Remote Sensing

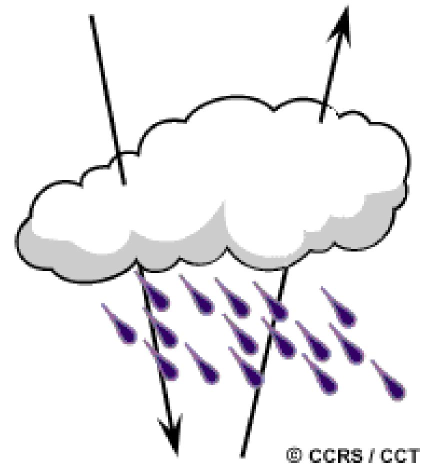
Ch. 3 Microwaves (Part 1 of 2)

3.1 Introduction

- **Microwave** (**1cm** to **1m** in wavelength) sensing encompasses both **active** and **passive** forms of remote sensing.

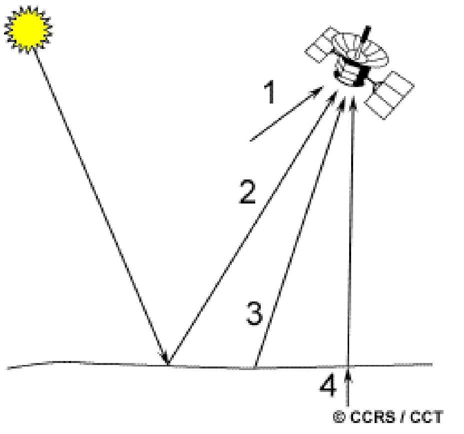
- **Longer wavelength** (compared to the visible and IR) **microwave radiation can penetrate through cloud cover, haze, dust,** and **all but the heaviest rainfall** as the longer wavelengths are not susceptible to atmospheric scattering which affects shorter optical wavelengths.

- This property allows detection of microwave energy under **almost all weather** and **environmental conditions** so that data can be collected at **any time**.



3.1 Introduction

Passive microwave sensing



- All objects emit microwave energy of some magnitude, but the amounts are generally **very small**. The microwave energy can be emitted by **the atmosphere** (1), **reflected from the surface** (2), **emitted from the surface** (3), or **transmitted from the subsurface** (4).

- The **naturally emitted energy** is related to the **temperature** and **moisture** properties of the emitting object or surface.

- Because the wavelengths are so long, **the energy** available is quite **small** compared to optical wavelengths. Thus, **the fields of view** must be **large** to detect enough energy to record a signal. Most **passive microwave sensors** are therefore characterized by **low spatial resolution**.
- In passive **microwave sensors**, an **antenna** is used to detect and record the microwave energy.

- **Applications** : (a) **Meteorology** - to determine water and ozone content in the atmosphere. (b) **Hydrology** - to measure soil moisture since microwave emission is influenced by moisture content. (c) **Oceanography** - mapping sea ice, currents, and surface winds as well as detection of pollutants, such as oil slicks.

3.1 Introduction

Active microwave sensors

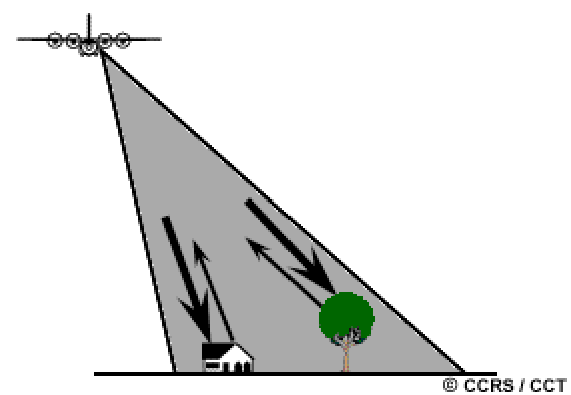
- provide their **own source of microwave radiation** to illuminate the target.

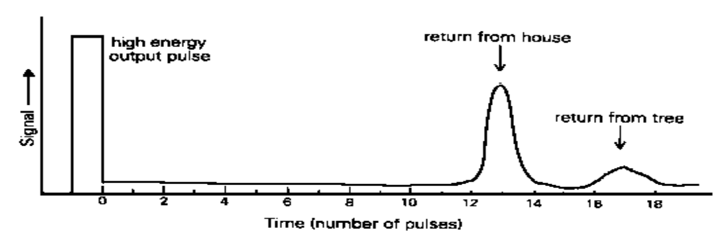
- Active microwave sensors are generally divided into two distinct categories: **imaging** and **non-imaging**.

- **Imaging microwave sensors** :

  - The most common form of imaging active microwave sensors is RADAR. **RADAR** is an acronym for **RA**dio **D**etection **A**nd **R**anging.

  - The sensor transmits a microwave (radio) signal towards the target and detects the backscattered portion of the signal. The **strength** of the backscattered signal is measured to discriminate between different targets and the **time delay** between the transmitted and reflected signals determines the **distance** (or **range**) to the target.





3.1 Introduction

- **Non-imaging microwave sensors :** These are **profiling devices** which take **measurements in one-dimension**, as opposed to the two-dimensional representation of imaging sensors.

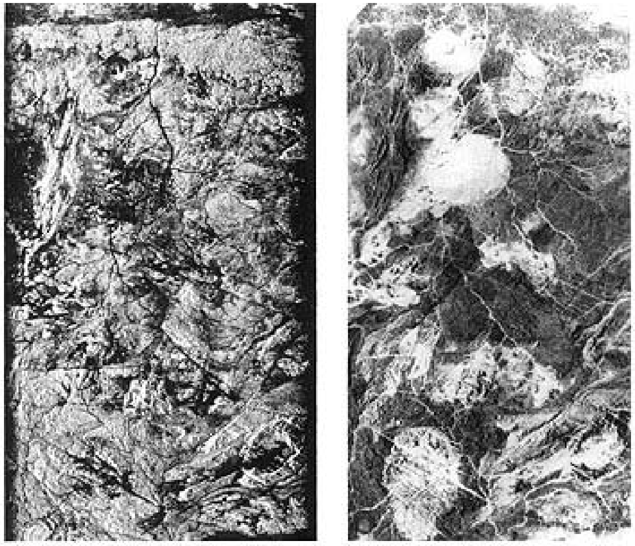
  - **Radar altimeters** transmit short microwave pulses and measure the round trip time delay to targets to **determine their distance from the sensor**. Generally altimeters look straight down at nadir below the platform and thus **measure height** or **elevation**. **Radar altimetry** is used on aircraft for **altitude determination** and on aircraft and satellites for **topographic mapping** and **sea surface height estimation**.

  - **Scatterometers** are used to make precise **quantitative measurements** of the amount of energy **backscattered** from targets. The amount of energy backscattered is dependent on the surface properties (roughness) and the angle at which the microwave energy strikes the target. **Scatterometry** measurements over ocean surfaces can be used to estimate **wind speeds** based on the sea surface roughness. **Ground-based scatterometers** are used extensively to accurately measure the backscatter from various targets in order to **characterize different materials** and **surface types**. This is analogous to the concept of spectral reflectance curves in the optical spectrum.

3.1 Introduction

• As with passive microwave sensing, a major **advantage of radar** is the capability of the radiation to **penetrate through cloud cover and most weather conditions**. Because radar is an **active sensor**, it can also be used to image the surface **at any time, day or night**. These are the two primary advantages of radar: (1) **all-weather** and (2) **day or night** imaging.

• Because of the fundamentally different way in which an active radar operates compared to the passive optical sensors, a **radar image is quite different** from and has special properties unlike images acquired in the visible and infrared portions of the spectrum. This is obvious in this pair showing Egyptian crystalline terrain image by RADAR (left) and Landsat (right).



• Because of these differences, **radar** and **optical** data can be **complementary to one another** as they offer **different perspectives** of the Earth's surface providing **different information content**.

3.1 Introduction

The origins and history of imaging radar,

- The first demonstration of the **transmission of radio microwaves** and **reflection** from various objects was achieved by **Hertz** in **1886**.
- In the **1900s**, the **first rudimentary radar** was developed for ship detection.
- In the **1920s** and **1930s**, experimental **ground-based pulsed radars** were developed for **detecting objects at a distance**.
- **The first imaging radars** used **during World War II (1939~1945)** had rotating sweep displays which were used for detection and positioning of aircrafts and ships.
- **After World War II**, **side-looking airborne radar (SLAR)** was developed **for military** terrain reconnaissance and surveillance where a strip of the ground parallel to and offset to the side of the aircraft was imaged during flight.
- In the **1950s**, advances in SLAR and the development of higher resolution **synthetic aperture radar** (**SAR**) were developed **for military purposes**.

3.1 Introduction

- In the **1960s** these radars were **declassified** and began to be used for **civilian mapping applications**. Since this time the development of several airborne and spaceborne radar systems for mapping and monitoring applications use has flourished.

- The **first operational civilian radar satellite**, **SEASAT**, was an experimental L-band radar whose primary mission was to measure ocean surfaces. It failed several months after launch in **1978** but did return many images that **verified "proof of concept**".

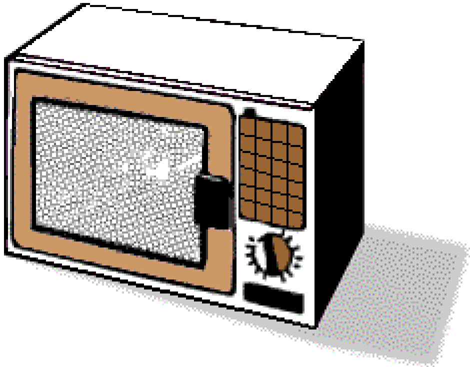
- Over the **1980s** and early **1990s**, several research and commercial **airborne radar** systems have collected vast amounts of imagery throughout the world **demonstrating the utility of radar data** for a variety of applications.

- With the launch of ESA's **ERS-1** in **1991**, spaceborne radar research intensified, and was followed by the major launches of Japan's **J-ERS** satellite in **1992**, **ERS-2** in **1995**, and Canada's advanced **RADARSAT** satellite, also in **1995**.

3.1 Introduction

Did You Know?

'S' band magnetrons are typically used for microwave oven power sources. They operate in the range of **2-4 GHz**. The corresponding wavelengths are **15 cm to 7.5 cm.** The screening mesh used on microwave oven doors is sufficiently fine (much smaller than 7.5 cm) that it behaves as a continuous, thin, metal sheet, preventing the escape of the radar energy, yet allowing good visibility of the interior (using visible wavelengths, which are much shorter yet).



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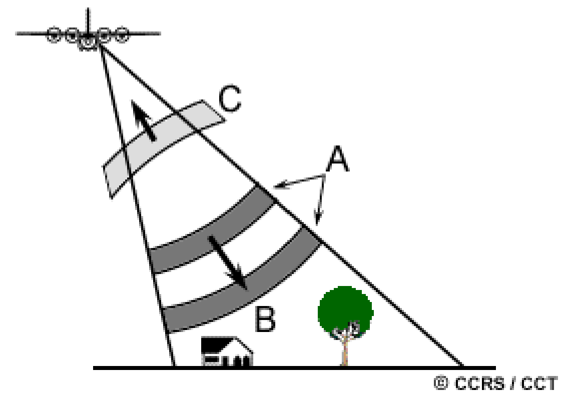
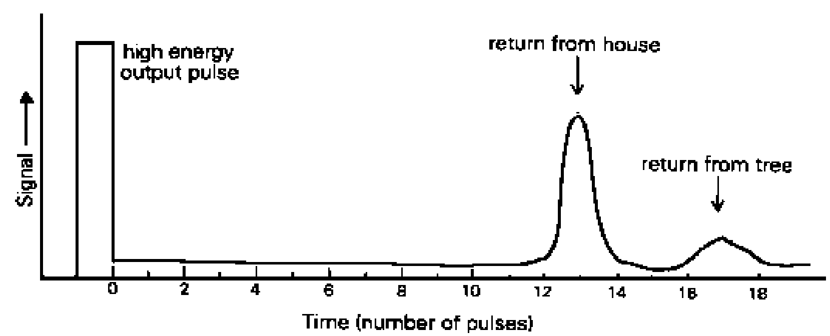
3.2 Radar Basics

- A **radar** is essentially **a ranging** or **distance measuring device**.
- It consists fundamentally of **a transmitter**, **a receiver**, **an antenna**, and **an electronics system** to process and record the data.
- The transmitter generates successive short bursts (or **pulses of microwave (A)** at regular intervals which are focused by the antenna into **a beam (B)**. The radar beam illuminates the surface **obliquely** at a right angle to the motion of the platform. The antenna receives a portion of the transmitted energy **reflected** (or **backscattered**) from various objects within the **illuminated beam (C).**



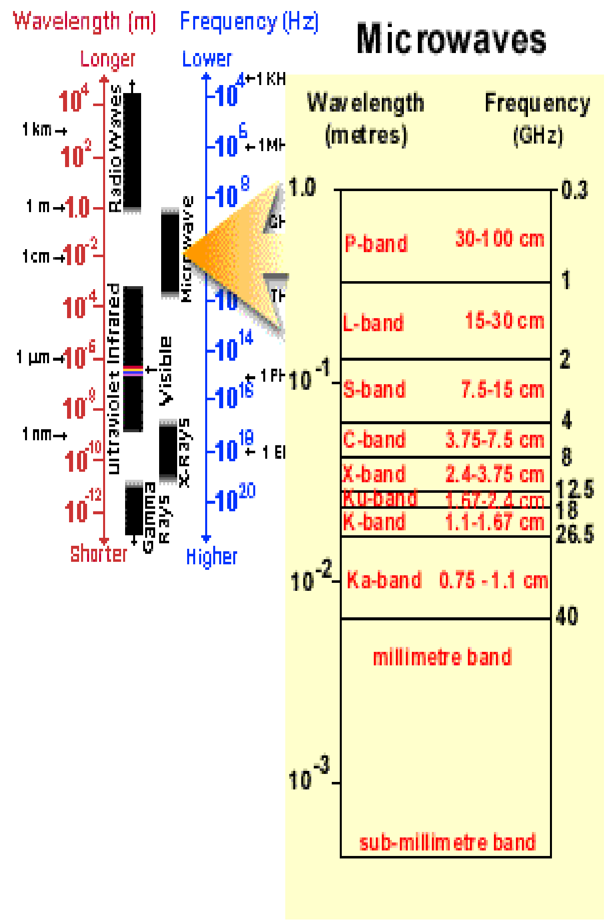
- By **measuring the time delay** between the **transmission** of a pulse and the **reception** of the backscattered "echo" from different targets, their distance from the radar and thus their location can be determined.
- As the sensor platform moves forward, recording and processing of the backscattered signals builds up a **two-dimensional image** of the surface.



3.2 Radar Basics

- The **microwave region of the spectrum** is quite large, relative to the visible and infrared, and there are several wavelength ranges or bands commonly used which given code letters during World War II, and remain to this day.

- **Ka, K**, and **Ku** bands: **very short** wavelengths used in early airborne radar systems but uncommon today.
- **X**-band: used extensively on airborne systems for military reconnaissance and terrain mapping.
- **C**-band: common on many airborne research systems (CCRS **Convair-580** and NASA **AirSAR**) and spaceborne systems (including **ERS**-1 & 2 and **RADARSAT**).
- **S**-band: used on board the Russian **ALMAZ** satellite.
- **L**-band: used on board American **SEASAT** & Japanese **JERS-1** satellites & NASA airborne system.
- **P**-band: the **longest** radar wavelengths, used on NASA experimental airborne research system.



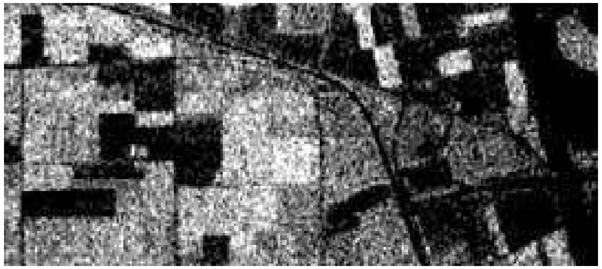
3.2 Radar Basics

- Here are two radar images of the same agricultural fields, each image having been collected using a **different radar band**.

The one on **the top ➔ C-band** radar
The one **below ➔ L-band** radar

- You can clearly see that there are **significant differences** between the way the various fields and crops appear in each of the two images. This is due to the different ways in which the radar energy interacts with the fields and crops depending on the radar **wavelength**.

Two radar images of the same agricultural fields

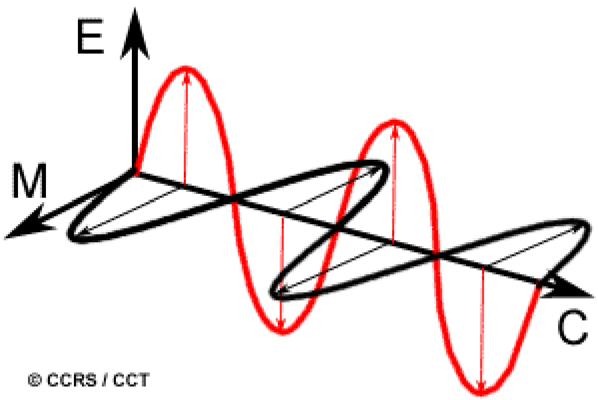


C-Band Radar Image

L-Band Radar Image

3.2 Radar Basics

- **Polarization** of microwave radiation refers to **the orientation of the electric field (E)**. Most radars are designed to transmit microwave radiation either horizontally polarized (H) or vertically polarized (V). Similarly, the antenna receives either the horizontally or vertically polarized backscattered energy, and some radars can receive both. These two polarization states are designated by the letters **H** for **horizontal**, and **V** for **vertical**.



- Thus, there can be four combinations of both transmit and receive polarizations as follows:
  - **HH** - for horizontal transmit and horizontal receive,
  - **VV** - for vertical transmit and vertical receive,
  - **HV** - for horizontal transmit and vertical receive, and
  - **VH** - for vertical transmit and horizontal receive.

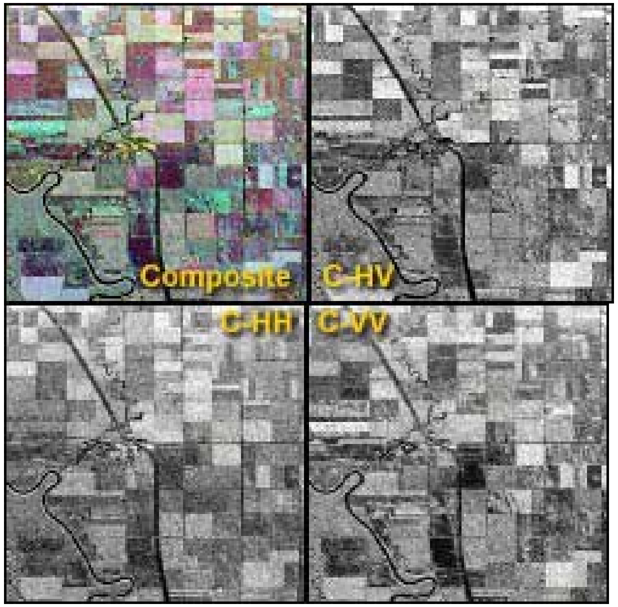
- **The first two** polarization combinations are referred to as **like-polarized** because the transmit and receive polarizations are the same. **The last two** combinations are referred to as **cross-polarized** because the transmit and receive polarizations are opposite of one another.

3.2 Radar Basics

- These **C-band images** of agricultural fields demonstrate the variations in radar response due to **changes in polarization**.

- The bottom two images are like-polarized (HH and VV, respectively), and the upper right image is cross-polarized (HV). The upper left image is the result of displaying each of the three different polarizations together, one through each of the primary colors (red, green, and blue).

- Similar to variations in wavelength, depending on the transmit and receive polarizations, the radiation will interact with and be backscattered differently from the surface.



C-band images

- **Both wavelength and polarization affect how a radar "sees" the surface**. Therefore, radar imagery collected using different polarization and wavelength combinations may provide different and complementary information about the targets on the surface.

3.2 Radar Basics

Quiz How could we use radar images of different wavelengths and/or polarizations to extract more information about a particular scene?

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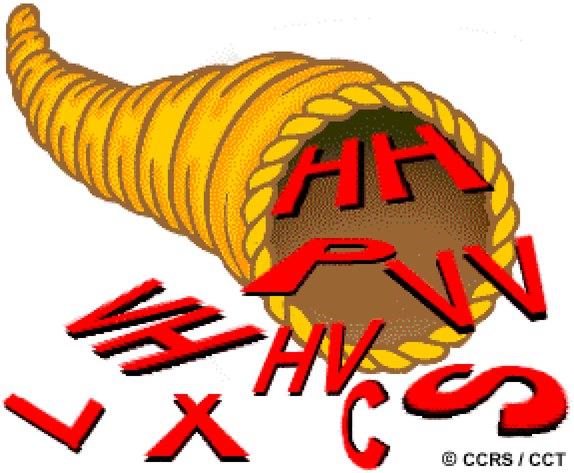

3.2 Radar Basics

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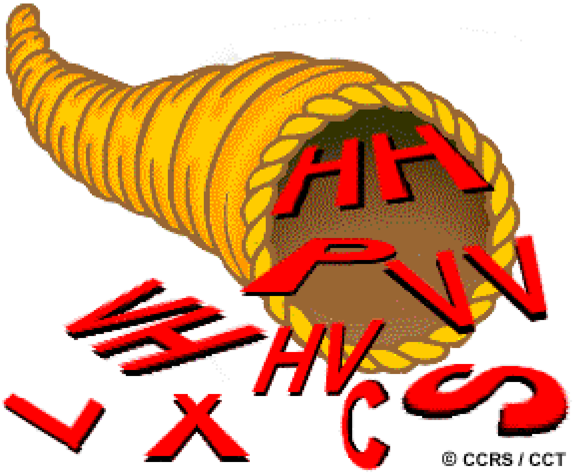


ANS Much the same as with **optical sensors** that have **different bands or channels** of data, **multi-wavelength** and **multi-polarization radar images** can provide **complementary information**. Radar data collected at different wavelengths is **analogous to the different bands of data in optical remote sensing**. Similarly, the various polarizations may also be considered as different bands of information. Depending on the wavelength and polarization of the radar energy, it will **interact differently with features** on the surface. As with multi-band optical data, we can combine these different "channels" of data together to produce color images which may highlight subtle variations in features as a function of wavelength or polarization.

3.2 Radar Basics

Quiz Explain how data from a non-imaging scatterometer could be used to extract more accurate information from an imaging radar.

ANS

3.2 Radar Basics

Quiz Explain how data from a non-imaging scatterometer could be used to extract more accurate information from an imaging radar.

ANS A scatterometer is used to **precisely measure the intensity** of backscatter reflected from an object or surface. By accurately characterizing (i.e. measuring) the intensity of energy reflected from a variety of objects or surface types, these measurements can be used to generate typical **backscatter signatures**, similar to the concept of spectral signatures with optical data. These measurements can be used as **references for calibrating** imagery from an imaging radar sensor so that more accurate comparisons can be made of the response between different features.

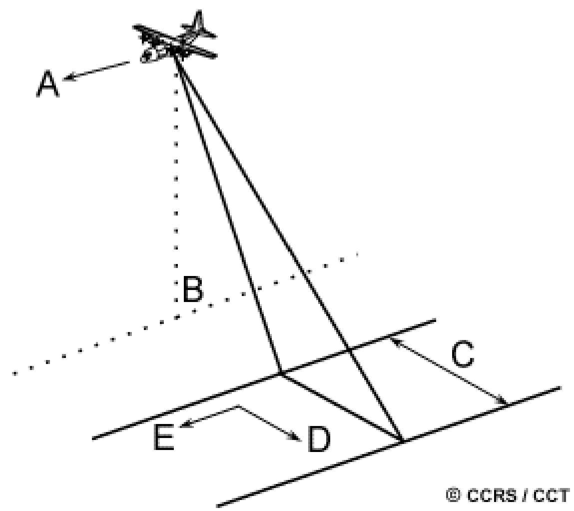
3.3 Viewing Geometry and Spatial Resolution

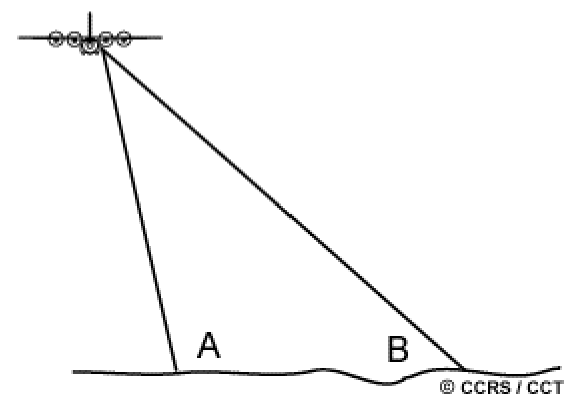
- The **imaging geometry** of a radar system is **different** from the framing and scanning systems commonly employed for optical remote sensing.

- The platform travels forward in the **flight direction (A)** with the **nadir (B)** directly beneath the platform. The microwave beam is **transmitted obliquely** at right angles to the direction of flight illuminating a **swath (C)** which is offset from nadir.

- **Range (D)** refers to the across-track dimension **perpendicular to the flight direction**, while **azimuth (E)** refers to the along-track dimension **parallel to the flight direction**. This side-looking viewing geometry is typical of imaging radar systems (airborne or spaceborne).

- 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)**.

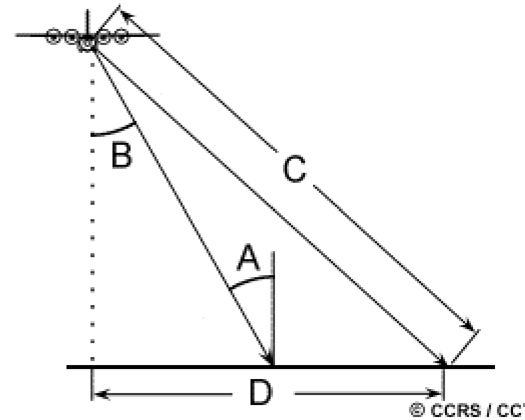


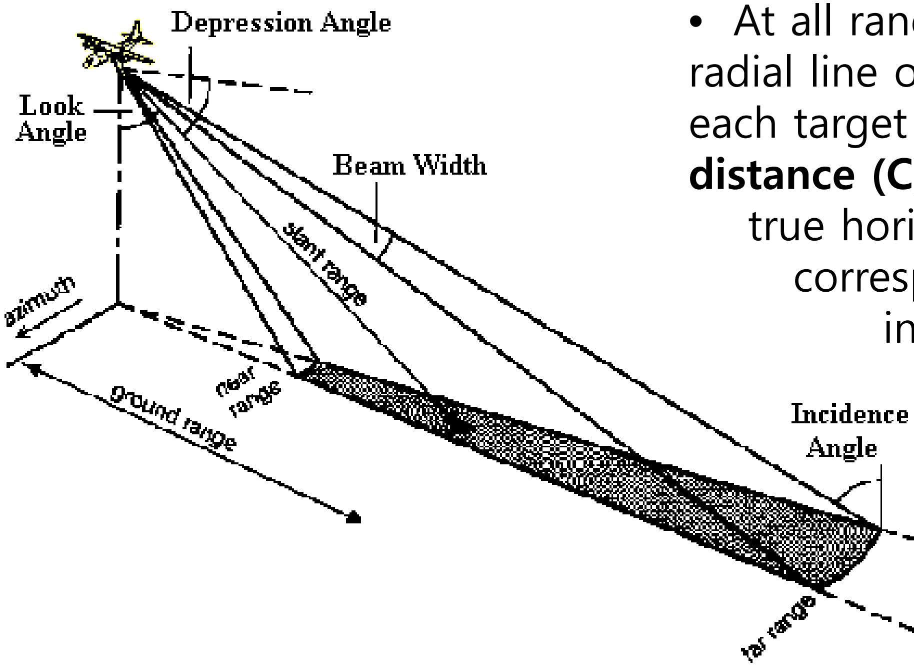


3.3 Viewing Geometry and Spatial Resolution

- The **incidence angle (A)** is the angle between the **radar beam** and **ground surface** which increases, moving across the swath from near to far range.

- The **look angle (B)** is the angle at which the radar "looks" at the surface. In the **near range**, the viewing geometry may be referred to as being **steep**, relative to the **far range**, where the viewing geometry is **shallow**.

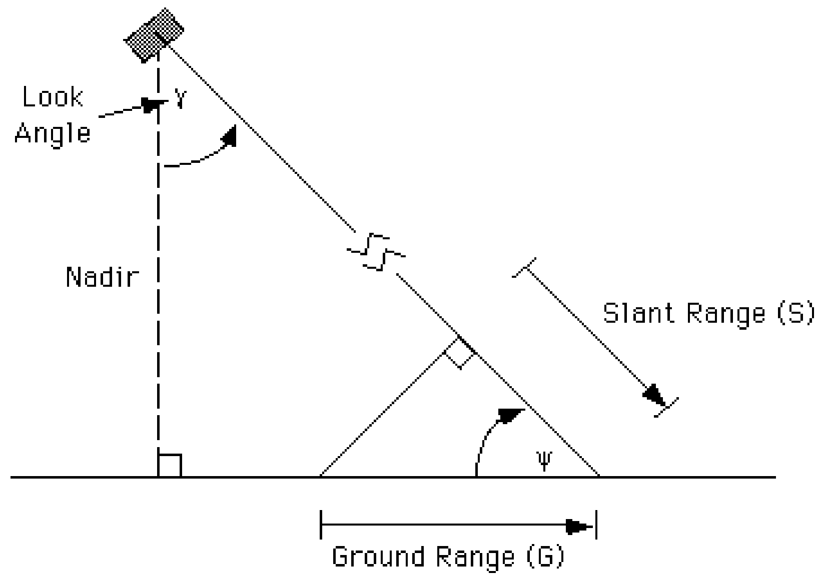




- At all ranges the radar antenna measures the radial line of sight distance between the radar and each target on the surface. This is the **slant range distance (C)**. The **ground range distance (D)** is the true horizontal distance along the ground corresponding to each point measured in slant range.

3.3 Viewing Geometry and Spatial Resolution

Slant Range vs. Ground Range



$$S = G * \cos(\psi)$$

$$\psi + \gamma = 90 \text{ degrees} \quad => \quad \psi = 90 - \gamma$$

$$S = G * \cos(90 - \gamma) \quad \& \quad \cos(90 - \gamma) = \sin(\gamma)$$

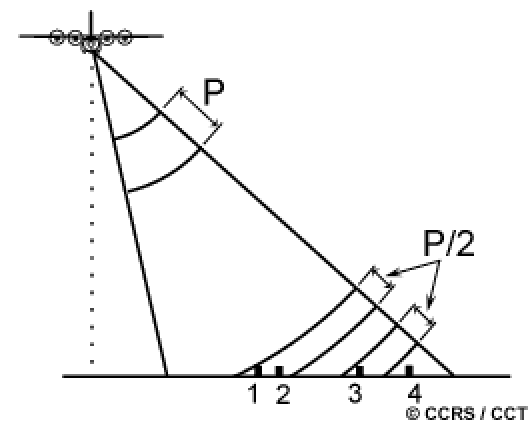
$$S = G * \sin(\gamma)$$

ERS-1 data has approximately 8 meter slant range spacing. Since ERS-1's look angle is about 23 degrees, the data's ground spacing turns out to be around 20 meters.

3.3 Viewing Geometry and Spatial Resolution

- Unlike optical systems, a **radar's spatial resolution** is a function of the specific properties of the microwave radiation and geometrical effects.

- If a **Real Aperture Radar (RAR)** is used for image formation (as in Side-Looking Airborne Radar) **a single transmit pulse** and the backscattered signal are used to form the image. In this case, the resolution is dependent on the **effective length of the pulse in the slant range direction** and on the **width of the illumination in the azimuth direction**.

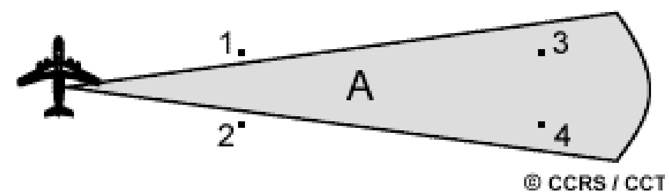


- The **range** or **across-track resolution** is dependent on the **length of the pulse (P)**. Two distinct targets on the surface will be resolved in the range dimension if their separation is **greater than half the pulse length (P/2)**. For example, targets 1 and 2 will not be separable while targets 3 and 4 will.

- **Slant range resolution** remains **constant**, independent of range. However, when projected into ground range coordinates, the resolution in ground range will be dependent of the incidence angle. Thus, for fixed slant range resolution, the **ground range resolution** will **decrease with increasing range**.

3.3 Viewing Geometry and Spatial Resolution

- The **azimuth** or **along-track resolution** is determined by the **angular width** of the radiated microwave beam and the slant range distance. This **beamwidth (A)** is a measure of the width of the illumination pattern.



- As the radar illumination propagates to **increasing 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 beamwidth** 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.

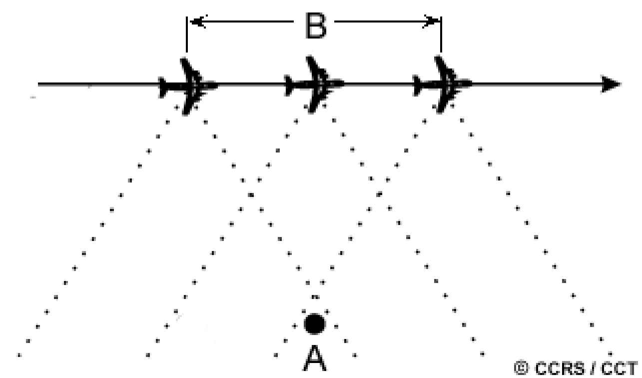
- **Finer range resolution** can be achieved by using **a shorter pulse length**, which can be done within certain **engineering design restrictions**.

- **Finer azimuth resolution** can be achieved by **increasing the antenna length**. However, the actual length of the antenna is limited by what can be carried on an airborne or spaceborne platform. For **airborne radars**, antennas are usually limited to **one to two meters**; for **satellites** they can be **10 to 15 meters** in length.

3.3 Viewing Geometry and Spatial Resolution

- To overcome this size limitation, the forward motion of the platform and special recording and processing of the backscattered echoes are used to **simulate a very long antenna** and thus **increase azimuth resolution**.

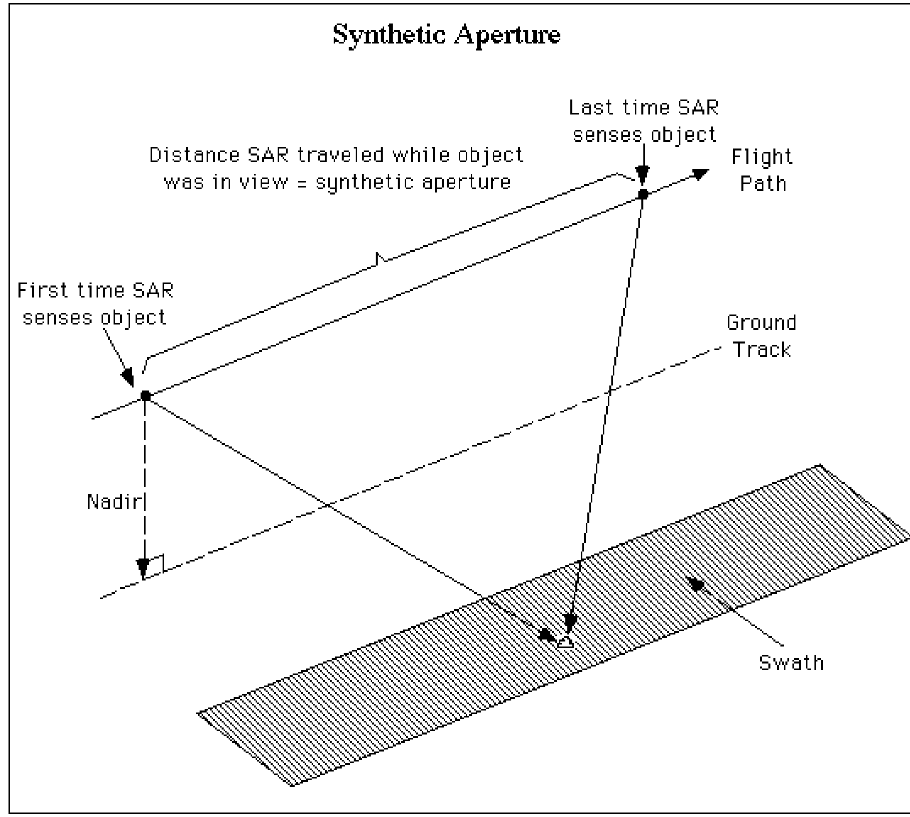
- This figure illustrates how this is achieved. As a **target (A)** first enters the radar beam (1), the backscattered echoes from each transmitted pulse begin to be recorded. As the platform continues to move forward, all echoes from the target for each pulse are recorded during the entire time that the target is within the beam. The point at which the target leaves the view of the radar beam (2) some time later, determines the **length** of the **simulated** or **synthesized antenna (B)**.



- Targets at far range, where the beam is widest will be illuminated for a longer period of time than objects at near range. The expanding beamwidth, combined with the increased time a target is within the beam as ground range increases, balance each other, such that **the resolution remains constant across the entire swath**. This method of achieving **uniform, fine azimuth resolution** across the entire imaging swath is called **synthetic aperture radar (SAR)**. Most airborne and spaceborne radars employ this type of radar.

3.3 Viewing Geometry and Spatial Resolution

- The **ERS-1** satellite's SAR sends out around 1700 pulses a second, collects about a thousand backscattered responses from a single object while passing overhead, and the resulting processed image has a **resolution** near **30 m**. The spacecraft travels around 4 Km while an object is "within sight" of the radar, implying that ERS-1's **10 m x 1 m radar antenna** synthesizes a **4 Km-long stationary antenna**.



3.3 Viewing Geometry and Spatial Resolution

Quiz Explain why the use of a synthetic aperture radar (SAR) is the only practical option for radar remote sensi from space.

ANS

3.3 Viewing Geometry and Spatial Resolution

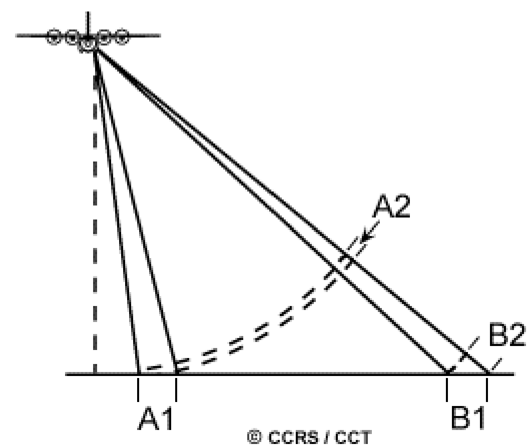
Quiz Explain why the use of a synthetic aperture radar (SAR) is the only practical option for radar remote sensing from space.

ANS The high altitudes of spaceborne platforms (i.e. hundreds of Km) preclude the use of real aperture radar (RAR) because the azimuth resolution, which is a function of the range distance, would be too coarse to be useful. In a **spaceborne RAR**, the only way to achieve fine resolution would be to have a very, very narrow beam which would require an **extremely long physical antenna**. However, an antenna of several Km in length is physically impossible to build, let alone fly on a spacecraft. Therefore, we need to use synthetic aperture radar to synthesize a long antenna to achieve fine azimuth resolution.

3.4 Radar Image Distortions

- The viewing geometry of a radar results in certain **geometric distortions** on the resultant imagery. However, there are key differences for radar imagery which are due to the **side-looking viewing geometry**, and the fact that the radar is fundamentally **a distance measuring** device (i.e. measuring range).

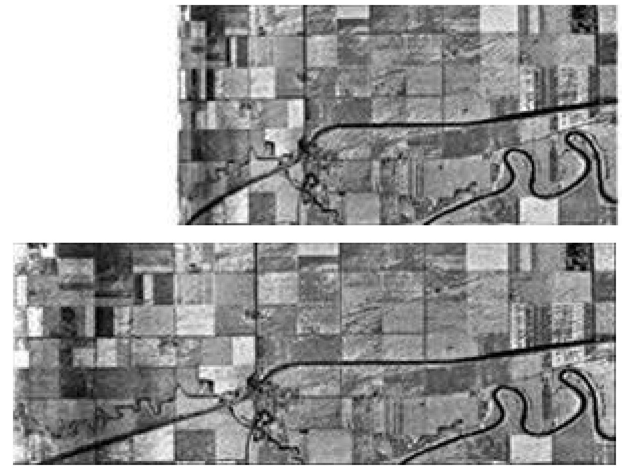
- **Slant-range scale distortion** occurs because the radar is measuring the distance to features in slant-range rather than the true horizontal distance along the ground. This results in a **varying image scale**, moving from near to far range.



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

3.4 Radar Image Distortions

- **This conversion comparison** shows a radar image in **slant-range display (top)** where the fields and the road in the near range on the left side of the image are compressed, and the same image converted to **ground-range display (bottom)** with the features in their proper geometric shape.

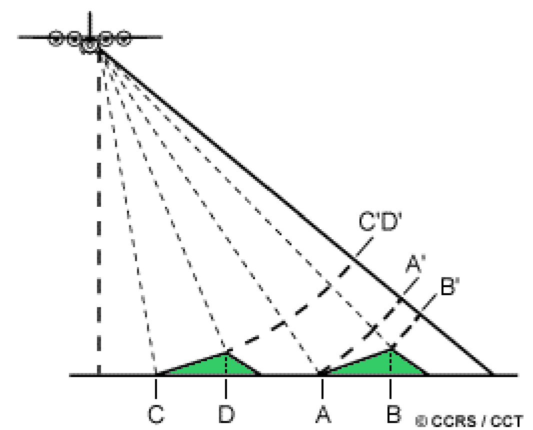


3.4 Radar Image Distortions

- Radar images are also subject to 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 **reversed with targets being displaced towards**, instead of away from the sensor. Radar **foreshortening** and **layover** are two consequences which result from relief displacement.

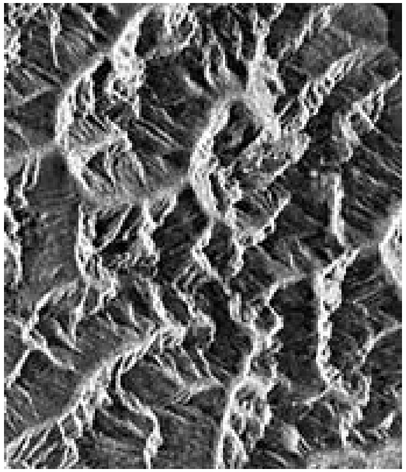
- **Foreshortening** : When the radar beam reaches the base of a tall feature tilted towards the radar (e.g. a mountain) before it reaches the top **foreshortening** will occur. Again, because the radar measures distance in slant-range, **the slope** (A to B) will appear **compressed** and the length of the slope will be represented incorrectly (A' to B').

- Depending on the angle of the hillside or mountain slope in relation to the incidence angle of the radar beam, the severity of foreshortening will vary. **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').



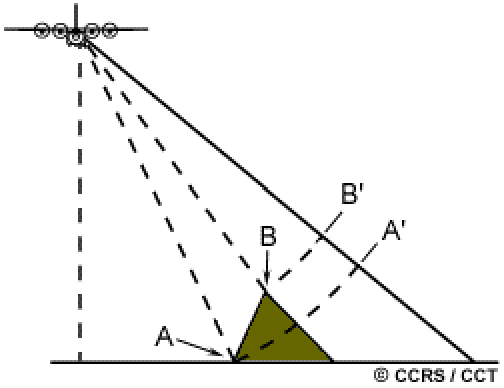
3.4 Radar Image Distortions

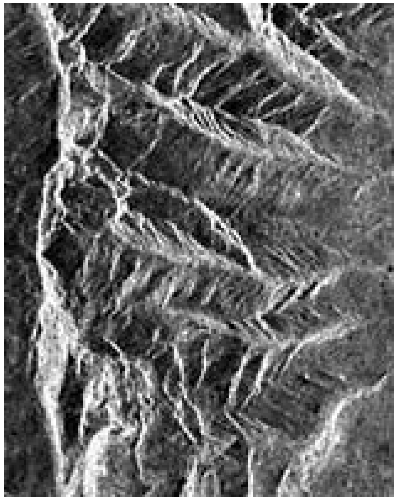
- The figure in the right shows a radar image of **steep mountainous terrain** with severe foreshortening effects. The foreshortened slopes appear as bright features on the image.



- **Layover** : occurs when the **radar beam reaches the top of a tall feature (B) before it reaches the base (A).** The return signal from the top of the feature will be received before the signal from the bottom. As a result, the top of the feature is displaced towards the radar from its true position on the ground, and "lays over" the base of the feature (B' to A').

- **Layover effects** on a radar image look very similar to effects due to foreshortening. As with foreshortening, layover is most severe for small incidence angles, at the near range of a swath, and in mountainous terrain.



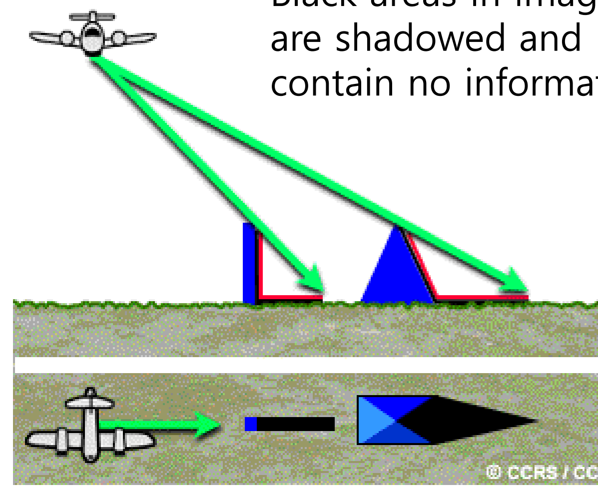


3.4 Radar Image Distortions

- Both foreshortening and layover result in **radar shadow**. Radar shadow occurs when the radar beam is not able to illuminate the ground surface. 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. This image illustrates **radar shadow effects** on the right side of the hillsides which are being illuminated from the left.

Red surfaces are completely in shadow. Black areas in image are shadowed and contain no information.



3.4 Radar Image Distortions

Did You Know?

...although a radar's side-looking geometry can result in several image effects such as foreshortening, layover, and shadow, this geometry is exactly what makes radar so **useful for terrain analysis**. These effects, if not too severe, actually **enhance the visual appearance** of relief and terrain structure, making radar imagery excellent for applications such as topographic mapping and identifying geologic structure.