Principles and Techniques of Modern Radar Systems
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Lecture - 08
Tutorial Problems on Basic Concepts of Radar (Part I)

Key Concepts: Tutorial Problems on Basic Concepts of Radar

Welcome to this NPTEL lecture on Principles and Techniques of Modern Radar Systems. In previous classes, we have seen basic concepts of radar. So, in that we have seen unambiguous range, minimum range, then integration of pulses, then radar cross section etcetera. So, based on that we will today do the first tutorial; we are calling it tutorial 1.

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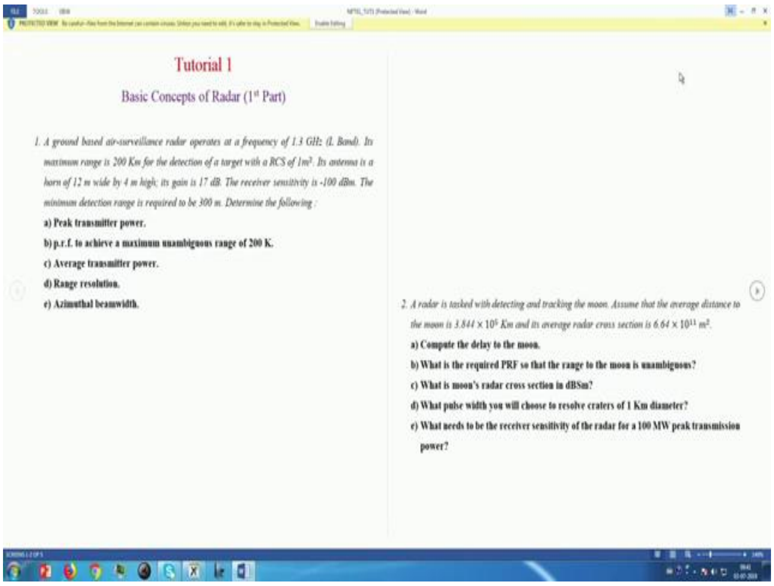

Actually, the next lecture also we will continue the tutorial because there are several concepts. So, one by one we will do that. The first problem for this tutorial is this that a ground based air surveillance radar operates at a frequency of 1.3 gigahertz; 1.3 gigahertz means radar people call it L Band. Its maximum range is 200 kilometre for the detection of a target with a RCS of 1 metre square. Its antenna is a horn of 12 metre wide by 4 metre high; its gain is 17 dB. The receiver sensitivity we have introduced this term minus 100 dBm. The minimum detection range is required to be 300 metre.

Now, based on this information determine the following the peak transmitter power; p.r.f to achieve a maximum unambiguous range of 200 k; average transmitter power; range resolution and Azimuthal beamwidth ok.

So, we will; you see this if you read this question it will be clear that there should be some equation which we need to solve to get one by one these parameters. So, what we will do, we will first write what is given. So, note down the problem then we will write that what is given the so, I will say this is the solution one.

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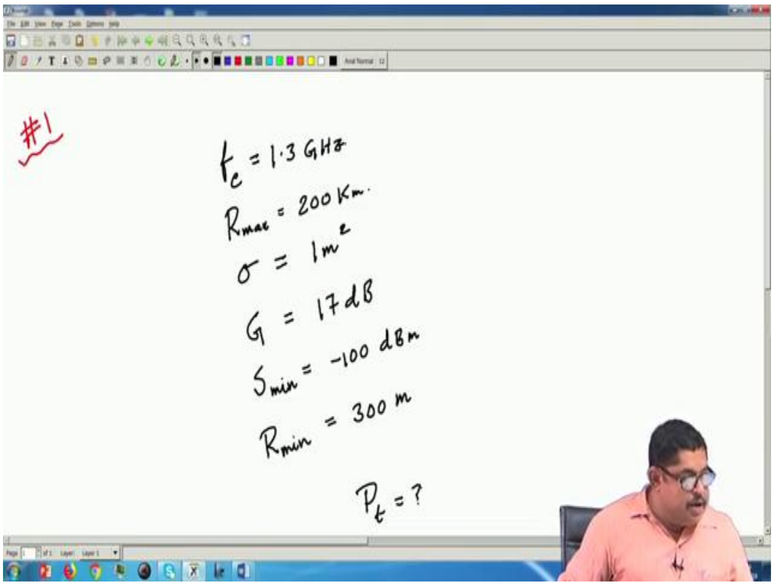

So, for problem 1, I am doing the solution. So, if you read it is given that frequency; that means, the carrier frequency is 1.3 gigahertz, then maximum range R max is 200 kilometre, then RCS of the target that is to be detected is 1 metre square. Now, antenna dimension is given. So, that but the antenna gain is 17 dB and receiver sensitivity S min that is given as minus 100 dBm. You know that receiver sensitivity is basically the power minimum power that is detectable by the receiver so that it is, it will say that a signal is present.

Now, power's unit is minus 100 dBm I think you know these conversions that if we call 0 dBm; that means, 1 milliwatt of power. So, accordingly you can calculate 100 dBm minus 100 dBm etcetera. The minimum detection range; that means, R min that also needs to be 300 meters; that means, at least 300 metre beyond it should be able to see. So, we are asked that what is the P t. So, it is clear that we have done a modelling so, the basic radar range equation which that time we called a model that will now help. So, we can immediately write the radar range equation.

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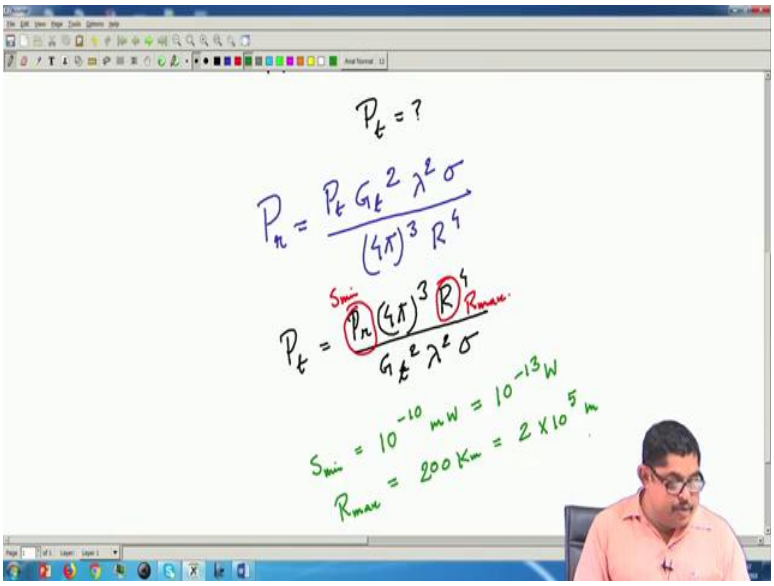

So, if you recall the radar range equation was or let me use this colour. So, radar range equation was P r is equal to P t G t square I am assuming this is the same antenna; that means, monostatic case lambda square sigma by 4 pi whole cube r to the power 4 so, but I have been asked P t. So, I can now write what will be P t? P t will be just P r 4 pi whole cube R 4 by G t square lambda square sigma.

Now, it is given that; obviously, this P r this is minimum when we have the maximum range, so, that is called nothing, but S min. So, S min is given; so, we can put that . So, here we can write that if we put in place of P r the S min then we will have to put in place of R R max. So, both these values are given so, that we will do. So, that means, we will now write that S min is it is given minus 100 dBm. So, that is 10 to the power minus 10 milliwatt or we can call it 10 to the power minus 13 Watt. So, I am trying to come to the SI units. Similarly, R max is given as 200 kilometre.

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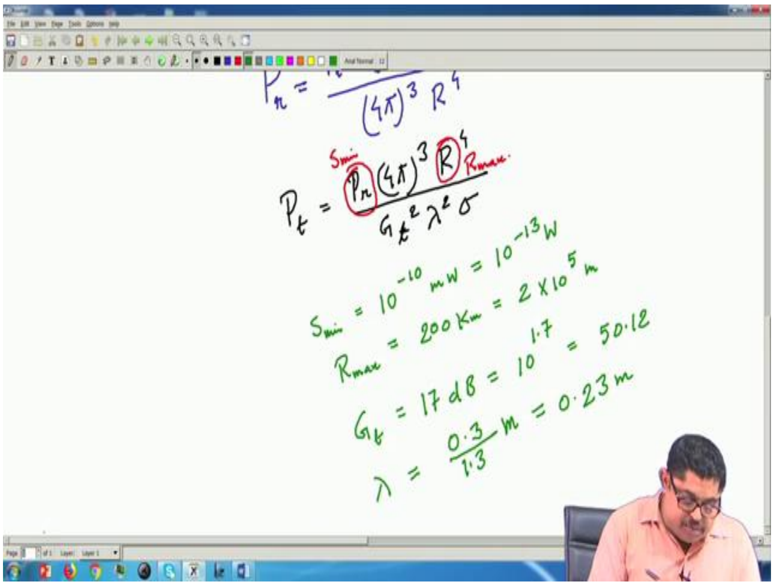

So, that is 2 into 10 to the power 5 metre R max and G t is 17 dB; 17 dB is 10 to the power 1.7. So, that turns out to be 50.12. Now, lambda frequency is given 1.3. So, you can find out because lambda will be 0.3 by frequency in gigahertz. This is the way otherwise also possible from that C by lambda f C and lambda their relation from that you can always get 0.23 metre and sigma is given.

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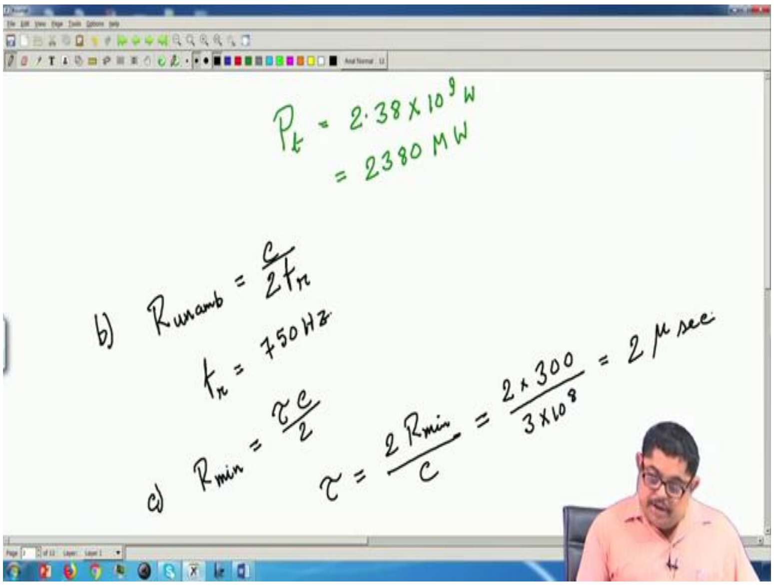

So, then if you put all those you get the value of P t. So, P t will now you can put there. So, it will turn out to be 2.38 into 10 to the power 9 Watt or in terms of megawatt you can say 2380 megawatt or you can say 2.38 gigawatt. So, this is the remember this is the peak power.

Then let us go to part b. In part b we were asked to find out what is the p.r.f? p.r.f. to achieve the maximum unambiguous range of this. So, we know that maximum unambiguous range and p.r.f. they are related that relationship is R unambiguous is equal to C by 2 f r. So, f r is to be find out unambiguous range is given that 200 kilometre. So, you can from here you can calculate f r will be 750 Hertz ok.

Now, come to part c. What is part C saying that average transmitter power, you see that we have found peak power. So, we have seen that if we know the duty cycle we can find out. Now, what is a pulse duty cycle you see here directly it is not said, but indirectly it that has been said. Actually, you see the minimum detection range is required to be 300 metre; that means, that minimum detection range is R min; now, what is R min? Basically it is related to the pulse width that we have seen in the basic concept that tau C by 2. So, from here we will get the value of tau; tau will be 2R min by the speed of light C. So, we know R min is 300 metre and C is 3 into 10 to the power 8. So, this will give you a pulse width of 2 microsecond ok.

The moment pulse width is done so and we have already found the p.r.f. So, we can find the average power.

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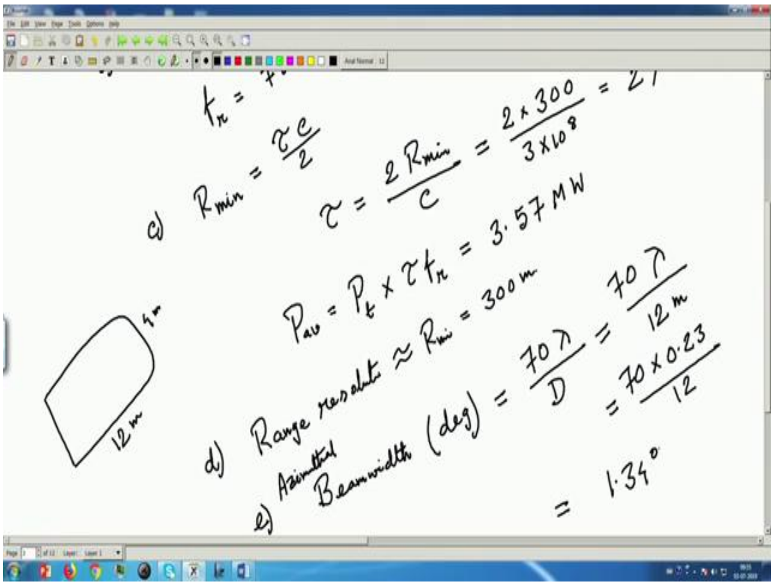

So, P average we have seen that P average is P t into tau into f r. So, now, all these are available P t is already we calculated tau here and f r here if you put all this value it will turn out to be 3.57 megawatt. So, you see that what was the peak power it was 2.38 gigawatt and average power is reasonable the 3 or 4 megawatt 3.5 megawatt something ok.

Now, next part is the part d that what is the range resolution? Now, range resolution roughly we said that it is equal to the pulse width. Later we will see that it is not pulse width, it is a fraction of pulse width. But, for time being we can say that range resolution is approximately pulse width. So, a range resolution is that range distance according to a; that means, the R min what is called sorry not this corresponding to the tau what is the R min. So, that will be 300 metre.

And, the other one is azimuthal beam width. Actually from antenna classes we know that beam width for an horn antenna in the azimuthal plane, this beam width if we have it in degree then there is a formula for azimuthal beam width. So, we can say that azimuthal beam width for horn that is 70 lambda by D, where D is the maximum dimension of the horn.

So, in our case we know the value of lambda and D in our case is I think 12 metre. It was said that the horn is 12 metre wide and 4 metre high. So, this will be 12 metre and lambda is 0.23 metre by 12. So, this will turn out to be 1.34 degree 1.34 degree is a typical radar azimuthal beam width. So, you see who helped us to get all these things? The thing is the our radar range equation.

You see this is the second problem, problem 2. A radar is tasked with detecting and tracking the moon; suppose a radar is tasked with detecting and tracking the moon. Assume that the average distance to the moon is so and so kilometre and it is average radar cross section is you see huge thing because several metres square. Now, why you can say that moon does not look so high, but if you see the illumination of the moon, moon is quite bright to the radar because lot of reflection comes from there that is why it has a high radar cross section.

Now, first part is compute the delay to the moon that is; then what is the required p.r.f., so that the range to the moon is unambiguous. I want that this range this 3.844 into 10 to the power 5 kilometre that should be at least my unambiguous range. Now, then what is moon's radar cross section in dBSm? Actually this is in absolute value the value is given. It is just that in dB scale to have you practiced this what is the convert it to dBSm.

What pulse width you will choose to resolve craters of 1 kilometre diameter? It is an interesting question that is anything to choose a pulse width because I will have to find craters. You know in moon various craters are identified by various moon mission. Suppose, you have made a radar or your country has made a radar and you want to have at least craters of 1 kilometre diameter that you want to detect so, what pulse width you will choose, interesting question.

And, last part is what needs to be the receiver sensitivity of the radar for a 100 megawatt peak transmission power. This is important because suppose you cannot have more than 100 megawatt suppose you decided that I will have a 100 megawatt peak transmission power then how would or what will be the requirement from your receiver. So, what needs to be the receiver sensitivity, how sensitive the receiver needs to be so that it can achieve it can detect the moon ok.

So, please note down the problem or this problems will be later shared with you. So, let us see and solve this problem. How to solve? Again, I think you understood that we will have to go to the radar range equation.

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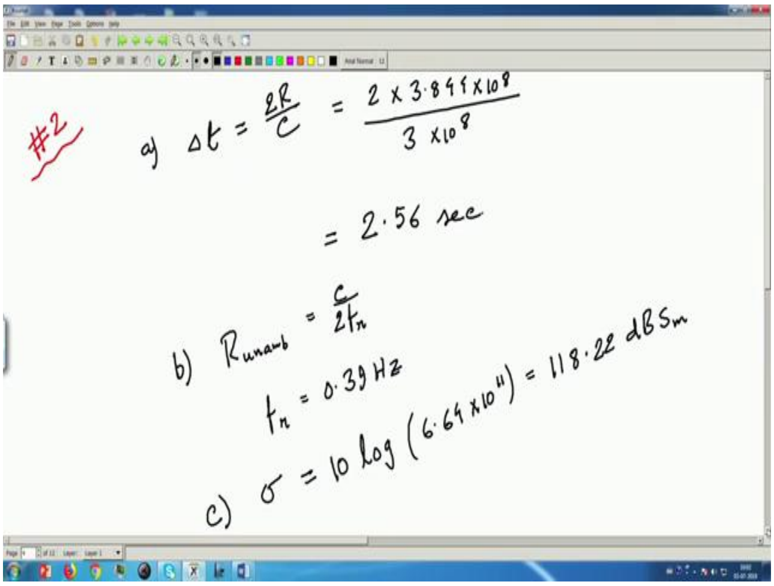

So, now I will start with problem number 2. Now, here the first part is easy that what is the delay? So, you can say that time delta t for 2 way travel. So, that will be 2R by C and you know distances are given 3.844 into 10 to the power 8 by 3 into 10 to the power 8. So, this will give you 2.56 second; that means, if you send a pulse you will receive it after almost 3 seconds. So, you should remember that that is why this problem is given and what is the p.r.f? So, in problem 1 also we have done that. So, we will use this R unambiguous is C by 2 f r. So, from here we will find the f r. So, f r is 0.39 Hertz ok.

So, that is required because otherwise you would not get you have a large time for travel. So, that is why your p.r.f cannot be high that is why it is less than even 1 Hertz ok. These are reasonable things then that conversion that convert the RCS given in metre square to dBSm. Now, remember what is the definition of RCS because here to convert it to dB, which multiplier we should use 10 or 20? I think you know that for primary quantities like voltage current etceter,a we use 20; multiplier as a multiple. 20 as a multiplier and, for second order quantities like power, energy etcetera we use 10.

Now, what is sigma? Though sigma is not an dimensionless, but what is it is a thing that dimension it is having a metre is the unit, but that does not give the clue. So, basically it is a ratio of power; if you see our definition of RCS so, it is the power that is radiated etcetera. So, that is why we will have to take 10 log. So, this is important that you should remember that for RCS we will have to take 10 log. So, it is given 6.64 into 10 to the power 11. So, that will be 118.22 dBSm square metre. So, this all it was done.

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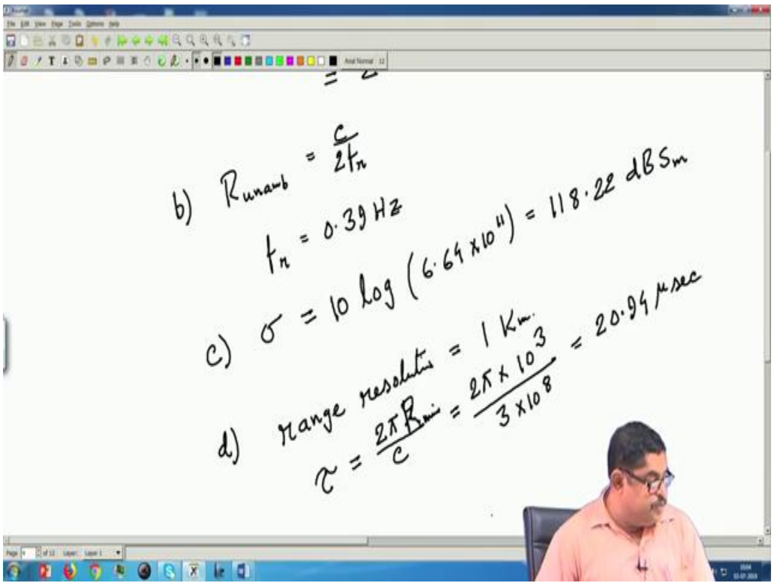

Then part d, what pulse width you will choose that interesting problem that resolve craters of 1 kilometre diameter; that means, your range resolution because craters will be in the direction of your range; so, range resolution should be 1 kilometre range resolution 1 kilometre.

Now, what is the relation of that with the pulse width? I think we have seen that that what; that means, the minimum travel time. So, we can say that this will give that tau is equal to 2 pi r by C because this is the time that if you have this. So, you can get this minimum thing. So, this will be 2 pi r or this is capital R you can say tau R min. So, 1 kilometre means 10 to the power 3 metres by 3 into 10 to the power 8. So, this will be 20.94 microsecond ok.

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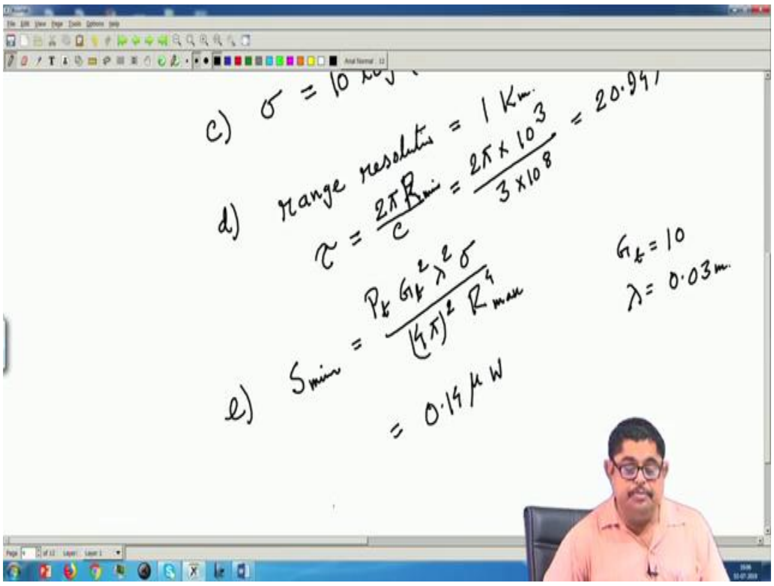

And, last part is some calculation that what is the receiver sensitivity? So, basically what is S min? S min we know is given by P t G t square lambda square sigma by 4 pi cube R to the power 4; this R should be R max. In this case the distance from the moon to consider that. So, if you assume that G t value is not given. So, assume G t is 10 dB typically or 10 dB and 10 (Refer Time: 24:15).

So, I can say 10 also, let us say absolute value G t 10 and lambda let us say 10 gigahertz, 3 centimetre that is 10 giga hertz. So, that is 0.03 metre, then you will see that this comes to 0.14 microwatt. So, 0.14 microwatt or 140 milliwatt it should be able to sense. Sorry, 0.14 microwatt; that means, even less than 1 microwatt it should be able to scene.

So, it needs to be a very sensitive receiver that is why generally radars from the ground do not generally observe a because this is a real limitation. You have a radar sensitivity of these is not so easy to very very sophisticated receiver etcetera. That is why you see that radar astronomy projects that those which are observing various stars etcetera where very costly. Generally, various nations are now different countries are coming together making consortium and having those things installed etcetera.

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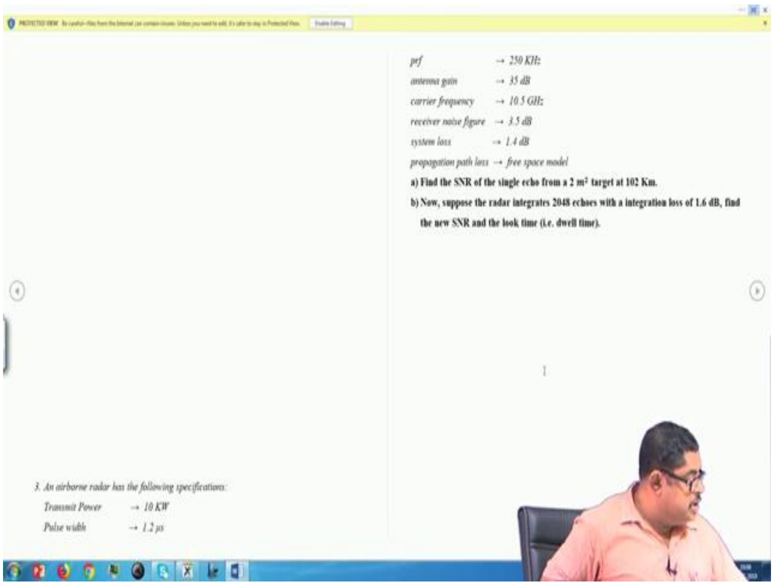

You see an airborne radar has the following specifications: transmit power given, pulse width given, p.r.f. given, antenna gain given, carrier frequency 10.5 giga hertz, receiver noise figure is these, system loss propagation path loss it is as free space model. What you have to do? Find the SNR of the single echo from a 2 metre square target at 102 kilometre.

And, then it is saying that now suppose the radar integrates 2048 echoes with the integration loss of so and so find the new SNR and the look time; that means, for how long time a target is looked by a radar. So, this is a problem on concept of integration of pulses so, that we will see. The first part you will see that obviously, from radar range equation it will come, with those receiver noise figure etcetera; that means, the loss etcetera needs to be taken into account.

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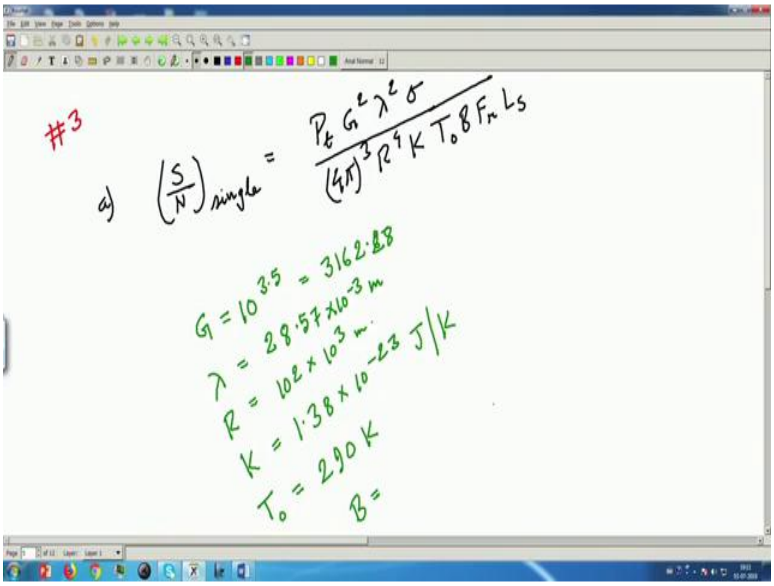

Correct. Let us come to I think this is our problem number 3. So, we can say that this is the first part that for a single pulse S by N we know it is given by from the again radar range equation because S is the received power by N. So, P t G square sigma square and a lambda square sigma by 4 pi whole cube R to the power 4 K, this is the noise part K T B. So, K T naught B then you multiply with the noise figure and then any other system loss. So, this is the SNR expression for a signal that we have seen.

So, now, you will have to put all those values. What are the given values? Given is G is given as 35 dB; that means, 10 to the power 3.5. So, that will turn out to be 3162.28 then lambda is 28.57 into 10 to the power minus 3 metre, that you can calculate from the given frequency of 10.5. So, it will be nearly 3 centimetre, a bit less than 3 centimetre that is why you see this one.

Then R is given; R is 102 into 10 to the power 3 metre, then K I think you know. K is Boltzmann constant 1.38 into 10 to the power minus 23 Joule per Kelvin. Then T naught; T naught is the reference for noise calculations referrence temperature that is 290 K. Then B, in this case B is said system loss; B is not said. You see in the given specification if we again see the given specifications so, nowhere the receiver bandwidth is said, but pulse width has been said. So, what can be done; we can do that roughly we can say that it is the inverse of the bandwidth.

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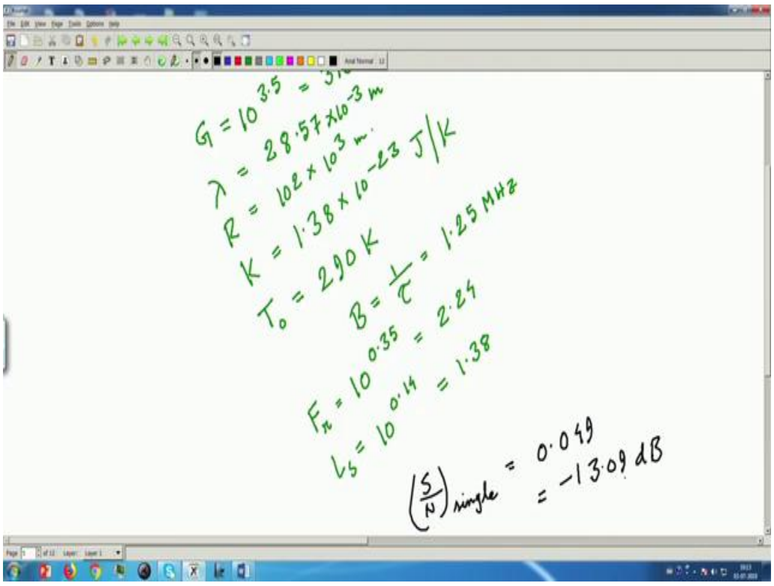

So, if you do that; that means 1 by tau. So, that if you do, it will turn out to be 1.25 megahertz, then F r it is said that receiver noise figure is 3.5 dB; again noise figure so 10, 10 to the power 0.35. So, that will be 2.24 absolute value and the system loss other losses in various cables, various joints etcetera that is I think 1.4 dB. So, that means, 10 to the power 0.14. So, if you put that you get the value that we are looking for that S by N single pulse that will be 0.049 or minus 13.09 dB.

So, you see that the noise is much more stronger than signal if we consider only one single echo. So, this is generally the radar receiver is not able to detect it because its sensitivity is not so high. So, that is why we need to integrate; so, now for integration what will happen?

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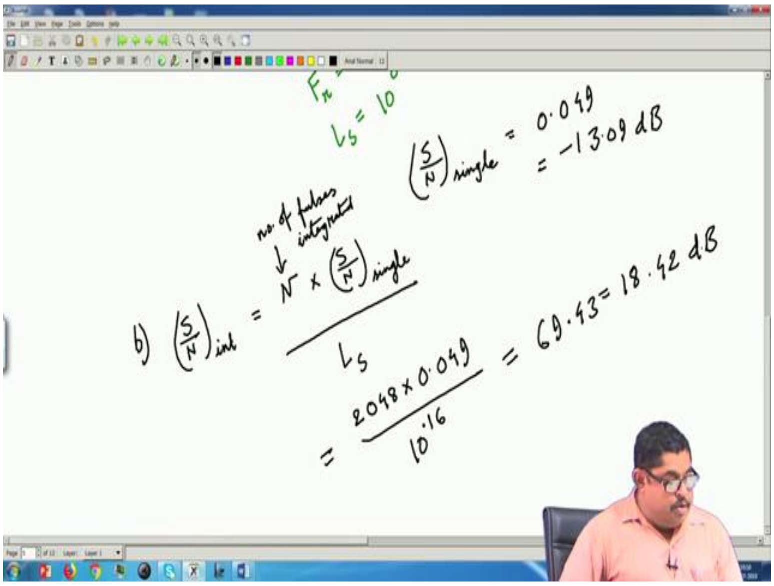

So, part b is we are integrating; so, S N integrated that time the SNR gets multiplied 2 meter square target and now only thing is with an integration loss of 1.6 dB. So, for integration because if you do not coherently add there can be a loss. So, you will have to take that, but I can say this will be N, this is the number of pulses to be integrated; number of pulses integrated S N single. If there was no loss this is ok, but now there will be loss.

So, we will have to take that L S in absolute value. So, that will be nothing, but 2048 into 0.049 by 10 to the power or what is that value, that value directly we can put 1.38; no, 10 to the power 0.16. So, that will turn out to be 69.43 which is 18.42 dB ok.

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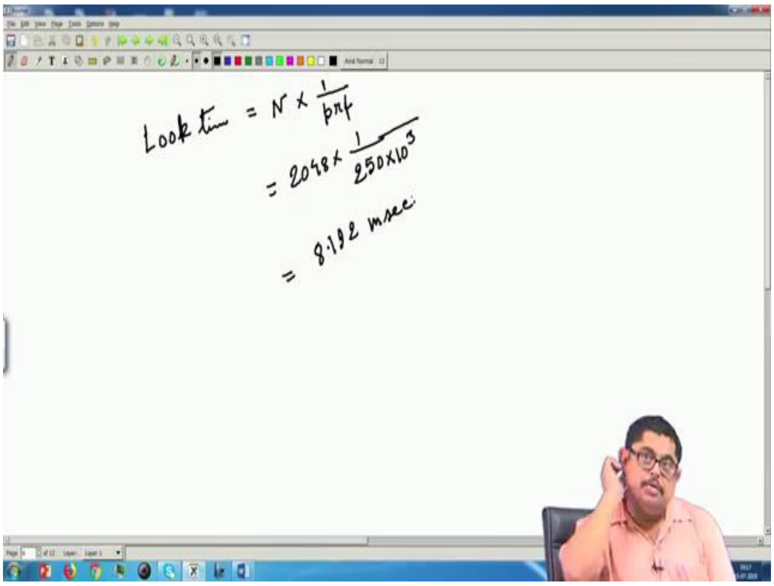

And, then the question is what is look time? So, look time I can say that for so many pulses N number of pulses into what is the one pulse how long it looks at a target? I can say 1 by prf. So, for N pulses this will be the time. So, this is 2048 into 1 by prf is 250 kilo hertz so, if you do it will be 8.192 millisecond. So, for this much time the thing is looked here.

So, we have seen three problems. So, one was remaining due to lack of time in this class. We would do in the next tutorial we will cover that ok.

Thank you.