Remote Sensing: Principles and Applications
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Lecture-44
Active Microwave Remote Sensing-Radar-Part-1

Hello everyone, welcome to the next lecture in the course remote sensing principles and applications. In the last lecture, we discussed and concluded the topic of passive microwave remote sensing or passive microwave radiometry. From this lecture onwards we are going to discuss about active microwave remote sensing especially the imaging radar.

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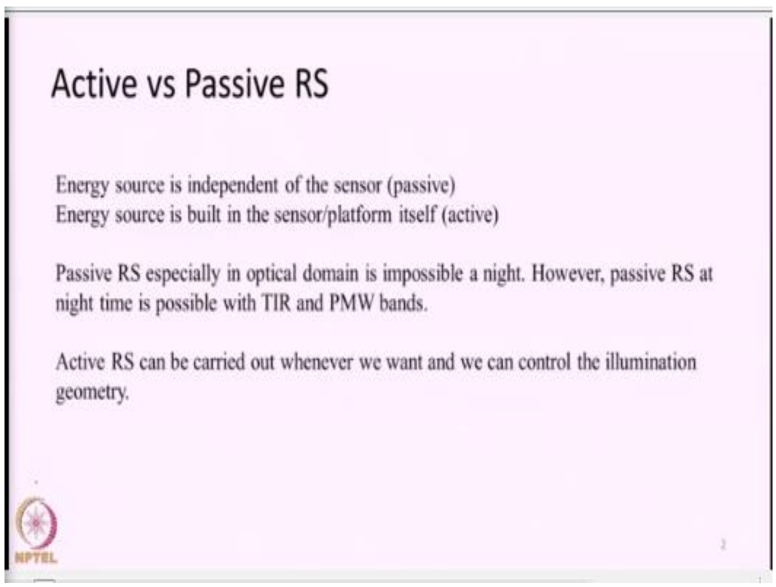

First of all, we will quickly recap what is active remote sensing and what is passive remote sensing? In passive remote sensing the sensor observes passively the energy coming in from the earth, the sensor is a mere observer of the energy that is coming in from whatever be the source, say earth surface.

In active remote sensing, the sensor produces electromagnetic radiation, transmits it towards the target of interest and gets the signal back. So, in active remote sensing, the sensor itself acts as both source and receiver of electromagnetic radiation. Whereas, in passive remote sensing the source of electromagnetic radiation is something else, say in optical remote sensing and visible, NIR domain, the source of electromagnetic radiation is the sun.

In thermal infrared domain, the source of electromagnetic radiation is the earth surface. So, these are all passive mode, the sensor is not producing any EMR, it is a mere observer. In active mode, the sensor itself will produce electromagnetic radiation and send it. So, what we are going to get introduced to is an active mode of remote sensing. That is, the remote sensing system itself will generate electromagnetic radiation, and here we are going to talk about microwave radiation.

So, the wavelength ranges is in the order of centimeters. So, the sensor itself will produce electromagnetic microwave radiation, it will transmit towards the earth surface and it will get the signal that are received back from the earth surface. So, what advantages do active remote sensing have over passive remote sensing? In active remote sensing, we can collect data in any time of the day.

If you take passive remote sensing, especially the optical that is visible, NIR and SWIR wavelengths, we can collect data only during morning hours, when there is sun or daytime. During nighttime we cannot collect data in visible and NIR domain, in thermal it is possible anyway because earth emission is going to keep on continuing whether it is day or night.

In active remote sensing also, it is possible to collect data at any time we want, that is a major advantage. And second is we can control the geometry between the source of EMR, the target of interest and the sensor. That is in optical mode we have seen that objects will look different based on differing illumination conditions and the sensor viewing conditions, that can be controlled to some extent in active remote sensing.

We can decide especially if we are doing remote sensing from an aircraft. It is almost possible for us to control the object of interest we would like to image it from this particular angle at this particular height and everything. We can control it to good extent which is completely not in our hand in optical remote sensing.

So, this control over the source or target and the sensor geometry is a major advantage in active remote sensing. And we have already seen, microwave provides us complimentary information to what we get from optical visible and NIR wavelengths. Complimentary means, in visible and NIR wavelengths, we get information about the chemical composition offered, the structure of the objects, within it, discontinuation and all.

In microwave remote sensing, we will get to know the properties of the land surface which are highly controlled by the electrical and physical nature like, the dielectric constant will influence the microwave emission. So, the electrical nature of the object, the surface roughness that is the geometric properties of object, all these things which are complimentary information to what we get from optical remote sensing. So, these are all some comparison between active and passive mode of remote sensing especially in the microwave domain.

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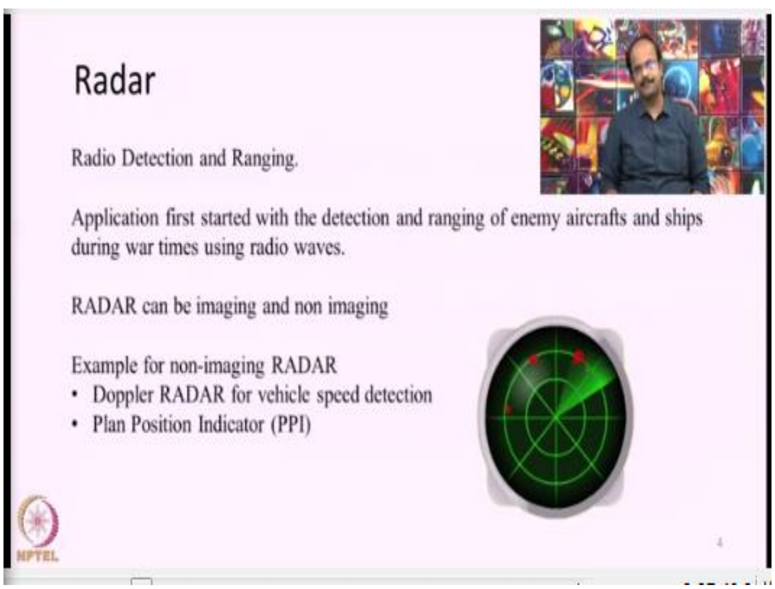

So, what exactly is active microwave remote sensing? In active microwave remote sensing what we are going to discuss is the imaging radar. So, what exactly radar is? Radar is an acronym that stands for radio detection and ranging. So, in the earlier days, during world war times, this particular technology was used for surveillance of incoming enemy aircrafts. That is, microwave transmitters will be fitted along the borders and they will be transmitting radar pulses continuously.

If at all any metallic objects like aircrafts comes in within this vicinity of electromagnetic pulse, the microwave pulse will be reflected back and it will be received at the radar indicating it. So, these are all some of the earliest uses of radar, and even the nomenclature of microwave, the PLSCX band, those uncommon names do not have any meaning or physical sense. They are also framed especially for strategic purposes, people wanted to designate each frequency using a secret code. So, they were all actually the secret codes that we have used in the olden days for military applications. So, the radar technology was developed for mainly military purposes.

But later people realized the civilian applications for which those systems can be used. Nowadays we use ground based radar for monitoring clouds, for rainfall forecasting over a city. Major cities have their radar systems fitted at certain locations which will be able to monitor the clouds moving in or moving outwards a city. Even in airports we have this plan position indicator which will be indicating, where an aircraft is. Similarly our police officers can track the over speeding vehicles using a Doppler radar. So, these are some of the examples for which radar is widely used.

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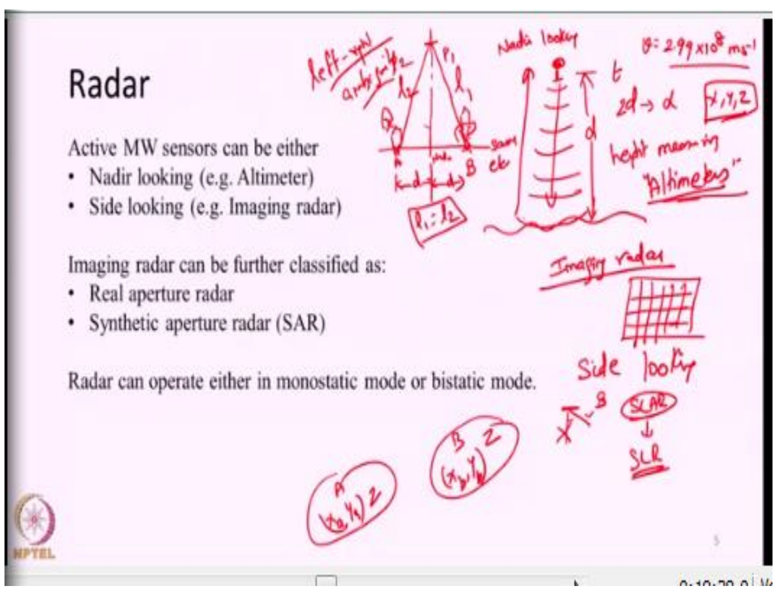

So, a radar is basically a sensor which will transmit microwaves. Here even though the acronym stands for radio detection and ranging, initially when it was formed, it was formed with respect to radio waves which is as much longer wavelengths. So, we have a system which will produce electromagnetic radiation with a given frequency and that will transmit the electromagnetic radiation, then it will receive the signal back.

So, most of the radar operations happen by calculating the time taken for this electromagnetic radiation to go and come back. Say it measures the distance between the source of EMR, that is the sensor itself, and the object that is any earth surface features by calculating the time taken for this electromagnetic radiation to pass 2 way. It has to first go, if there is an object it will be reflected and it will come back.

So, the time will be used to calculate the distance, that is one thing, and then the system will also record the incoming power in some form, how much power the system transmitted, how much power came back? It will measure the power of the incoming signal and the system can also measure the polarization of the electromagnetic wave that is being received. So, polarization is nothing but the orientation in which the electric field is vibrating.

So, that information can also be saved. So, essentially radar is like sending some signal, measuring it back and calculating the distance, calculating the power and it will measure all these things to give us some useful information. So, the active microwave sensors or radars are airborne or satellite based systems either nadir looking or side looking, so what exactly these are?

Say we have an aircraft and it will have a radar system. Let us say this is a nadir looking system. So, this nadir looking system will transmit microwave signals which will move towards the earth surface. Then it will interact with the terrain surface feature, then once it hits the terrain surface feature, it will go back. Based on the time taken, we know the velocity of EMR which is roughly 2.99×10^8 m/s. So, we know this velocity, we can calculate what time it takes for the electromagnetic radiation to travel from here, reach the surface and go back. So, that will give us this distance d. When calculating the time, we will calculate 2d, one in the downward direction and one in the upward direction. By knowing the velocity and time, we can derive the distance between the radar antenna and the ground surface.

These are actually height measuring devices or height measuring sensors which we call technically as altimeters. Like the class of radars, which looks at nadir, exactly at downwards, which measures the distance between them, we call them as altimeters. And we use them for measuring the elevation of various objects on earth surface with respect to certain data. Whereas, the radar that we use or we are going to see in our class comes under the classification of imaging radar. Altimeters will provide us x, y, z information, they are not imaging systems, they provide ground elevations for different positions on the earth surface. Whereas, we are going to discuss about imaging radar, which will produce a 2-dimensional image of the terrain.

So, the 2-dimensional image of the terrain will be produced by radar that is side looking not nadir looking. That is, if this is the aircraft platform, the radar will be looking at some angle away from the nadir. So, it will not be looking at nadir like this, it will be looking at an angle away from the nadir. So, essentially the imaging radar all are side looking radar. we can call it as SLAR side looking airborne radar.

So, why imaging radar are sides looking radars? Basically this is to avoid what is known as a left, right ambiguity. That is let us say we have 2 points on the ground surface, A and B. Both of them have the same elevation. So, let us say we have a radar that is looking at the nadir and let us say the horizontal distance is exactly the same from the center point. If this is the case, we know that radar measures basically the distance, so essentially the distance between this point and this point. Point A and similarly point B are one and the same right because they form like a similar triangle.

So, this distance let us say L_1 and this is L_2, then L_1 and L_2 will be equal. If these 2 points are exactly at the same horizontal distance from the nadir point and also at the same elevation without any difference. If this happens, then for altimetric purposes that is ok, that is point A has a coordinate Xa, Ya, it has an elevation of Z, point B has a separate planimetric coordinate Xb and Yb, it again has an elevation Z, no problem for us. We can record it and use it, but let us say if we need to image them, we have an imaging radar. Let us say we have a house here, we have a tree here, and our system is capable of producing image of both of these. So, whenever the range comes in, it will measure the distance and then it will measure the power that is returned back. Since these 2 features are different, the power that is returned back will be different.

Say the power returned from one feature will be P_1 and the other will be P_2. But once these 2 reach the system both of them will reach at the same time because of the same distance. There will be an ambiguity in the system and there are chances that these 2 objects are swabbed in the horizontal position. By some mistake, this point A can be mistakenly taken as tree, this point B can be mistakenly taken as a house.

It is possible; this is what we call as the left-right ambiguity. So, in order to avoid this, the radar is going to spread in 2 directions and going to measure the distance. But if we need to produce an image out of it, there are some chances the image points or the ground points may be swabbed because both the features are at the same distance. So, there can be a confusion in the radar system. In order to avoid this sort of ambiguity for imaging systems, the imaging radars are will work with the principle of side looking, they will not be nadir looking; they will be side looking**.** If you are just measuring x, y, z elevation information, no problem we can do it, nadir looking as like people will normally do it altimeters. But for imaging purposes, this may not work for certain circumstances; it may produce some sort of ambiguity.

So, the side looking radar will work by looking at like this, then it will be transmitting the pulses and receiving it back. Hence, if a platform is moving in one particular direction, the image will be created only in one side of the platform. Let us say this is the satellite, it is moving like this, coming in towards the screen view. So, let us say that radar is looking something like this, so the radar will be moving like this. So, only that portion of the terrain that is on the right side of the satellite will be imaged. So, the features on the left side will not be imaged. So, the side looking radar just maps only one side in order to avoid this left right ambiguity. Whereas if it is a nadir looking, it will measure the entire terrain both on the left side and right side of the satellite that will give rise to this left right ambiguity.

The side looking radar itself can be classified as real aperture radar and synthetic aperture radar. So, real aperture radar means the antenna length whatever is there fitted in the system is treated as the true length of antenna. In synthetic aperture radar, by data processing means we increase the antenna length, increase means not physically, but electronically we increase it, so that it will improve the image characteristics, we will see it in detail later in the lecture. So, it can be real aperture radar or synthetic aperture radar that is another way of classification of imaging radar. And the radar systems can be monostatic or bistatic, what exactly monostatic and bistatic is? See the radar itself has to produce EMR, transmit and receive back. So, there can be 2 radar antennas for sending and receiving the pulses.

Like in passive microwave radiometry we just got to know the concept of antenna. So, the antenna can be the same. One single antenna will transmit electromagnetic radiation, then it will switch to receiver mode and then you will receive the signals reflected back, this is called monostatic configuration. Only one antenna is present, transmission and reception both are happening within that only one antenna. Whereas, in some radar systems there can be 2 antennas in which one can transmit and one can receive. So, this kind of system is also possible. So, one will transmit and one will just receive, so 2 antennas are doing 2 different functions. So, such system which has more than one antenna to transmit and receive are called bistatic radars. But most of the satellite based radar systems are monostatic, they have the same antenna that will act as both transmitter and receiver. So, we already got to know a very brief introduction about how a radar system works, we will just see it little bit in more detail.

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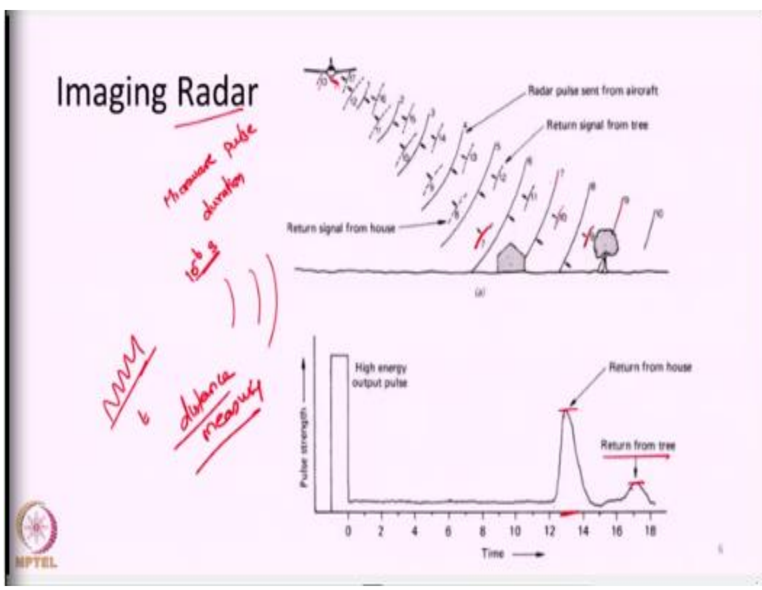

So, this is the aircraft in which the radar is mounted, the antenna is looking like this. So, this will transmit a microwave pulse, we call it as pulse for a certain duration of time, that is let us say 10^{-6} seconds. So, this will transmit some electromagnetic radiation for certain length of time. For a time period of T it will be transmitted, so there will be one pulse in the air.

So, this electromagnetic pulse will start slowly spreading out once it is transmitted like plane waves. So, it will start slowly spreading out and it will come here. There are features on the earth surface and then at this particular instant it is going to interact with this house. So, when it interacts with this particular house, it will generate a signal here. This is the reflected signal from the house at time instance 7. Similarly there is a tree at a little bit farther distance from the aircraft, so the radar takes little bit more time to reach this, gets reflected back and it again moves away towards the radar itself. So, this is the return from house that is recorded at this particular instance, this will reach the aircraft first. Because of the shorter distance this will be reflected soon and it will reach the aircraft first, so it will be recorded here. Then the tree which is at a farther distance from the aircraft, will reflect and the signal will reach the aircraft a little bit later time. So, the radar system will calculate that the house is nearer to the radar system, the tree is farther to the radar system. So, the distance will be calculated like that, and the power that has returned will be also recorded.

So, essentially a radar is a distance measuring device, it measures distance in order to map the surface that is underneath it. So, it calculates the time or it calculates the distance based on the time taken for the electromagnetic radiation to travel through from the point of origin to point of reflection and then coming back.

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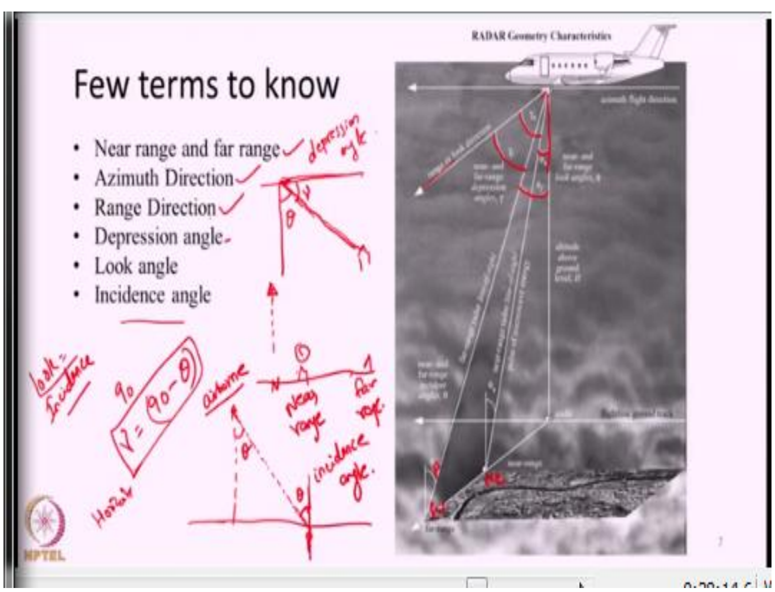

So, before we move further in understanding the concepts of active or imaging radar, we will first get introduced to few terminologies that we use in active microwave remote sensing. The first thing is 2 terms known as range direction and azimuth direction. While we discussed about how a optical satellite collects data in optical and NIR domain, we came across 2 terms along track and across track, similar terminologies are used here. So, if you measure anything along the direction of the motion of the aircraft or satellite, we call it as azimuth direction. The direction that is perpendicular to the direction of motion of the platform or satellite, we call it as range direction that is across track.

Hence, we measured the range, that is we measure the distance in a direction that is perpendicular to the direction of motion of this platform, and hence we call the direction as range direction. So, if some object is present near to the aircraft, we call it as near range that is closer to the nadir point. So, near range means closer to the radar system and far range means away from the radar system. We have seen now, these 3 terms azimuth direction, range direction, and near range and far range. The depression angle is the angle made by the horizontal, say this is the point in which the radar antenna is positioned. So, we draw an horizontal plane with respect to that point, then say this is a object of our interest. Draw a line from the object of our interest connecting all the way up to the radar antenna, this will form a straight line, along this line we will measure the distance, say from the antenna to this object.

The angle that is made with respect to a horizontal plane and this line connecting the object with the radar, we call it as depression angle**.** So, this is depression angle, here the horizontal is measured like this, so depression angle of different points are given here. So, for point N the depression angle is with respect to this, similarly for point F, the depression angle is this, so this is near range, this is far range.

The look angle or complementary of this 90- depression angle is look angle, that is the angle we measure with respect to this vertical we call it as look angles. So, here this is the vertical from the antenna. So, with respect to this vertical, the look angle is this for near range point N, this is the look angle for far range point F. So, depression angle and look angle are complementary to each other. So, depression angle equal to 90 - look angle and vice versa.

So, depression angle is your measuring angle with respect to horizontal plane, look angle is your measuring angle with respect to vertical line. Then what exactly incidence angle is? Incidence angle will tell us the angle at which microwave signals reach a particular terrain point, that is let us say we have an horizontal point on the earth surface, horizontal ground, this is like the aircraft.

So, this is the radar point and this is the line connecting the radar and our object of interest, say this is the point P at which we are interested upon. So this particular angle θ is the incidence angle that is the line joining the ground point and the radar antenna. So, for a flat horizontal surface the look angle and incidence angle are one and the same. So, if we are doing remote sensing from aircraft. Then essentially the look angle and incident angle will be one and the same for flat horizontal surfaces. If the surfaces not flat or if the surface is sloping, then the incidence angle and look angle will differ.

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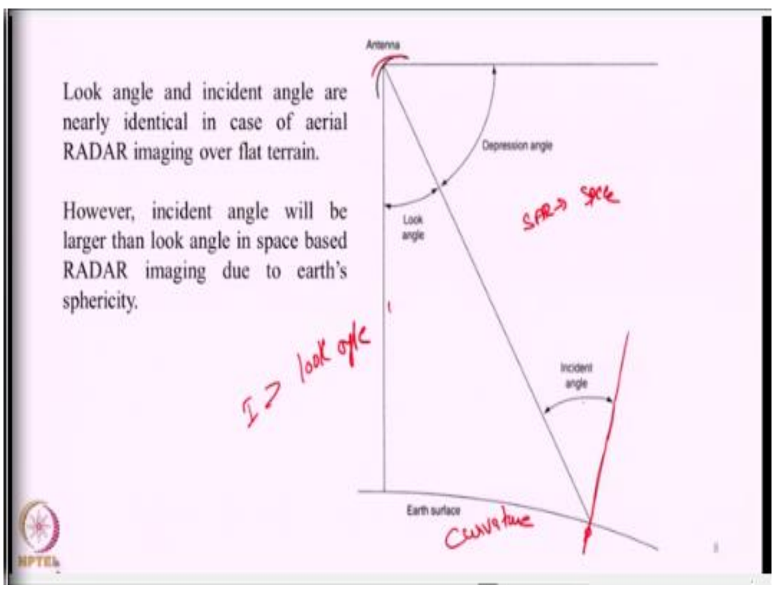

Also for curved surface like earth, when you are measuring from satellite where the curvature of earth comes into picture. Then the incidence angle will always be greater than look angle. Say this is like earth surface which is curved; you are measuring it from antenna like a satellite. The distances will be huge and hence this is the point P, this is the local vertical or vertical establish at that particular point. This incidence angle will always be larger than the look angle, when we take into account the curvature of earth into picture. And when we are doing SAR remote sensing or active remote sensing from space satellites when the height involved will be in the order of say

600, 700 kilometers effectively the curvature of earth will come into picture. So, the incidence angle and look angle will not be the same.

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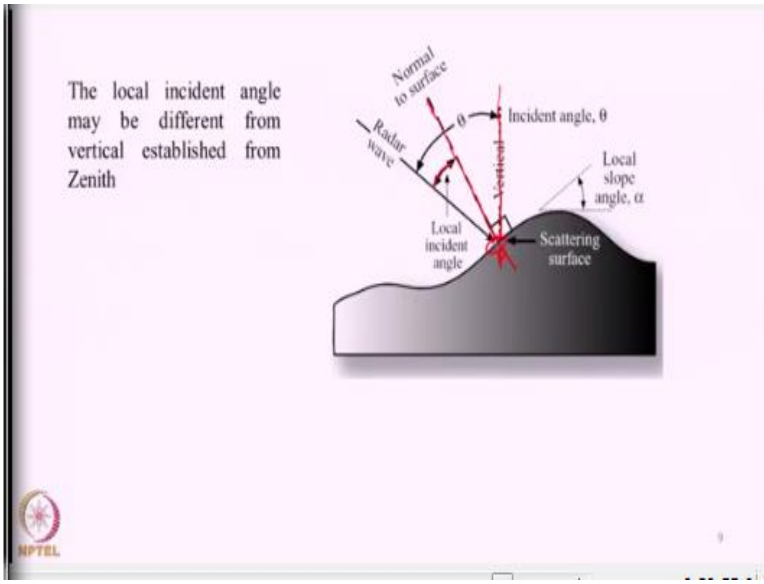

And similarly, if the surface is not flat, if the surface is having a slope, here the incidence angle be measured with respect to normal to the surface. So, the local incident angle will be different from the zenith angle at that particular point. So, in order to make it clear, let us just look at this again. Let us say we are flying here, we are observing it from here, and here there is this radar antenna. If you are looking it from the space, you will see the straight line, this will be the nadir point, this will be the zenith point. So, if you are like looking exactly down when you are flying, so the zenith and nadir are established like this. But the normal to the surface, is not this vertical, this is somewhat oriented away from this vertical because the surface is now sloping. So, at this particular point the surface is sloping. So, you draw a tangent to that particular point and then you draw a 90 degree to that particular tangent in order to define the normal to the surface.

So, this normal to the surface you defined by drawing a tangent and the zenith line you define that is by the true vertical. If you are flying exactly looking back that will define the vertical line, these 2 will be different because of the local slope and the local incident angle. For this particular point P will be different from what you calculate from the satellite. Because the terrain may be more or less flat and only at one location it can be like this.

So, on an overall you can assume especially for an aircraft platform, we will be thinking the look angle θ is equal to the incidence angle on a overall picture. But these local points which are at different slopes, they can have local incidence angle that is different from this particular look angle. So, the incidence angle that we calculated as equal to look angle, they can vary based on whether that particular local surface as any slope within it. And also when we take the curvature of earth in the picture, then definitely the incidence angle will be different from the look angle. Because, the incidence angle are always defined with respect to normal to the surface, whereas if the surface is sloping, the normal will move away from the vertical thereby changing the incidence angle.

So, as a summary, in this lecture, we got introduced to the concept of active microwave remote sensing. And we also got defined few terms that we commonly use in microwave remote sensing. With this we end this lecture.

Thank you very much.