Remote Sensing and GIS
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Lecture - 15
Microwave Remote Sensing

In this lecture, we will see more about this Microwave Remote Sensing. In my previous lecture I already covered little bit of introduction as well as what advantages and disadvantages we have when we are using microwave remote sensing. So let us understand more about this Microwave Remote Sensing. So let us start with what are the different types of radar system we have till date.

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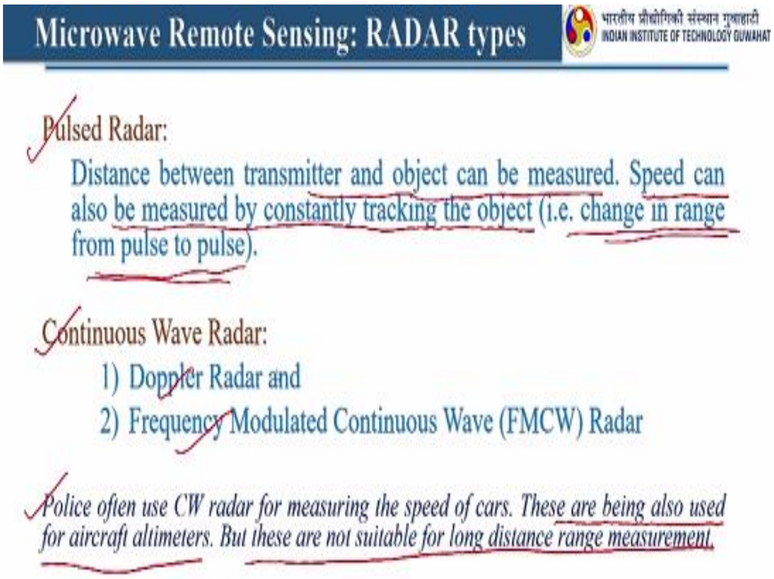

So this is the first type where we have pulsed radar. So in pulsed radar distance between transmitter and object can be measured and the speed can also be measured by constantly tracking the object that is change in range from pulse to pulse. So when you are having track of your transmitter location and the object location so this is possible. You can track the speed of the object.

So if you have the pulsed radar installed somewhere and you are looking at maybe a moving car. You can easily track them, but here we have another type of radar which is actually more suitable for that application. So in Continuous Wave Radar we have Doppler radar and Frequency Modulated Continuous Wave Radar. So in this case it is more suitable for your measurement of speed of any vehicle and nowadays people are using it.

So police have already installed this in traffic signals and they are monitoring the speed of the car. So these Continuous Wave Radar they are actually used for aircraft altimeter, but these are not suitable for long distance range measurement. So in this case we have two different types of radar system. First one is Pulsed Radar another one is Continuous Wave Radar. In Pulsed Radar distance between transmitter and object can be measured and speed can be monitored that is because of the change in range from pulse to pulse.

Whereas in Continuous Wave Radar you have two different types of system. First one is Doppler Radar second one is Frequency Modulated Continuous Wave Radar and Continuous Wave Radars are very popular nowadays and people are using it for day-to-day life perposes.

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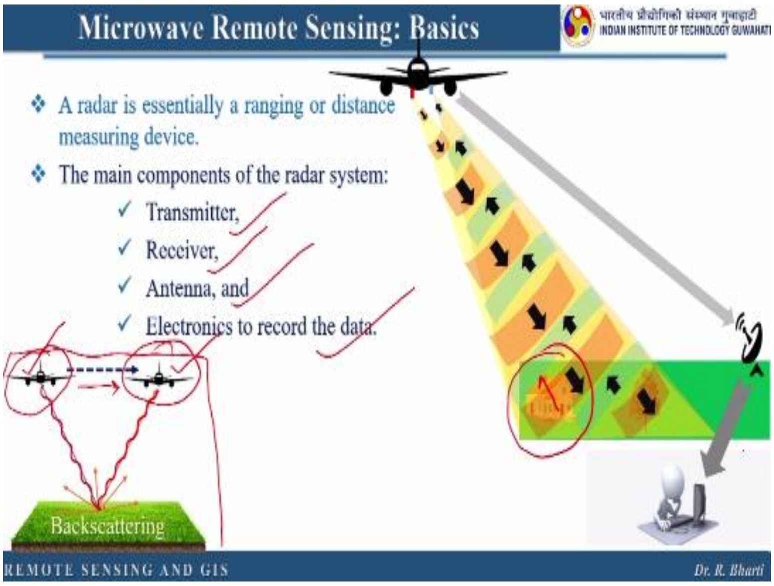

Now here let us understand what are the different types of component we have in Microwave Remote Sensing. So the main component of radar system are transmitter, receiver and antenna, electronics which records the received energy right. So here in this figure you can see this is in case of active radar system where the system itself has a capability to illuminate this particular surface and the surface will react and then it will give you the backscattering value right.

So the scattered value will go back to satellite or your sensor which is located either in this space or maybe in airborne and that will be captured by this particular sensor. So here you can see this particular system has illuminated this area from this particular position, but whereas in this one here it has moved and it has captured the backscattering values. Now let us understand here the satellite which is illuminating this particular area will release the pulses and the moment the first object which interacts with this echoes that will get backscattered.

And this will give you backscattering values right. So the backscattered value will again go back to your satellite or sensor and then that will be recorded and subsequently the recorded data will be transmitted to your ground station and the ground station will receive that energy and in form of image and that will be distributed and analyzed. So this is how we are doing in case of Microwave Remote Sensing right.

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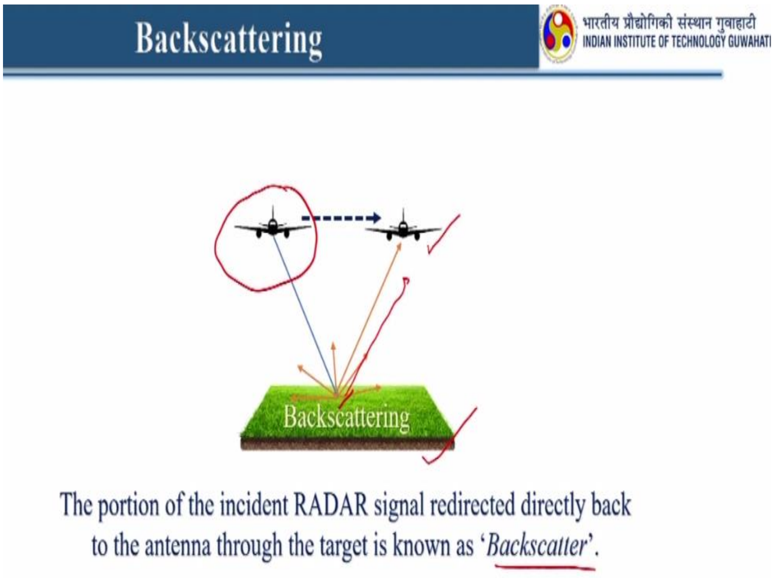

Now let us understand this backscattering, what is this backscattering how it is different from reflectance or emission. Here already you know this particular flight has active radar and it is illuminating this particular surface and the surface will either absorb this energy, transmit this energy or reflect this energy or scattered this energy. So here since we are talking the Microwave Remote Sensing data.

So here microwave energy they are the longer wavelength and they will get backscattered right. So the backscattered value will be received by this object which are scattering this or which is involved in this scattering phenomena is known as backscatter and the energy which has been received by your active microwave sensor that is actually that energy is known as backscattering right.

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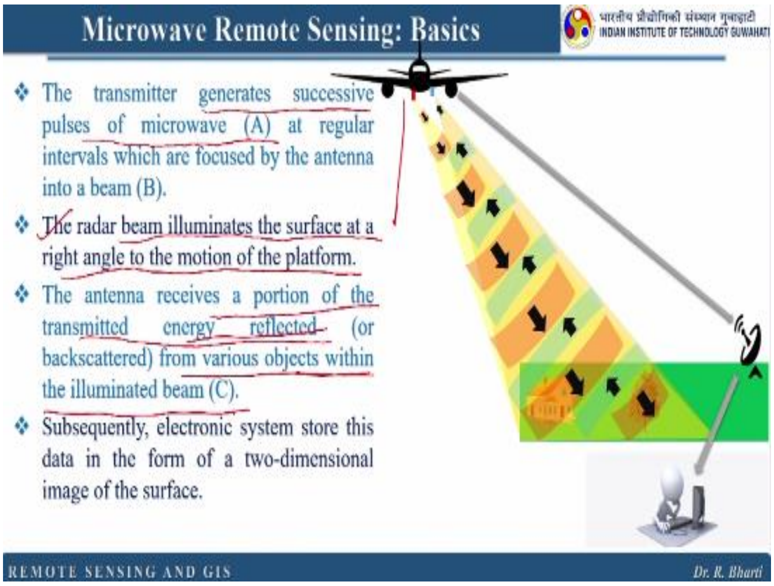

Let us understand what exactly is happening here. The transmitter generate successive pulses of microwave A so the microwave energy right. So the successive pulses. So the pulses will be sent in a FOV and that will reach to our surface and the moment the object interact with your pulses they will start backscattering and the same time it will go back right like this and it will be recorded by your sensor.

So in between the radar beam illuminates the surface at a right angle to the motion of the platform so this is the movement direction in this case right. I cannot draw the third direction so this is actually for the visualization. The antenna receives a portion of the transmitted energy reflected from various object within the illuminated beam C. So here the transmitted energy is A right focused by antenna into a beam that is B and then C is the energy reflected or backscattered from various object right.

Now subsequently electronic system store this data in the form of two dimensional image of the surface and then it will be transmitted to your ground station and subsequently it will be analyzed right. In Microwave Remote Sensing polarization plays a significant role.

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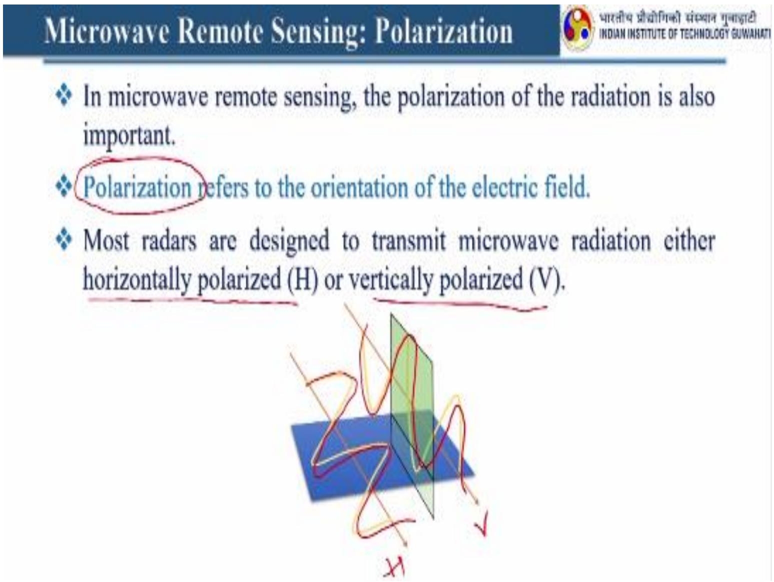

So here the polarization of the radiation can be used as an advantage. So how let us see. So let us understand first this polarization what do you mean by polarization. So polarization refers to the orientation of the electric field and most radars are designed to transmit microwave radiation either horizontally polarized or vertically polarized. So I have a figure for you. Here you can see the active microwave radar sensors what they will do.

They will illuminate the surface but how they will illuminate by emitting some light in microwave region and how they will be aligned or how this electric field will be managed. So either they will be using this horizontally polarized light or vertically polarized right. So in this case if you see this is moving like this. In this case it is moving like this. So one is horizontal another is vertical. So this is in case of transmitter.

Here we are only talking about the transmitter, but do we have the flexibility so that we can transmit horizontal, but receive vertical, is it possible in Microwave Remote Sensing then answer is yes.

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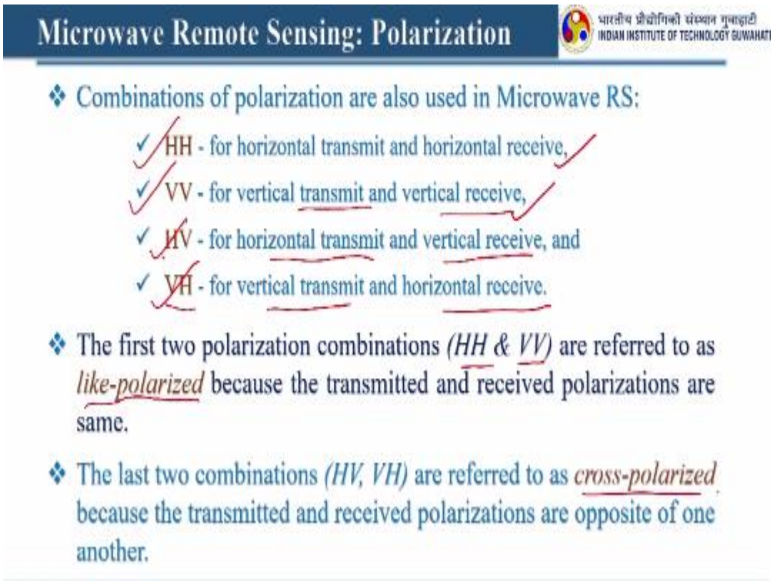

So here the combination of polarization are also used in Microwave Remote Sensing and first one is your HH. So HH means the transmitter will be in horizontal polarization and receiver will be in horizontal polarization. In the next one is VV. So vertical transmit vertical receive. In HV it is horizontal transmit vertical receive. In VH vertical transmit horizontal receive. So here basically we are making use of the technology.

And we are trying to extract maximum information using this microwave energies and basically here we are measuring the backscattered right. Among these four the first two which is actually your HH and VV they are known as like polarization because both are in same polarization domain. So first one if you see the HH basically horizontal, horizontal so they are like each other vertical, vertical.

But in the next one these two they are basically different from each other. They are known as cross polarized. Here you can understand.

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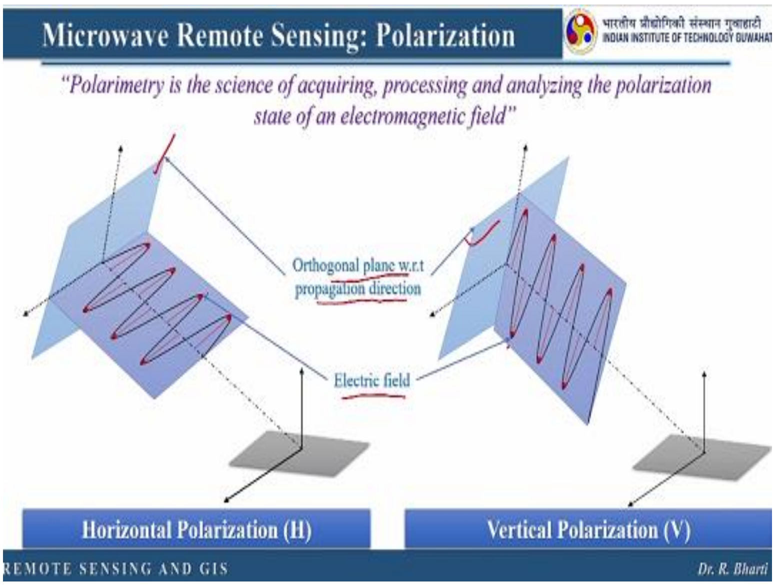

Here you can understand this how these electric fields have been generated and this is just for the visualization and here you can see this plane is basically orthogonal plane with respect to propagation direction. So these two are basically the plane orthogonal to your propagation direction whereas if you see these signals so the electric field is basically here and here.

So one is your horizontal another one is vertical right. So in polarimetry what we do we acquire process and analyze the polarization state of an electromagnetic field. So this is what we are going to use in Microwave Remote Sensing when we are talking about the polarization or Polarimetric SAR right.

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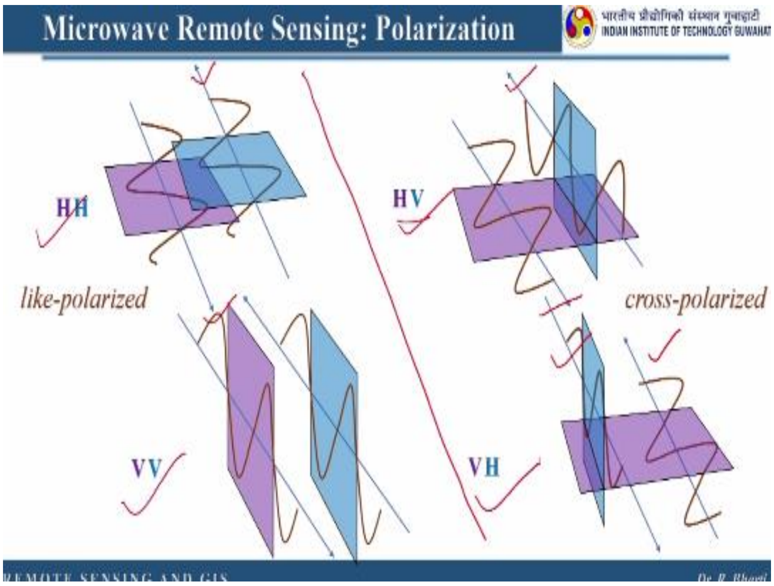

So in polarization you have first one is HH where the transmitted and received energy both are in same polarization that is horizontal. In the next one you have HV so first one is transmitted is in horizontal direction, horizontal polarization and received is vertical polarization in VV both are vertical in VH the transmitted is in vertical whereas received in horizontal.

So if we divide this into two groups so HH and VV they are known as like polarized and HV and VH are known as cross polarized. I hope this is clear to you. Now here we have seen all the four cases, but can we get some additional information by changing this polarization whether in transmitter or in receiver yes. We have some different information when we are using HH when we are using HV, VV or VH. So what exactly we will get.

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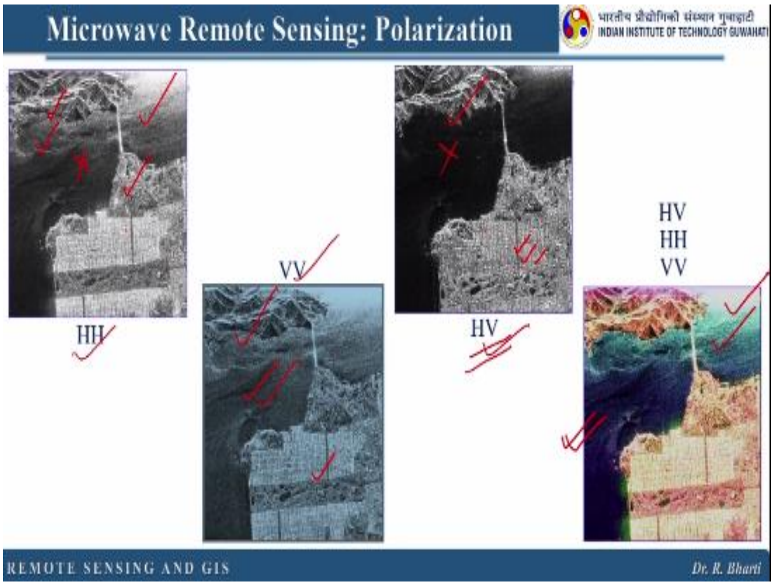

So that I am going to show you some example. So this is one HH image so here the transmitter has used horizontal polarization and receiver in horizontal polarization. Here VV then third one is HV. So you can see all these three images and can you find out the difference or some additional information which you are getting in different polarization. So here if you see this HH this particular area is actually better than others right.

If you see VV you can see this particular area this is water body. So here you can find some features which was not visible in this one and not even this one, but if you see HV your settlement or the building information or the geometry of smaller objects are better. So if we use this our information will be different if you use this our information will be different if you use HH our information will be different.

But can we use our basic understanding about remote sensing and how do we visualize this images. So I hope you remember this color composite. So in case if we can generate a color composite using these here images whether our information will be different or it will remain like only like this or this or this. So let us see when we combine HV, HH, VV to together to generate a color composite let us see.

I hope you can easily find out the differences between the first, second and third image and this is the color composite image right. So here the information which has been highlighted by this HH and VV and HV all are merged together and all the information captured by these three different combination of polarization has been included here. So in case if you find a data in all these 3 or 4 polarization you can generate a color composite.

And you can make use of this polarization to extract your target in better way right. So remember here in this course I am going to teach you all the basic understanding as well as the advanced processing of this remote sensing data. It does not matter whether it is in optical or microwave domain, but you have to select the best method which is giving you best results for your application or your problem right.

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Microwave Remote Sensing: Satellites

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Parameters	Seasat	ERS-1,2	JERS-1	Radarsat	SIR-C	ENVISAT	Radarsat -2
Launch	June 1978	July 91 & Apr 95	Feb. 92	Nov. 95	Apr & Oct. 1994	March 1, 2002	Dec. 14, 2007
Frequency (GHz)	1.275	5.3	1.275	5.3	1.2, 5.3, 9.8	5.3	5.3
Wavelength (cm)	23.5	5.6	23.5	5.6	23.5,5.6,3.1	5.6	5.6
Resolution(m)	25	30	18	10 - 100	25	30	10-100
Swath (km)	100	100	75	35 - 500	15 - 90	150–1km	35 – 500
Look angle	23	23	35	20 - 50	20 - 55	20 - 50	20 –50
Polarization	HH	VV	HH	HH	HH,VV,HV	HH,VV	HH,VV
Looks	4	4	3	1-4-14	1,4		

So here I have listed some of the satellite which are working in microwave domain and this is not the complete list. This is selected satellite so first one is Seasat next is ERS 1, 2 JERS –I, radarsat 1, SIR-C, Envisat, Radarsat II. So these satellites are available in space and the datasets are also available to us some of them are paid, some of them are freely available. So in case if you want any of these datasets or maybe the recent launch datasets.

So you have to contact the space agencies and if it is freely available you can directly download them. If it is paid, then you have to do the formalities right. As I mentioned earlier this Microwave Remote Sensing is completely different from your optical remote sensing. So here the imaging techniques which we used in optical remote sensing that is not followed here.

So to understand that you have to understand what are the different imaging techniques we have in microwave domain.

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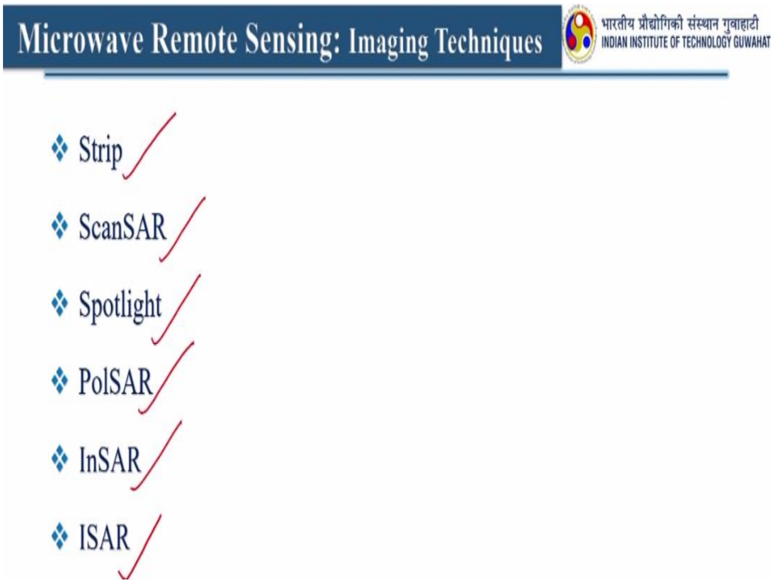

So first one is Strip. Then ScanSAR, then spotlight then PolSAR then InSAR then ISAR right. These are different imaging techniques available in microwave domain and now let us see some of them to understand how they are playing big role in your data generation.

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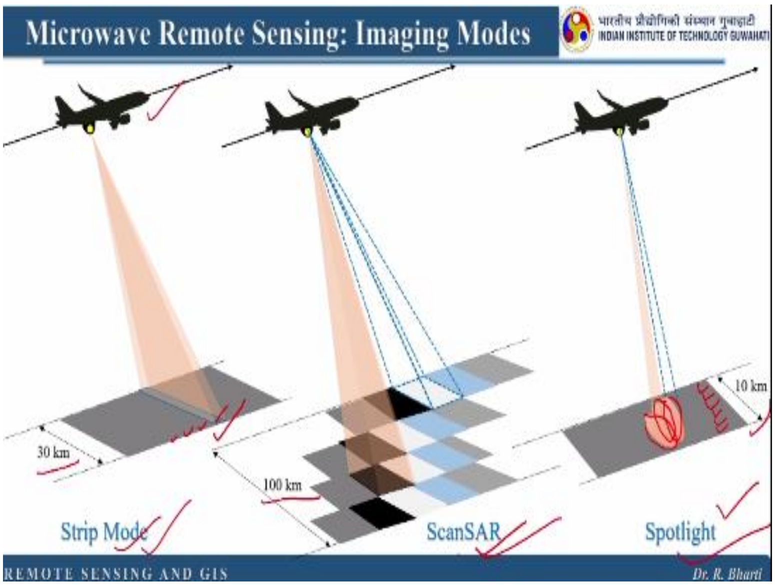

In this first one strip mode you can see this particular flight is carrying a active remote sensing sensor and which is illuminating this particular surface and it is sensing this area in strip. So first strip will be generated then next will be generated then so on and subsequently using this strips image will be formulated right. In the next one here is ScanSAR what you will do you will acquire the images in frames and the frames will be used together to generate the image right.

In the third one you have spotlight and spotlight again this will be generated like this. So one object will be seen from two or three different position and then you will generate this complex images. So here if you compare this strip, ScanSAR and spotlight you will find the difference in the swath. So here when we are using strip mode this 30 kilometer swath has been reported.

When we are talking about this ScanSAR this 100 kilometer was reported then spotlight this is 10 kilometer. So the swath is basically the width of your image right. So in that width you will have several pixels. So here also you will have pixel, but the calculation of spatial resolution and others will be different.

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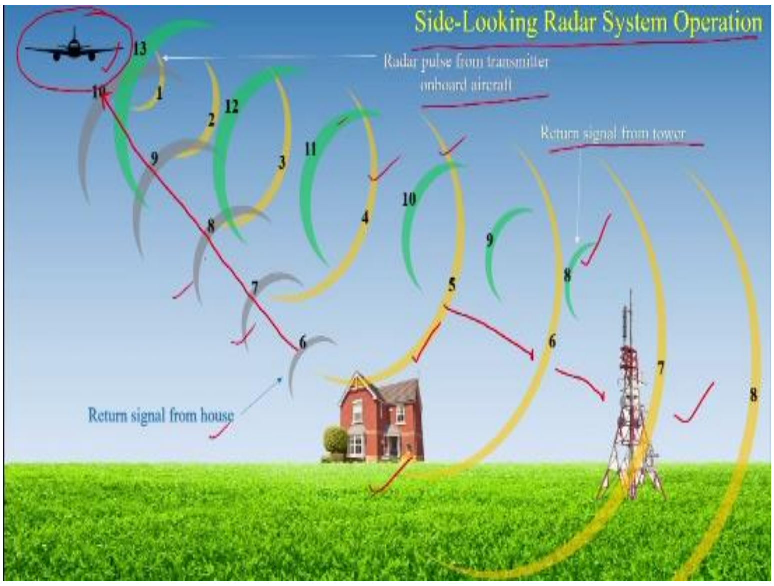

So in Microwave Remote Sensing it is interesting to know about the side looking radar system operation. Here let us understand this particular flight is carrying a active remote sensing sensor. So it will start illuminating or transmitting the microwave signal which will subsequently reach to your target. So here you can see once it has reached to this particular position it has already interacted with the first object right.

As soon as this object get this transmitted signal what will happen your backscattering will start. So the backscattered value will start travelling towards your sensor and the same time this transmitted energy will keep on traveling to your next target and once it reaches to this tower then it will again sent back the next echo right. So the backscattering will start from this tower as well as from this house.

Depending upon their position and the time when they interact with your transmitted signal. So once it is over then it will reach to your sensor and then they will be recorded separated and your microwave image will be generated. So here already everything is mentioned. So these are basically radar pulse from transmitter onboard aircraft this yellow color right and the return signal from tower right and the return signal from tower they are in green and return signal from your house they are in gray color. I hope this is clear to you.

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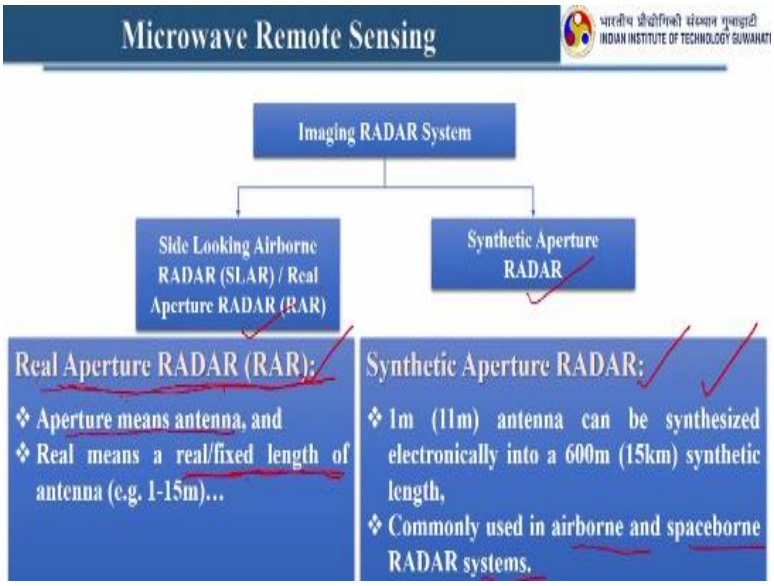

Now let us understand this imaging radar system how we can do this imaging and what are the different types of imaging radar systems available nowadays. So first one is side looking airborne radar system or it is also known as real aperture radar. In the next one it is synthetic aperture radar and in the first one the real aperture radar basically this refers to fixed length of antenna.

So let us understand this assuming this is my microwave sensor and these are antenna and your transmitter is located here and this is your receiver. So this will illuminate this surface. So once we receive this backscattered value it will be stored and it will be transmitted further. So here in this case in real aperture radar we are referring the fixed length of antenna so this is the antenna right and aperture means antenna.

So real aperture means antenna radar. So we are not going to synthesize or we are not going to mathematically change the length of this antenna in RAR right. In the next category. In the next category we have SAR right. In SAR basically what happens the 1 meter antenna can be synthesized electronically into a 600 meter synthetic length. So here we have used fixed length here we are using synthetic length which is synthesized maybe multiples of the real value and commonly used in airborne and space borne radar system.

So this is more popular because here you do not have to make big antenna only mathematically or electronically you will synthesize the length of the antenna into more.

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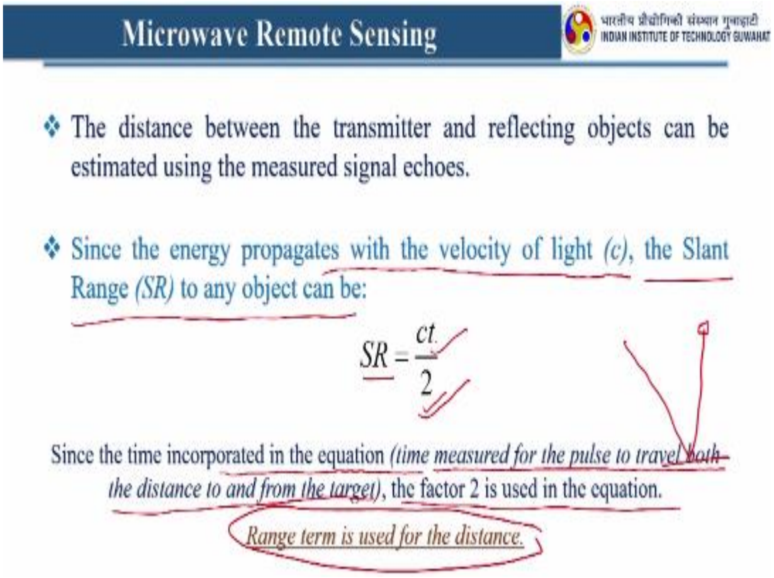

In microwave remote sensing the distance between transmitter and reflecting object can be estimate using the measured signal echoes. The measured signal echoes means backscattered value. Since the energy propagates with the velocity of light C is known the slant range to any object can be calculated. So what exactly we mean by slant range. So remember range term is used for distance right. So the slant range= ct/2 and t is basically your time.

So here we are measuring this time from this transmitter to your surface and how much time it is taking to reach to your sensor the backscattered value. So here that is why we are using this two factor. Since the time incorporate in equation time measured for the pulse to travel both at the distance to and fro the target the factor 2 is used in the equation right. So this is very simple I hope you have understood.

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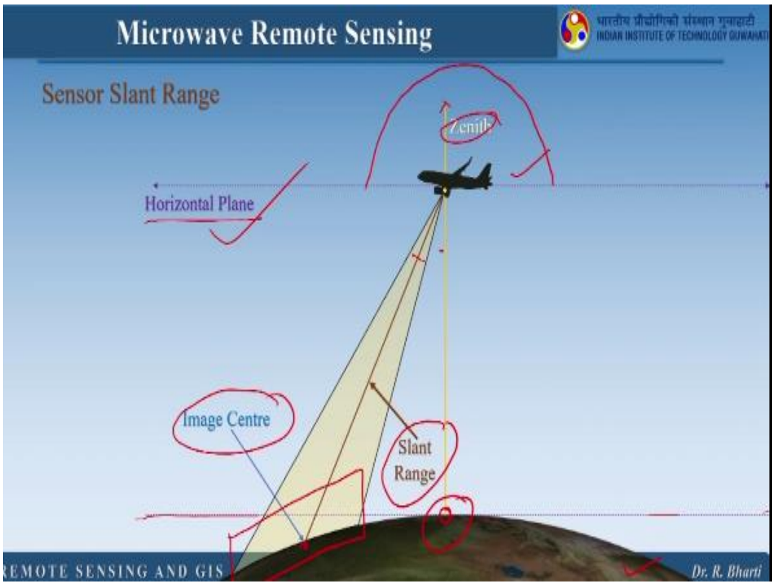

Now the next point is sensor slant range for that I would like to use this animation. So here this is basically your surface and you have a sensor located here right and you can easily draw the horizontal plane along which your flight is moving assuming there is no change in the altitude sudden change in the altitude. Here you can draw a tangent and this is basically horizontal plane you have drawn right.

And once you just see vertically down from your sensor or from your satellite or from your airborne platform what will happen you can easily mark this Nadir. So Nadir is vertically down projected point on the ground right and as we know that this will illuminate this surface with this FOV right and once you have this image generated for this particular area you can easily find out the center of the image.

And once you have this center the distance between the center of the image and the flight or the spaceborne sensor that is referred as slant range and image center already you know this is your Nadir this is your horizontal plane and this is the direction of your zenith. So zenith will be like this. In Microwave Remote Sensing we use different nomenclature for the geometry.

So let us see what are the different viewing geometry we use in this microwave remote sensing.

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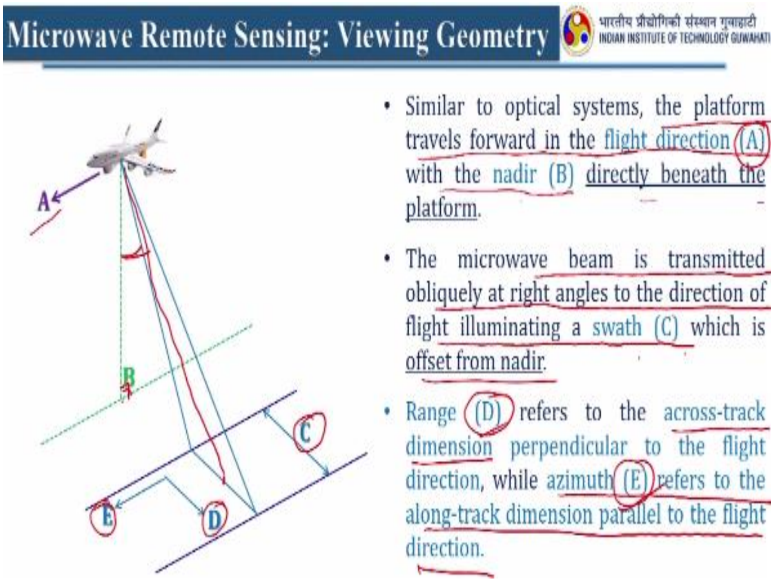

The first one is let us understand similar to optical system the platform travels forward in the flight direction A so the flight direction is A with the Nadir B directly beneath the platform.

So if you draw it will be like this so this is the direction of your flight this is your Nadir which means vertically down projected point on the surface right. So this angle will be 90 degree.

Now with some angle we actually illuminate our surface so the microwave beam is transmitted obliquely at right angle to the direction of the flight illuminating a swath C. So swath is your width of your image. So here it is C which is offset from Nadir. So this is your Nadir and this is the offset so if we calculate this will be slant range sorry this has to be straight line. So suppose this is the center of the image so this angle will be your offset.

The range D refers to the across track dimension right this one while azimuth refers to the along track dimensional parallel to the flight direction. So this is E. So D and E. So I think nomenclature is clear to you the direction is A Nadir is B, swath is C range is D right and azimuth is E and this is basically 90 degree right.

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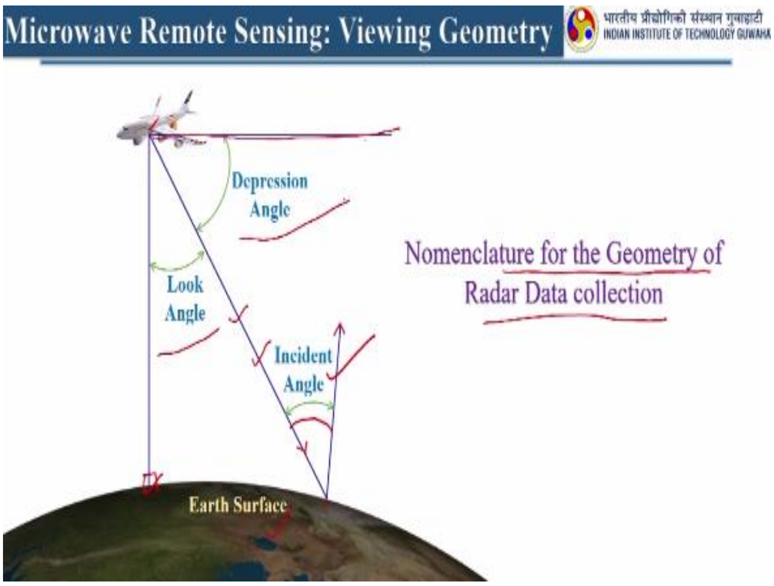

In this diagram the nomenclature for the geometry of radar data collection has been highlighted. So let us understand again this is carrying your sensor and this is definitely our earth surface. Now let us draw the perpendicular on this surface so this will be this line and if we are illuminating this area this angle will become incident angle and the angle between your illuminated beam and the perpendicular this is basically your nadir.

This angle is known as look angle right and the horizontal plane which we have drawn which is basically which tell us about the direction of your flight along which your flight is moving.

So the angle between this and the beam will be depression angle. I have another image to explain all these geometries.

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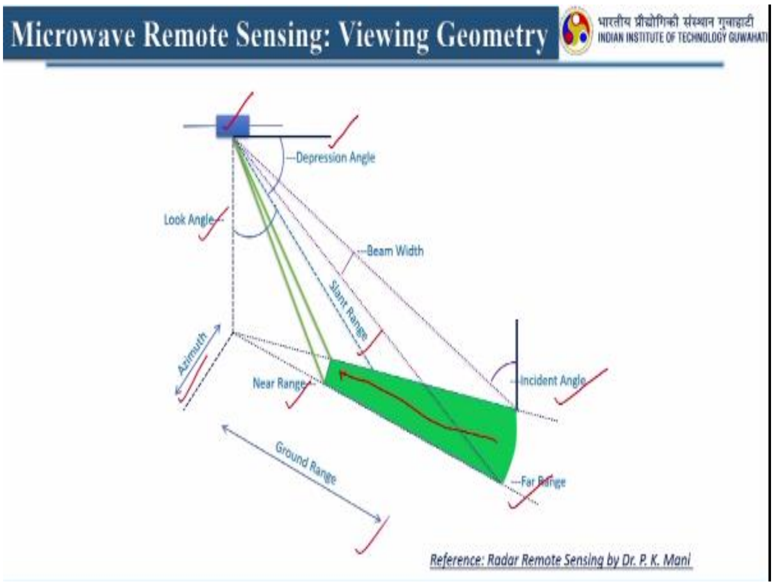

So let us see here. This is your satellite or the sensor does not matter where it is it can be in space or maybe airborne platform. Now let us go one by one. Here you can see this is the image which has been generated or we are trying to generate let us understand in this way. Now in this image this is basically your sensor and you can draw the Nadir by looking downward and which will make 90 degree with the surface.

Here you have this image which we are trying to generate. So now let us see what are the different nomenclature we have for this geometry. So just see I am going to highlight all this terms one by one. So this is your depression angle right. So here the angle between the slant range and horizontal plane is known as depression angle right, is it clear. Now next one is look angle.

This is with respect to your Nadir. So here we are going to measure this angle and this will become your look angle. Now next is your incident angle this is with respect to perpendicular on the ground and this angle will be your incident angle. Can you see this one. Now next one is azimuth in this direction and next is near range. So near range is this one right. So in near range and far range what is the difference.

Basically near range is the range which is close to your Nadir far range which is far from your Nadir right and this is slant range. I hope you remember the distance between the center of the image and the satellite or the sensor that is known as slant range right and this is basically your beam width and this is the ground range. So just to make sure whether you have understood this or not I am going to repeat this once again.

Because this is very important to understand this geometry right. In this image this has been used to represent a sensor active microwave sensor and here you have depression angle which is the angle between this horizontal plane and this slant range then look angle then your incident angle, azimuth, near range which is close to your Nadir, this is far range which is far from your Nadir.

This is the slant range and this is the beam width this is how we are going to generate this image and this is the ground range. I hope all these things are explained in very simple manner.

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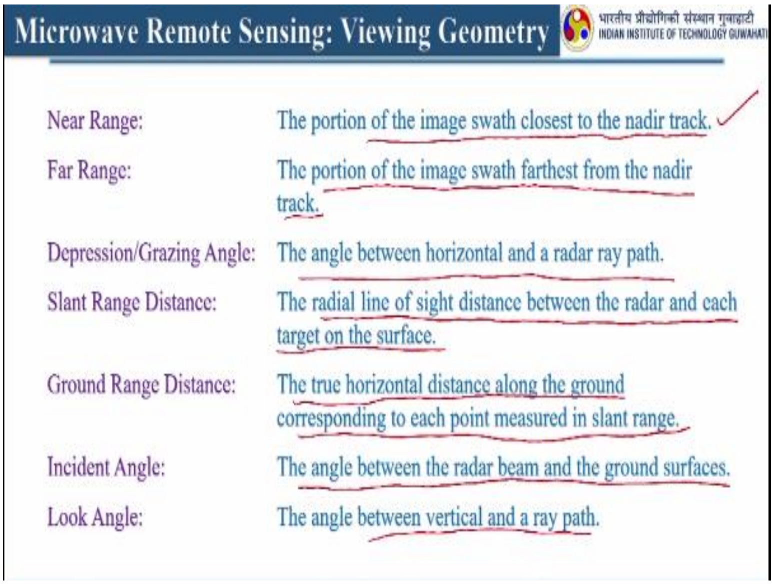

Now let us see how we can explain this like sometimes you have to write some definition or sometimes you have to write what do you mean by near range, far range then how will you write. So by using that diagram as well as you can use this text how to explain all this view in geometry. So near range the portion of image swath closes to the Nadir track. Far range the portion of the image swath farthest from the Nadir track.

The next one is depression angle the angle between the horizontal and radar ray path. Slant range distance the radial line of side distance between the radar and each target on the surface. The next one is ground range distance the true horizontal distance along the ground corresponding to each point measured in slant range. Then incident angle the angle between the radar beam.

And the ground surfaces and the last one is look angle which is the angle between vertical and ray path right.

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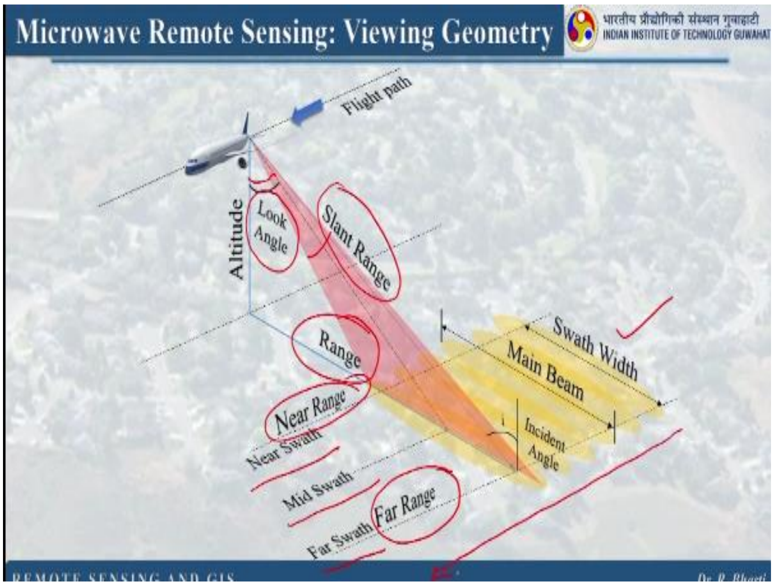

So the same thing has been again put on this image and you can see here we have highlighted this slant range, look angle, range, near range and this is the far range in between because if this is 100 kilometer long strip then you can have mid swath, near swath, far swath because depending upon the view angle or the angle from this Nadir look angle your image will be different right.

Here this is the swath and this is the area which you are trying to acquire right. How do we define range resolution.

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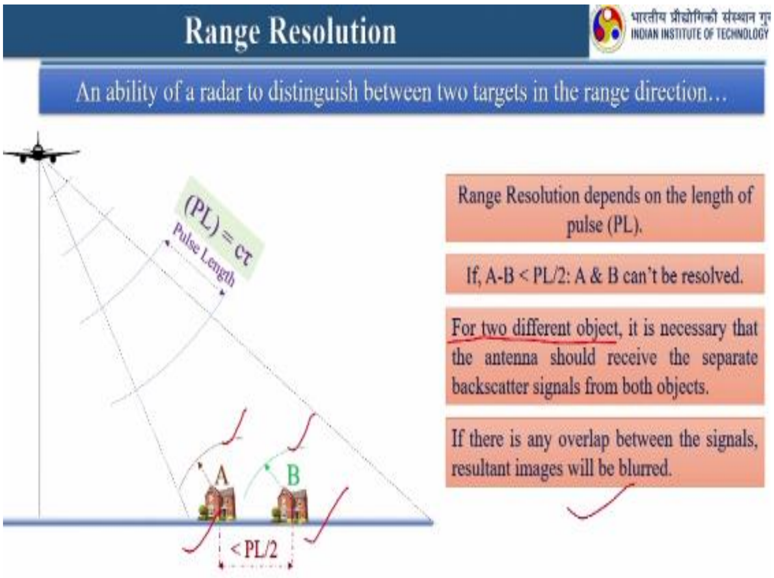

So range resolution is basically an ability of a radar to distinguish between two radars in the range direction and here in this diagram this particular sensor which is located here is releasing the pulses and where we are trying to illuminate this A and B target or let us consider this whole area right. So in this case what will happen we will release the pulses which will reach to our surface at some point of time.

And then once it interact with the target then it will start giving the backscattering echoes. So the backscattered values will be sent back to your sensor. Here the length of the pulses plays very critical role in order to identify these objects in Microwave Remote Sensing data. So if A-B that means the distance between A and B is<PL/2 then we cannot identify these objects in microwave data.

But if A-B is bigger than PL/2 right then you can divide or you can identify these objects right. So for two different objects it is necessary that the antenna should receive the separate backscattering signal from both objects otherwise what will happen they will get merged with each other. So I hope you remember this optical remote sensing where you have concept of pixel, spatial resolution.

So if one pixel is having a tree and a house together what will happen? Basically we store only one DN number here. So we cannot resolve this DN number in terms of house or tree right. But if we have several pixels here then we can easily find out different parts of this tree and different parts of this house right. So in that case it will be very easy the same thing applies here where the two different object it is necessary that antenna should receive separate backscattering value.

Then they will be identified as two different objects in your image right. If there is any overlap between this and this then what will happen your image will get blurred.

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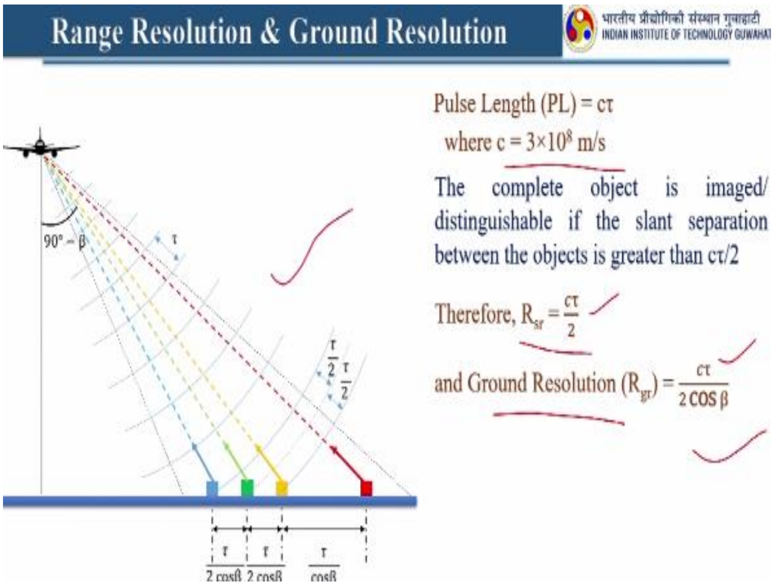

Here in this case what is happening the range resolution and ground resolution. How do we define these two terms. So the pulse length PL is basically c tau. I hope it is understood in the previous slide. So basically this is your tau right and this is also known as pulse of the length where c is your speed of light and the values are known. The complete object is imaged or distinguishable if the slant separation between the object is>ct/2 right.

Therefore, Rsr is c tau/2 and ground resolution is c tau/2 cos beta right. I guess it is clear from this diagram. So here basically we want to make sure that A-B is< PL/2 or c tau/2 then these will not be resolved in your image, but if you want to resolve then what will happen the slant separation between the object should be>c tau/2 right.

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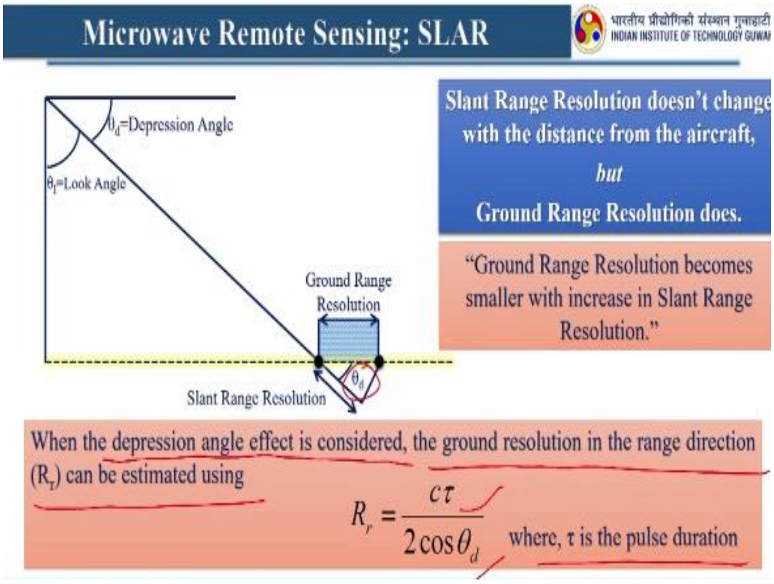

Here in this case what is happening we have already understood this part depression angle and look angle and now we are having a object here or this object or this place we want to sense. So what we will do so we will illuminate from here and that illuminated or the transmitted signal will reach to this particular surface and then it will interact with this area or the object.

So the slant range resolution does not change with distance from the aircraft right the slant range resolution because this is one angle at which we are looking this particular area. So it will not get affected by the altitude distance from the aircraft, but ground range resolution will get affected when you are changing the distance between object and the aircraft. Ground range resolution become smaller if increase in slant range resolution.

And when the depression angle affect is considered the ground resolution in the range direction can be estimated using this formula. So here c tau/2 cos theta d and theta d is basically here and tau is the pulse duration right.

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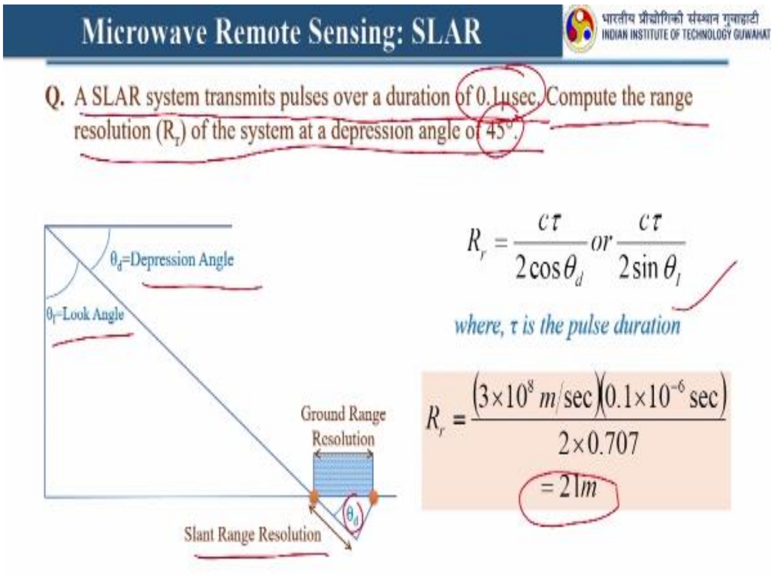

I have a problem for you a SLAR system transmit pulses over a duration of 0.1 microsecond then you have to compute the range resolution of the system at a depression angle of 45 degree. So first you have to understand this question then you draw the geometry and then it will be very easy. So before solving you do not see my next part of this lecture. First you solve yourself then you go for the next video.

Now here we have drawn this is the depression angle this is look angle and this is slant range resolution this is theta d so what value we have. We have depression angle of 45 degree and this pulse over a duration of 0.1 microsecond. So you can use this formula and you can calculate the value. So here this result will be 21 meter. We have already discussed this synthetic aperture radar in the previous slide. So where we had this RAR and synthetic aperture radar right.

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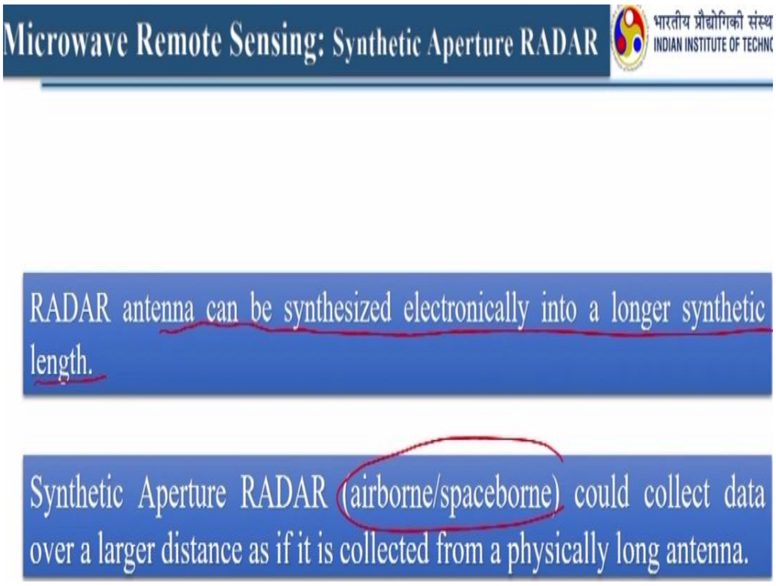

So let us see what exactly we can do in synthetic aperture radar. So radar antenna can be synthesized electronically into longer synthetic length. So this is the advantage when we are going for SAR so SAR is synthetic aperture radar. Synthetic aperture radar which can be airborne or spaceborne could collect data over a large distance as it is collected from physically long antenna. So this is the advantage you have when you have SAR.

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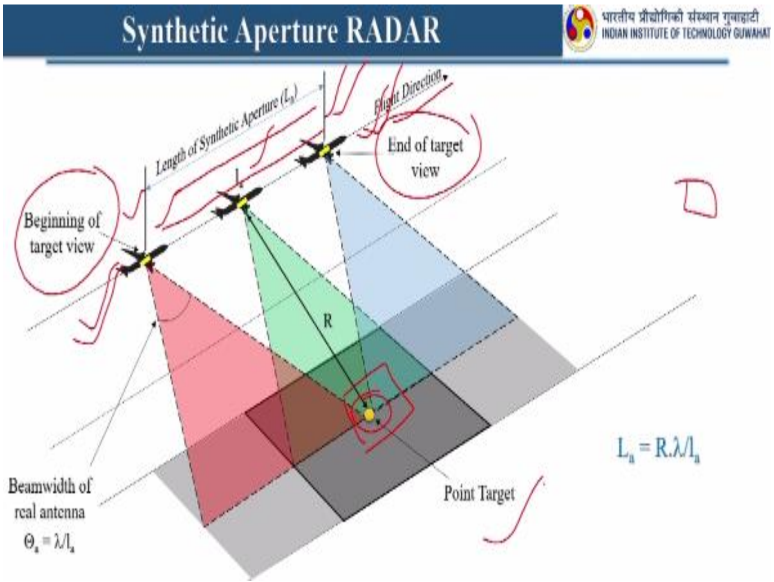

Now in this line basically I want to explain you how this synthetic aperture radar works. So here in the first position and the third position you can compare the position has been shifted right. So what is happening here this is the beginning of the target view. So from here it will see this particular target then this is the length of synthetic aperture radar and how it is done because the signal will be transmitted from here.

And the shift from here or here right that is the length of the antenna we are going to synthesize and this is the flight direction this is end of target view. So if you see this particular target have been targeted from the beginning and here it was done. So this antenna maybe 1 meter, but this distance could be 1 kilometer. So this has been synthesized using this electronic device.

So here this is the flight direction this is the end of view this is basically the first view then second and third view and this is the point target right. I hope you have understood this one.

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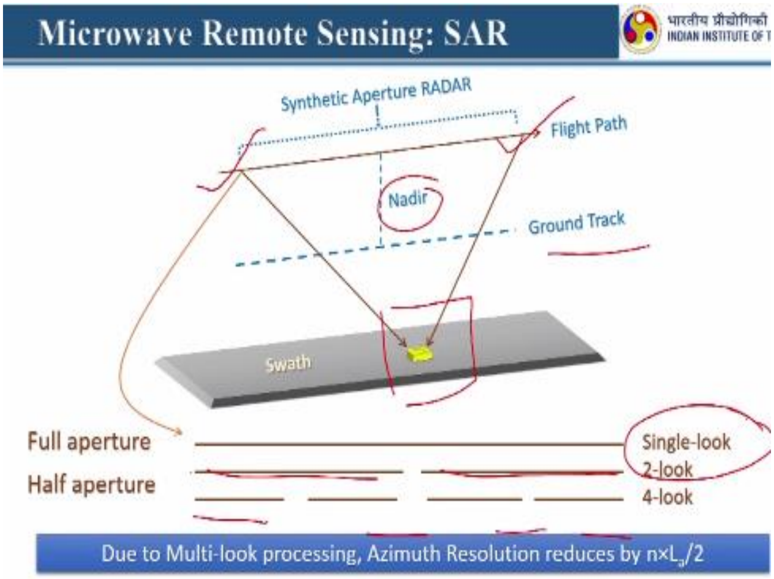

Now let us understand how we can image this particular object using this synthetic aperture radar. So assuming the position of this target here and this is synthetic aperture radar and if you draw a perpendicular vertically down and which meets to your ground that will be your Nadir which is here right and then you have ground track and you can obviously see as they have seen in the previous slide.

You can target this particular object either from here or you can illuminate from here or you can sense from here. In full aperture basically this is known as single loop. When you are having 2 loop that means you are dividing into 2 parts. In 4 it will be known as four loop. So in case if you are having single look image that means it will have certain limitation. When you are having 2 look that means you are going to add more information when you are having 4 look it will have further more information.

So you can increase this look depending upon the device you are going to use or the technology or the technique which you are going to follow.

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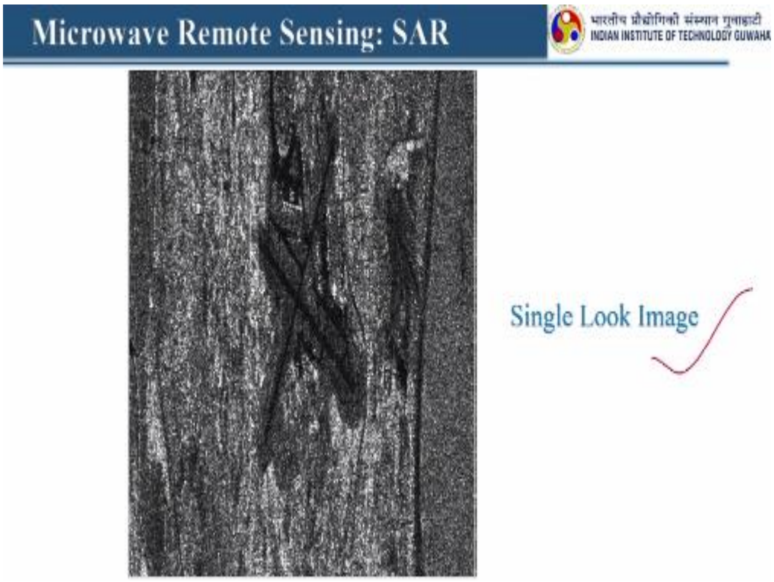

Here in this case the single look image will look like this.

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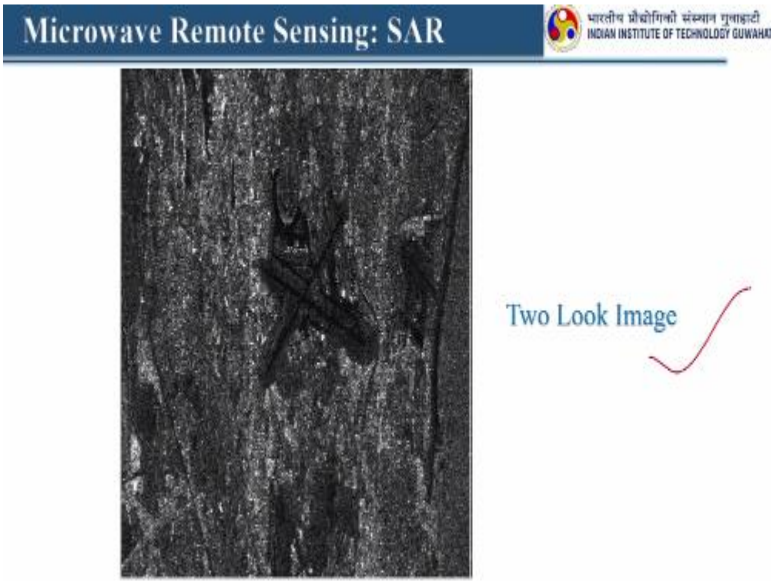

Then Two look images will look like this.

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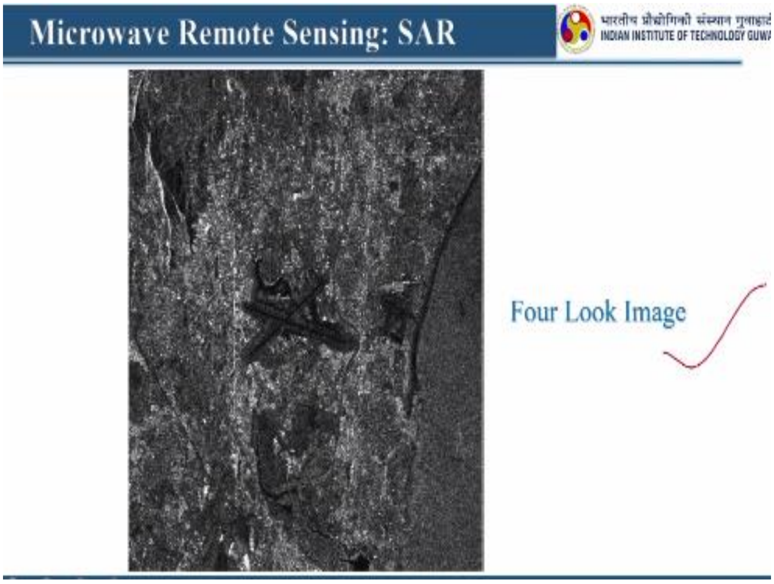

Four look like this.

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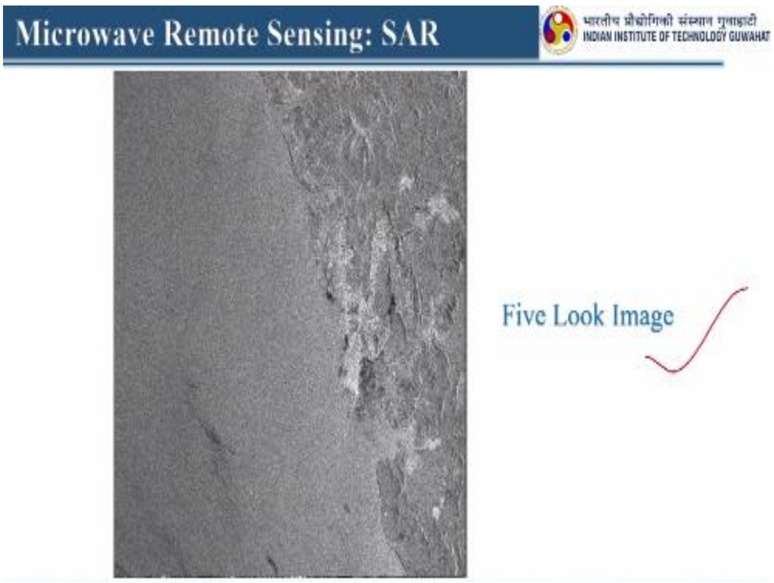

Five look like this.

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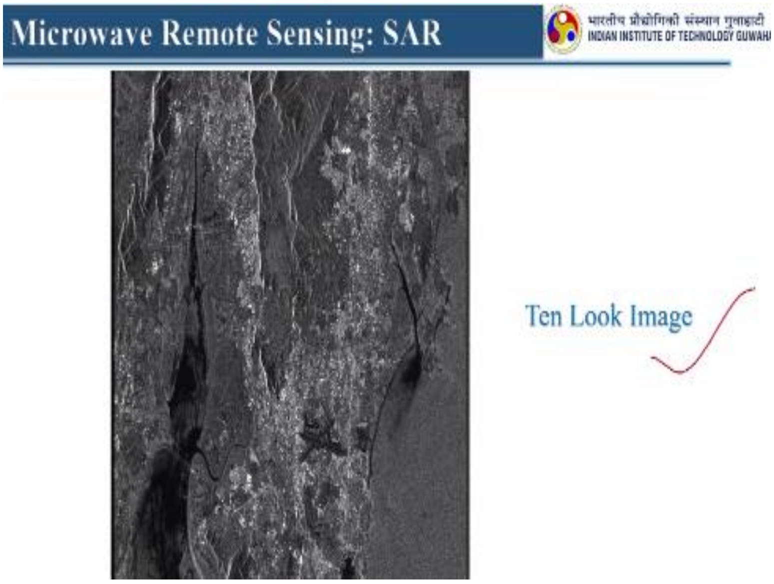

Ten look like this. So obviously the 10 look will have maximum information about the area or the target right. So in Microwave Remote Sensing especially in synthetic aperture radar since we are going to synthesize the length of the antenna we can image the area from maybe 2 or 3 or maybe 4 positions and then accordingly we can generate multi look images right.

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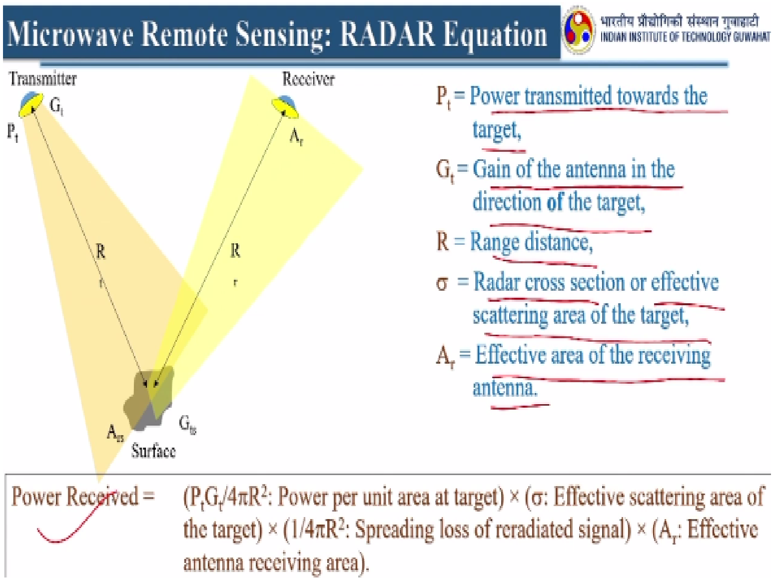

So how basically this image has been generated using the radar equation. So you can see here we are using this power transmitted towards the target then Gt is basically gain of the antenna in the direction of the target R is range distance and sigma is radar cross section or effective scattering area of the target then Ar is basically effective area of the receiving antenna. Using this we have calculated the received power right.

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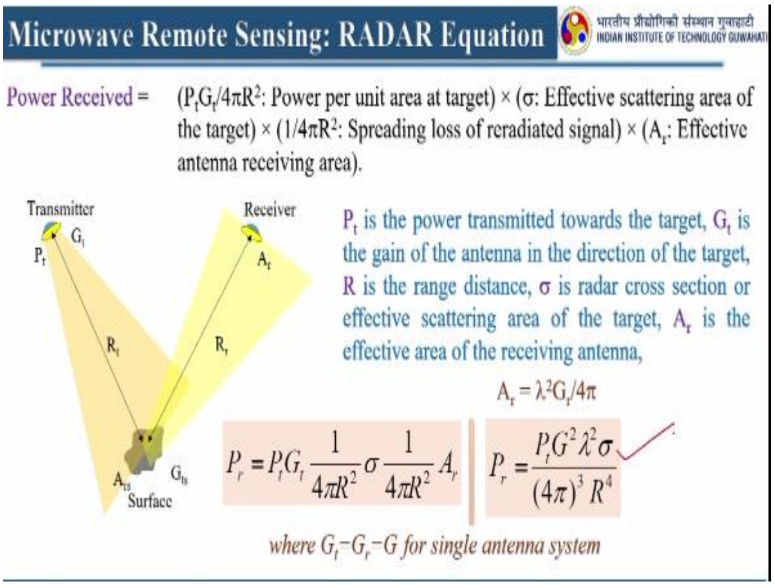

Here further we want to modify it because we want to make it simpler and then finally this is your equation for power received.

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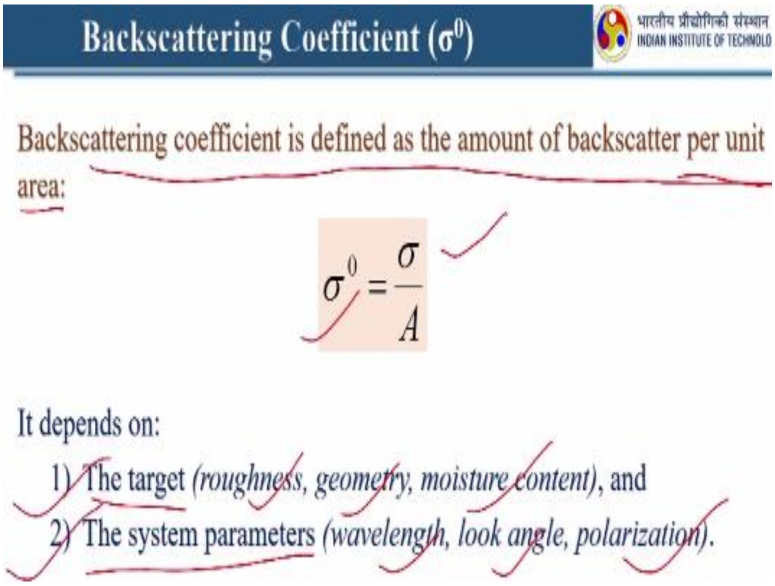

In backscattering the coefficient plays a very significant role. So backscattering coefficient is defined as the amount of backscatter per unit area right. So this is sigma ^{0} and this is basically sigma/A. So sigma is backscattered value and A is your area so that will become per unit area and it depends on two main things. The first one is the target and the second one is the system parameter.

So the target will play a very critical role here because roughness, geometry, moisture content they are the properties of your target whereas the system parameter like which wavelength you are using what look angle you are using, what polarization you are using that will also affect this backscattering coefficient. So in case if you are having different backscattering coefficient for the same target.

That means either you have changed this target properties or the system parameters have been changed.

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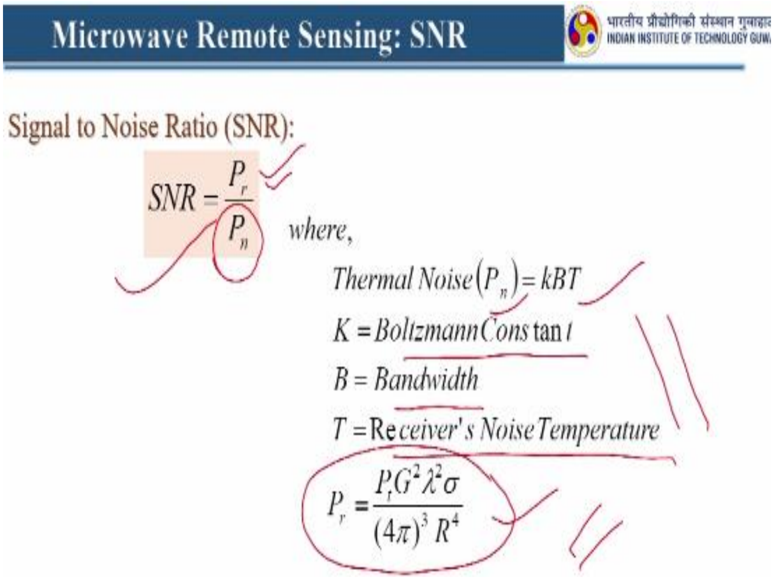

Now the signal to noise ratio this is very important to assess the strength or the quality of your signal. So here the signal to noise ratio is calculated this Pr/Pn. So PR is basically your kBT right and K is basically Boltzmann constant, B is your bandwidth and T is receiver's noise temperature and Pn is basically our signal that we have already discussed in the previous slide.

So this is the equation from radar equation and Pn you can calculate from here. So once you are having this you can easily calculate what is the strength of your signal or what is the quality of your signal using this signal to noise ratio formula right. So here you can see if Pn Pn basically your noise thermal noise. So if Pn is more what will happen the value will be less right. If Pn is very less, then Pr will be more right.

So if the signal to noise ratio is less or low accordingly you have to decide what is the quality of your information. So now as we discussed in the previous few slides different types of imaging technique.

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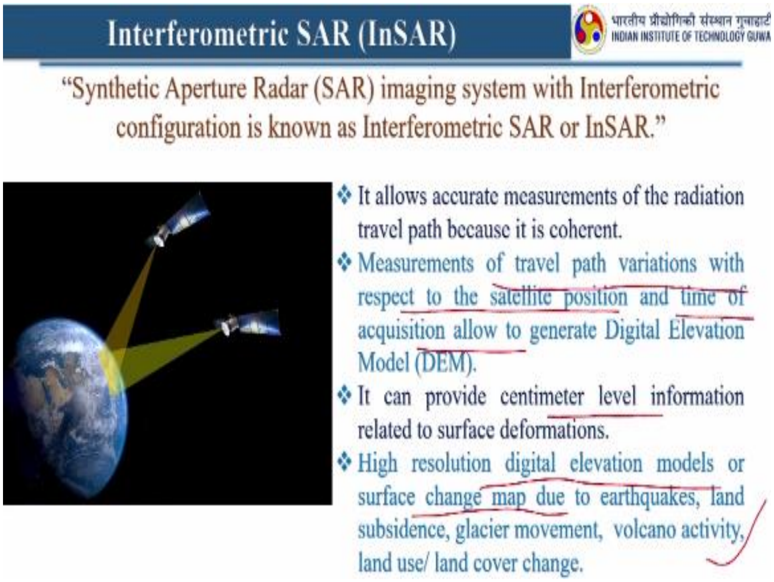

So this is another type of imaging technique which is known as interferometric SAR which is also known as InSAR. So it is InSAR is very popular. So synthetic aperture radar imaging system with interferometric configuration is known as interferometric SAR or InSAR right. So what it does is it allows accurate measurement of the radiation travel path because it is coherent.

Measurement of travel path variation with respect to satellite position and time of acquisition allow to generate digital elevation model right. It can provide centimeter level information related to surface deformation and the next point is high resolution digital elevation models or surface change map due to earthquake, land subsidence, glacier movement, volcanic activity, land use land cover change can be estimated accurately using this InSAR.

Why because it is something like Photogrammetry I have taught you if you are changing the position of the observer and if you see the same material from two different position the information will be different and you can exactly pinpoint there properties especially the geometric properties. So that is why in InSAR you have capability to measurement of travel path variation with respect to satellite position and time of acquisition.

And which actually allows us to generate the digital elevation model and it can centimeter level accurate. High resolution digital elevation model or surface change map are very common product from this InSAR and the application of this InSAR is in land subsidence, earthquake, glacier movement, volcanic activity, land use, land cover change. So these are very popular application of this InSAR technology.

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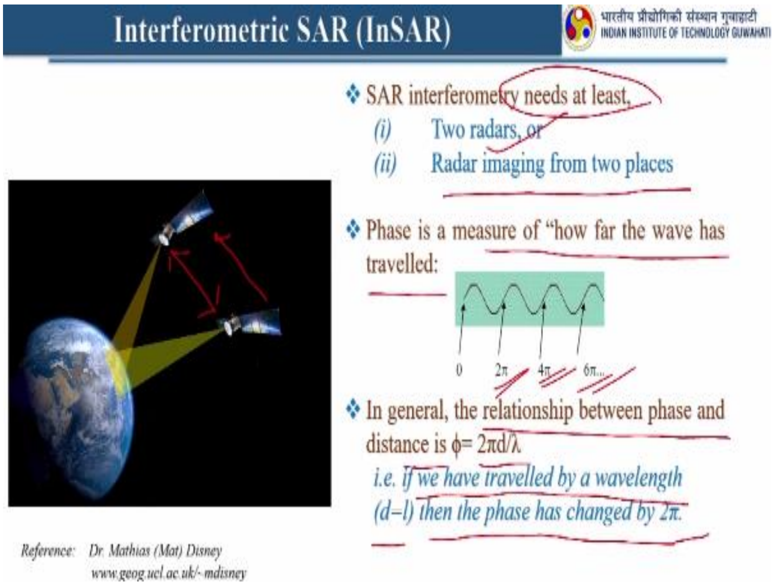

So how do we do this SAR Interferometry. So basically we need at least two radar right. We can have this two different radar or radar imaging from two places right. So maybe this itself will move after certain time and then it will see that object from there, but the time lag should not be high. The phase is measured of how far the wave has travelled. So if it is here then it will be 0 then 2 pi, 4 pi, 6 pi accordingly this phase difference will be measured.

In general, the relationship between phase and distance is 2 pi d by lambda. So that is if we have travelled by a wavelength d=1 then the phase length has changed by 2 pi that is why this is 2 pi, 4 pi, 6 pi right. So this is in case of InSAR.

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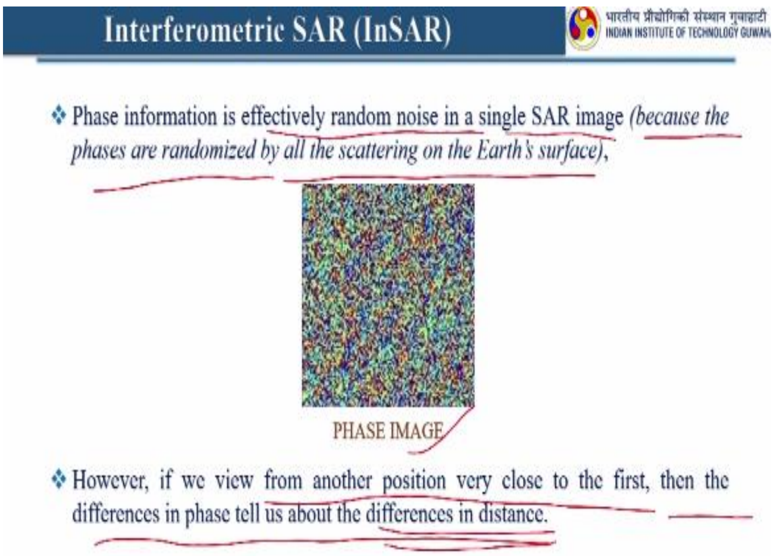

In InSAR the phase information is very important and we are generating this phase information why because we want to effectively calculate or estimate the random noise in a single SAR image because the phase are randomized by all the scattering of the earth surface. So your phase image will look like this and once you have this phase image then you can predict your material.

However, if we view from another position very close to the first then the difference in phase tell us about the differences in the distance. So basically if we have measured the same target from two different location we can generate the phase information and once we have the phase information you can easily identify the differences in distance and then you can use this data.

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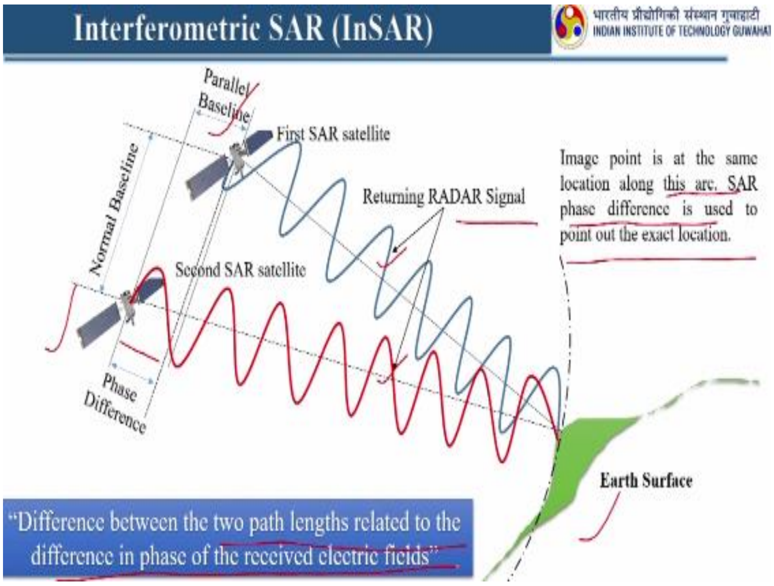

So here if you see normal baseline that is the distance between these two satellites right and this is the phase difference. So here the phase difference is this distance and the returning radar signal is 1 and 2 and image point at the same location along this arc. SAR phase difference is used to point out the exact location because in DEM generation you need to be very sure about the location and basically the accuracy has to be more.

This is our earth surface so difference between two path length related to the difference in phase of the received electric field.

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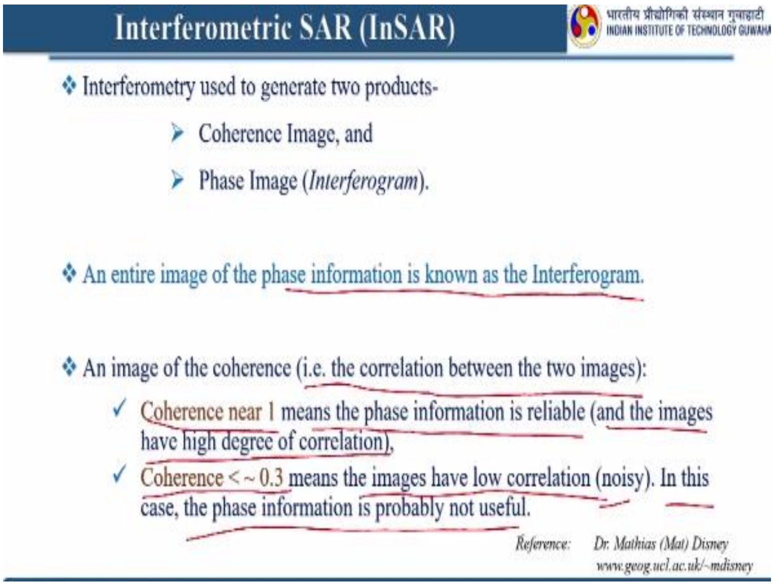

So in Interferometry basically we generate coherent image and phase information. So the entire image of the phase information is known as Interferogram and image of the coherence that is the correlation between the two images. So if the coherence near 1 that means the phase information is reliable right and the image has high degree of correlation because you have generated both the images from different position.

Now the coherence< or = or close to 0.3 means the image have low correlation and basically it is noisy. In this case the phase information is probably not useful. So before analyzing your phase information right or the Interferogram you have to generate the coherence image and the coherence image value need to be checked for the consistency or the accuracy of your data right. In Microwave Remote Sensing the level of information is different the quality of the information is different.

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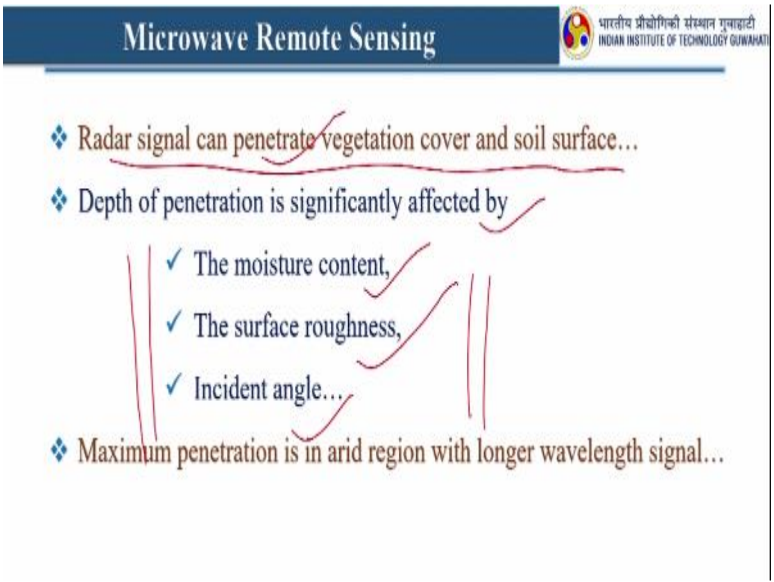

So let us understand what exactly we can do here which we cannot do in optical remote sensing. So radar signal can penetrate vegetation cover and soil surfaces why because wavelength is long. Now the next is depth of penetration is significantly get affected here because the depth we are saying it can penetrate, but how far so that defined by moisture content of your surface and the roughness and the incident angle.

So it is very important if you are going for subsurface studies or the geometry related studies or the moisture content estimation then you need to understand these are the limitations of the Microwave Remote Sensing data. So it can give you the information, but you need to take care of all this. Maximum information about this penetration can be achieved with the longer wavelength.

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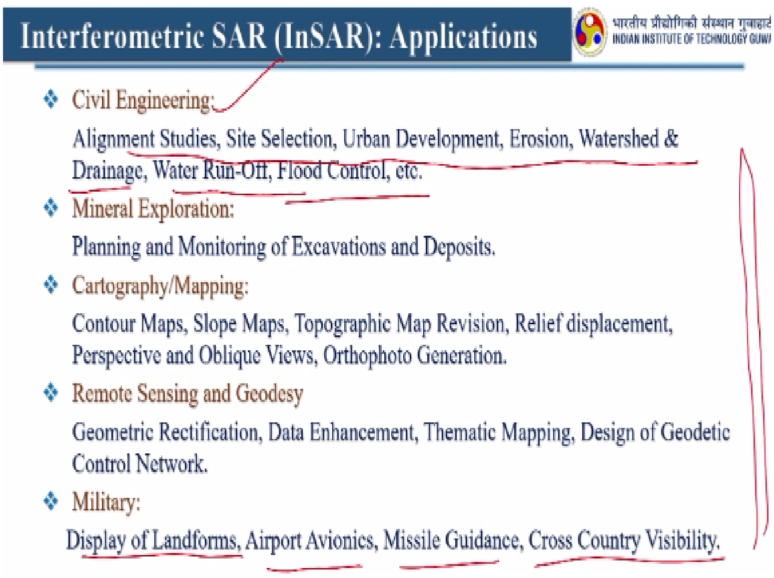

And several application of InSAR have been reported. You can see many papers in civil engineering, in mineral exploration, cartography or mapping, remote sensing and geodesy and military application. So if you see civil engineering, alignment study, site selection, urban development, erosion, watershed, drainage, water runoff, flood control etcetera are common application.

In military display of landform then airport avionics, missile guidance then cross country visibility. So this is actually a brief list of the application of InSAR data right. You can go through it, you can search some paper where people have already use this InSAR technique.

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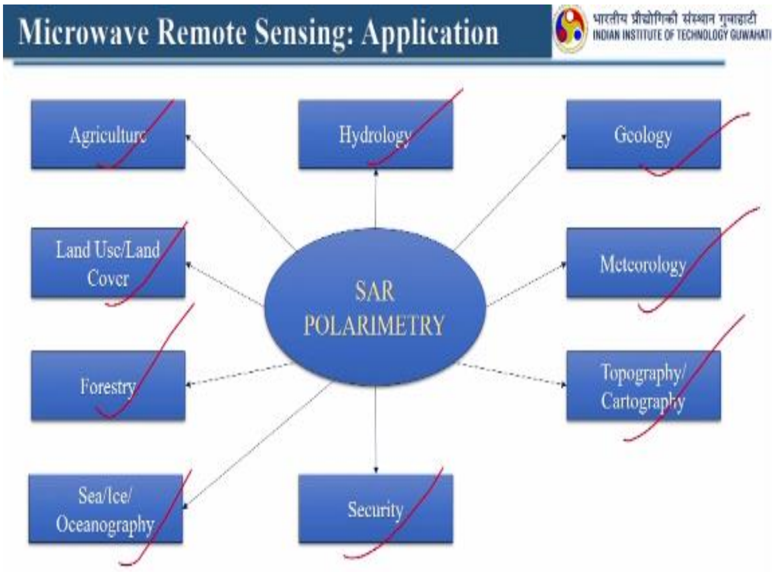

So altogether Microwave Remote Sensing has application in all the areas. So starting from geology, meteorology then topographic at cartography securities, Sea ice, oceanography, forest, land use, land cover, agriculture, hydrology. So everywhere it can be used provided you should take care of the data generation and the analysis.

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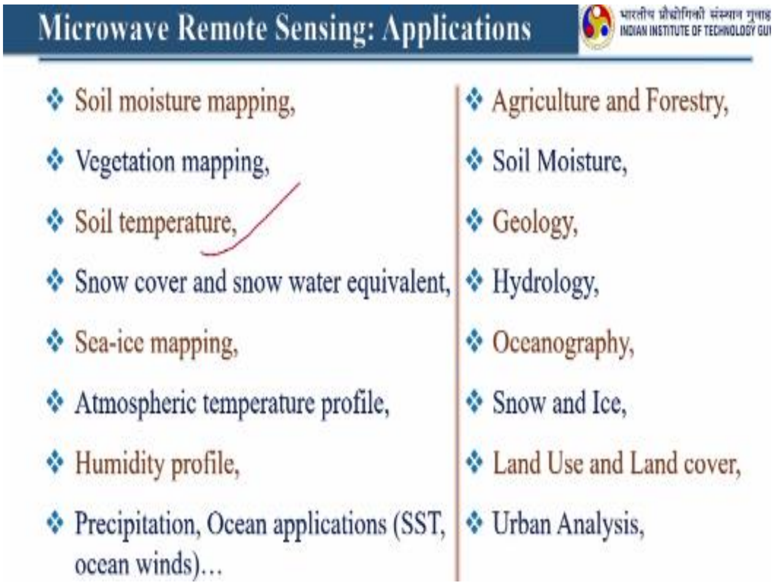

And here we have some list like soil moisture mapping, vegetation mapping, soil temperature, snow cover and snow water equivalent, sea ice mapping, atmospheric temperature profile, humidity profile, precipitation, ocean application right in other application like agriculture and forestry, soil moisture already this soil temperature I have mentioned, geology, hydrology, oceanography, snow and ice, land use, land cover, urban analysis.

You can use this technology you should be able to interpret the data. So before that you need to go through all this basic, understand the technology and then accordingly select a appropriate data for your application right. So that is all for today. Thank you.