Higher Surveying
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Module – 8
RADAR (RADARgrammetry)
Lecture - 27
RADAR fundamentals-I

Hello everyone, welcome back in the course of Higher Surveying. And, today we are going to start a new module called RADAR it is module 8 ok; if, you recall our last module that was the LiDAR. That, LiDAR was the active remote sensing technique, where we have used the source of energy, which was not the natural source of energy or rather LiDAR uses it is own source of energy. Similarly, RADAR is also an active remote sensing technique. And, we want to use the RADAR for the purpose of topographic mapping right.

So, let us go ahead in this module. So, we have 5 lecture or we have a series of 5 lecture in this module. And, the first lecture that we are going to talk today is about the geometric aspects of the RADAR fundamentals. And, these are the books here, like Introduction to Microwave Remote Sensing, Introduction to Modern Photogrammetry by Mikhail, and Principles and Applications of Imaging RADAR right.

So, these books again I will say they are very very expensive and 1 should go to some library or join some institute library, in order to refer these books. Moreover, this lecture series is sufficient enough for the fundamental knowledge. However, someone is interested in higher knowledge should definitely go to the library ok. So, let us get into the module here.

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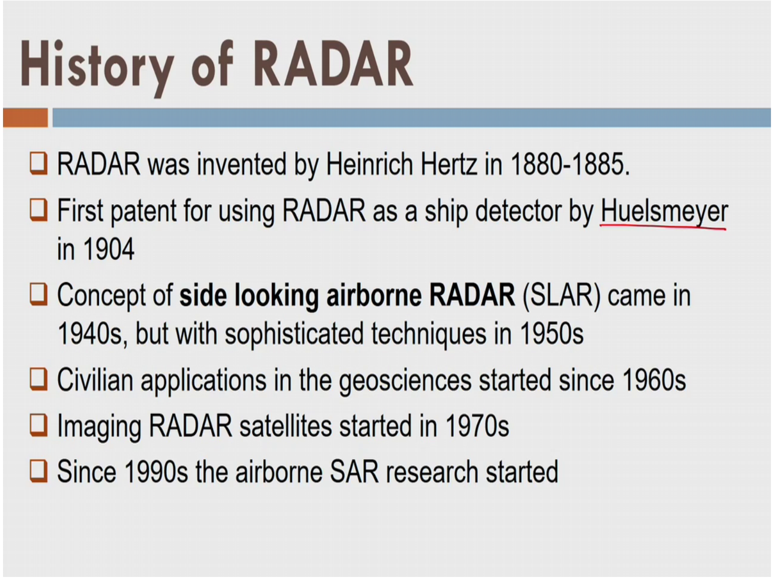

History of RADAR

- RADAR was invented by Heinrich Hertz in 1880-1885.
- First patent for using RADAR as a ship detector by Huelsmeyer in 1904
- Concept of **side looking airborne RADAR** (SLAR) came in 1940s, but with sophisticated techniques in 1950s
- Civilian applications in the geosciences started since 1960s
- Imaging RADAR satellites started in 1970s
- Since 1990s the airborne SAR research started

Now, first of all let us discuss the history of the RADAR. And, I would like to say one thing hear that, the RADAR is stands for radio detection and ranging right ok, but it has it is own course of development. Originally this was developed by Heinrich Hertz by some experiments, where he has conducted his experiments from year 1800 to 1885. And, during this period he has proved the existence of RADAR as well as it is usefulness further in 1904, the first patent was filed by the scientist called Huelsmeyer here and it was the file patent was all about the detecting a ship is in RADAR ok.

Then, the concept of side looking airborne RADAR came into 1940s right. And, it is sophisticated application came in 1950s right. There, thereafter around 1960s the RADAR was used in for the civilian applications. For example, in topographic mapping and maybe some other kind of stuff right finally, the RADAR was first launched on a satellite in 1970s.

Thereafter, it has been widely used as a satellite tool or as a satellite mapping system also right. Finally, in around 1990s the Airborne RADAR research started. So, that is the kind of history, we can get into this thing. And, let us start what is the RADAR basically ok. So, we got the importance of the RADAR in the last previous right, where we have realised that it is almost 100 years old technology. Because, it has invented originally around 1880 and so it is more than 100 years now right.

So, you can understand that how nicely it has been developed and how mature it is now? Ok. Let us start with the RADAR.

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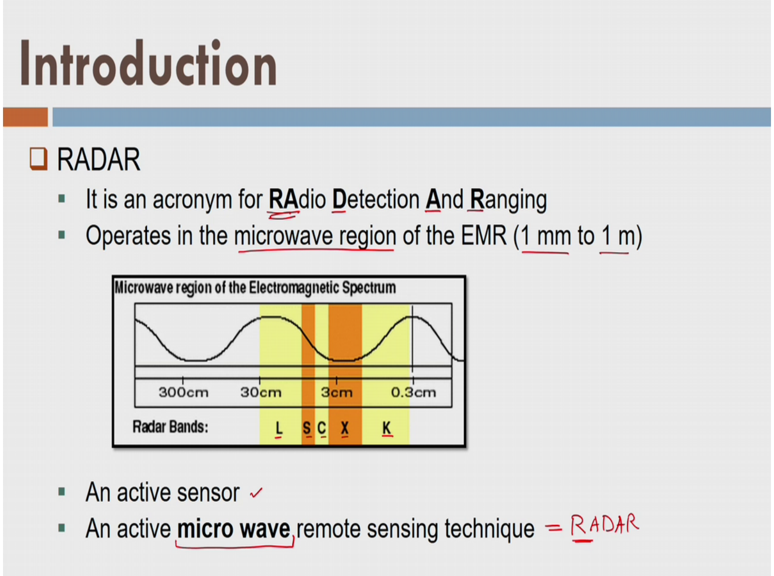

Introduction

- RADAR
  - It is an acronym for **RA**dio **D**etection **A**nd **R**anging
  - Operates in the microwave region of the EMR (1 mm to 1 m)

  - An active sensor ✓
  - An active **micro wave** remote sensing technique = RADAR

So, RADAR stands as I already told RADAR stands for the radio detection and ranging right. And, it operates in the microwave region of 1 millimetre to 1 meter wavelength range. You can see here this RADAR bands are indicated here I band S band C band X band and K band. Well, we have many more bands, but as I already told it is an active sensor.

And, moreover since the RADAR works in the range called microwave wavelength range and that is why we use microwave remote sensing technique or we got to call as RADAR. So, you might be surprised, that why this RADAR has a radio detection here be, but it is using the microwave. So, we will get into this thing as we progress in this lecture.

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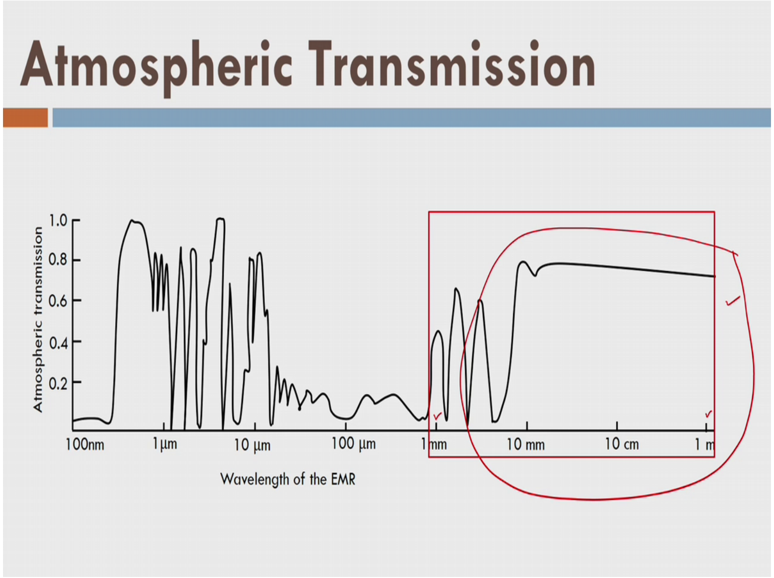

Atmospheric Transmission

Now, we can see here that, this is my electromagnetic radiation. And, the microwave region is also located on the electromagnetic region. And, this microwave region if I indicate 1 mm to 1 meter, it is from this point here to this point here right. And, you can see that the major portion of this electromagnetic spectrum is transparent to the atmosphere, which means that someone who is have who is on the earth surface, if he is sending some RADAR energy or the RADAR signal it will passed through the atmosphere and it can go to satellite or maybe some other place.

Similarly, RADAR signal if it is sent from the satellite, it will definitely be received at the earth surface, because you can see here that the complete atmospheric window is available for this range. And, that is a fundamental advantage of the RADAR and this region is called the microwave region fine.

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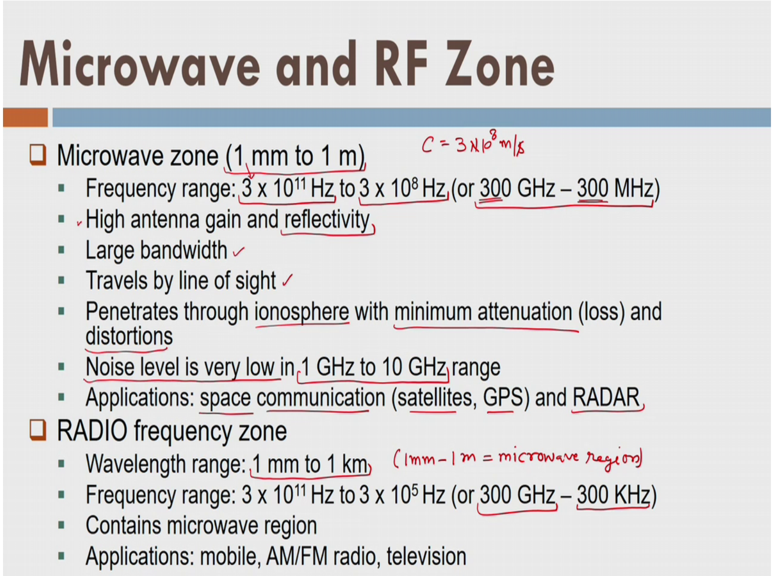

Microwave and RF Zone

- ☐ Microwave zone (1 mm to 1 m) $C = 3 \times 10^8$ m/s
  - Frequency range: 3×10^{11} Hz to 3×10^{8} Hz (or 300 GHz – 300 MHz)
  - High antenna gain and reflectivity
  - Large bandwidth ✓
  - Travels by line of sight ✓
  - Penetrates through ionosphere with minimum attenuation (loss) and distortions
  - Noise level is very low in 1 GHz to 10 GHz range
  - Applications: space communication (satellites, GPS) and RADAR
- ☐ RADIO frequency zone
  - Wavelength range: 1 mm to 1 km (1mm – 1 m = microwave region)
  - Frequency range: 3×10^{11} Hz to 3×10^{5} Hz (or 300 GHz – 300 KHz)
  - Contains microwave region
  - Applications: mobile, AM/FM radio, television

Now, says we are using a word radio detection and ranging and we are using the microwave region. So, what is the difference between the 2? So, let us look into this thing.

So, microwave zone or the microwave wavelength range is given from 1 millimetre to 1 meter on the electromagnetic radiation. And, if I convert this 1 mm to corresponding frequency assuming the speed of the light as 3 into 10 is to the power metre per second. Then, I can find out the 1 mm corresponds to 3 into 10 is power 11 hertz and 1 metre corresponds to 3 into 10 is power 8 hertz or I can write this thing like this.

So, 300 megahertz frequency to 300 gigahertz frequency is my microwave zone ok. The microwave zone has some speciality like it has high antenna gain. What is the meaning of high antenna gain? If, you have a television definitely you might be having a television at your home and if you have a some dish antenna and earlier days to have to have some different antennas.

So, in case of antenna the antenna receives the signal ok. So, if I assume that there are some ideal conditions; that means, speed of the light is ideal, atmosphere is ideal, and there are no losses at all. Between the transmission from the satellite or the source in that case I will have some value of the received signal. At the same time if I now assume that everything is practical or everything is real; that means, atmosphere is real speed of the light is not the way it we assume it is actual value.

So, during those real conditions if I find out for the reflected signal of the antenna, then if I take the ratio of the real case to the ideal case for the receive signal. So, I define this parameter as antenna gain. So, the antenna gain is very high in case of microwave region. And, that is the reason we are using the microwave region right.

Similarly, we have high reflectivity of the received signal; that means the surface where the signal is reflecting it is also behaving with high reflectivity in this microwave region. So, basically surface is a surface, but it is sensitivity towards the microwave region is higher for reflectivity. And, that is a reason you prefer the microwave region ok. Then, it has large bandwidth; that means the frequency range over which signal is transmitted it is called bandwidth. So, microwave region is very having very large bandwidth.

Now, it travels by line of sight which means remember in case of LiDAR, we have some kind something called line of sight; that means, aligned along which we send a transmitted pulse or transmitted signal. At the same if similarly in case of RADAR, we can throw the signal in certain direction. And, the RADAR pulse or the RADAR signal will follow the direction and that is what we call it travels in line of sight.

So now, we can take it is advantage of this situation and we can do the topographic mapping right ok. Now, as we have already seen it penetrates through the ionosphere and it has minimum attenuation, while it was travelling to the atmosphere or the ionosphere right. So, what is the attenuation? Attenuation is the reduction in the magnitude of the signal.

Similarly, it will have distortion so; distortion is nothing but the change in the shape of the signal. So, the shape of the signal will not be changed or it will change minimum, as well as the magnitude of the signal will be reduced by minimum quantity. And, that is why this is the advantage offered by the microwave region.

Finally, the noise level is very very low in this particular range called 1 Gigahertz to 10 Gigahertz within the microwave region. Now, what is the meaning here? Meaning is very very simple, if the signal is of low strength still we can detect it, because the noise level is minimum. And, what does then what is the role of noise? Noise, basically if it is compatible with the original signal it will confuse the receiver, whether it is a noise or it is a proper signal and that is why we always expect low amount of noise. And, now in this range 1 gigahertz to 10 gigahertz we have very low level of noise inherently in the signal and that is the advantage.

So, we are some applications like space communication for satellites and GPS and the radar. So, all these applications are possible in the microwave region of the electromagnetic radiation ok. What about the radio frequency? First of all I would like to tell you that, radio frequency overlaps or it contains the microwave region; that means, radio frequency starts or radio frequency zone starts from 1 mm to 1 kilometre that is quite a wide range ok.

So, if I convert the same wavelength range into the frequency, it will be 300 kilohertz to 300 gigahertz right. Moreover, I can see you can see here that this range of 1 millimetre to 1 kilometre also contains the 1 millimetre to 1 meter range, which is the microwave region fine. So, now, what are the applications? The fundamental applications of the radio frequency zone, you might of heard that rf ids radio frequencies ids right. There is some small chip which is sensitive to the radio zone not in the microwave, but in the remaining part of the radio frequency zone. And, now we put that for the purpose of identification right. For example, if I want to identify your car I can put there and I will have remote I will use it like that fine.

So, other applications are the mobile phones; that means, what your cell phones that you have using mobile phones. And, then we have amplitude modified or the amplitude modulated or frequency modulated radios, what you called say for example, Radio FM or Radio Mirchi all these are FM Radios and then we have that television what we watch right.

So, all these are applications in the radio frequency zone right. So, I hope that the difference between the radio frequency zone and the microwave region of the electromagnetic spectrum is clear to you.

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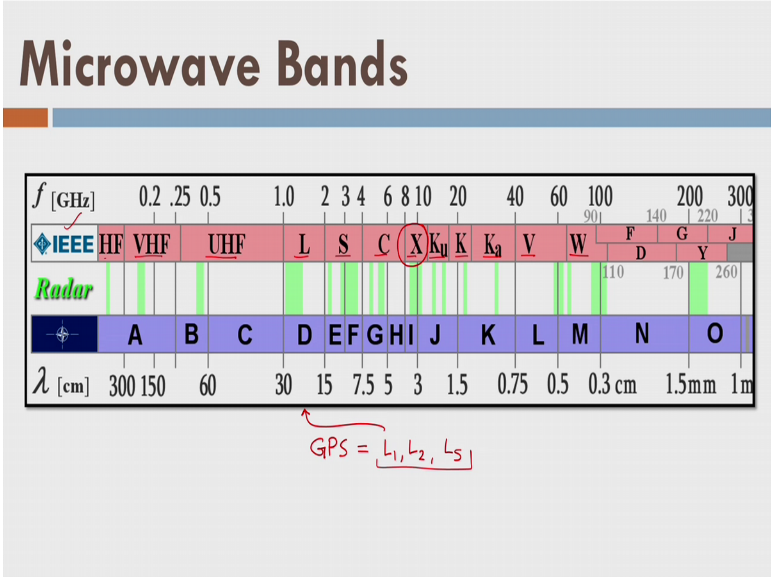

Microwave Bands

GPS = L_1, L_2, L_5

So what are the microwave bands; that means, within 1 mm to 1 meter wavelength range of electromagnetic radiation. How these range is divided; so basic definition is more popular why I EEE. So, I EEE has divided this wavelength range into high frequency, very high frequency ultra-high frequency L band, S band, C band, X band, K u band, K band, K a band, V band, W band and so on.

Now, I would like to tell one thing here that you might of heard that GPS is having frequency called L 1, L 2 and L 5. So, all these are belonging to the L band here. And, that is why they are called they are written as L 1, L 2 and L 5 frequencies right.

Similarly, we have so, many bands here and they have different-different applications. Especially, when we talk about the RADAR; RADAR is basically X band right. So, let us go ahead.

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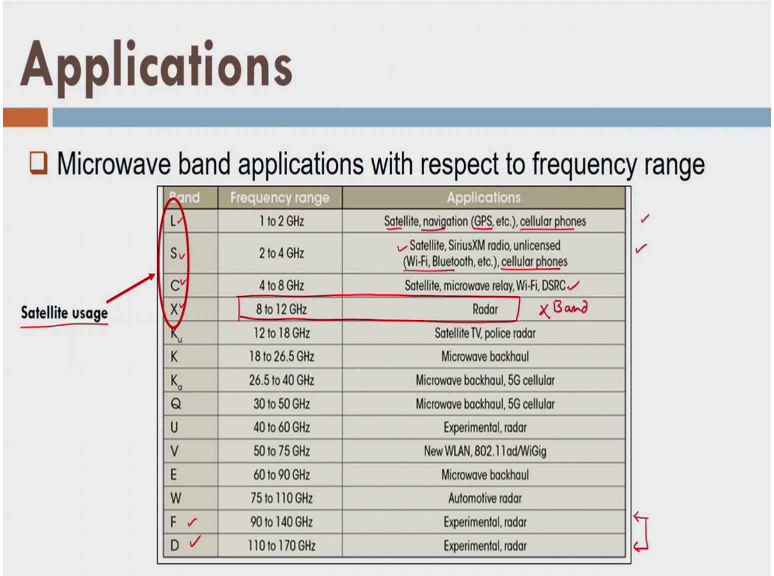

Applications

- Microwave band applications with respect to frequency range

Satellite usage

Band	Frequency range	Applications
L	1 to 2 GHz	Satellite, navigation (GPS, etc.), cellular phones
S	2 to 4 GHz	Satellite, SiriusXM radio, unlicensed (Wi-Fi, Bluetooth, etc.), cellular phones
C	4 to 8 GHz	Satellite, microwave relay, Wi-Fi, DSRC
X	8 to 12 GHz	Radar
K_u	12 to 18 GHz	Satellite TV, police radar
K	18 to 26.5 GHz	Microwave backhaul
K_a	26.5 to 40 GHz	Microwave backhaul, 5G cellular
Q	30 to 50 GHz	Microwave backhaul, 5G cellular
U	40 to 60 GHz	Experimental, radar
V	50 to 75 GHz	New WLAN, 802.11ad/WiGig
E	60 to 90 GHz	Microwave backhaul
W	75 to 110 GHz	Automotive radar
F	90 to 140 GHz	Experimental, radar
D	110 to 170 GHz	Experimental, radar

X Band

So, if I talked about the RADAR and other bands of the microwave. So, they are listed here, you can see here that what are the applications? So, what I request you, you read it yourself about this table. Moreover, I would like to indicate one thing that X band, which is here it is used for the RADAR and it is my X band here. So, we have 8 to 12 gigahertz of the frequency range for X band moreover you can see that, L band, S band, C band, and X band are used for the satellites.

So, different-different applications of satellite we can see here that satellite navigation, that is GPS cellular phones, satellite, radio and under Wi-Fi also due to cellular phones, satellite microwave relay and so on right.

So, now you can understand that we have different-different applications. And, moreover there are some applications called experimental RADAR, if you want to conduct an experiments using RADAR or in that case we will use f and d band. So, these are the applications.

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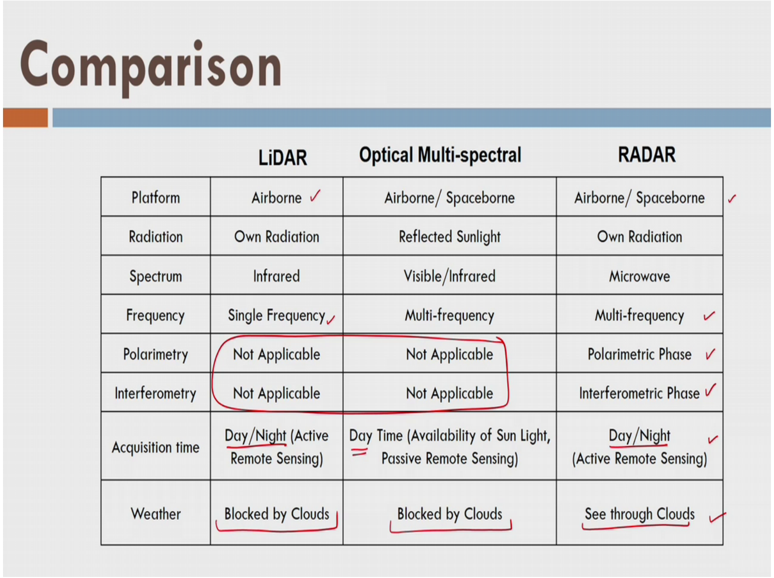

Comparison

	LiDAR	Optical Multi-spectral	RADAR
Platform	Airborne ✓	Airborne/ Spaceborne	Airborne/ Spaceborne ✓
Radiation	Own Radiation	Reflected Sunlight	Own Radiation
Spectrum	Infrared	Visible/Infrared	Microwave
Frequency	Single Frequency ✓	Multi-frequency	Multi-frequency ✓
Polarimetry	Not Applicable	Not Applicable	Polarimetric Phase ✓
Interferometry	Not Applicable	Not Applicable	Interferometric Phase ✓
Acquisition time	Day/Night (Active Remote Sensing)	Day Time (Availability of Sun Light, Passive Remote Sensing)	Day/Night (Active Remote Sensing) ✓
Weather	Blocked by Clouds	Blocked by Clouds	See through Clouds ✓

And, now let us compare the techniques that we have learnt so far; one is LiDAR, one is photogrammetry or we can say multispectral, because photogrammetry has 3 bands r b and g red blue and green and little more possible other bands are also possible, but photogrammetry has 3 bands fundamentally: red, blue, and green. So, we also said multispectral at the same time we have RADAR now. So, let us compare each other.

So, we can see here that this comparison is very easy that LiDAR offers only airborne while other 2 offers both space borne and airborne platforms. That means, these can be mounted on both airborne and space borne platform here. Moreover, you can read all those thing yourself at the same time I will only indicate important aspects of the RADAR and I will compare them.

First of all it is a multi-frequency compared to the LiDAR. There is only single frequency. Similarly, we have a multi frequency means the multiwave length or multi frequency as same thing. Moreover, we can use the polarimetry and interferometry. That, principles of polarization and interference we can use in case of radar.

However, it is not applicable here for the other 2 techniques. More, further it is an active remote sensing techniques; I can use in day and night similar to LiDAR, but does photogrammetry cannot be used here right. Finally, there is a one fundamental advantage that is offered by the RADAR and that it can see through the clouds. However, optical is blocked by the clouds and LiDAR is also blocked by the clouds. So, there are some fundamental additional advantages that we have marked here.

So, RADAR is also very very important technique today.

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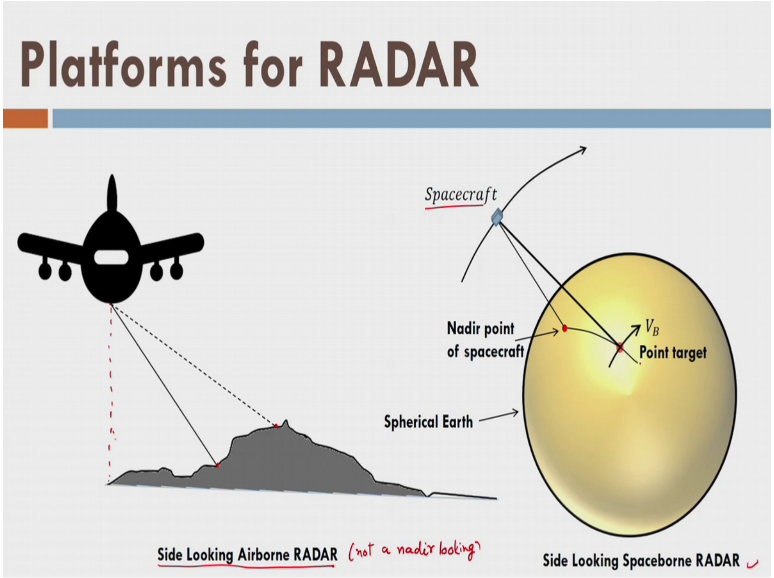

Platforms for RADAR

So, let us see what are the platforms for the RADAR? The, first platform we can see it is my airborne RADAR. So, here let us see there is 1 pulse that is been sent by the RADAR sensor that is mounted on the airborne platform, then we have another one right ok, but at the same time we can also mount over RADAR sensor on the spacecraft. And, that is called the side looking space borne RADAR here. You see it is a side looking airborne RADAR here, you can see here that this system is called the side looking airborne RADAR. Just note it is not a nadir looking RADAR right.

So, for we have used camera in optical wavelength range and we have used the LiDAR in infrared range and both are nadir looking; that means, around the nadir they acquire the data. At the same time now I am saying that RADAR is not be nadir looking it is rather side looking. We can see here that, if I draw the nadir it is my nadir portion. And. so my first pulse start from here itself and the last pulse is here itself. So, it is a side looking airborne RADAR.

Similarly, if you look into the space borne system as mounted on the spacecraft and it is also a side looking space borne RADAR right. This is your nadir point indicated here, but this is my first pulse and it is trying to target this point here right.

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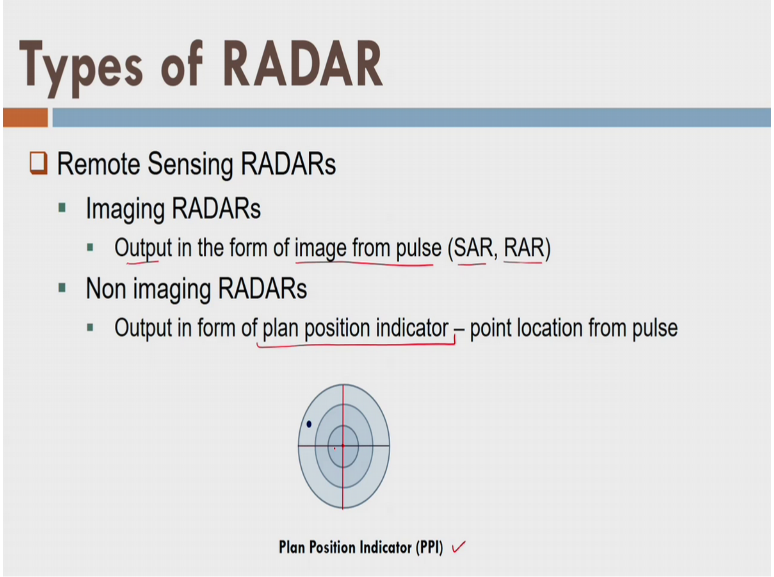

Types of RADAR

- ❑ Remote Sensing RADARs
  - Imaging RADARs
    - Output in the form of image from pulse (SAR, RAR)
  - Non imaging RADARs
    - Output in form of plan position indicator – point location from pulse

Plan Position Indicator (PPI) ✓

So, let us look into the types of radars we have 2 types of RADAR in general one is imaging radars and one is the; another is non-imaging RADAR ok. In case of imaging RADAR, we know that output is in the form of image from the reflected pulse right so, the synthetic aperture RADAR and real aperture RADAR an example of the imaging RADARs.

However, we have the non-imaging radars also. Here, we see that output in the form of plant position indicator alright. What is what is this plant position indicator or PPI, when let us say a there is a transmitter or that is a transmitter, that is sending the RADAR pulses towards an object. And, we know that object is around, but we want detect it is position.

So, what happens is; when the transmitted pulses interact with the surface. Surface, generally returns might be reflected signal. And, that reflected signal is received by the receiver, which is also associated with transmitter only ok. So, that is the way we can find out the position. However, in some cases it happens that the signal, which is transmitted once it reaches to the body or the reflecting surface. It becomes very big because of the large distance alright.

And, as a result what happens is the weak signal which is again reflected back no doubt it is the signal, which is accept which is received at the surface it is reflected back, but the signal received itself is so, weak that reflected signal will be further weak. As, a result we are some arrangement that there is a secondary RADAR, it is a primary RADAR in the transmitter which is let say based on the ground surface. And, there is a moving object in the sky, which is having a secondary RADAR.

That secondary RADAR once it receive the signal which very weak from the primary RADAR ok. So, what will you do it will generate it is own signal and the secondary RADAR transmits. Another, signal and that another signal transmits the signal and that signal is not weak and it is received by the receiver at the ground surface ok.

So, what is the use of that? What will happen that, I can find out the position of a moving object. And, generally this principle is used which is a non-imaging RADAR principle for be ATC, Air Traffic Controller. What happens here? That ATC let us say on the ground surface is having a transducer or what we call as transmitter right.

So, basically that it is a transmitter receiver assembly that is based on the ground surface right. And, then it is continuously transmitting the signals. Now, as soon as an aircraft that comes in the range of the ATC what will happen? That is an reflective surface ok. So, that once it received signal from the ATC, then it will start sending back or the reflecting back the signal.

However, signal is very very weak as we have already told, what will happen now the aircraft is also having a transponder or the secondary RADAR right. That, secondary RADAR immediately understands that there is some kind of position indicator is there and I need to convey my position. So, it transmits another position pulse to the ground surface or the ATC ok. So, this is the receiver and it receives a signal which is not weak. And, using this logic we can find out the position of a moving object also.

So, that is the function of the ATC and that uses the non-imaging RADAR. Now, you can see we are showing in the picture, the plank position indicator. And, let us see that this is the location of the ground surface station ATC. And, now what happens is as soon as an aircraft comes in the range of this circles, it is showing the basically the range. If an aircraft comes into this range, this is the position, right now by the black dot showing the position of the aircraft. And, now this in order to look at this position basically the secondary RADAR has send signal to the ATC or to the station at the ground surface. So, that is the principle of non-imaging RADAR.

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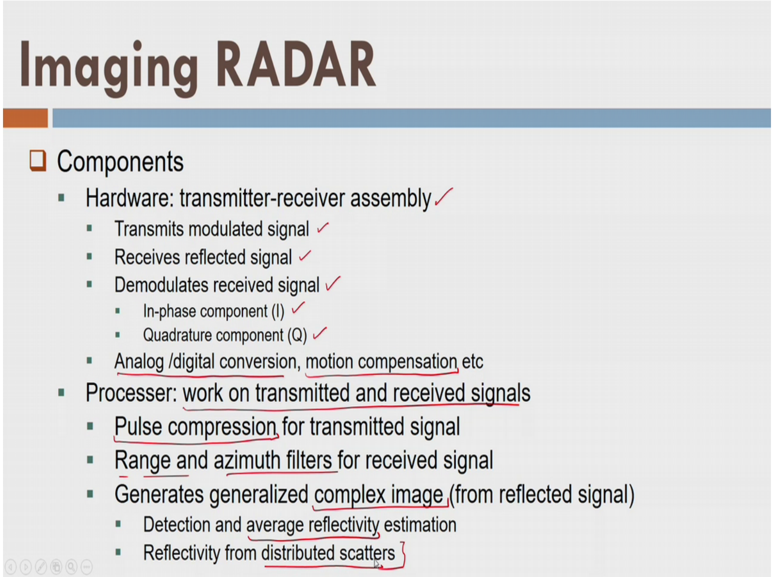

Imaging RADAR

- ☐ Components
  - Hardware: transmitter-receiver assembly ✓
    - Transmits modulated signal ✓
    - Receives reflected signal ✓
    - Demodulates received signal ✓
      - In-phase component (I) ✓
      - Quadrature component (Q) ✓
    - Analog /digital conversion, motion compensation etc
  - Processer: work on transmitted and received signals
    - Pulse compression for transmitted signal
    - Range and azimuth filters for received signal
    - Generates generalized complex image (from reflected signal)
      - Detection and average reflectivity estimation
      - Reflectivity from distributed scatters

So imaging radar so, what are the components of an imaging radar; that means, a system of RADAR, that is translating the signal. Signal is interacting with the surface reflected back towards the RADAR system. RADAR system has a receiver and it is receiving this reflected backscatter or back signal ok, that is recorded and that is recorded in the form of image.

So, that is my imaging RADAR imaging RADAR has 2 components; first is the hardware and other component is processor well. Hardware consists of an transmitter receiver assembly and it transmits the modulated signal. Further, it receives the reflector signal and it demodulates the receive signal in 2 components. One is phase component and another one is quadrature component of the brightness is resolved in 2 components. One is phase component another is quadrature component.

Then, it has analogue to digital conversion as well as it does the motion compensation also. The motion compensation is similar to the image motion compensation of the photogrammetry ok. Then, we have the processor, it basically work on the transmitted and received signals that are generated by the hardware. First of all it does the pulse compression and so, what is the pulse compression right.

So, RADAR signal has a certain wavelength range that is called the bandwidth. Over that bandwidth transmits the signal. Now, there are some noise also; that means, like LiDAR, we have a peak at the centre, but around that peak we have some noise. So, what is a meaning of pulse compression, we minimise the noise and other we compress the whole energy into very small wavelength range.

And, what do you do basically we increase the height of the peak of overall signal. What is the advantage of this pulse compression, the basic accuracy it depends on the length of the frequency or the bandwidth of the frequency. So, the lower the bandwidth, we have the higher the accuracy and that is a purpose of pulse compression right. So, we should always understand these fundamental concepts.

Now, we have some ranged and azimuth filters, for the receive signals with see all this thing. And, then it basically does it generate the complex image from received signal and then this signal is used to detection and relates the estimation of average reflectivity. Further, we also find out what is the reflectivity from various distributed scatters.

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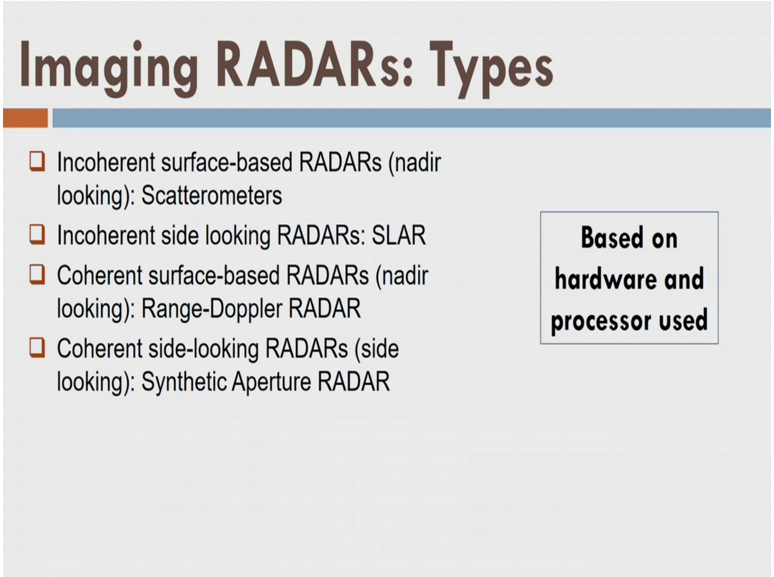

Imaging RADARs: Types

- Incoherent surface-based RADARs (nadir looking): Scatterometers
- Incoherent side looking RADARs: SLAR
- Coherent surface-based RADARs (nadir looking): Range-Doppler RADAR
- Coherent side-looking RADARs (side looking): Synthetic Aperture RADAR

Based on hardware and processor used

Now the imaging RADAR has 4 types fundamentally; that means, incoherent surface based RADAR that first thing they are nadir looking. So, 1 is example is Scatterometers. So, what is incoherent surface? What is the incoherent? Remember in case of LiDAR we talked about 2 types of reflector signal one is coherent and another is incoherent. So, LiDAR is originally coherent. So now, we are saying that RADAR can offer trade the incoherent reflected signal at the same time coherent cannot to be treated.

Similarly, we have the incoherent side looking radars they are called side looking airborne RADAR please note that side looking airborne RADAR can also treat the coherent signal and rather we prefer that coherent signal right. Then we have coherent surface based radars and they are nadir looking. So, one example is the range Doppler RADAR, ok.

Finally, we have that coherent side looking radars they are called side looking and they are called synthetic aperture RADAR. And also, hear I would like to say one thing that, in this lecture module we are going to discuss only the coherent 1. That is coherent or that is dealing with coherent energy or coherent power or the coherent electromagnetic radiation response.

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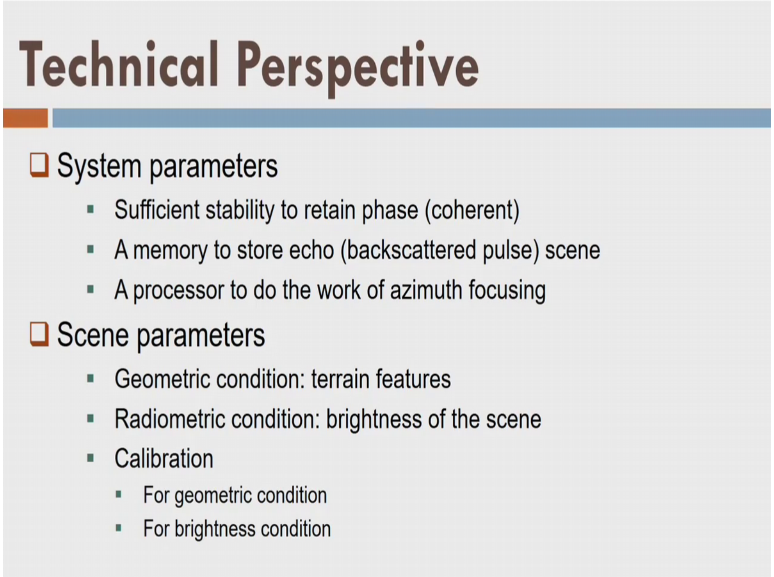

Technical Perspective

- ☐ System parameters
  - Sufficient stability to retain phase (coherent)
  - A memory to store echo (backscattered pulse) scene
  - A processor to do the work of azimuth focusing
- ☐ Scene parameters
  - Geometric condition: terrain features
  - Radiometric condition: brightness of the scene
  - Calibration
    - For geometric condition
    - For brightness condition

Now, let us look into the technical perspective of the RADAR. So, it has 2 kinds of parameters one is system parameter and another is scene parameter scene means terrain. So, it has 2 fundamental aspects of that thing. So, let us look into the system parameter system is nothing but consists of RADAR system that is hardware and processor. So, whatever parameters we can relate to those system that will call it a system parameters ok.

The system should have the sufficient stability retain the phase that is the coherent one property. Then, the reflected signal should also be stored right. What, we call is backscattered pulse or backscatter right and then we should have a processor to the work on the azimuth focusing. Now, I would like to explain the term azimuth focusing ok. Let us say that this is the flight direction of the airborne RADAR, where and RADAR system is mounted on aircraft the direction which is perpendicular to the flight direction and it is towards the surface of earth it is called the azimuth direction right.

So, this is my azimuth direction this is azimuth direction. So, it is basically maintaining a ninety degree angle with the flight direction. So, that direction called azimuth direction. So, what RADAR does basically it transmits the pulse in the azimuth direction towards the ground surface right. Now, the pulse has some response on the reflected energy or what you called backscatter and backscatter is received by the receiver ok.

So, what do we do here? We basically in order to improve the point estimation on the surface of earth; we reduce the area that is interacting with the pulse in the azimuth direction. What is the advantage here, that I can do the point estimation as I told for the purpose of point estimation; we reduce the area in the azimuth direction, where the pulse is interacting with the ground surface.

And, that is called azimuth focusing; that means, receiver will acquire only the energy or the reflected backscatter. In certain area of the surface of earth, where the angle is maintained around ninety degree that azimuth angle is 90 degree and that is called azimuth focusing fine ok.

So, what are scene parameters ok? So, one is the geometric condition; that means, I have terrain features, where are they located. Then, we have radiometric conditions that is the brightness of the scene. That means, what is the brightness coming from the reflected response or backscatter from the surface of earth, at the same time what is the reflectivity of the terrain surface.

So, we need to calibrate remember that in case of optical 1, we did not to calibrate other we calibrate from the automatic systems, what we calls camera software or similar to the LiDAR also we have the RADAR system, where some backscatter is coming and that backscatter has to be calibrated. That means, I should have some kind of the reference backscatter and compared to that back reference backscatter; what is the received backscatter?

So, you will say that with respect to that reference this is my value here that what I receive really ok. That is called a calibration and we need to the do the calibration for both geometric as well as radiometric conditions right. So, in this lecture we are going to talk about the geometric conditions only. In the next lecture, we will talk about the radiometric conditions.

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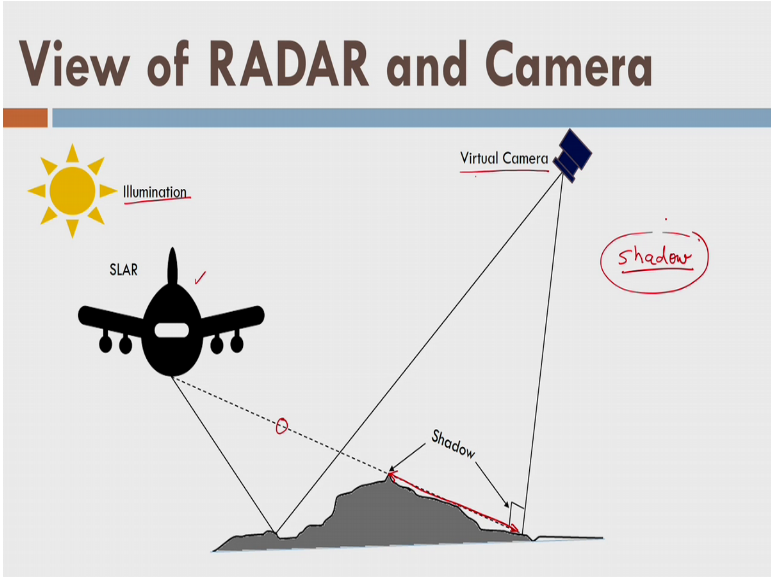

View of RADAR and Camera

So, that is the small comparison here of the RADAR and camera. And we have to understand what is difference between the RADAR system and let us say other system maybe LiDAR or camera. So, here we have a side looking airborne RADAR, which is mounted on the aircraft shown here ok. And, then it does not require any illumination because it is an active remote sensing technique.

So, this is my first pulse and this is my next pulse right ok. At, the same time there is a virtual camera here and that is working in the presence of the illumination of the sun ok. So now, let us look into this thing this is the reflected energy in the optical reason that is being received by the camera here ok. Now, you can see here, that we have the concept of shadow in case of optical system. Similar to this thing in case of RADAR; that RADAR is using microwave, but microwave is also creates the shadow. And, what is the shadow here, if you see here with this point of the terrain it is interacting with this pulse right.

Now, beyond this point it may not go. So, this complete region will be in the shadow and remember that RADAR is using microwave. So, whatever backscatter will be there that will be in the microwave region only. And secondly, since we are considering only the coherent component. So, that only coherent part will be received. So, here this is my shadow here shown this thing. So, that is the kind of similarity as well as this similarity of the optical and the RADAR system that we just discussed now. So, we both creates the shadow, but at the same time both work in the different wavelength ranges.

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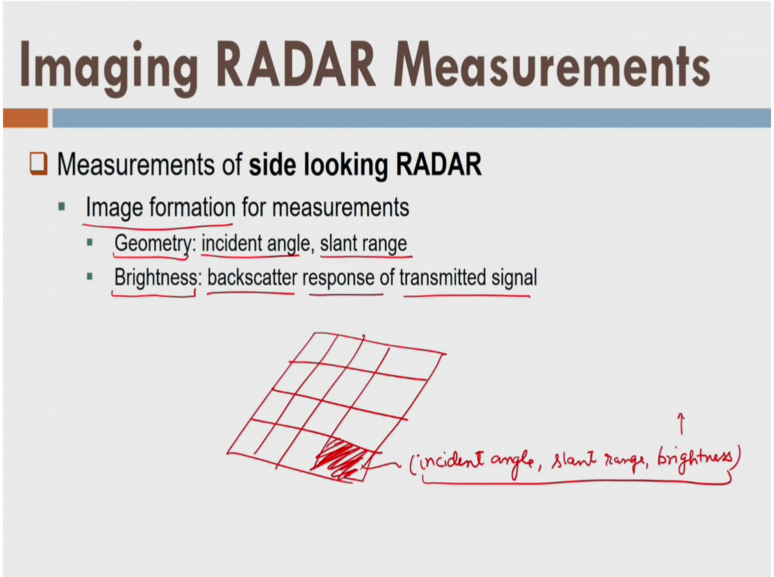

Imaging RADAR Measurements

- ☐ Measurements of **side looking RADAR**
  - Image formation for measurements
    - Geometry: incident angle, slant range
    - Brightness: backscatter response of transmitted signal

Now, we what are the measurements of the side looking RADAR or any RADAR system. First of all that image is formed using some observation, the first observation is in my geometry which is incident angle and the slant range ok. We will discuss this thing then we have brightness and that is nothing but the pixel value and it is backscatter response of the transmitted signal from the terrain surface right.

So, I can say if my RADAR this is my RADAR image right, then if I divide into the pixels. So, each pixel let us say this pixel, it is indicating 3 values one is my incident angle, second is slant range, and third is my brightness. So, brightness is nothing but the pixel value I can say here. So, basically a pixel has 3 such variables recorded right and we will see all this thing 1 by 1.

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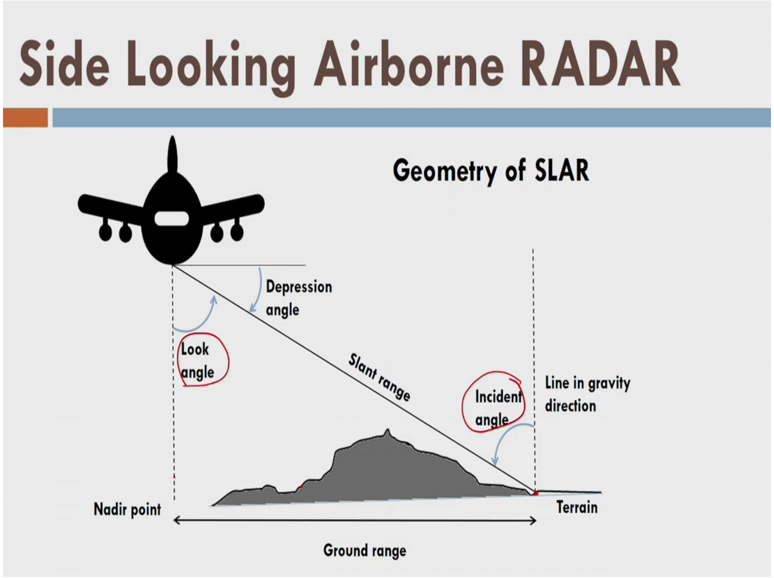

Side Looking Airborne RADAR

Geometry of SLAR

So, let us look into the geometry of the side looking airborne RADAR. So, an RADAR system is mounted on the aircraft. So now, we have this is the nadir point this is my first pulse. So, this is called the slant range. You can see in the animation ok.

And, this is called the ground range that is the distance from this point to nadir point this is my ground range that is along the terrain or along the joined. Now, let us consider another pulse which is this and this is slant range and this is my ground range. I hope you understand what is the meaning of slant range and ground range?

So, this angle, which is formed from the nadir to the line of sight, because this is the line of sight here ok, so this angle is called look angle ok. What about the angle from the horizontal. So, let us draw the horizontal here and then this angle it is called the depression angle. So, this is my depression angle right fine. So, these are the 2 angles we have learn now the depression angle and look angle. So, you can see here that look angle and look angle depression and depression angle are complementary to each other, because the summation of the 2 angle is equal to 90 degree ok. What about the terrain or the terrain, where the signal is interacting which is this point here.

And, if I draw vertical line, through this point in the direction of gravity so, this is the line in gravity direction and now this angle, which is shown in the animation it is called incident angle. So, I hope that animation has helped you to understand what is the look angle depression angle, slant range, ground range, and incident angle right.

So, that is called the geometry of the side looking airborne RADAR: yes, from this geometry you can see that look angle in case of airborne RADAR as equal to the incident angle here, but in case of Spaceborne RADAR. Since, the curvature of the earth is very very prominent and either result incident angle is not equal to the look angle. Or in order to calculate the incident angle we should consider the curvature of the earth right. So, will see all this things in this lecture incoming slides.

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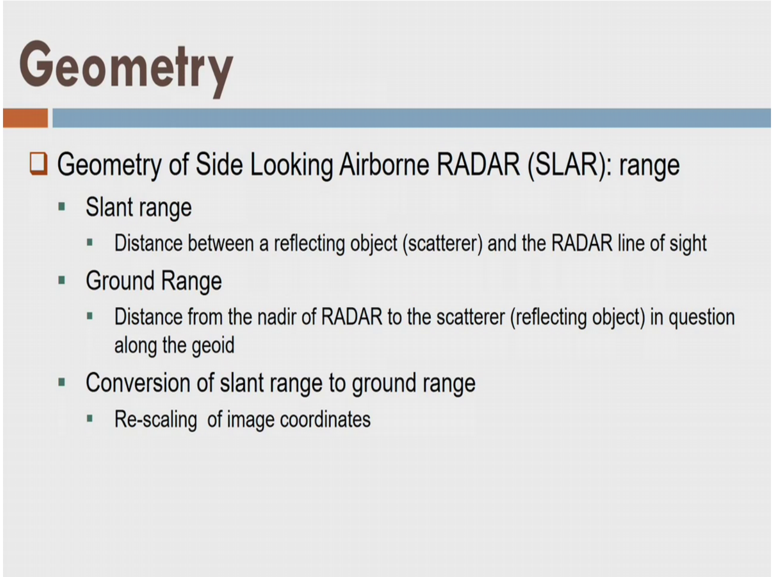

Geometry

- ❑ Geometry of Side Looking Airborne RADAR (SLAR): range
  - Slant range
    - Distance between a reflecting object (scatterer) and the RADAR line of sight
  - Ground Range
    - Distance from the nadir of RADAR to the scatterer (reflecting object) in question along the geoid
  - Conversion of slant range to ground range
    - Re-scaling of image coordinates

Now, if you look at the slant range, what is the slant range? It is the distance between a reflecting object the scatterer and the RADAR line of sight, or the we can say that RADAR transmitter yet RADAR transmitter, I can say RADAR system ok. What is a ground range? The distance from the nadir of RADAR to the scatterer right; in order to convert this slant range, which we measure to convert to ground range we need to do some kind of rescaling a some kind of multiplication factor we have to device right.

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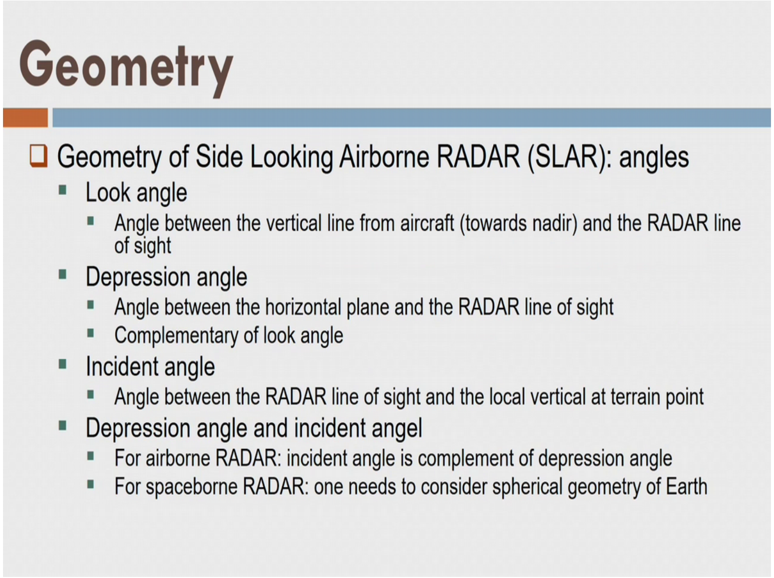

Geometry

- Geometry of Side Looking Airborne RADAR (SLAR): angles
  - Look angle
    - Angle between the vertical line from aircraft (towards nadir) and the RADAR line of sight
  - Depression angle
    - Angle between the horizontal plane and the RADAR line of sight
    - Complementary of look angle
  - Incident angle
    - Angle between the RADAR line of sight and the local vertical at terrain point
  - Depression angle and incident angel
    - For airborne RADAR: incident angle is complement of depression angle
    - For spaceborne RADAR: one needs to consider spherical geometry of Earth

Now, we see already seen what is look angle we have seen what is a depression angle?

So, that you can read it yourself the look angle is angle between the vertical line from aircraft towards nadir and the RADAR line of sight. Similarly, depression angle is compliment of the look angle. So, it is angle from the horizontal to the RADAR line of sight. Then, we have incident angle, which is angle between the RADAR line of the sight and the local vertical at terrain point.

Then, we have depression angle and incident angle right ok. Now, we have learn what is this slant range and ground range? What about the quality of that measurement that is what is the resolution of those? So, first define various type of resolution ok. Let me tell you one thing that these resolution types which are spatial, then we have radiometric resolution, temporal resolution, and the spectral resolution.

So, these 4 types of resolution are applicable to all remote sensing systems.

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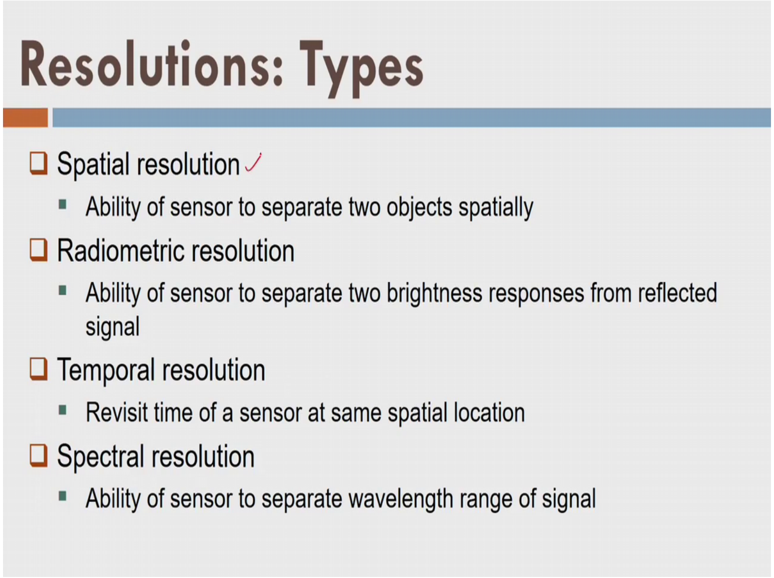

Resolutions: Types

- ☐ Spatial resolution ✓
  - Ability of sensor to separate two objects spatially
- ☐ Radiometric resolution
  - Ability of sensor to separate two brightness responses from reflected signal
- ☐ Temporal resolution
  - Revisit time of a sensor at same spatial location
- ☐ Spectral resolution
  - Ability of sensor to separate wavelength range of signal

Now, we are defining in context of the RADAR and the definitions of these 4 terms are always consistent for all types of remote sensing systems. Now, let us look these 4 terms in context of RADAR. First is my spatial resolution so, the spatial resolutions ability of a sensor to separate 2 objects.

So, I can say it is similar to the optical system, where we said that there are 2 pixels, if I want to differentiate 2 objects they should be separated by certain distance and that is called the resolution of the system same way the same definition is here. Now, coming to the radiometric resolution ok, let us say you have some brightness values for example, green colour.

So, even within the green colour you have different-different shades or within black colour you have different-different shades of grey. So, the ability of a system to distinguish between these different levels of brightness is called radiometric resolution right. Then, we of temporal resolution this term is mostly applicable for the satellite system, why because in case of satellite system. Satellites can travel a particular point of earth at repetition or satellite can make the repetition over a certain point of the earth. And so, we can detect the changes based on the it is repetition interval it could be 1 day it could be 1 month it could be 1 week and so on right.

So, the repetition rate or the time interval after which satellite repeats a certain point or satellite tracks a certain point, it is called the temporal Resolution of the satellite system.

So, this temporal resolutions not applicable or not relevant in case of airborne system, because aircraft is flown very few times. And, generally we do not prefer to repeat the service very frequently, unless we need it disparately ok. Then, we have spectral resolution, which means the dividing the wavelength the range in different-different frequency ranges small ranges.

So, for example, the best is idea is optical system; we have red, blue, and green in the optical wavelength range. So, there are 3 minutes. So, it has I can say all bands are almost 0.1 micro meter wide. So, that is the spectral resolution of the optical system, same way in case of the RADAR we have the some spectral bands. However, we are not going to include those things here.

So, basically for us spatial resolution and the radiometric resolution are very very important for the RADAR.

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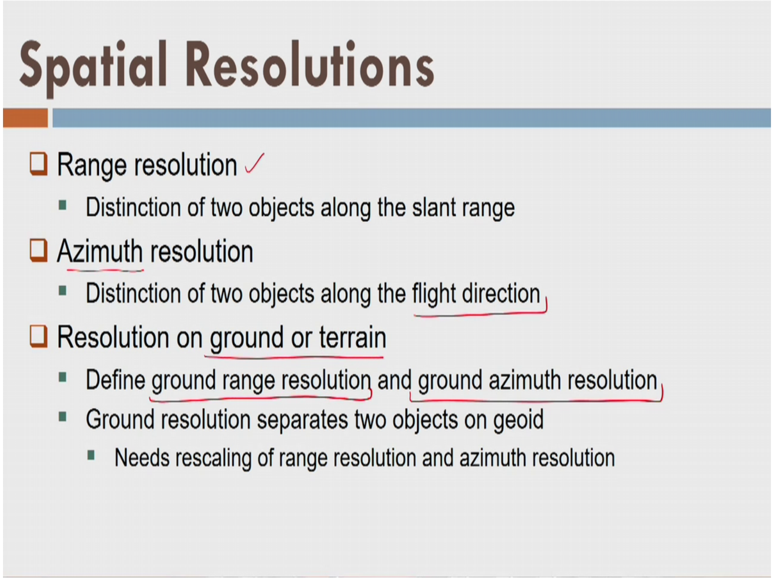

Spatial Resolutions

- ☐ Range resolution ✓
  - Distinction of two objects along the slant range
- ☐ Azimuth resolution
  - Distinction of two objects along the flight direction
- ☐ Resolution on ground or terrain
  - Define ground range resolution and ground azimuth resolution
  - Ground resolution separates two objects on geoid
    - Needs rescaling of range resolution and azimuth resolution

Now, in context of a spatial resolution of RADAR, let us define few terms. The first is range resolution remember or we can say it is ability of the sensor system to distinguish the 2 objects along the slant range. And, that is called the range resolution. Then, we have azimuth resolution remember, that Azimuth focusing we discussed. So, in the direction of azimuth we have certain resolution and that is called the azimuth resolution.

So, that the ability to create a distinction between the 2 object along the flight direction it is called the azimuth resolution. Now, we have defined slant resolution or we have defined azimuth resolution. So, what about the resolution on the ground surface because they are along the line of sight right the slant range? So now, we define the resolution on the ground or terrain as ground range resolution and the ground azimuth resolution right. So, we need to calculate the range resolution for the ground surface by some mathematical logic here because we measure the resolution along the slant range.

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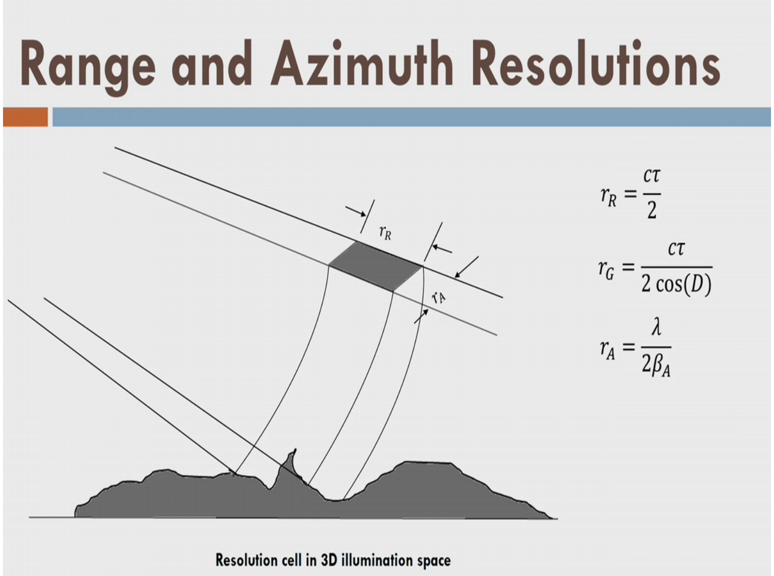

Range and Azimuth Resolutions

$$r_R = \frac{c\tau}{2}$$

$$r_G = \frac{c\tau}{2\cos(D)}$$

$$r_A = \frac{\lambda}{2\beta_A}$$

Resolution cell in 3D illumination space

So, now we have showing the range and azimuth resolution ok. You can see here, that this is the line of sight here. And, now this is my azimuth resolution and that is being created on the ground surface here. And, since we are showing in the air that is mean we are basically projecting the same thing here on the air. And this is my range resolution here of slant range resolution here. And, this is my azimuth resolution here.

And, you can see here that this is the line of sight; that means, this particular slant range can distinguish 2 objects if they are separated by this distance r R. Similarly I can separate 2 objects if they are away from this distance r A here. And, this r R is given by C tan the speed of the light and the tau; what is tau? It is the wavelength or it is the time range or which 1 wavelength of the RADAR signal travels. So, we can understand this is the tau here the time if I divide C into T divided by 2. So, that is my range resolution.

Similarly, what is the ground resolution, if I divide this range resolution by cos D, where D is my depression angle fine. So, it is called the ground resolution or ground range resolution. Similarly, we have the azimuth resolution, which is given by lambda by 2 beta, yes. I would like to indicate here it is given by lambda by 2 beta, in case of synthetic aperture. In case of real aperture RADAR it is lambda by beta A, ok. We will discuss all this thing right fine. Once we get this idea we should also know, what is the relationship between the resolution and my pixel ok.

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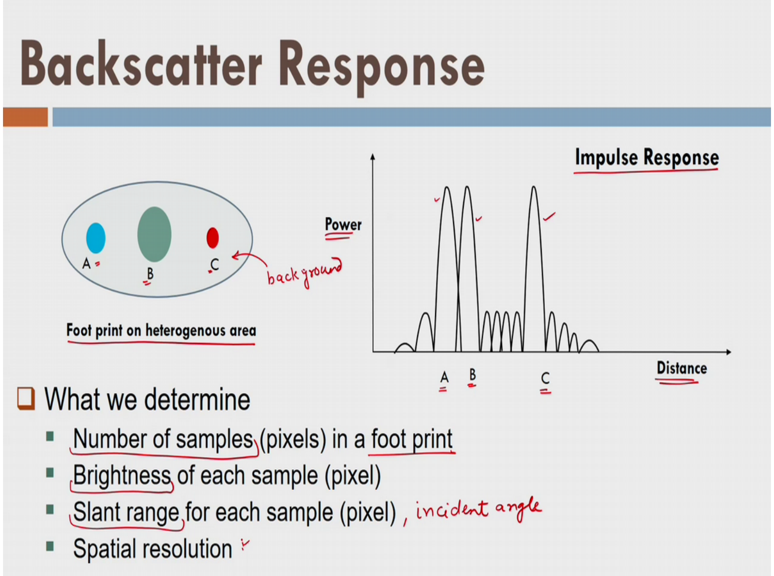

Backscatter Response

❑ What we determine

- Number of samples (pixels) in a foot print
- Brightness of each sample (pixel)
- Slant range for each sample (pixel) , incident angle
- Spatial resolution

So, let us see this thing here ok. What happens is let us see there is a foot print on heterogeneous area; that means, I have certain background here in one foot print that is majority of my area I called background ok. And, then we have 3 targets A B and C of different areas right.

Since, these foot print will be divided into small small elements and each element will be 1 pixel ok. So, when we note down the bright slant range for each pixel, what will happen. Since, we know the distance of point C is higher. So, it will appear like this distance of B is lesser than less than C and the nearest point is A. So, I will get 3 such logs at the peaks in my impulse response. And, this curve is called the impulse response here right.

In case of impulse response, what will happen now if I draw the distance and if I draw the power I will have such logs here right ok? And, that is the idea here fine, what will happen now. Based on this only I need to understand there are some different-different features and rest of the things are noise fine.

So, this curve again I repeat this called impulse response. So, that is nothing, but be backscatter ok. So, based on this data, what do you determine from this? First of all we determine the number of samples that is number of pixels in a footprint ok. Then, we for each pixel we will find out what is the brightness and what is the slant range? As well as incidence angle and then what is the spatial resolution here and how to decide the spatial resolution.

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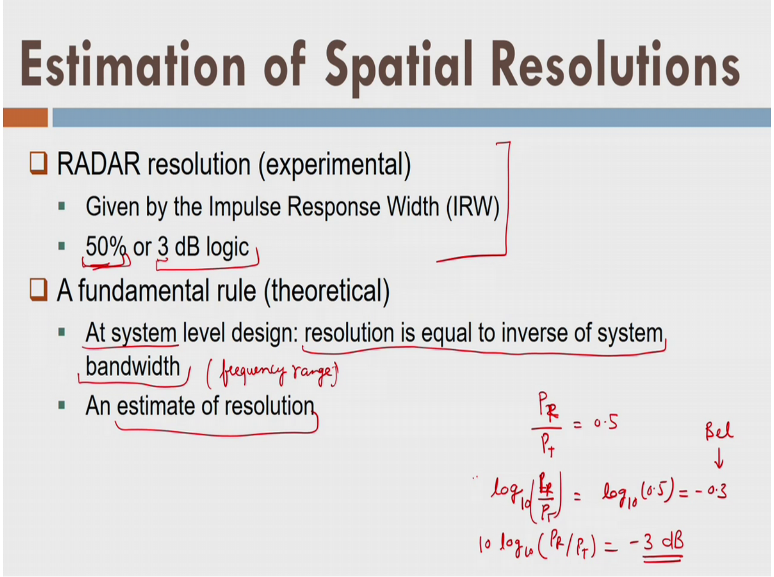

Estimation of Spatial Resolutions

- ❑ RADAR resolution (experimental)
  - Given by the Impulse Response Width (IRW)
  - 50% or 3 dB logic
- ❑ A fundamental rule (theoretical)
  - At system level design: resolution is equal to inverse of system bandwidth (frequency range)
  - An estimate of resolution

$$\frac{P_R}{P_T} = 0.5$$

Bel ↓

$$\log_{10}\left(\frac{P_R}{P_T}\right) = \log_{10}(0.5) = -0.3$$

$$10 \log_{10}(P_R/P_T) = -\underline{\underline{3\ dB}}$$

Let us look into this thing now. How to estimate the spatial resolution of the RADAR system? The logic is similar to the LiDAR first of all we will go for the 50 percent or 3 decibel logic, what is 50 percent? As, I told is reflected backscatter has the power more than 50 percent, I will say that yes this is appropriate signal that has being received from some surface right.

So, that is called 50 percent logic here or sometimes it is also called 3 decimal logic, what is the meaning here? So, if I take let us say the P received power and P transmitted power and if it is ratios 0.5 with this indicated here 50 percent. And, if I take the log of this one on base 10 and then, then I will get some value called minus 0.3 and if I multiply and this quantities called bel. So, the ratio of power and it is log right.

So, if I multiply it by 10 I will receive some quantity like this and it is called decibel, that 50 percent logic is equivalent of 3 decibel logic. So, if I have the minimum 3 decibel power from the reflected backscatter, I will say that it is my appropriate signal ok.

Now, we can see here that at system level design resolution is equal to the inverse of the system bandwidth. Remember bandwidth is nothing, but the frequency range of my transmitted pulse. So, if transmitted pulse has smaller frequency range, I will have more spatial resolution or the superior spatial resolution right. So, that is some kind of estimate of the spatial resolution here fine and that is a reality how do we measure it?

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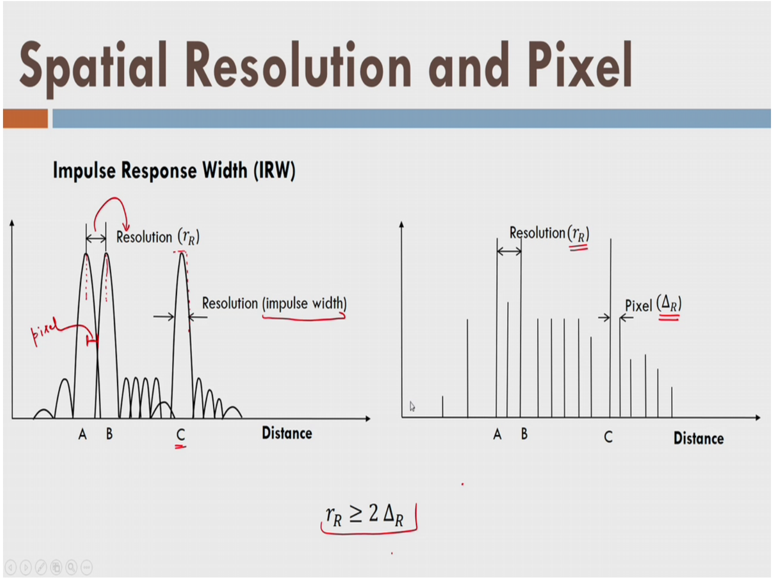

Spatial Resolution and Pixel

Impulse Response Width (IRW)

$r_R \geq 2\,\Delta_R$

Now, let us see there is an impulse response here. And, we are saying that this is my impulse width right. And, what is impulse width? Suppose there is a feature C which way show in the last previous slides ok. So, this value which is almost 50 percent here; remember in case of LiDAR, we have said something called 50 percent and we defined some kind of FWHM right, if you remember properly. So, same logic I am using here and I am saying that this is my impulse width, right.

So, now I have some impulse width here fine. So, for each we have (Refer Time: 46:38) width. So, what is the spatial resolution is it is the distance between the 2 central line of the peaks ok. And, what is my pixel? Pixel is half of this resolution or the distance between here to here, this is called pixel here and it is called my resolution here. And, you can see here that resolution is 2 times of my pixel right. So, here pixel is delta r and my resolution is r R, then I can write here now you can easily understand this thing ok.

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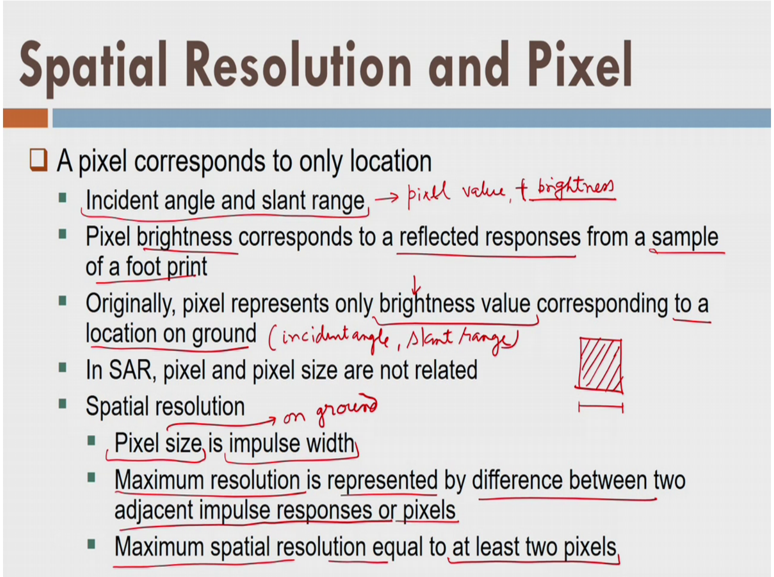

Spatial Resolution and Pixel

- ☐ A pixel corresponds to only location
  - Incident angle and slant range → pixel value, + brightness
  - Pixel brightness corresponds to a reflected responses from a sample of a foot print
  - Originally, pixel represents only brightness value corresponding to a location on ground (incident angle, slant range)
  - In SAR, pixel and pixel size are not related
  - Spatial resolution → on ground
    - Pixel size is impulse width
    - Maximum resolution is represented by difference between two adjacent impulse responses or pixels
    - Maximum spatial resolution equal to at least two pixels

Now, what is a importance of pixel and the spatial resolution or what is the relationship between the spatial resolution and the pixel in case of RADAR. First of all if you look that incident angle and slant range are indicated by a pixel here.

So, it is nothing but pixel value I can say and pixel value will also have brightness. So, brightness nothing but the ok, then the pixel brightness here corresponds to a reflected response or the backscatter from a sample a pixel of a foot print right that we have a discussed here. So, originally pixel represents only the brightness value ok. So, what is the meaning here?

That means, to a certain location on the ground, which is nothing but incident angle and my slant range and at this location I have certain brightness value and that is represented by a pixel like this ok. Here, we would like to highlight that, what the size of the pixel here it does not corresponds to the size of the pixel on the sensor. Remember, this is no sensor like photogrammetry where we have 3 mm size and 4 mm size and it is having so, many pixels no; that concept is not applicable in case of RADAR.

RADAR does not have any sensor of certain size rather it only records the reflected backscatter right. And reflected backscatter it is told in some numerical value and that numerical value is represented by a pixel. So, as such pixel does not have any size on the sensor, but at the same time when we define the pixel on the ground surface, it has the size of spatial resolution.

So, that there is no connection the in the between the pixel on the sensor and the pixel on the ground surface right because such there is no sensor, which has certain format a which is kind of a restoring device in case of optical centre we have we do not have such facility. And, as the result now we can say that the pixels, which are represented by the image of a RADAR. It does not represent any pixel size on the sensor. At, the same time it is just a displaying the brightness values at specific locations right.

So, now we have collected such information and we have created one array and that array is called RADAR image ok. So, pixel size on the ground is decided by the impulse width here. Remember I am saying pixel size on the ground not on the sensor ok. So, maximum resolution is represented by the difference between the 2 at the sense impulse response or pixels. So, I can say here the maximum spatial resolution or the best spatial resolution should be equal to at least 2 pixels here in case of RADAR. And so, that is the relationship I can understand let us go ahead.

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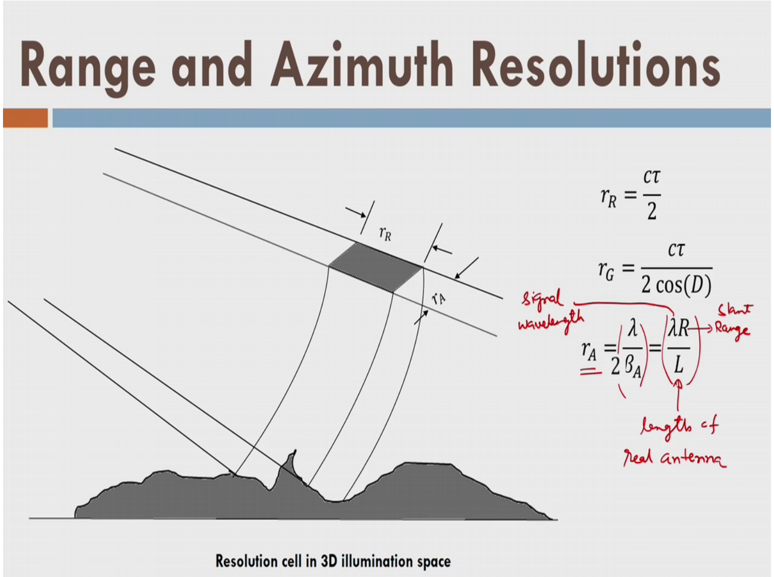

Range and Azimuth Resolutions

$$r_R = \frac{c\tau}{2}$$

$$r_G = \frac{c\tau}{2\cos(D)}$$

$$\underline{\underline{r_A}} = \left(\frac{\lambda}{2\beta_A}\right) = \left(\frac{\lambda R}{L}\right)$$

signal wavelength

Slant Range

length of real antenna

Resolution cell in 3D illumination space

Now, we have seeing that what is my range and azimuth resolution and we see that because of the azimuth focusing right. What happens is very small amount of signal is backscatter, because we have focusing under 90 degree exactly from the flight track.

And, that is called azimuth focusing. And, because of the azimuth focusing I have very less low signal and at the result I have very low resolution, in case of azimuth direction or the parallel to the flight track.

And, that is given by the lambda by beta A, where beta A is my beam width complete beam width ok. It is also given by lambda R by L, where L is length of my real antenna ok. R is my range or slant range and lambda is the wavelength of the signal or RADAR wavelength we can see here in the microwave region right and this is my azimuth resolution here fine.

Now, in order to improve the reflected backscatter from that azimuth location, we have scientist have device a simple another mechanism and that is called the synthetic aperture RADAR. So, let us look into the synthetic aperture RADAR, which is another geometric dimension of the RADAR.

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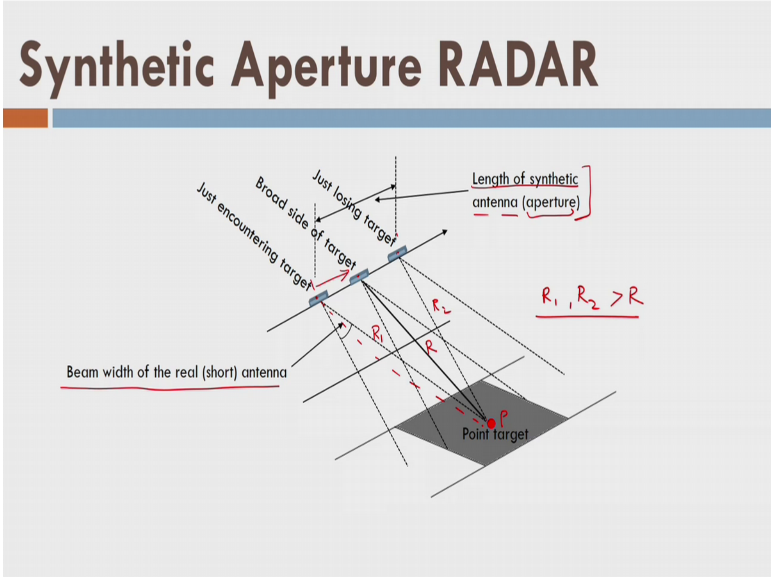

Synthetic Aperture RADAR

So, that is my synthetic aperture RADAR. In case of synthetic aperture RADAR, what do I do basically this is satellite or aircraft and it is moving it is an aircraft it is moving from this point this point and so on right. So, know this is my beam width here you see beam width of the real short antenna ok. We can see here from this point itself this point P is my visible or it is coming in the footprint of the 1 beam width from this position.

Similarly, when aircraft comes here that we have complete footprint belonging to this point, and then finally when aircraft comes to this position we have the last point or if tell this point is touching this thing. That means, this point P here, it is being imaged from here to here ok. Effectively, I can see that we have observed the point P from the long direction or from the long distances multiple times. And, that has improved that overall quality of the backscatter from this point P, because the (Refer Time: 52:58) signal is received from the multiple looks. And, that is why we see that this concept is synthetic aperture RADAR rather I can say that I have increased the length of the antenna from this point to this point right.

So, you can see here this is the length of my synthetic antenna; that means, I have increased the length of the antenna or length of the receiving antenna for a larger distance. And, that is called a synthetic length. In fact, the real length is this much only whatever the real length is there right, what that we indicated by length L ok. So, now, we have develop a synthetic antenna here or what we called aperture right. So, this technique is called synthetic aperture RADAR. So, let us look into the geometric aspects of the synthetic aperture RADAR.

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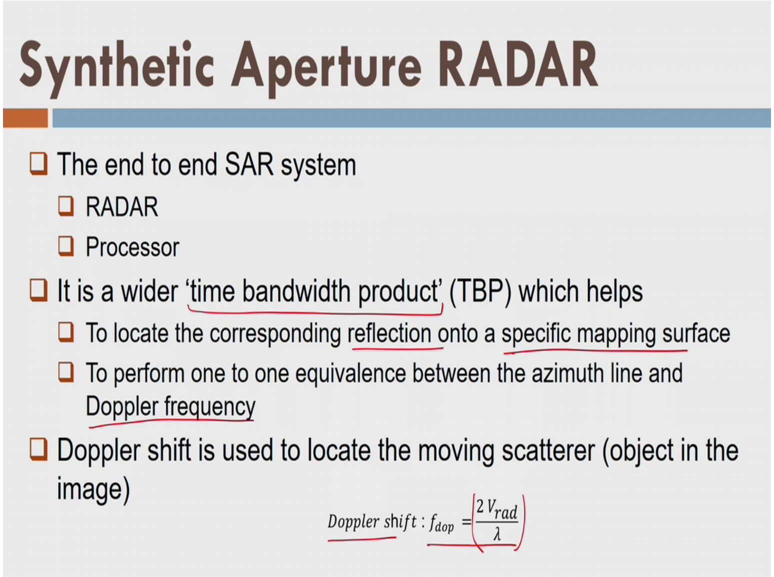

Synthetic Aperture RADAR

- The end to end SAR system
  - RADAR
  - Processor
- It is a wider 'time bandwidth product' (TBP) which helps
  - To locate the corresponding reflection onto a specific mapping surface
  - To perform one to one equivalence between the azimuth line and Doppler frequency
- Doppler shift is used to locate the moving scatterer (object in the image)

Doppler shift : $f_{dop} = \frac{2V_{rad}}{\lambda}$

So, it has the same RADAR processor and this one. So, it has a wider time bandwidth product we will see into that what is that? So, it helps in locating the corresponding reflection on a specific mapping surface and it also has some Doppler frequency criteria we will see what? So, first of all let me tell you what is the Doppler frequency? Here you can see here that, because of the movement of aircraft an aircraft is trying to see this point of P from multiple locations. What will happen, when it comes from this position to this position? Remember the effect of Doppler, when Doppler says that if the source comes closer to the point here this range is small R, here R L is lengthier bigger right.

So, what is happening here this is my R 1 and this is my R 2. So, R 1 and R 2 are bigger than R. So, as this aircraft come closer to point P; what will happen I will have change in the frequency? And, that is what we called in the Doppler Effect. So now, this Doppler shift in the frequency is given by V radial value of city of the aircraft divided by lambda.

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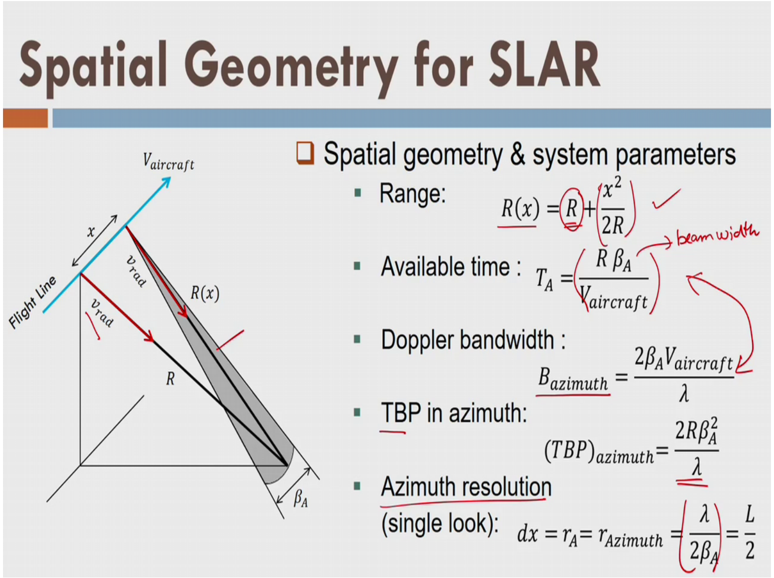

Spatial Geometry for SLAR

❑ Spatial geometry & system parameters

- Range: $R(x) = R + \left(\frac{x^2}{2R}\right)$ ✓
- Available time : $T_A = \left(\frac{R\,\beta_A}{V_{aircraft}}\right)$ → beam width
- Doppler bandwidth : $B_{azimuth} = \frac{2\beta_A V_{aircraft}}{\lambda}$
- TBP in azimuth: $(TBP)_{azimuth} = \frac{2R\beta_A^2}{\lambda}$
- Azimuth resolution (single look): $dx = r_A = r_{Azimuth} = \left(\frac{\lambda}{2\beta_A}\right) = \frac{L}{2}$

Now, we can see here that range is R x, which is in client range and it is the original range R, which is shortest range here and this x is nothing, but this length of my antenna here. So, my is this now what is available time? The time that aircraft takes to cross this distance on the ground is called R B A range into beta is my beam width.

So, this is the time available now Doppler bandwidth is given by this and time bandwidth product is given by the multiplication of these 2. And, it is this. So, now, we have the azimuth resolution, which is this and you can see here it is improved by 2 times compared to the real aperture RADAR.

So now, you see this is my v radial in order to calculate the Doppler frequency shift ok. So, this my redial value city of aircraft ok. Now, in case of space borne system we still have the facility of the synthetic aperture RADAR. In case of that case in that case what will happen if case spacecraft is moving on an elliptical orbit. So, the length of the antenna will be defined on the elliptical orbit of the spacecraft.

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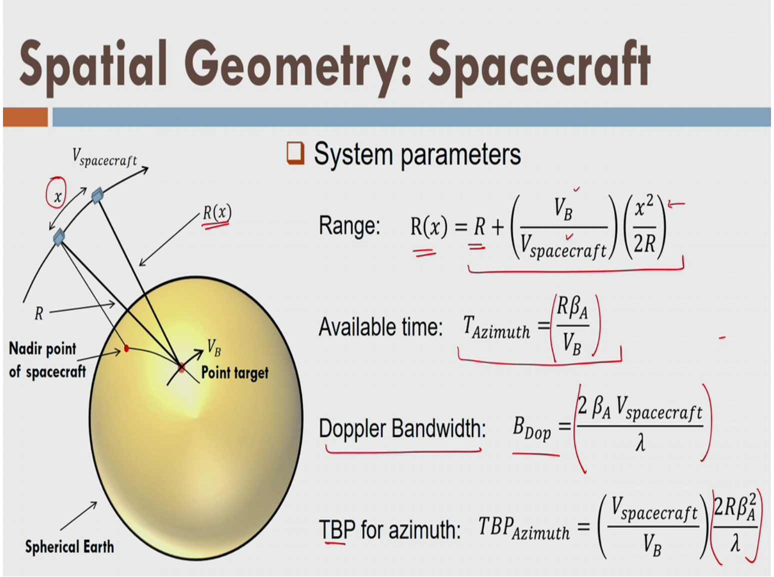

Spatial Geometry: Spacecraft

- System parameters

Range: $R(x) = R + \left(\frac{V_B}{V_{spacecraft}}\right)\left(\frac{x^2}{2R}\right)$

Available time: $T_{Azimuth} = \left(\frac{R\beta_A}{V_B}\right)$

Doppler Bandwidth: $B_{Dop} = \left(\frac{2\,\beta_A\,V_{spacecraft}}{\lambda}\right)$

TBP for azimuth: $TBP_{Azimuth} = \left(\frac{V_{spacecraft}}{V_B}\right)\left(\frac{2R\beta_A^2}{\lambda}\right)$

So, there is a spacecraft shown in the animation here right ok. So, what will happen this is another position of the spacecraft after moving the distance x ok. So, here this is my point. So, this is the range R ok. So, this is a nadir position right. So, we can see nadir position here. And, now this is the distance along the geoid or the curve edge the curved surface of the earth ok.

Now, what happens is this is the range R and this is another range maybe R x at a distance x. So, this range R x is a function of x here. Fine, now we can see that this is the speed of the RADAR beam is called V B speed of the RADAR beam on the surface of earth is called V B. So, now, this is a mechanism of the synthetic aperture RADAR in case of space borne RADAR system.

So, this is my system parameters R x is given by this and you can see here that V B divided by V spacecraft will modify this x square by 2 R right and we have this expression. Similarly, the time available; that means, the time in order to cross this point here that is the foot print it will be R B A divided by V B. And then Doppler bandwidth is given by this formula and finally, the time bandwidth product which is multiplication of this we have this thing we spacecraft by V B into this.

So, we can see here compared to the airborne system all the terms are modified by this ratio of the speed of the spacecraft to the speed of the beam.

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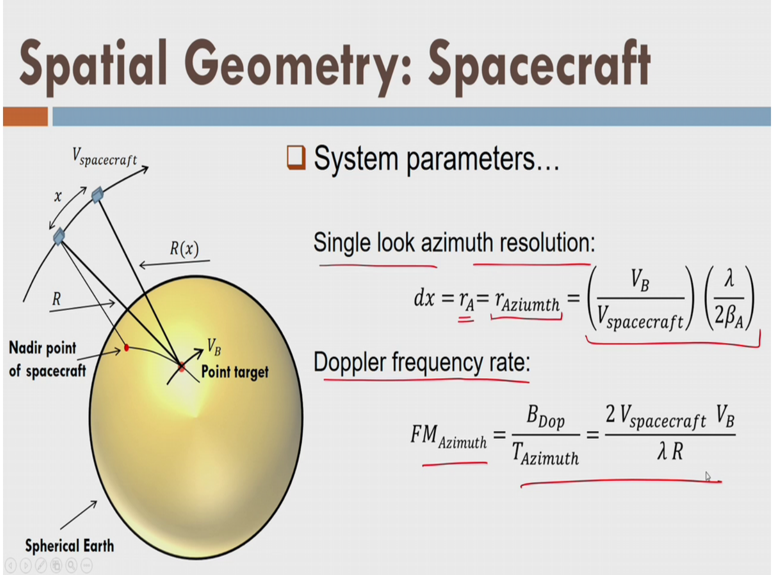

Spatial Geometry: Spacecraft

❑ System parameters…

Single look azimuth resolution:

$$dx = r_A = r_{Aziumth} = \left(\frac{V_B}{V_{spacecraft}}\right)\left(\frac{\lambda}{2\beta_A}\right)$$

Doppler frequency rate:

$$FM_{Azimuth} = \frac{B_{Dop}}{T_{Azimuth}} = \frac{2\,V_{spacecraft}\;V_B}{\lambda\,R}$$

Now, we can see the other parameters like single look azimuth resolution; that means, as if we have observed that azimuth from many many locations, that is from distance x over distance x, but finally, the expression because what we do? We take the brightness values and we average it over multiple looks. And finally, the azimuth as if we are looking from one look right it is given by this value, and you can see here it is also improved by 2 times what about the Doppler frequency rate it is given by this formula ok.

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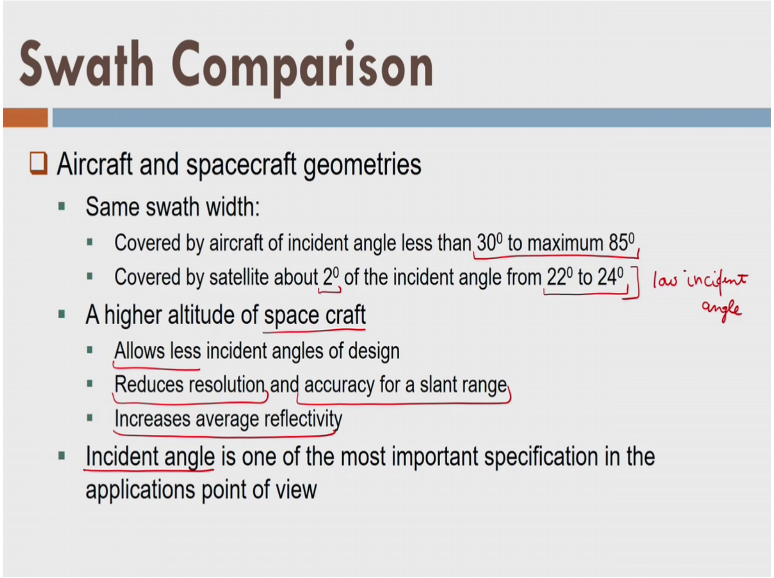

Swath Comparison

- Aircraft and spacecraft geometries
  - Same swath width:
    - Covered by aircraft of incident angle less than 30^0 to maximum 85^0
    - Covered by satellite about 2^0 of the incident angle from 22^0 to 24^0
  - A higher altitude of space craft
    - Allows less incident angles of design
    - Reduces resolution and accuracy for a slant range
    - Increases average reflectivity
  - Incident angle is one of the most important specification in the applications point of view

low incident angle

So, now, we are comparing the swath of the 2 system; one is space borne RADAR and another is airborne RADAR. Where simply we can see here that in case of airborne we need to have the let us say 30 degree to 85 degree look angle. And, then it will create some swath. Assumed, that I want to create the same swath using the satellite RADAR. What will happen here I need only from 22 degree to 24 degree; that means, only a difference of 2 degrees of the look angle; that means, my look angle is very small in case of space borne. Why because the spacecraft is situated at height of thousands km or so, similar range aircraft is situated at very less distance maybe some kilometres ok.

So, now we can see here, that the higher altitude of the spacecraft it covers larger area larger foot print and as a result what happens is I have low resolution compared to the airborne system ok, but at the same time I have very low incidence angle. In case of the spacecraft system the incident angle value are very small and that is that is the advantage somehow, but because I am getting the proper reflectance from a surface; and that is why it increases the average reflectivity, but it has low resolution and so, accuracy is also low ok.

So, we can see here that my incidence angle is one of the most important specification of the RADAR system, whether it is a space borne system or it is airborne system and we have done they comparison also. So, here I would like to say very clearly, that we have almost finishing the geometric aspects of my RADAR system, whether it is space bond and whether it is air bond or whether it is real aperture or it is synthetic aperture. So, we have finished all the geometric aspects, that is relevant to our lecture series in this module.

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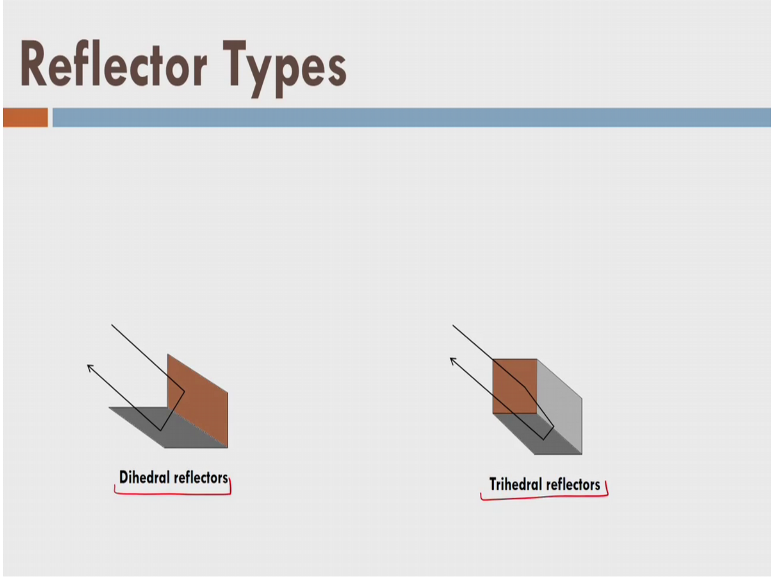

Reflector Types

Now, let us talk about the type of reflector. We have basically 2 type of reflectors. Let us say there is surface like this and transmitted pulse is coming this way if it is reflected from here, then here and retaining back towards the receiver and that is called the dihedral reflectors ok. Then, we have the trihedral reflector. Let us assume that there is a Q or we call cubicle in our offices here at one response surface, it is impinging the transmitted pulse, then it is going to this surface. And finally, the horizontal surface so, there are 3 returns, one here, second here, third here and reflecting back towards the receiver and that is such reflectors are called trihedral reflectors.

So, here we finish this we conclude this lecture and we have realised what are the geometric aspects of the RADAR system ok.

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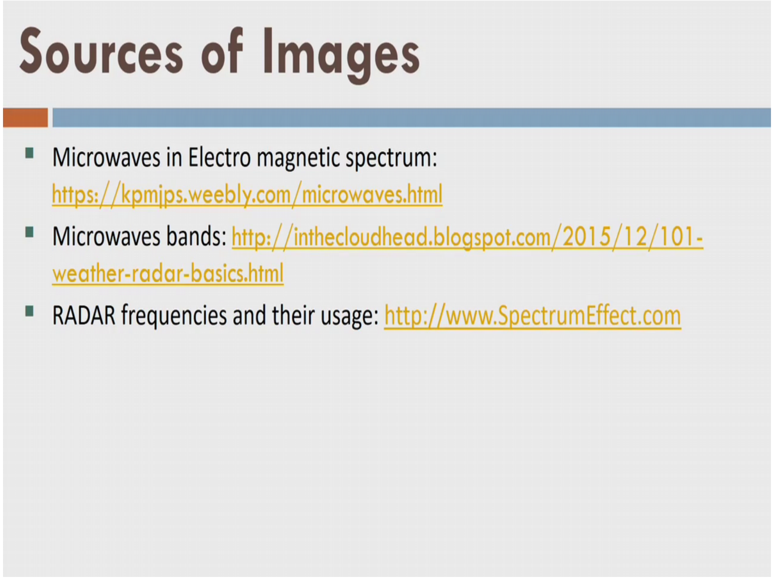

Sources of Images

- Microwaves in Electro magnetic spectrum: https://kpmjps.weebly.com/microwaves.html
- Microwaves bands: http://inthecloudhead.blogspot.com/2015/12/101-weather-radar-basics.html
- RADAR frequencies and their usage: http://www.SpectrumEffect.com

So, with this would like to thank you. And we have taken some of the images from these sources about the electromagnetic spectrum and so thank you.

Thank you very much.