Principles and Techniques of Modern Radar Systems

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

Lecture - 05
Some Basic Concepts of Pulsed Radar (Contd.)

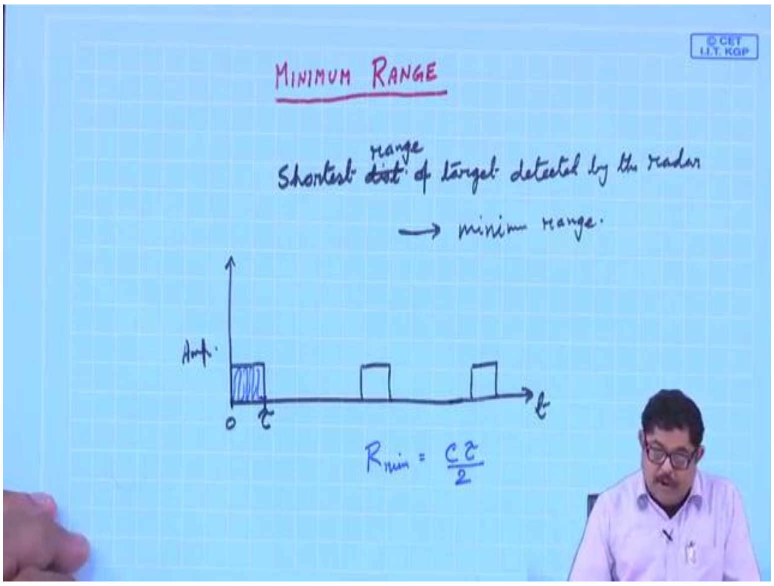
Key Concepts: Range resolution, minimum range, average power, duty cycle, PRF staggering

Welcome to this lecture on Principles and Techniques of Modern Radar Systems; we were seeing some of the basic principles and parameters of radar. So, we have covered three already that range; the maximum range, unambiguous range, integration of pulses. So, today we will see the minimum range. Now you see that how close I can see, actually in our eye also we will see that we cannot see very close to our eye.

Now similar thing, but in a magnified scale is also there for radar because what happens actually generally the radars pulse radars they are operated the same antenna is used for transmitter and receiver. So, when an antenna is radar is transmitting that time it is a high power transmission. Now that time if the receiver is kept on then that high power will come to the receiver. Now receivers we have seen radar receivers they are very sensitive because they will have to detect very low signal.

So, if that high signal comes transmitting signal comes to the radar; the receiver will get saturated and sometimes also may get damaged. That is why the when transmitter is on the receiver needs to be switched off. So, as long as the pulse is getting transmitted; the receiver cannot listen to any echo. So, if any echo comes by that time that will not be detected by the radar; that is why the there is a minimum range if the range of any object is smaller than that then radar cannot detect it. Now who determines this minimum range?

(Refer Slide Time: 02:31)



You see so, first let us say the basic definition is the shortest distance of the target shortest distance or shortest range of the target you can say in better shortest range of the target detected by the radar. So, this is called your minimum range. Now in a pulse radar, we are sending; we have seen that the at a pulse repetition frequency, we are sending the thing now let us say that the on time of this.

So, this is t this is the amplitude of the pulse; please remember this I am giving a caution actually a pulse cannot be transmitted at a very high range. So, actually all these are basically RF signal; whose envelop is like this. That means, the actual signal is an very high frequency RF signal in gigahertz range or may UHF range.

So, the signal is this, but if you do the take its amplitude that is here that is why we will show like this. Please do not think that a pulse radar sends a pulse actually it sends a high frequency carrier whose envelop will be like this. Also always rectangular pulse is not seen that we will see later; that there are other shapes which are performed better than this rectangular one. But to start with we are taking that there is a rectangular pulse repeated at PRF.

So; that means, during this 0 to tau this time period if any return comes that does not get a detected by the radar. So, tau; that means, if any object which is at such a distance that two wave travel from the radar to that; that means, going and coming of the wave that time it is the two way trouble time is equal to t; then that t will be detected. So, you can easily find out because we have seen what is R.

So, I can say that R minimum then will be

$$R_{min} = \frac{c\tau}{2}$$

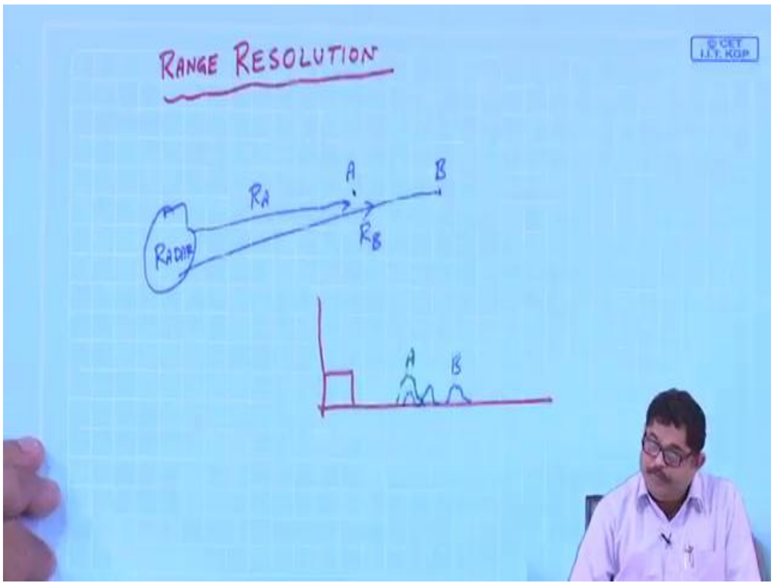
So, if this pulse width; that means, what is tau? It is a pulse width. So, if the pulse width is you can do 1 micro second; then the minimum range turns out to be 150 meter. So anything closer than the 150 meter; the radar cannot see it.

Now; so you see that to reduce this minimum range, someone may tend to say that you should make the tau very small. But if you make the tau very small there is one more thing; that means, the power that you are sending; that means, the average power that is going down.

So the if this tau is small the strength of the echo signal or the power of the echo signal that will be also small. So, it will create problem for the receiver; we have seen that every receiver has a sensitivity. So, you will have to have much higher sensitive receiver; so that will add to the complexity of the thing and cost of the thing. So, it is always not advisable and generally radars are not required to see such a small distances because those things can be seen by eyes; radar is main for seeing at larger distance.

So, this minimum distance though it should be known, but because nowadays radars are used for close sensing also; in that case these parameters becomes important, but for normal aircraft detection or seeing at long ranges this parameter is not so important ok. The next parameter that we will be seeing, that is a very important parameter, that is called the resolution.

(Refer Slide Time: 07:03)



So, any measurement system has a concept of resolution; we will first discuss that here we will discuss mainly the radar measures range; so range resolution in that context we will discuss. But the concept of resolution is general actually what is resolution? Please understand that if I have two objects and I am trying to detect them. Now I am sending some pulse in case of radar suppose these two objects; they are at same angular distance, but at different distances let us say two objects A and B.

So, B is at a further range from the radar let us say this is my radar. So, I will get a return from A; I will also get after some time a return from B and I will be able to say that there are two objects at the respective ranges of R A and R B. Now let us say that I am reducing this distance; so the; so let us see in the time domain what is happening.

Suppose this is my transmitted pulse and let us say that this is my echo from A and let us say this is my echo from B. Now if I reduce this; this echo of B that will come closer. So the question is that what is the minimum distance when still this; when they have come very closer, but still I will be able to say that they are two different echos. That means, gradually actually this is coming near suppose it has come here also I will be able to say, but if it goes here then I will not be able to say.

So, resolution is the minimum distance where from their returns I will be able to resolve the echo. So, that means, if I produce a wide transmitted pulse that will also produce a wide echo hence narrower the transmitted pulse the resolution become improves.

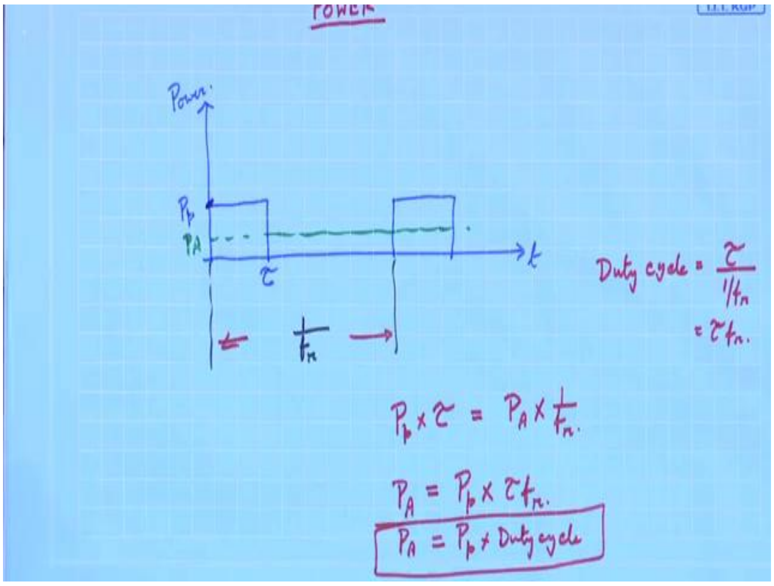
So, roughly we can say that pulse width affects the resolution now initially you are think we will assume that resolution is nothing, but the pulse width. But later we will see that it is not true generally resolution depends on pulse width, but it is not exactly equal to the pulse width. So, how to define then this concept of resolution or range resolution? The smallest distance which can be discriminated by the radar detector is called the range resolution of the radar.

So, targets which are closer than this range resolution; they are the detected as one single object instead of the separate objects; so this is the concept. So, and also then pulse width approximately determines the range resolution of the radar. We will go with that later in the detection theory we will see that what is the best possible resolution. And there we will learn a technique called pulse compression where this range resolution can be made much much lower than this pulse width; actually you can the whole thing is in the hand of designer.

So, you can have several order of magnitude lower you can make this resolution compared to this. Also the range resolution there is also an resolution in the angular direction or in terms of range; it is called cross range resolution. So, we will see there is a concept of down range resolution, cross range resolution those will come later one by one; now we are not entering there. So, this is one parameter resolution this is an important thing and basically you know that for cameras etcetera; you always deal with this resolution.

If you want to go and buy a camera you say that I want the; so, many pixels or so many dots per inch actually that is a concept of resolution. So, you want it as finer as possible then the image will be better. So, same is true for radar if your resolution improves then your imagery etcetera will be better, your detection also whether there are the two objects nearby that you can detect.

(Refer Slide Time: 12:27)



So, let us come to the next thing that what is the transmitted power of the radar? So, for that we have already seen this time domain picture of the transmitted pulse. So, we are sending pulses one by one. So, here let us say now the; this diagram this is time, this to calculate power; this is our power. So, let us say that the; this is the previously I was calling this as amplitude domain. So, power will also be similar type of curve and let us call that this pulse pick power that is P p.

So, the radar is when it is transmitting from P p for P p it is transmitting up to time tau and then it is going off. So, transmitted power is off again it is coming. So, obviously; that means, what is my time period? That let me say that this will be my time period and previously we have seen that generally radar people call it either; it is capital T, PRI or 1 by fr; where fr is the PRF. So; that means, this is my whole this is my period time period of the repetition. So, then there will be we can easily calculate what is the average is power?

So, average power will be something like this let me call that P A; P subscript A average power now; so can we calculate what is average power? Because generally transmitters they are average power is told, but remember that in radar equation, we are interested only with the peak power. Because radar gives detection etcetera all depends on peak power, but transmitters etcetera the what is the average power that is a specification. So, we need to relate this P p and P A.

So, can I say that P p. So, what is the total energy in the single pulse? P p into tau and that should be equal to that energy in the whole period; that is P A into 1 by f r.

$$P_p \times \tau = P_A \times \frac{1}{f_r}.$$

So, from this we can get the important relation that

$$P_A = P_p \times \tau f_r$$

Now for a pulse repetitive pulse we have a concept of duty cycle.

So, what is duty cycle? Duty cycle is the on time by the total time. So, that turns out to be

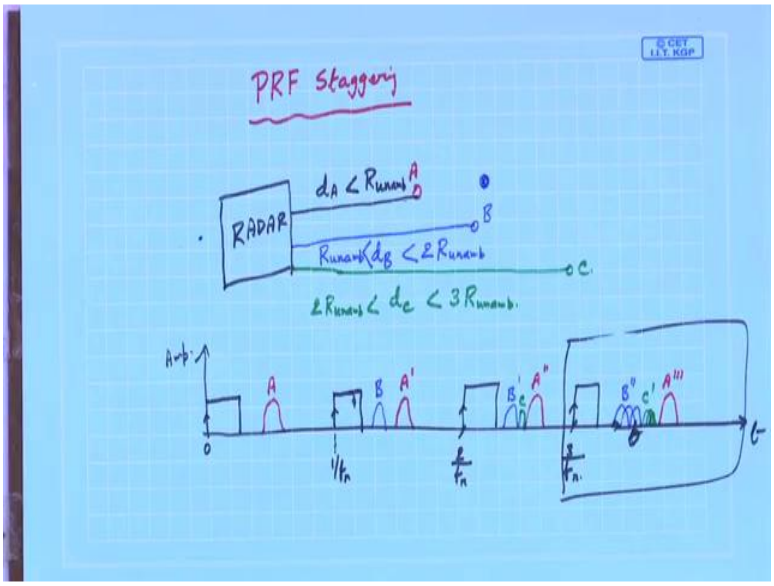
$$\text{Duty cycle} = \frac{\tau}{1/f_r} = \tau f_r.$$

That means, we can also write that

$$\boxed{P_A = P_p \times \text{Duty cycle}}$$

So, this is the relation that what is average power? Average power is peak power into duty cycle. So, usually the peak power maybe as kilowatt megawatt and then you can find out depending on the what is there; there will be problems based on these thing in your assignments.

(Refer Slide Time: 16:15)



Next we come to another concept that is called PRF staggering. Now actually this is a concept already we discussed is earlier when we discussed the range ambiguity. That time we have seen that when measuring range; there is a ambiguity in the measurement if the range of the target is beyond the maximum unambiguous range.

So, let us understand this concept of PRF staggering by a thought experiment. So, let us say that this is my radar and I have three objects; one is I am calling A; it is at a distance from the radar I am deliberately choosing it so that the distance is d A and d A is less than R unambiguous. Actually maximum I am not writing, but in anything is maximum it is less than maximum unambiguous range.

Then there is another object let me call it B; actually there are all in the same line, but since on the same I am not drawing, but please remember that actually A is here, B is here. Actually B should have been here, but to make those things not confusing you; I am writing them actually from that are there at the same radial line and this object is be. So, its distance I am calling d B; d subscript B.

So, what is I am choosing d subscript B; so such that is less than d B and less than 2 R unambiguous ok. So, it is greater than the unambiguous range, but less than 2 R unambiguous range. Similarly, there is another object that is at C and what is this distance and calling it d C. So, this is 2 R unambiguous is less than these and this is 3 R unambiguous ok. So, these are the three objects placed; in the same angular direction from the radar, but at three different distances chosen in this way.

Now let us see what happens in time domain. I am sending pulses. So, this is t; this is the amplitude I am getting and so, let us say that I am sending pulse then at the second one, I am sending another, another pulse. Then I am sending another pulse then I am sending another pulse; this is going on. So, each one of these; so I can say that this is time 0.

So, this one this time I am if I am considering this is my reference. So, these are my references. So, this is I can say t is equal to 1 by f r; so this one will be 2 by f r, this one is 3 by f r etcetera; now let us see what will be the returns. So, for A; A is red color; so A is; suppose A has come here. So, this I am calling A and you see that since only A's distance is less than unambiguous range; so that means, within this period only A will come, others will be second time around echoes and third time around echoes etcetera.

So, then in this interval what will happen? This A will again come here against this. So, let us say A is here, but I am calling it now A dashed because it has come after the second pulse has been transmitted. There will be A double dashed then I am not drawing there. Now what will B? So, first B will arrive here and let me say that B is here.

So, you see compared to this range this is larger, but it has come after the second pulse has been transmitted. So, this is the first occurrence of B. So, B will again come, but this will be here B; so I am calling it B dashed. And here again you see no C will come; C will be coming only here. So, now let us say that C has come here C ok. So, now you see actually after some initial measurement; this thing will go on now repeating, if these three objects are there then next one also be like this.

So, if I extend these time; then the returns will be like this that first there will be a B, then there is a C and then there is A. So, I can call this one as A triple dashed, this one is B double dashed and this will be C dashed. And this thing will be at after sometime; that means, after this; that means, third pulse onwards the screen will be like this; this is the steady state, this one this picture will be finally, in the radar display.

So, you see now from here what will be the inference of the radar? Radar will say B is the closest, C is the next one and A is this, but how do I know; here actually you see only A's range is measured correctly and there is ambiguity in the measurement of B and C object. But how do I know that A is unambiguous, A’s range measurement is unambiguous and range measurement of B and C are unambiguous? For that what people do or what radar people have been find out that now suppose I am changing the PRF; that is called the PRF staggering.

So; that means, to distinguish multiple time around echoes, from unambiguous echoes the PRF is varied this is that is called PRF staggering. Now what will happen? That if I change the PRF; that means, this positions are changed. Let us say that this if I change the PRF then suppose the instead of sending; this pulse this pulse will be send here, this pulse will be send here.

So, what will happen then actually if you see that the A; since this measurement is correct always A will be like this. But I am changing PRF; that means, now I am changing at a certain interval; the next pulse I am giving at a different interval. So, there will be the display will look something like this that for B and for C also it is something like this.

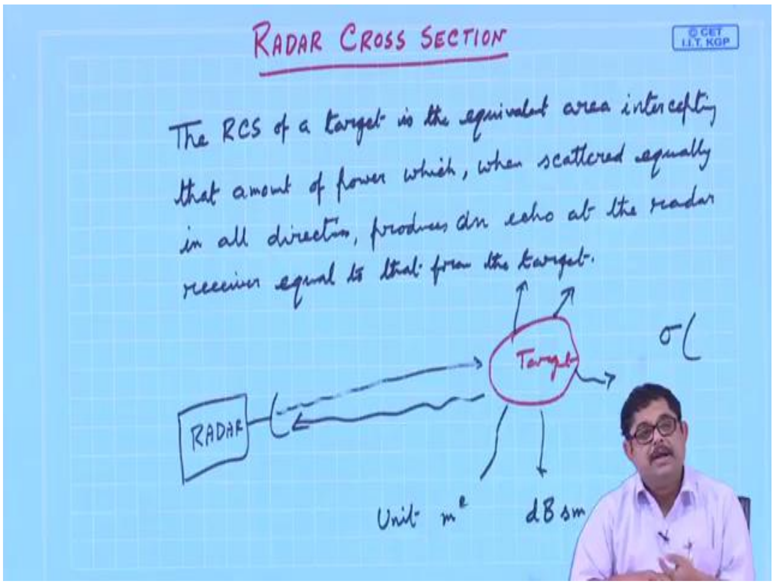
So, actually there are spreading over a finite range for unambiguous ranges, but sorry ambiguous range measurements and unambiguous one that will be always the echo will come on the same point. So, now I understand that these two are unambiguous ambiguously measured and this one is unambiguously measured.

Now you can correct for that also that we will see later; that by PRF staggering how to choose those PRF’s so that you can correct for what and for how much ranges you can do that. So, now this change of PRF that may be done continuously or varied discreetly among several predetermined values.

And if you have only second time around echoes; then only two PRF’s are needed; that means, you change over only two PRF’s. If third time (Refer Time: 26:12) echoes is also present; then you will have to vary three PRF’s etcetera. These are very practical method and radar can easily find out that thing and correctly measure the ranges.

So, that thing we will seen, but now we are introducing that this is a basic concept that PRF is not fixed; generally radars vary the PRF to understand whether there is any ambiguity in the measurement ok; so this parameter.

(Refer Slide Time: 26:46)



Next we come to another very important parameter of the radar; this parameter we have introduced in the radar equation, but here it requires some separate understanding. So, this are very very basic and one of the fundamental parameters of radar; it is called radar cross section. First let me give the definition because that definition actually we will have to understand for some time; it is a new definition. So, you may find it a bit a; that is why I am writing the exact thing then we will discuss.

The RCS of a target is the equivalent area intercepting that amount of power; which, when scattered equally in all directions produces an echo at the radar receiver equal to that from the target; this is the definition. Now, let us understand actually the radar cross section that has got two fundamental properties and in the definition that is captured.

Now it is an cross section means it is an area, but as I said also in the range equation discussion; that it is not the physical area, it is the electrical area which the radar sees or it is an; now antenna you see any antenna also has similar type of concept that effective area. So, we have seen that in antenna classes we have seen that what is the equivalent electrical area? Now RCS is not only that because RCS is one thing that it is actually receiving the energy.

So, while receiving this effective area comes because we can calculate what is intensity power intensity at a point; then that multiplied by the area is the total power. But actually the target that is a scatterer so; obviously, it is taking the power, but it is not taking the power as a antenna radiator, it is depending on its shape etcetera it has an effective area; so it is taking that power.

But more importantly then its scatters which is not present in antenna; in antenna it only radiates. But here it is taking the power then it is radiating and then it is scattering and that scattering is not equal in all direction; so there is a directional property. We want to find out in the return direction of the radar what is the scatter?

So, let me draw that this is the target, this is the radar; this is the antenna of the radar. So, first this is going; so we can find out it is in this direction. what is the power intensity coming; then that target that is taking that power then it is radiating in various directions; not in equal amount and then what is coming here; so everything; that means, this to properties that how much power it is capturing? How much it is scattering and in which direction it is scattering?

All these are capture and then the effective and equivalent area is defined. As I said earlier this sigma is; obviously, dependent on this angles; that means, the in which direction the target is getting illuminated by the radar; in which direction the scattering is coming by the radar and out of what power it has taken, how much it is scattering back all those are there?

So, it is function of that and that I have said already depends on shape size etcetera, but RCS is an equivalent thing for all that is the equivalent area intercepting that amount of power; which if this scatterer was isotropic scatterer then it would have radiated equally in all directions; scattered equally in all direction. So, if I say that what is the area that will scatter equally in all direction and that power which is coming back to the radar will be equal to the actual case that is the equivalence there.

Now; so the unit of radar cross section will be meter square unit is the meter square and if we express it in dB scale; it is dBsm. So, say we will continue this discussion, now this is the definition, but to understand it we require a mathematical form of this definition that we will discuss in the next class.