MICROWAVE REMOTE SENSING

Introduction

Analyzing the information collected by the sensors that operate in the microwave portion of the electromagnetic spectrum is called as Microwave Remote Sensing. Microwave portion of the spectrum includes wavelengths within the approximate range of 1mm to 1m. These longer waves have the capability of penetrating through the clouds thus overcoming the atmospheric effects that we often encounter in the visible and infrared regions of EMR. Microwave reflection (backscattering), in active mode, and emissions, in passive mode, from earth surface are not bound by the time of data acquisition and hence microwave sensors are time independent. And also, these reflections and emissions don't have any relation with their counter part in the visible, infrared or thermal portions of the spectrum.

On the other hand, the amount and nature of backscattered electromagnetic radiation can provide information about the size, shape, configuration and electrical properties, etc of the surfaces and objects irradiated. These responses afford us a markedly different view of the environment. The amplitude, polarisation and phase of the return signal can be measured, although the simplest systems only record the amplitude.

Microwave Remote Sensing, due to the above said unique responses, has the following advantages over remote sensing in the other regions of EMR.

1. Time independent.
2. Weather independent.
3. Sensitive to moisture in soil, vegetation and snow.
4. Enhancement of surface roughness / relief.
5. Penetration of soil and vegetation cover.
6. Ability to collect data which are far away from flight path.

These advantages make them valuable for timely monitoring of soil moisture, crop/vegetation, snow cover, geological features, coastal zone, urban extent, man made targets, ocean wind vector, wave spectra, wave height and atmospheric parameters.

Sensors

Microwave sensors can be grouped into two major groups viz. passive and active. Passive sensors are the Radiometers. Under this multi frequency scanning/imaging radiometers, atmospheric sounder etc. fall.

Radar acronym Radar Detection and Ranging Active is an active microwave remote sensing system. Various systems used to describe imaging radar are Side Looking Radar (SLAR) or Real Aperture Radar (RAR), Synthetic Aperture Radar (SAR), Active Microwave Imager (AMI). Scatterometer, Altimeter and Rain Mapping Radar etc. also fall under active microwave sensors.

Radiometers

Radiometers are basically high sensitive receivers operating in different frequencies depending on the application. Radiometers receive the natural electromagnetic radiation emitted by the target in the desired frequency and process it to provide the geophysical information. The data is used for studying the soil moisture and snow cover on land, salinity and surface wind speeds in oceans and water vapour and liquid water content in atmosphere. Radiometers also can be used for generating imageries of the target/terrain of interest.

Scatterometer

Scatterometer is also a Side Looking Radar, but configured to measure the Radar cross section/scattering co-efficient of the target accurately rather than mapping it. Ground based scatterometers are used to collect the Radar cross section of various targets of interest as a function of the sensor and target parameters. From spaceborne platforms, the scatterometer is mainly used to measure the ocean surface wind speed and direction. This can generate this wind data over a wide area (500 - 800 Km.) with good accuracy.

Altimeter

It measures the ocean surface topography, significant wave height and surface wind speed. It can also be configured to measure the terrain evaluation on land. It operates in nadir looking mode.

Rain mapping Radar

It is meant for measuring the rainfall in the tropical region. The Radar transmits coherent high-energy pulses at microwave frequencies and receives the back-scattered power from rain drop and processes to provide information on the rain rate, vertical distribution etc. It can measure rainfall rate upto 0.5 mm/hr.

Side Looking Radar

Real Aperture Radars are less complex. But the resolution is directly linked to the physical length of the antenna and distance to the target. This is overcome by the Synthetic Aperture Radar, though a complex system, using signal processing techniques.

RADAR OPERATING PRINCIPLE

Radar uses an electromagnetic carrier frequency. The radar generates a pulse for each transmission that is radiated by an antenna and propagates to the scene. A fraction of the incident energy is reflected back towards the radar which is gathered by the receiving antenna. The receiving signal being weak is vulnerable to additive noise, which accompanies the signal through rest of the system. Both signal and noise are amplified in the receiver, demodulated from the carrier frequency to a low pass or video frequency.

SLAR system typically consists of a radio frequency generator and amplifier, a timer, a transmit - receive switch (TR), an antenna, a receiver, a cathode ray tube (CRT), oscilloscope and a camera Fig 1.

A long rectangular antenna is mounted on the body of an aircraft, parallel to its longitudinal axis. The antenna emits, fan-shaped essentially plane 'pulses' of electromagnetic energy in a direction normal to the antenna's longitudinal axis. The pulse travels along this plane until it illuminates a narrow strip on the ground, sideways below the aircraft. The Radar records the `delay time' i.e. the time taken by the transmitted pulse to reach the target, interact with the target and to return back to the receiver, which depends on the distance of the target from the antenna. The radiation received by the antenna is transformed by the receiver into an electric analogue signal. This signal modulates the intensity of the flying spot of a CRT. The CRT screen is imaged sharply on a photographic film such that one scan line on the ground is covered by one sweep of the flying spot. By moving the photographic film at a speed proportional to the speed of the aircraft, a continuous strip map of the terrain is formed. The analogue signal can be transformed into digital numbers by the analogue digital converter and it can be recorded in a computer compatible tape on-board or transmitted to the earth tracking station. Fig2 illustrates a strip of terrain imaged using SLAR.

Radar Equation

$$W_r = (W_t G^2 \lambda^2 \sigma)/(4\pi)^3 R^4$$

Where
- W_r - Received power
- W_t - Transmitted power
- G - Gain
- R - Distance from transmitter to target
- σ - Effective backscatter area
- λ - Wavelength

In this equation, it is very difficult to measure the parameter effective backscatter area. This can be simplified by replacing the same by the multiplication of scattering coefficient (σ^o) and ground resolution cell. And hence the simplified equation becomes,

$$W_r = (W_t G^2 \lambda^2 \sigma^o A)/(4\pi)^3 R^4$$

Where
- σ^o - Scattering coefficient
- A - Ground resolution cell

The ground resolution is again dependent on the slant range distance of the target and pulse duration, which can be understood from the following equation

$$A = (\beta h.\ R).(C\tau/2\sin\theta)$$

where βh - Effective beam width
- R - Slant range distance of the target
- c - velocity of EMR
- τ - Pulse duration
- θ - Angle of incidence.

Definitions

Incidence Angle

Incidence angle (θ) is defined as the angle between the radar line of sight and local vertical with respect to the geoid Fig. It is a major factor influencing the radar backscatter and appearance of objects on the imagery caused by foreshortening or radar layover Fig 3.

Look Angle

Look angle (ϕ), also referred to as elevation angle, is defined as the angle between the vertical of the antenna to the ground transmitted ray at the point of incidence. Look angle increase from near to the far range and is the complement of depression angle (90^o - β) Fig 3.

Depression Angle

Depression angle (β) is the angle between the vertical antenna to the ground and transmitted ray to the point of incidence Fig. Depression angle increases from far range to near range and is complement of look angle (90^o-ϕ) Fig 3.

Azimuth Angle

Azimuth angle is the angle between the azimuth direction, which is parallel to the flight line, and the range direction, which is perpendicular to the flight line or across track direction. In most cases azimuth angle is 90^o Fig 3.

Spatial Resolution in RADAR

The ability of the sensor to distinguish objects spatially is the spatial resolution. It is necessary that reflected signals from different targets are to be received at different times to distinguish them as different features, otherwise they will appear as one large object (Fig.4).

Range resolution

Spatial resolution in the range direction, is determined by the duration or length of the pulse of the transmitted energy and is theoretically equal to one half the pulse length.

Range resolution R_r is given by

$$R_r = \frac{(C\tau)}{2\text{Cos}\,\theta}$$

Where τ - pulse length (in time units)
C - speed of electromagnetic radiation(3 x 108m/sec.)
θ - depression angle (angle between horizontal plane and the line connecting target and antenna.

For a depression angle of 50° and pulse length of 0.1 microsecond, the range resolution R_r is 23 m. Hence, objects separated by less than 23 m. in the range direction would not be resolved. At a depression angle of 35°, R_r would be 18 m. The range resolution is poor for objects nearer the flight line Fig 4(a).

Azimuth resolution:

Azimuth resolution R_a is determined by the angular width of the terrain strip illuminated by the radar beam. To be resolved in azimuth direction, targets must be separated by a distance greater than the beam width on the ground. As the beam width is narrower in the near range azimuth resolution is greater in the near range.

The azimuth resolution R_a is given by

$$R_a = 0.7\ S.\lambda/D$$

Where S - slant range
λ - Wave length
D - antenna length.

For a slant range of 8 km . wavelength of 0.86 cm and antenna length of 490 cm., R_a would be 9.8 m. in the near range. For a slant range of 20 km. R_a would be 24.6 m.

The resolution can be improved by using a longer antenna and a shorter wavelength. But there is a limit to the length of the antenna which can be carried outside an aircraft and shorter wavelengths will not have enough power to penetrate a moist atmosphere or clouds as much of the energy would be scattered. And this can be overcome by Synthetic Aperture Radar where signal processing techniques are used to have synthetically longer antenna Fig 4(b).

Synthetic Aperture Radar:

The real aperture radar uses an antenna of the maximum practical length to produce a narrow beam width in the azimuth direction. The synthetic aperture radar employs a relatively small antenna that transmits a moderately wide beam but the effective length, which is achieved by electronic data processing, is many times the actual length. The beam width is uniform after processing in the case of synthetic aperture radar, while it is fan shaped in the real aperture radar. And hence finer resolution is achieved.

The concept used to achieve the constant and finer resolution in Radar is the Doppler frequency shift. In this concept the shift in wave frequency of the received signal is considered as the relative movement of the target with respect to the platform. The targets ahead of the antenna suffer from upshift in frequency while the targets behind the antenna suffer from downshift in frequency. This change in wave frequency is processed to identify the targets in a narrow beam exactly in the line of the antenna Fig (5).

RADAR Return and Image Signatures

Energy reflected from the terrain to the radar antenna is called radar return. The following parameters strongly affect the radar return.

a) System properties

- i) Wavelength / frequency
- ii) Polarization
- iii) Incidence angle

b) Terrain properties

- i) Dielectric constant
- ii) Surface roughness
- ii) Feature orientation

System properties

Radar Wavelength /Frequency
Radar signals may be transmitted at a range of wavelengths. The standard band widths used and their letter codes are given in the following table

Band code	Wavelength (λ) in cm	Frequency(ν) GHz
Ka	0.8 - 1.1	40 - 26.5
K	1.1 - 1.7	26.5 - 18.0
Ku	1.7 - 2.4	18.0 - 12.5
X	2.4 - 3.8	12.5 - 8.0
C	3.8 - 7.5	8.0 - 4.0
S	7.5 - 15.0	4.0 - 2.0
L	15.0 - 30.0	2.0 - 1.0
P	30.0 - 100.0	1.0 - 0.3

The radar return mainly depends on the wavelength or the frequency used. The terrain features have a unique interaction in a particular wave band and hence the return is also unique for the wave band used. Shorter wave bands have atmospheric effects because of the interaction with the atmospheric water vapour. Longer wave bands comparatively penetrate through the skin of the earth surface also Fig 6.

Polarization
Resolving the EMR into its horizontal and vertical component is called polarization. As electromagnetic energy propagates through a medium the particles will oscillate in all directions. But when the EMR is passed through a polarizing crystal the outcoming wave will have particle oscillation in only one direction i.e. either horizontal direction or vertical direction and the EMR is

said to be plain polarized and the outcome waves are called as horizontal component or vertical component respectively.

In passive microwave system the sensor receives either H component or V component and the data product will be either H image or V image as case may be. In active microwave remote sensing, since the sensor sends the microwave pulses also, H or V component is sent and either H or V component is received. Independent of the transmitted polarization, the reflected energy will be depolarized as a function of the frequency, angle of incidence, the morphology and the composition of the terrain. If a system transmits horizontally polarized energy after interaction it will contain both horizontal and vertical components. And there will be HH image or HV image or VV image or VH image. HH image and VV image is called as like polarized images and VH image and HV image are called as cross-polarized images. The Radar system containing single antenna can receive only image type i.e. either of the like polarized or either of the cross-polarized. If the Radar system contains two antennas it can receive two image types simultaneously i.e. either both like polarized or both cross-polarized or one like polarized and one cross polarized.

A comparison of like and cross-polarized returns might reveal differences leading to terrain identification. Water and trees appear the same in like and cross-polarized images while swamps appear brighter in like polarized and darker in cross-polarized imagery. Grasslands appear darker in like polarized image and brighter in cross-polarized image.

Incidence angle

Incidence angle is defined as the angle between the radar beam and a perpendicular to the surface. Look angle is the angle between the plumb line and the line of illumination at the antenna. Complement of the look angle is the due look angle. For flat terrain incidence angle is same as the look angle.

Rough surfaces produce relatively uniform radar return irrespective of the incidence angle. Smooth surfaces give a stronger return at depression angles near vertical but little or no return occurs at lower depression angles.

Terrain properties

Dielectric constant

The electrical properties of matter influence the interaction with electromagnetic energy and are called the complex dielectric constant. Dielectric constant can be stated as the ability of the material to get depolarized when electromagnetic field is applied. This material depolarization in turn is related with the amount of polarization of the interacting energy i.e. if the material has very high dielectric constant will depolarize the incident EMR better and hence the intensity of received signal will also be more which gives rise to brighter tone. Dielectric constant for some common targets is listed below.

Table 2: Dielectric constant for some common materials

Material	Dielectric Constant
Vacuum	1.00000
Hydrogen	1.00025
Nitrogen	1.00055
Air	1.00059
Glass	4 to 7
Ethanol	24.3
Water (0°C)	87.8
Aluminum and iron (apply)	2 to 5
Dry rocks and soils	3 to 8

Surface roughness

Strength of the radar return is determined by the relationship of surface roughness to radar wavelength and to the depression angle of the antenna.

Surfaces can be either smooth or rough or intermediate. Smooth surfaces reflect all the energy away from the antenna and will be resulted in dark tone. Rough surfaces diffusely scatter the energy equally in all direction irrespective of the angle of incidence. Intermediate surfaces scatter the energy diffusely but not equally since a portion of the energy is specularly reflected and the rest diffusely scattered. This property depends on the intermediate surface's smoothness towards the smooth surface Fig 6.

The Rayleigh criterion considers a surface to be smooth if

$$h < \frac{\lambda}{8 \sin \Upsilon}$$

where h = height of surface irregularities

λ = radar wavelength

Υ = grazing angle (angle between the terrain slope and the incident radar wave).

and, defines the rough surface if

$$h > \frac{\lambda}{8 \sin \Upsilon},$$

Peake and Oliver's modified Rayleigh criterion defines the smooth rough as well as intermediate surfaces in the following way.

If $h < \frac{\lambda}{25 \sin \Upsilon}$, they are termed smooth;

If $h > \frac{\lambda}{4.4 \sin \Upsilon}$, they are termed as rough; and

If $\lambda/4{,}4 \text{ Sin}\Upsilon < h > \lambda/25 \text{ Sin}\Upsilon$, then they are termed as intermediate surfaces.

Feature Orientation

Orientation of the linear features with respect to the look direction affects the Radar return in such a way that if the feature is oriented perpendicular to the look direction then the identification of the same becomes possible since it gives strong return. On the other hand if the linear feature is oriented parallel to the look direction then, identification of the same becomes very difficult because of the weak return and poor contrast with the neighbouring features.

Forms of Radar Return

Nature of Radar interaction with terrain feature decides form of energy return to Radar. It can be

a. Specular Reflection,
b. Corner Reflection, or
c. Diffused Scattering.

Specular Reflection

If the surface is smooth with respect to the wavelength used, the energy is totally reflected away from the sensor at the surface of the target and the feature looks dark in the image. It is the case with calm water bodies.

Corner Reflection
Adjacent smooth surfaces which are perpendicular to each other cause the double reflection at the surfaces and the total energy is reflected back to the sensor giving rise to very bright tone. This occurs with buildings, dam structures etc.

Diffuse Scattering
Intermediate to rough surfaces cause the diffused scattering due to the interaction within the feature and scattering occurs in all directions. Example is the vegetation where the individual scatterers cause the volume scattering within the vegetation volume. This interaction gives moderate return and the image looks in medium to bright tone.

RADAR Image Characteristics

Slant Range distortion

As the Radar records the delay time it is directly related to the slant range distance of the target from the antenna. As illustrated in figure 3 the ground range distances AB and BC in near range will be compressed to A'B' and B 'C' in the slant range representation. It is seen from the figure that the compression effect goes on reducing in the far range. This type of distortion occurs only in slant range display systems. To record the return signals in the ground range display hyperbolic time correction is required.

Relief displacement

The displacement due to relief is perpendicular to the flight line. When a vertical feature is encountered in a Radar pulse the top of the feature is reached before the base Fig 7. If the terrain is sloppy and the degree of the slope affects the slant range distance difference between the top and base of the hilly terrain which results in the relief displacements called

a) Layover
b) Foreshortening
c) Radar Shadow.

Layover
If the terrain slope is facing towards the antenna and steeper than the line perpendicular to the direction of Radar pulse then the top is sensed before the base is reached. Hence in the image, return from top is recorded previous to the return signal from the base. At near range the layover effect is more than the far range because at far range the look angle becomes more and the terrain looks less steep than the near range.

Foreshortening
If the terrain slope is facing towards the antenna and less steeper than the line perpendicular to the direction of Radar pulse then the base is sensed before the top. Hence in the image, return from base is recorded previous to the return signal from the top. The resulting effect is foreshortening as the facing slope is shortened.

Radar Shadow
Terrain slopes inclined towards antenna will show strong reflections while terrain sloping away from the flight line shows no reflection and consequently appear as shadows. Radar shadows record no information whereas the shadow in optical remote sensing records weak energy return. Shadowing effect increases in length as the angle of incidence decreases from near to far range.

Parallax and stereo capability
Radar, by its side looking nature, gives the parallax due to relief which can be used for stereo image analysis. By changing the altitude or by scanning the same area from a parallel flight path with opposite viewing Radar stereo images can be collected.

Speckle

Speckle is the random noise in Radar images due to interference phenomenon. In a ground resolution cell the individual scatterers differ in their delay time but not recorded as different features because of the resolution limitation, gives resultant signal, the summation of signals from individual scatterrers which differ in phase. This phase difference causes the interference and due to this the resultant may vary from zero to the absolute sum of the individual signals. It can be noted that it is a time dependant phenomenon and image collected at time t1 may have the speckle for a particular ground resolution cell and may not have the speckle for the same ground resolution cell at time t2.

Spaceborne SAR

The airborne SAR systems proved their capability in many application fields and hence some experimental as well as operational space borne SAR were launched. The first spaceborne SAR was the on board SAR carried by Lunar Module of the APOLLO 17 mission in the year 1972. The first major mission of civilian Remote Sensing using SAR was the SEASAT spacecraft launched by NASA during 1978. This carried a L-band SAR with a capability to provide 25 m by 25m resolution and 100 km swath. This was a single frequency and single polarization (HH) system. The data was transmitted to the ground in analog. It was processed using optical processor or was processed using digital processor after the data was digitized on the ground. Subsequent to SEASAT, SAR systems have flown on board SHUTTLE (SIR-A in 1981, SIR-B in 1984), ALMAZ, ERS-1 AND JERS-1. Some of the salient features of these systems are summarized in table 3.

These systems have provided enormous amount of excellent SAR data products. Development of methodology, techniques and algorithms to analyze these data products is being carried out by many groups all over the world. The future missions like SIR-C, ERS-2, RADARSAT, ENVISAT, ALMAZ-2 EOS etc. are planned to provide advanced SAR technology like multi- polarization data, multi frequency data or multi look angle data.

TABLE 3: Salient features of spaceborne SAR systems

Mission	Year	Frequency	Polarisation	Look angle(deg)	Swath(Km)	Resolution (m)
SEASAT(USA)	1978	L-Band	HH	20	100	25
SIR-A(USA)	1981	L-Band	HH	47	50	40
SIR-B(USA)	1984	L-Band	HH	15-65	20-50	30
ALMAZ(RUSSIA)	1987	S-Band	HH	30-60	20-45	15-30
ALMAZ-1 (RUSSIA)	1991	S-Band	HH	30-60	20-45	15-30
ERS-1(EUROPE)	1991	C-Band	VV	23.5	80	25
JERS-1(JAPAN)	1992	L-Band	HH	35	75	18
SIR-USA/GERMANY	1994	L, C & X-Bands	HH&VV HV&VH VV	15-55	15-90	30
ERS-2(EUROPE)	1994	C-Band VV	23.5	80		25
ALMAZ-2(RUSSIA)	1996	-	-	-	-	-
RADARSAT(CANADA)	1995	C-Band	HH	20-40 20-40 37-49 49-59 49-59	100 150 45 300/500 75	25 35 10 100 30
EOS(USA)	1998	L, C & X-Bands	VV,HH HV&VH HH&VV	15-55	30-20 700(Scan)	30 15
ENVISAT(EUROPE)	1998	C-Band	VV,HH	20-50	100-400	30

Interpretation of RADAR Imagery

The imagery should be oriented in such a way that the radar shadows fall towards the observer. The radar imagery is interpreted in a similar way as the aerial photographs using interpretation elements like tone, texture, pattern and shape.

Strong or bright signal returns (light tones) are usually indicative of prominent cultural features or manmade features. Intermediate energy returns (medium grey tones) may indicate areas of open country or areas of no return, as in the case of flat and smooth terrain of an airfield. Weaker returns, denoted by black images commonly indicate the presence of water and hydrologic features.

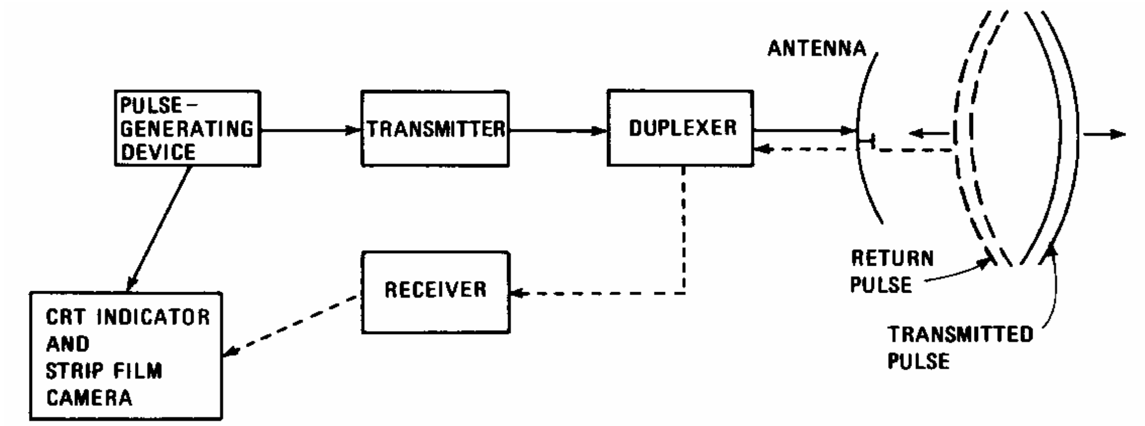

Fig. 1: Components of Radar Imaging System

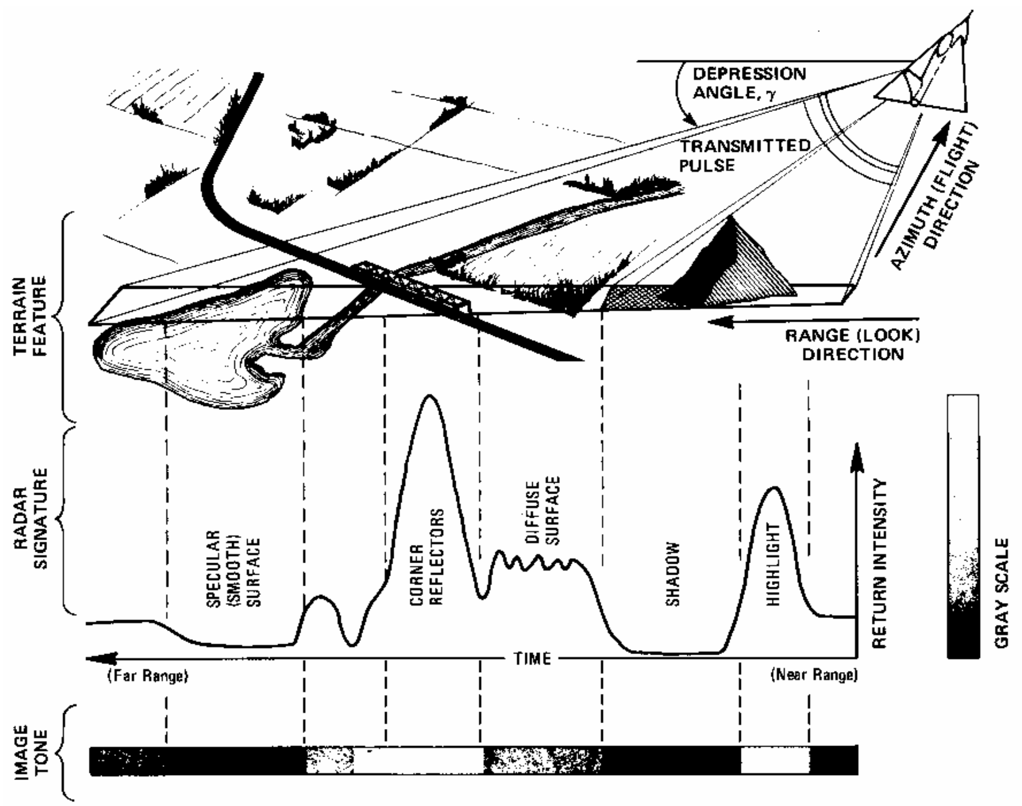

Fig. 2: Radar returns from terrain and signal processing of a pulse of radar energy

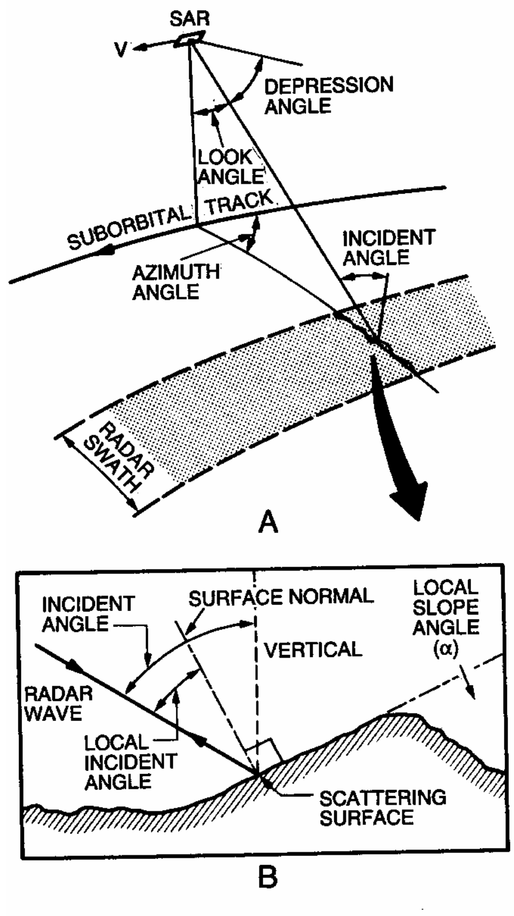

Fig. 3: Relationship between Depression angle, Look angle and Incidence angle.

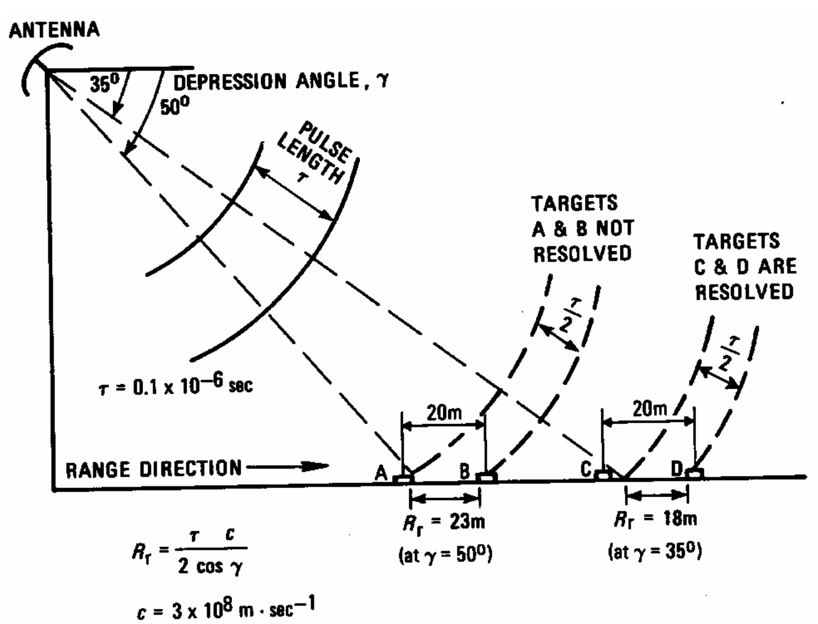

Fig. 4 a) Resolution in Range Direction

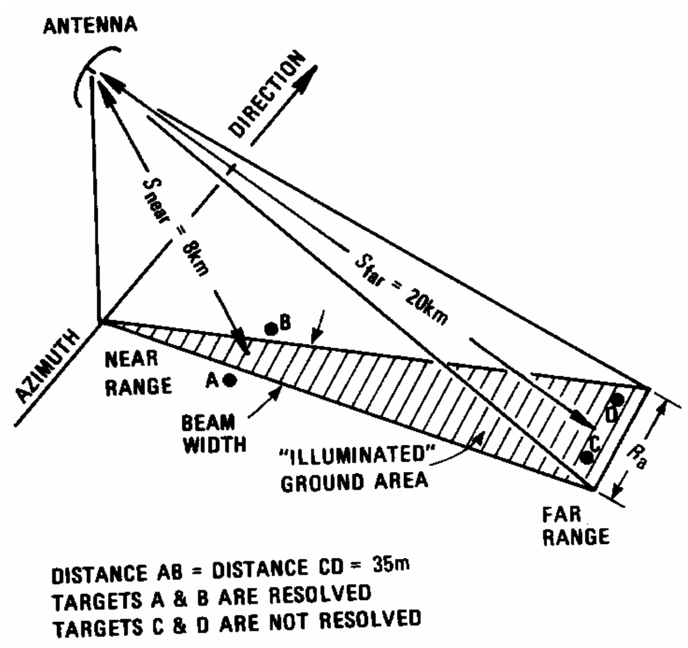

Fig. 4 b) Resolution in Azimuth direction

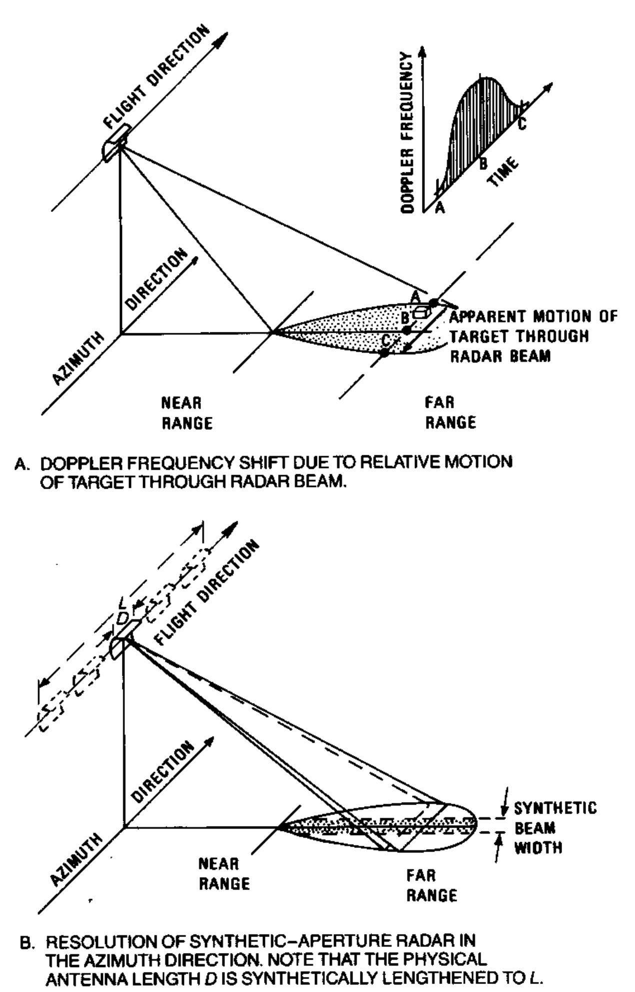

Fig. 5: Synthetic Aperture Radar system

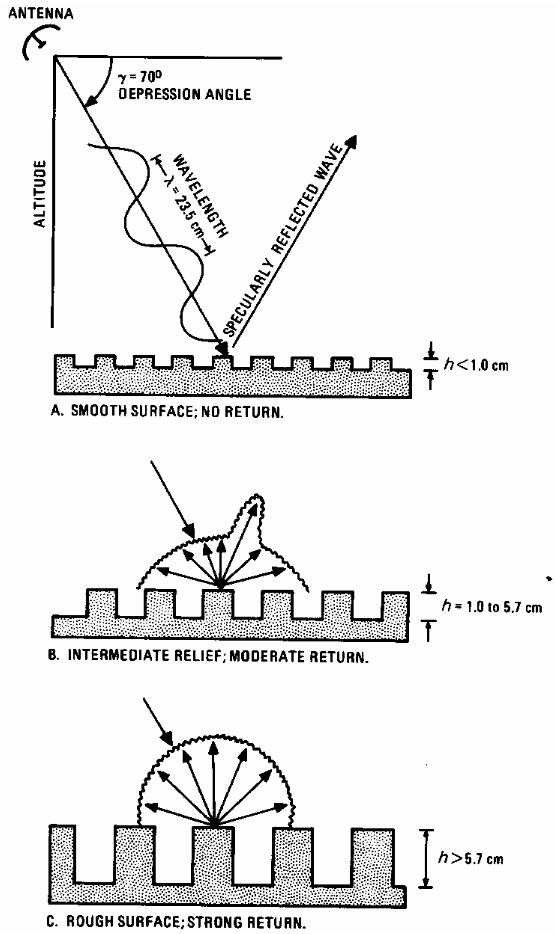

Fig. 6: Surface Roughness Criteria

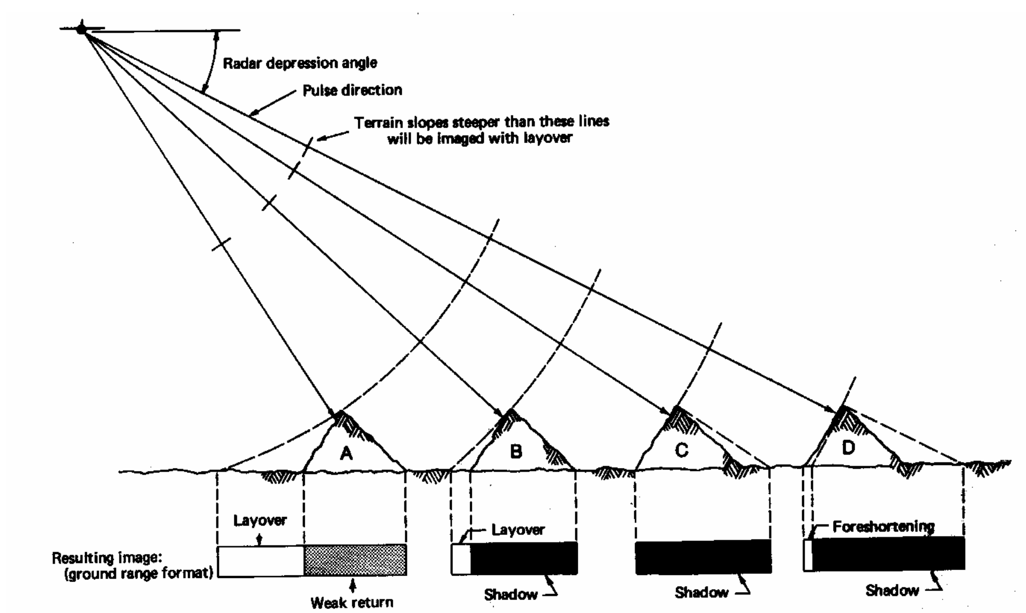

Fig. 7: Effects of Terrain Relief (Layover and Fore shortening) effects