

MODULE – 7 LECTURE NOTES – 2**RADAR INTERFEROMETRY****1. Introduction**

Radio Detection And Ranging (Radar) is a system which uses microwave signals to detect the presence of an object and its properties. Pulses of radio waves are sent from the radar antenna towards the objects. The objects scatter back a part of this energy falling on them, which are collected at the same radar platform. Energy reflected from the terrain to the radar antenna is called radar return.

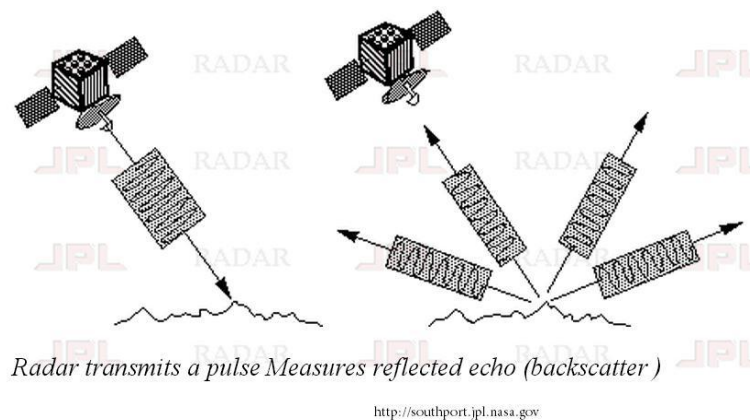


Figure 1. Principles of radar remote sensing

When an object scatters the radar signal, the scattered signals differ from the original in amplitude, polarization and phase. Thus, the radar information consist complex information in terms of both amplitude and phase of the signals. The difference between the pulses sent and received indicates the properties of the object and the distance of the object.

Principles of radar interferometry are used in the radar remote sensing to generate high resolution DEMs with near global coverage.

This lecture covers the basic principles of radar imaging and radar interferometry. The methodology used to derive DEM from radar interferometry is also covered in this lecture.

2. Radar imaging from a moving platform

In radar imaging, the radar systems are generally operated from a moving platform, either airborne or space-borne. The radar imaging is based on the Side Looking Airborne Radar (SLAR) systems. In SLAR systems, the microwave pulses are emitted to the side of the aircraft/ space shuttle as it moves forward, and the radar return is recorded using the antenna. Each pulse has a finite duration and it illuminates a narrow strip of land normal to the flight direction as shown in Fig.2. The radar image is generated by using continuous strips swept as the aircraft/ moves in the azimuth direction.

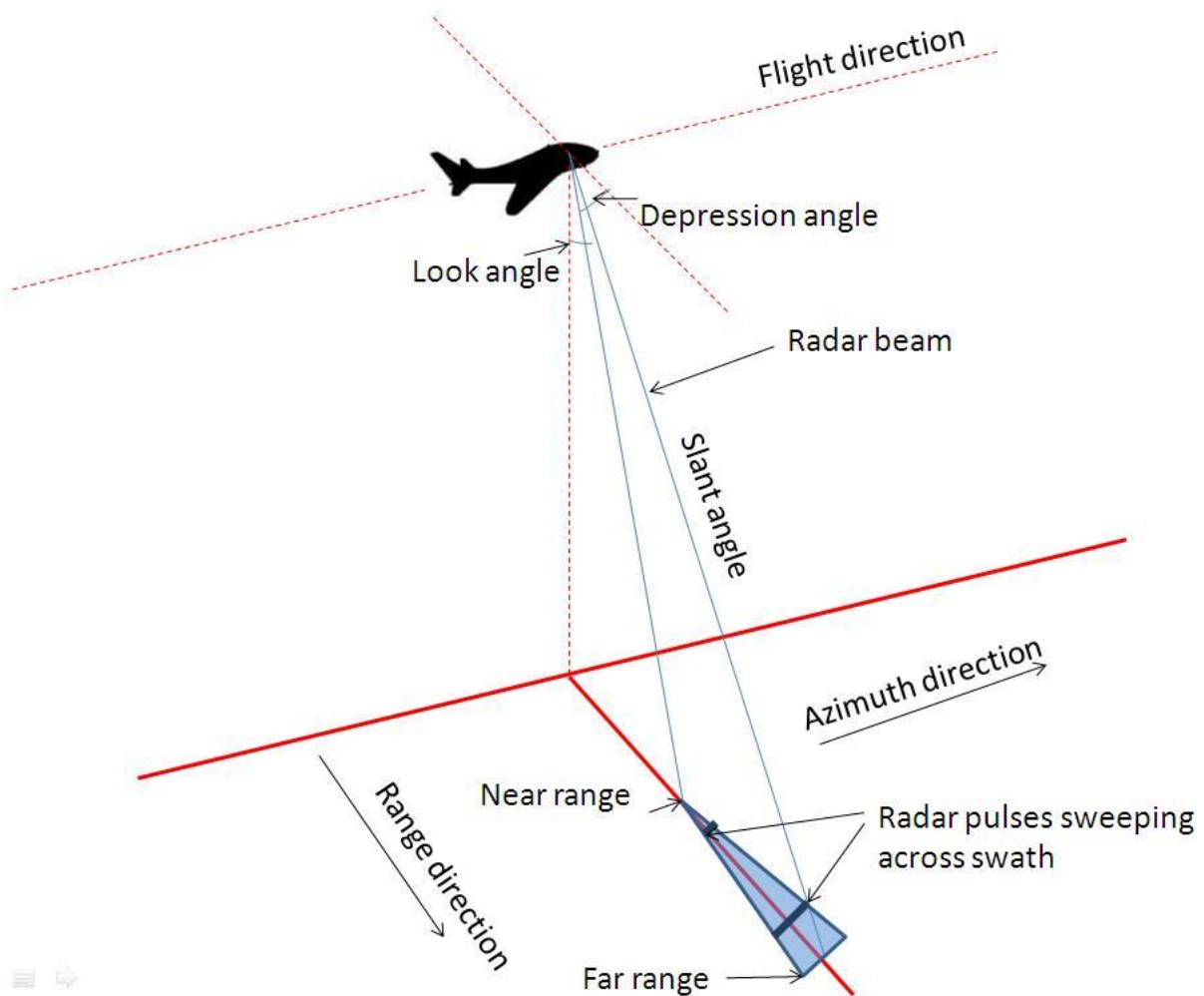


Figure 2. Radar imaging from a moving platform

3. Characteristics of the radar signals

3.1. Wavelength

Microwave remote sensing uses the electromagnetic spectrum with wavelength ranging from a few millimeters to 1 m. Each wavelength band is denoted by a letter, as shown in Table 1. The bands that are commonly used in the radar remote sensing are highlighted in the Table.

Table 1. Microwave bands commonly used in remote sensing

Band	Wavelength (cm)
Ka (0.86 cm)	0.8-1.1
K	1.1-1.7
Ku	1.7-2.4
X (3 and 3.2 cm)	2.4-3.8
C	3.8-7.5
S	7.5-15.0
L (25 cm)	15.0-30.0
P	30.0-100.0

(From Sabins, 1978)

The selection of wavelength depends on the objectives of the analysis. Smaller wavelengths cannot penetrate through the clouds and hence are generally less preferred for imaging from airborne/space-borne platforms. Larger wavelengths like L bands are capable of penetrating through the cloud, and hence the satellite-based radar imaging uses the larger wavelength bands.

Longer wavelengths can penetrate through the soil and hence can be used to retrieve soil information. However, they provide less information about the surface characteristics. On the other hand, the shorter wavelengths get scattered from the surface and give more information about the surface characteristics. Hence shorter wavelength bands C and X are used in radar interferometry to extract the topographic information.

3.2 Velocity

Microwave bands of the electromagnetic spectrum are used in the radar remote sensing. Therefore these signals travel at the speed of light ($c = 3 \times 10^8 \text{ m.sec}^{-1}$).

3.3 Pulse duration or pulse length

The pulses sent from the radar have a constant duration, which is called the pulse duration or pulse length. The amount of energy transmitted is directly proportional to the pulse length. Resolution of the radar imagery in the range direction is a function of the pulse length. When the pulse length is long, larger area on the ground is scanned by a single pulse, leading to a coarser resolution.

3.4 Phase of the signal

Phase is used to mention the phase of the wave cycle (crest or trough). The phase of the radar return depends on the total distance travelled from the radar to the terrain and back in terms of the total wave cycles.

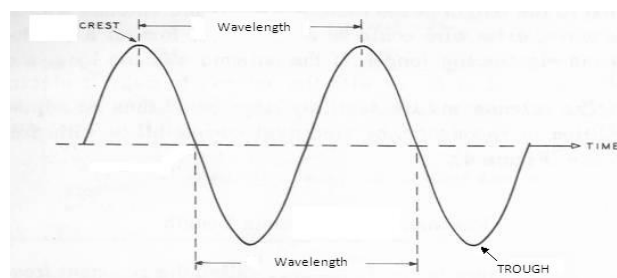


Figure 3. Phases of a signal

3.5 Look angle, depression angle and incident angle

Look angle is the angle between the nadir and the point of interest on the ground. Depression angle is complementary to the look angle. Angle between the incident radar beam and a line normal to the ground is called the incident angle. These are shown in Fig.4.

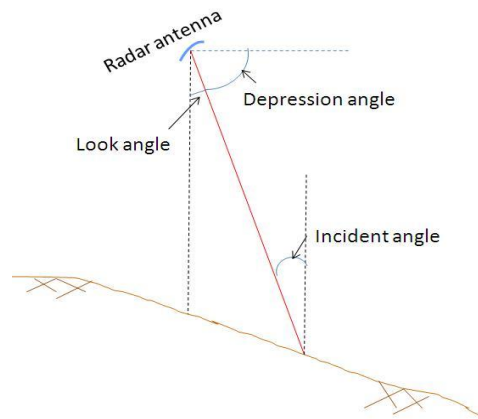


Figure 4. Concept of look angle, incident angle and depression angle in radar remote sensing

4. Resolution of the radar image

Spatial resolution of a radar image is controlled by the pulse length and the antenna beam width. Radar image resolution is specified in terms of both azimuth and range resolutions. A combination of both determines the ground resolution of a pixel.

4.1 Range resolution

In order to differentiate two objects in the range direction, the scattered signals from these two objects must be received at the antenna without any overlap. If the slant distance between two objects is less than half of the pulse length, the reflected signals from the two objects will get mixed and the same will be recorded as the radar return from a single object. The resolution in the range direction is therefore controlled by the pulse duration or pulse length. The slant-range resolution of the radar image is equal to one half of the pulse length (i.e., $\tau/2$).

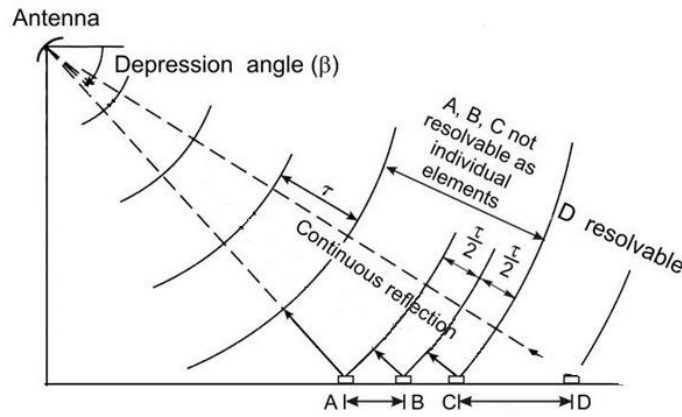


Figure 5. Range resolution of the radar imagery

(Courtesy: <http://what-when-how.com/remote-sensing-from-air-and-space/theory-radar-remote-sensing-part-1/>)

Ground resolution (R_r) in the range direction, corresponding to the slant range resolution is calculated as follows.

$$R_r = \frac{\tau c}{2 \cos(\beta)}$$

where τ is the pulse length measured using the units of time, c is the velocity of the signal (equals velocity of light = 3×10^8 m/sec) and β is the depression angle.

Thus, shorter pulse lengths give better range resolution. But shorter pulses reduce the total energy transmitted, and hence the signal strength. Therefore electronic techniques have been used to shorten the apparent pulse length and hence to improve the resolution.

5.2 Azimuth resolution

Resolution in the azimuth direction (R_a) is controlled by the width of the terrain strip illuminated by the radar beam (or the radar beam width of the antenna), and the ground range. Smaller beam widths give better resolution in the azimuth direction. Since the angular width of the beam is directly proportional to the wavelength λ , and inversely proportional to the length of the antenna (D), resolution in the azimuth direction is calculated as follows.

$$R_a = \frac{S \cos(\beta) \lambda}{D}$$

where, S is the slant range. Since the radar antenna produces fan shaped beams, in the SLAR the width of the beam is less in the near range and more in the far range as shown in Fig.2. Therefore, the resolution in the azimuth direction is better in the near range, than that in the far range.

Resolution in the azimuth direction improves with the use of shorter wavelengths and larger antennas. Use of shorter waves gives finer resolution in the azimuth direction. However shorter waves carry less energy and hence have poor penetration capacity. Therefore the wave length cannot be reduced beyond certain limits. Also, there are practical limitations to the maximum length of the antenna. Therefore, Synthetic Aperture Radars are used to synthetically increase the antenna length and hence to improve the resolution in the azimuth direction.

6. Synthetic Aperture Radars

In radar remote sensing, since the spatial resolution is inversely related to the length of the antenna, when the real aperture radars are used, the resolution in the azimuth direction is limited. In Synthetic Aperture Radar (SAR), using the Doppler principle, fine resolution is achieved using both short and long waves.

6.1. Doppler effect

Doppler principal states that if the source or the listener are in relative motion, the frequency of the sound heard differs from the frequency at the source, frequency will be more (or less) depending upon whether the source and the listener are moving close to (or away from) each other, as shown in the figure below.

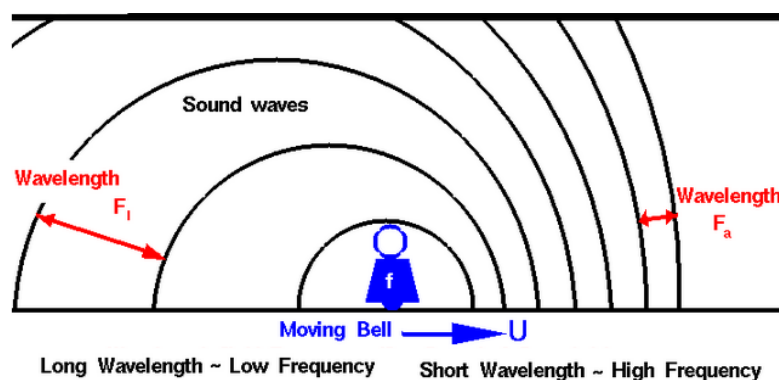
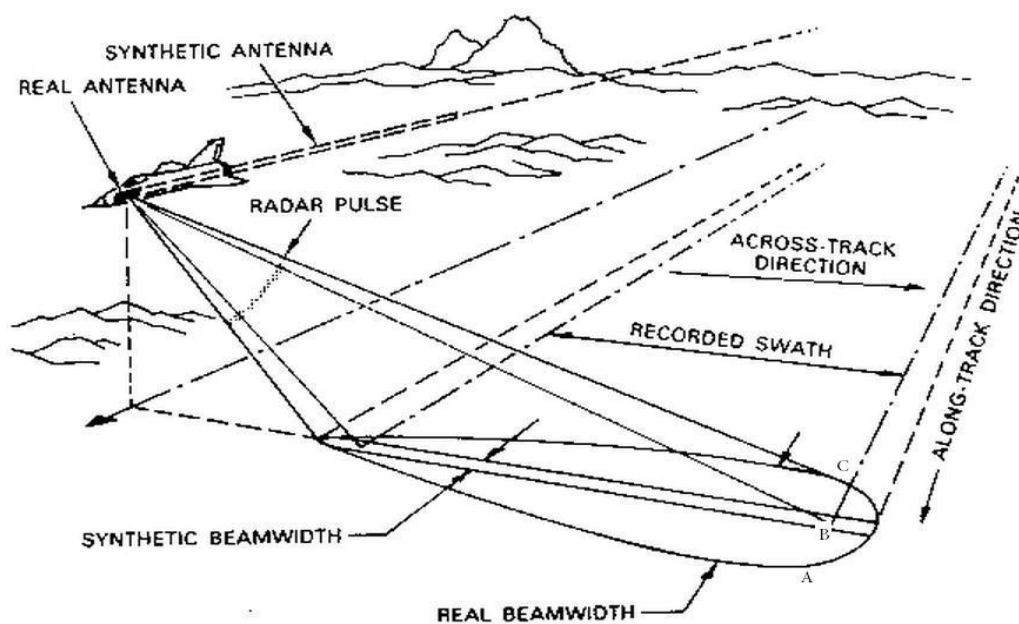


Figure 6. Doppler principle of sound (Source: grc.nasa.gov)

6.2 Application of Doppler principle in SAR

The Doppler principle is used in the SAR to synthesize the effect of a long antenna. In SAR, each target is scanned using repeated radar beams as the aircraft moves forward, and the radar returns are recorded. In reality, the radar returns are recorded by the same antenna at different locations along the flight track (as shown in Fig.7), but these successive positions are treated as if they are parts of a single long antenna, and thereby synthesize the effect of a long antenna.



Source: <http://www.fao.org/docrep/003/T0355E/T0355E04.htm>

(After T.E. Avery and G.L. Berlin, 1985)

Figure 7. Synthetic Aperture Radar imaging

In SAR, the apparent motion of the target through continuous radar beams is assumed (from A to B and then from B to C) as shown in Fig. 7. When the target is moving closer to the antenna, according to the Doppler principle, the frequency (and hence the energy) of the radar return from the target will be more. On the other hand, when the target is moving away from the antenna, the resulting radar return will be weak. The radar returns are processed according to their Doppler frequency shift, by which very small effective beam width is achieved.

7. Radar interferometry

Radar interferometry is the technique used to survey large areas giving moderately accurate values of elevation. The principle of data acquisition in interferometric method is similar to stereo-photographic techniques. When the same area is viewed from different orbits from a satellite at different times, the differences in phase values from the scattered signals may be used to derive terrain information. Radar interferometry makes use of the phase changes of the radar return to measure terrain height. Two or more radar images can be used effectively to generate a DEM. This technique is largely used for hazard monitoring like movement of crustal plates in earthquake prone areas, land subsidence, glacial movement, flood monitoring etc. as they give a high accuracy of upto a centimeter in elevation.

7.1. Interference Concept

Interference is the superposition of the waves travelling through the same medium. Depending upon the phases of the waves superpose, the amplitude of the resultant wave may be higher or lower than the individual waves. When the two waves that meet are in phase i.e., the crest and troughs of the two waves coincide with each other, then the amplitude of the resultant wave will be greater than the amplitude of the individual waves, and this process is called constructive interference. On the other hand, if the two waves are in opposite phase, the amplitude of the resultant wave will be less than that of the individual waves, which is called destructive interference.

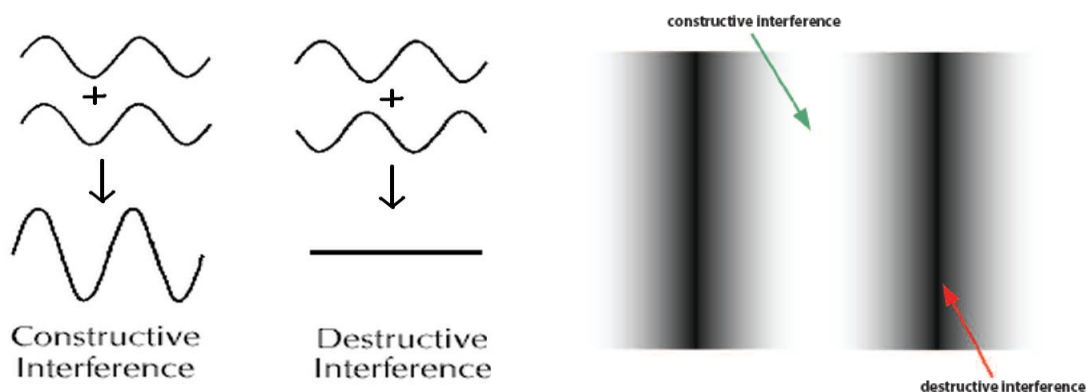


Figure 8. Basics concept used in the light interference

The phase of the resulting signal at any point depends the distance to the point from the source, distance between the sources, and the wavelength. Therefore, if the wavelength of the signal, phase of the resultant signal, and the distance between the two sources are known, the distance of the point from the source can be estimated.

7.2. Principles of radar interferometry

In radar interferometry, the principles of light interference are used to estimate the terrain height. The principle of data acquisition in interferometric method is similar to stereo-photographic techniques. The radar return from the same object is recorded using two antennas located at two different points in space. Due to the distance between the two antennas, the slant ranges of the radar returns from the same object are different at the two antennas. This difference causes some phase difference between the two radar returns, which may range between 0 and 2π radians. This phase difference information is used to interpret the height of the target.

The phase of the transmitted signal depends on the slant range, and the wavelength of the pulse (λ). Total distance travelled by the pulse is twice the slant range (i.e., $2S$). The phase induced by the propagation of each signal is then given by

$$\phi = 2\pi \frac{2S}{\lambda} = \frac{4\pi S}{\lambda}$$

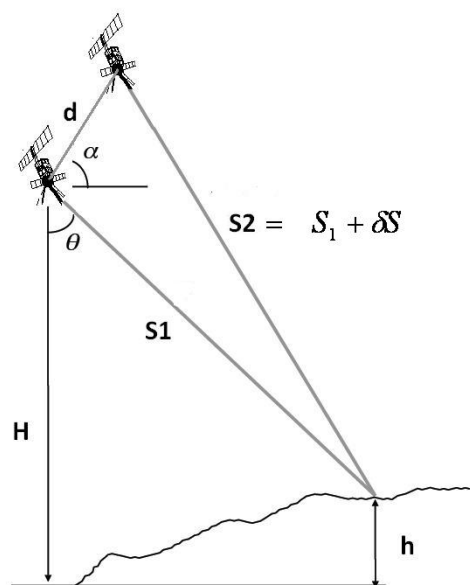


Figure 9. Principle used in the radar interferometry

When the radar returns are recorded at two antennas separated at a distance d as shown in Fig. 9, the difference in the phase is given by

$$\phi_1 - \phi_2 = \frac{4\pi}{\lambda}(S_1 - S_2)$$

When a single antenna is used to send the signals and the radar returns are received at two antennas, the phase difference is given by

$$\begin{aligned}\phi_1 - \phi_2 &= \frac{2\pi}{\lambda}(S_1 - S_2) \\ &= \frac{2\pi}{\lambda}[(S_1 + S_1) - (S_1 + S_2)] \\ &= \frac{2\pi}{\lambda}[S_1 - S_2] \\ &= \frac{2\pi}{\lambda}\delta S\end{aligned}$$

In radar interferometry, the images recorded at two antennas are combined to generate the interferogram (also known as fringe map), which gives the interference fringes, as shown in Fig. 10.

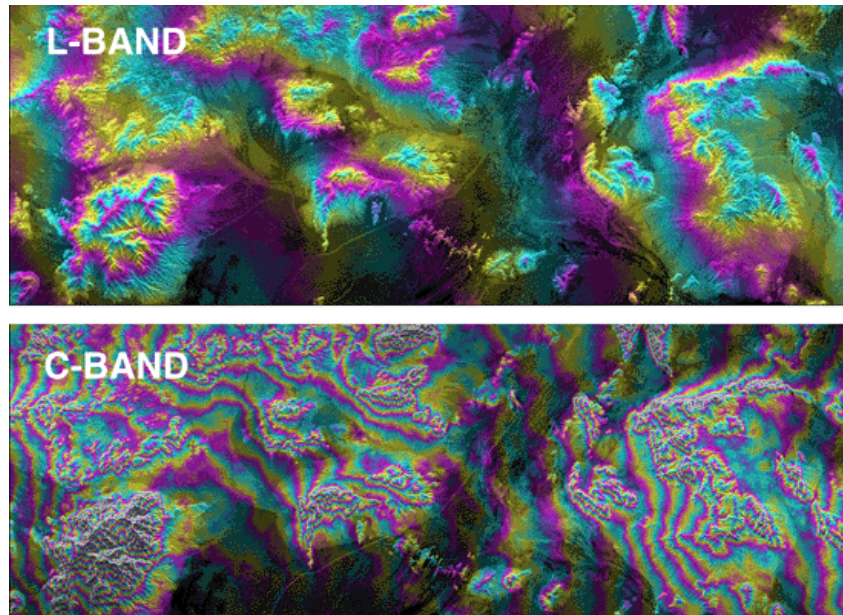


Figure 10. L-band and C-band radar interferogram for the Fort Irwin in California (Source: <http://www2.jpl.nasa.gov>)

The interference fringes are used to accurately calculate the phase difference between the two signals for each point in the image. Knowing the wavelength and phase difference, δS can be calculated.

From the principles of trigonometry, the slant range S_1 can be calculated using the following relation.

$$\sin(\theta - \alpha) = \frac{(S_1 + \delta S)^2 - S_1^2 - d^2}{2S_1 d}$$

where d is the base length or the distance between the two antennas, θ is the look angle and α is the angle of inclination of the baseline from the reference horizontal plane.

The slant range S_1 is related to the height of the antenna above the ground, terrain height and the look angle as given below.

$$h = H - S_1 \cos(\theta)$$

Thus, in radar interferometry, knowing the height of the antenna above the ground level (H), look angle (θ), base length (d), inclination of the base from horizontal plane (α), and wavelength of the signal (λ), the measured phase difference is used to estimate the elevation (h) of the terrain.

7.3 Types of radar interferometry

Single-pass interferometry: Two antennas are located at a known fixed distance apart. Signals are transmitted only from one antenna and the energy scattered back are recorded at both the antennas.

Repeat pass interferometry: In this only one antenna is used to send and receive the signals. The antenna is passed more than once over the area of interest, but through different closely spaced orbits.