**Principles and Techniques of Modern Radar Systems**
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**Lecture - 04**
**Some Basic Concepts of Pulsed Radar**

**Key Concepts**: Radar range, integration of radar pulses, unambiguous range, pulse repetition frequency (PRF) and pulse repetition interval (PRI)

Welcome, to the today's lecture on the Radar Principles. So, in the last class we have derived a mathematical model called radar equation. So, that equation we have left it here that this is the radar equation.

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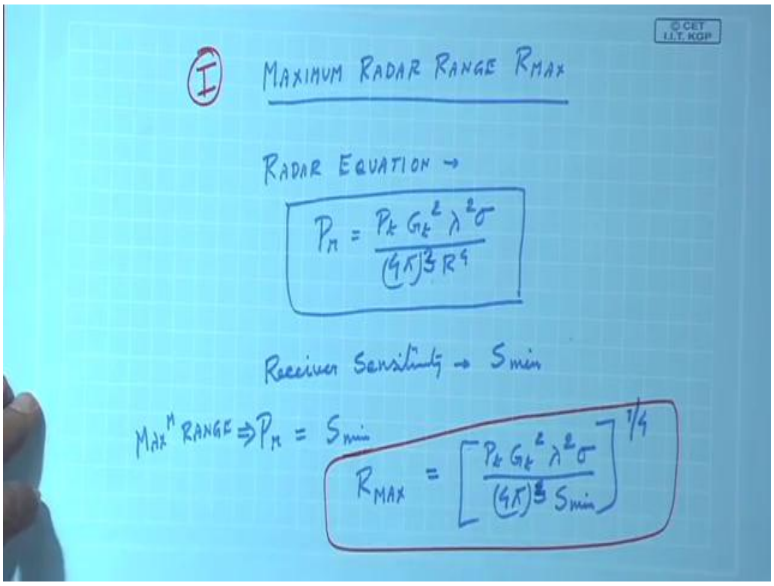


Today we will see, the first parameter that what is the radar range maximum range of a radar; that means, given a radar system with its transmitter, with its antennas etcetera and given a target with its radar cross section. And obviously, when I have given a radar system it has a transmitting frequency.

So, I know Lambda also is given. Now what is the maximum range? Now that depends on; you see that what is the power that my receiver can detect. Now every receiver actually you see in presence of noise. Now we are coming with practical problems, that there are noise in the environment. So, receiver cannot measure any amount of power, because the receiver itself is an electronic circuit. So, it has a even if in the environment there is no noise, but still the receiver will produce its own electronic noise and so, unless and until signal is far above that noise floor of the receiver.

Receiver would not be able to detect. Now so, every receiver has a specification that is called the receiver sensitivity. I think you have any electronic student; knows this that receiver has a receiver sensitivity. So, let us call that parameter receiver sensitivity that we generally call it S min. So, minimum signal that I can detect. Actually that is some 8 10 dB above depending on what system you etcetera, but it should be sufficient margin over the noise floor of the whole system.

So, suppose I know this; that means, what is the minimum signal I will be able to detect. Because for maximum range; as the range is increasing the received signal is decreasing, that means, Pr is decreasing. What is the minimum value of this Pr? So that is, now I assume that for maximum range maximum range of the radar. This actually implies that Pr is equal to S min. So, its a known quantity. So now, I can say that, maximum radar range from this equation will be Pt Gt square Lambda square sigma by 4 Pi wholes you see.

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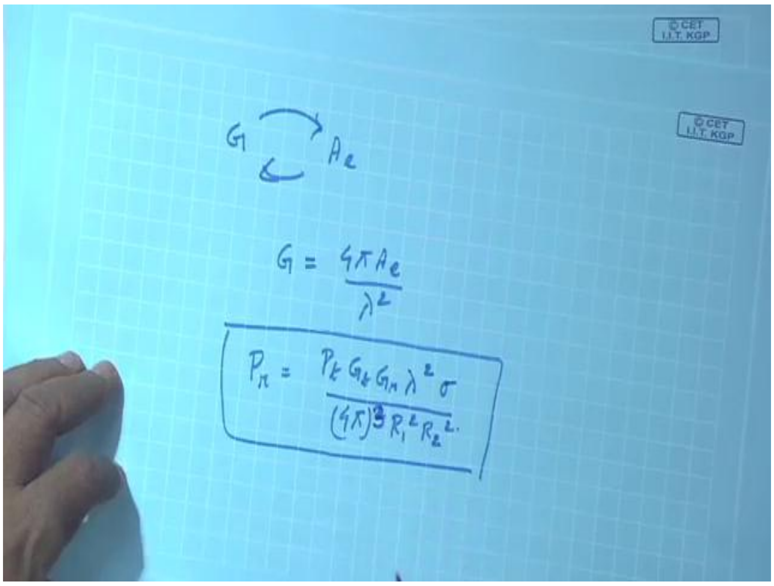


You see I have started when this 4 Pi has come actually this should have been. In earlier then you correct this should have been 4 Pi cube.

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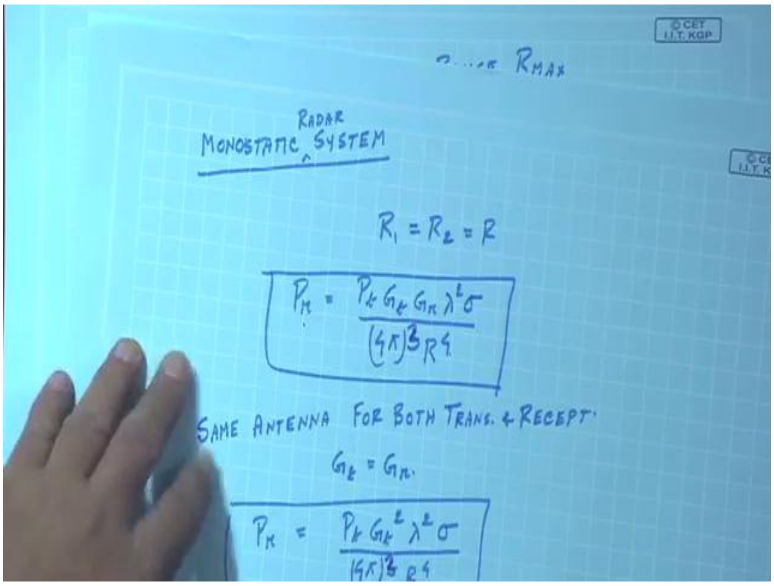


So, these are all 4 Pi cube. So, this is also 4 Pi cube. So, now, here it is 4 Pi cube S min. In the previous lecture actually I have written when we are relating g and the gain transmitting gain of the antenna. And here there is a 4 Pi that extra comes that is why it is a 4 Pi cube. So,

$$R_{MAX} = \left[ \frac{P_t G_t^2 \lambda^2 \sigma}{(4\pi)^3 S_{min}} \right]^{1/4}$$

This is the maximum range a radar can give.

So, you see that in your tutorial classes or assignments you will be finding various thing that, you if you know the various parameters of radar, you can find out the this thing. Now actually in reality what happens that if I send some power and when I see the echo actually the echo is much less than this receiver sensitivity; that means, the minimum signal that the receiver can detect. So, what radar people do? They go on sending various pulses. Now here again when I am being specific that, the radar can be c w radar a and this equations are all valid there, but I am there how to tackle it its difference, but I am assuming for your understanding the radar system initially that it’s a pulse radar. So, it is go on sending pulses.

And so, when it is looking at a target actually; after some millisecond or something it is sending the target. So, it sends several signals and gets back the returns, stores it and then it sums those echoes and then after summing it becomes something comparable to the receiver sensitivity. So in, So generally, no pulse radar detects a target by just getting 1 return from the target. It requires several returns, that is called our second parameter that is integration or its a process integration of pulses.

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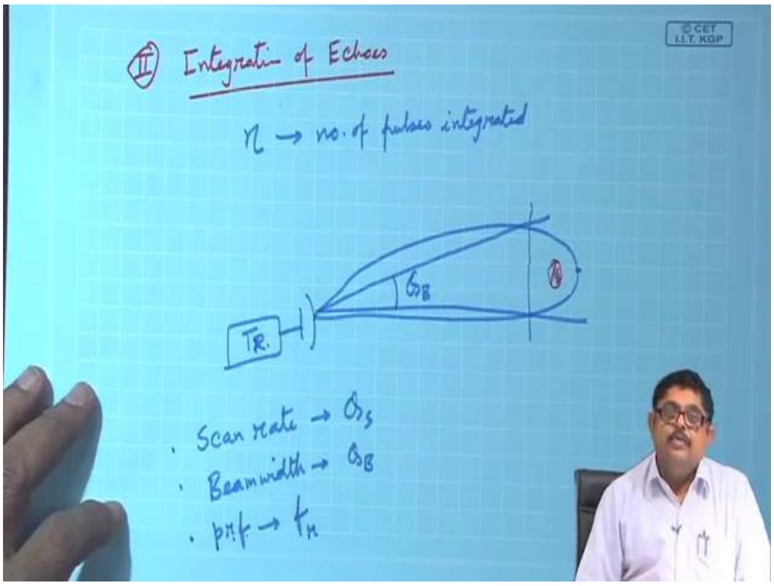


Radar people call it integration, integration of echoes. So, let us say that, we have n or n will be, so ok, n; n is the number of pulses integrated. Now we need to calculate that given a radar system, how many pulses we can integrate? Obviously, that depends on your receiver sensitivity etcetera. Now we will not do that, but we will try to say that, you see when any transmitting antenna suppose I have this transmitter and connected with a transmitting antenna.

So, you know that in microwave it is not like optics or laser source. So, any microwave source or any microwave antenna when it radiates that radiates by a beam. We cannot radiate in straight line its a beam and in antenna classes we have done; you can see the NPTEL lectures of mine on antenna. There we have seen that the basically we can say, that there is a beam width we define it there are various definitions that from these peak, there are 3 dB down etcetera. So, that beam width is generally called theta B antenna beam width. Generally for power patterns we take 3 dB beam width.

So that means, if the target is inside this, we say that that is getting illuminated. Now actually any antenna, any radar actually; radar does not know where is the target. So, it scans. So, it has a scan rate, but while scanning for sometime this target this is the target. This target is in the beam width of the antenna. So, pulses return in that time will be all coming from the same target. Those are integrated.

So, how many I need to integrate. So, for that you will have to also ask me that, what is the rate at which the antenna is radar antenna is moving? That is called scan rate of the radar. Scan rate, let us call that theta s I have already said the parameter beam width of the transmitting antenna.

So, beam width we are calling it theta B and n is the number of pulses. Also you see that how frequently radar is sending that is given by a parameter called prf, prf stands for Pulse Repetition Frequency. So, it is typically in some 200 300 hertz etcetera. That means, the in once again the 100 or 200 pulses. That is why generally after some millisecond 1 pulse is sent something like that, its not that fast.

So, because the a mechanical system its rotate. If you go to any airport etcetera you can see that one antenna always is moving on atc on various surveillance a thing. So, that is this candidate usually it is some rpm etcetera. So, now prf. So, how much radar is sending that is generally called fr we will use this moment lecture though out our this course.

So, if we know this can we relate the number of pulses integrated in terms of these parameters? Yes we can do, by simple mathematics that we will now see if I have scan rate theta s I can say that.

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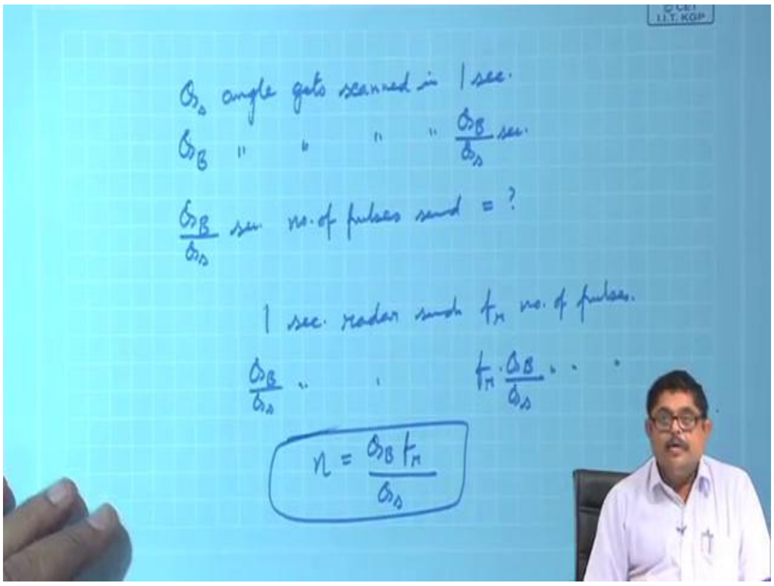


Theta s angle gets scanned in 1 second. My question is how much time it takes to move the radar antenna by an angle theta B, why that is required? Because suppose; let us say the let me draw another pulse.

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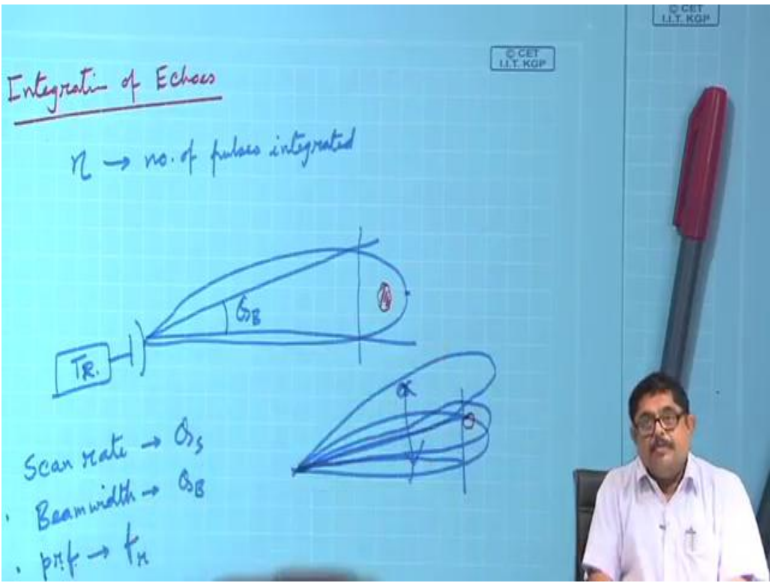


Suppose a this is the beam width; that means, this angle and suppose the as the radar is scanning there is a target. Let the target is here. So, after suppose the scanning is going on in this direction antenna is scanning. So, beam is also moving now this has come within this beam width the target. As the antenna moves further the beam will be somewhere here. Sorry, at the now this scanning is here. So, the beam will be next the beam will be more here.

So, the it has come in the middle of the target like that it will go from this side. So, throughout this theta B this beam is illuminating the target. So, that is why it is better to answer the question that how much time it takes for the antenna to cover an angle theta B. So, theta B angle gets scanned in how many seconds? That will be theta B by theta s second.

And now so, I have got the time for which the target is getting illuminated and I will get the beam; get the echoes from the target. But how many pulses I have sent in that time. So, that answer will come so; that means, in this time in theta B by theta s second, number of pulses sent is how much. So, that I can answer because prf is given fr. That means, in 1 second radar sends fr number of pulses.

So, in theta B by theta s second radar sends fr into theta B by theta s number of pulses. And that is nothing but; that means, those are the pulses or those are the echoes that are return from the same target. So, I can say

$$n = \frac{\theta_B f_r}{\theta_s}$$

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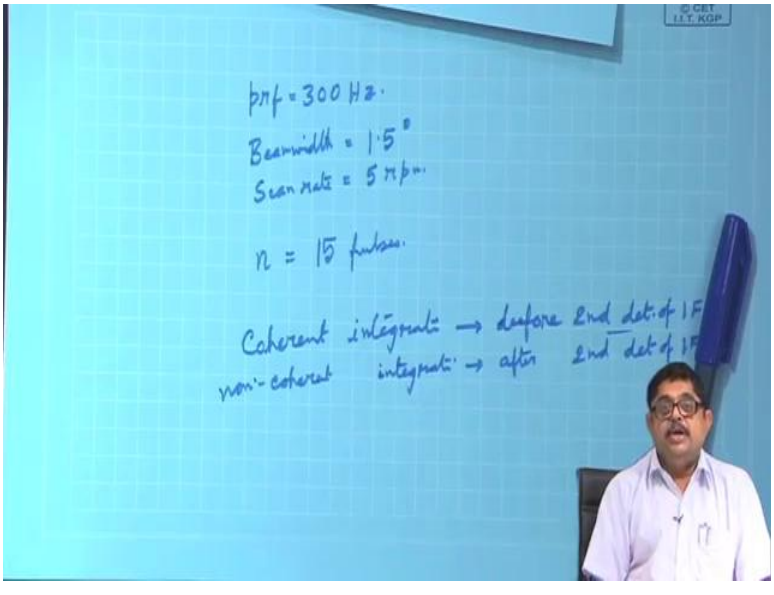

So, to understand suppose I give you some numbers that, let us say the prf of the radar is 300 Hertz. Now beam width is 1.5 degree and scan rate is 5 rpm. So, you can calculate remember that I have given beam width 1.5 degree, but be careful. Because this equations here, theta B theta s they should be angle in terms of radian.

So, if you do that, we will come that this n. So, theta B theta s that will be 15 pulses so, I am integrating. Now you can ask that suppose though we are assumed there are no noise, but in life noise will be there. So, you see that SNR of the system, does it improve if I do integration? Because the point is that when I am integration means I am adding.

So, the signal power and noise power both are getting integrated. So, how I am saying that my detection will improve by this thing. One thing it is coming closer to the receiver sensitivity, but it is also increasing the noise. The answer is not, because if you remember that signal; that means, what I am sending that is the deterministic signal. Noise is an random signal. So, if you add a noise corrupted signal always signal power will add up, but noise power will go to its mean.

So, if you have 0 mean sort of noise, then more and more number of integration you would more and more number of pulses you use for integration your noise will go down. And that is an added advantage of detection. Because I have not said that, but later we may not again discuss, but actually it’s an added advantage of these. That SNR of the system also get improved by integration. Though the one point of doing integration is that signal echo power is weak receive signal is weak.

So, I am pumping that I am waiting for some time, getting more and more echoes coming, I am adding that. But in a noisy system people may say that that will deteriorate your detection. Because your actually your noise will improve, but answer is no. If you do it for a 0 noise Gaussian thing or very low noise; low mean noise signal. Actually you it will improve added the SNR also. Now 2 more things that this addition of pulses, but you remember this is an rf signal. They have the amplitude, they have phase.

So, if you do the integration vectorically that is called coherent integration, coherent integration. If you do not do it vectorically, it is called the non coherent integration. Obviously, what we discuss that, we are just improving the SNR if you actually if you integrate coherently n number of pulses, your SNR after integration will be n times the original SNR. But if you do non coherent then it would not be such. Now we have not discussed the radar receiver, actually radar uses a superheterodyne (Refer Time: 18:37) receiver. So, there are 2 detector stages.

So, and in the actually from second detector of the, IF stage the signal phase is lost. So, if this integration then needs to be performed before the second detector of the receiver. Then only you will get coherent integration that will see later, but you remember because that time this thing will be recalled. So, if it is I can say that before second detector of IF. This meaning that time it will be cleared. Because we have not discussed what is the second detector etcetera, but write this and generally the non coherent integration is after second detector; anywhere you can make that will keep this per that will be adding some loss because his non coherent integration will add to some loss of signal ok.

Now I will come to we have already found the maximum radar range, we have seen the process of integration, this is new to the radar. In communication generally we do not do because again I see that from the radar equation this comes that received radar signal is very weak.

So, all radars need to do a process called integration. This is a new concept compared to other systems.

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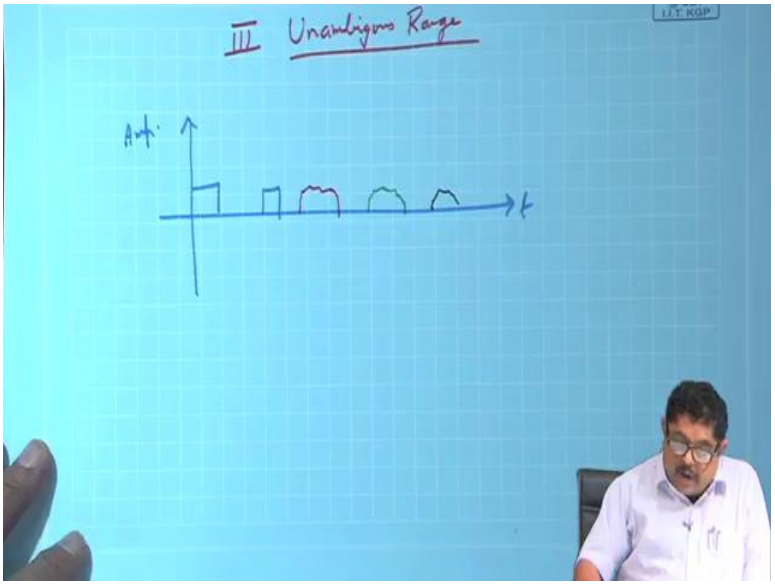


Now let us see that when I send various pulses and measures actually what a radar does in the time domain if I see now that radar sends us a pulse sends a pulse, then that pulse will come. Suppose this was the pulse and after sometime, let us say that the pulse something else come. Now if there is an another object that may also come here. Then if there is another object further away then it will take more time. That is why actually this is my time domain thing, this is my received amplitude of the signal.

So, this is transmitted you will see, but I am understanding that pulse is coming. Now the question is the integration means I will have to go on sending so; that means, I will have to send this another signal. So, if I send the next transmitted signal here. You see then though in response to this they have come, but I will think that after this return this has come. So, this range if I calculate it will be very small. Where has in reality it is much larger.

So; that means, the measurement that will be ambiguous. So, this is called ambiguity in the range measurement. Actually the ambiguity is coming because I am sending repetitive pulses. And now I am using the reference that which one to response to which one I have send; if I could have put some references in successive pulses, that could have helped, but that will complicate the transmitter.

So, but now will find out that there are ways by which we can do that. So, this is our next parameter of study that is unambiguous range. Because I want to know what is unambiguously the range. You see these are practical problems of measurement since radar is a measuring device of range. So, we need to understand that.

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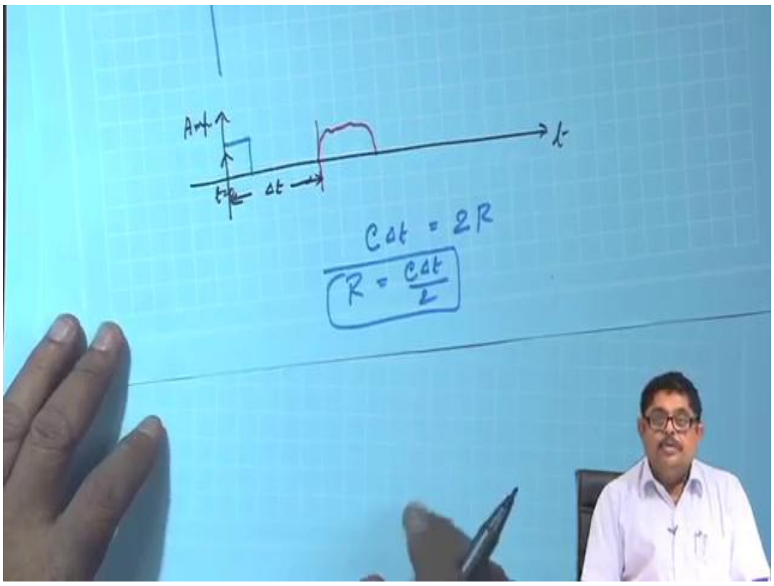

Now, let us change that, come to the actual diagram again this same graph amplitude versus time, I have this transmitted thing let me call that that is given at t is equal to 0. I am sending the pulse now, when I am sending the pulse let us say that this rising edge of the pulse that is my reference.

So, and as I said that suppose this thing has come here. So, this rising edge is here. So, I will say that this difference, I will measure this difference of time; that means, I have send a signal, now I am stopped then the echoes are coming.

So, let us say an echo has come like this. And I measure that from my transmission to this the time elapsed is delta t. So, I can now easily calculate range why because the signal has gone to the target, hit the target, target has scattered, it has come back the whole thing. So, I can easily say; now everything has gone in the form of light, velocity of light my light means electromagnetic signals they are in free space their velocity is this.

So, I can easily say that my equation will be

$$C\Delta t = 2R$$

So, from that I can tell that

$$\boxed{R = \frac{C\Delta t}{2}}$$

This is okay. Now the question is understand that I am sending repetitive pulses.

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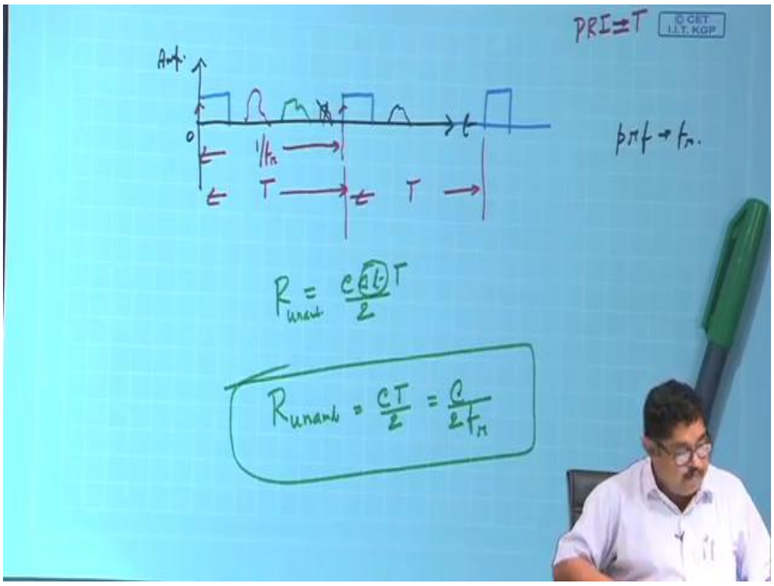

So, again let me draw that this is my amplitude, this is my time, this is my 0 then I have sent a pulse here, I will send a pulse I will send a pulse here.

So, what is this time? This is getting determined by prf. Let us assume that our prf is a fr. So, what is the time between; so, this is my reference point let us say, it can be in middle it can be a; I am now understanding them. So, this time is; I can say 1 by fr. Actually we will also sometimes use another thing capital T for this time. Same, but fr is usually specified by the radar, T is called pri. Usually its not specified in terms of PRI. It is specified in terms of prf. Pulse Repetition Interval, that I am calling PRI is equal to T.

So, basically T is equal to 1 by fr. So, after every this thing so, again this time is if I calculate it is again T or 1 by fr. Now so, what I expect that, if my entire range measurement is to be unambiguous what I expect that all the echoes from the various targets at various ranges. If they arrive because if suppose the first echo that arrives here. Let us say the second echo is here. The third echo is here, then I do not have any problem.

So; that means, I understand the black one is the at the far maximum distance or its range is maximum. So, if I measure then I will get it so; that means, my what is my maximum unambiguous range?

There is no ambiguity in my measurement if all the echoes from the maximum ranged target that arrives before I transmit the second pulse next pulse this is if I call this is first pulse, before I transmit the second pulse if I receive all the echo I get that there is no ambiguity in my measurement all the range measurement will be unambiguous. But if some of these echoes instead of coming here comes here suppose this last one instead of coming here it has come here, but it was in response to my this. Actually then this is this was my range, but actually by that time I have already sent the second one.

So, radar will think that this is the range. So, it will calculate it very small because these delta t is very small. So, now, can I answer this that what is my unambiguous range? My unambiguous range is that if what is that equation R is c delta t by 2 delta t is the time between the transmitter pulse and the received echo.

So, if this delta t I replace by T that means, the PRI. So, that is the maximum possible. So, then if I put it T is becomes unambiguous so; that means, R unambiguous range maximum that is CT by 2 T is not usually specified or radar. So, in terms of fri if I say this is

$$R_{unamb} = \frac{cT}{2} = \frac{c}{2f_r}$$

This is another important parameter of radar thus unambiguous range actually.

So, what is the unambiguous range we required that determines the prf. If prf is too high; that means, these value is high and our ambiguous range is very small. So, you will get various echoes similarly if prf is too large your unambiguous range is more, but the problem is; that means, your fr if that is very less; that means, on an average your power is falling. So, actually you are not using sufficient utilization of the receiver; receiver could have transmitted more average power, but you are not utilizing that power is costly the rf power.

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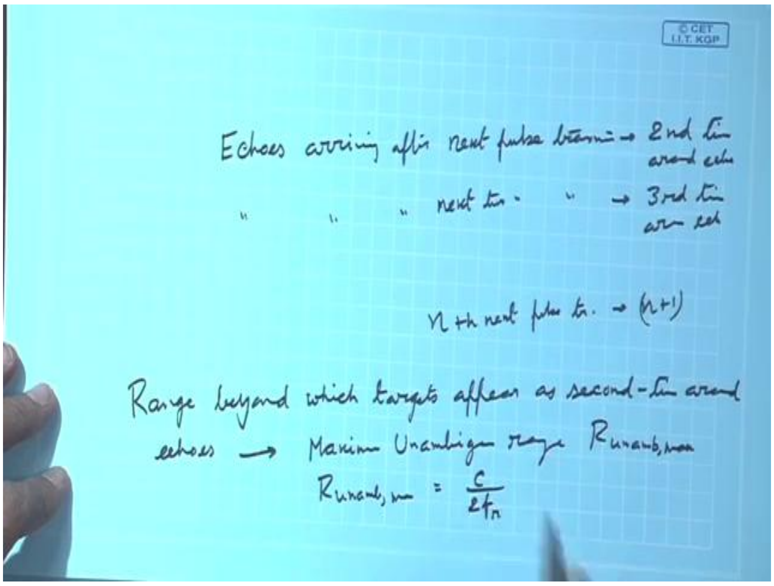


now there are few more terminologies here that echoes arriving echoes arriving after next pulse transmission this is called second time around echo the meaning is obvious similarly echoes arriving after after next 2 pulse transmission that will be called third time around echo.

So, echoes arriving after nth next pulse transmission that will be called n plus 1 time around echo etcetera. So, for unambiguous thing we want that no even second time around echo, third time around echo none are present that will give us unambiguous range. So now, we can define what is an unambiguous range because I have described it qualitatively, now actual definition is the range beyond which targets appear as second time around echoes is called the maximum unambiguous range.

So, I write the definition range beyond which targets appear as second time around echoes is called maximum unambiguous range R unamb max and mathematically

$$R_{unamb,\max} = \frac{c}{2 f_r}$$

where c is the velocity of light.

So this so, 3 parameters we have learned basic parameters the first one was the range maximum range, the second one was the integration, number of pulses and third one is the maximum unambiguous range. There are few other parameters because we have not answered what is minimum range, what is rcs which already you have used. So, those things will see the next lecture.

Thank you.