Higher Surveying

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Module – 8
Lecture – 28
RADAR (Radargrammetry)

Hello everyone, welcome back in the course ofHigher Surveying. Today, we are in the second lecture of module 8, that is a RADAR, ok. In the last module, if you can recall, we have discussed The Geometric Aspects of The RADAR and in this module, we are going to discuss the Radiometric Aspects of the RADAR ok. So, let us go ahead.

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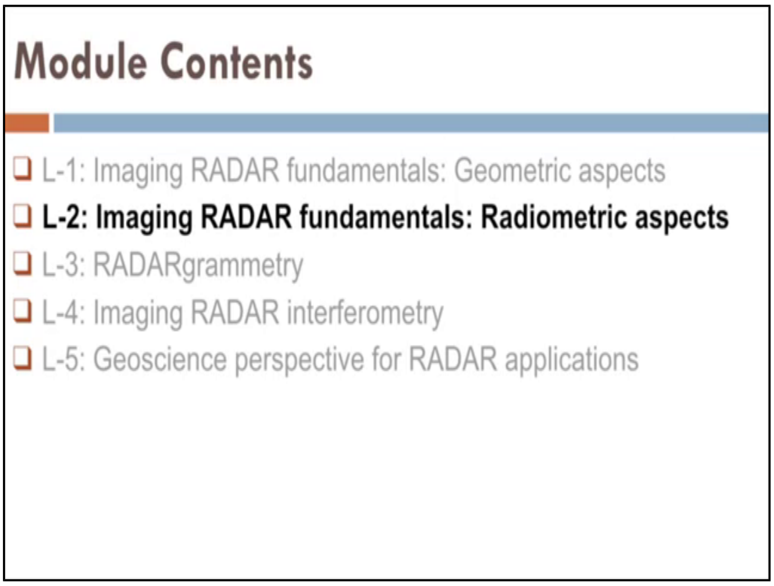

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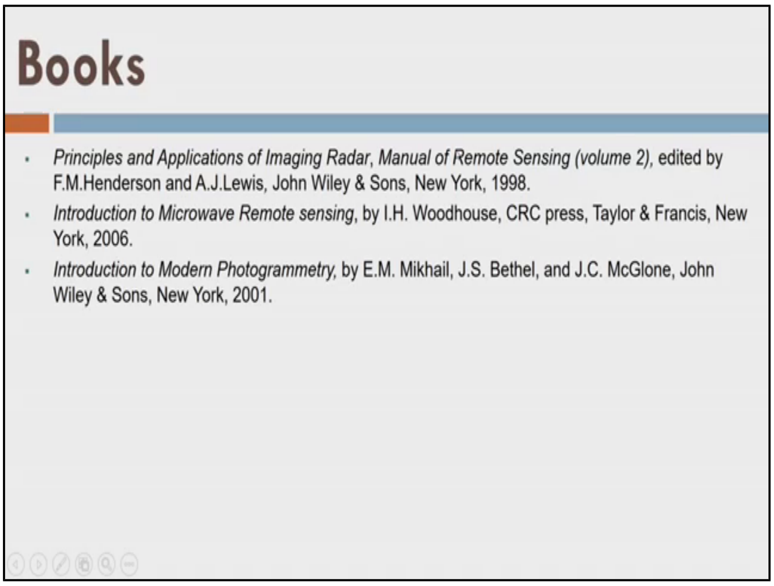

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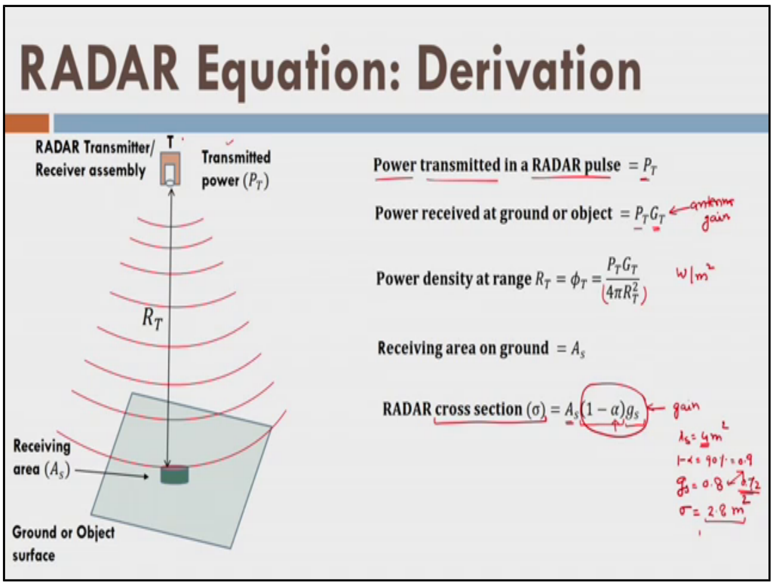

So, this is my second lecture of the lecture series on RADAR. So, these are the books, we have already shared with you and here, first understand the RADAR equation. Remember, in case of the geometric aspects, in last lecture we have assumed, that we are getting some responses, what we call impulse response and based on that impulse response, we have defined the impulse response width and resolution and the pixel and so on, right.

The question is, we have said there, that if the response or the impulse response is more than 50 percent of the transmitted signal, then we will accept that impulse response as a reflected back scatter. The question is how to decide that or how to measure or how RADAR sensor or receiver measures this response or the impulse response. So, let us look into this thing here ok.

Let us see, there is a RADAR transmitter receiver assembly and there is a transmitter here. So, transmitter is transmitting some power P T andso, let us see this is the distance between transmitter and the ground surface equal to R T or the distance between the transmitter and the surface of object right. So now, let us see that transmitter has transmitted the pulse or the signal in the form of wave front. So, wave fronts are reaching towards the surface of earth like this and the radius of the wave front becomes R T right ok. What happens next here?

So, let us say there is a target and so that, this target will reflect or back scatter this, transmitted power right ok. So, we can see here, that this is the area receiving area A S and so, what are the power that is transmitted in a RADAR pulse is equal to P T right. So, power received at the ground surface will be P T into G T. G T is my antenna gain or the efficiency of this antenna of the transmitter, see, at it is less than 1 always. So, I think whatever energy we put into the system and the transmitter transmit it.

So, what is the efficiency of the transmitter? For example, 100watt energy is put there, if it finally, transmits 90 wattpower,so, efficiency is 0.9 and that is my G T ok. So, the power received at the ground or object is this one. So, the power density at range, if I divide by the area of the sphere of wave front, I will get the power density, that is watt per metre square, ok. Then receiving area on the ground is A S, as we have already indicated. So, RADAR cross section we define like this, what is my alpha? Alpha is my the absorption of the material.

So, material will first absorb part of the impinging energy or the energy, which is falling on that. Now, if this is my absorption; so, what will happen this is my reflectivity and this is again an ideal reflectivity right. So, for example, if absorption is 10 percent,so, reflectivity will be 90 percent ok; however, again we say that this is an ideal case, ok. Let us say that, material has some efficiency of reflecting the energy and which is again here G S. So, what we call here issome kind of gain. Here, it is called the antenna gain.

Similarly, we can say, other gain term, which is because of the material here, right and depends on the material on the surface ok.As a result now, we can see that if this is the area, so I can say that if I multiply by this factor, here RADAR cross section. So, RADAR cross section is specifying that if my A S is 4 metre square. Let us say, rho is 10 percent. So, 1 minus alpha is my 90 percent or 0.9 and gs is again let us say 80 percent or 0.8. So, I will get sigma equal to approximately 2.8 metre square.

So, I can say here, that only 2.8 metre square area is reflecting a unit reflectivity. It has this much area or I can say that and this is area, which is having 4 metre square area, but it is 0.72 timesit has reflective of 0.72. So, that is the idea you can have here right.

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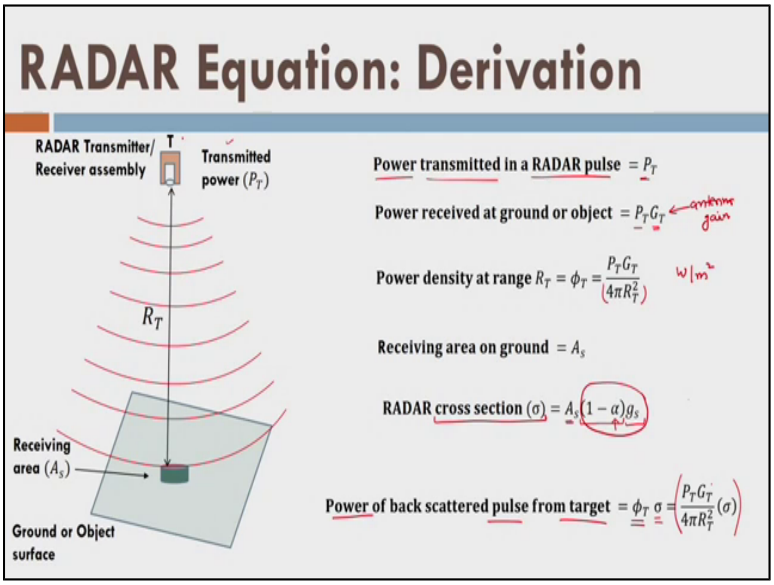

So finally, the power of backscattered pulse from a target is nothing but power density intocross section area. So, I get this term here right, you can do it yourself.

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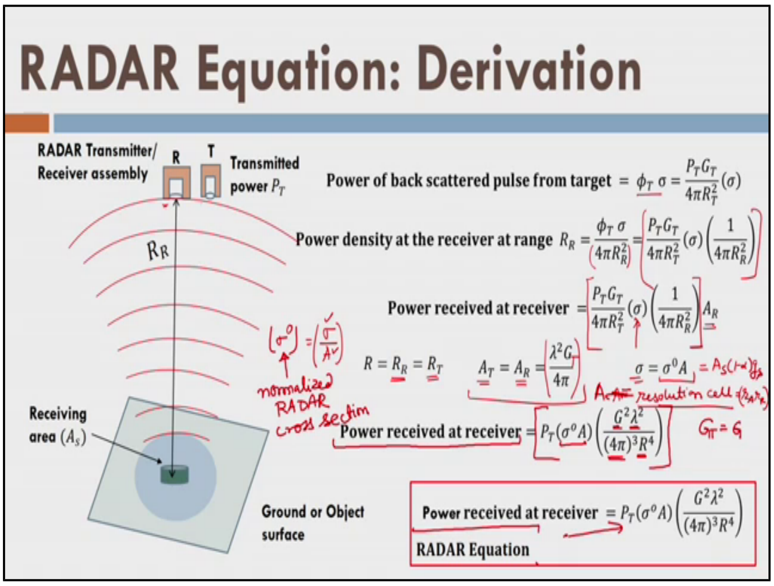

Now, that is the power of back scattered at the surface area. So now, will see again the surface area is there and there is a receiver here. Now, in the place near to transmitter right; so, receiver has a distance of RR from the surface area, ok. What happens is surface area behaves like reflector like this. So, it is reflecting the power or the energy in all around its surrounding right. So, as a result, again that reflected backscatter will travel to receiver in a wave front form like this.

So, radius of my wave front is now R R ok. So, the power of back scatter pulse from target is nothing but again, we have written the same term from the previous slide. So, power density at the receiver at range R will be what?Again we divide by the area of the wave front. So, we get finally, this term here. I hope you agree with that.The power, received at the receiver, is this one that is power density and then multiplied by the area of the receiver fine, ok.

Now, let us make some assumptions. First of all, we assume that be transmitter and receiver are located very nearby. So, the distance R or the slant range R for the receiver, as well as transmitter to the surface is same. The second one is this one, that area of transmitter and area of receiver are also same and we designed them in such a way that lambda square into G or I can say G T here or G 1 and the same thing divided by 4 pi is my area of transmitter or receiver.

So, this is a kind of design consideration, we have here right.Finally, there is a sigma RADAR cross section here, we can see here it. So, we redefine it in such a way that it equal to sigma 0 A and where A is my resolution cell. Remember, we have defined sigma equal to As into 1 minus alpha G S. Now we say that, let us define a factor sigma 0, such that this sigma is equal to sigma 0 times A and A is my resolution cell which is equal to if you remember R A into R R right, we have defined like that ok.

On the ground surface, what is the reason for defining sigma? The reason is very simple. I have calculated my sigma according to the area A S. Now, I want to do the same calculation for the resolution cell, which would be smaller or which could be larger than the A S. Now, logic is very simple, I am taking some kind of proportional; that means if my area of the resolution cell is smaller than A S or the sigma, what will I do? I will take the higher value of sigma 0 fine. So, that my sigma is equal to sigma 0 into A and vice versait is also true.

So, that is the kind of ideahere that means, I will take a ratio here, which is called sigma 0, which is nothing but sigma that is RADAR cross section divided by resolution cell here right. So, we have done some calculation for sigma area and now, I am going to do the calculation for A. So, this is a factor, proportionality factor here, fine. So, we write like this, I am sorry it should be sigma 0 not here. So, this is called, this factor is called the normalised RADAR cross section A, fine. Now, it is just a kind of proportionality factor here.

So, let us look into that.What happens to my equation? So, this equation becomes this,here.You see here that, we have replaced this G T equal to Ghere and so, we have G square lambda square 4 pi cube R to power 4 and sigma 0 A here, and where A is my resolution cell written here, ok. Then this equation, what is called the power received at the receiver is called the RADAR equation here fine and that says that, how much power has been received at the RADAR receive.

So, that is my RADAR equation and now, I will decide whether this power is more than 50 percent of the transmitted one, then I will accept it as a backscatter. Otherwise, I reject it saying that, there could not be any object or the object is so far away, that we are not interested to measure it ok. I hope that you got the idea here. So, it is this equation of the RADAR equation is similar to the Lidar equation, but the terminology and the things are quite different here and that is why we have included it here.

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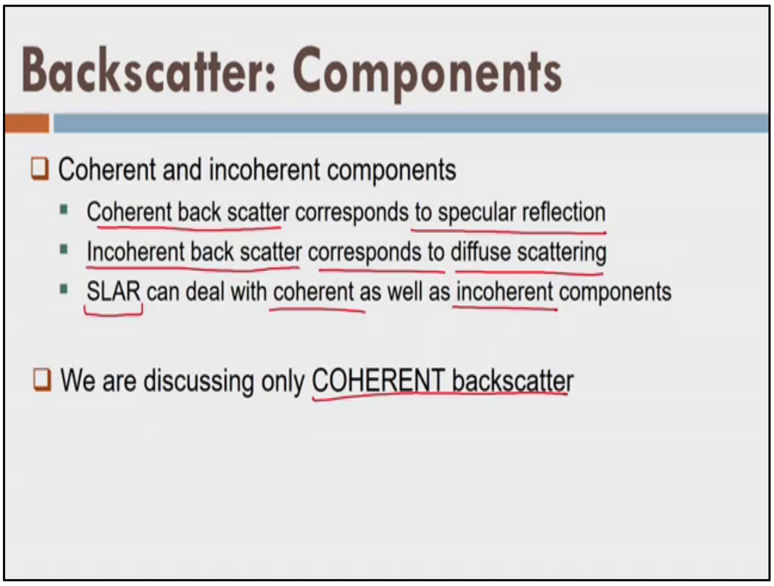

So, let us go ahead.Now, in the backscatter we have two components, one is coherent component and one is incoherent component. What is coherent component? If the all the photons in the reflected backscatterare in the same face, we say that it is a coherent backscatter. Otherwise, if they are in different faces it is call incoherent backscatter right. These concepts of coherent and incoherent comes from the physics and it is applicable to all of the remote sensing techniques, fine.

So, now, the coherent backscatter corresponds to the specular reflection that means,or say specular reflection, a particular directional reflection or deflection in certain direction is called specular reflection. The incoherent backscatter corresponds to the diffuse scattering that is a scattering happens in all directions. For example, like this; that means, from a given surface power is reflected in all the directions because, they are incoherent and thus, this is the characters of the incoherent and coherent backscatter fine.

The Side Looking Airborne RADAR can deal with coherent as well as incoherent; however, in this whole lecture series of RADAR, we are only talking about the coherent backscatter. So, please note it right. So, even we use synthetic aperture RADAR even we use side looking airborne RADAR or side looking spaceborne RADAR, we are talking about only coherent backscatter fine ok.

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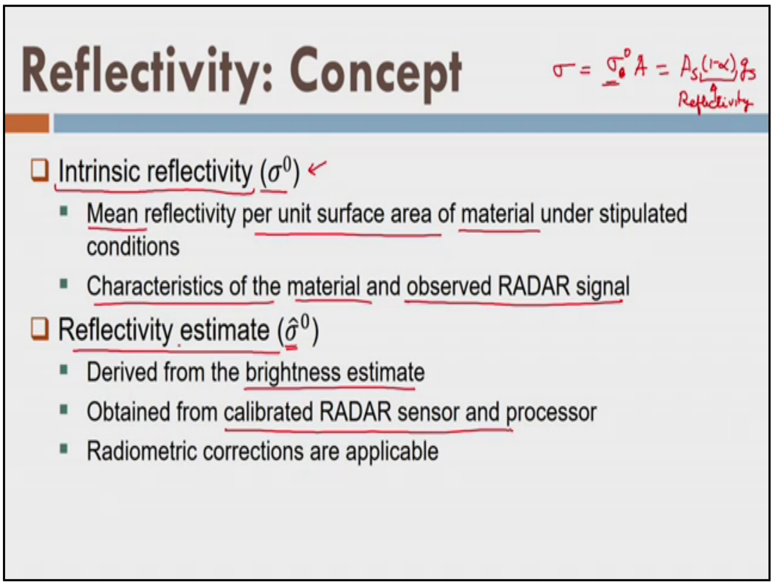

Now, we have realised one thing here, if you just go back to the back equation here, that we have defined something a 1 minus alpha into sigma. So, then we have defined something a sigma here, remember and then we say that, it is equal to sigma naught into A here and what was sigma naught? We say that, it is kind of normalised RADAR cross section, why? Because, here if you see carefully, it was equal to A S into 1 minus alpha into gs and this factor 1 minus alpha is nothing but the reflectivity right. So, reflectivity is basically affecting the backscatter from the surface.

Now, you can see in the whole equation, if you go back here in this term, P T is the power transmitted controlled by the manufacturer, A is a resolution cell control by the manufacturer, G squareagain, antenna gain, lambda generated by the system, R is a distance. So, we do not have any control over the R, as well as the sigma 0 or I can say the reflectivity 1 minus alpha.

So, now, we should understand that, how this reflectivity changes or affects the brightness or the response on the backscatter right. So, now, let us understand that, what is the concept of the reflectivity and how do we characterize it, in a sense, how does it affect the backscatter signal ok. So, in order to understand that, let us define the reflectivity fundamentally from the theoretical concept ok.

So, I have intrinsic reflectivity what we call sigma naught here and it is a nothing but mean reflectivity per unit surface area of material under stipulated conditions right there. First of all, I am defining this termso that, I can measure the reflected response or reflected backscatter at the RADAR receiver. So, it, this terms are basically used, basically for the RADAR receiver ok. So, these depend on the characters of the material and the observed RADAR signal ok.

That is a kind of theoretical definition, but in reality, how do we measure it, that is more important. We measure it by call reflectivity estimate we call it sigma hat naught ok. So, it is derived from the brightness estimate from the calibrated RADAR sensor and processor. So, remember we are defining these definitions for the sensor.

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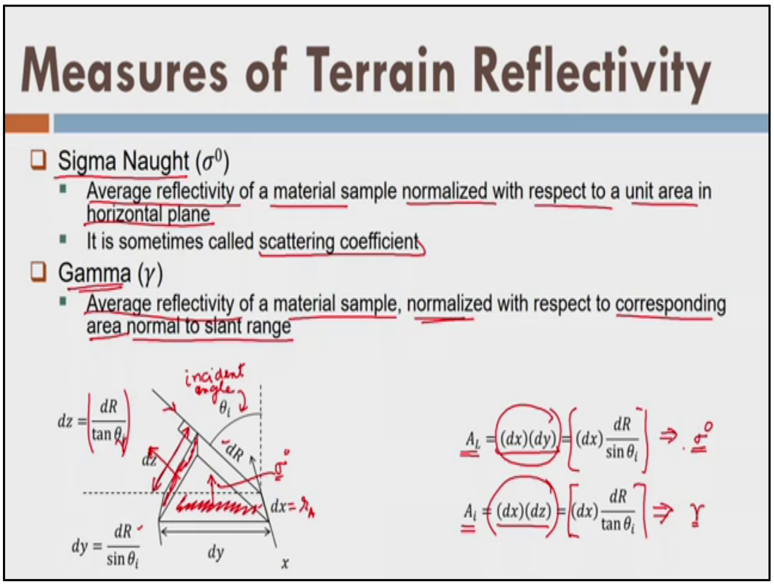

Now, how do I really measure it on the ground surface? So, what do we define it there for a ground or terrain? So, we defined call quantity sigma naught right, it is an average reflectivity of a material sample normalise with respect to the unit area in the horizontal plane ok, will see what is meaning here and it is sometimes call the scattering coefficient. Remember, we call it the sigma naught in the last equation in previous slide that is the normalised RADAR cross section. Now, we are saying it is a scattering coefficient when they are measuring on measuring it on the surface of the terrain right.

Now, we have the gamma one more term, which is an average reflectivity of material sample normalised with respect to the corresponding area normal to the slant range; that means, this is one area here, which is normal to this line of sight and this is another area on a horizontal one. So, if I draw the area vector is like that and this area vector is like that. So, I am defining my gamma based on this area vector, for this area and I am defining my sigma naught for this area vector ok.

So, let us look how do we say. So, this is my range, resolution here D R and this is my incident angle theta i ok. So, now, this is my x direction or the flying direction and this is my d x, which is nothing but azimuth resolution I call it r A ok. So, this is my d y, which is nothing but a resolved factor of d R. So, I can write here d y is equal to the d R upon sin theta i, here similarly, I can say d z, which is nothing but d z is this direction, this one is d z from here to here. So, d z is nothing but d R upon tangent of theta i.

Now, let us define these areas, one is the along the fly direction or we can say that, it is on the level plain. So, this is nothing but this d x d y. So, it is d x time d R by sin theta here and over this area if I calculate the average reflectivity, I define the term, corresponding to this term is my sigma naught here on a ground surface. Now, if I reduce my d x d y, I can make a point also making them very small, but going beyond the or going smaller than the resolution cell is meaningless now, right.

Similarly, inclined area is my d x into d z and now this is this much ok. So, what happens here is this is nothing but my we define the gamma based on this thing; that means, average reflectivity on this area is my gamma and average reflectivity on this area is my sigma naught, right. I hope that you understand those terms ok.

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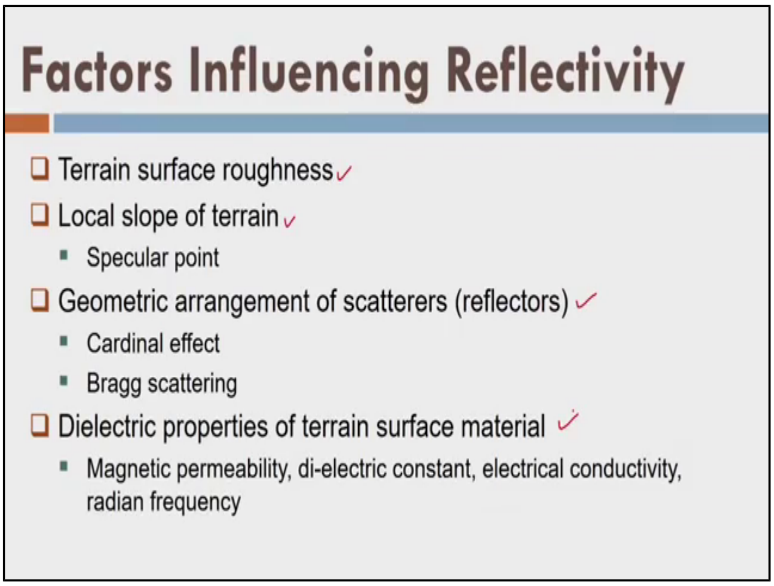

So, after defining this theoretical idea, let us see what are the factors that influences the reflectivity. The first is the terrain surface roughness, then we have the local slope of the terrain, then we have geometric arrangement of the reflectors or the scatterers and then we have dielectric properties of the surface material. So basically, these are the four factors, that influences the reflectivity of the material on surface of earth. That means, how do they respond to the incoming radiation of the RADAR and so, it generates the backscatter; higher the reflectivity higher the backscatter and higher the more reliable response we get at the sensor. So, we are saying that here terrain surface roughness.

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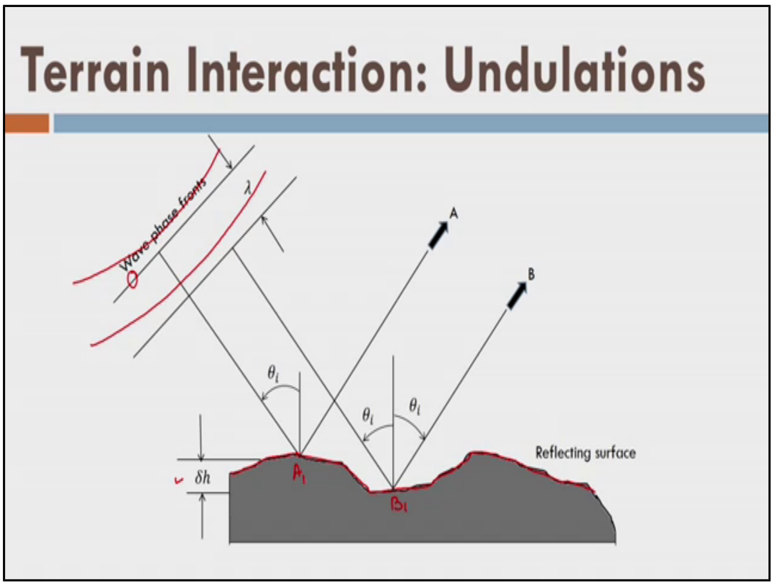

So now, we are defining the terrain surface roughness in terms of its undulations. What is the meaning here? Meaning is very simple, let us say this is my undulations, which is an average undulation d h, it is shown here. So, my ground is like this ground surface,we can see here. So, because of this, I can say that average undulation is my d h. So, this is my reflecting surface also. Now, if this is the wave front; so, there is a lambda is my wavelength. So, wave fronts are approaching like this fine, ok.

So, as a result this wave front, which is here, this wave front has approached this terrain 0.4 and now, it is reflected undulation A. Similarly, when this wave front has further proceeded, it has interacted with other part of the terrain, which is at slightly lower elevation. So, like this; so, it is reflected towards B right.Now, if I measure the angle theta i here for this point; letus say point A and point B here, let us say B 1 and A 1 ok. So, at point A 1 we have theta i and at B 1, also we have the same theta i angle, incidence angle and so on right.

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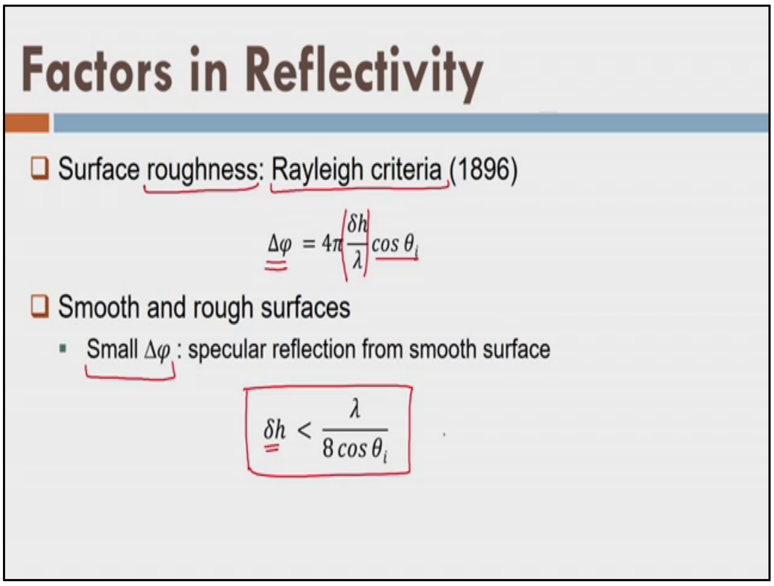

So now, we say that the surface roughness is revised by this factor, called data phi here and it is given by 4 pi times d h by lambda into cos theta i and it is called the Rayleigh criteria, ok. Now, if this is small, this delta phi we call it the specular surface right or surface is smooth and this criteria is given by the smooth surface. If my overall average deviation in the elevation is less than lambda divided by 8 cos theta i is called smooth surface, else it is called rough surface right ok.

So, smooth surface gives me specular reflection and rough surface give me the diffuse reflection. Diffuse reflection gives incoherent component, but we take only the coherent component into consideration. A specular reflection gives me the coherent component. So, in case of specular reflection, reflection will be higher or the reflected response or max scatter power will be higher.

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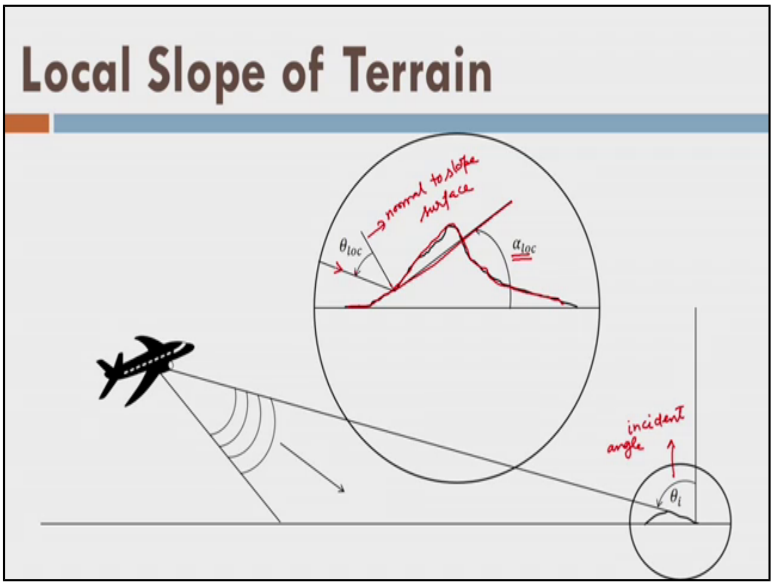

Now, coming to the slope of the terrain; well, we have defined here the angle called incidence angle, here right. If you see if you zoom it here on this place, if you see this real terrain is like this and we can see that, this is the slope of the terrain here and this is indicated by the local slope. What happens is this is my incoming radiation here and this is the enormous of this slope, ok. Now, what happens is this angle is called a local incidence angle of the radiation ok. So, how does it make a difference?

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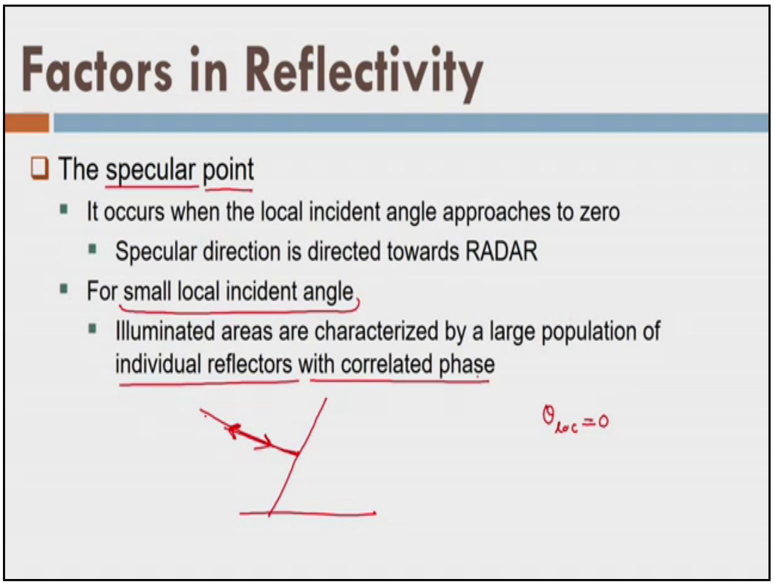

Now, we get some kind of phenomena called a specular point.What is this specular point? When this theta local it becomes 0, what does it mean? That means, let us say this is the incoming radiation and my surface is perfectly normal to that and so that normal of this surface and my incoming directions are 180 degree or they are basically coinciding and as a result what happens, whatever radiation comes here, that is reflected back completely and this is called the specular point. So, it depends on the surface slope as well as the combination of the incoming radiation and the surface slope.

So, when let us say, it is coming like this or the line of sight of the RADAR signal is perfectly normal to the local slope, what will happen? It will be reflected back and this surface will be appearing as smooth surface and this backscatter will be very high. So, that is effect of my local slope, such a phenomenon, where by chance it happens that the slope as well as the radiation line of sight, the normal of this slope and the line of sight of the RADAR signal coincides and it creates this specular point, ok. In case of small local incidence angle, that illuminated areas are characterised by the large population of the individual reflectors; that means, I get high reflectivity or I get because, I get high back scatter and that is the effect of the specular point.

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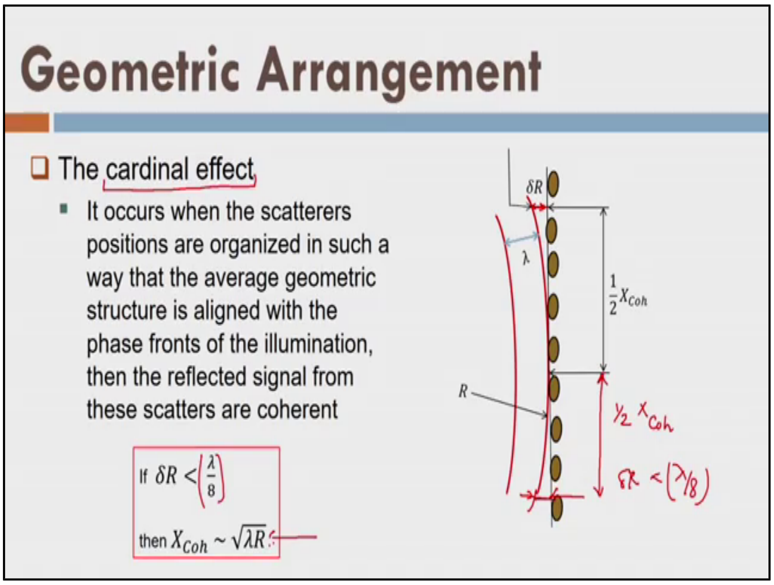

Now, third one is the geometric arrangement. What is the geometric arrangement? So, according to geometry arrangement, we have two terms; one is called the cardinal effect and another is called the backscattering.

So, let us look into the cardinal effect first. I t occurs when you can see here that wavelengths this wave fronts are exactly parallel to the or they are rather kissing or they are very-very touching it with respect to the surface and the geometric arrangement of the sensor as well as terrain is such that, the wave fronts are coming and they are kissing the surface, ok. What will happen here? This is my surface, which is quite horizontal let us say right and it is another position I am defining.

So, this is my wave front, which is kind of curvilinear surface here. So, that is a difference between the wave front and the surface. So, this difference of the surface here, that makes some difference and if that difference is less than certain threshold, I will say that surface is behaving like a smooth surface and this effect is called the cardinal effect. And it is shown here, that what will happen because of the cardinal effect if my delta R is less than lambda by 8 as shown here, this is my delta R, you notice this is my delta R, here this distance; similarly, this distance on this side will be delta R like this.

So, if delta R is less than lambda by 8 right, the whole length here that means, the specific part of the material length will behave a length which is giving you the coherent backscatter right and this is given by lambda into R right ok. So, if the lambda is higher, what will happen the coherent length over which I will get, the coherent response will be higher. Similarly, if my range or the slant range is higher automatically wave front at larger distance will be behaving like a flat surface and that is the reason it will this, affect will be more visible there; that means, I will get more length on the material surface, that will behave as a coherent length.

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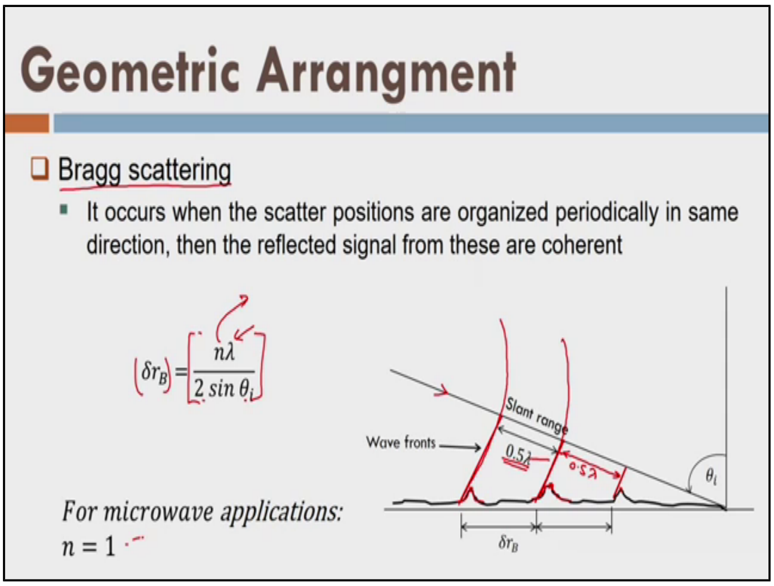

Next is the Bragg scattering; Bragg scattering is an another phenomena that is also coming from the geometric arrangement of the line of sight as well as the terrain features. So now, let us see, this is the case here and this is the line of sight here, and now features are like this. It is these features like this and after that, there is another feature like this and these features are so arranged that they are exactly at the 0.5 lambda, this is also 0.5 lambda. So, all these features, this feature, this feature and this feature will provide me the coherent backscatter and this phenomenon is called the Bragg scattering and notice that this arrangement is again by chance.

So, it is kind of geometric arrangement that is occurring because line of sight by chance is falling in such a direction that these are my wave fronts like this and through these wave fronts are touching or they are interacting with the terrain surface, which are by chance arranged at 0.5 lambda right. So, in this case the delta r B is given by this distance basically is given by n lambda times 2 times of this thing ok.

So, if I measure on ground surface, if there is a delta r B equal to this one and we select lambda accordingly. I will, I can expect the Bragg scattering provided the line of sight is such that, ok. So, line of sight is in favour.

Now, for microwave applications, we generally take n equal to 1 here in this case fine. So now, you go to ground, try to measure this thing, if you find some periodic placement of the features and if you select appropriate lambda, you can extract the Bragg scattering on the ground surface ok.

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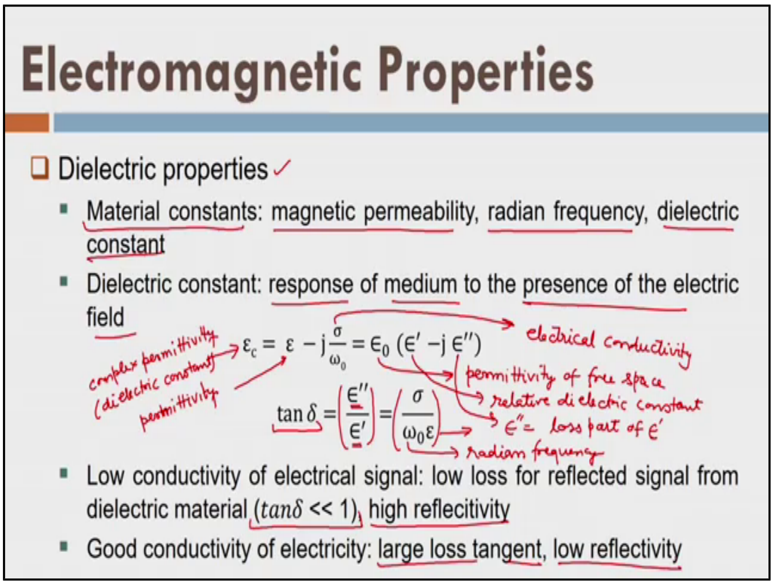

The last property is the electromagnetic properties ok. Here, we have some dielectric properties of the surface material and that is nothing but electromagnetic properties of the surface material. Here, we see that material constants that play a role magnetic permeability, radian frequency and dielectric constant of the material. So, what is dielectric constant? It is the response of the medium to the presence of electrical field; that means, if there is suddenly an electrical field around that what will happen? It will respond and that response is called the dielectric constant, ok.

In this equation if you see here, so, this is called this epsilon c small epsilon c, it is called dielectric constant or complex permittivity or it is called dielectric constant of material. That epsilon is the permittivity, fine. Then we have sigma, this sigma is not scattering. Please note, it is electrical conductivity ok. Then omega is my radiant frequency here ok. What about this epsilon 0? It is permittivity of free space, free space means vacuum and then we have epsilon that is relative dielectric constant. This factor is called relative dielectric constant and this epsilon double dash is called the loss part of epsilon dash.

So now, we can see if this ratio that means, if my loss in the dielectric property is less, because of the interaction with the RADAR radiation with the material then, what will happen? I need to understand this tangent delta term right, which these ratio of the loss to the relative dielectric constant right, of the material. Now, if loss is higher what will happen, tangent delta will be higher and that will become my good conductive material ok.

On the other hand, if I want more reflectivity of the material, what should happen? The material should not absorb or material should not allow the radiation to pass through it right or rather it should reflect it and now that is, if that happens, my epsilon double dash will be very-very small and as a result, this tangent delta will be very-very less than 1 and that is called a reflective material and if the material is the good conductivity of the electricity, what will happen?

It will allow the radiation to pass through it or it will right and in that case, I will have large loss, tangent delta will be close to 1and I will have low reflectivity. So, such material will give me less reflected backscatter in case of RADAR. But similarly, if there is a low conductivity material what will happen? It will back scatter more RADAR impulse or it will back scatter of the RADAR will be more from that surface ok. So, that is the factors here. So, now this criterion; so, this criterion is given by attenuation constant alpha and the penetration depth.

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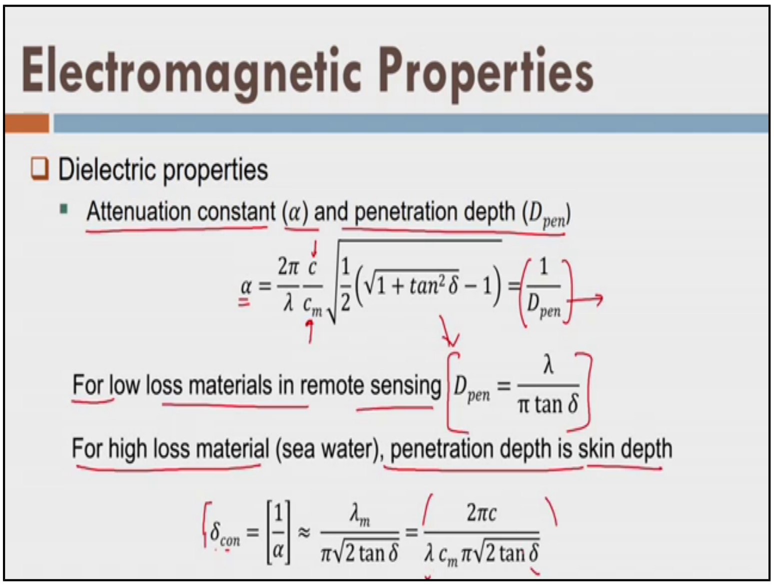

So, this is the relation, where c is the speed of the light in the air or vacuum and c is the light in the medium and this is given by this one and 1 upon penetration depth is this term, ok. So, you can calculate up to what depth it will penetrate, the RADAR signal or the RADAR radiation will penetrate. So, for low loss material in remote sensing, it is given by this term, which is an approximation here only ok.

For a high loss material, high loss means, the conduct electrical conductivity is more and as a result, the RADAR incoming radiation will be absorbed or passed through by the material like seawater, sea water is saline water.

So, it allows the flow of electricity through it. So, that penetration depth is my skin depth only; that means, the RADAR radiation will interact at the skin, slightly reflected and that low reflection will be just able to tell some depth of the surface right and that is called the skin depth and which is given by this delta con and it is 1 upon alpha, which is approximately equal to this 1, ok.

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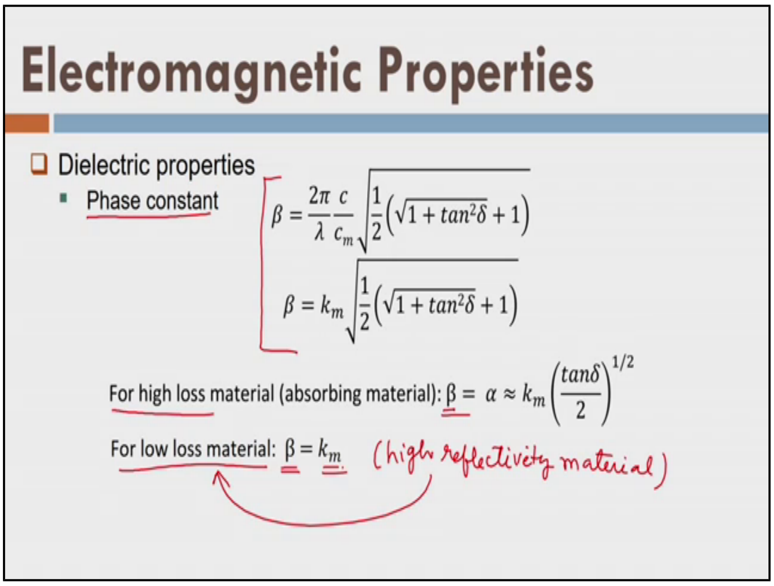

One more thing, that phase constant, although we do not use it, but still for the sake of completeness, we are telling that phase constant is given by this formula. So, for high loss material, I have beta equal to this much and for low loss material that means, high reflectivity material is beta is this much.

So, now, we have seen that we have taken some bright break here and we have seen that how the reflectivity of the material influences the brightness or the backscatter towards the RADAR receiver.

Now, let us look into again the same aspect that means, we have measured the reflected backscatter from the RADAR receiver, right. We see that what do we observe there because, we want to convert that backscatter into the image form where we will have the position, as we told in the last lecture, that my each pixel will tell me the position ok. I can say that the complete footprint will be divided into many-many elements, each element is my one pixel and one pixel will be having three data.

One is brightness, one is location, that is the incident angle and the slant range. So, this total three data are there in each pixel right. So, we have noted down by my RADAR equation that, what is the time flight. Secondly, whether a signal we have received it or not. If we have received signal, that is the if the reflected backscatter is more than 50 percent of the transmitted one, we shall right, yes, we have received it ok. Then we say that how much is there fine, then based on that reflective back scatter, we say that how much is the brightness level compared to the other one and that is what we call the calibration process. So now, we need to have calibration, but before that try to understand what are the noise in the data that we expect.

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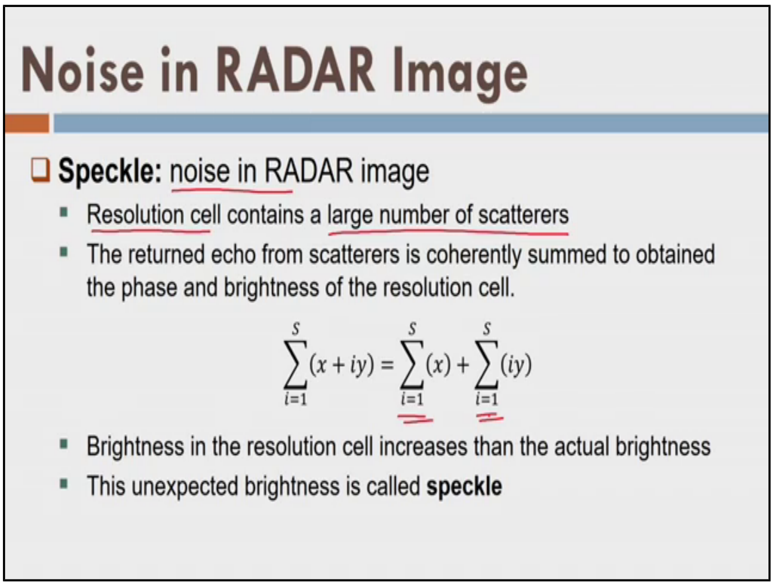

The noise in the RADAR image is called speckle fine. So, what is a speckle? It is nothing but noise. Now, we see that, the resolution cell contains the large number of scatters right. So, within one cell we have many scatters or reflective objects right. So, that written echo from this scatter is coherent, as we have already discussed, we are considering only the coherent component.

So now, if we sum up these coherent components because, they are linearly connected or they can be added linearly, what will happen? The brightness has two components; one is the imaginary, one is the real one. So, we add the real ones, we add all the imaginary component and finally, we will get some final resultant, ok. Now, assume that there is some noise. Noise is also contributing to this one. The speckle is also contributing to my signal.

So, there is a one main signal around that, there is some noise fine. What will happen? This summation and this summation will give me the resultant one. So, because of the noise what will happen? We have some extra radiation in each pixel and that is called speckle or noise and that will contribute some higher value of the brightness right and how to remove it, we should now consider it. So, first of all what is my speckle?

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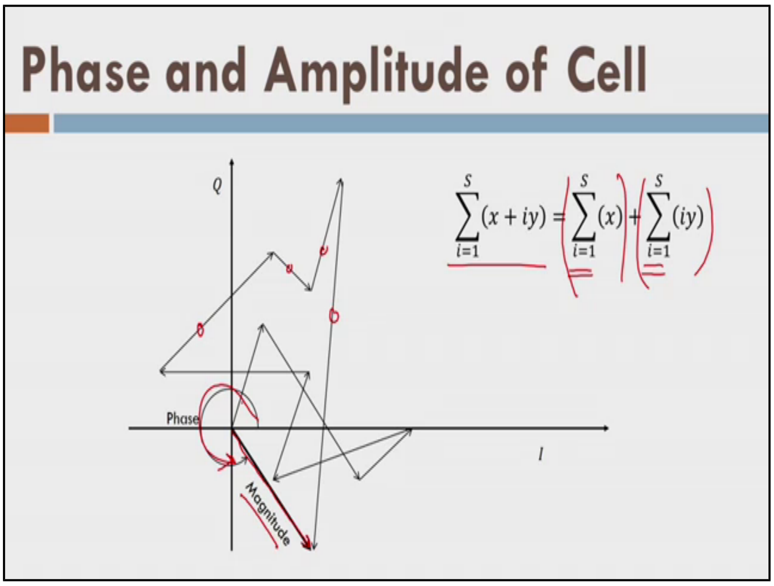

So, if I take the algebraic summation here of the real component and imaginary component, what will happen? I will have the final magnitude is this one, right. This my magnitude and this is the phase here. So, that one is imaginary component and one is a real component ok. So, it is there let us say, in one pixel we observe all these components, coherent components right and we are summing up them. So, it is shown graphically and mathematically we sum it like this only directly. So, it is not the kind of vector sum. It is shown although like a vector sum, but mathematically we do like this.

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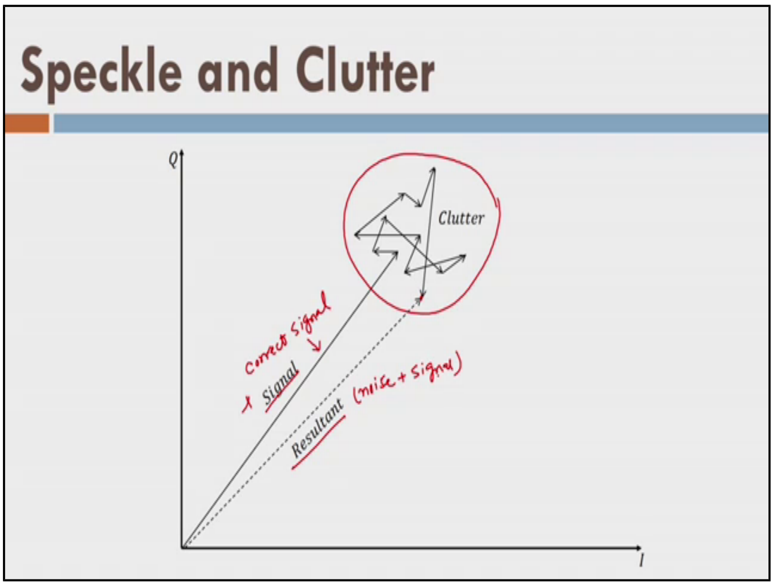

So, it is shown here graphically that this is my real signal without error, but this is a clutter here, clutter is nothing but the noise.

Now, if I add this noise what will happen? I will get, this is my resultant one, because the component on the noise are bringing this point and as a result I say that this is my resultant, which I observe and not this one. This is my original signal or I can say correct signaland this is resultant one, which is having noise. So, I hope that you are clear with what is speckle, ok.

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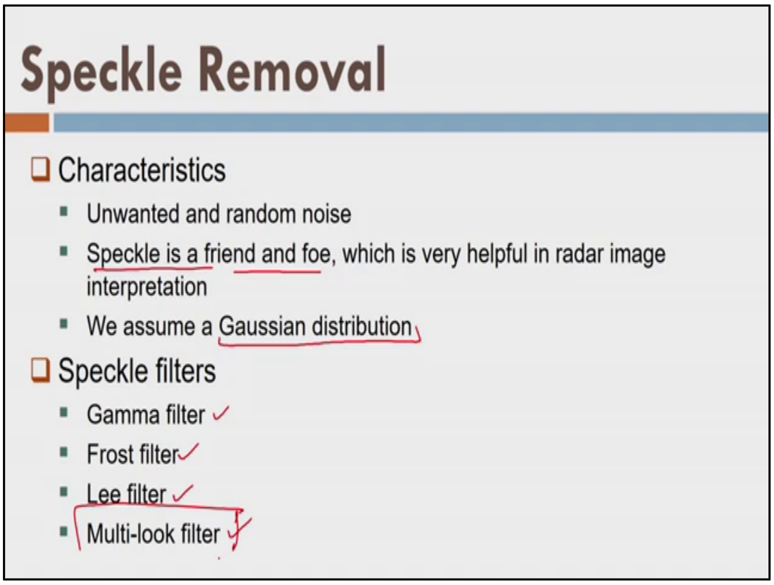

So, what are the characteristics of the speckle? It is an unwanted random random noise and a speckle is friend as well as foe, because it is useful quantity sometimes in terms of image interpretation and sometimes it is not desired. So, it is kind of you know there is a compromise between the two aspects. So now, in order to remove the speckle, we assumed that over a pixel, the distribution of the energy or the power is Gaussian fine and using that we say that, we have some gamma filters, frost filters, lee filters and multi look filters. So here, we are considering in this lecture the multi look filter.

So, what do we do in case of multi look filter? So, remember one concept, in case of geometric aspect, in case of synthetic aperture RADAR, we said that we are looking a point multiple times from different-different places and hence, I observe more brightness from there or more reflected backscatter from that place. What is the result of that?

Result of that I am more confident, I will get more backscatter. So, if I take the average, I will have more reliable value as well as my resolution is improved. That was the aspect we talked about the azimuth resolution or using synthetic aperture RADAR.

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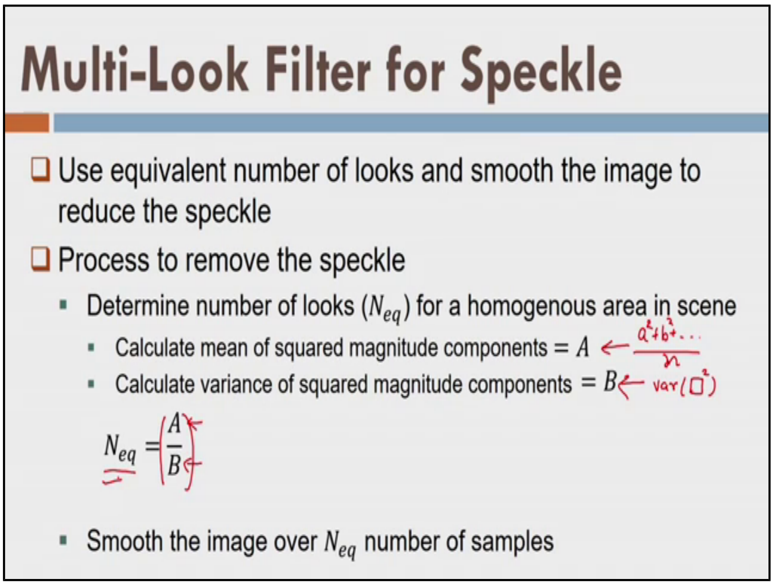

Now same thing, I am repeating here also that I want to calculate the equivalent number of looks and smooth the image to reduce this speckle, what do we do? Basically, we take a homogeneous area on the terrain surface and we know that it is homogeneous. So, I should expect from that homogeneous area that each pixel should contribute to the uniform value or the same value; that means, if I take the mean of couple of pixels in that uniform area;, I should get a constant mean or there will be minimum variation in the mean value or I can say the variance of the mean should be minimum. What will happen? Now, if I take the ratio of this quantity A, which is nothing but my mean of the all pixels, brightness value right. So, instead of that since, we say that it is a complex function, each image is a complex number, it can be negative or positive right.

So, what do we do? We take the square of the magnitude factor and then we take the mean of those is square factor for each pixel. You can say that, A square plus B square plus C square and so on. So, we take mean. Now for those all quantities A square B square and so on, we take the variance of those quantities and we call it B. So, first mean is my A, I can say here A square plus B square plus divide by n number pixels.

Similarly, I find out the variance of my square quantities, let us take for n pixels again right, so then, we say that take the ratio of A by B. Now, if my variance is less, which is homogeneous area, for the homogeneous area, I should expect low variance or minimum variance. What will happen? This A by B will be higher; that means, I have looked or I have observed that particular point, that homogeneous area from different-different many-many points, more than one point, fine. I hope that you got the idea and that is why since, I observed it from multiple points I have more reliable readings or more reliable observation of backscatter.

So, that is the idea. So, now, we decide this thing and we calculate N equivalent and using that N equivalent, we smooth the image over this N equivalent number of samples or pixels and this is the way, we remove the speckle, ok. So, that is the idea about the multi look filters and ok.

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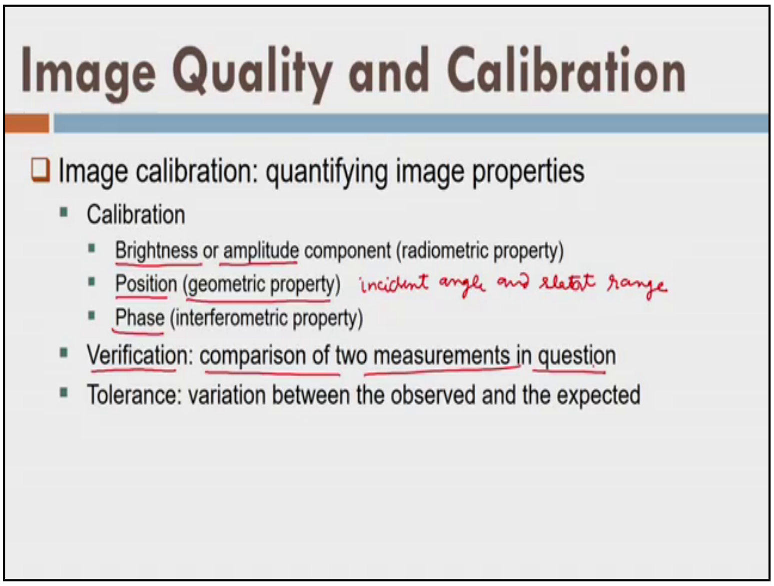

So, let us say that you have received a RADAR image and you have removed the speckle. Now, you want to calibrate your RADAR image. Why because you know the calibration will give you that, what is the value of digital number at a certain point ok.

So, what we do? You take a reference value. Remember, reference value concept? Reference value is nothing but what is an ideal value or what is the reference that we should understand if this is a given area; that means, for a grass I have reference value, for a stone I have a reference value, for electrical wire I have reference value. For some other material, let us say, sand we have reference value and this concept of calibration you can understand it. Another example, if you see in the television, there are many washing powder advertisements, where that this is a dirty shirt and there is a very clean cloth, absolutely white.

So, absolutely white cloth is a reference and your dirty shirt is kind of noisy data. So, once you go through some process of washing, using washing powder or what you call filter, what will happen? That because of this calibration process all the noise will be removed and it will become the, your dirty shirt becomes the reference cloth or the dirty clothe becomes your reference cloth, right and still we say, we always know that it can never become the reference or the absolutely correct them. So, there will be some difference between the after this processing also whatever output we get from the dirty cloth and the reference cloth, there will be some difference and that difference we call tolerance.

Similarly, in case of a RADAR or any system, when we do celebrate it, we go through some process, we calibrate it and we try to compare the reference and the modified input or modified pixel value and then we say that , there should be a within some tolerance and that is my calibration process. Otherwise, if the difference is more than tolerance, we reject that particular pixel and we say that, calibration could not be done or calibration is not appropriate, right.

So, here we calibrate for the brightness values, we calibrate for the position, that is geometric property. So, using the same process, what we say, let us celebrate our brightness; let us calibrate slant range incident angle and finally, the phase also. Phase will be required for the interferometric purposes fine. And in case of brightness, we have two components, as you said amplitude and phase. So, we do it for both. So now, after doing this thing we have a calibrated image. I hope you got the idea completely fine. Then we do the verification, we compare the two measurements in the question.

So, what is the meaning here? Through the calibration process after calibration, we got some values of the image and then we take couple of pixels randomly and we try to see, what is the reference value of those in the real field, then we compare the two and if this using this comparison, if the difference between the observed and the reference is within some threshold, we say that, we have done our calibration successfully. So, that is the idea here of the calibration or RADAR image.

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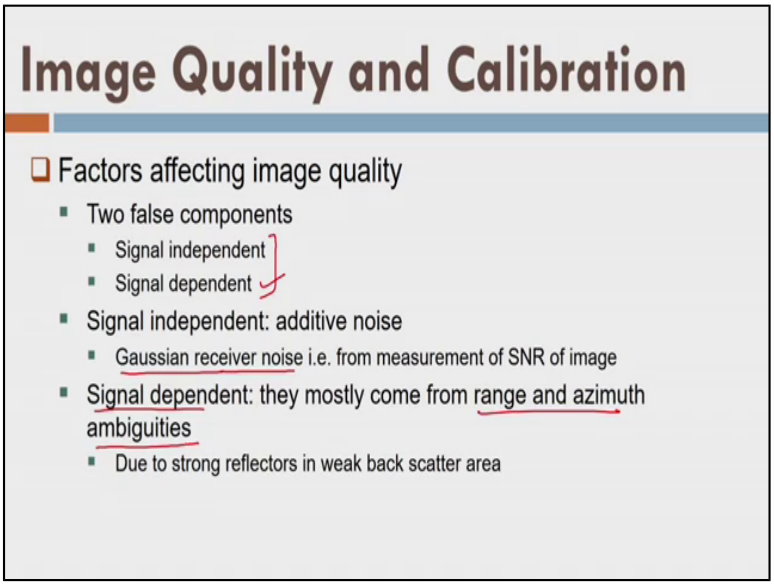

Then what are the factors that affect the image quality right. So, we have done the calibration process and now we have to define image quality, what is the quality of my image ok. So, we have two false components; one is related to the signal independent and another component is signal dependent.What is the signal independent? That means, we are saying that signals are coming the backscatter signal, right. So, backscatter signal from terrain; so, that is my signal dependent and the it is received at the receiver.

So, if we have some problem at receiver that is signal independent. So, those factors will be called signal independent at the receiver end. At the terrain end we call it signal dependent because, the backscatter is sent from the terrain ok. In case of single independent factors, we take the signal to noise ratio, so that we can find out what is efficiency of my receiver. At the same time for signal dependent, it is caused by the range and azimuth ambiguities.

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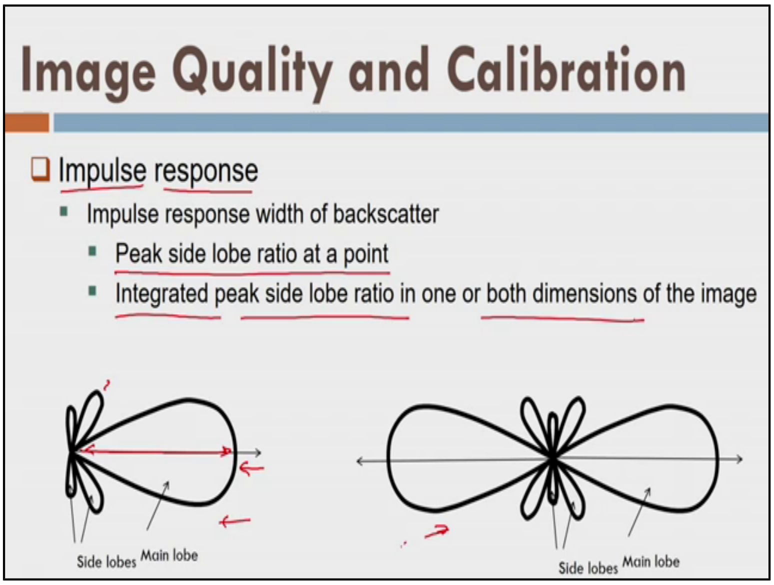

Now, how to quantify my image quality? So, if you see the impulse response here right, which is like this; this is my main lobe, what we call the main peak and these are the side lobes. So, if I take, so the side lobes are creating the noise and this is my main. So, if I take the ratio of this main lobe to the side lobe that will decide my quality of my image observation or the quality of my backscatter.

Sometimes in a book this kind of figure is also shown right ok. So, this ratio we take and then we take the integrated peak size this ratio in both dimensions of the image right and this is the way, we decide whether if I measure these two ratios. Then, we based on this ratio we say, what is the quality of my RADAR image ok.

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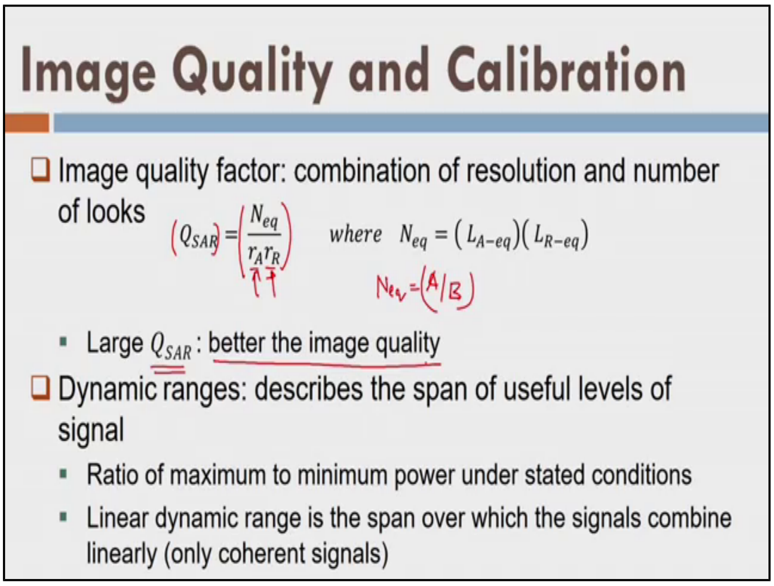

Then we also define, what is the quality of my synthetic aperture RADAR Q SAR and this quality is defined by here N e q divided by r A by r R. This is nothing but azimuth resolution and this is my range resolution right and N e q is already explained in the previous slides, that this N e q equal to A by B, we can refer it, what is meaning here ok. So, if the large Q SAR, if I get, its better the image quality; that means, if one pixel or one resolution cell is looked at by different positions or multiple positions of the sensor, it is a better image that is the simple interpretation here.

What about the radiometric part? Well, in case of radiometric part, we have two phenomena here right. The first of all, what do we do basically in case of radiometric part? There should be a certain range over which only we observe the coherent signal; that means, there is a limit up to which I can mix the coherent signal even signals are coherent, but still up there is a limit to mix them and we decide such limit that minimum and maximum and that is decided based on the sensor characteristics or the RADAR sensor characteristics and that is different for each and every sensor right.

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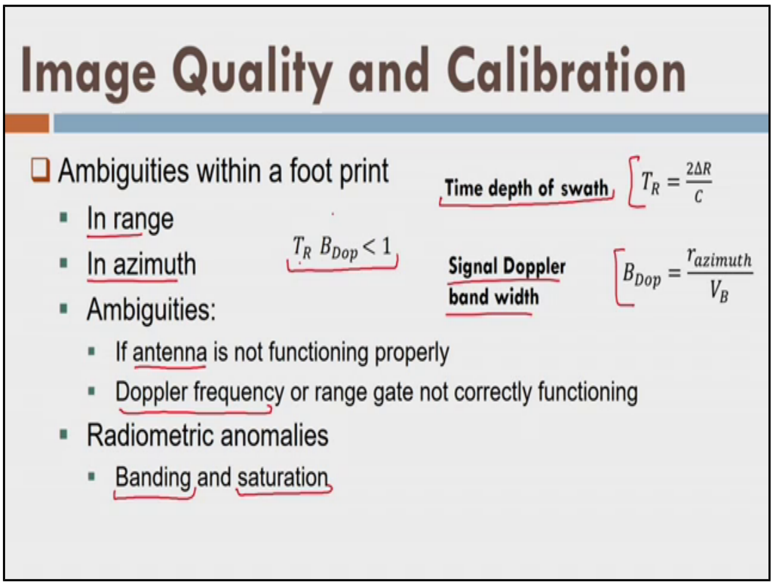

Now, we have ambiguities also. So, we have ambiguities in the range, we have ambiguities in the azimuth, so and then we have ambiguities contributed by the receiver antenna and we also have ambiguities by Doppler frequency right and then we have some phenomena called banding and saturation. What is the saturation? Saturation is the point over which, even the power of reflector signal is coming, but my sensor cannot measure. What is banding? Banding is happened in the flight direction, where bands are created in the RADAR image. So, that is called banding and these are also kind of ambiguity, fine.

Now, if I measure this time depth of swath, remember T R and similarly, signal Doppler bandwidth is given by this right. So, system is designed in such a way, that in order to minimise the ambiguities T R into B Dop should be less than 1. So, this is the way systems are designed in order to minimise the or in order to maximize the quality of my output RADAR image ok. So, these are the qualities, fine.

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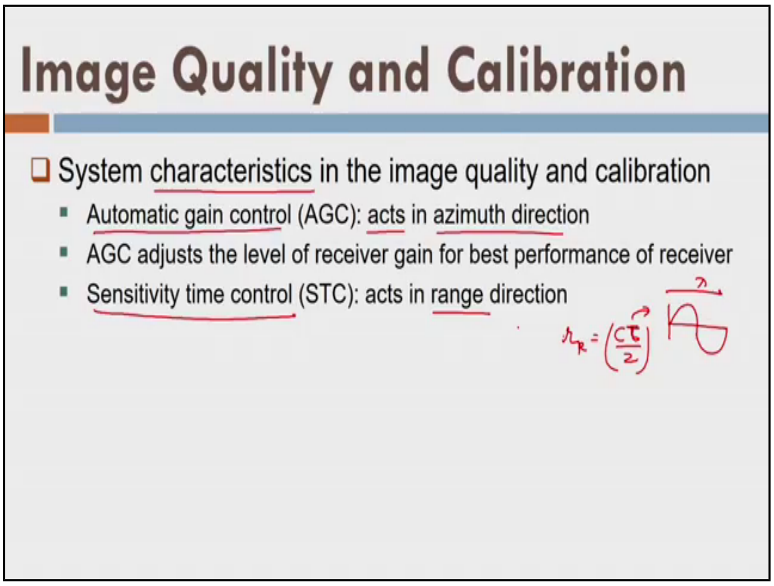

Now, we also should understand that system characteristics or the hardware characteristics also contribute to the image error or image quality. First of all, what about the automatic gain; that is receiver gain; that is GT if we defined, any error in that it will be giving error in the azimuth direction, then we have sensitivity in the time control.

So, remember if I r R is given by c tau by 2, that is the and this tau is nothing but the time interval to travel by the 1 wavelength fine. So, this my lambda here, fine. Now, what happens is in any error in this tau will be reflected in my range direction or the range resolution. So, that is the kind of factor we should also consider, in order to decide the image quality fine.

So, I hope that you have understood how the radiometric aspects are dealt in case of RADAR. So, once we learn how to do it, we have the RADAR image. After observing, we have some noise, what we call speckle and then we remove it the speckle. Then we calibrate our image and then we find out what is the quality of my calibrated RADAR image, so that can use it for the topographic mapping or any other purpose in higher surveying ok.

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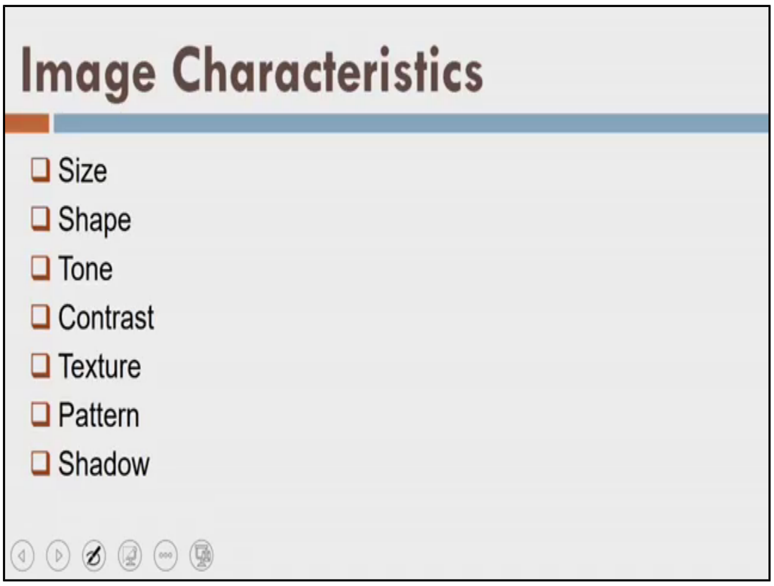

So, once we observe, once we get our corrected RADAR or celebrated RADAR image then we should have some kind of reliable properties about my ground features. So, what are the properties? Size, shape of the features, tone that is nothing but the colour, contrast that is a difference in the tone; for example, if I have grass, if I have rock, I should get the difference in the colour and it is nothing but the contrast in tone then the texture. What is a texture? Texture is the repetition of certain elements fine. What is right pattern? Pattern is repetition of the texture and then shadow. Remember, shadow is very important factor, sometimes in image interpretation.

So, we should have all these features, reliably expressed by my RADAR image, right. So, I hope that you got complete idea about the radiometric aspects of my RADAR, right. Here, we finish this lecture and we will be considering the next lecture on the RADAR grammetry and that is the 3D topographic mapping using the RADAR image ok.

Thank you very much.