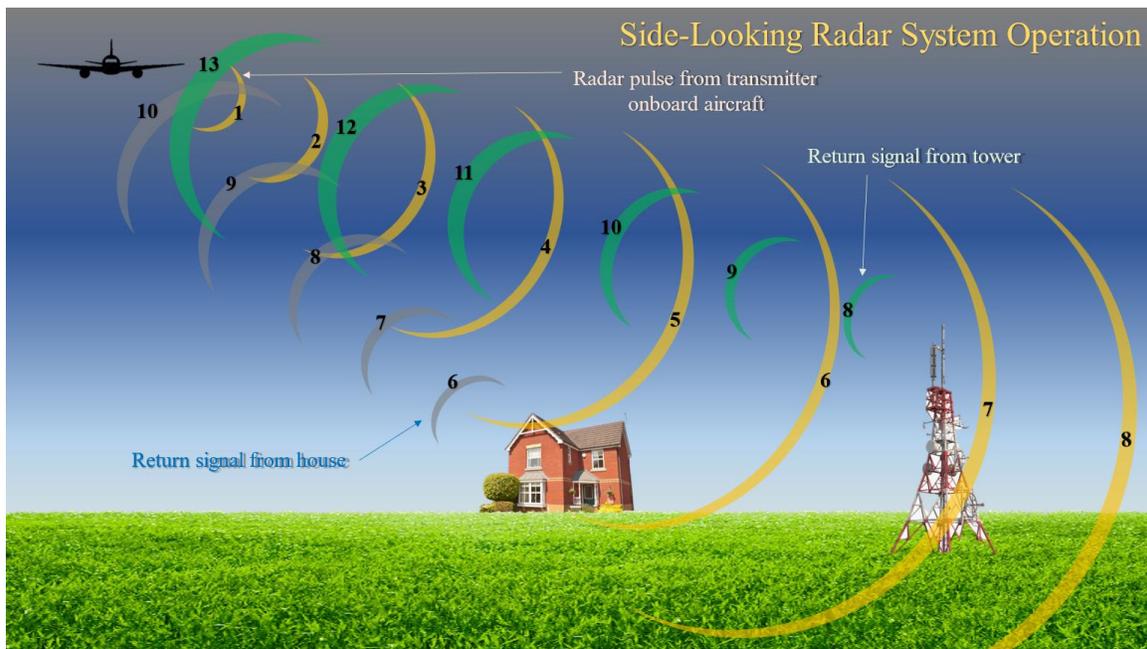


REMOTE SENSING FOR NATURAL HAZARD STUDIES

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Lecture 6a: Microwave Remote Sensing-II Part A

Hello everyone, this is the sixth lecture on microwave remote sensing. In the previous lecture, we started this microwave remote sensing, and in this lecture, we will continue it. So, this is just the basics of microwave remote sensing. How do we measure the backscattered energy? So, I hope you understood this concept in the previous lecture. I want to make sure that you understand this concept. So, here you can see that this particular tree is interacting first with this incoming microwave radiation, reflecting right before this house.



So, you can see this has already started giving the backscattered signal, and then it is going back. and it will reach to our sensor. So, this is when we have our own source of light if the sensor has its own source of light. So, as per the definition, this will be the active microwave remote sensing, whereas in another scenario, where the sun is our source of light illuminating this particular target, the incoming radiation is getting scattered back or reflected in the longer wavelength region, and then we have the sensor where it is reaching, So, this is an example of active radar; this is for the passive radiometer, So, in both

scenarios we have, we have working sensors in both the active and passive microwave remote sensing domains.

This was meant to explain the concept of a side-looking radar system. Here you see that this particular aeroplane has a sensor that is active in the microwave domain, So, it is illuminating this area and at the right angle. So, you can see the pulse has reached this particular target first so that it will start reflecting back, and this backscattered energy will reach the sensor first, in this particular scenario, what are the things we measure? We are measuring time and backscattered energies. So, these two things are stored, and with this information, over time we will be able to mark the presence of the house in its own position because it is appearing before this tower.

Microwave Remote Sensing



- ❖ The distance between the transmitter and reflecting objects can be estimated using the measured signal echoes.
- ❖ Since the energy propagates with the velocity of light (c), the Slant Range (SR) to any object can be:

$$SR = \frac{ct}{2}$$

Since the time incorporated in the equation (time measured for the pulse to travel both the distance to and from the target), factor 2 is used in the equation.

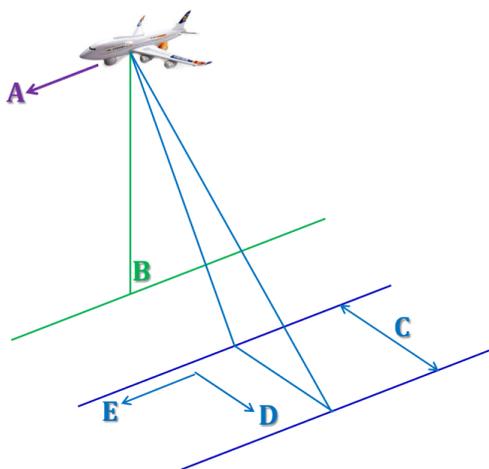
Range term is used for the distance.

In this particular field of view, this is coming after the house; the height is different because here we are talking about this side-looking radar system, So, the distance between the transmitter and reflecting objects can be estimated using measured signal echoes; measured signal echoes are basically your backscattered energy, Since the energy propagates at the velocity of light (c), the slant range (SR) to any object can be calculated using this formula. So, here ct is divided by 2; c is the speed of light, and t is your time. It is divided by 2, and the factor 2 is used because we are measuring the pulse to travel both the distance to and from the target. Remember, this slant range is used to denote this distance. So, the term "range" is used for the distance. So, here I hope you understand that $SR = ct/2$ and t by 2 is basically the time it takes to travel to and fro from the sensor to the target and then back to the sensor, Sensor Slant Range: Here you can understand this; you have this particular airborne sensor that is available to this particular aircraft.

Here, this is the horizontal plane; you can consider this as the flight path, and this is the surface, this is the surface, so you can draw a tangent here. Let us say this is the tangent. Now, if you just draw a pendulum from here, it will reach this particular surface; it will touch this particular surface, which is vertically beneath this aircraft, So, this is called nadir. So, this is nadir. Now, since we are talking about the slant range, this particular microwave sensor is looking at the ground at a certain angle. So, this is the zenith. So, from here, you can measure the angle. So, what we will do is put a middle line here, So, this is the slant range, this particular point, which is available here, will basically become the center of your image.

I hope this is a clear, very simple concept, but it is very important to understand, Now, we will talk about a few viewing geometries that are involved in microwave remote sensing because we have to be very, very careful, and we should have all the information about the viewing geometry to calibrate and characterize the microwave remote sensing data, So, similar to optical system. The platform travels forward in the flight direction A with the nadir B, which is directly beneath the platform. Remember the nadir we have discussed: if you have a pendulum hanging vertically downward, it will touch the ground somewhere, and it does not matter at what angle your sensor is active, but this will become your nadir and here you have a center line, which is your slant range. So, here is what it says: similar to an optical system, the platform travels forward in the flight direction A, with the nadir B directly beneath the platform.

Microwave Remote Sensing: Viewing Geometry

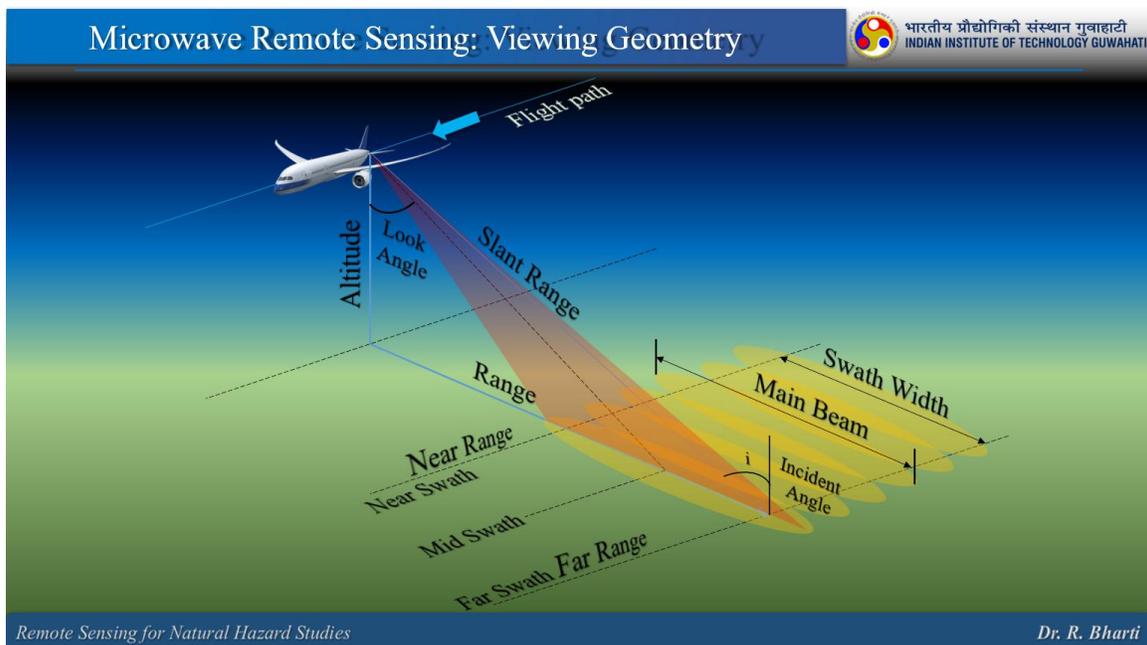


- Similar to optical systems, the platform travels forward in the **flight direction (A)** with the **nadir (B) directly beneath the platform**.
- The microwave beam is transmitted obliquely at right angles to the direction of flight illuminating a **swath (C)** which is **offset from nadir**.
- **Range (D)** refers to the **across-track dimension perpendicular to the flight direction**, while **azimuth (E)** refers to the **along-track dimension parallel to the flight direction**.

So, here this is the A, and this is the B, which is the nadir point, and now this particular sensor is capturing this particular area, the microwave beam is transmitted obliquely at a right angle to the direction of the flight, illuminating a swath C; this is swath C, which is

offset from nadir. Offset means it has an offset; it is not at the nadir. Range D refers to the across-track dimension perpendicular to the flight direction, while azimuth E refers to the along-track dimension parallel to the flight direction. So, this is E, and this is D, So, E is the along track dimension and D is the across track; this is across track. Now, we will have some nomenclature that is given to these geometries, and that we should remember if you are willing to work in the microwave remote sensing domain.

So, this is a very, very important concept, So, let us say that when the flight is moving in this direction and it is looking at the ground at some angle from the nadir—nadir will be here, remember—so the angle that it makes with the vertical line will be the incident angle, And then, from the nadir, how much angle it has deviated is the look angle, So, the look angle is here, and the incident angle is here, and the depression is with respect to the horizontal line drawn along with this flight or with this sensor. So this is your angle on depression. So it is very simple: depression angle, look angle, and then incident angle. Now we will examine these terms in detail. The first one is the depression angle, So, you see the angle between the horizontal and a radar ray's path.



So, this is the depression angle, and this is the radar ray path, I hope you remember the previous slides. Then you have the look angle; you see it is getting highlighted here. Be careful with this slide, So, you can see it is getting highlighted. So, it is with respect to the nadir look angle. So, the angle between the vertical and a ray path. Then the third one is the incident angle. So, here if you draw a perpendicular on top of this surface with respect to that, what angle does it make the beam So, that is the incident angle. So, the angle between the radar beam and the ground surface is called the incident angle. Then comes the azimuth you see here. Notice that this is the azimuth; then comes the near range.

So, the portion of the image swath is closest to the nadir track. Now, this is towards the nadir, this is nadir. So, this is the closest point to the nadir track, So, this is very close to the nadir, So, this is called the near range. You see, now this is far range. So, the far range is basically the farthest point from the nadir track, Then, this is the slant range that we have already seen in the previous slide.

So, the radial line of sight distance between the radar and each target is on the surface. So, that is your slant range. Now comes the beam width: what is the width of the beam that is being used in this particular measurement? Then the ground range distance is the true horizontal distance along the ground corresponding to each point measured in slant range. So, this is ground range distance. I hope all this nomenclature that we are using in microwave remote sensing is clear to you, The same thing has been plotted here for better understanding; you can see this is the flight path that is looking at this particular ground.

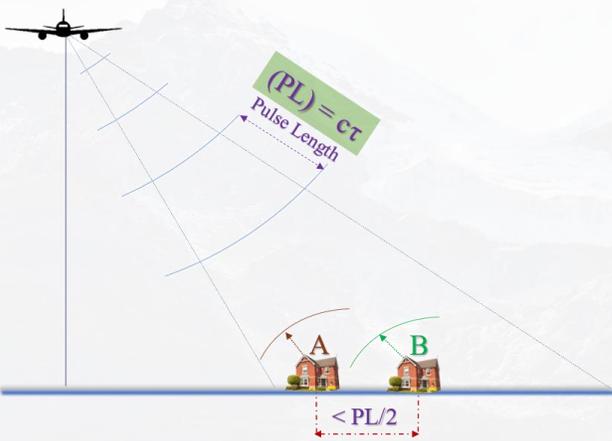
This is the swath width, and this is how it is moving; the first measurement was taken, and then it has moved to this. Then to here, and now it is here, I hope this is clear. So, now with the perpendicular on the ground, the beam's slant range is making the angle I , which is the incident angle, and from the flight path, it is making the angle called the depression angle from the nadir. If this is the nadir, then this is called the look angle, And the altitude at which this spacecraft or aircraft is flying is the height of the sensor above the MSL, and here you can see the mid swath, far swath, or near range; this is the near swath. So, I hope you have understood all this nomenclature.

Microwave Remote Sensing: Range Resolution



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The ability of a radar to distinguish between two targets in the range direction...



Range Resolution depends on the length of pulse (PL).

If, $A-B < PL/2$: A & B can't be resolved!

For two different object, it is necessary that the antenna should receive the separate backscatter signals from both objects.

If there is any overlap between the signals, resultant images will be blurred.

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Now, you will understand the range resolution, the ability of a range to distinguish between two targets in the range direction; that is range resolution. So, here you can see that this

particular aircraft is illuminating this area with these pulses. All these are pulses released at a particular interval, and they have a fixed width; the width of the pulses is also fixed. So, what is happening here is the distance between the first and the second pulse, which is called pulse length. So, PL is equal to $c\tau$, or you can say c tau, So, this is what we are using here. So, now it is interacting with these objects A and B, and if A is near, it is close to the nadir, it will interact first, and then it will start releasing this backscattered energy, So, the range resolution depends on the length of the pulse. So, here is the length of the pulse that is very, very important if A-B, if the distance between A and B is less than $PL/2$. This is PL , and here this is A-B. So, this distance is less than PL by 2. Why PL by 2? Because again we are using this factor of 2, So, if it is less than that, we will not be able to identify these two objects separately in our image, but if A minus B, or if the distance between A and B is greater than PL by 2, then we will be able to distinguish them in our microwave image. For 2 different objects, it is necessary that the antenna receives the separate backscattered signals from both objects. So, here you can see both are giving you separate signals. So, in this case, we will be able to resolve them into two objects. If they are giving only one signal correctly, we will not be able to separate them in our image, or we will not be able to identify them in our image correctly. If there is any overlap, the resultant image will be blurred. Now, let us see a scenario where these two have separate signals, but somehow they are getting overlapped. So, in this case, what will happen is that the image will be blurred. So, this is not advisable, but we cannot do it; it all depends upon the pulse length and the distance between A and B. That is very, very important when we talk about the range resolution.

Microwave Remote Sensing: *Range Resolution & Ground Resolution*



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Pulse Length (PL) = $c\tau$
 where $c = 3 \times 10^8$ m/s

The complete object is imaged/ distinguishable if the slant separation between the objects is greater than $c\tau/2$

Therefore, $R_{sr} = \frac{c\tau}{2}$

and Ground Resolution (R_{gr}) = $\frac{c\tau}{2 \cos \beta}$

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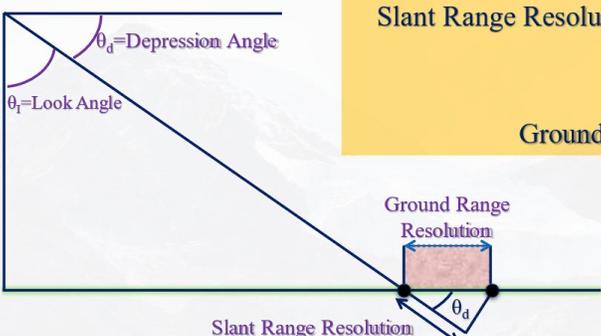
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Now, what are the range resolution and the ground resolution? So, you have understood range resolution; now we will talk about ground resolution. So here you see, first

understand this figure; this is a microwave sensor that is looking at this particular ground where we have all these objects: 1, 2, 3, and 4 objects, So, all of them are having separate incoming radiation. But depending on their distance, whether we will be able to identify them in our image or not will be decided by the pulse length. So, the pulse length, the pl, is equal to ct , where c is equal to 3 times 10 to the power of 8 meters per second, which is the speed of light, The complete object is imaged or distinguishable if the slant separation between the objects is greater than ct by 2.

Microwave Remote Sensing: SLARR


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Slant Range Resolution

Ground Range Resolution

Slant Range Resolution doesn't change with the distance from the aircraft,

but

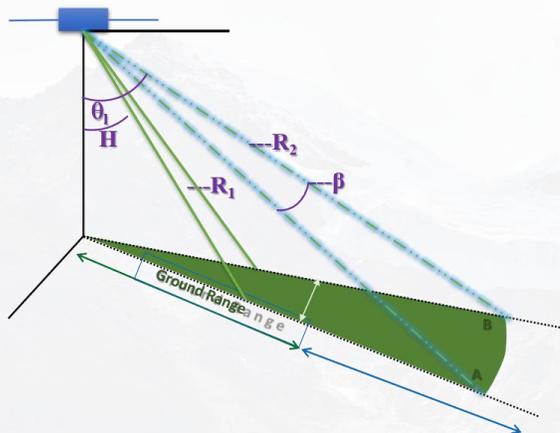
Ground Range Resolution does.

“Ground Range Resolution becomes smaller with the increase in Slant Range Resolution.”

When the depression angle effect is considered, the ground resolution in the range direction (R_r) can be estimated using

$$R_r = \frac{c\tau}{2 \cos \theta_d} \quad \text{where, } \tau \text{ is the pulse duration}$$

So, therefore, the range resolution R_{sr} is cut by 2, and the ground resolution R_{gr} is cut by $2 \cos \beta$, So, here it is very, very important to identify what ground resolution my data has, or what my sensor has, or what range resolution it has, now you see this particular image where the object is present. So, in this case, we have considered a bigger object, and here is your sensor, which is illuminating this particular target with this beam. So, this is your depression angle, this is your look angle; if you draw a vertical line here, that will be your incident angle, So, the slant range resolution does not change with the distance from the aircraft, but the ground resolution or the ground range resolution does. Because slant range resolution does not change, it does not matter what the distance is from the target to the aircraft, but the ground range resolution will change accordingly. I hope this is clear: ground range resolution becomes smaller with the increase in slant range resolution.



$$R_a = R \cdot \beta$$

where, $\beta = \text{Azimuth beam width}$

$$\beta = \lambda / L$$

$L = \text{Length of antenna}$

$$R_a = R \cdot \lambda / L$$

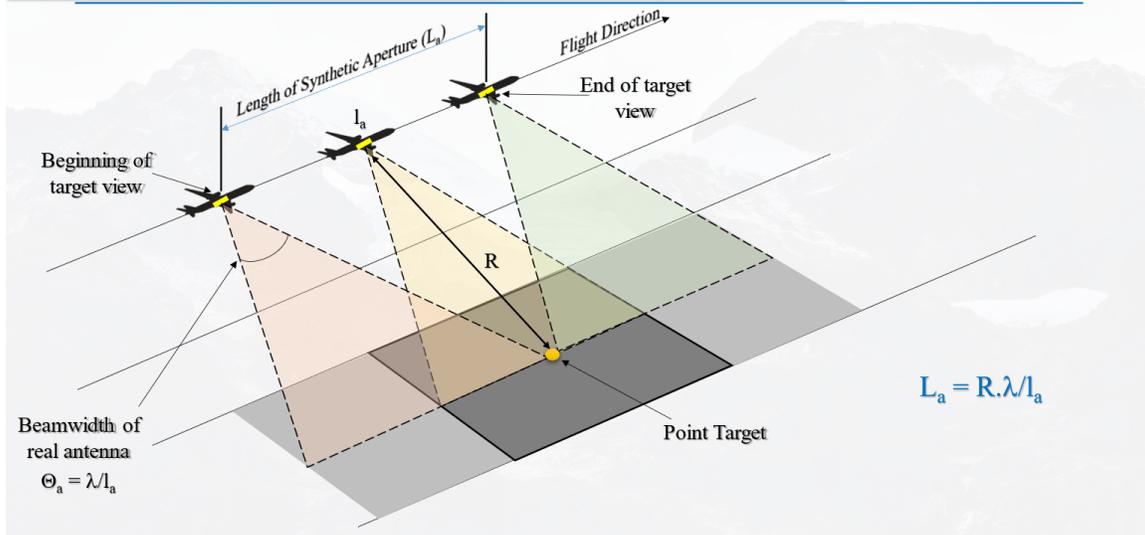
where, $R = H / \cos \theta_1$

Estimate R_a value when $H = 16 \text{ km}$, $\theta_1 = 25^\circ$, $\lambda = 5.666 \text{ cm}$ and $L = 15 \text{ m}$?

When the depression angle effect is considered, the ground resolution in the range direction R_r can be estimated using this formula, where t is the pulse duration; this is very, very important. Now, we will understand what azimuth resolution is because we have seen the azimuth, but what is the azimuth resolution? So, here you can see that R_a is equal to R times β , where β is the azimuth beam width, and here β is basically the wavelength divided by L , where L is the length of the antenna. So now we can modify this equation. And here, R_a is equal to R times wavelength divided by the length of the antenna, and R is equal to H divided by $\cos(\theta_1)$. Now, what is $\cos(\theta_1)$? So, in this equation, $\cos \theta_1$ is here, So, this is θ_1 , and H is here; this is H , So, estimate the R_a value when H is equal to 16 kilometers. So, you can practice this by trying to solve this numerical estimate of the R_a value when H is equal to 16 kilometer.

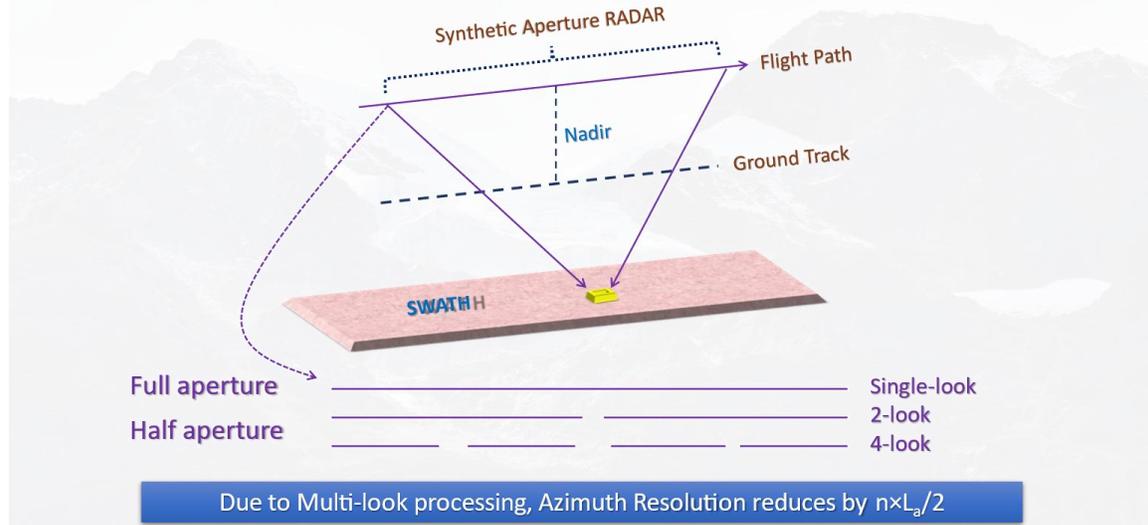
The height of this is 16-kilometer, θ_1 is 25 degrees; this is basically 25 degrees, and λ is 5.66 centimeters. This λ is 5.66 centimeters, and L is 15 meters; the length of the antenna is 15 meters, so then you calculate the R_a value; you need to solve this, So, this is one example of how we utilize this concept to calculate the range azimuth correctly. Now, we will learn about synthetic aperture radar.

Synthetic Aperture RADAR



Remote Sensing for Natural Hazard Studies Richards, John Alan Remote sensing with imaging radar, Vol. 1, Berlin: Springer, 2000, Dr. R. Bharti

So, the radar antenna can be synthesized electronically into a longer synthetic length. I explained this in the previous slides: we have SAR, which is synthetic aperture radar, where the antenna length is not real; it is synthesized electronically to a longer length. So, that helps us to keep our payloads lighter and that has other benefits also. Synthetic aperture radar, which can be airborne or spaceborne, could collect data over a large distance as it is collected from a physically long antenna, So, here we consider this to be a real aperture radar. So, this is, let us say, 1 meter, but electronically it will be synthesized to, let us say, 11-meter, 15-meter. So, it has a calculation. So, based on that, you can calculate what synthetic length you will have with 1 meter of real aperture radars, this can provide you with more information about how we measure using this synthetic aperture radar. So, here you can see this is the first scene that is being generated, So, this particular airborne microwave sensor is looking at this particular ground with this beam width. So, the beam width of the real antenna. But when it moves to this particular position, it measures that particular area. Then, when it reaches this, it measures this particular area.

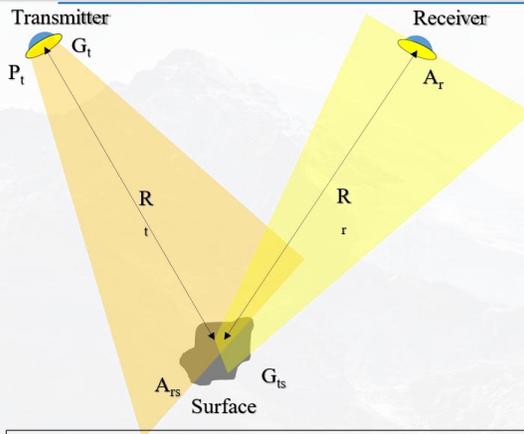


So, here it is illuminating the target, but measurement is happening here, here, here. , and this is called the length of the synthetic aperture. So, this is L_a , and this is the flight direction. Now, here you see for this particular target how many images we have and how many times we have measured. So, we had 3 measurements: 1, 2, and 3 from 3 different positions where this particular object is being captured.

So, this is the point target; there is one example. Now, with this, we will try to understand how the synthetic aperture radar works, and then how it behaves or how it provides information about the target. So, just to make sure that you follow me, this is the flight direction, this is the end of the target, this is the first, this is the second, and this is the third, This is the point target, and here you can calculate the L_a , which is the length of the synthetic aperture radar, assuming this is a particular area that has a particular target that needs to be captured in our microwave remote sensing data, So, the synthetic aperture radar is available here, and this is the nadir if you draw this. So, this will come here, So, this is the ground track. So, this is the flight path, and from these three locations, you are trying to measure this or trying to capture this particular object, and this is the swath, So, if we talk about the full aperture radar, we have a single look; we can have 2 measurements.

So, this is a look. Then we have 1, 2, 3, and 4. So, this is a 4 loop. So, this is full aperture; these two are half aperture, So, due to multi-loop processing, azimuth resolution was reduced by n to L_a by 2. So, this is very, very important. So, due to multi-loop processing, the azimuth resolution referred to in the previous slides will allow you to correlate them. So, this is an example of a single look image you see from one measurement of how this particular target focuses on this; here you see this kind of feature is present.

Microwave Remote Sensing: RADAR Equation

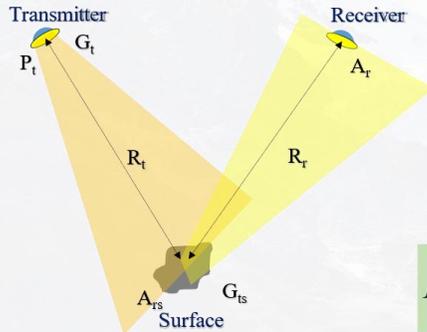


- P_t = Power transmitted towards the target,
- G_t = Gain of the antenna in the direction of the target,
- R = Range distance,
- σ = Radar cross section or effective scattering area of the target,
- A_r = Effective area of the receiving antenna.

$$\text{Power Received} = (P_t G_t / 4\pi R^2: \text{Power per unit area at target}) \times (\sigma: \text{Effective scattering area of the target}) \times (1/4\pi R^2: \text{Spreading loss of reradiated signal}) \times (A_r: \text{Effective antenna receiving area}).$$

So, keep on watching this particular object; this is with 2, earlier it was single. Look, this is with 2, this is with 4, and this is with 5. So, you can see how the image appears when you change the look; this is the 10 looks. So, this is 10 looks now you see your target. So, this is just an example of how synthetic aperture radar works and how the look improves, or what your objective is and how you actually want to utilize this information in your study. Now we will talk about this radar equation. So, here the power received can be calculated using the power per unit area at the target, the effective scattering area of the target, and the spreading loss of the reradiated signal. An effective antenna receiving area is. So, here there are different terms which are explained here: P_t is the power transmitted towards the target, and G_t is the gain of the antenna in the direction of the target.

Power Received = $(P_t G_t / 4\pi R^2$: Power per unit area at target) \times (σ : Effective scattering area of the target) \times ($1/4\pi R^2$: Spreading loss of reradiated signal) \times (A_r : Effective antenna receiving area).



P_t is the power transmitted towards the target, G_t is the gain of the antenna in the direction of the target, R is the range distance, σ is radar cross section or effective scattering area of the target, and A_r is the effective area of the receiving antenna.

$$A_r = \lambda^2 G_r / 4\pi$$

$$P_r = P_t G_t \frac{1}{4\pi R^2} \sigma \frac{1}{4\pi R^2} A_r \quad \Bigg| \quad P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

where $G_t = G_r = G$ for a single antenna system

So, the gain will be provided by the space agency that is launching this particular satellite; R is range distance, and σ is the radar cross section or effective scattering area of the target. A_r is the effective area of the receiving antenna, So, all of these are used here to calculate the power received by the remote sensing sensor in the microwave domain. Furthermore, it is explained that both the transmitter and receiver are here. So the P_t is the power transmitted to the target, G_t is the gain of the antenna in the direction of the target, R is the range distance, and σ is the radar cross section or the effective scattering area of the target. And A_r is the effective area of the receiving antenna, so then we are calculating the power received, and based on that, it is getting modified, and finally, we are using this to calculate the P_r . Here, the G_t is equal to G_r , which is equal to G . For a single antenna system, this is important to note. Now we will see how we can calculate the backscattering coefficient, which is very important in microwave remote sensing. So, the backscattering coefficient is defined as the amount of backscatter per unit area. So we call it the sigma naught value. The sigma naught is equal to σ divided by A , and it depends on the target and the system parameters.

Backscattering coefficient is defined as the amount of backscatter per unit area:

$$\sigma^0 = \frac{\sigma}{A}$$

It depends on:

- 1) The target (roughness, geometry, moisture content), and
- 2) The system parameters (wavelength, look angle, polarization).

Now, the roughness, geometry, and moisture content will be controlling this target parameter, as well as the wavelength, look angle, and polarization: remember HH, HV, VV, or VH, the like polarization, or cross polarization. So, those things will be here. To define the target and the system parameter, they will be controlling this sigma naught value. Then it is very important to characterize our data: what is the strength of the signal, whether it has noise, and what is the intensity of the noise in our data. So, we calculate the signal-to-noise ratio (SNR), which is very commonly used in different areas.

Signal to Noise Ratio (SNR):

$$SNR = \frac{P_r}{P_n}$$

where,

$$\text{Thermal Noise } (P_n) = kBT$$

K = Boltzmann Constant

B = Bandwidth

T = Receiver's Noise Temperature

$$P_r = \frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 R^4}$$

So, in the signal-to-noise ratio here, we calculate the thermal noise P_n ; kBT is used, where k is equal to the Boltzmann constant, B is the bandwidth, and T is the receiver's noise temperature. So, here this is used to calculate the signal-to-noise ratio. And then this PR , if you remember the PR we are using. So, the PR will be referred to here.

So, in this equation, the P_r can be calculated using this. P_n will be calculated using kBT , where K is the Boltzmann constant, B is the bandwidth, and T is the receiver's noise temperature. So, I will continue this microwave remote sensing concept in my next lecture, which is part 2 of lecture 6.

Thank you very much.