Principles and Techniques of Modern Radar Systems

Prof. Amitabha Bhattacharya
Department of E & ECE
Indian Institute of Technology, Kharagpur

Lecture - 07
Some Basics Concepts of Pulsed Radar (Contd.)

Key Concepts: Measurement of RCS, Scaling Method of RCS measurement, Doppler effect in radar, Development of expression for velocity measurement

Welcome, to this NPTEL lecture on Modern Radar Systems. Now, we were discussing a very important parameter radar cross section. Now, today we will discuss that measurement of RCS because as we have seen that analytically RCS is not always very tractable, but with the now advancement of the numerical techniques people do simulate; simulators are available where you can do that. But, the correctness of all those things ultimately requires a measurement.

Now, because suppose you are producing an military aircraft you need to evaluate these RCS and find out whether the enemy radars, how it will detect it etcetera. So, people do RCS measurements, so for RCS measurement you see RCS depends on many things. So, you will have to see it over various frequencies or at least the frequencies in which enemy radar can operate over that whole thing you need to find the RCS because RCS is a strong function of that frequency.

Also, you need to see that you need to have a facility for rotating the object and changing at various aspect angle what is the RCS because you see that in which direction the enemy radar is looking depending on that RCS will change, if you see any practical RCS a thing that with aspect it changes a lot.

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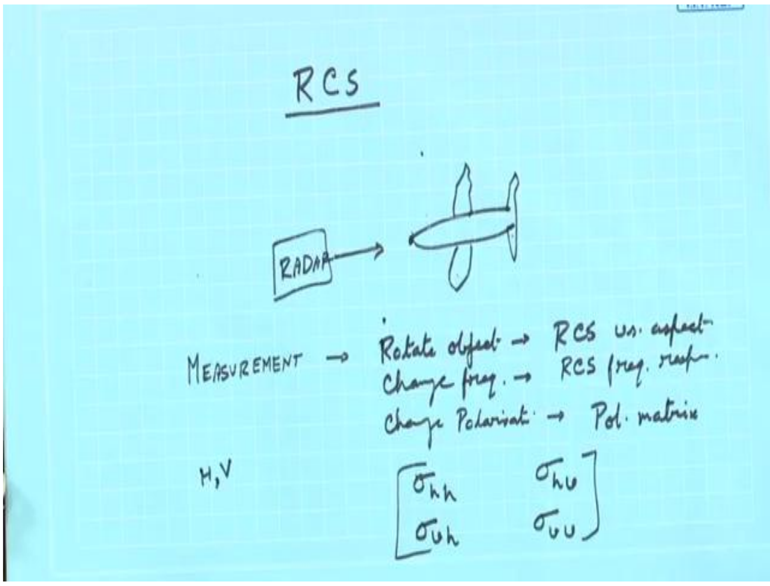

Now, generally you see that when an aircraft is approaching an enemy radar; the enemy radar is looking it from a nose end direction. Suppose this is a radar and let us say that this is the aircraft. So, this is called nose, so from nose end it is seen. But, suppose it is maneuvering that time some other aspect also suppose the there are wings here. So, this wings also may be seen, this is the tail end that may be seen etcetera. So, that means, you need a facility to rotate it etcetera, so; that means, for measurement you will have to have suppose a aircraft you will have like to move, a ship you will have to move.

So, that is a huge technical challenge, but people have made it that in ships in the sea it should rotate then also sea environment is different from air because fortunately for air it is a clean environment no returns comes, but sea that has various states the sea state. So, because of the wind the turbulence in the ocean etcetera, so that will also give a return, now you will have to clear that and find out what is RCS of the ship etcetera.

Now, what happens that so that means, for RCS measurement I can say that measurement you should have that rotation of object rotate object that will give you RCS versus aspect angle, then you change frequency that means, your system measurement system should be able to change the frequency that will give you the RCS frequency response.

Also you should be able to change polarization of the waves; that means, polarization of the transmitting antenna, polarization of the receiving antenna. So, change polarization and for that; that means, it will turn out to be RCS should be given in terms of a polarization matrix why because suppose your transmitting antenna has a actually polarization generally we define please refer to our NPTEL lecture on microwave antenna there we have defined what do you mean by polarization of a wave, polarization of an antenna.

Generally, if it has an horizontal and vertical polarization this two polarization so, suppose when the incident; that means, transmitting antenna is having a horizontal polarization and the receiving antenna is also having horizontal polarization, then the RCS will be called sigma h h. Now, let us say that the transmitting antenna polarization is H, but receiving antenna polarization is V, so it will be sigma h v.

Now, transmitting antenna polarization is v and receiving antenna polarization is h and transmitting antenna polarization is v receiving, so- you need to give all these parameters for all aspect all frequency. So, it is a huge challenge it is a very time consuming thing etcetera.

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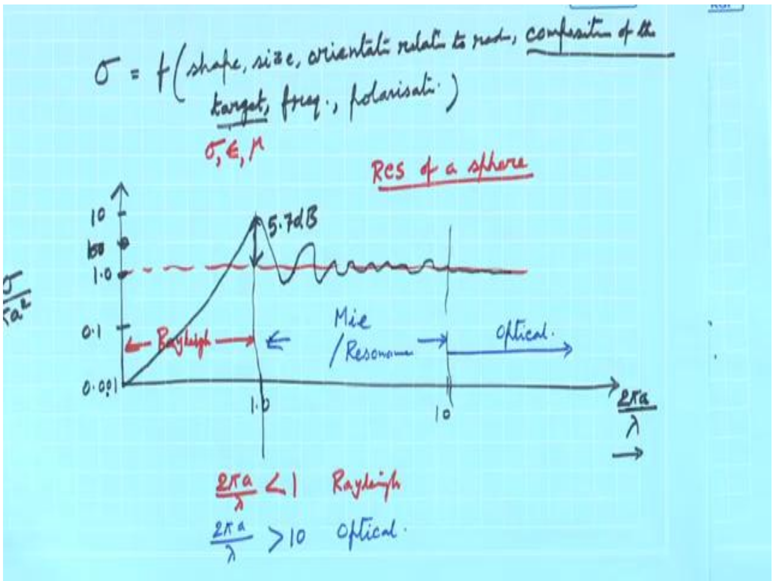

Now, what happens, so, you see people sometimes have a measurement that instead of you refer to let us refer to this. Actually you see that 2 pi a by lambda; 2 pi is a constant, so a by lambda. What is it? It’s the I can say the a is something like the link, a or 2a is the diameter of the thing. Now, for general bodies any body that parameter is called L by lambda.

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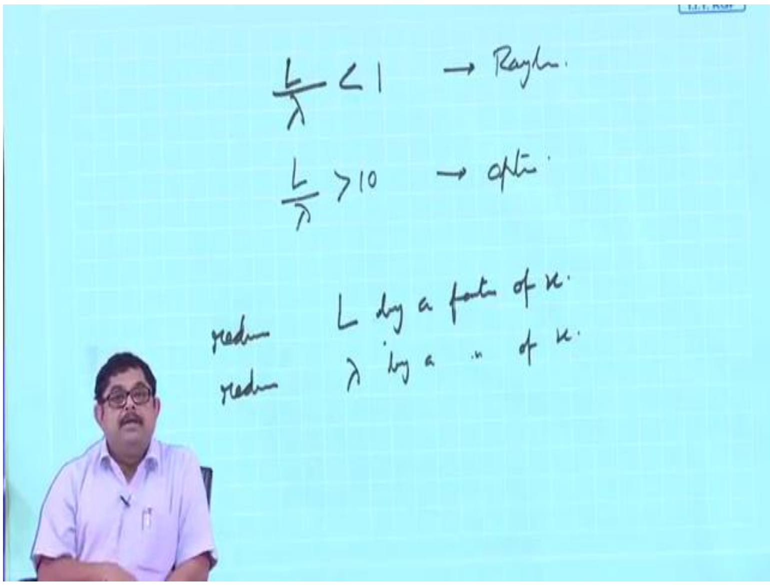

Now, L by lambda actually is this that L by lambda less than 1 you are at Rayleigh region, L by lambda greater than 10 you are at optical region; L by lambda in between you are in the Mie region. Now, generally microwave frequencies and the objects that they see they fall in this Mie region.

Now, you see that they are from this graph it is seen now I say that x axis is L by lambda. So, L by lambda what will be the for a particular L by lambda what will be the RCS that is known. So, people have suggested that if suppose I reduce L by a factor of x and you also reduce lambda by a factor of x. So, the RCS will remain invariant because RCS depends on this L by lambda parameter. So, if you do this you are not changing the L by lambda, so the RCS will also be same.

Actually, this was the principal in which you know India the first aircraft it produce to us the LCA, Light Combat Aircraft, combat aircraft not I am saying other aircraft, combat aircraft LCA. So, this principle was used to measure that L by .So, what they do that you can reduce the size; that means, make a scaled model reduced scale model of the actual thing all finer details geometrical details share the material details you keep, but you make it small then it is easier to rotate it, then it is easier to do all the mechanical parts that get reduced.

And, so, when you are making a scale model measurement then you will have to scale up the lambda; that means, lambda also you reduced by that factor; that means, actually you scale up in frequency. So, suppose L is reduced by a factor of suppose a typical aircraft is 3-4 meter fighter aircrafts, suppose a 4 meter aircraft. So, if you reduce it by 10 times it becomes 40 centimeter; instead of 400 divided by 10, 40 centimeter which is quite small. So, 10 times you scale up the frequency; that means, if you were seeing at 10 gigahertz you will have to go to go to 100 gigahertz. So, depending on what facility you have you go there measuring.

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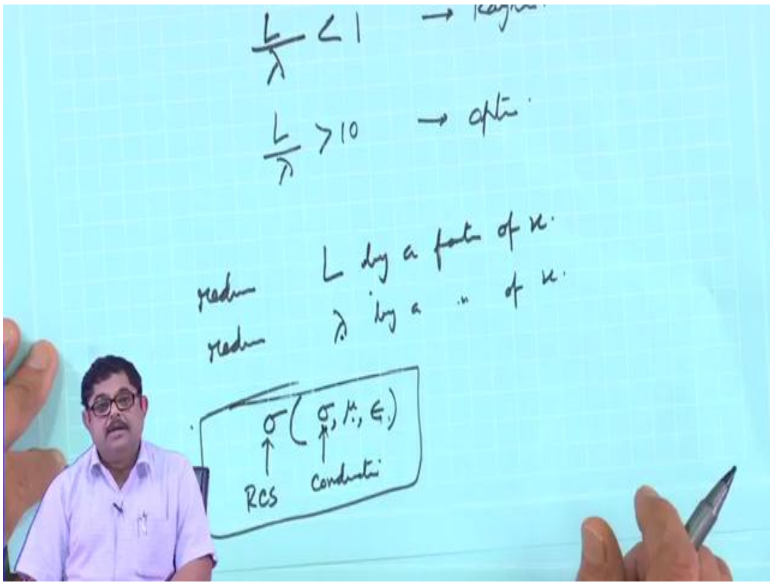

But, remember that there is a very serious concern here that actually as I said that RCS is functions of many things. So, it is also function of sigma, mu and epsilon of the medium making that. Now, aircraft etcetera they are not made for metals. For metals if any aircraft is made of metals or conductors there are no problem; this scaling method measurement by a reduced scale model that is perfectly.

But, nowadays no aircraft is made of conductors they are made of composite material, so there are some non-metallic parts basically various reinforced metals, ceramics etcetera they are used. So, they have their epsilon mu and sigma they are not linear functions of frequency, for conductors these parameters are linear functions of frequency. But, for non-conductors they are not linear functions of this; please do not get confused this is RCS the that two this is the conductivity of any material.

Now, this conductivity mu and sigma they are not linear functions of frequency. So, this scaling you cannot do because actually when you are do the scaling the inherent assumption is all the parameters are linear functions of frequency. So, if you scale up and down does not matter, but this if it is not there then you cannot do the scaled reduce scale measurement you will have to do the full scale measurement ok.

So, people have developed various numerical codes for that, but then there are that the codes needs to be simulating the actual physical phenomena which sometimes they cannot because codes take into account some of the things, but physically there may be some other things. So, there are various questions on that codes etcetera. Measurement is definitely good, but it is a very very costly thing etcetera. Also, how to reduce RCS that stealth thing I was talking.

Now, there are various shapes particularly in the geometrical shape of anybody if there is a discontinuity; that means, the slope of the radius of curvature if that has a discontinuity then there is lot of scattering. So, stealth techniques required that the shapes should be as smooth as possible. So, shaping the object, but you see that if you do those type of shapings actually an aircraft also will have to fly.

So, there are aerodynamic considerations for that and generally this making it smooth etcetera is modern aircrafts there aerodynamics is completely opposite. So, aerodynamics once it not so smooth, so; that means, this stealth requirement for shaping and the aerodynamic requirement of shaping they do not see generally eye to eye. So, there is a compromise that generally needs to be done.

So, many times suppose an aircraft has been made from these aerodynamic thing because ultimately it will fly. If it is a very good stealth, but ultimately if it cannot fly then there is no point and that happened. Actually the very best stealth aircrafts that has been designed by mankind they were not very effective as a flyer, so that is why.

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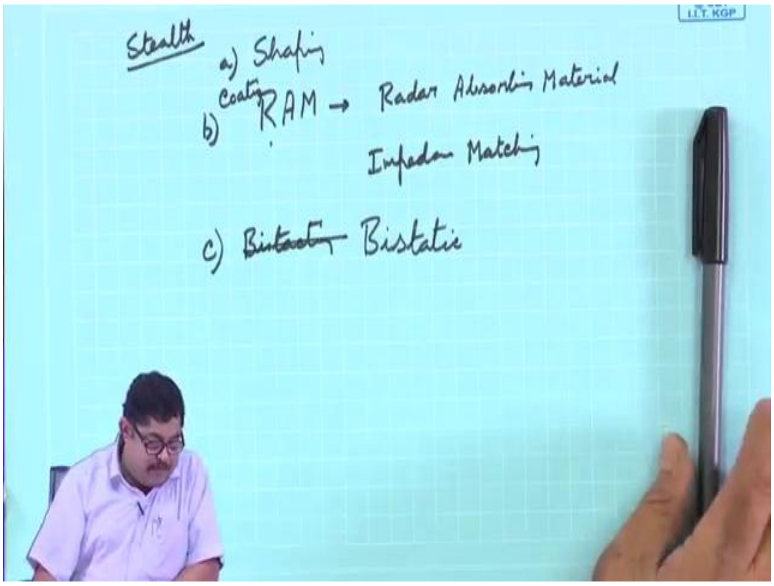

So, another technique is once and thing is aerodynamically designed etcetera, then you apply some material on the things typically some paints etcetera. So, or some sheets or some jackets covering those are called RAMs those are very important the Radar Absorbing Material RAM; Radar Absorbing Material.

So, name Salisbury screen, Dallenbach screen etcetera various, then now-a-days the requirement is now radars also their frequency is increasing, so, you want wideband RAM. Still that is challenge that what is an wideband RAM; what material is to be used. Actually the principal of all these things is radar absorbing material is you know that a wave incoming wave has an impedance that is called wave impedance. Whereas, a material the suppose the aircraft or that is made of the material. So, that material has their intrinsic impedance.

Now, if you can match these two impedances the wave impedance of the incoming wave and the intrinsic impedance of the aircraft or target, then the wave will come to the radar and then in the material if you have good amount of conductivity and also the good amount of imaginary part of the conductivity; that means, the loss tangent of the dielectric things. Then the wave after entering will be loss, so that will get absorbed. So, those are the principles of design of this RAM.

So, I should say that first there is a shaping these are all for making the design stealth. So, one is shaping that is the best one, but shaping always is not possible though, then this method is called coating; out of that there are various schemes of coating either paint or putting some metal all those are RAM. So, they work on the principle of impedance matching.

Please remember, which impedance that is important that is the intrinsic impedance of the material and then a on all these RAMs generally particularly the broadband ones they are multi-level things because at one go you cannot change the impedance. So, gradually they are multilayer structures and gradually there thing. Nowadays meta materials are being used there various other frequency selective surfaces are used there. So, these are huge huge area of research, lot of research is going on, lot of scope of research is there here.

And, also another way is that if you can use an bistat radar in a bistatic mode because if RAM etcetera suppose has been design for monostatic thing, but if you change your receiver position many of the times it happens that the RCS get enhance. So, an enemy radar will be able to detect because actually what happens in one direction you are taking the energy, so in some other direction you should have a leave that energy and there it is easier to detect. So, that is also another thing that you can have your radar in bistatic bi static operation.

But, then and then electronics is a challenge because transmitter and receiver they are at two different positions. So, at such high frequency and such distance there should be perfect synchronization between them that will see when we will discuss various radars functions that transmitter and receiver always should be synchronized. So, that synchronization is a challenge in bistatic, but it is a very good way of detecting an enemy target, an enemy radar ok. So, this is somewhat brief discussion on RCS.

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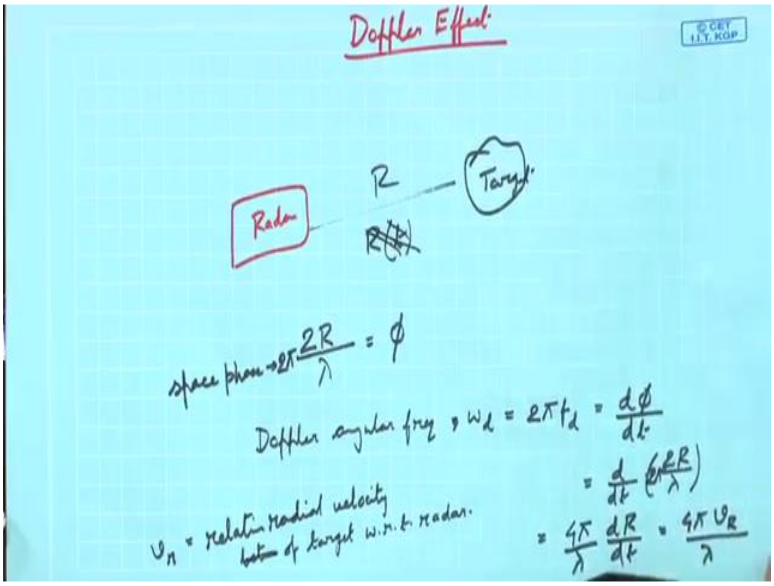


Now, we will see another parameter and we will close actually after range measurement the very one more important measurement that the radar does is the velocity of the target. Now, I can say that suppose a radar; so the parameter that I am going to effect is Doppler effect. We all know from our elementary, college level a thing that whenever there are two bodies and there is a relative velocity between them, the frequency of the signal that is falling on the body and coming back, the frequency will get change that is called Doppler effect, so that we know.

Now, that means, if there is a relative velocity between the target and the radar, then when the echo will come it will have a Doppler change if I can detect that Doppler change I can predict the relative velocity. But, one question can be asked that suppose I have a radar, I have a target this is target and this is radar. Now, radar is making a range measurement. So, basically it is making the measurement R and it is doing it over time; so, it knows R t.

Now, if you differentiate R t you get velocity. So, what is the need of measuring the Doppler frequency? Because Doppler frequency making is you see that frequency measurement also you are sending a gigahertz sort of signal of frequency and the velocity that is a terrestrial velocity that is not like the stars velocity etcetera which is quite high that is why Doppler was earlier detected etcetera.

But, in this case the change won't be small some kilo hertz change may be there at the most. So, on a gigahertz frequency a change of kilo hertz you think that what is the order. So, detecting that is not so easy, but still this is not used that we will discuss later, but always Doppler is used. Actually the reason for that we will discuss this is a food for thought for now think of that, but the Doppler is usually measured. So, what is the principle very briefly say this Doppler effect that. Let say that R is the distance between the radar and the target.

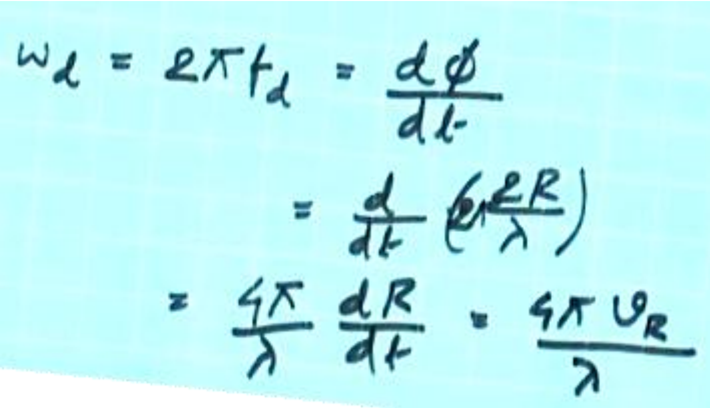
Now, we know that what is actually the wave it is the target is at far field of the radar. So, it is I can assume that the plane wave is going, a plane wave going a distance R and then getting scattered back and coming here. So, the total distance travel is 2R. So, the total space phase that will be associated with this two way travel that will be

$$\text{space phase} \rightarrow 2\pi \cdot \frac{2R}{\lambda} = \phi$$

Now, we know that what is frequency? Rate of change of phase is frequency. So, we can easily find out what will be the Doppler frequency. So, I can easily derive that mathematically Doppler angular frequency. Let us call it omega d that will be 2 pi f d and that is nothing, but if I call this space phase as phi. So, I know that it is time rate of change of space any phase that is called frequency.

$$\text{Doppler angular freq}, \ \omega_d = 2\pi f_d = \frac{d\phi}{dt}$$

So, this is the relation we know; so this is d dt of now let me put this value 2R by lambda. So, can I say that this is 4 d dt of sorry space phase it will be 2 pi into 2 pi over lambda ok.



where v R what is v R? v R is the relative velocity between the or I can say let me define v R, that v R is relative radial velocity between velocity of target with respect to radar. Generally, we take it with respect to radar because radar is generally not moving, but in airborne radars it moves in that case you can adjust, so with respect to radar the relative radial velocity.

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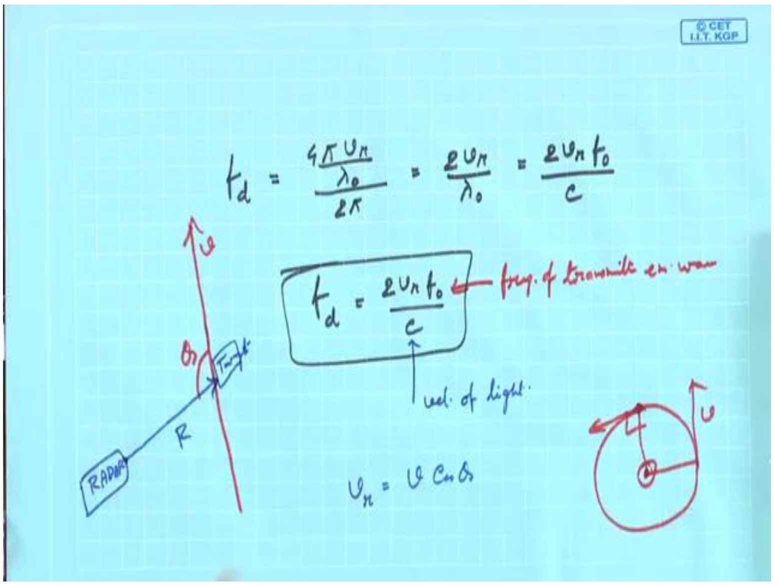

So, now I can write what is Doppler frequency change f d. So, this is the Doppler frequency. So, that from this relation you can easily find out 2 pi f d is this. So,

$$f_d = \frac{\frac{4\pi v_r}{\lambda_0}}{2\pi} = \frac{2 v_r}{\lambda_0} = \frac{2 v_r f_0}{c}$$

$$\boxed{f_d = \frac{2 v_r f_0}{c}}$$

So, this is the expression for Doppler frequency change, where what is f naught? f naught is the frequency of the transmitted wave.

So, write this frequency of transmitted em wave. What is c? c you know it is velocity of light. So, from that you can calculate that suppose I am sending a 10 gigahertz signal and let us say the velocities you know the aircraft speed fighter rates be there given in Mach; 1 Mach means 1 speed of sound. So, you know speed of sound you can take 330 meter per second or even you can take 300 also 320, 330 some. So, you can easily find out that how much Doppler shift will be there that will be given in the exercise.

And, remember one thing that when I am saying the velocity actually here I have given you everything simply as a scalar thing, but in actual suppose the this is the radar, this is the target. So, in a frame of reference attached with the radar this is the radial distance and suppose the target is moving this is the trajectory of that ok. So, if this angle it makes is theta. So, this is the let us the trajectory of the thing, velocity is in this direction. So, then we will say that what is this v r this you know easily that this is

$$v_r = v \cos\theta$$

where theta is this angle.

So, this expression should be then change the or v r is there, but you remember that v r is the projection of the velocity vector in the direction of the radial direction of the target from the radar. So, remember that if this angle theta turns out to be 90 degree; that means, from this radial direction actually the velocity vector is a orthogonal to that, then Doppler will not be detected. So, that means, if suppose you are at a earth thing and something suppose some satellite is suppose this is the earth ok, you are observing and this is the a satellite is moving.

Now, here there are no Doppler’s because always you see this is the velocity vector, this is the radial vector that is 0, so that means, Doppler shift is 0. Similarly, the target is here; here this is again 90 degree. So, in this case the Doppler will not be there, but in if you have any other angle there will be some component, so that will come. So, Doppler shift will be there (Refer Time: 28:52) we will see that various say, but this is the basic principle. Now, all this whatever we have discussed starting from range, the maximum range, unambiguous range, maximum unambiguous range, minimum range, integration of pulses, then the radar cross section, then this Doppler effect, the Doppler frequency, these are the basic concepts we have learned.

Next, we will go to various radars. So, we will start with the simplest radars which is CW radar, though we have understood this with pulse radar because this is easier to understand and pulse radar is the modern things. But, when radar was invented in the history you think probably noticed that initially pulse radar did not come because pulse radar is an advanced concept. CW radar was first invented because it is easier to make CW radar, we will also start with CW radar.

Now, you can ask that why we study that because we are studying modern radar and pulse radar we have already this concepts are understood and that is will, but still CW radar is used. CW radar very easier to make, pulse radar is quite complicated electronics; pulse radar is quite costly, CW radar is quite cheap and there is a there are various applications where pulse radar is an overkill. So, in that cases CW is used also you see that nowadays the radar technology is being used in civilian cases and there mostly CW radars are used.

One example is you are measuring the speed of anything particularly in today’s automobiles you see that in cars they always try to find whether there collision will be there or police try to find what is the speed, whether you are exceeding speed, all of them use the with the CW radars. So, it is a very good even a cheap thing, you can always make. Nowadays, the chips are fully available for CW radars in 2, 3 dollars you can buy those chips; particularly you know for automobile industry they make that chip.

So, CW radar is very important and that has lot of applications particularly in the civilian side in the defense side that or a huge radars generally they are not CW and so, we will start with that in the next class.

Thank you.