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1. Learning Outcomes

After studying this module you shall be able to:

- Understand microwave remote sensing
- Learn about active and passive microwave remote sensing
- Learn about some applications of the microwave remote sensing

2. Introduction

The microwave region of the electromagnetic spectrum extends from wavelengths of about 1 mm to about 1 m and is divided in bands based on the wavelength as shown in Table 1. This region is, far removed from those in and near the visible spectrum, where our direct sensory experience can assist in interpretation of images and data.

Table 1. Bands in Microwave region of the EM spectrum

Designation	Frequency range	Wavelength range
L band	1 to 2 GHz	15 cm to 30 cm
S band	2 to 4 GHz	7.5 cm to 15 cm
C band	4 to 8 GHz	3.75 cm to 7.5 cm
X band	8 to 12 GHz	25 mm to 37.5 mm
Ku band	12 to 18 GHz	16.7 mm to 25 mm
K band	18 to 26.5 GHz	11.3 mm to 16.7 mm
Ka band	26.5 to 40 GHz	5.0 mm to 11.3 mm

The microwave remote sensing has many advantages compared to optical remote sensing such as

- microwaves penetrate the atmosphere through clouds and rain as the longer wavelengths are not susceptible to atmospheric scattering
- detection of microwave energy is possible under almost all weather and environmental conditions
- day and night operation as independent of the sun as source of illumination
- penetration depth into vegetation and soil and subsurface penetration
- allows accurate measurements of distance

3. Active and Passive microwave remote sensors

3.1 Active microwave sensors

Active microwave sensors provide their own source of microwave radiation to illuminate the target. It consists fundamentally of a transmitter, a receiver, an antenna, and an electronics system to process and record the data. Thus, an active microwave sensor broadcasts a directed pattern of energy to illuminate a portion of the Earth's surface, then receives the portion scattered back to the instrument. This energy forms the basis for the imagery we interpret. Active sensors generate their own energy, so their use is subject to fewer constraints, and they can be used under a wider range of operational conditions. Further, because active sensors use energy generated by the sensor itself, its properties are known in detail. Therefore, it is possible to compare transmitted energy with received energy to judge with more precision than is possible with passive sensors the characteristics of the surfaces that have scattered the energy. Active microwave sensors are generally divided into two distinct categories: imaging and non-imaging

3.1.1 Imaging radar

Imaging radar is similar to a photograph taken by a camera, but the image is of radar waves, not visible light. The most common form of imaging active microwave sensors is RADAR. RADAR is an acronym for RAdio Detection And Ranging. 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. 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. Since, the energy in air propagates at approximately the velocity of light, the slant range, SR is equal to ct/2, where c is speed of light, t is the time between pulse transmission and echo response. For the radar to distinguish between two objects, the spatial resolution should be equal or greater the half the pulse length as shown in Fig.1 . Even though the SR does not change with the distance of the transmitter, the ground-range (GR) resolution varies. As shown in Fig. 2, GR becomes smaller with the increase in SR range

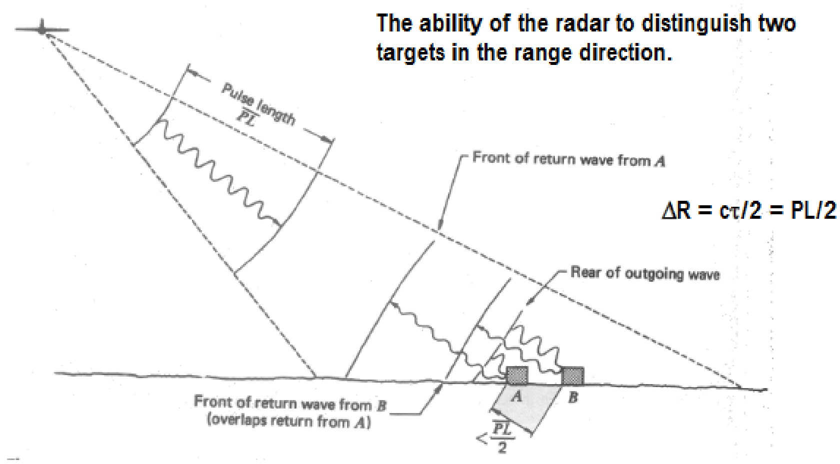

Fig 1. Range resolution is dependent on pulse length

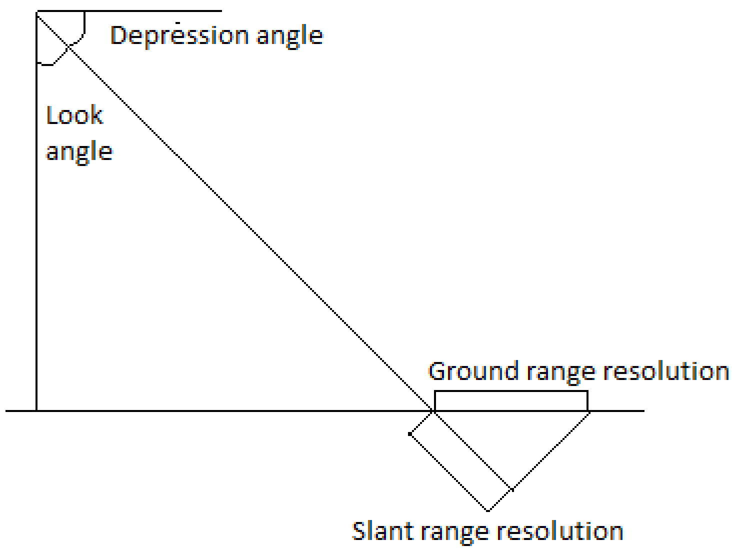

Fig 2. Relationship between GR and SR

Thus, $GR = \frac{c\tau}{2\cos\theta_d}$, where τ is pulse duration, θ_d is the depression angle.

The imaging radar finds its application in distinguishing the sea ice as it typically reflects more of the radar energy emitted by the sensor than the surrounding ocean, which makes it easy to distinguish between the two. However, the amount and character of reflected energy are functions of the physical properties of the sea ice and thus, can be difficult to interpret radar images of sea ice. In general, though, thicker multiyear ice is readily distinguishable from younger, thinner ice because radar energy bounces back to the sensor from the bubbles in the ice left when brine drains. This feature makes synthetic aperture radar (SAR), shown in Fig. 3, an especially useful tool for measuring the extent of thick vs. thin sea ice. e.g. The RADARSAT mission, managed by the Canadian Space Agency provides with detailed images of sea ice. SAR employs a short physical antenna and through utilization of techniques, it synthesizes the effect of a very long antenna. So here a single physical antenna is linked into array linked antennas. Thus, SAR map variations in microwave backscatter at fine spatial scales (10 to 50 m), and is used to create an image, which measures the variations in surface roughness and surface moisture.

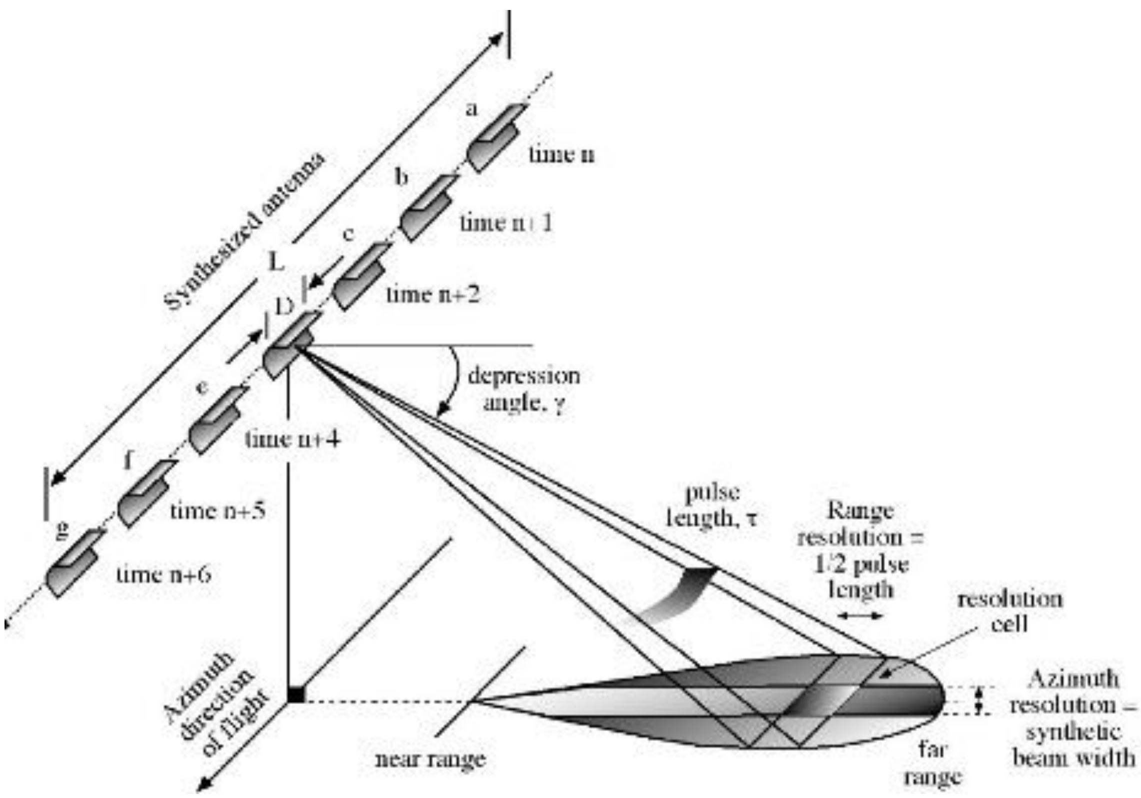

Fig 3. Illustration of SAR

3.1.1 Non-Imaging radar

Non-imaging radar are profiling devices which take measurements in one linear dimension, as opposed to the two-dimensional representation of imaging sensors. The example instruments for non-imaging radar are Scatterometer and altimeters. Scatterometer - It makes 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. Ground-based scatterometers are used extensively to accurately measure the backscatter from various targets in order to characterize different materials and surface types. The SeaWinds sensor aboard NASA's Quick Scatterometer (QuikSCAT) satellite provides daily, global views of ocean winds and sea ice. Altimetry sensor sends a pulse of radar energy toward the earth and measures the time it takes to return to the sensor. The pulse's round-trip time determines how far the satellite is from the reflecting surface. Altimeters look straight down at nadir below the platform and thus measure height or elevation. With a known reference, this information is used to measure the altitude of various features at the earth's surface. With enough precision, a radar altimeter can determine the height of the sea ice surface above sea level, which is utilized to calculate the total thickness of the sea ice. Thus, non-imaging radar finds application in ocean topography, glacial ice topography, sea ice characteristics and classification of ice edge.

3.2 Passive microwave sensors

A passive microwave sensor detects the naturally emitted microwave energy within its field of view. Passive microwave sensors don't rely on reflected sunlight as with the passive optical sensors. Thus, they don't need to be placed in sun-synchronous orbits so they can be placed on almost any platform. Passive microwave sensors receive the emitted energy in microwave region of EM spectrum from the objects on the ground. The Objects at the earth's surface emit not only infrared radiation;

they also emit microwaves at relatively low energy levels. The microwave energy recorded by a passive sensor can be emitted by the atmosphere (1), reflected from the surface (2), emitted from the surface (3), or transmitted from the subsurface (4). E.g. of Passive microwave sensors - Radiometers. Since, 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. The process of the passive type is explained using the theory of radiative transfer based on the law of Rayleigh Jeans, which in the microwave region gives, $Tb=\varepsilon_{\lambda}T$, where Tb is the brightness temperature and ε, is the emissivity of the object. Emissivity is the emitting ability of a real material compared to that of a black body that varies with composition of material and geometric configuration of the surface. It is a ratio and varies between 0 and 1 and for most natural materials, it ranges between 0.7 and 0.95.

In both active and passive types, the sensor may be designed considering the optimum frequency needed for the objects to be observed. In passive microwave remote sensing, the characteristics of an object can be detected from the relationship between the received power and the physical characteristics of the object such as attenuation and/or radiation characteristics.

3. Microwave scattering

When microwave strikes a surface, the proportion of energy scattered back to the sensor depends on

- Surface factors such as surface roughness and orientation of the feature relative to the radar beam direction
- Physical factors such as the dielectric constant of the surface materials

- Internal structure
- Microwave wavelength, polarization

3.1 Surface roughness

A surface is classified as smooth or rough by comparing the height deviations with the wavelength. A same surface can be categorized as smooth or rough based on the microwave band being considered. Since, the wavelength is inversely proportional to frequency, high wavelength implies low frequency and thus the penetration power of the wavelength increases. Also, back scattering is less and the surface appears smooth as shown in Fig. 4 On the other hand, at low wavelength, the back scattering is high and thus the surface appears rough.

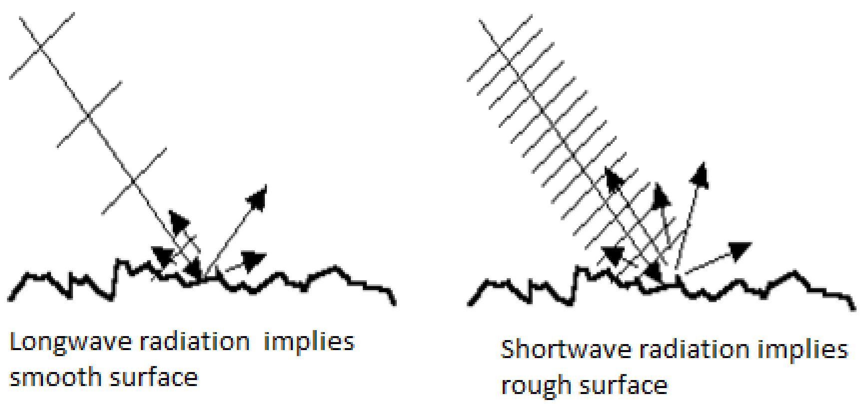

Fig 4. Comparison of smooth and rough surfaces

Now, the surface in Fig. 5 is considered smooth if $h < \lambda / 32 \cos\theta_i$. Based on the band and the given equation an example table, Table 2 is given to determine the roughness category in various bands by calculating the required 'h'.

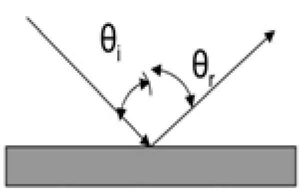

Fig. 5 Transmittance and Backscattered energy from a surface

Table 2 Estimation of roughness category

Roughness category	K-band (λ=0.86 cm)	X-band (λ=3 cm)	L-band (λ=25 cm)
Smooth	h<0.05	h<0.17	h<1.41
Intermediate	h<0.05-0.28	h<0.17-0.96	h<1.41-8.04

3.2 Polarization

Polarization refers to the orientation of the electric field. The active microwave sensors have both a transmitter and a receiver. So, radars are designed to transmit radiation either horizontally polarized (H) or vertically polarized (V). Similarly, the receiving antenna receives the horizontally or vertically polarized backscatter energy. Thus, the active sensors can have four possible combinations of transmitting and receiving that are- HH, VV, HV and VH. Here, HH and VV are known as co-polarized while HV and VH are known as cross-polarized. Also, the passive microwave sensors do not have a transmitter and therefore, they measure backscatter as V or H polarization.

3.3 Microwave wavelength

The short wavelength microwaves interact with the top of canopy unlike the longer wavelengths which are able to penetrate deeper into the canopy. Thus, depending on the microwave band, the penetration power varies. For example, X-band (3 cm) backscatters from the top of canopy, C-band(6 cm) may backscatter from mid of the canopy while L-Band (23 cm) may penetrate deeper and may backscatter from the soil surface along with multiple scattering between the canopy and soil. The multiple scattering is also known as the volume scattering.

3.4 Internal structure

A smoother surface usually has a specular reflection as the speckle created by radar illumination of separate scatterers are too small to be individually resolved. On the other hand, heterogeneous structures result in backscattering in multiple directions, which cause diffuse scattering. Depending on the structure, there can also be corner scattering. The various scattering types are shown in Fig. 6.

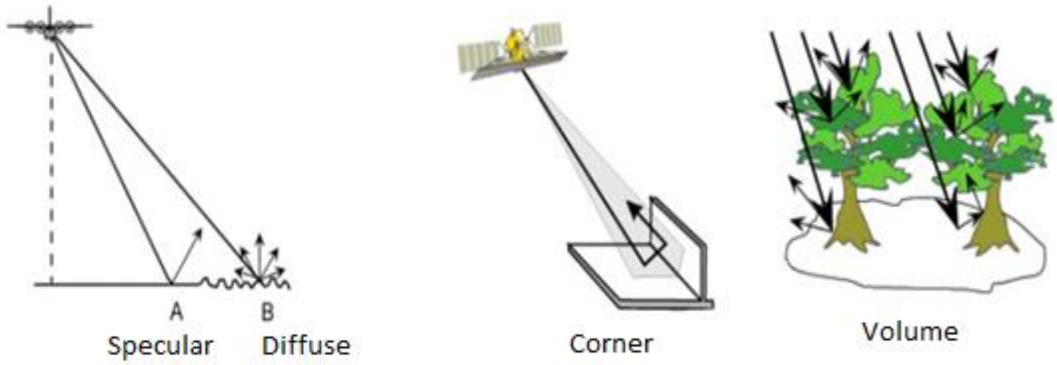

Fig. 6 Illustration of the various scattering scenarios

6. Applications of microwave remote sensing

Microwave remote sensing finds its application in various fields a given below

1. Meteorological applications: Allows measuring the atmospheric profiles and determine water and ozone content in the atmosphere.
2. Hydrological applications: measure soil moisture since microwave emission is influenced by moisture content. So microwave remote sensing can be utilized for oceanographic applications like mapping sea ice, currents, and surface winds detection of pollutants, such as oil slicks.

Various satellites are available, which utilize the microwave remote sensing

1. AQUARIUS - It is a combination of radiometer and radar. Radar measures winds for correcting for the effect of surface roughness. It was the first instrument to measure *global* ocean salinity. Passive and active microwave instrument operate at

L-band, with a Resolution - Baseline 100km, Minimum 200km. The global coverage is in 8 days and the accuracy is 0.2 psu.

2. TOPEX/Poseidon and Jason-1 - It is a joint NASA-CNES Program, where TOPEX/Poseidon launched on August 10, 1992 and Jason-1 was launched on December 7, 2001. It consists of Ku-band and C-band dual frequency altimeter. It also has microwave radiometer to measure water vapor, GPS, DORIS, and laser reflector for precise orbit determination. The sea-level measurement accuracy is 4.2 cm

3. SRTM : It has C-band single pass interferometric SAR for topographic measurements using a 60m mast. It has been useful for providing DEM of 80% of the Earth's surface in a single 11 day shuttle flight. It covered 60 degrees north and 56 degrees south latitude at 57 degrees inclination. The current best estimate of the SRTM accuracy is 10 m horizontal and 8 m vertical.

4. ESA's Soil Moisture Ocean Salinity (SMOS) – Earth Explorer mission is a radio telescope in orbit, which has Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) radiometer. It picks up faint microwave emissions from Earth's surface to map levels of land soil moisture and ocean salinity. The satellite captures images of 'brightness temperature', which correspond to radiation emitted from Earth's surface

5. NASA's Soil Moisture Active Passive satellite can provide accurate coarse-resolution soil moisture information at 40 km. Measurements from the Copernicus Sentinel-1 satellite can then be applied to improve the resolution to 'field scale'. By combining measurements from different sensors the spatial resolution is increased from 40 km to 100 m.

6. CloudSAT - CloudSAT measures the vertical structure of clouds and quantify their ice and water content. It helps in improving weather prediction and clarify climatic processes. The mission has been able to investigate the way aerosols affect clouds and precipitation. It also allows the utility of 94 GHz radar to observe and quantify precipitation in the context of cloud properties.

FAQs

Q 1.Differentiate passive microwave sensors and passive optical sensors

Ans. A passive microwave sensor detects the naturally emitted microwave energy within its field of view. Passive microwave sensors don't rely on reflected sunlight as with the passive optical sensors. Thus, they don't need to be placed in sun-synchronous orbits and can be placed on almost any platform. Passive microwave sensors receive the emitted energy in microwave region of EM spectrum from the objects on the ground as the objects at the earth's surface emit not only infrared radiation but also emit microwaves at relatively low energy levels.

Q 2.Explain non-imaging radars

Ans. Non-imaging radar are profiling devices which take measurements in one linear dimension, as opposed to the two-dimensional representation of imaging sensors. The example instruments for non-imaging radar are Scatterometer and altimeters. Scatterometer - It makes 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. Ground-based scatterometers are used extensively to accurately measure the backscatter from various targets in order to characterize different materials and surface types. On the other hand, altimetry sensor sends a pulse of radar energy toward the earth and measures the time it takes to return to the sensor. The pulse's round-trip time determines how far the satellite is from the reflecting surface.

Q 3.Explain polarization

Ans. Polarization refers to the orientation of the electric field. The active microwave sensors have both a transmitter and a receiver. So, radars are designed to transmit radiation either horizontally polarized (H) or vertically polarized (V). Similarly, the receiving antenna receives the horizontally or vertically polarized backscatter energy. Thus, the active sensors can have four possible combinations of transmitting and receiving that are- HH, VV, HV and VH. Here, HH and VV are known as co-polarized while HV and VH are known as cross-polarized. Also, the passive microwave sensors do not have a transmitter and therefore, they measure backscatter as V or H polarization.

Q 4.Differentiate Altimeter and Scatterometer

Ans. Scatterometer and altimeters both are non-imaging radars.

Scatterometer - makes precise quantitative measurements of the amount of energy backscattered from targets, which dependent on the surface properties (roughness) and the angle at which the microwave energy strikes the target.

On the other hand, altimetry sensor sends a pulse of radar energy toward the earth and measures the time it takes to return to the sensor. The pulse's round-trip time determines how far the satellite is from the reflecting surface.

Q 5.Write a note on SMOS and SMAP mission

Ans. ESA's Soil Moisture Ocean Salinity (SMOS) – Earth Explorer mission is a radio telescope in orbit, which has Microwave Imaging Radiometer using Aperture Synthesis (MIRAS) radiometer. It picks up faint microwave emissions from Earth's surface to map levels of land soil moisture and ocean salinity. The satellite captures images of 'brightness temperature', which correspond to radiation emitted from Earth's surface. NASA's Soil Moisture Active Passive satellite can also provide accurate coarse-resolution soil moisture information at 40 km and utilizes the passive radiometer. SMAP satellite also had the radar. However, the radar malfunctioned. Therefore, now the measurements from the Copernicus Sentinel-1 satellite are being applied to improve the resolution to 'field scale'. By combining measurements from different sensors the spatial resolution is increased from 40 km to 100 m.

MCQs

1. Spatial resolution of SMAP is

   a) 25 km

   b) 40 km

   c) 30 m

Ans: b

2. To distinguish between two objects, the pulse length (PL) of the RADAR should be

   a) less than PL/2,

   b) greater than PL/2

Ans: b

3. Which of the following is true for the microwave bands

   a) C-band wavelength < X-band wavelength < L-band wavelength

   b) X-band wavelength < C-band wavelength < L-band wavelength

c) L-band wavelength < C-band wavelength < X-band wavelength

Ans: b

4. Microwave passive sensors need sun-synchronous orbits

   a) false

   b) true

Ans: a

5. Radiometer is an active microwave sensor

a) false

b) true

Ans: a

6. L-band wavelength results in

a) specular scattering

b) volume scattering

Ans: b

7. Microwave passive remote sensors can penetrate clouds but cannot operate in night

a) true

b) false

Ans: b

8. A good absorber is a good emitter

a) true

b) false

Ans: a

9. The instruments which provide electromagnetic radiation of specified wave length or a band of wave lengths to illuminate the earth surface, are called :

a) active sensor

b) passive sensor

Ans: a

Summary:

In this module, we looked at the advantages of microwave remote sensing over the optical remote sensing. It can be seen that microwave remote sensing allows data collection through all weather, day and night due to its penetration through cloud and atmosphere. Both active and passive sensors are available with multiple applications. Although the spatial resolution of passive radiometers is very coarse, it can be fused with radar data to improve the spatial resolution. When microwave strikes a surface, the proportion of energy scattered back to the sensor depends on various factors like EM polarization, surface roughness, dielectric constant, and wavelength of the microwave energy. The RADAR data helps in making precise quantitative measurements of the amount of energy backscattered from targets. The RADAR sensor sends a pulse of radar energy toward the earth and measures the time it takes to return to the sensor. The pulse's round-trip time determines how far the satellite is from the reflecting surface. Thus, it is also utilized to map the Earth's terrain.

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