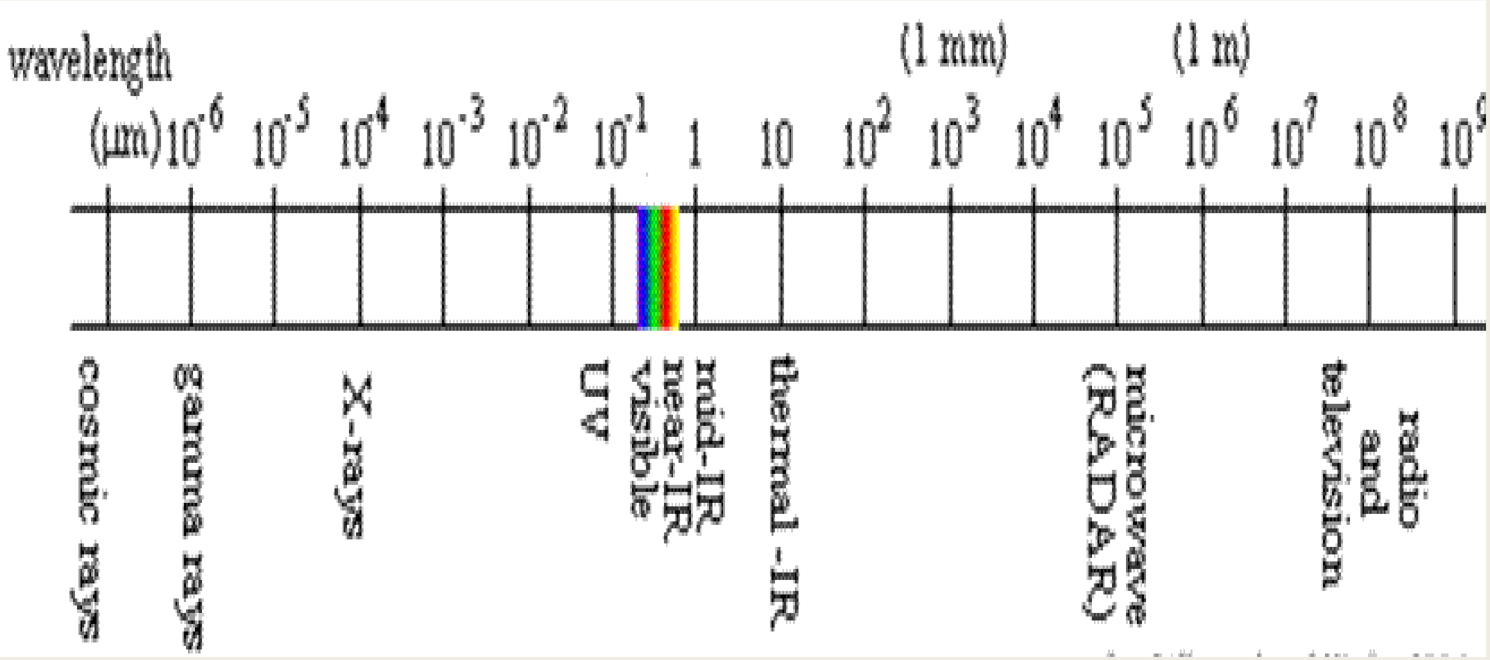
MICROWAVE REMOTE SENSING

PAPER CODE: ADVANCED REMOTE SENSING & GIS (GIS 09)
SEMESTER: II
PG DIPLOMA IN RS & GIS
DR. SHYAMA PRASAD MUKHERJEE UNIVERSITY, RANCHI

Microwave Remote Sensing

- Sensors operate in the microwave portion of the EM spectrum
- Wavelengths range from 1mm to 1m
- Special characteristics:
  - *Microwave EMR Can penetrate the atmosphere under all conditions*
  - *Microwave EMR is not influenced by cloud cover, haze and dust*
  - *Microwave wavelengths are less prone to atmospheric scattering which affects optical wavelengths*
  - *Microwave EMR can be influenced by very heavy rain*

The electromagnetic spectrum



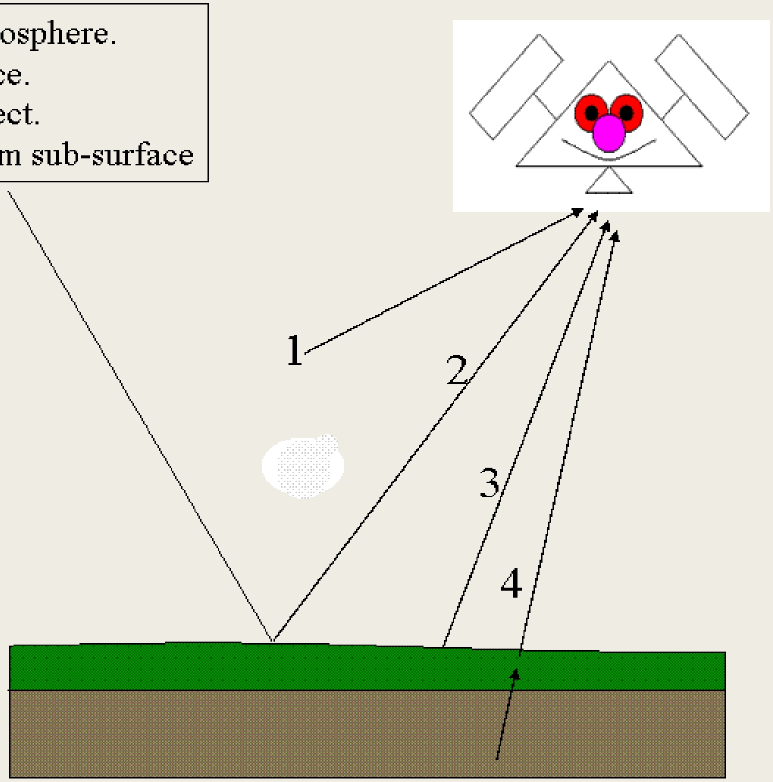
Types of Microwave Sensing Systems

- Airborne and spaceborne
- Active (radar) and passive (microwave radiometer)
- Lidar: active sensor but uses laser light pulses rather than microwave energy

Passive Microwave Sensing

- This type records the naturally occurring microwave EMR-both from the surface and atmosphere
- It uses wavelengths of between 0.15 cm-30 cm (typically shorter wavelengths)
- Operationally similar to thermal sensing
- Collected signal includes components due to:
  - *Object emittance*
  - *Atmosphere emittance*
  - *Surface reflectance*
  - *Subsurface transmission*
- Weak and noisy signal, difficult to interpret
- Have very low spatial resolutions (Kms)
- Examples: microwave radiometer, passive microwave scanner

Passive Microwave Sensing



1 = emitted by atmosphere.
2 = reflected surface.
3 = emitted by object.
4 = transmitted from sub-surface

Passive Microwave Sensing

- Passive Earth observation has numerous applications, for instance:

  - Global surface brightness temperature
  - Geological mapping applications
  - Soil studies – soil temperature, soil moisture
  - Outside surface studies – oceanography, atmospheric sciences

Active Remote Sensing Systems

The most widely used active remote sensing systems include:

- Active microwave (RADAR), based on the transmission of long-wavelength microwaves (e.g., 3 – 25 cm) through the atmosphere and then recording the amount of energy back-scattered from the terrain;

- LIDAR, which is based on the transmission of relatively short-wavelength laser light (e.g., 0.90 mm) and then recording the amount of light back-scattered from the terrain; and

- SONAR, which is based on the transmission of sound waves through a water column and then recording the amount of energy back-scattered from the bottom or from objects within the water column.

LIDAR

- Light Detection and Ranging
- Active sensor, pulses of laser light
- Calculates distances based on pulse return time
- Used in measurement of terrain elevation
- Modern systems are not affected by slopes or shadows, and may record up to 5 returns per pulse

Available Systems

- ICESat (Ice, Cloud, and Land Elevation Satellite) from NASA'S EOS: launched Jan. 2003, carries one instrument (Geospatial Laser Altimeter System)
- Used to study ice sheets and clouds
- For more information: http://icesat.gsfc.nasa.gov/index.html

Active Microwave Sensing: Radar

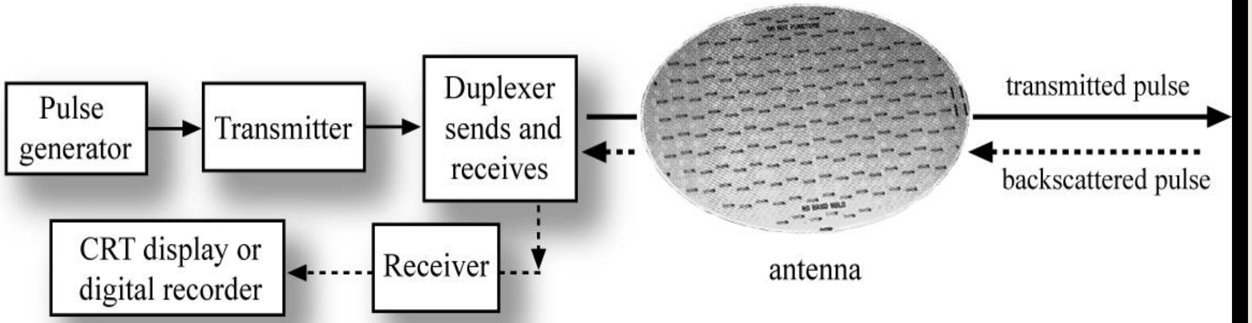
- Acronym: RAdio Detection And Ranging
- What: Radio waves are used to detect the presence of objects and determine distances and angular positions
- How: Pulses of microwave energy are transmitted towards areas or interest, and the strength and origin of reflections is recorded.
- Output: Images can be produced

Radar Types

- Doppler radar: non-imaging radar type, typically used to measure speed of vehicles
- Plan Position Indicator (PPI): A radial sweep indicates the position of radar echos around its rotating antenna
  - *Commonly used in air traffic control, navigation, and weather forecasting.*
- Side-Looking Radar (SLR) or Side-Looking Airborbe Radar (SLAR): Airborne and spaceborne radar remote sensing use an antenna fixed below the aircraft (or spacecraft) and pointed to the side
  - *They produce continuous strips of imagery*

Side-looking Airborne RADAR (SLAR) System

a. Intermap LearJet 36 Star 3*i*.



b. Typical active microwave system components.

Sending and Receiving a Pulse of Microwave EMR - System Components

- The pulse of electromagnetic radiation sent out by the transmitter through the antenna is of a specific wavelength and duration (i.e., it has a pulse length measured in microseconds, μsec).

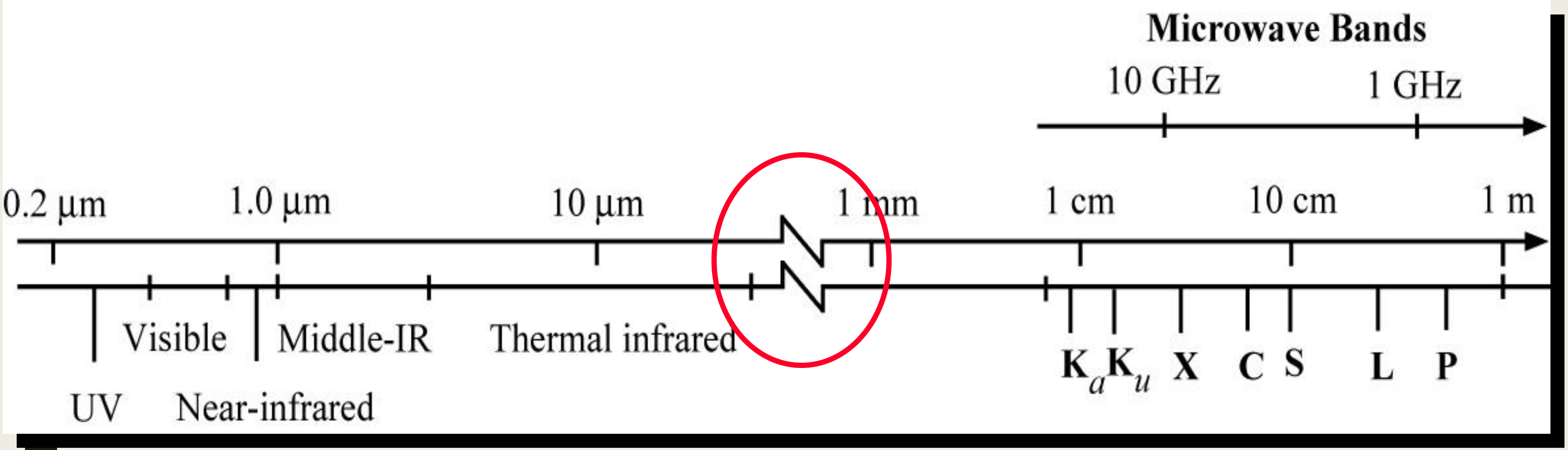
- The wavelengths are much longer than visible, near-infrared, mid-infrared, or thermal infrared energy used in other remote sensing systems. Therefore, microwave energy is usually measured in centimeters rather than micrometers.

- The unusual names associated with the radar wavelengths (e.g., K, Ka, Ku, X, C, S, L, and P) are an artifact of the original secret work on radar remote sensing when it was customary to use the alphabetic descriptor instead of the actual wavelength or frequency.

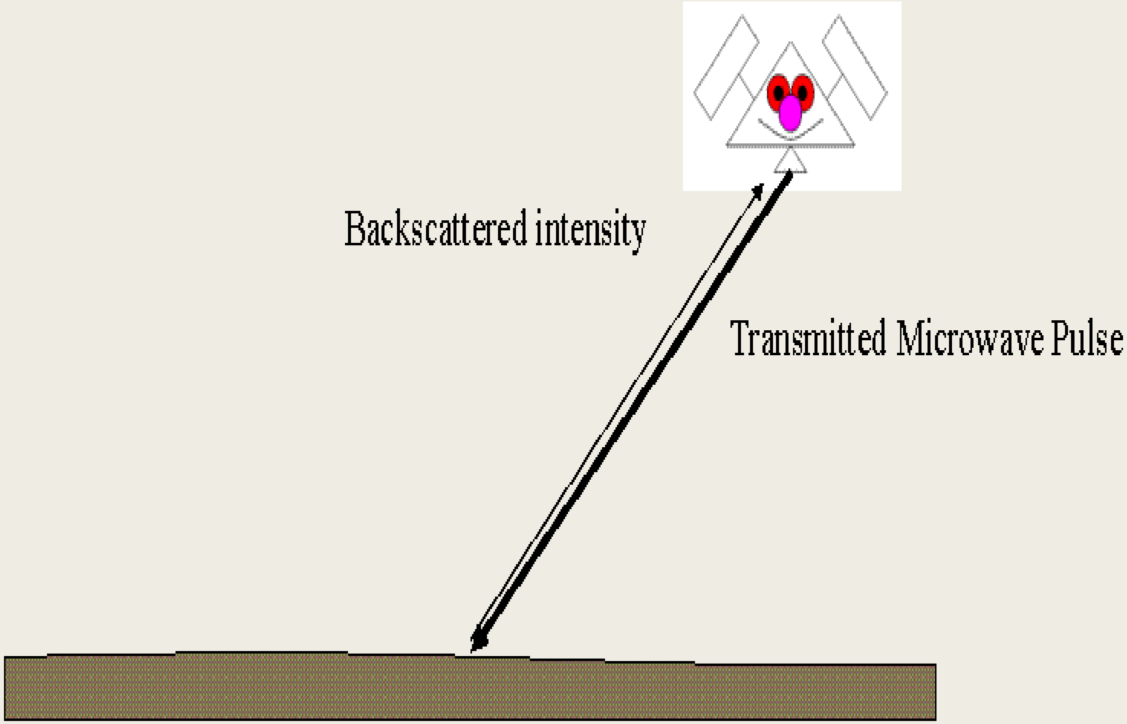
Active Microwave Sensing

- Active microwave wavelengths tend to be divided into typical wavelength regions or bands:
  - *P-band = 30-100cm = 1.0-0.3 GHz.*
  - *L-band = 15-30cm = 2.0-1.0 GHz.*
  - *S-band = 7.50-15cm = 4.0-2.0 GHz.*
  - *C-band = 3.9-7.50cm = 8.0-4.0 GHz.*
  - *X-band = 2.40-3.75cm = 12.5-8.0 GHz.*
  - *K-band(s) = 0.75-2.40cm = 40-12.5 GHz (rarely employed).*

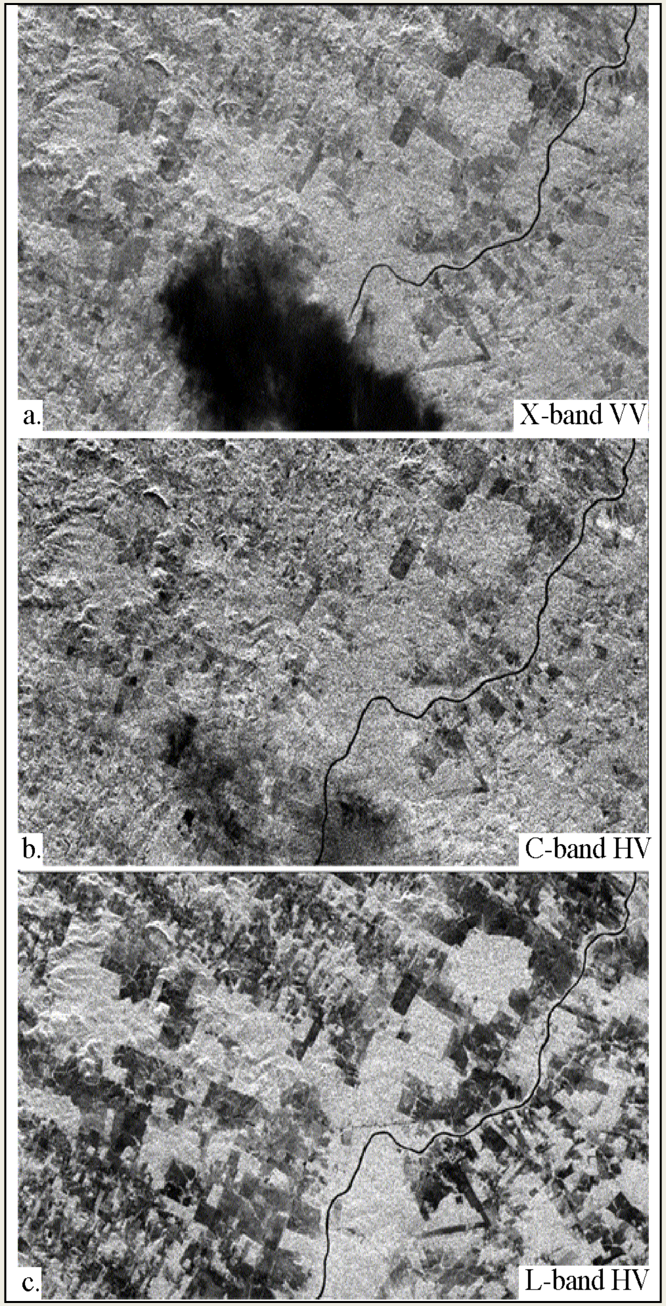
Active Microwave (RADAR) Commonly Use Frequencies



An illustration of the transmitted pulse and ts backscatter return in an active system



SIR-C/X-SAR Images of a Portion of Rondonia, Brazil, Obtained on April 10, 1994



Overview of Radar Use

- Radar-based projects started producing results as early as 1967
- Widely used in areas of perpetually adverse weather conditions (e.g. cloud coverage)
- Difficulties in analyzing the collected imagery as several aspects of expected object behaviors are still unknown
- Spaceborne: Seasat (1978)
  - *ESA Envisat: the most advanced to date* [*http://envisat.esa.int/*](http://envisat.esa.int/)
  - *Radarsat-2 and ALOS (2004)*

Side-Looking Radar System Operation

- Energy propagates in air at the velocity of light *c*, so the slant range to any object is:

$$\overline{SR} = \frac{ct}{2}$$

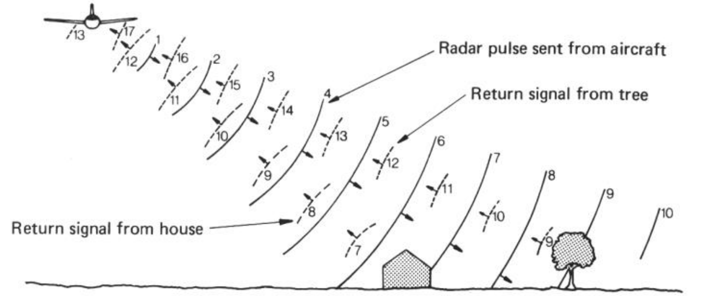
where

SR is the direct distance between transmitter and object (slant range)

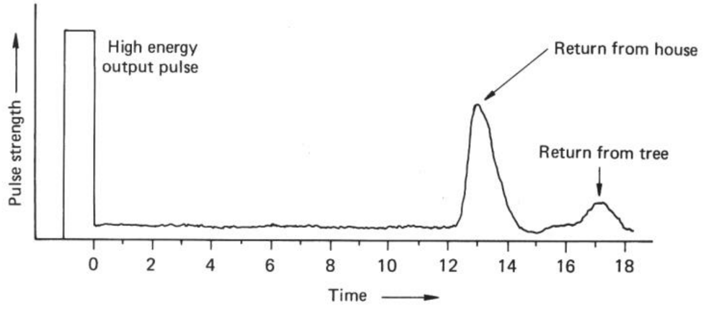
c is the speed of light (known) ($3 * 10^8$ m/sec)

t is the time between transmission and echo (return signal) reception

The factor 2 enters into the equation because the time is measured for the pulse to travel the distance both to and from the target

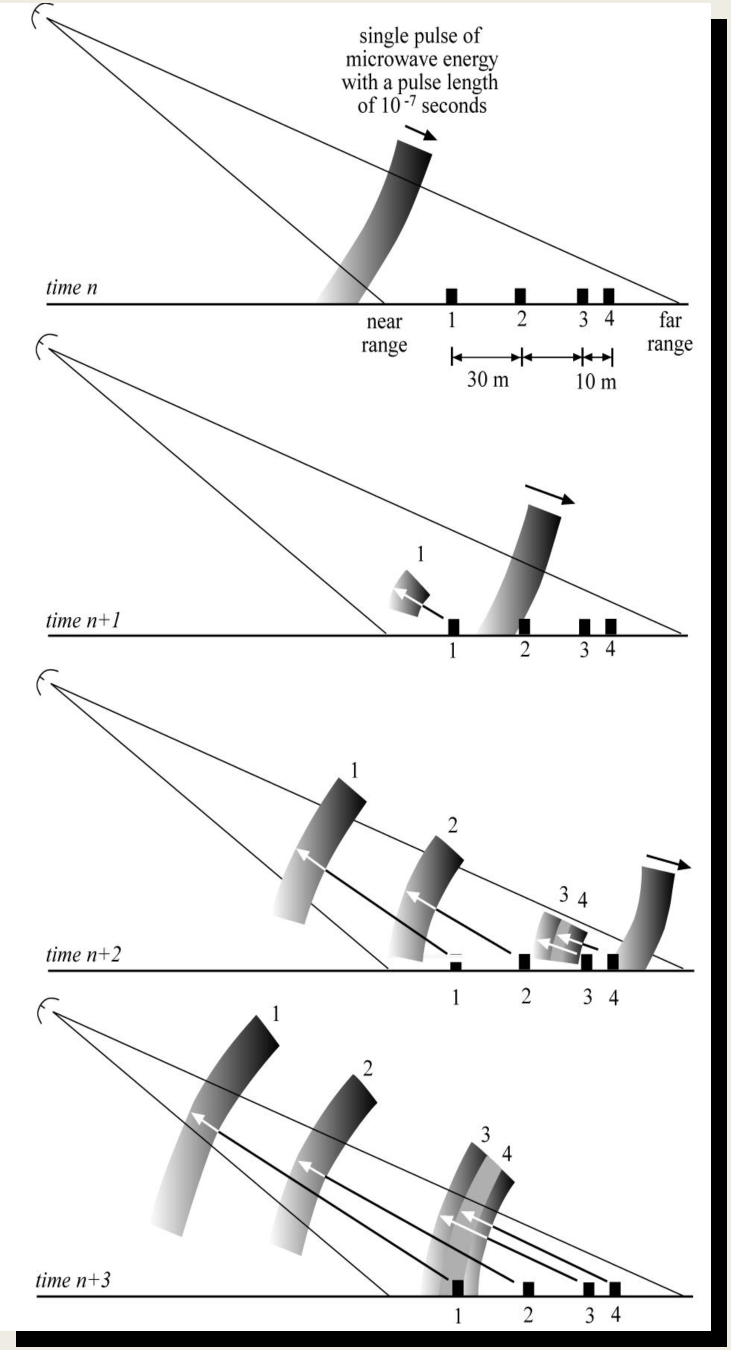


(a) Propagation of one radar pulse (indicating the wavefront location at time intervals 1–17)



(b) Resulting antenna return

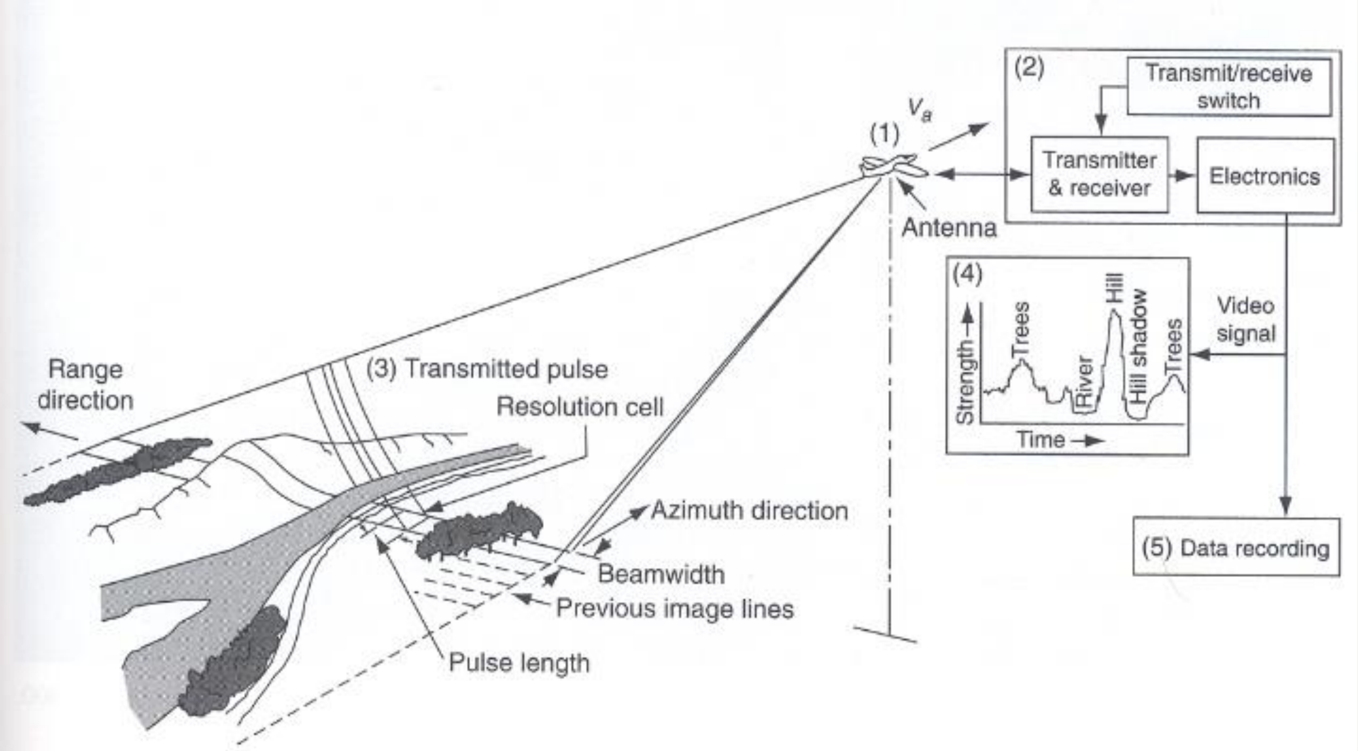
RADAR logic


single pulse of microwave energy with a pulse length of 10 -7 seconds
time n
near range
1
2
3
4
far range
30 m
10 m
time n+1
1
2
3
4
time n+2
1
2
3
4
time n+3
1
2
3
4

SLR Image Formation Steps

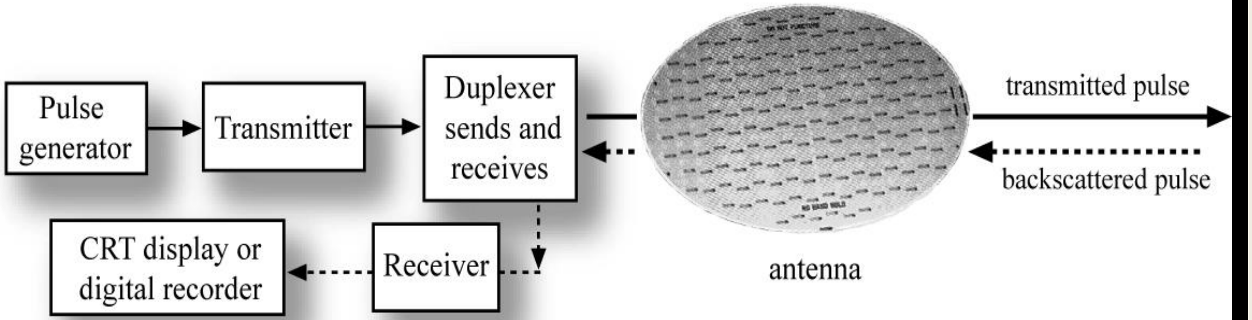
1. As the aircraft moves, the antenna is repositioned along the flight line at the aircraft velocity V_a
2. A synchronized switch switches the antenna from a transmitter to a receiver mode
3. A portion of each transmitted pulse is received back as echo from the terrain objects that happen along each antenna beamwidth
4. The signal from one line of data
5. Echos (returned signal) are received by airborne antenna, processed and recorded

Side-looking radar system operation



Side-looking Airborne RADAR (SLAR) System

a. Intermap LearJet 36 Star 3*i*.

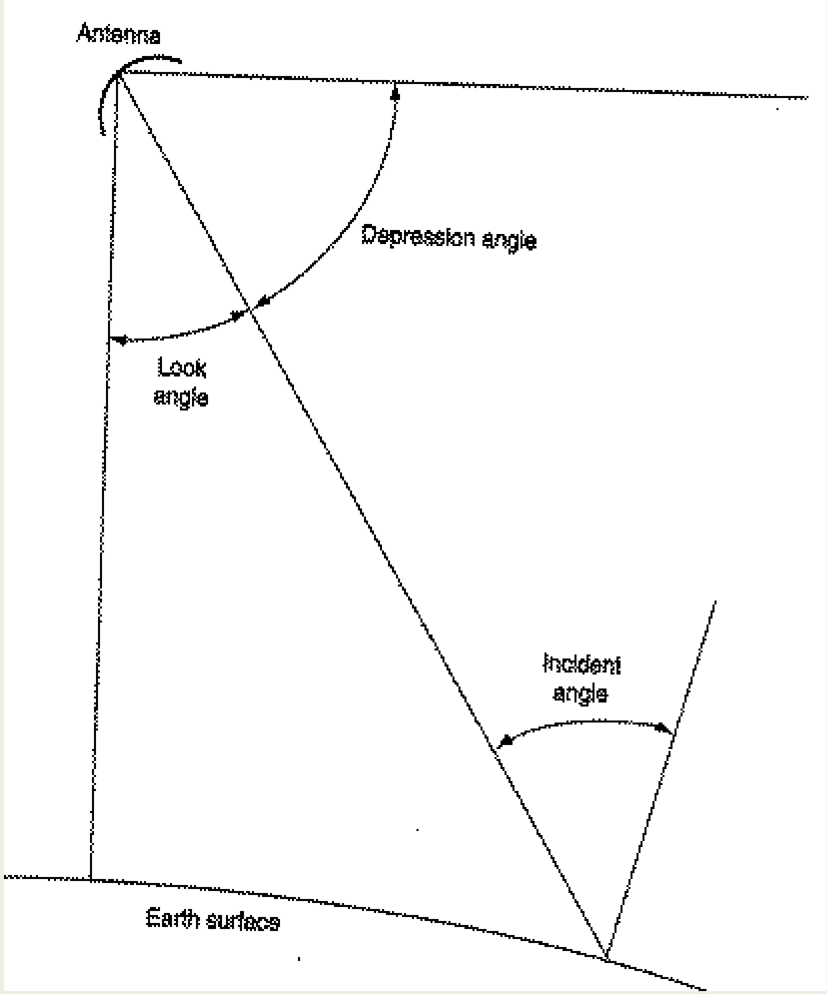


b. Typical active microwave system components.

Geometry of Radar Data Collection

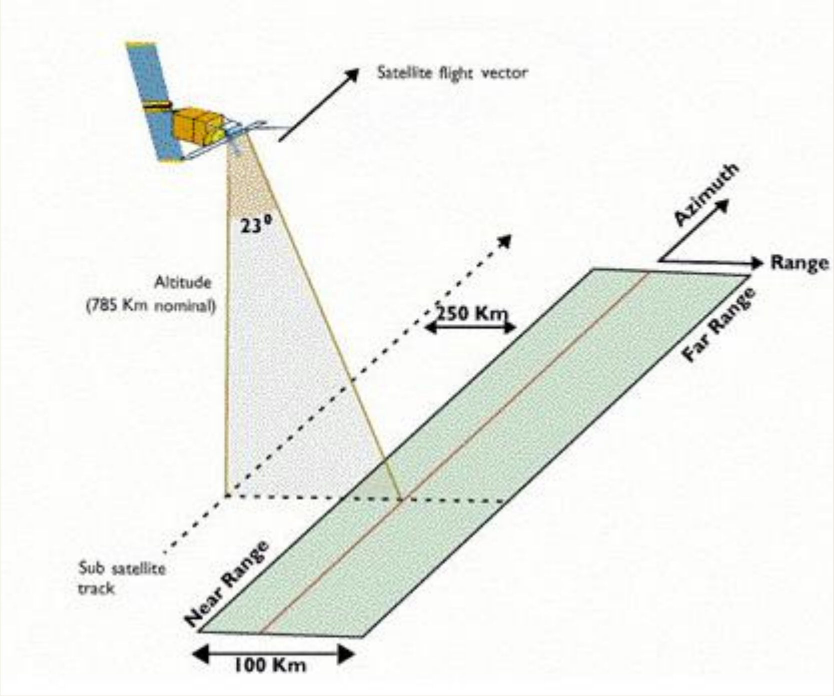
- Look angle: the angle from nadir to a point of interest on the ground
- Depression angle: the complement of look angle
- Incident angle: the angle between the incident radar beam at and the ground surface
- In the case of airborne imaging over flat terrain, the incident angle and look angle are equal

Geometry of Radar

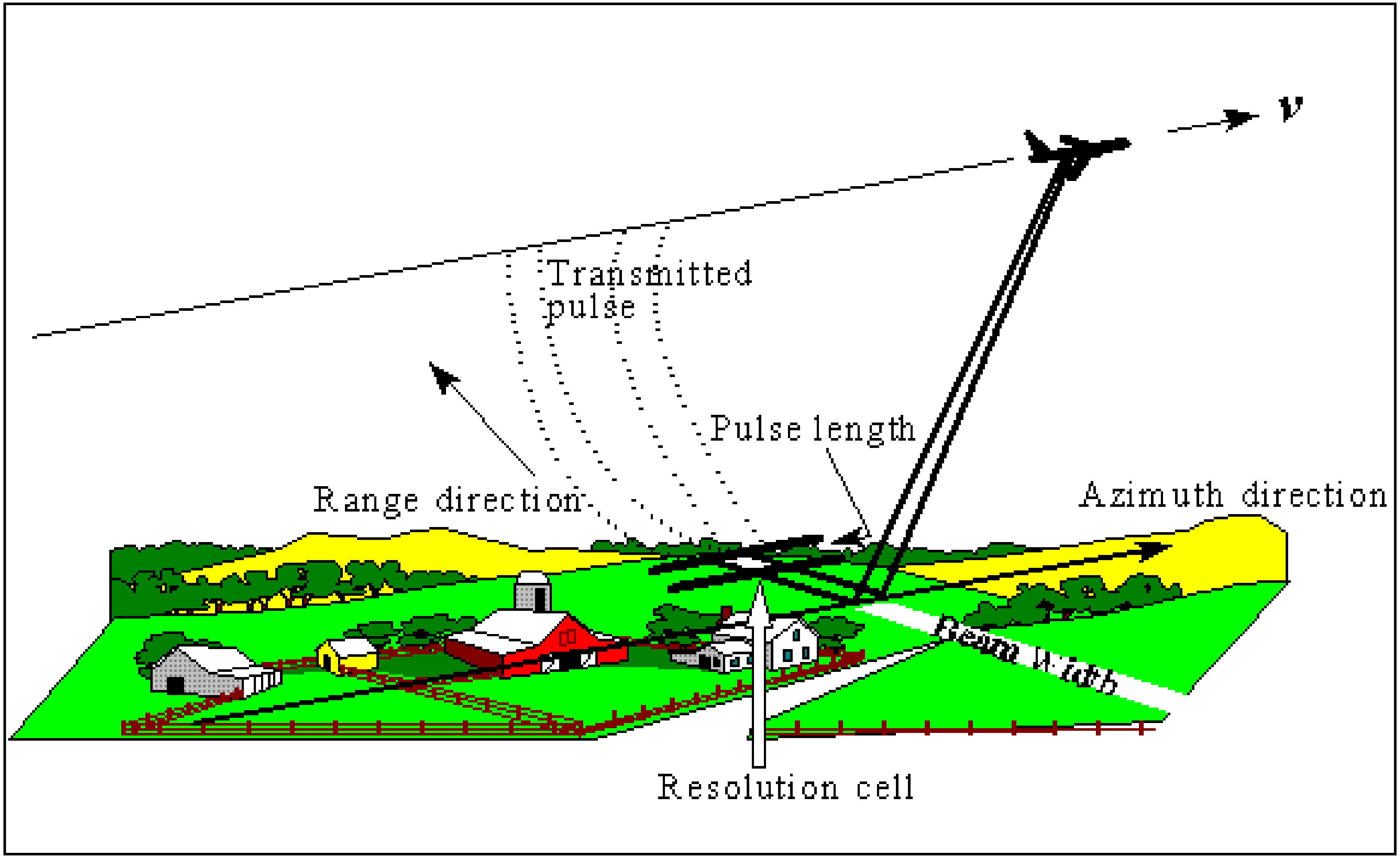


SLR Resolution

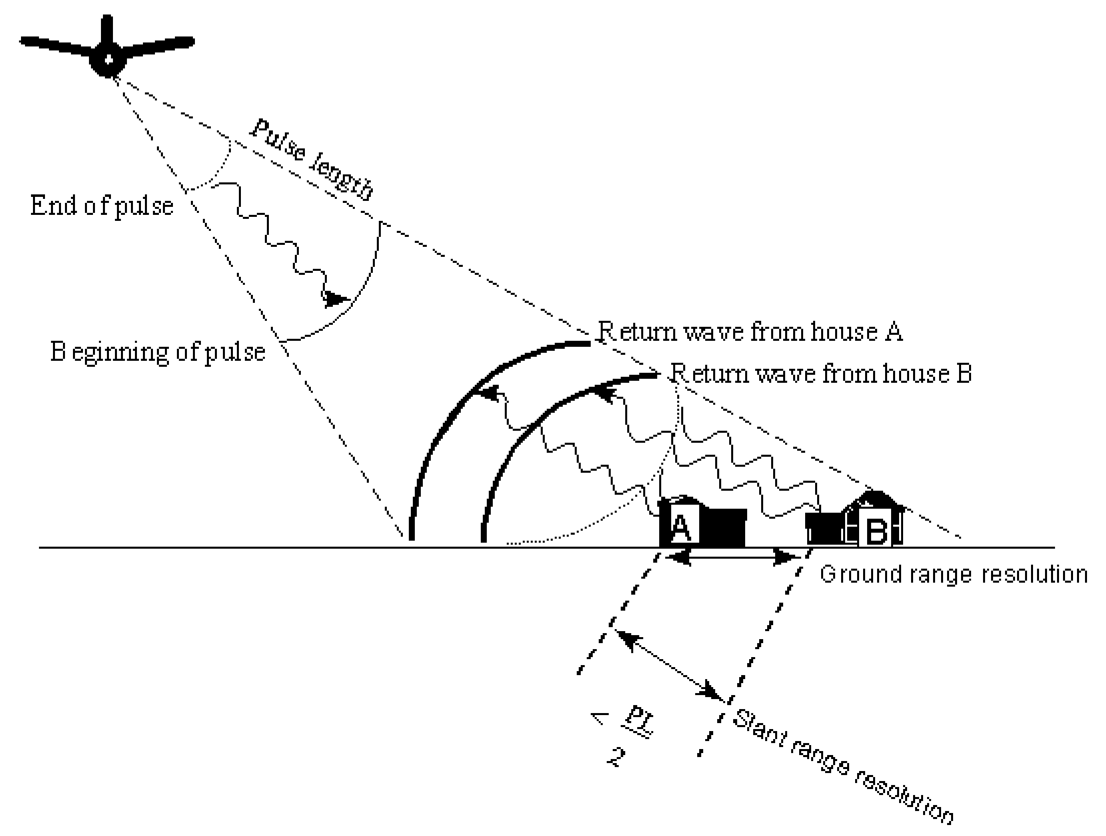
- **Spatial Resolution of SLAR Systems**
  - *Pulse length of the radar signal, affects resolution in the range direction (direction of energy propagation): determined by the length of time the antenna emits the pulse*
  - *Antenna beamwidth, affects resolution in the azimuth direction (flight direction): determined by the width of the antenna beam*


Satellite flight vector
23°
Altitude
(785 Km nominal)
250 Km
Azimuth
Range
Far Range
Sub satellite
track
Near Range
100 Km

SLR system operation



Dependence of range resolution on pulse length



-If the distance between the two houses labeled A and B were greater than {Pulse Length ÷ 2} they would be distinguished as two separate features.

-If the slant range distance is less than {Pulse Length ÷ 2}, the reflected signals are fuzy

-Slant range resolution does not vary with increasing distance from the aircraft, but ground range does

Ground Range Resolution

- Ground-range resolution becomes smaller when slant-range increases

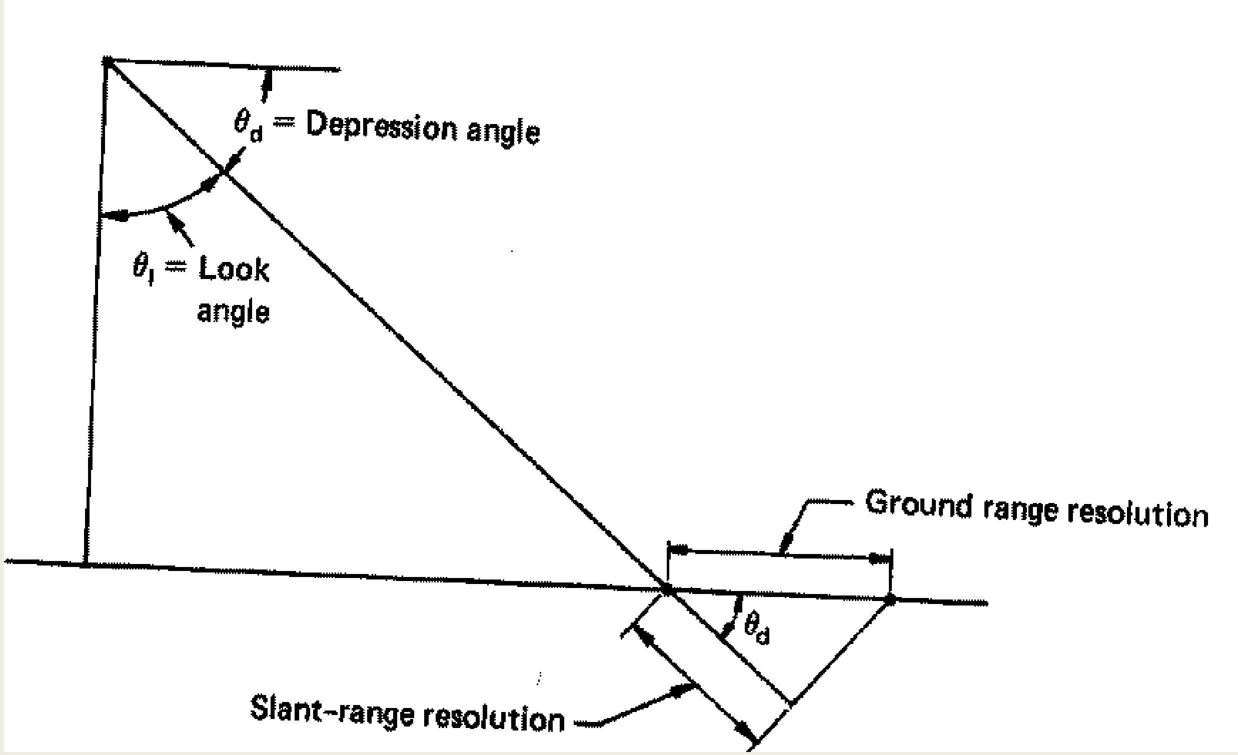
$$R_r = \frac{c\tau}{2\cos\theta_d}$$

R_r : ground resolution in the range direction

τ : pulse duration

θ_d : depression angle

Ground Range Resolution



-As the pulse duration decreases, the ground resolution (horizontal distance) decreases (meaning that the image can show greater spatial detail)

Azimuth Resolution

- The azimuth resolution is the ground distance definition in the azimuth direction (the direction of the airplane/satellite is moving).

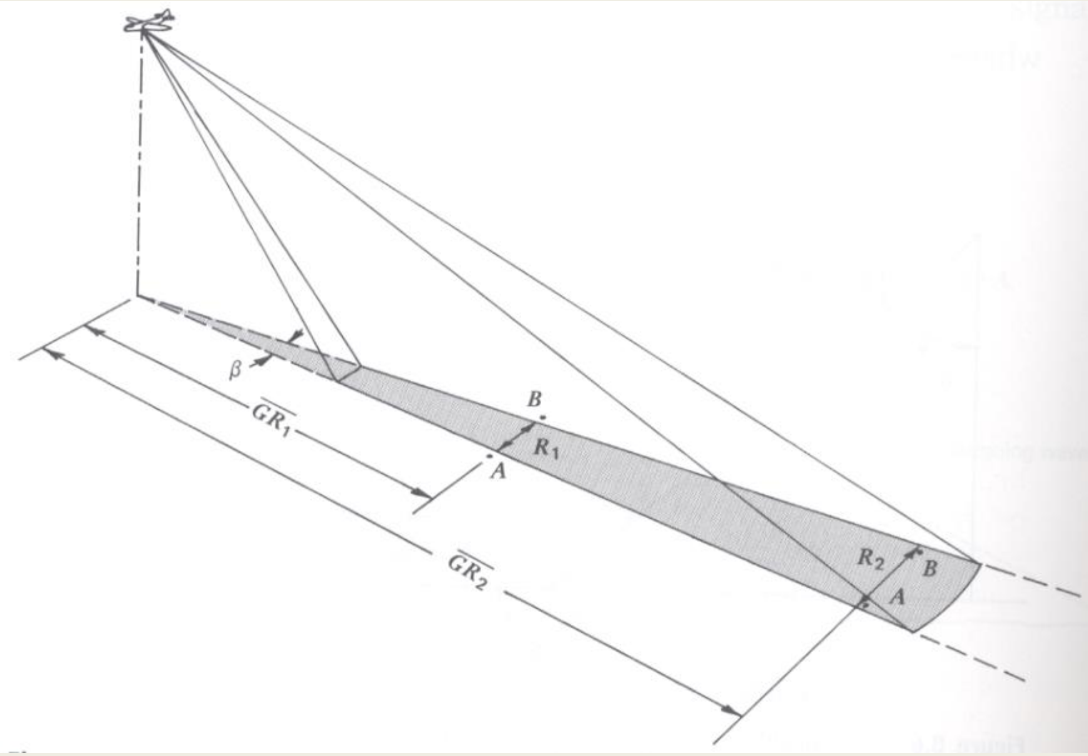
- Azimuth resolution (R_a): determined by the angular beam width of the antenna β and the ground range GR:

$$R_a = \overline{GR} \cdot \beta$$

- The beam width is directly proportional to wavelength of transmitted pulses and inversely proportional to the length of the antenna

Beam width=Wavelength ÷ Antenna Length

Dependence of azimuth resolution on antenna beam width and ground range



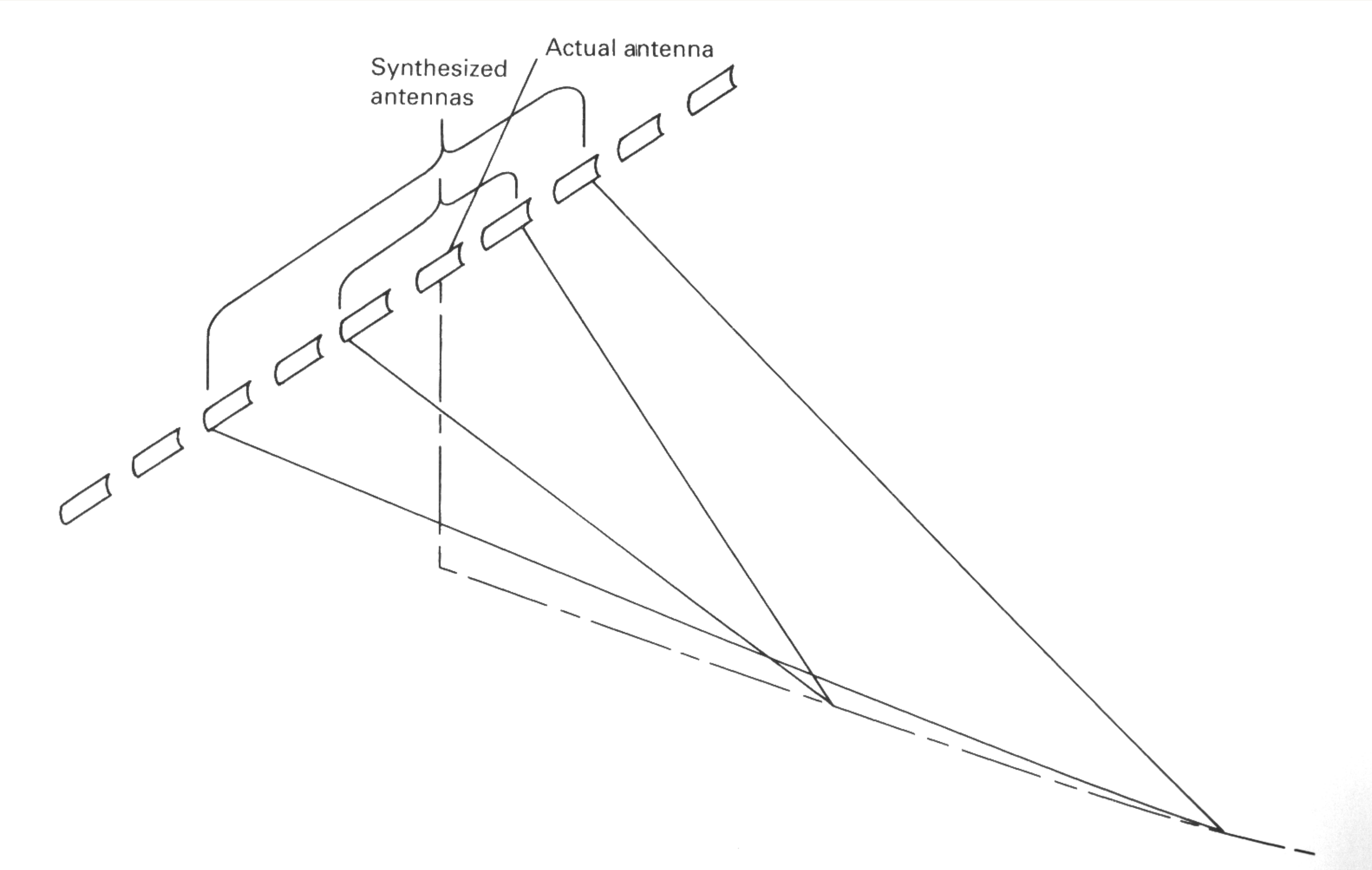
Real Aperture Radars

- Radars in which antenna beam width is controlled by its physical length are called real aperture radars
- Relatively simple design and data processing
- Restricted to short range, low altitude, short wavelengths
- Limited area of coverage, and because of shorter wavelengths, more affected by the atmosphere

Synthetic Aperture Radar (SAR)

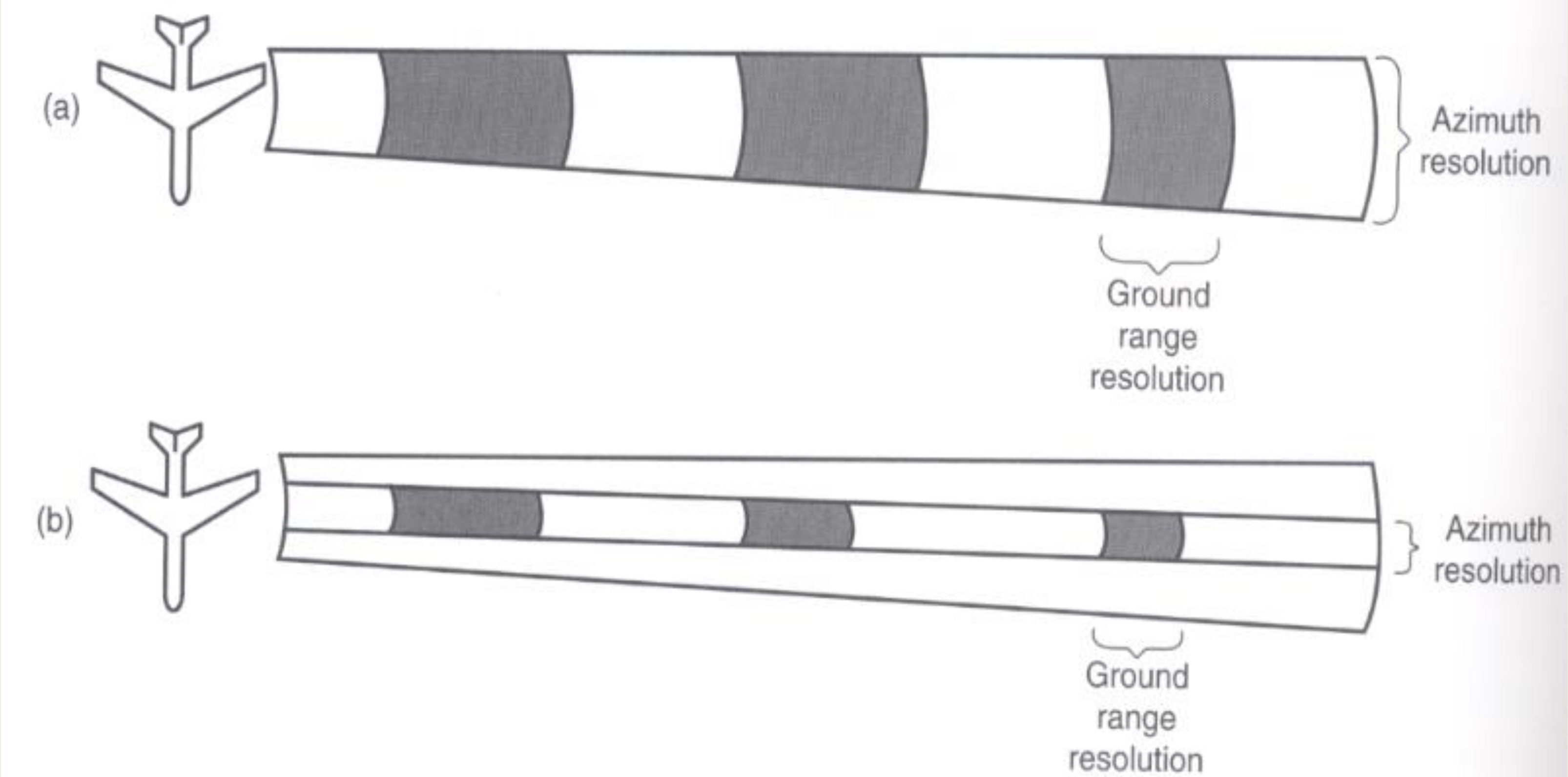
- The most common form of active microwave radar sensors
- Antenna of short physical length but able to synthesize the effect of a long antenna (up to 100 m) to attain high spatial resolution images
- Along track motion is used to create an array of antennas that can be linked together mathematically
- Effective antenna length increases with range
- As a result, we have virtually constant azimuth resolution irrespective to range

Synthetic Aperture RADAR (SAR)



A longer antenna is "synthesized" electronically by using the same antenna but moving it. Recall that the azimuth resolution gets better with longer antennas in SLAR systems.

Variation with distance of spatial resolution of real Aperture (a) versus synthetic aperture (b) SLR system



-As the distance from the aircraft increases, the azimuth resolution size increases with real aperture systems and remaining constant with

-The ground range resolution size decreases with both systems

Synthetic Aperture Radar (SAR)

- Unfocused and focused systems
- In focused systems resolution is 1/2 the actual antenna length, which means the shorter the antenna the better the resolution, independently of range or wavelength
- In contrast, in unfocused systems, the theoretical resolution is a function of wavelength and range, but not antenna length

Geometric distortions in RADAR

- Foreshortening: higher objects are closer to the sensor (Higher is smaller than expected), so will appear to have a shorter ground range, and therefore appear closer to the sensor than it really is
- Layover: an extreme case of foreshortening, when the top of an object is detected before the bottom
- Shadowing: Objects may block radar from hitting objects behind them

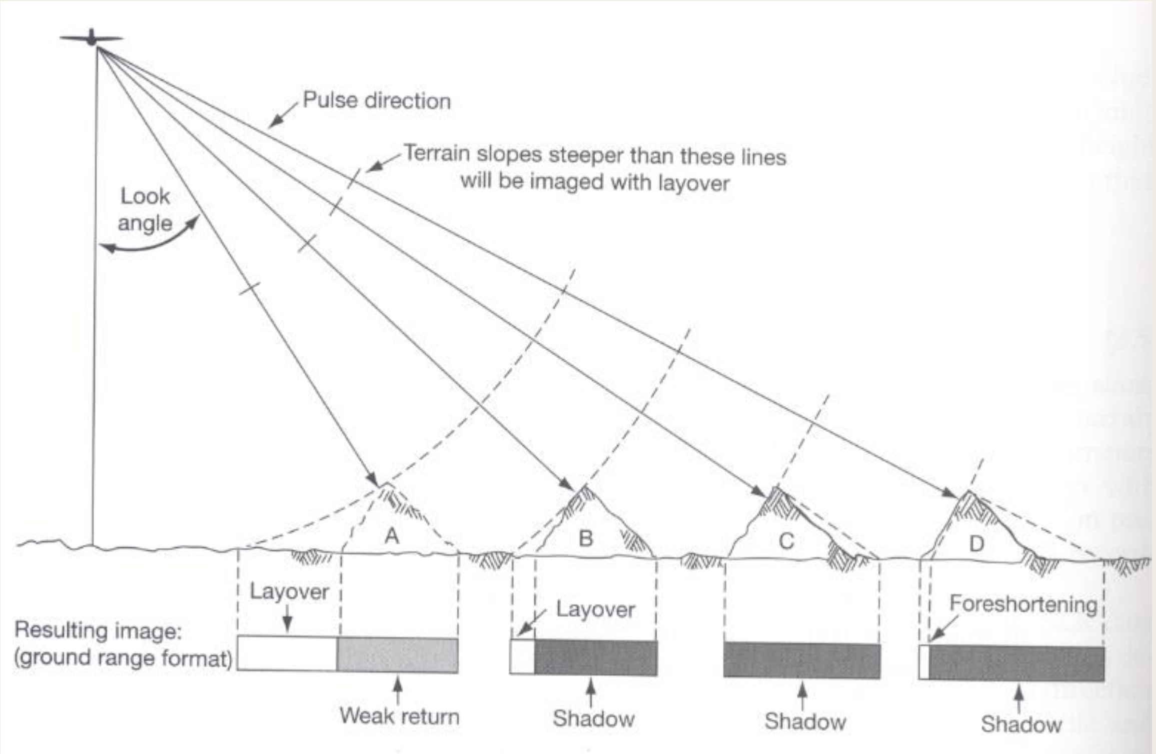

Pulse direction
Terrain slopes steeper than these lines will be imaged with layover
Look angle
A
B
C
D
Layover
Layover
Foreshortening
Resulting image: (ground range format)
Weak return
Shadow
Shadow
Shadow

Image Interpretation

- Factors that affect the intensity of radar returns: geometric and electrical characteristics of objects, wavelength, incident angle, signal polarization

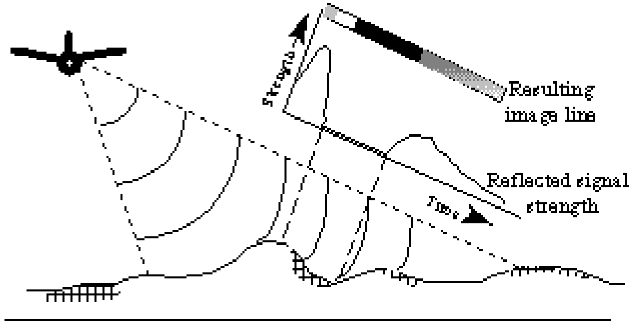
Electrical Characteristics

- Complex dielectric constant: indication of reflectivity and conductivity of material
- Moisture increases dielectric constant of materials, thus increases radar reflectivity
- Type of object (e.g. plant) and atmospheric conditions affect dielectric constant and thus reflectivity

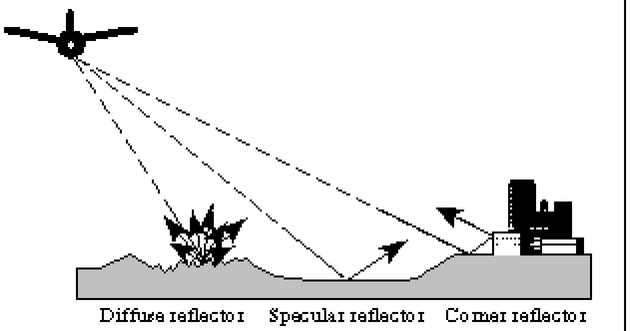
Transmission and Return Characteristics of Radar Signals

- Atmosphere attenuation increases as wavelength decreases (Wavelengths smaller than 3 cm)
- When using wavelengths longer than 3 cm, Earth surface features influence the reflection or scatter of incident radar waves
- Precipitation is more an issue than clouds not only because of potential attenuation or scattering but also since it affects surface and vegetation and thus can affect backscatter

Transmission and Return Characteristics of Radar Signals



Effect of sensor/terrain geometry on SLAR imagery.
(Lillesand and Kiefer, 1994)



Radar reflection from various sources (Lillesand and Kiefer, 1994).

-Slopes at near-orthogonal orientations to the incident radar pulse will generally reflect the energy intensely.
-The strength of the return signal from these gradients is translated into a "bright" response on the final image.
-Those areas that are blocked from radar "illumination" will yield no return at all.
-These areas will translate into totally black areas on the radar image
-The very high contrast results of many radar images are due to these geometric phenomena.

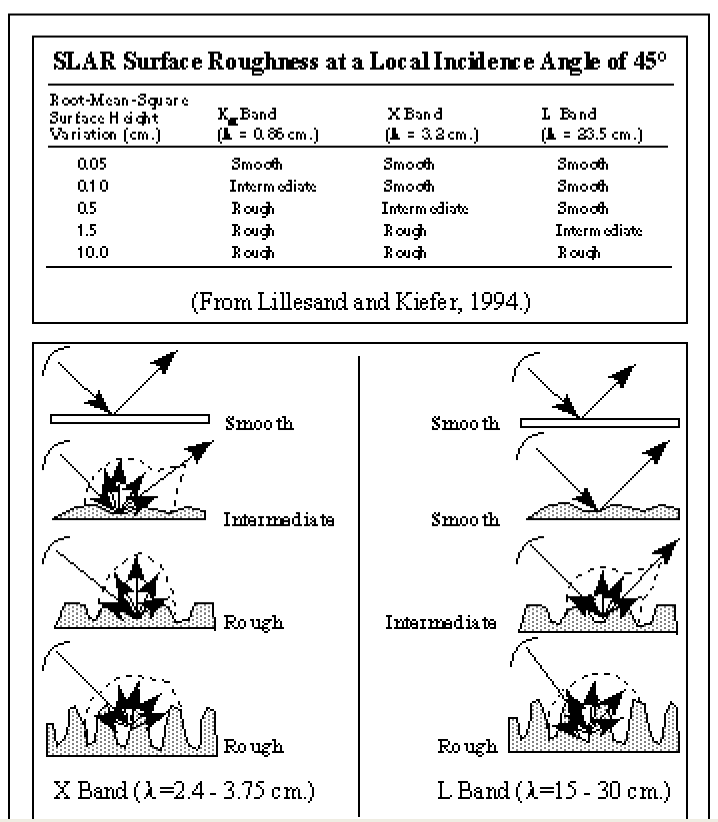
Geometric Characteristics

- Local incident angle:
  - *High returns from slopes facing the antenna and low or no returns form the slopes that are facing away*
  - *As related to surface properties backscatter is dominated by:*
    - 0 - 30 degrees ⇒ radar backscatter is dominated by slope
    - 30 - 70 degrees ⇒ radar backscatter is dominated by surface roughness
    - > 70 degrees ⇒ radar backscatter is dominated by shadows

Geometric Characteristics

- Rayleigh criterion: terrain roughness is defined by rms of height of surface variations as compared to **wavelength** (λ/8) over cosine of local incident angle
  - *Diffuse vs. smooth (specular) reflectors: diffuse produce high signals, specular produce low ones*
- Modified Rayleigh criterion address intermediate roughness
- More specular surfaces in radar imagery than on photographs
- Shape and orientation of objects also affects return signal strength, e.g. corner reflectors (strong signal, bright spots)

X-band and L-Band radar reflection from surfaces of varying roughness



SLAR Surface Roughness at a Local Incidence Angle of 45°

Root-Mean-Square Surface Height Variation (cm.)	K_a Band (λ = 0.86 cm.)	X Band (λ = 3.2 cm.)	L Band (λ = 23.5 cm.)
0.05	Smooth	Smooth	Smooth
0.10	Intermediate	Smooth	Smooth
0.5	Rough	Intermediate	Smooth
1.5	Rough	Rough	Intermediate
10.0	Rough	Rough	Rough

(From Lillesand and Kiefer, 1994.)

The Use of SLAR as a Surface Roughness Detector

- Surface characteristics of a smaller scale also affect radar return signals
- Surfaces are considered "rough" when the root-mean-square (rms) height of the surface variations exceeds one-eighth of the wavelength of sensing (wavelength/8) divided by the cosine of the local incidence angle
- The instrument would gather significant radar echoes from the "rough" surface, but would receive no reflected energy from the "smooth" surface.
- Specular reflectors are defined as those features with rms height variation of less than wavelength/8 divided by the cosine of the incidence angle.
- Particularly strong signals are acquired by "corner reflectors," where the incident energy is reflected twice in such a way that almost all of it is directed back to the sensor.
- Anthropogenic structures such as buildings may appear as extremely bright features on radar images

Electrical Characteristics

- Complex dielectric constant: indication of reflectivity and conductivity of material
- Moisture increases dielectric constant of materials, thus increases radar reflectivity
- Type of object (e.g. plant) and atmospheric conditions affect dielectric constant and thus reflectivity

Polarization

- In addition to slope orientation, surface roughness, vegetation cover, and water content, polarization also affects signal strength and thus information content of resulting imagery

Summary

- Strong signals received by:
  - *Facing slopes*
  - *Rough objects*
  - *High moisture content*
  - *Metal*
  - *Corner reflectors (urban areas)*
- Medium signal is received by most diffuse reflectors
- Low signal is received by specular reflectors (water, pavement)
- No signal from radar shadow areas