CHAPTER-2

SAR APPLICATIONS FOR VEGETATION STUDIES

Remote sensing is the art or science of acquiring information about an object (target) by using sensors located at a distance from the target that are not in physical contact with the target. The principle of remote sensing is based on measurements made by these sensors in different wavelength regions of electromagnetic spectrum, on interactions between the targets and electromagnetic radiation (EMR).

2.1 ELECTRO MAGNETIC SPECTRUM:

The electromagnetic (EM) spectrum extends from gamma rays with highest frequency to radio waves with lowest frequency. The EM spectrum is shown in the fig 2.1.

![EM Spectrum](image)

**Fig. 2.1(a):** EM spectrum showing different wavelength bands

![Microwave Bands](image)

**Fig. 2.1(b):** Different wavelength bands in microwave region
2.2 MICROWAVE REMOTE SENSING – GENERAL PRINCIPLES:

Remote sensing can be classified into optical and radar remote sensing with respect to the region of the EMS in which it is acquired. The optical wavelength region extends from 0.30-15.0 nm and is further subdivided as Visible (0.38-0.72nm), Near IR (0.72-1.30nm), Middle IR (1.30-3.00nm) and Far IR (7.00-15.0nm). Multi-spectral scanners operating in visible and infrared regions of the EMR are widely used to study a variety of land-ocean-atmospheric processes and interactions. Microwave region extends from 0.3 to 300 GHz frequency in the EMS. Different microwave regions are represented by P-, L-, S-, C-, X-, K-band as indicated in the fig 2.1(b) and table 2.1.

Table 2.1: Different wavelength bands in Microwave region

<table>
<thead>
<tr>
<th>Band</th>
<th>Frequency (GHz)</th>
<th>Wavelength (cm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P</td>
<td>0.3-1</td>
<td>30-100</td>
</tr>
<tr>
<td>L</td>
<td>1-2</td>
<td>15-30</td>
</tr>
<tr>
<td>S</td>
<td>2-4</td>
<td>7.5-15</td>
</tr>
<tr>
<td>C</td>
<td>4-8</td>
<td>3.8-7.5</td>
</tr>
<tr>
<td>X</td>
<td>8-12.5</td>
<td>2.4-3.8</td>
</tr>
<tr>
<td>K</td>
<td>12.5-40</td>
<td>0.7-1.7</td>
</tr>
</tbody>
</table>

Remote sensing can be classified into active and passive types with respect to the technique applied in acquiring the information and Active
remote sensing detects reflected responses from objects that are irradiated from artificially generated energy sources. They provide their own illumination and hence comprises of a transmitter and a receiver (e.g., RADAR) while passive remote sensing detects the reflected or emitted electro-magnetic radiation from natural sources. Passive sensors are receivers that measure the radiation backscattered from the scene under observation (microwave radiometers).

2.3 RADAR PRINCIPLE:

Radar works on the principle of transmission and reception of pulses. The received signal gives information on magnitude, phase, polarization, Doppler frequency and time interval between transmitted and received signal.

A pulse is transmitted from SAR and once the pulse strikes a target, signal returns to the antenna. The time delay between transmitted and received signal gives the distance between target and sensor. As the speed of light at which the pulse propagates is much faster than the platform velocity, the echo of the pulse from the ground is assumed to be received at the same spacecraft position at which the pulse was transmitted (ESA, 2005).
Synthetic aperture processing combines the signals received by the radar and synthesizes a very long antenna by combining signals along its flight track to improve resolution (FAS, 2000). SAR works on Doppler’s history of the radar echoes generated by the forward motion of the platform to synthesize a large antenna, enabling high azimuth resolution in the resulting image despite a physically small antenna.

SAR works on the principle of Doppler Effect, a property of waves reflected by moving objects. If a wave is reflected or emitted by an object approaching a receiver, its frequency as observed by the receiver is increased which are termed as up shifted frequencies and if the object is receding, its frequency as observed by the receiver is decreased which are termed as down shifted frequencies. As the object passes through the centerline of the beam, it ceases to get closer to the aircraft and its reflection ceases to be Doppler shifted. Returns from features near the centre line of beam width have less or no frequency shift. This is used to distinguish objects inside the beam, achieving an angular resolution that is higher than the beam's physical width. The principle of SAR is explained in fig 2.2.

Comparison of Doppler-shifted frequencies to a reference frequency allows many returned signals to be "focused" on a single point, effectively increasing the length of the antenna that is imaging at that particular point (Imaging Radar, 1996). The result is a very narrow effective antenna beam width, even at far ranges without requiring long antenna or short operating
wavelength. The azimuth resolution attained in this manner is half a wavelength divided by the change in viewing angle during the aperture formation process (Imaging Radar, 1996).

Imaging radars used for remote sensing carries a side looking antenna perpendicular to the flight direction of the platform and transmits radar pulses in a direction different from the flight path. The return signals intensity-modulates the line on the cathode-ray tube and produce a different image on a line on the film adjacent to the original line. As the platform moves forward, a series of these lines is imaged onto the film, and the result is a two-dimensional picture of the radar return from the surface (Imaging Radar, 1996).

The area continuously imaged from the radar beam is called the ‘swath’ and is divided into near range and far range.

2.3.1 Slant range and Ground range:

Distance from the radar to the target is called range. As the radar is located at some altitude above the ground, this is not same as distance along the ground. Thus, the dimension in the image is called ‘slant range’.

The fig 2.3 shows two types of radar images: slant range image, in which distances are measured between the antenna and the target. A slant range coordinate is defined in a direction normal to the flight path and an azimuth coordinate is defined in the direction along the flight path. In ground range
image, distances are measured between the platform ground track and the target, and placed in the correct position on the chosen reference plane.

Transformation to ground range requires correction at each data point for local terrain slope and elevation. Ground range resolution ($R_r$) is the horizontal expression of the slant range resolution and is expressed mathematically as:

$$R_r = ct \div 2 \cos \theta_D \quad (2.1)$$

$\theta_D$ is the depression angle, ‘c’ is the velocity of light and ‘t’ is the pulse duration.

SAR systems have operational parameters that influence the interaction between the pulses transmitted and the targets on the Earth’s surface.

**2.3.2 SYSTEM PARAMETERS:**

**2.3.2.1 Wavelength:** As discussed above, the electromagnetic spectrum (refer fig 1(a)) illustrates wide range of microwave wavelengths/frequencies. The interaction between microwaves and targets is dependent on the
wavelength used. The different SAR sensors and the wavelengths they operate are given in fig 2.4.

![Figure 2.4: Satellites launched in different wavelengths of microwave region](image)

**2.3.2.2 Polarization:** The temporal and geometric behaviour of the electric field vector of an electromagnetic wave transmitted or received by a radar system is the polarization (CCT, 2005). Remote sensing radars are designed to transmit either vertically polarized or horizontally polarized radiation and receive either vertically or horizontally polarized radiation, or both. The letters H and V designates the transmitted and received polarization for horizontal and vertical.

There are four types of polarizations:

- HH - horizontal transmit and horizontal receive
- VV - vertical transmit and vertical receive

\[ \{\text{Co-polarizations}\} \]
- HV - horizontal transmit and vertical receive
- VH – vertical transmit and horizontal receive

Cross-polarized signals are due to multiple scattering by the target and are weaker than the co-polarized. The backscatter of an object depends on polarization of the incident wave and also the geometric structure of the object.

A radar system which can record two orthogonal polarizations is a dual polarization Radar. Radar that is capable of acquiring more than one independent polarization measurement, either simultaneously or separately is multi-polarization Radar. Multi-polarization radar may have only one channel, which acts as a switch between different polarizations. Radar systems designed to collect image data of a scene using two orthogonal transmit polarizations and the same two polarizations on receive is Quadrature polarization or Polarimetric Radar. The detailed explanation of polarimetry is given in Chapter 6 of the present study. Transmit and receive channels are in orthogonal, and four channels (HH, HV, VV & VH) are required to make the measurements.

**2.3.2.3 Incident angle:** The incident angle ($\theta$) is defined as the angle between radar pulse and a line perpendicular to the Earth’s land surface (CCT, 2005). In a flat surface, $\theta$ is the complement of the depression angle, $\gamma$ (Jensen, 2000).
For steep incident angles (less than 30°) SAR images has geometric distortions due to layover and foreshortening; and for broad incident angles, geometric distortions reduce but radar shadows increases.

### 2.4 RADAR EQUATION PRINCIPLE:

Radar equation gives the relation between the target and received signal. It predicts performance in terms of signal-to-interference ratio based upon the radar hardware, the distance to the target, the target's radar cross section, and the total system noise (Aerospace, 2007).

Signal strengths are given by five factors and are explained in the radar equation: (1) the density of radiated power at the range of the target, (2) the radar reflectivity of the target and the spreading of radiation along the return path to the radar, (3) the effective receiving area or aperture of the antenna, (4) the time over which the target is illuminated, and (5) signal losses caused by physical phenomena (Aerospace, 2007).

**Fig 2.5** shows the geometry of scattering from an isolated radar target with the parameters that are involved in the radar equation.

\[ P_t \] is the power transmitted by an antenna with gain \( G_t \).
Power per unit solid angle in the direction of the scatterer is $P_t G_t$. Power density at the scatterer $S_s = (P_t G_t) \left( \frac{1}{4\pi R^2} \right)$ \hspace{1cm} (2.1)

$(1/4\pi R^2)$ is the reduction in power density related with spreading of the power over a sphere of radius ‘R’ surrounding the antenna. Total power intercepted by the scatterer is obtained by the product of power density and effective receiving area of the scatterer: $P_{rs} = S_s A_{rs}$ \hspace{1cm} (2.2)

‘$A_{rs}$’ depends on the effectiveness of the scatterer as a receiving antenna.

Power received by the scatterer is absorbed; ‘$f_a$’ in losses and the rest ‘$(1-f_a)$’ is reradiated in various directions. Therefore, the total reradiated power is

$$P_t = P_{rs} (1 - f_a)$$ \hspace{1cm} (2.3)

Let ‘$A_{rs}$’ gives the direction of the incoming beam. The reradiation pattern may not be the same as the pattern of ‘$A_{rs}$’, and the gain in the direction of the receiver is the relevant value in the reradiation pattern (Elbakly, 2010).

Thus, $S_s = P_{ts} G_{ts} \left( \frac{1}{4\pi R_{ts}^2} \right)$ \hspace{1cm} (2.4)

where $P_{ts}$ is the total reradiated power, $G_{ts}$ is the gain of the scatterer in the direction of the receiver. Radar has two spreading factors and if $R_r = R_t$, the total distance is $2R_t$.

Therefore, $(1/4\pi)^2 (1/R_t)^4$

The power entering the receiver is given by; $P = SA$; where the area $A_r$ is the effective aperture of the receiving antenna, not its actual area.
The equation is given in 2.5

\[
P_s = \left( \frac{P_t G_t A_t}{(4\pi)^2 R_t^2 R_r^2} \right) \left[ A_n (1 - f_a) G_n \right] \tag{2.5}
\]

The factors associated with the scatterer are difficult to measure individually and these are given in square brackets in Eqn 2.5. Therefore, they are combined into one factor, the radar scattering cross section:

\[
\sigma = A_n (1 - f_a) G_n \tag{2.6}
\]

The cross-section, ‘\(\sigma\)’ is a function of the directions of the incident and backscattered signals, scatterer shape and dielectric properties. Radar equation in final form is given in Eqn. 2.7

\[
P_s = \frac{P_t G_t A_t}{(4\pi)^2 R_t^2 R_r^2} \sigma \tag{2.7}
\]

Transmitter and receiver distances, gains and effective apertures of antenna are same. Therefore, \(R_t = R_r = R; G_t = G_r = G; A_t = A_r = A\) (Elbakly, 2010).

Effective area of an antenna can be written in terms of gain by \(A = \frac{\lambda^2 G}{4\pi}\).

Therefore, the radar equation is given in Eqn. 2.8

\[
P_s = \frac{P_t G \lambda^2}{(4\pi)^3 R^4} \sigma = \frac{P_t A^2 \sigma}{4\pi \lambda^2 R^4} \tag{2.8}
\]

The targets scatter the energy transmitted by the radar in all directions and the energy scattered in the backward direction is recorded by the radar which is known as backscatter. It is measured as a complex number, which contains the information of both amplitude and phase (Baltzer, 2001). For
SAR applications other than interferometry (detail explanation is given in Chapter-7) and polarimetry (Chapter-6), the phase information can be removed (Oliver and Quegan, 1998). After linear, square-law detection and processing, SAR data are converted to amplitude and inturn intensity images.

2.5 BACKSCATTER CO-EFFICIENT:

The energy backscattered is referred as radar cross-section ($\sigma$), and is defined as the amount of transmitted power absorbed and reflected by the target. The backscatter coefficient ($\sigma^o$) is the amount of radar cross-section per unit area (A) on the ground (Jensen, 2000).

Backscatter coefficient is a function of wavelength, polarization and incidence angle, as well as target characteristics such as roughness, geometry and dielectric properties. The targets are distinguishable in radar images if their backscatter components are different and the radar spatial resolution is adequate to discriminate between targets (Trevett, 1986).

2.6 RADAR REFLECTOR SURFACES

RADAR reflectors represent the geometric orientation of the target and can be described in 3 groups: specular, diffuse and corner or double-bounce.
In general, shrub and forest cover types and some crops represent diffuse reflectors where the radar pulse is diffused at different angles and some of the energy is directed back to the receiver thus the signal received is neither high nor low. A specular reflector is a mostly flat or non rough surface (calm water, grass field, bare soil, beach, etc). The pulse hits the flat surface and most of the energy is directed out away from the surface at a right angle away from the receiver thus little energy is recorded. A corner reflector usually involves two adjacent surfaces (double bounce) and is a combination of a specular surface and a vertical object (e.g., trees) or a surface with strong angles such as a building. The RADAR pulse hits the specular surface first and the signal going out at a right angle (1st bounce) then interacts with a vertical or angular surface (2nd bounce) thus directing most or nearly all of the energy directly back to the receiver. This is the highest signal thus the object (tree or building in this case) would have a bright appearance on a SAR image.

2.7 ELECTRICAL CHARACTERISTICS

The electrical characteristics of targets determine the intensity of backscatter. The dielectric constant measures electrical characteristics of objects which indicates the reflectivity and conductivity of various materials (Lillesand and Kiefer, 2000). The moisture content within materials has a direct influence on the dielectric constant and reflectivity. Forest canopies appear bright in the image because of the leaves high moisture content,
while dry soils absorb the radar signal and produce very low (or no) backscatter (Jensen, 2000).

2.8 SAR IMAGE CHARACTERISTICS:

2.8.1 Speckle:

Speckle is due to the variation in backscatter for non-homogenous cells which is caused by constructive and destructive interference from the multiple scattering returns. It gives a grainy appearance to the Radar images due to combination of narrow band width and surface roughness at the wavelength scale. Speckle is caused by the high coherence of the illumination source that causes phase interference from random scattering points. It is the unwanted and dominating noise which degrades the SAR image products.

The salt-and-pepper texture of speckle is related to radar system parameters and the nature of the surface being imaged. When illuminated by the SAR, each target contributes backscatter energy, with phase and power changes, is coherently added for all scatterers. This summation can be either high or low, depending on constructive or destructive interference (CCRS, 2005).

Speckle carries the information about the imaging system and is useful in describing the texture of image, identifying terrain features, examining the reflectivity and system transformation processes. It is generally desirable to
reduce speckle prior to interpretation and analysis as it is a form of noise and makes interpretation more difficult. The speckle effect is reduced by using the multi look images and also by averaging the number of samples, increasing the time bandwidth products. Multi-look processing reduces speckle at the cost of spatial resolution. Filtering can reduce the speckle still inherent in the actual SAR image data, which tend to reduce statistical variance in conventional image classification schemes (CCRS, 2005). Speckle reduction can be achieved in two ways: multi-look processing and spatial filtering.

Multi-looking is carried out during data acquisition. This processing divides the radar beam into several narrower sub-beams which provides an independent look at the illuminated scene. Summing and averaging the looks form the output image which reduces the speckle.

Speckle reduction by spatial filtering is performed on the output image in a digital image analysis environment. A moving small window of nxn window size is considered and over each pixel in the image, mathematical calculation is applied using the pixel values within that window and new value is replaced by the central pixel of the window (CCRS, 2005). The window is moved in horizontal and vertical directions until the entire image is covered. Smoothening effect is attained and speckle is reduced (CCRS, 2005).
Both multi-look processing and spatial filtering reduce speckle at the expense of resolution, since they both smoothens the image. Speckle reduction techniques should be chosen based on user application; for fine detail information extraction slight or no multi-looking/spatial filtering should be done. For broad-scale interpretation and mapping speckle reduction techniques should be appropriate and acceptable (CCRS, 2008). The speckle suppression techniques used in the present study are explained in Chapter-4.

2.9 RADAR IMAGE DISTORTIONS:

The Radar image obtained has distortions due to slant range geometry, topographic variations etc. Some of these distortions are Scale distortions and Relief distortions.

As the radar measures the distance to targets in slant-range than horizontal distance along the ground Slant-range, scale distortion occurs (CCRS, 2008). From near to far range, image scale is varied. Consider the two targets, \( A_1 \) and \( B_1 \) and the radar sees as \( A_2 \) and \( B_2 \). Although targets \( A_1 \) and \( B_1 \) are the same size on the ground, their dimensions in slant range \( A_2 \) and \( B_2 \) are different (CCRS, 2008). In near range, the targets appear to be compressed relative to the far range.
2.9.1 Relief Displacement: Radar foreshortening and layover are two consequences of relief displacement.

2.9.1.1 Foreshortening: It is a special case of elevation displacement and occurs when radar beam reaches the slope of a tall feature e.g. a mountain, at the same moment; the foreshortening will occur (Ourazeddine, 2002).

When the radar beam reaches the base of a tall feature tilted towards the radar, before it reaches the top of the target; the slope appears to be compressed and slope length will be represented incorrectly. This depends on incidence angle and angle of mountaintop. Consider the target of slope A to B, the slope A to B will appear compressed and is imaged incorrectly as A' to B' (Ourazeddine, 2002). Foreshortening is maximum when the radar beam is perpendicular to the slope (CCRS, 2008).

2.9.1.2 Layover: Layover occurs when the radar beam reaches the top of a tall feature (B) before it reaches the base (A). 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' (Ourazeddine, 2002). Layover is most severe for small incidence angles, at the near range of a swath, and in mountainous terrain (CCRS, 2008).
2.9.2 **Radar Shadow** occurs when the radar beam is not able to illuminate the ground surface. Both foreshortening and layover result in radar shadow. Shadows occur in the down range dimension, behind vertical features or slopes with steep sides (Ourazeddine, 2002). 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 (CCRS, 2008). As incidence angle increases from near to far range, 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 that are being illuminated from the left (Ourazeddine, 2002). In shadow regions, there is no return signal and the targets in image appear black on an image (CCRS, 2008).

With this introduction to Radar image characteristics, we now discuss the Radar remote sensing of forests and its applications using various wavelengths and polarizations.

2.10 **RADAR REMOTE SENSING OF FORESTS:**

Microwave remote sensing is very useful in the application of the forestry as the microwaves are capable of penetrating through the forest canopy and contribute to the monitoring of the forest and to understand the ecosystem processes.
Microwave radiation penetrates significant distances into a vegetation canopy and interacts strongly with structures (leaves, stems etc) on scales comparable with the radiation’s wavelength. Depending on wavelength and polarization, radar can penetrate the canopy to different depths (fig 2.2), and can sense plant parts of different sizes, shapes, and water content. This ability of radar to probe the canopy, and the expectation of retrieving biophysical forest descriptions, underlie much of the international impetus for forest radar research (Sun et al., 1998).

Microwave interaction depends on the angle of incidence and wavelength of the Radar. It is illustrated that there exists the relationship between the C, L, P-band radar backscatter and forest biomass and growing stock volume (Tansey et al., 2004). Hence, these bands are used to retrieve the canopy biophysical parameters.

Radar remote sensing is also used to achieve biomass estimates and carbon accounting. Radar data also provides information about terrain surface and vegetation canopies (Heri et al, 1999). Synthetic Aperture Radar (SAR) provides important characteristics of soil and vegetation covers for instance, inundation below closed canopies, fresh woody biomass of forested areas, freeze/thaw conditions of soil and vegetation, soil moisture and surface roughness in areas of low vegetation, and information on the orientation and structure of objects on the ground that reflect the incoming microwave radiation (Kasischke et al., 1997; Morrissey et al., 1996).
Trees and other vegetation are usually moderately rough on the longer wavelength scale. Hence, they appear as moderately bright features in the image. Structures of trees affect the backscattering coefficient (Touzi et al., 2004). Backscattering and penetration varies within a forest canopy. In longer wavelengths, the effect of the trunk is very large. In shorter wavelengths, leaves play an important role in backscatter. This is due to the forest composition, tree density, and canopy thickness. The scattering properties are governed by size, shape and orientation of surface within forest canopy (Floyd et al., 1998). The parameters that are important in forest inventory are tree density, stand age and timber volume. These parameters are interrelated and also they depend on the tree growth and stand development. By visual interpretation, the different types of land cover classes are discriminated using the backscatter intensity and texture. The different types of forests can be discriminated from polarimetric SAR data and image fusion technique. The changes in tone and texture are related to crown closure or foliage density. Backscatter is dependent on crown closure than height (Floyd et al., 1998). Backscatter is also sensitive to the target's electrical properties, including water content.

Consider the backscatter of vegetation in X, C and L wavelength bands. In X band, the backscatter is from upper part of the canopy viz., leaves, twigs and small branches. At C band, secondary branches and leaves contribute to volume-scattering. At longer L and P band wavelengths, the penetration
into the vegetation is more and trunks, branches contribute to the backscatter (fig 2.10).

Different scattering mechanisms takes place in vegetation canopy which contributes the backscatter and they are explained in fig 2.11.

A. Direct backscatter from canopy top
B. Multiple scattering and volume scattering in the vegetation.
C. Direct backscatter from land surface.
The combination of multiple channels and polarizations provides greater advantage for estimating total biomass. This is due to SAR unique capabilities to distinguish woody from herbaceous biomass and to penetrate the vegetative canopy to detect underlying surface conditions. Cross-polarization SAR gives accurate results in estimating aboveground biomass. Measurement of species diversity and biomass on both a spatial and temporal level may be possible through appropriately chosen remote sensing data types.

The intensity of radar backscatter is sensitive to the forest parameters such as girth at breast height (gbh) and tree mean height. The saturation problem is also common in radar data. The saturation levels depend on the wavelengths, polarizations and the characteristics of vegetation stand structure and ground conditions. The variation in the allocation of the biomass to various structures such as stems, branches, leaves; their sizes, numbers and orientation influence backscatter. From earlier studies, it is known that backscatter saturates at a biomass, which is related to Radar wavelength and polarization (Floyd et al., 1998).

Biomass estimation from SAR data has been under investigation for the last two decades, the main conclusions being that the retrieval accuracy increases for increasing radar wavelength and the interferometric SAR (InSAR) coherence has the potential to provide stem volume estimates in some cases comparable to in situ data.