Principles And Techniques Of Modern Radar System
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Lecture – 11
CW Radar Mathematical Model and Applications

Key Concepts: Analytical expression of echo of the CW radar for a stationary target, Analytical expression of echo of the CW radar for a moving target, Merits of a CW radar, Application of CW radar

Welcome to today's lecture on these NPTEL course on Techniques and Principles of Modern Radar. We were discussing CW radar. So, today we will see this echo signal expression as I mentioned in the closing remarks of the last class. So, let that with respect to the diagram that we have previously discussed block diagram.

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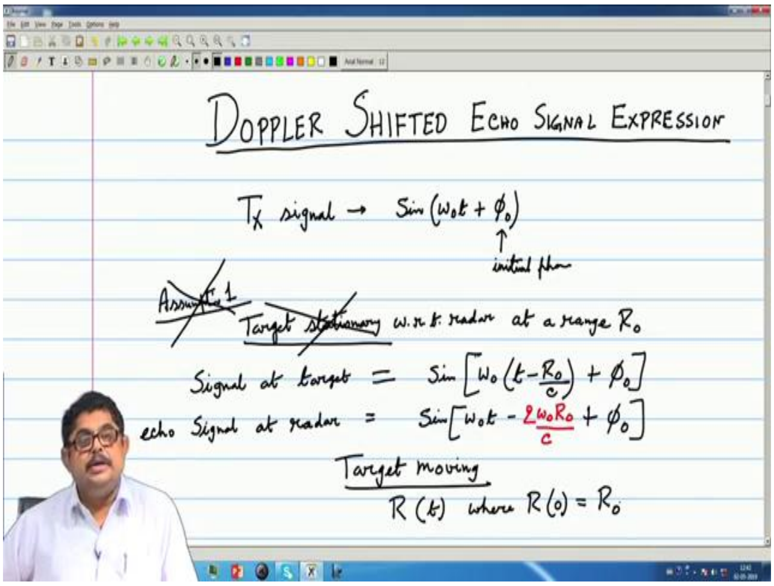
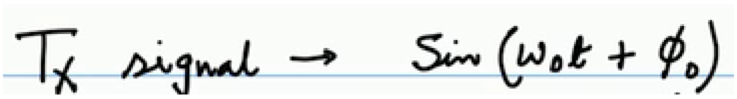


So, let the transmitted signal is of the form, you see in previous cases I have taken cos that time I said that I can take sin. So, now, I will take sin, so that you get confidence that anything because it is a sinusoidal signal, so either sin or cos only the phase will change initial phase.



So, take that the phi naught is the initial phase.

So, this is your I can say that initial phase of the signal, omega naught is the angular frequency of the signal that is getting transmitted. And the amplitude I am not putting I could have put an A or E1 something, but actually as you seen that we will be mixing the signal. So, in a Doppler detection these amplitude is not required, if you want you can also put always that a will be there, so I am not putting.

Now, initially we assume that assumption 1 that target stationary. So, if target is or relatively the target is stationary with respect to radar target stationary with respect to radar. And will target stationary with respect to radar at a range R naught, these R naught is fixed, so R naught is the initial range, but here the target is stationary, so it is not changing.

So, I can say that signal at target. So, if I send the signal; obviously, the if I see in time domain when I am sending the transmitted signal immediately the signal is not reaching the target it will require some time how much time R naught by c. So, it would; that means, that this signal is at a is a the at target it receives with a delay that is given by that c.

So, I can write what is the expression for signal at target,

$$\text{Signal at target} = \sin\left[\omega_0\left(t - \frac{R_0}{c}\right) + \phi_0\right]$$

Again the signal comes back, here we are assuming; obviously, the amplitude will change depending on the RCS of the target etcetera, but as we are not bothered about amplitude.

So, I can say that signal or echo signal at radar; that means, what comes back at radar that can be written as

$$\text{echo Signal at radar} = \sin\left[\omega_0 t - \frac{2\omega_0 R_0}{c} + \phi_0\right]$$

So, target stationary this was the assumption. Now, I remove this restriction, so if the target is not stationary what will happen? This R that time I will call this range R and that is not a constant at t is equal to 0 the R's value is R naught, but as that target is moving R is a function of time, so I remove this assumption now. So, if I remove this assumption target is not stationary what is target? So I will say that target moving ok. So, target moving means R is a function of time where R is 0 is R 0; that means, at t is equal to 0 R is 0 this initial range I know.

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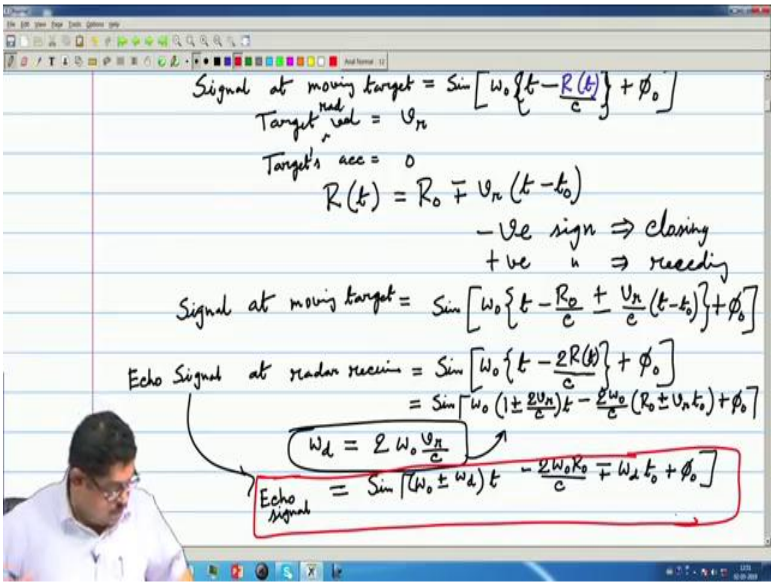

So, I can write signal at moving target is sin omega naught t minus let me change color R t by c, so you can make this second bracket ok.

$$\text{Signal at moving target} = \sin\left[\omega_0\left(t - \frac{R(t)}{c}\right) + \phi_0\right]$$

Now, I assume that targets velocity or target radial velocity radial relative velocity, radial relative velocity is let us say v r. And let us assume targets acceleration is 0, if it is there we will be later understanding how to handle that, but for initially we are assuming this.

So, what is a expression of R t then,

$$R(t) = R_0 \mp v_r (t - t_0)$$

Can I write this where this we took a v that this minus sign this minus sign that implies what? That implies a closing target. Because you see that if the target is closing then it is range is decreasing and the positive sign is for receding target receding, so I can now use the expression.

So, signal at moving target that signal will again come back, you see for moving target the range is changing. So, initial range when the signal was transmitted, but when it is reaching the target that range is changing. Again when that is coming back to the radar the thing is changing, but I do not have any problem because I am writing it in terms of algebra that is the beauty of mathematics, that otherwise I will have to find out how much change etcetera, but here not a problem.

So, signal at moving target; that means, that expression, now I will put the value of R t in terms of it is initial value R naught and vr. So, I can write that,

$$\text{Signal at moving target} = \sin\left[\omega_0\left\{t - \frac{R_0}{c} \pm \frac{v_r}{c}(t - t_0)\right\} + \phi_0\right]$$

So, this is a signal at moving target. So, I can write what is the echo signal echo signal at radar receiver

$$\text{Echo Signal at radar receiver} = \sin\left[\omega_0\left\{t - \frac{2R(t)}{c}\right\} + \phi_0\right]$$
$$= \sin\left[\omega_0\left(1 \pm \frac{2v_r}{c}\right)t - \frac{2\omega_0}{c}(R_0 \pm v_r t_0) + \phi_0\right]$$

Now, remember that we have in the basic principles found out that what is the angular frequency due to Doppler that was omega d is equal to 2 omega naught v r by c. We have defined it in terms of f d you can find out, so these if we put here then the echo signal can be written as that sin omega naught plus minus you see here.

So, I can write it

$$\text{Echo Signal at radar receiver} = \sin\left[\omega_0\left\{t - \frac{2R(t)}{c}\right\} + \phi_0\right]$$
$$= \sin\left[\omega_0\left(1 \pm \frac{2v_r}{c}\right)t - \frac{2\omega_0}{c}(R_0 \pm v_r t_0) + \phi_0\right]$$
$$\omega_d = 2\omega_0\frac{v_r}{c}$$
$$= \sin\left[(\omega_0 \pm \omega_d)t - \frac{2\omega_0 R_0}{c} \mp \omega_d t_0 + \phi_0\right]$$

Now, mathematically what does this mean, this is a very interesting thing. So, I will that is why highlight these that or I may write omega d sorry not omega d, this is the echo signal echo signal.

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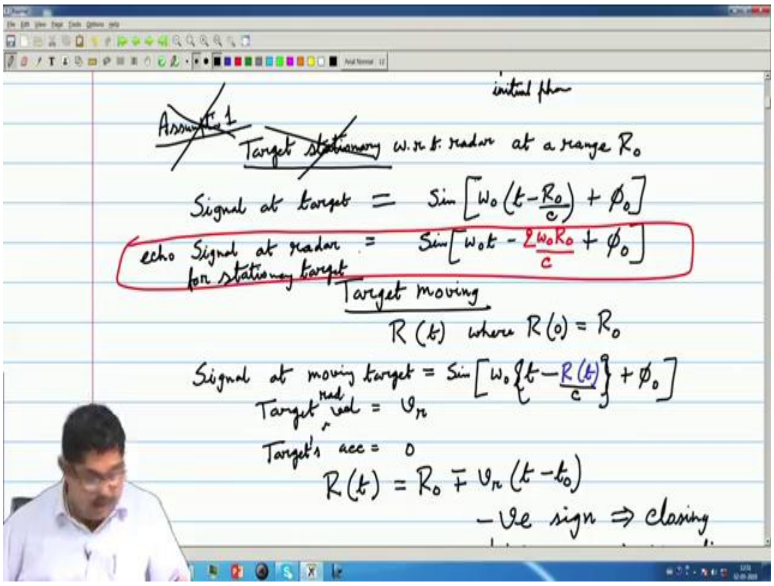

So, see the expression that compared to now compare actually I have not done that this one that previous case echo signal at radar echo signal at radar I will say for stationary target. So, this expression and you compare this with the moving target expression you see that.

So, what is different moving target gives an indication that the echo signal is shifted by a frequency omega d angular frequency omega d. And also is phase changes by how much you see phase changes by plus minus plus omega d t naught. So, you see what does this says? It says that I can make a phase detection, I can also make a frequency detection and if I want to do that you see that if I do frequency detection I can find the velocity relative velocity. If I do the phase detection that also give me the frequency velocity, so depending on which one is easier you can find out and, so this we will see later that important.

So, now I summarize what we have seen in the this CW radar that, so you see that the circuitry block diagram we have seen we know how to what is a mixer. So, just by mixer actually we are detecting the f d and that is highly practical circuits. So, for detection at a targets at short and moderate ranges CW radar is a very good choice it is having a simpler equipment than a pulse radar of equivalent detection range capability.

So, it is much smaller in size and way compared to pulse radar. So, for small detection small range detection is very much preferred, however it is limitation is it cannot determine range also the receiver since it is detecting the you see the normal targets are not very high velocity targets.

So, the bandwidth of receiver that also is much smaller than pulse, usually in a pulse radar the bandwidth receiver, bandwidth needs to be mega Hertz. So, noise also will be more there, but here some kilo Hertz bandwidth is sufficient for most of the detection of the velocities that we encounter and another advantage here is no high voltage modulator.

So, less electrical breakdown problem, then in principle as we have seen that the CW can operate against very close targets also short range targets. Whereas, for pulse radar we have seen that there is a concept of minimum range, actually that concept is not here because here is the transmitter is not putting. Or that means, receiver can be on when the transmitter is also on in CW radar in pulse radar that is not possible that is why there is a concept of minimum range.

So, now also you can see that CW can discriminate easily between stationary target and moving target as it uses Doppler. Because if it sends that Doppler in the Doppler shift is 0 it will be saying that the target is stationary. So, for stationary target detection no extra circuitry is required and actually stationary targets are very important in radar because we will see that when a something is flowing. Now, suppose the radar instead of when it is looking at a target there is a hill there is when you are looking down there is earth these are stationary things but their returns are heavy.

So, sometimes radar thinks that these are thinks these to be targets. But immediately it understands whether it is target or it is a stationary thing which is not of interest. So, in radar terminology that stationary objects which are not of interest they are called clutter a very important term I should write it here that clutter.

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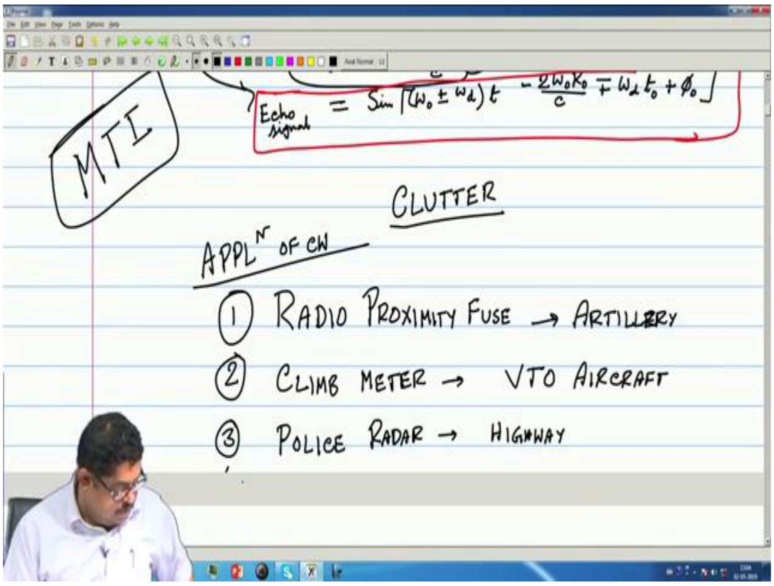

Now, how you can find out whether a thing is clutter? It is very easy because find out it is velocity clutter does not have much velocity, it is a stationary target. So, you can always find out and stationary targets are not have of any concern, so clutter removal is very easy in case of CW radar.

Whether in a pulse radar you can do, but for that we will see that you require a extra circuitry which is called moving pulse indicator sorry moving target indicator MTI. So, this MTI capability to be separately it will have to be added and it is a bit complex. So, pulse radar also can remove clutter by this MTI technique.

Also both these CW radar and these pulse radar with MTI facility they are called MTI radars are blind to targets with 0 or small radial velocities. As we have seen that if the radial velocity is because there may be many times that a target is having sufficient velocity. But that velocity does not have a radial component, one classic example if it is trajectory is orthogonal to the range direction so; that means, in the cross range direction it may be moving with a very high velocity but radar will say it is not moving.

So, that is a problem for both of these radars, so CW and MTI they are blind to targets with very small velocity even though that may have a many thing. So, for that we will see that what are the techniques that can be used and simple CW radar generally it is meant for detecting a single target. Its ability to handle multiple targets can be increased by providing extra resolution in the Doppler frequency domain that is done with giving a bank of Doppler filters that we will see when though in the context of pulse radar we will see the Doppler filter bank.

So, if you put various Doppler filter bank, so various targets with order of magnitude difference of velocities they also can be defined. So, the number of targets that the radar can resolve at any time is equal to the number of Doppler filters it has. Now, what limits the maximum power or maximum range of CW radar, who governs that is an important thing that how much power we can give to a CW radar that you see is dependent on that what isolation is necessary between the transmitter and receiver, because receiver it requires a certain amount of isolation in any a thing.

So, if we give very high power to CW radar and that leakage if it goes it may saturate the thing, though the case is not as severe as pulse radar. But still that isolation requirement that is there and also the noise in the transmitter, because any high power device relatively high power device.

So, there will be noises, so that noise will also make this thing. So, CW radar power handling capability or range that depends on this isolation and the transmitter noise. Whereas, pulse radar does not have any limitation you can give any high amount of power, because transmitter and receiver are not simultaneously operated, so there you can go to any power. Now, if we come to the applications that you see now also the CW radar is always used.

Actually this is from world war time that they are used in there is a term called radio proximity fuse. Actually with artillery; that means, a heavy shale etcetera is being fired, there is always a small CW radar actually that gets destroyed. So, when it comes near the target the fuse that gets fused and then the artillery is fired.

So, this that is called radio proximity fuse, see in our country this proximity fuse it is new versions people are still doing Indian army heavily uses this radio proximity fuse. So, it is an artillery requirement, so in all modern artillery these are there starting from world war days this is maintained, then another thing is the when an aircraft takes off.

So, second application, so these are all applications of CW which are still used I am not saying new that is the climb meter. Climb meter is when a vertical takeoff aircraft. So, they are the earth is the target and from earth you are getting the returns. So, what is the velocity with which you are going that can be measured by this.

So, this is in a VTO, Vertical Take Off Aircraft these climb meter is there, so that gives the velocity with which you are moving. Then see one very common example is the police radar where they detects the speed of a vehicle in highways, if we take exceeds then you are fined etcetera or you get nowadays even they are making the vehicles stop when it exceeds. So, police radar in highways etcetera, so that is always this CW and it is the most extensive use.

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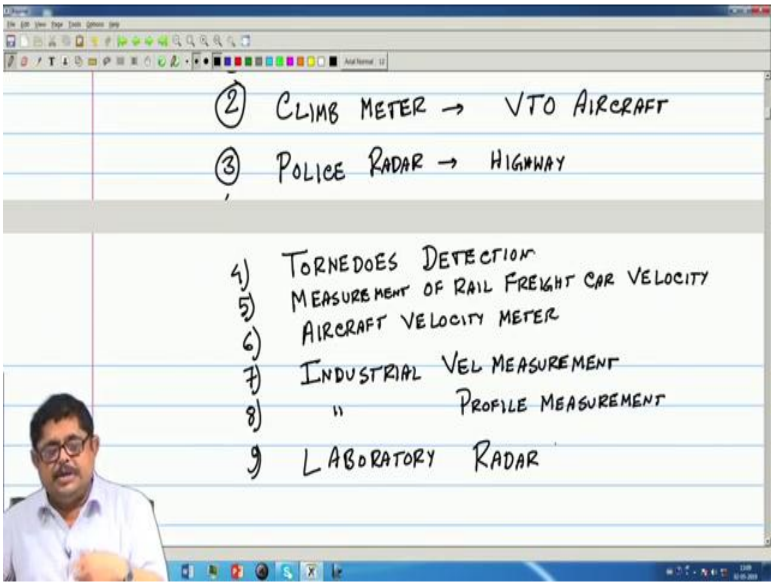

Then you can also suppose all these tornedoe detection. Tornedo whether there is a tornedoe what is the speed of the velocity of the tornedoe even the angular velocity of tornedoe, so tornedoe detection that is done. Then in railways when the freight cars they are put actually from a hump they are placed and then the velocity needs to be adjusted. So, that the formation is made. So, that is called rail measurement of rail freight car velocity.

So, railways have humping yards in those humping yards in the line this thing is put. Then the also the velocity you will see that when you nowadays you go with you fly that what is the speed of the aircraft. So, those are generally done by the CW radar, so I will say that the aircraft velocity meter these are all these radar. Then I will say another very important thing is in industrial applications that you see an industry radar technology is very useful actually laser etcetera can be used. But, lasers or light scatter a lot and in industrial climate there are a lot of particles here and there moving.

So, radar technology is very heavily used. Suppose, in industrial cases in blast furnace the where is the blast furnace because blast furnace needs to be broken, so that the molten metal can come out. Now, that needs to be done very precisely, so that exact velocity is etcetera exact range that we will see that extension of CW can give you range also.

So, that time exact position then trolley movement in industrial. So, I will say that industrial trolley it is velocity measurement, because if they collide there will be huge catastrophe. So, velocity should be very exactly measured in industrial climate if that velocity may be very small, but very accurately it should be known otherwise there will be a lot of accidents.

So, industrial velocity measurement is a very important thing also industrial various measurement then in industrial climate there are lots of profile suppose some things are getting dumped. Now, how much that thing is how much material is there that needs to be done by making a profile measurement that also is done to CW radars.

So, I will say profile industrial environment profile measurements lot all these steel plants etcetera there these then ports there these CW radar is used. And for us teachers, for you researchers there is a use that laboratory radar; in laboratory you it is very difficult or cost costly thing to make pulse radar, but if you want to have radar made for our research purposes etcetera we make use of CW radar.

So, CW radar is very important you all can make a CW radar after going through these classes you can easily make your own radar. In laboratory you will see that to have radars for your research use etcetera this is very very heavily used. Now, here some of the applications I said where range measurement is necessary, suppose this profile measurement etcetera then other things. So, that will see that the by an simple extension of the CW radar it will have the measurement range measuring capability that is called a FMCW radar frequency modulated CW radar that we will start in the next class.

Thank you.