Principles And Techniques Of Modern Radar System
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Lecture – 48
SAR Processing

Key Concepts: Introduction to Synthetic Aperture Radar (SAR), introduction to the mathematical model of range in SAR processing

Welcome to this NPTEL lecture on Techniques and Principles of Modern Radar System. We have seen the resolution concept previously and we have seen a technique called pulse compression by which in the range direction we can improve the resolution. Now, today we will see another technique by which improve the resolution in the cross range direction.

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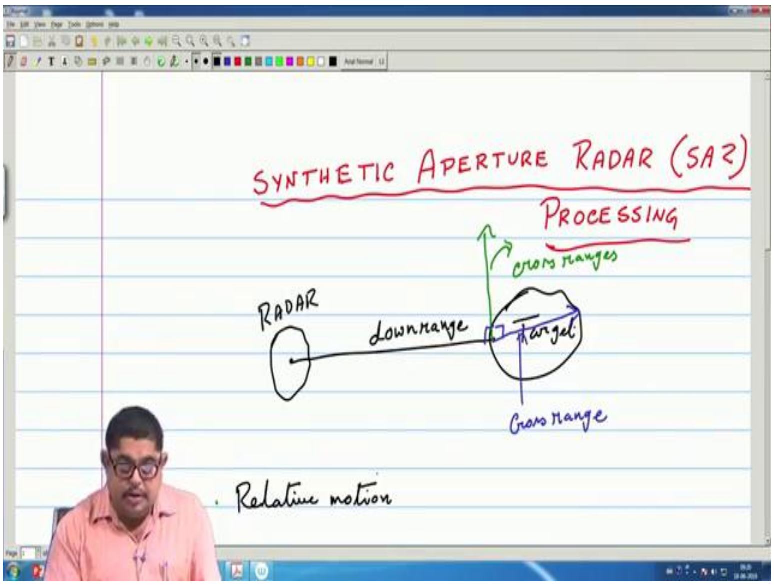

In this connection I want to say that suppose you have your radar here and the target here. So, if there is a point here is our reference point. So, this direction radial direction this is called range or in radar people call it downrange. So, to these downrange there are 2 perpendicular directions, there are 2 perpendicular directions to these.

So, these two are called cross ranges. So, there are to every downrange there are two cross ranges. Now, synthetic aperture processing SAR processing that actually gives you the improves the resolution in the cross range directions. So, downrange pulse compression and SAR processing in the cross range. So, it is a very novel concept and as the name suggests that synthetic aperture; that means, actually you know that, if I make an antenna larger and larger it is beam width will be narrower and narrower.

And, basically the beam width is that resolution, because anything coming from the beam width we say that it is coming from one single object. Even, if there are 2 3 number of targets in the one beam width, but we say that is one….

So, that that is why if I can go on increasing the antenna size, then I can improve the resolution in the cross range reduction, but that is not possible because generally the radars etcetera. If they cannot have any amount of antenna size because then they would not be able to move etcetera. So, for a limited antenna, if we synthesize from that limited size antenna, if we synthesize a large aperture antenna then that is called synthetic aperture processing.

Now, how we do that out we synthesize the aperture that we will discuss today. Now, here I want to say that there is one requirement for any SAR processing that there should be a relative motion, relative motion not in the actual scenario, but in the measurement scenario; that means, either the radar or the target. So, there should be a relative motion either the radar is moving or the target is moving in a predefined way then only we can synthesize an large aperture.

So, relative motion between radar and target is a prerequisite of synthetic aperture technique.

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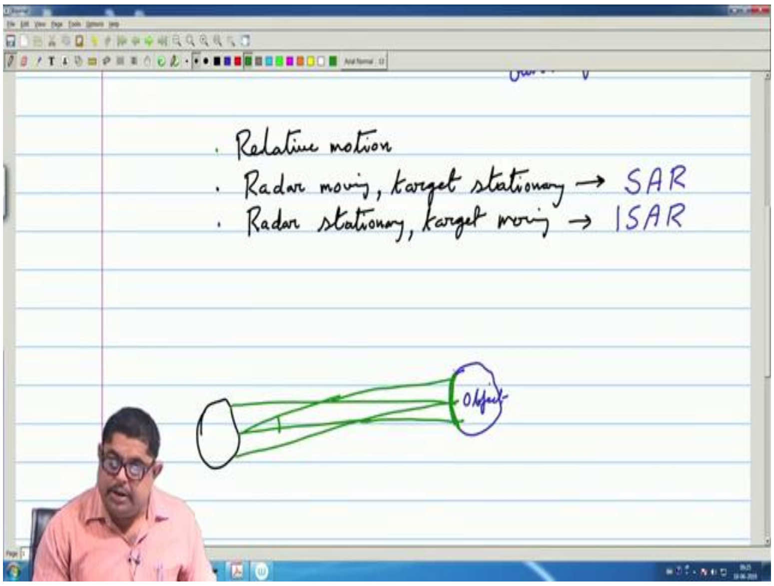

Now, in that there are two nomenclatures, that radar moving, target stationary then that is called SAR and if you have the opposite that, radar stationary and target moving, then the technique is called inverse synthetic aperture radar ISAR.

So, actually all these synthetic aperture processing generally in imagery, remote sensing not sense remote imagery, remote satellite based imagery, then aircraft based imagery, basically ground imagery, or a planet's surface planetary surface, planetary ground that imagery there this technique is heavily used. And, so, actually you see that this movement relative motion between the radar and the target that creates a Doppler in the echo signal; that means, whatever signals suppose we have sent, but due to this movement there will be an Doppler and that Doppler is intelligently processed.

So, if in the actual scenario there is a Doppler; that means, if there is a moving target etcetera then this technique is not applicable. That is why in the basic technique of pulse radar we have not discussed it, because moving targets they have their own Doppler, but here we are deliberately creating a Doppler for creating a synthetic aperture. So, these two generally gets confused.

Now, this is the basic thing, nowadays with advanced computational resources people are still handling these two cases, but let us consider that moving objects are generally not resolvable by classical SAR technique, but in ground imaging etcetera or remote sensor based imagery there the ground is not moving. So to say, because from the inertial frame fixed to earth it is not moving.

So, that is why it is not a problem we can apply the synthetic aperture technique. Now, radar pulse radar I already said that radar pulse width controls the illumination width in the range direction and antenna beam width determines the illumination in the cross range direction. Now, a narrow beam has final resolution, a narrow beam requires a long real antenna, which may be difficult to implement in SAR based radar systems, signal processing is used to make a short antenna relatively short antenna behave as a long one ok.

Now, this SAR signal processing is basically a coherent phase compensation technique, that we will see that correct for the specific phase history of the signal. Actually, we can first qualitatively understand the concept; suppose I have an object here, suppose this is the object and I want to observe it. Now, if I had an real antenna then that real antenna will produce a beam. So, this beam width let us say this beam width that governs so, here if it gets projected here.

So; that means, anything in these zone that beam width that is the resolution of the a thing. Now, instead in SAR what is done the object is same.

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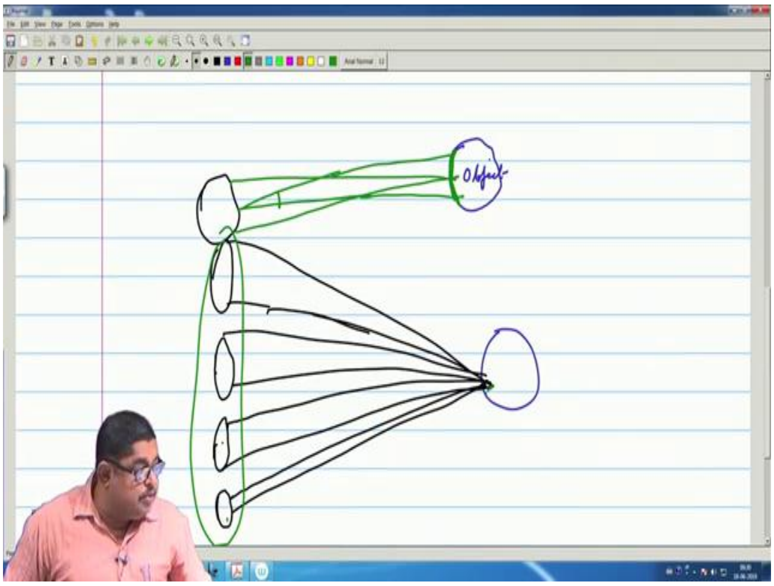

But, the antenna is suppose first is placed once and partially it illuminates this object ok. And, the return is obtained and stored, then let us say the by this time the radar has moved here. So, again from here this same object is illuminated. And, this return echo that is obtained and stored, then it goes here, from here, it sees the same object again it comes here and stored, it goes here as long as it can illuminate this point it goes on doing that.

So, all these are stored and it is assumed that throughout this whole process the whole scenario is stationary. So, as if instead of a single antenna, if I had an antenna as big as this and illuminated this thing, that is synthesized. So, for synthesizing actually you see that if an antenna is here and it is illuminating or if the antenna is here it is illuminating the phase, space phase of the returned echo signals are different.

Now, it judiciously compensates that phase shift and that is called coherent signal phase compensation by that it behaves as if there was a real large antenna very large and that is from all its portion it is simultaneously sending the beam and that is why the resolution gets improved. Actually with this phase compensation only returns from this point are constructively added, but; obviously, when it is from here it is illuminating these other portions also we will send the return. But, in the phase compensation they are removed, because we are looking only at this point or the whole surfaces are is focusing on this point. So, the returns from others are removed.

So, this compensation can be deduced that, what to how much phase compensation we will have to give if we find out the phase history of the point for a plane wave sort of thing we know the plane wave. So, we can easily calculate that phase history and that compensation we can give ok.

So, this is the basic qualitative understanding of a thing. The or sometimes I use another analogy that, suppose I want to see minutely at the front of me. Now, I have 2 things to see minutely I need a very good spectacle etcetera or whatever spectacle I have what I can do, I can start from the right of the room and see the same point, many times I see also while I am seeing I am traversing from the right of the room to the left of the room.

So, many times I am seeing the same point from various angles and if I can store all those things and then always try to find out, what I have seen about that point at this is if we. So, I am seeing it from the right I am seeing it from the middle right, I am seeing it from the center, I am seeing it from the left middle I am seeing it from the extreme left. And, every time if I know that how at what phase I am getting the signal and I can accordingly adjust that? So, as if instead of seeing it one times I have seen it many times the same thing.

So, if I do that the for all other points the returns will cancel out this is the basic understanding of SAR ok. So, with this understanding physical understanding I will now find out a basic geometry of SAR. And, with that mathematically try to find out the SAR this phase compensation how much phase we need to adjust etcetera. So, for that I am giving a basic drawing.

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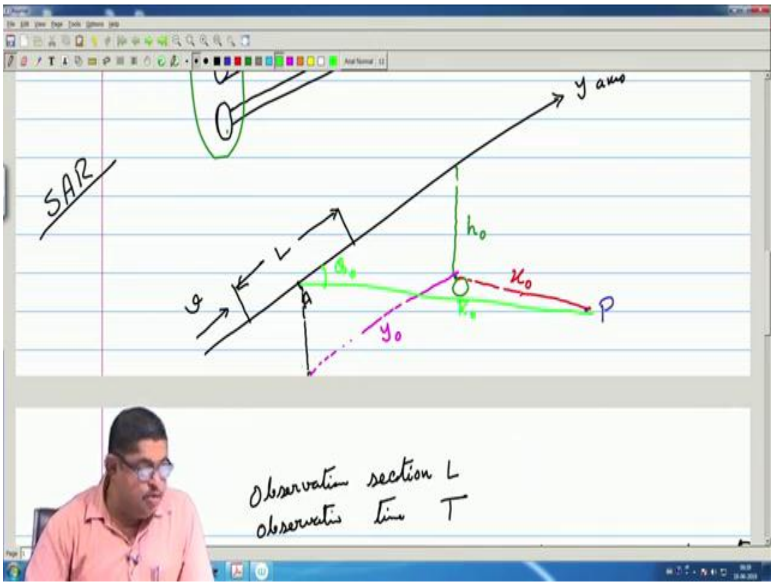

That suppose the we are classically discussing SAR; that means, the radar is moving the targets which you can assume ground in this case. So, ground is stationary. So, this is the that a radar is moving with a uniform velocity v along a line, let me call these y axis and we have a point in the ground actually this radar is moving at a height and in the ground we have a point P. We are trying to look at this point P or we are trying to image this point P.

So, the radar is moving with a constant velocity v the course is at a constant height h. So, what I can do I can find out suppose, I can drop a perpendicular on the ground that this is at a height h naught. So, always the radar is moving at a height h this is the ground and let us say that this is our origin of the thing this point is at the ground ok.

And, let us say that the radar is looking at point P, you see always it cannot look at because the antenna is oriented in a particular direction so, beam is coming. So, let us say from here to here let me call that the midpoint of that is A. So, from a distance L the radar is observing this point ok. So, let us say that our time T starts when the radar is at point A. So, we can say capital L is the observation length and observation period at corresponding to that will be T.

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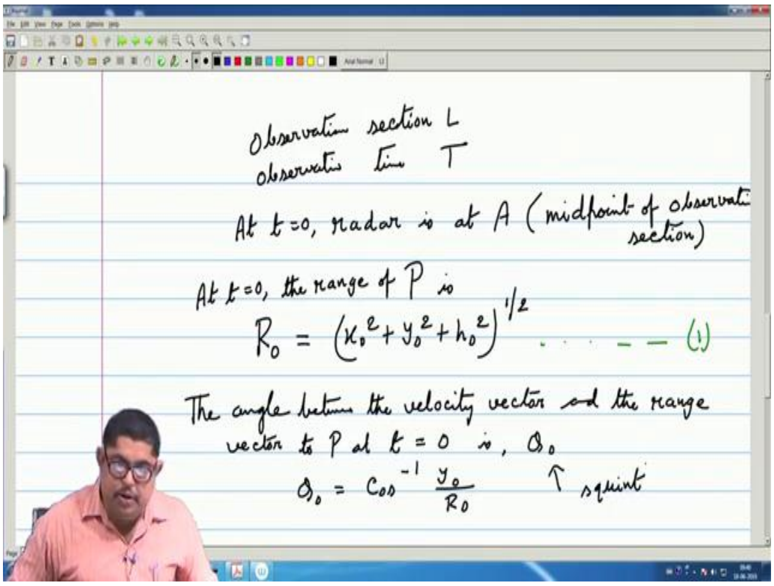

So, it will be I can write observation length or section we can say observation section L and observation time T observation of that point ok.

Now, let me give some more information about these that, these origin from origin to P what colour… I can say this is my x axis, this is y axis perpendicular to that there will be x axis let that is x naught and so, A this point A if it is also projected this will be parallel to this point because all these are at a constant height. So, I can say that let me use another different colour.

So, along y axis A’s coordinate this distances y naught so; that means, A it is coordinates are that it is at a y naught, x naught, an h naught, I can say that also there is an angle necessary, because a is at the height. So, if I join A to P, then that angle it is making I am calling it theta naught. Actually, if I go to another point it will be a different angle, theta naught I am saying because we are assuming one thing that our time at t is equal to 0, radar is at A, what is A midpoint of of observation section.

So, I can say that at t is equal to 0 the range of A sorry range of P is R naught again at different points the ranges will be different, but I am using the subscript 0 to say that at t is equal to 0 my range R naught will be given by x naught square plus y naught square plus h naught square. So, let me call this is my equation number 1.

$$R_0 = (x_0^2 + y_0^2 + h_0^2)^{1/2}$$

And, at A the angle between the velocity vector v and the range vector R. So, I should better write with this green colour this R naught, yes this angle is theta naught. So, from these geometry can easily say, that what is theta naught theta naught is cos inverse y naught by R naught. So, that is my second equation the angle between the velocity vector and the range vector to P, at t is equal to 0 is theta naught, where what is theta naught cos inverse, y naught by R naught.

$$\theta_0 = \cos^{-1} \frac{y_0}{R_0}$$

Now, in radar people call this theta naught as a squint angle.

Now, during the observation period L the point P will be within the real beam of the antenna. During the observation period L the point P is within the real beam, once radar moves further the beam fails to touch this point. Similarly, if it is prior to this points also the beam is not illuminating P, but throughout observation section or observation period T it is illuminating P. Now, what is the observation time?

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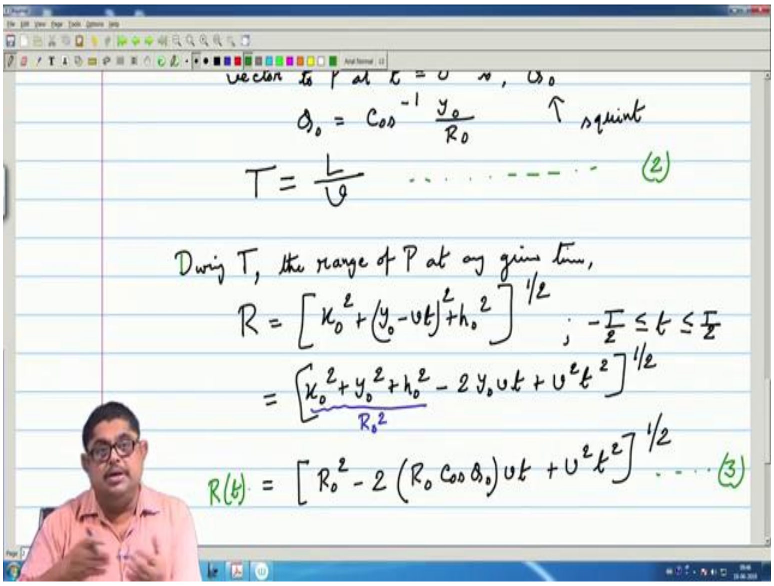

I can write observation interval T is simply because the radar is moving with a constant velocity v. So, this will be my equation number 2.

$$T = \frac{L}{v}$$

Now, during T, during T the range of P at any given time will be R, not R naught, R naught is the range at t is equal to 0. So, R, I can easily right from the geometry as the position of the… the radar is moving at y axis. So, x and z there are no movements. So, those will be same and only it is moving in the y axis.

So, I know that this will be the range at any time T so; that means, I can say that minus T by 2 less than equal to less than T by 2.

$$R = \left[x_0^2 + (y_0 - vt)^2 + h_0^2\right]^{1/2} ; \quad -\frac{T}{2} \leq t \leq \frac{T}{2}$$

So, this is my range equation. So, this if I expand it becomes x naught square plus y naught square plus h naught square minus 2 y naught v t plus v square t square to the power half. Now, I can easily say this this is nothing, but R 0 square.

So, you can write it as R 0 square minus 2. Now, this y naught from this cosine relation what is y naught y naught is R naught cos theta. So, I can write instead of y naught R naught cos theta naught v t plus v square t square to the power half. So, this I will call my equation 3.

$$= \left[\underbrace{x_0^2 + y_0^2 + h_0^2}_{R_0^2} - 2 y_0 v t + v^2 t^2\right]^{1/2}$$

$$R(t) = \left[R_0^2 - 2\left(R_0 \cos\theta_0\right) v t + v^2 t^2\right]^{1/2} \quad \cdots (3)$$

So, I have written the range R, R is a function of time as these parameters R 0 R naught theta naught v, that is all these are all SAR’s parameter.

So, these R is a function of t. So, I can write more specifically this is R t is equal to this. Now to get what is the range in general, what I can do I can expand this range equation R, in Taylor series about t is equal to 0. That will do and that will tell us what is the how the range is varying and from that we will find out the phase history of various points; that means, if the radar at various points the echo signal what will be the phase that will be able to do. So, that will do at the next class, but remember. So, please brush up Taylor series, because we will be using Taylor series to expand this r t equation 3 we will expand in the next class.

Thank you.