Remote Sensing: Principles and Applications
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Lecture-46
Active Microwave Remote Sensing-Radar-Part-3

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. In the last lecture, we were discussing about the concepts related to imaging radar or active microwave remote sensing. Last class, we discussed about the slant range nature of radar image acquisition where all the distances are measured in terms of the slant range, the line connecting the antenna and the ground point rather than talking in terms of horizontal distances.

Also, we started discussing about the resolution concepts of imaging radar, especially the real aperture radar. So, in imaging radar, the resolution has to be defined separately in 2 directions, in range direction and azimuth direction. So, yesterday we discussed about how the resolution will be in range direction which is determined by the pulse length of the radar system.

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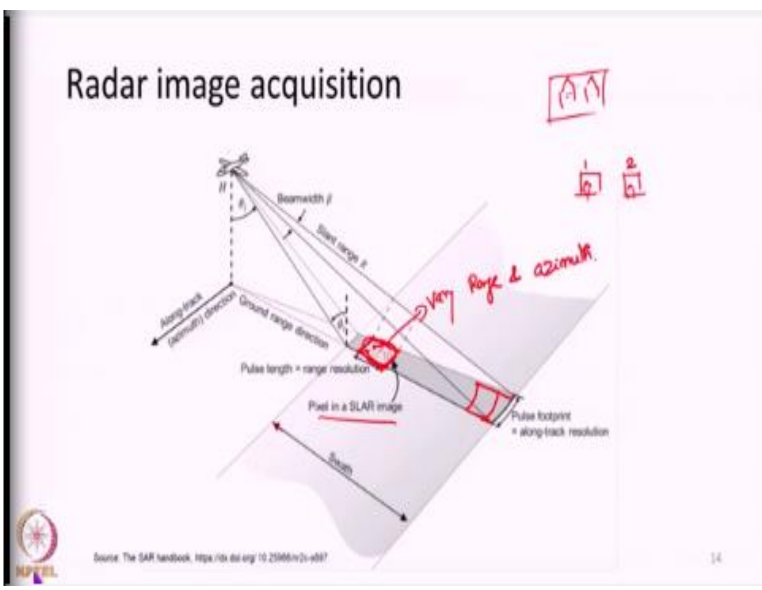

So, here if you look at this picture, we were discussing concepts related to the pixel size. And this pixel size will vary in both the range direction and azimuth direction.

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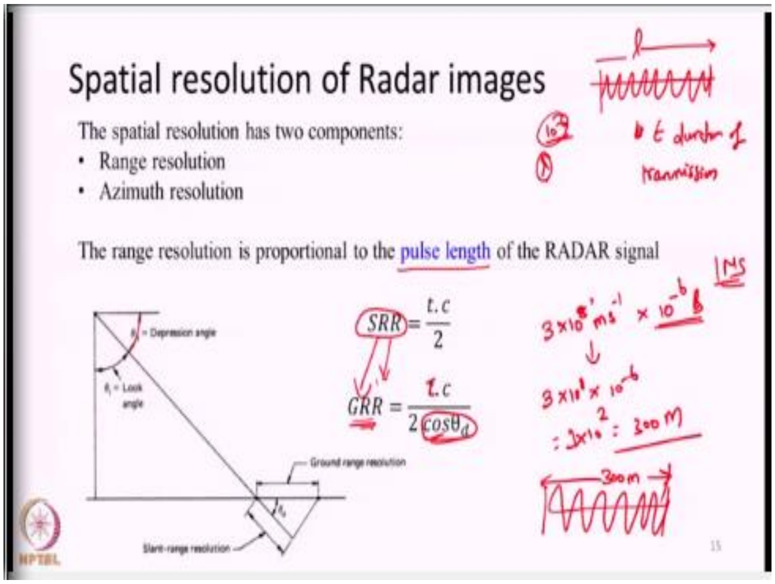

And we discussed about the variation of this resolution in the range direction. So, yesterday we noted that in range direction, the pulse length is determined by t the duration of our transmission of the microwave pulse. So, this will determine the range resolution.

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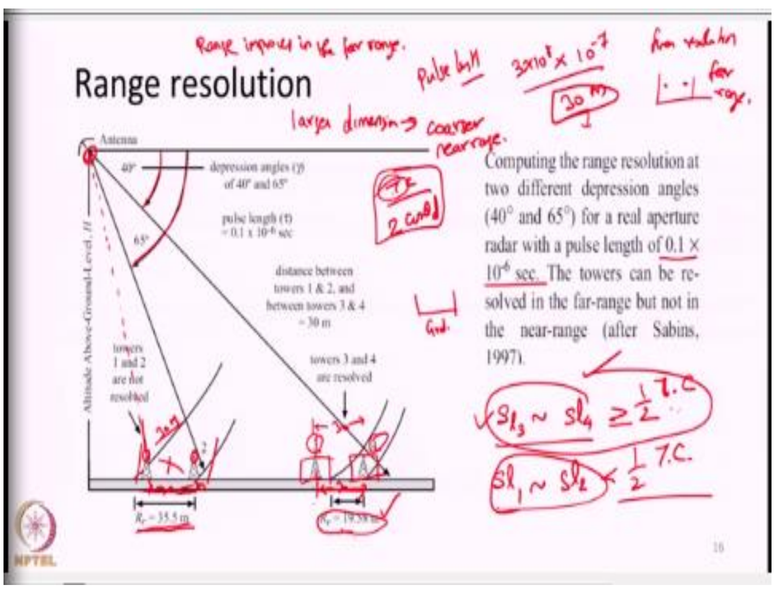

So, along the slant range, if the slanting distance between them is greater than half of the pulse length, two objects will be resolved independently. On the other hand, if the slant range distance is less than half of the pulse length, then those objects will not be resolved. That is most likely those two objects will be imaged within the same pixel in the range direction. So, the slant length or the slant range distance is constant.

However, the exact horizontal distance between the objects which determines the pixel size or spatial resolution in terms of the ground range distance will vary with respect to whether the objects are present in the near range or far range. Because the equation to convert slant range resolution to ground range resolution is given by θ_d the depression angle.

So, based on the depression angle, the ground range resolution will vary. So, in general, the pixels will have a larger dimension or coarser resolution in the near range and pixels will have finer resolution in the far range. So, we also saw an example in the last class that the length of the pixel here is 35.5 meters, whereas here on the far range it is just almost 20 meters. So, two towers separated by a distance of 30 meters on horizontal ground distance will not be resolved in the near range, whereas they will be resolved in the far range.

So, when you move from near range to far range the range resolution will be becoming finer and finer. So, as we noted the range resolution depends on the time duration for which the pulse is transmitted τ. If we reduce this time of transmission, that is if τ is reduced to a significant extent, we can achieve a finer spatial resolution in the range direction.

But that will reduce the total power transmitted, because the power transmitted will depend upon the frequency of the wavelength and the duration for which the wave is transmitted. So, if we reduce the pulse length or a duration of the pulse transmission that will affect the power of the outgoing electromagnetic signal which in turn will affect the power that will be received back.

Because whatever the power transmitted, only a fraction of it will be received back, so that fraction again will go down. So, the system will suffer from lower SNR ratio and it may not get enough power back in order to differentiate it from noise. So, there should be a balance or a tradeoff between the pulse length, the range resolution and the power that we want to receive with the signal. So, there are some limitations, we cannot keep on decreasing the pulse length in order to achieve a finer resolution in the range direction.

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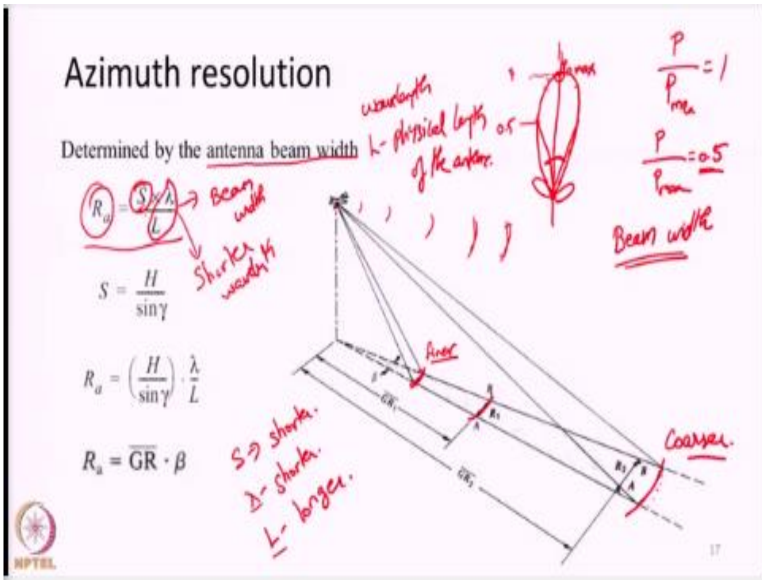

Next, we are going to discuss the azimuth resolution that is the resolution in the azimuth direction that is along the direction of flight, this depends on antenna beam width. So, what exactly is antenna beam? Simply put, when we discussed about the passive microwave radiometry, I briefly told you or showed you this kind of antenna pattern, that is an antenna is a highly directional element, which will basically transmit or receive radiation from one particular direction.

So, there will be a primary direction in which almost all the power will be coming in or the maximum power received by the antenna will be focused upon. This is the primary direction and along this direction the antenna will be receiving its primary or maximum power capacity. So, the power received in this direction is the maximum. So, if you take the ratio P/P_{max} you will get ratio of 1, when you move away from this primary direction the power either transmitted or received will be decreasing. So, there will be a point at where this power ratio is 0.5. So, if you joint this and if you measure the angle between them, that will define the beam width.

So, essentially the direction which is covered by the antenna in order to transmit or receive back half of the power is very similar to the concept of full width at half maximum. Say the angle subtended by the antenna at which the power transmitted or received back is at least half of its maximum capacity, so that will determine the beam width. If the beam width is narrower, if the antenna is highly directional, then the azimuth resolution will be better.

On the other hand, if the beam width is wider, then the azimuth resolution will be poorer. So, the beam width depends on basically the direction at which the microwave begins properly. Because once the microwave starts spreading from the antenna, it will be spreading before it reaches the target. So, if you look at the slide, the azimuth resolution depends on the slant range distance between the antenna and the object and λ/L. This factor λ/L comes in terms for beam width and λ is the wavelength in which the antenna is operating and L is the physical length of the antenna. So, this suggests that the azimuth resolution will become larger and larger or coarser and coarser when the slant range distance increases.

That is the antenna beam will be spreading continuously when it is transmitting. So, whatever objects that fall within one full beam, they will be imaged as one single pixel. Say when the antenna beam starts spreading, whatever objects that are present within the single beam width will be imaged as one single pixel. So, in the near range, the azimuth resolution will be finer, because of the less spreading of the microwave beam, whereas the slant range resolution will be coarser in the far range. So, the width will become coarser. Also, this depends on λ/L. So we should have a shorter wavelength, because lower this wavelength, lower will be the number. So, lower will be the number, finer will be the resolution that is the concept.

So, slant range distance should be shorter that is object should be near range, λ should be shorter wavelength and L should be very long. So, if these conditions are satisfied then essentially the range resolution number will be finer or smaller leading to a smallest pixel size. So, just look at this equation from which we can determine the azimuth resolution. It varies with slant range distance, the wavelength used and the antenna length.

But once the system is launched, we cannot change the λ and physical length of the antenna. So, the λ/L should be fixed even before the system is launched and S anyway will vary based on whether it is in a near range or in a far range. Similar to the example that we saw for the range resolution, we will also look at one more example to demonstrate the concept of azimuth resolution.

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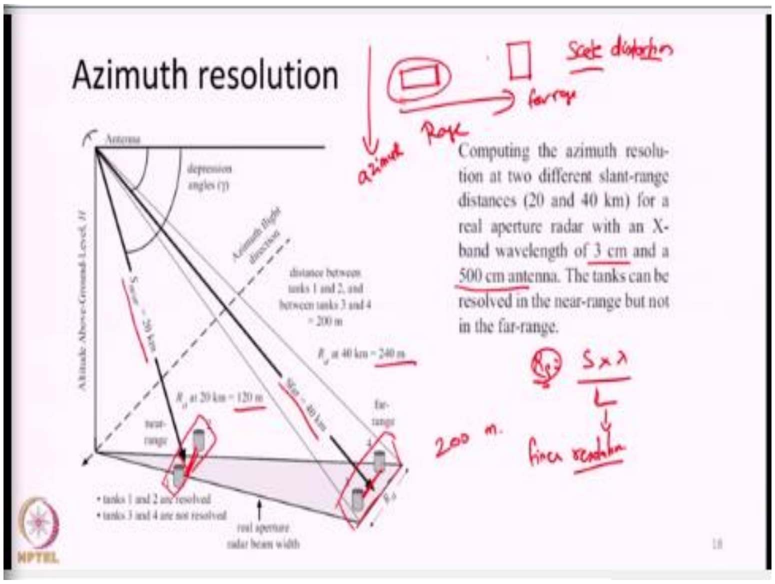

So, just look at this particular slide, here we have 2 towers, 1 and 2 in the near range 3 and 4 in the far range, these 2 towers have a horizontal distance of 200 meters between them. So, the slant range distance from the antenna to the towers in a near range is 20 kilometers and the slant range distance to the towers in the far range is 40 kilometers. And it is operating with the wavelength of 3 centimeters and the physical length of antenna is 500 centimeters.

So, $R_a = S \times \lambda / L$, so if we substitute all the values and work out, then the near range azimuth resolution will be 120 meters and the far range azimuth resolution works out to be 240 meters. So, it just doubles as the slant range distance doubled. So, this suggested the towers which are separated by horizontal distance of 200 meters will be resolved as 2 different things in the near range, because here the pixel size is just 120 meters. So, these 2 towers will be there in 2 pixels, here just 1 pixel size itself is 240 meters. So, both of them will be covered within 1 pixel and they may not be resolved properly. So, this suggests that, as the slant range distance increases, azimuth resolution will become coarser and coarser. In fact, real aperture radar systems what we just discussed cannot be used for space-borne satellites.

Because the slant range distance will be in the order of 100s of kilometers and orbital height itself will be around few 100 of kilometers. So, the slant range distance will be very long. Real aperture radars cannot be used for space-borne systems, if we want to achieve a good spatial resolution. So, this is a major limitation of real aperture radar to be used for space-borne systems. But the wavelength can be changed or the physical length of the antenna can be changed even before the system is launched. That parameter lies with the system designers, wavelength anyway it is fixed on the application for which it has to be used. As we all know the limitation of shorter wavelengths in microwave, they undergo a very large attenuation in atmosphere, their penetration capacity is low and all those things. So, for certain applications, scientists will prefer to work in longer wavelength range. So, that depends on the application in which the scientists want to work. So, the parameter that can be changed freely is L, the physical length of the antenna. Having a very long antenna will reduce the azimuth translations say $R_a = S \times \lambda / L$. So, larger the L, lower will be this number and hence finer will be the resolution.

So, increasing the antenna length is a possibility, but physically increasing antenna length in terms of 100s of meters is not practical in airborne base systems. In airborne base systems they can have few meters of antenna length. Even in space-borne the antenna length can be tens of meters but not more than that. But we may need to have 100s of meters of antenna, if you want to achieve very fine spatial resolution in the azimuth direction from space-borne systems. So, there are some practical limitations, the antenna length has to be limited, because it will increase the weight, it may change the stability of the aircraft or the satellite. So, we cannot keep on increasing the antenna length also. So, what is the way to overcome this? In order to limit this or in order to overcome this limitation synthetic aperture radar concept was developed.

But before going on to the synthetic radar concept, we will just quickly summarize the resolution concepts of this real aperture radar. So, in real aperture radar, the pixel size will be coarser in the range direction in the near range, finer in the azimuth direction in the near range. So, there will be a large scale distortion in the radar image especially for the real aperture radar systems, we can see how the pixels oriented here with the longer pixel size in the range direction and shorter pixel size in azimuth direction and exact opposite in the far range. So, the pixel dimensions and the look of pixel and everything will change and there will be a scale distortion across the image in the real aperture radar system. So, this is another limitation of the aperture radar, the resolution or the pixel size will be keep on varying based on whether the objects are in near range or in far range. So, this is how a radar image will basically be acquired.

Now, we will go to the concept of synthetic aperture radar. So, as the name suggests, in synthetic aperture radar, the antenna length is synthetically increased, synthetically means artificially increased or people will call it as antenna length synthesized. So, what does it mean? We know that the radar systems will collect the power, that is received back and also the polarization information. Similarly, the phase of the incoming wave can also be recorded, say whenever microwaves are transmitted they will be coherent waves and there will be fixed phase relationship between the different pulses that are transmitted.

Similarly, after getting scattered back by the objects from the ground, they will be received back and a radar system will also record this phase information. So, based on the relative position of different features with respect to this particular antenna, there will be a doppler shift in the frequency of the received microwave signal. Whenever there is a relative motion between the source of EMR and the target, the frequency of electromagnetic radiation will be appearing to change. So, it is an apparent shift in frequency, say when the source and receiver are moving towards each other the frequency will appear to increase, when the source and object are moving away from each other, the frequency will appear to decrease, so this is like an apparent shift. Noting this apparent shift we will be able to calculate the doppler velocity or the relative velocity between the source and the target. So, this principle will be used in the synthetic aperture radar data processing.

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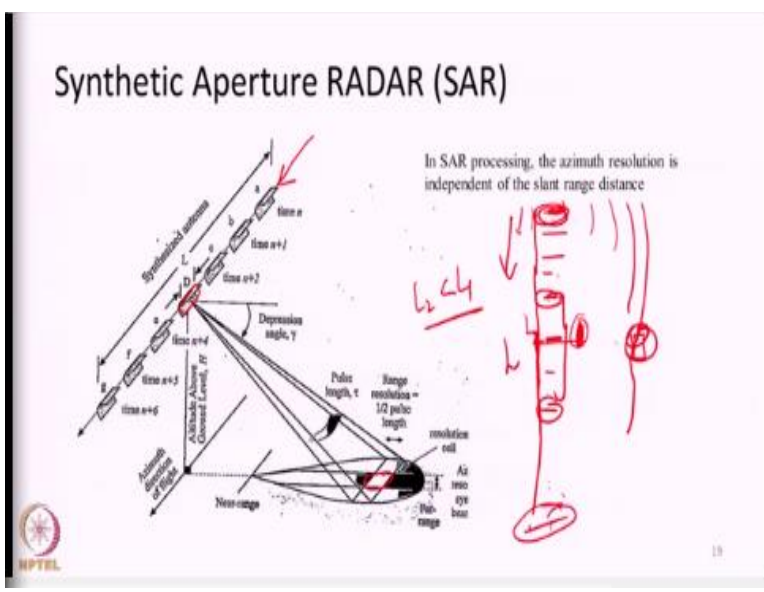

So, here system and everything are remained the same, but by recording the phase information people will be able to synthesize a very long length of antenna. Here we have a conceptual example where the physical antenna length is D. Let us say there is an object. So, when the system is moving in a particular direction, the object present here will be seen by the antenna. Whenever some object is at a far distance we need not come exactly perpendicular to the object to see it, we can see the object from little farther distance, because the microwave signals will be also spreading out as it moves.

So, even object that is far will be sensed by one particular signal, say the object is here the beam width maybe transmitted like this. So, as the distance increases the beam width may spread across and it may fall over the subject. So, the actual position of radar will be here, but just due to the spreading of antenna beam width this object signal will be received when the radar position is here itself. Slowly as the radar is moving from different, different positions the same object will be imaged by this radar system. So, when the radar system becomes exactly perpendicular again it will be recorded and it will slowly move away from the picture, after a certain distance this object cannot be seen by the radar system. So, after this, the object will vanish from the radar system.

So, essentially a same object can be imaged by the radar system from different, different positions, say this is the physical length of the antenna. But, imagine if there is a way to process all the data, such that all these different positions can be combined together. That is all the signals that were received from this object from different, different position of the antenna that can be combined. So, that all the antenna lengths can be added together to synthesize a very long antenna length. So, the concept is, same object can be seen from different, different positions in the azimuth direction as the flight is moving or the satellite is moving. When that happens the data processing system will try to collect all the signals that came from one particular object from different positions. And add up all using the phase information, the antenna length will be keep on adding up. So, if the object is farther, we can see the object from a very farther distance. So, till we move for a very long distance, object that is a bit far in this particular in the range direction can be seen.

On the other hand, if an object is very near to the range direction, that object can be seen. Say if an object is here let us say, this object cannot be seen from this particular antenna location, maybe this will appear in the image from this location to this location. So, for the distance for which this particular object is seen will naturally be lesser than the distance for which the object in far range is seen. So, as the object moves away and away in the range direction, the total length for which the object can be seen by the radar system will be longer.

So, just combine all these radar locations and based on the object's position in the range direction, the antenna length will be keep on varying. If an object is very far it will be seen by the antenna for a very long distance. So, combine everything to produce a very long antenna, if the object is in near range, it will be seen only for a shorter length of shorter distance. So, combine everything to produce another antenna length. So, essentially the antenna length is synthetically increased, so the different signals received from different positions of antenna from the same object are all combined together in order to produce a very fine spatial resolution. This is the very simple conceptual explanation of SAR, we are not going to discuss in detail about how this is processed, but the way it is processed uses the doppler frequency shift.

So, as the antenna moves with respect to this object, the frequency will be keep on changing. The doppler frequency shift will be keep on increasing as the antenna is moving towards the object. Then, when the antenna is exactly perpendicular to the object, doppler frequency shift will be 0. As the antenna again moves away from this object, doppler frequency shift will again beginning to appear and slowly the object itself will disappear from the radar’s point of view.

So, using this doppler frequency shift concept, each and every object in the range direction can be imaged from multiple locations and everything are processed together to synthesize a very long antenna length, so this is the concept of synthetic aperture radar. So, theoretically it can be shown that the spatial resolution in the azimuth direction for synthetic aperture radar is L/2. In this example it is d/2, half of the physical length of the antenna. Say if the antenna physical length is 20 meters, then the spatial resolution can be 10 meters.

And this theoretical resolution is independent of the slant range distance; object whether it is in near range or far range each pixel size can have a uniform spatial resolution. So, this is a major advantage of SAR system. Here is an example, for real aperture radar system, range resolution will be keep on changing, azimuth resolution also will be keep on changing. Slowly the azimuth resolution is becoming coarser and coarser whereas in the SAR system, the azimuth resolution becomes independent of the slant range distance and hence it will be treated more or less constant.

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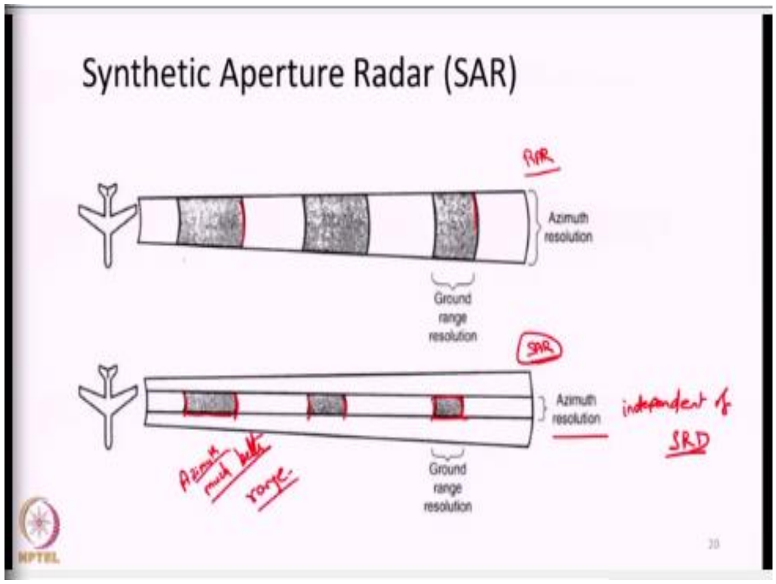

So, azimuth resolution will be many orders better than the range resolution. The range resolution will be coarser in the near range finer in the far range, there is no change in the range resolution, the azimuth resolution improves drastically in SAR systems. So, normally for SAR systems, the azimuth resolution will be much better than the resolution in the range direction. So, this is the basic conceptual working principle of SAR, not the real working principle. And also one thing to keep in mind is the azimuth resolution has now become independent of the range. Like in the real aperture radar system the azimuth resolution will be keep on becoming coarser and coarser as a slant range distance increases. For SAR systems, the azimuth resolution is almost independent of the slant range distance and will be more or less constant even if the objects are at a very far range.

So, in this particular lecture, we discussed the concept of spatial resolution of radar systems like the azimuth resolution, range resolution and also the limitation of real aperture radar systems. And we got introduced basically to the synthetic aperture radar systems. With this we end this lecture.

Thank you very much.