Principles and Techniques of Modern Radar Systems
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Lecture - 23
Pulsed Doppler Radar

Key Concepts: Design aspect of a N-Stage MTI filter, Mathematical description of a N-Stage MTI filter transfer function, Limitations of MTI filter, Introduction to Doppler filter.

Welcome to this NPTEL lecture on Principles and Techniques of Modern Radar Systems. In the previous class, we have seen the various performance matrices of MTI filter that is clutter attenuation, MTI improvement factor, sub clutter visibility. We have seen the optimal MTI filter implementation, and we have seen that what it achieves that optimal it guarantees that MTI improvement factor is maximum, the detection probability is maximum, but it still leaves some or it does not guarantee two things that notch near the dc value or near the f is equal to zero frequency and also uniform pass band response. So, those are open problems etcetera. Now, question is that how to choose the number of stages.

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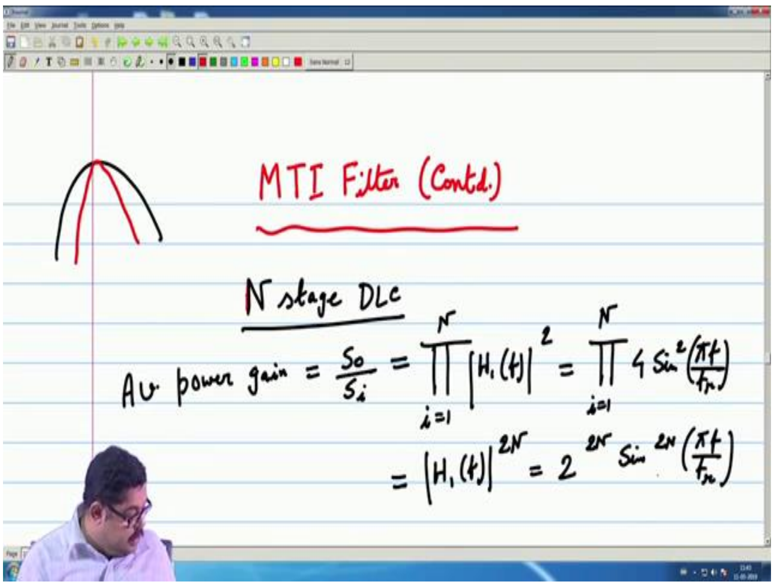

So, for that we can see that the power gain; average power gain for an N stage DLC N stage DLC the average power gain is we have seen this expression, this actually comes in the improvement factor. So, this actually is given by this. This is the multiplication of terms for an N stage DLC; so, these in H 1 f whole square. So, this means it is nothing but we have seen this is 4 sin square pi f by f r, so that means, that we have H 1 f whole to the power 2 N and that will be 2 to the power 2 N sin of 2 N pi f by f r.

$$\frac{S_o}{S_i} = \prod_{i=1}^{N} |H_1(f)|^2 = \prod_{i=1}^{N} 4\sin^2\left(\frac{\pi f}{f_r}\right)$$
$$= |H_1(f)|^{2N} = 2^{2N} \sin^{2N}\left(\frac{\pi f}{f_r}\right)$$

So, you see that if average power gain is this, so the blind speed is not getting improved because the this function is same as single DLC or double DLC that will be same, only more and more stages is making this sin square you are multiplying sin square with another sin square with another sin square. So, the blind speed would not change, but what will change is the roll off near stop band notch. Suppose, if I have a one sin square is these, so if I make another sin to the power four that will be this, then so that means the stop band notch that is getting changed. So, roll off is getting better.

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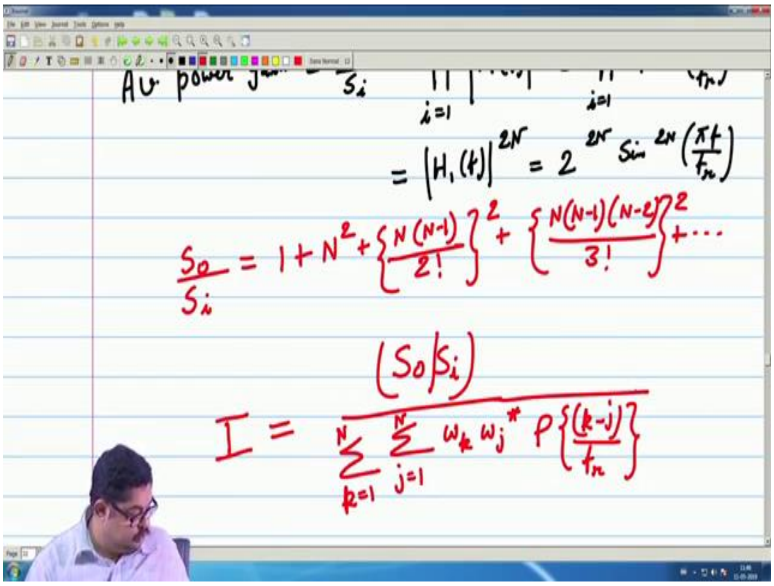

So, we can say that blind speeds, they are independent of the number of stages used. And people have expanded this sin function, and found out that you can write these 0 by expression in terms of explicitly this N, 1 plus N square plus N into N minus 1 by factorial 2 square plus N into N minus 1 into N minus 2 by factorial 3 square etcetera.

$$\frac{S_o}{S_i} = 1 + N^2 + \left\{\frac{N(N-1)}{2!}\right\}^2 + \left\{\frac{N(N-1)(N-2)}{3!}\right\}^2 + \cdots$$

So, the N gets determined by the required signal power gain to achieve a given MTI improvement factor. So, you know that what MTI improvement factor you want, so that you can have a meaningful detection or you can meet a probability of detection.

So, the clutter attenuation part is separate that comes from these type of expression that f by sigma f etcetera. So, you can separate that how much power gain signal power gain I need, and then from this expression you can easily find out the what is the thing obtained. And also we can say that in these terms you can actually we can relate whatever I said now that for a given improvement factor how much S naught I want. So, for that people have also found out a expression that if you have a N stage that tapped delay line implementation, then I, the MTI improvement factor, is related to these by this formula.

$$I = \frac{(S_o/S_i)}{\sum_{k=1}^{N}\sum_{j=1}^{N} w_k w_j^* \rho\left\{\frac{(k-j)}{f_r}\right\}}$$

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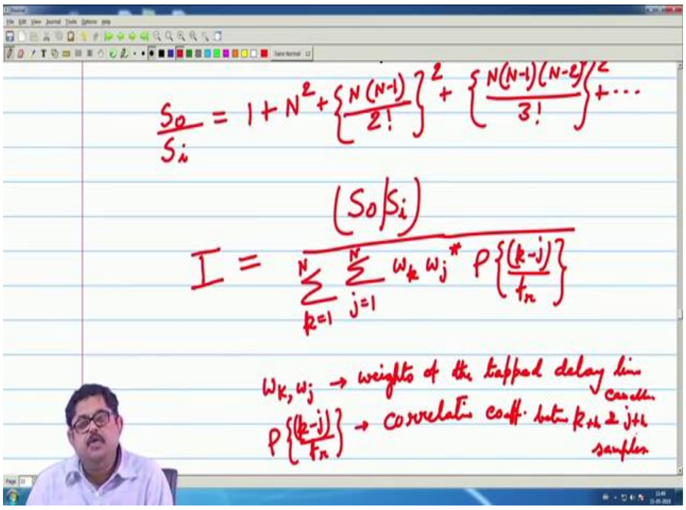

So, where I need to now define w k and w j are weights of the tapped delay line canceller. And what is the rho? It is the rho that thing k minus j by f r, this is the correlation coefficient between the k th and j th samples. So, if you find that out, then you can find that what is MTR. And from these and at present what is what type of received samples are coming? Echos are coming from that we can find the correlation coefficient that nowadays is very easy by digital signal processing there are electronic tools for these.

So, you can find these. And from that you can find S naught by S i. From S naught by S i you can find what is N. So, this completes that how to design a MTI filter for a given thing. So, this is the whole design things this may be a bit advanced topics. But I have indicated that this is the way by which a modern radar designer uses the designs the MTI filter.

Now, please remember that MTI is not the only way of or the way we have discussed that is actually a you can say time domain processing to detect moving target or to reject clutter. Now, this is not the only option, actually there are other options also. But to have that first let me tell what is the limitation of this MTI filtering. Actually we have seen that for low frequency or if we want to suffer the reduction in unambiguous range, then MTI filtering is a good example. So, I can say that what is its plus point.

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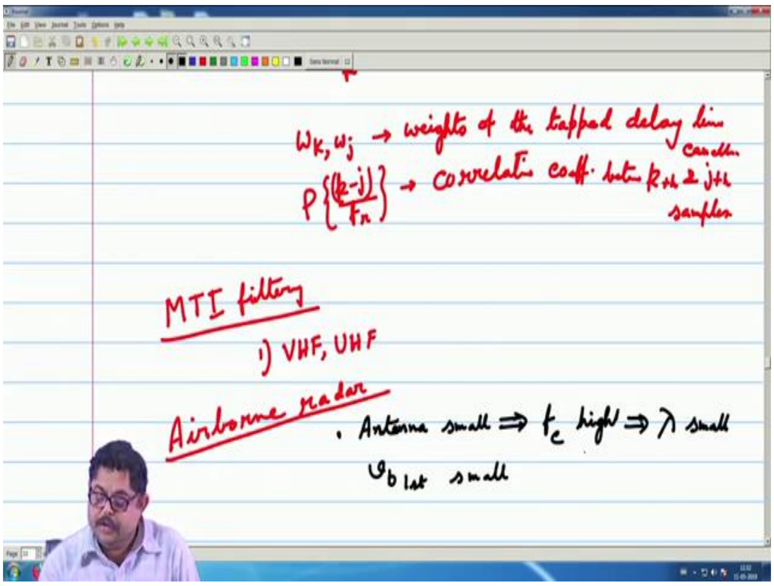

So, these MTI filtering this plus point is that at VHF, UHF, it is a very good technique to detect the moving target buried in clutter. Because here we are ready to tolerate the blind speeds will try to push the blind speeds further away by staggering etcetera. So, these can be done. But if consider a case where airborne things actually AWACS the early warning systems, where the radar is airborne and it is flying and observing whether any enemy things are coming or not.

Now, in that case, so let us see that its negative points MTI filters' negative points, suppose the airborne radar actually the purpose of this airborne radar is a high speed missile etcetera type of thing is coming, you want to detect that as early as possible. So, airborne radar means its antenna size is small. So, its antenna is small, because it cannot take a large antenna. Antenna small dictates that this implies that the radar should have the sorry radar should have the carrier frequency high, f c high, that means, lambda, that means, its lambda is small ok. So, its blind speed is the V b 1st is small because f lambda is small we know that this is small.

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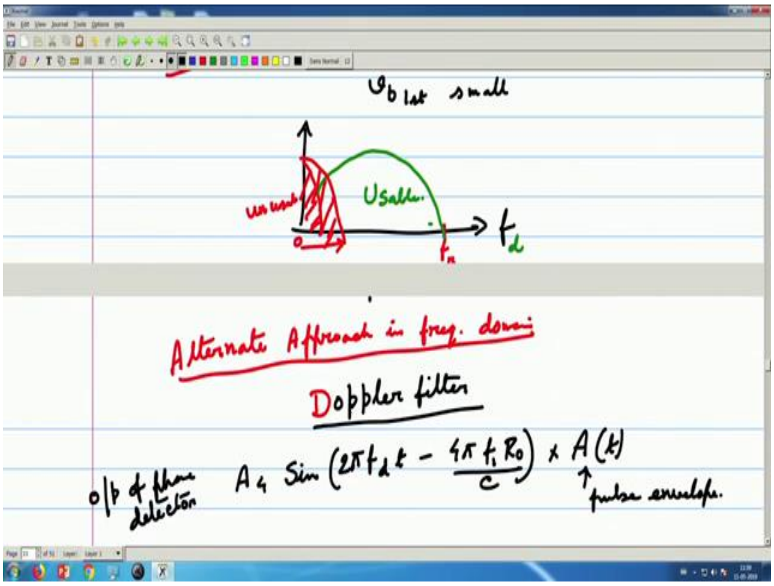

So, we can say that, now, I have a space frequency domain if we see that the Doppler spectrum let us say is this. So, this is an unusable thing. So, I can say that this is unusable, that means, up to this frequency I cannot use 0 to this. And then suppose this is my f r.

So, I can say that this space is my usable space. Now, problem is if the blind speed comes in this space; this is the space I have in that if the blind speed is small, it may come here. So, blind space come within the desired target Doppler space. This is actually usable space; this is the target space, so I want to detect it actually this should be f d. Now, then airborne radars due to their clutter, they have lot of platform motion because the radar is moving.

So, these things also get extended, that means, the usable space again gets reduced because the clutter spread increases. Now, on the other hand, you want to detect a high velocity target. So, you need to have this usable space that should have been extended much more, because you want to have much more high velocity targets; that means, this frequency should actually should have gone near.

Also the you see pulsed radar pulsed radar means it will have the whole this thing gets repeated at f r. So, lot of clutters from other spaces they fold over here and makes these usable space less or degrades the SNR. Due to pulse radar operation the clutter gets fold over because from all the various repeated next pulsed. So, all the pulses they are cluttered thing that gets enhanced, so that degrades the SNR. So, that is why people think that this or people have seen that MTI filtering at this AWACS type of thing airborne radar is not the option.

So, what are the other options there? Now, to understand that option that is called actually the you can extract Doppler, because ultimately we are trying to detect moving targets. So, Doppler you will have to extract, but instead of doing this MTI filtering which is basically a time domain approach, can we do it in the frequency domain that approach. So, I will say that alternate approach in frequency domain. So, let us see it is the thing, that means, we will now we will not put a delay line canceller, but we will put a filter let us call that a Doppler filter. So, it is not like that delay line canceller type of thing, it is a Doppler filter by which we will extract.

But here are some problems one problem is that please refer to the pulsed radar block diagram that we have seen that the there was a phase detector. Now, output of that phase detector we can write it that time we have written it probably like this, that output let me write output of phase detector in that blog diagram of pulse radar from where we have come to that MTI filter discussion. So, if you refer output of that phase detector was something like A 4 sin 2 pi f d t minus 4 pi f 1 R naught by c into the now I am multiplying that that time we have not done this, but actually the pulse envelop is there. So, with that it will get multiplied so ok.

$$A_4 \sin\left(2\pi f_d t - \frac{4\pi f_1 R_0}{c}\right) \times A(t)$$

Now, here you see that apart from Doppler there is also the range information in the phase ok, range information is in the phase of the signal. Now, a radar is not only whatever pulsed Doppler radar, so that should also extract the range, also it will extract the velocity through the Doppler.

Now, our scheme is we are using a Doppler filter. So, after phase detector, we are instead of putting MTI filter if I put a Doppler filter, there a there is a problem that actually this Doppler filter needs to be narrowband to extract. But actually what we are getting is a pulse, so pulse has a large bandwidth now, so that means, to have that pulse processing these Doppler filter will needs to be more its band.

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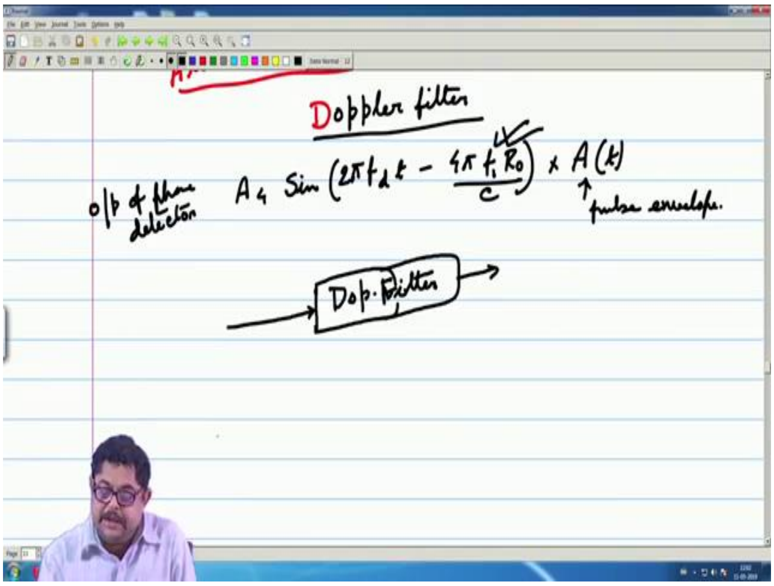

So, the problem what is a problem suppose I am having a Doppler filter. Now, now this Doppler filter the output is coming. If the spectrum of these input pulse is larger than the bandwidth of the Doppler filter, then there will be severe distortion in the signal, and this phase that will get lost.

So, this dictates the Doppler filters should have a large bandwidth. But if that happens the resolution of range gets destroyed the and also what happens that if you have a large Doppler filter bandwidth, then lot of noise will come, and you are ultimately will suffer in detection. So, this is a problem you see that if you have a filtering here, then the problem is the range information is getting destructed.

So, people then came up with an idea that we will filter later because filtering will have to do with definitely a narrowband thing, but instead of the phase detector output, first we will put extract the range information, then it does not matter because now everything is in the this frequency, so that can be easily filtered out.

So, they are changing the scheme from MTI filter, MTI radar. That MTI radar first gets the Doppler information then finds the range here the range is extracted first. So, this is called range gating. So, the idea is will it extract range first, and then will then we do not bother about the shape of the signal, so that time we will extract the Doppler by Doppler filter.

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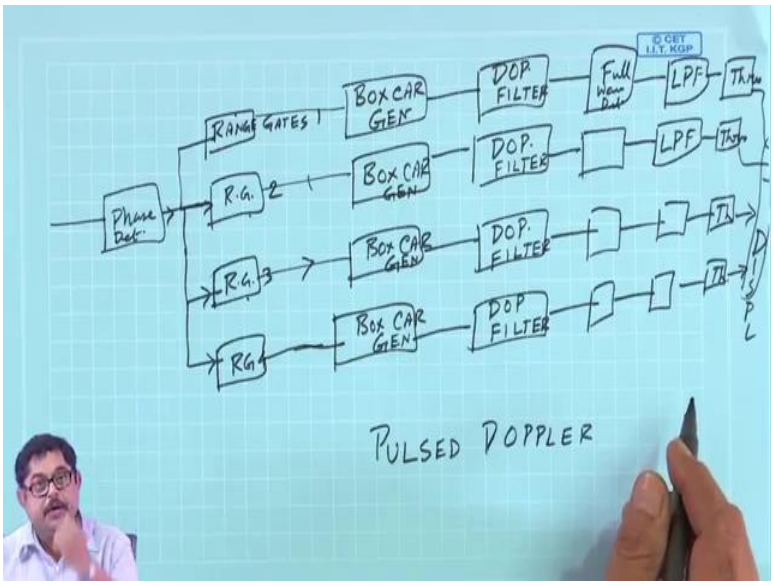

So, what is done with respect to the phase detector of the pulsed pulse radar block diagram? After phase detector you are putting range gates. You can put several of them, only difficulty here is the range gates once it is put to the range gate you lose the thing actually the range gets quantized, because suppose I am putting four range gates. So, am calling this range gate 1, this is range gate 2, this is range gate 3, this is R G 4. So, let us say that from 100 to 500 kilometer, I want to gae. So, the same signal after phase detector output that is put to these range gates.

Now, what happens that this range gate is nothing but a switch. So, I know that what is the time when if there is an object, there is a target from 100 to 200 kilometer, I know during which time it will come after the transmission of my pulse. So, during that time this range gate will be on. Then the after that it will be closed, and the second one will come; after that the range gate 3 will be on similarly. So, only the difficulty that we are getting is that the during 100 to 200 kilometer, I am not able to resolve. So, I am saying everything within 100 to 200 kilometer will be called the 100 kilometer or 200 kilometer.

So, actually the it is something like quantizing the range, but that is fine because that fine resolution is not required. So, after this range gates, we are extracted the range that means now the phase is not important. So, I can rebuild the signal that is done by boxcar generator. So, it makes again the rectangular pulses ok. Now, once that is done, then we put the narrowband Doppler filter. This was the idea that initially if we had put this Doppler filter here, but here you see that the for a range gating, actually this concept the number of elements are increasing. So, obviously, the more circuitry is needed because instead of a single Doppler filter now we require so much, but nowadays these are becoming cheap that is why this is possible. Also this range gating in a high speed cases this range gates should be very fast electronics.

So, after Doppler filter, you have the wave detector. So, the basically this is a making a bipolar to mono polar. So, we call it full wave detector. I am not write same thing in every path. Then after that we have a low pass filter because you have detected, so you need to smoothen it, so LPF. And then you put a threshold, so you have a threshold detector. And then from them you put to a display.

So, now I have said I think everything boxcar generator, a sample hold type of circuit, full wave detector is for converting bipolar video to unipolar the display shows targets with different ranges, and thresholding is there to remove the false alarms which are suppose birds etcetera that if you put the threshold properly those false alarms you can do.

So, different target in different range gate, so the detection of a desired target is separated from undesired ones like false alarms. So, this is a good scheme that this can be used actually modern radars uses that. So, MTI filter is no more used, but these are for AWACS etcetera where this electronics needs to be very fast and because range gates you need to operate.

So, this scheme is called as I said that pulsed Doppler radar, the price paid is cost of Doppler filter is very narrowband, so that Doppler resolution is good and good clutter rejection. So, usually the MTI improvement factor of pulsed Doppler radar is much greater than low PRF MTI. Also many range ambiguous pulses are entering the Doppler filter. So, more improvement factor is needed here ok.

So, this is a good design etcetera. I think we have covered the pulsed radar in detail. Now, from the next class will see some other aspects of radar that functional radars that what radar because now we have first said that whether the radar is continuous or pulsed, we have discussed both these varieties. Now, what is the intention of the radars, whether it is a search radar or track radar, and we have seen how to extract range we have seen how to extract the velocity through Doppler. But we have not seen how to find out the angular position of the target actually that will be done by the those tracking radar, so that we will enter next from the next class.

Thank you.