Remote Sensing: Principles and Applications

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Lecture-45
Active Microwave Remote Sensing-Radar-Part-2

Hello everyone, welcome to the next lecture in the topic of active microwave remote sensing, where we are discussing about the imaging radar. In the last lecture, we discussed how radar works, its principle and also we got introduced to few terms. In this lecture, we will discuss further in knowing more about the imaging radar systems.

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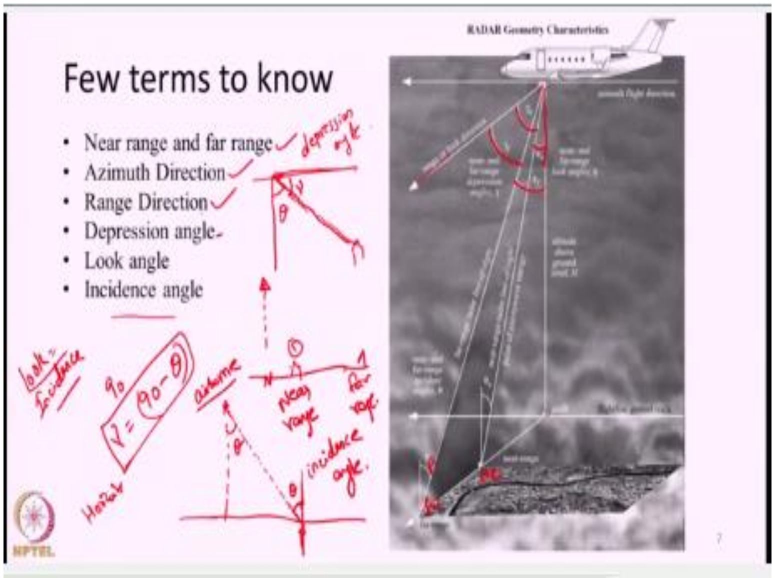

Few terms to know

- Near range and far range
- Azimuth Direction
- Range Direction
- Depression angle
- Look angle
- Incidence angle

So, last class we defined few terms like azimuth direction, range direction, near range, far range, depression angle, look angle and incidence angle. So, basically with respect to all these we will be defining our image acquisition characteristics. And based on these look angle and image angle, the terrain also will look different to us. In the last lecture I told you that the radar basically measures the distance between the source and the target and it measures the incoming power in some form. One more important thing to understand in microwave remote sensing is we also measure polarization. Because in microwave, polarization of electromagnetic radiation will give us additional information about the object of interest in the terrain.

So, normally most of the active microwave systems will record the incoming radiation in different, different polarizations. So, polarization is nothing but the direction in which the electric field of the EMR is oriented, we have seen it in detail in the earliest classes. We have also seen that the polarization can be horizontal, vertical, circular, elliptical in different directions.

But normally in microwave systems, we use horizontal polarization or vertical polarization or both. So, let us say we have a system that can transmit electromagnetic radiation only in horizontal polarization.

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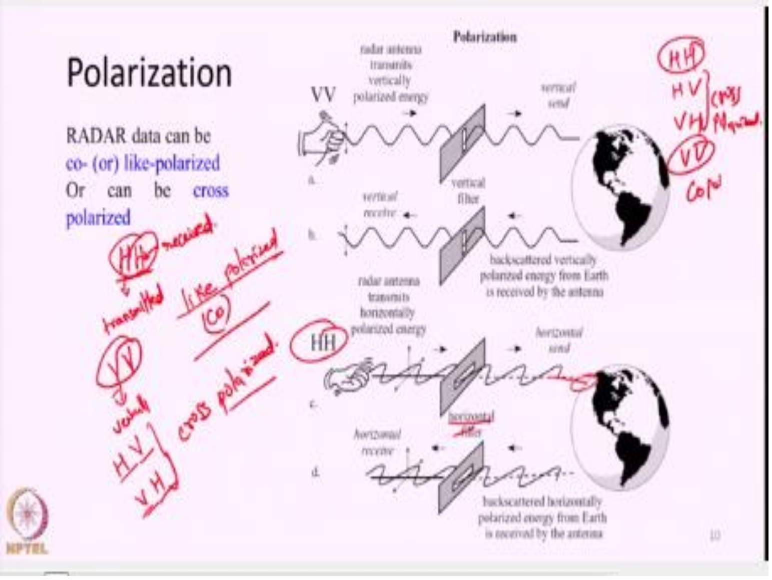

Polarization

RADAR data can be co- (or) like-polarized Or can be cross polarized

So, the system is going to transmit only in horizontal polarization, we indicate with the label of H. Then this system will move towards the object, will get reflected and come back. Let us say the system is also going to receive only EMR that is horizontally polarized. So, the first H indicates the polarization of the wave that is transmitted. The second H indicates the polarization of the wave that is received.

So, this HH indicates the system transmitted microwaves that are horizontally polarized and that horizontally polarized waves will go to the object of earth surface, it will interact, some may preserve the orientation, some may change the orientation that can happen. And whatever the total signals that came back, the system allowed only the horizontally polarized light. So, this system is receiving only the horizontal polarized EMR and hence we again label it as HH polarization.

Similarly, some systems can be VV, transmit vertically polarized signal, receive vertically polarized signal alone. So, such systems in which both the transmitted signal and the received signal are having the same polarization, we call them as like polarized or co-polarized**.** That is, like polarize means same polarization used for transmission as well as reception. But certain systems are capable of transmitting in one polarization and receiving the wave that are coming in the other polarization HV or VH, transmission is H, reception is V, transmission is V, reception is H, such systems are called cross polarized**.**

So, essentially if you combine, this microwave systems can operate at HH, HV, VH, VV. So, these are co-polarized and these are cross polarized. So, some systems have the capability of measuring all these, like transmitting both H and V; receive in both H and V, giving rise to 4 different images. Similar to optical remote sensing, each wavelength band we get one image, say 0.4 to 0.5 one band, we get one image, 0.5 to 0.6 one band one images. In microwave, objects will look different in different, different polarizations and hence with the wavelength remaining the same but because of this change in polarization of the transmitted and received signals, we will get one image per polarization, HH we will have 1 image, HV polarization we may have another image. So, some systems that are quadruple polarization which can have all these 4 combinations that I just listed. So, it can produce 4 images with the same wavelength, where each image represents how objects look when illuminated by radar with different polarization and when the reception happens in different polarization HH, HV, VH and VV.

So, with the same given wavelength, we can have more than 1 image in a radar system acquired with different, different polarizations. And each polarized image can give us different information about the land surface and also polarimetric SAR data processing will provide additional information. That is a whole new research field where a lot of active researchers are working on understanding how different polarization helps us in understanding more about the earth system, earth surface and it is properties.

So, normally whenever we come across the radar image, we will also have to look at which polarization it is, whether it is HH polarization, HV, VH or VV. The first letter indicates the polarization with which the wave was transmitted; second letter indicates the polarization with which the wave was received back.

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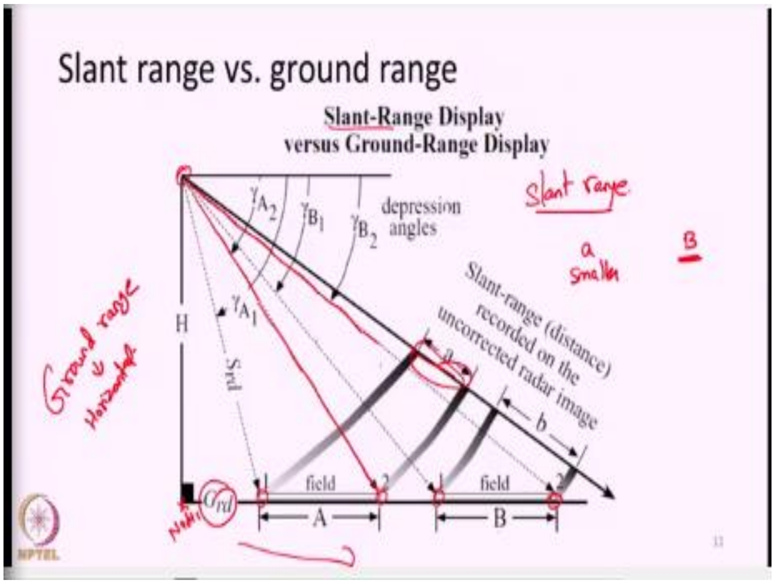

Slant range vs. ground range

We will now go little deeper and try to understand the working principle of this side looking radar and especially the real aperture radar. So, first we will understand the real aperture radar concepts and then we will move on to synthetic aperture radar briefly and try to understand the similarities and differences between them. So, I told you a radar image basically works based on measuring the distance.

Assume flight is flying and it calculates the distance between different objects on the earth surface from this particular point. The distance is actually measured what is known as a slant range that is the radar is looking at some angle away from the nadir. So, the line joining the antenna and any point on the ground surface is measured along the line in this particular direction.

So, the distance is not measured with respect to the horizontal, but the distance measured is with respect to the slant line that connects the antenna with every different point on the ground surface. So, the radar essentially measures the slant range distance or slant range. Normally what we will need for our applications is, the distance of features away from the radar acquisition system in a horizontal plane. We will be interested in measuring the distance of each feature from the nadir point horizontally, and we call it as ground range. So, the ground range is nothing but the horizontal distance of different features from the nadir point of the imaging radar system but the radar will measure only the slant range.

Because of this slant range image acquisition, the images or objects that are in the near range will be compressed in compared to the objects that are in the far range. Assume we have two features A and B, 2 fields, both of them have the same linear dimensions. But since A is in near range and B is in far range, A will appear compressed in the radar image in comparison with B.

So, we may think A as a smaller field with smaller dimensions when we compare with field B, this can happen because of this slant range measurement. But if we convert the slant range to ground range, if we calculate the true horizontal distance of each field, then we will realize, both of the field have the same linear dimensions. So, this is a major difference between how a normal photographs are taken and how radar imaging system works. So, for a flat horizontal surface, it is always easy to convert this slant range to ground range using simple trigonometry.

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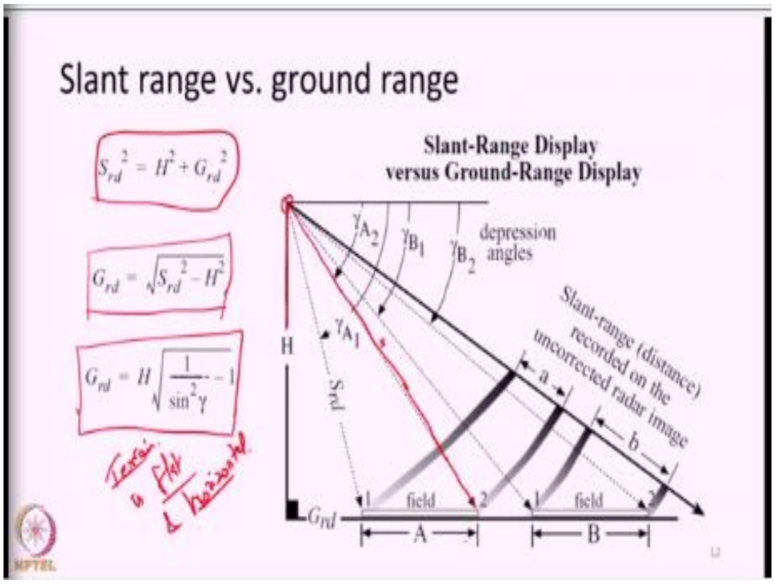

Slant range vs. ground range

$$S_{rd}^2 = H^2 + G_{rd}^2$$

$$G_{rd} = \sqrt{S_{rd}^2 - H^2}$$

$$G_{rd} = H\sqrt{\frac{1}{\sin^2\gamma} - 1}$$

Terrain is Flat & horizontal

Say this is the slant range that is measured by the radar system along this line. So, for example here field A point 2, the distance will be measured from this antenna will be along this line, what is the length of this line, that will be recorded as the slant range distance. So, in order to convert this slant range distance to ground range distance if we know this flying height, it is always easy to convert using simple trigonometry.

So, using basic Pythagoras theorem, we can write it as

$$(\text{slant range})^2 = (\text{ground range})^2 + (\text{height of the platform})^2.$$

On rearranging this, we can calculate the ground range distance, it is a very simple trigonometry principle. Also using this depression angle or the look angle, we can estimate the ground range distance. So, these equations assume that terrain is flat and horizontal. Most of the times the terrain may not be flat giving rise to some complexities in the image acquired and there we may have to do correction using a digital elevation models. For each pixel on the terrain x, y, we need to have the elevation information z using which we can correct the image geometry distortions.

So, normally the radar images will be acquired and the distances will be measured in the slant range. And for our purposes we may have to convert that image to ground range in order to get a proper representation of terrain features. This slant range image acquisition also causes lot of distortions in the image when the surface is not flat and it has some topographic features within it.

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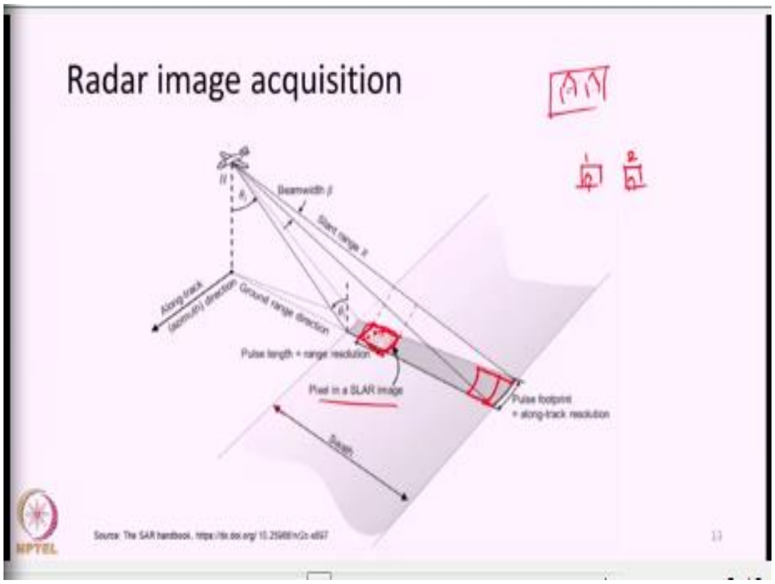

Radar image acquisition

Source: The SAR handbook. https://dx.doi.org/10.25966/nr2c-s697

So, how a pixel is defined in radar? What is the concept of GIFOV in radar image acquisition? We know how a GIFOV is formed in our normal visible or thermal remote sensing**.** Say whatever the sensor dimension, physical dimension of the detector is based on the orbital height; it will have a small area projected on the ground. So, whatever the energy within that particular ground will be recorded in the imaging system as one single unit, that we call as GIFOV**.** Here the concept is a bit different. So, the formation of GIFOV, one single pixel element is not a straightforward task, it forms in 2 dimensions. In across track direction that is the range direction and azimuth direction, this will differ. So, in the range direction we will be forming image and this is one single pixel in a side looking airborne radar image SLAR image. So, this pixel will be keep on varying. So, the pixel will have a different dimension in the range direction and a different dimension in the azimuth direction and the total angle for which the radar beam transmits will define the swath width. So, the entire footprint covered by this radar beam in the across track direction will define the swath, whereas each pixel in the range direction azimuth direction will be defined independently based on 2 different properties of the radar system. So, the spatial resolution or the pixel size in a radar image is defined differently in 2 directions, the range direction and the azimuth direction.

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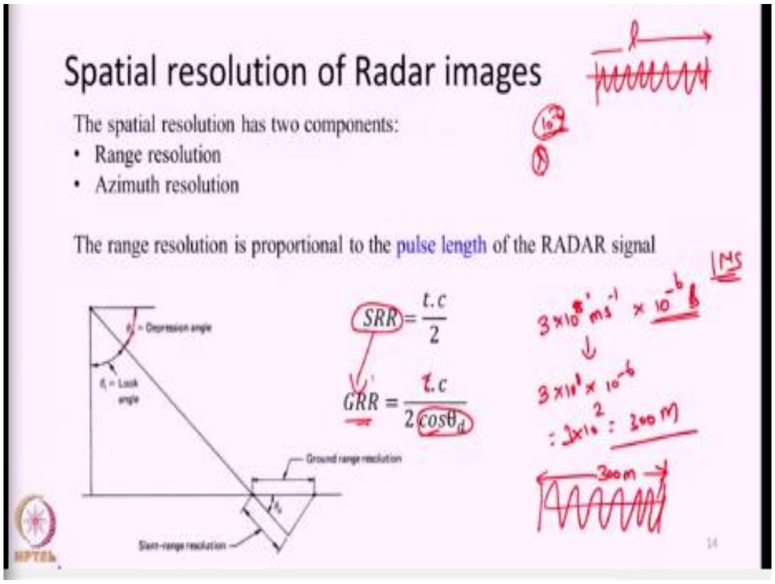

Spatial resolution of Radar images

The spatial resolution has two components:

- Range resolution
- Azimuth resolution

The range resolution is proportional to the pulse length of the RADAR signal

$$SRR = \frac{t.c}{2}$$

$$GRR = \frac{t.c}{2\cos\theta_d}$$

$3\times10^8 ms^{-1} \times 10^{-6}$ s

1MS

$3\times10^8\times10^{-6}$

$= 3\times10^2 = 300$ M

So, we call it as range resolution and azimuth resolution. Range resolution is nothing but the dimension of each pixel in the range direction. When satellite is moving and acquiring image in this particular direction, the length of each pixel in the range direction is called as range resolution. Similarly, the pixel size in horizontal or in the azimuth direction is called as azimuth resolution. So, whatever be the features present within the same pixel element defined by the range and azimuth resolution that will produce one single power return or that will be recorded as one single power unit. So, most likely, the features present within this single resolution element may not be resolved independently. Say we have 2 towers within the same pixel element, we may not be able to see those 2 towers separately, we may think there is one tower only present there, it can happen.

But if there are 2 pixels, and if these 2 towers are located in 2 different pixels, then we can think of, this is tower 1, this is tower 2, there are 2 towers, it is easy for us. So, this is what the pixel size or the dimension of the pixel in both the azimuth and range direction will influence whether we are able to resolve or distinguish 2 features on the ground or not. First we will discuss about the pixel size or the resolution of the radar system in the range direction, what we call it as the range resolution. In range resolution 2 objects will be resolved as 2 different features if they are separated by a distance of at least half of their pulse length. First let us see about pulse length. Each radar system will send microwave in terms of pulses for a certain duration, say for 10^{-6} seconds and the radar transmits the wave. So, each microwave wave will have a certain length based on the time for which it is transmitted because it is not wavelength. So, pulse length is based on the time of transmission of the radar antenna and each pulse will have a certain distance on the ground that is called as pulse length.

Let us assume the velocity is 3×10^{8} m/s and let us say a system transmits microwave for 10^{-6} seconds, that is 1 µs. So, the total length of the pulse that will be transmitted is $3\times10^{8}\times10^{-6}$ that is equal to 3×10^{2} that is 300 meters. That is, the length for which the microwave got transmitted is 300 meters and thus this pulse has a length of 300 meters. So, the time duration for which the pulse is transmitted will determine the pulse length. If two objects have difference in distance more than half of the pulse length, then they will be resolved as 2 different features.

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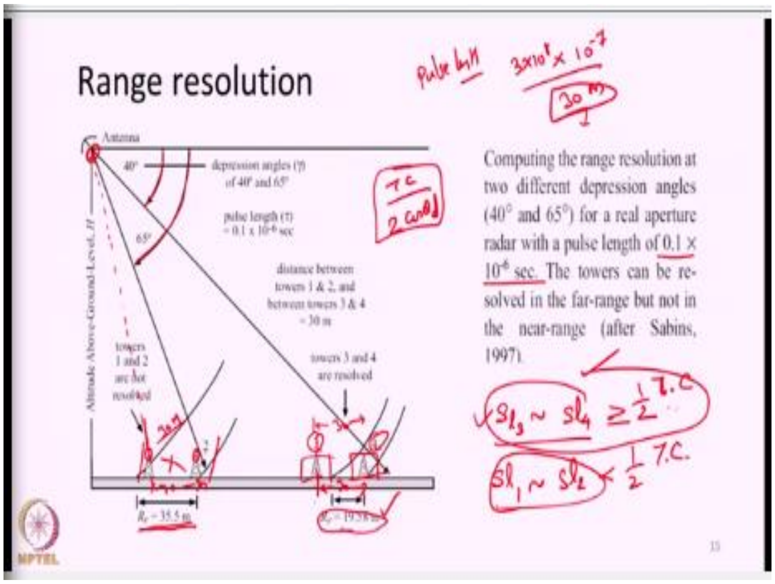

Range resolution

Pulse length $3\times10^{8}\times10^{-7}$ $\boxed{30\text{ m}}$

$\boxed{\frac{\tau c}{2\cos\theta}}$

Computing the range resolution at two different depression angles (40° and 65°) for a real aperture radar with a pulse length of 0.1 × 10^{-6} sec. The towers can be resolved in the far-range but not in the near-range (after Sabins, 1997).

$sl_3 \sim sl_4 \geq \frac{1}{2}\tau.c$

$sl_1 \sim sl_2 < \frac{1}{2}\tau.c$

Say here we have 2 towers, let us say tower 3 and 4, horizontally on ground they are separated by a distance of 30 meters. The radar system measures slant range to tower 4 as distance SL_4 and measures slant range to tower 3 as distance $SL_{3.}$ If this difference is more than half of the pulse length, then these 2 towers will be resolved independently or labeled as 2 different features.

On the other hand if the distance between them is less than half of the pulse length, then the pulse that is transmitted by this radar antenna reaches tower 1and will be reflected back. So, the 300 meter pulse has to completely reflected back by this object. In the same time the pulse would have reached here and even before the 300 meter pulse got reflected from this tower 1. The signal from tower 2 will also be beginning to reach the system. That is the signal or the reflected microwave pulse from both tower 1 and 2 will have some time of overlap in the system. If that happens, then these 2 features will be recorded as one single feature.

Radar will think it as one single feature if signals are coming at very short time intervals. So, the condition we have seen is based on slant range distance, if the slant range distance between 2 features is more than half of the pulse length, 2 features will be imaged independently. But when we form pixels in the image or when we try to understand the distance between features, we always think in ground range distance that is the horizontal distance between the nadir point and the features on the ground. Looking at that in order to convert the slant range to ground range, we can use the look angle formula.

$$Ground\ Range = \frac{t\ c}{2\cos\theta_d}$$

Where θ_d is the depression angle. So, using this formula we can convert the slant range to ground range. If we do this, we will realize the same slant range distance, but the ground range keeps on changing because of this**.** Let us go back to the same example. tower 3 and 4 and tower 1 and 2. If these 2 towers are horizontally separated only by a distance of 19.58 meters, they will satisfy this criteria. The difference in slant range distance between them will be more than or equal to half of the pulse length. But in near range if these 2 objects are separated by a horizontal distance of close to 36 meters, then only they will satisfy this criteria. So, if two objects are differing in distance by half of pulse length along the slant range, they will be image separately. But in order to satisfy that criterion, the actual horizontal distance between them should be really far apart, that is if objects are closer to each other, they will be most likely be imaged as one single feature. In order to convert this slant range resolution to ground range resolution, in this example we have 2 towers 1 2, 3 4. So, for measuring tower 1 and 2, the depression angle is 65 degrees, that means they are at the near range. For measuring tower 3 and 4 the average depression angle is 40 degrees between them. A real aperture radar is working with a pulse length of 0.1 microsecond, 0.1×10^{-6} seconds.

So, the pulse length is equal to the actual distance between them which is equal to $C_3\times10^8\times$(time duration). So, the actual length of the pulse is 30 meters and hence both of the towers are separated by horizontal distance of 30 meters. So, just by using this formula $tc/2\cos\theta_d$, we can calculate for towers 1 and 2 to be resolved independently as 2 separate fingers. Then the horizontal distance between them should be at least 35.5 meters then only this condition will be satisfied. The slant range distance between them is more than half of pulse length. But here in our example, we see towers 1 and 2 are separated by horizontal distance of 30 meters. Hence, most likely they will be forming a part of the same pixel and they will be not resolved independently.

On the other hand in the far range, 2 towers are again separated by 30 meter horizontal distance. Using the same formula, the ground range distance between them comes to 19.58 meters. That means, these two towers 3 and 4 will be resolved as 2 separate features if the horizontal distance between them is more than 19.58 meters. So, this indicates that the pixel size along the range direction varies, if two objects are separated by good distance in the near range, then only they will be resolved. But in the far range away from the image acquisition system, objects even which are closely spaced with each other will be imaged separately. So, this will define the resolution of the radar system in the range direction.

So, in the next class, we will look at the resolution of the radar system in the azimuth direction and we will also see how the pixel size will vary, as the distance is moved. With this we end this particular lecture.

Thank you very much.