Principles and Techniques of Modern Radar Systems
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Lecture - 27
Tracking Radar (Contd.)

Key Concepts: Monopulse technique, monopulse receiver, squinted beam technique and its mathematical formulation, monopulse axis

Welcome to this NPTEL lecture on Principles and Techniques of Modern Radar Systems, we were discussing Tracking Radars. So, in the last class we have started our discussion on a very sophisticated type of tracking radar called monopulse radar.

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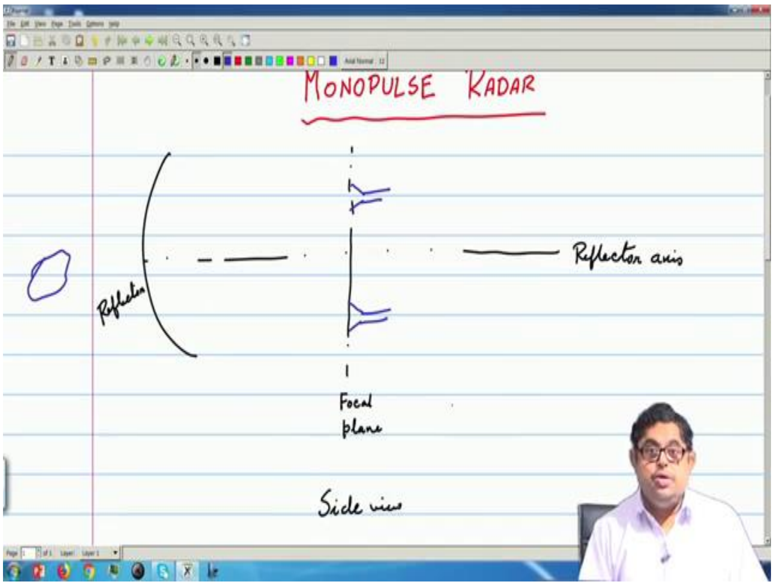

So, we have seen the side view of the monopulse antenna system, there is a reflector and in the focal plane there are four feed horns; now since we are seeing this is the side view. So, two are seen actually they are offset from the axis. So, these are from side if I see only two are seen, the other two are on the back side so, they are not seen.

So, reflector is a parabola reflector antenna the cluster of four feed horns in the focal plane, horns are symmetrically offset about the axis. So, in the if we see in the axial view we will be able to see this is the axial view.

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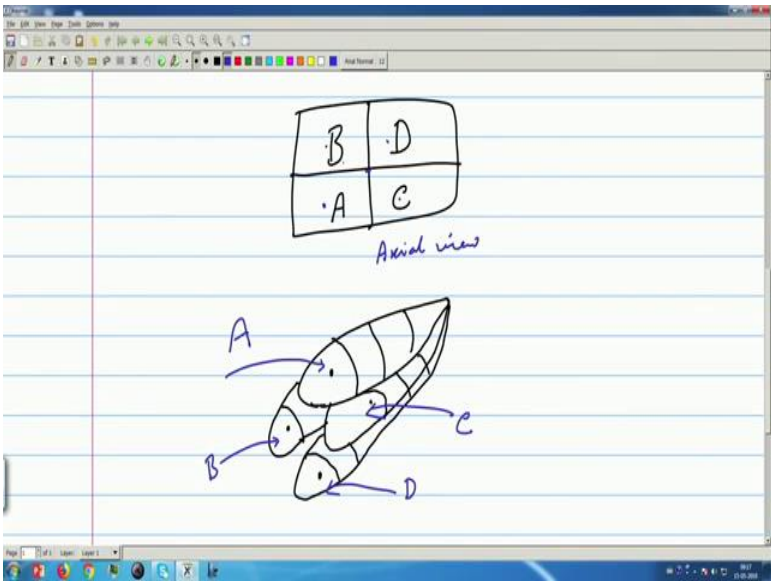

So, we can see the horn and here, you can see that the though the horns look square actually the horns are not square, horns are rectangular, but since they are offset actually this is the offset point. So, if this is the axis point then, this are the offset. So, you see that each side symmetrically they have offsets. So, in general the horns the apertures are rectangular. Now, this 4 horns so, if they are excited, then they would form squint beams. So, the squint beams will be these you see that 4 feed horns, they produce this 4 squint beams due do these offsets this squint comes. And, you can note that upper horns they produce the lower beams, because that is the squint.

So, you see upper horns are B D. So, they are producing B D here, A C are the lower horns, they are producing AC here. Now, suppose a wave is coming or a echo pulse is coming from a target. So, generally when the echo pulse come it is in the far field of the scaterrers.

So, a plane wave we can assume is illuminating. So, if a plane wave illuminates these 4 horns, then if this 4 horns are connected to 4 separate identical receivers; that means, each horn is connected to one RF receiver. So, the phase due to the offset the phase of the signal received by each receiver, they will be same, but amplitude will not be same, because amplitude is will differ, according to the beam pattern and the direction of the arrival of the plane wave.

So, now, this cross over point in any squint beam system, we have the cross over point. Generally the cross over point as I have shown that this is the crossover point and so, it is lying on this axis. So, reflector axis is also the crossover axis. So, if a target is let us say that, a target is on this axis; that means, a target is here suppose a target is here, then they will be the all the equal the receivers will get equal amplitudes. So, they will be now able to say that ok, that target is on the crossover axis, but if the target is off axis, anyway either up down or in left right, then there will be difference in that. So, by sensing it will be able to say that the target is not on the crossover axis.

And, in which direction whether the whole from the crossover axis the target is up and down or left and right, that can be ascertained just like the sequential lobbing things. So, at one go it can be done, but the problem is that in sequential lobbing etcetera we have seen that, we need to rotate the whole system and that rotation gives an idea that what is the azimuth or elevation of the target, but here we would not do that what we will do that it can be that can be done, but just by getting this thing.

If we do a processing of those RF signals we will be able to find out that, I think actually from the you see initial days these 4 receivers they were exactly synchronized. So, we know that if at the reflector axis anything is there the receive voltages will be all same both in amplitude and phase. And, if it is off axis then there will be a change in that voltage some of them or all of them. So, from that it could have been ascertained, but people found that this way lot of error comes in the measurement why, because every RF receiver has a local oscillator.

So, the reference is though all the reference may be synchronized, but with time there is drift and that drift produces a lot of error. So, the actual measurement error was a thing erroneous and angle measurement was not so, precise. So, then people found out from experiments that you can get exact thing if you do ratioed measurement. We have seen that in vector network analyzer also this ratioed measurement; that means, if you take the ratio of the received signal with respect to a reference, that is a very good thing, but one thing we have not seen that, you see what is the from this squint beam. Suppose, I know that is squint beam patterns, but from that how can I determine the angle, the quantified angle.

If, I rotate I can find, but that will take some time, but immediately how I can find, that we will see now that how a squint antenna system, that can produce that, then we will understand what this ratioed measurements will do.

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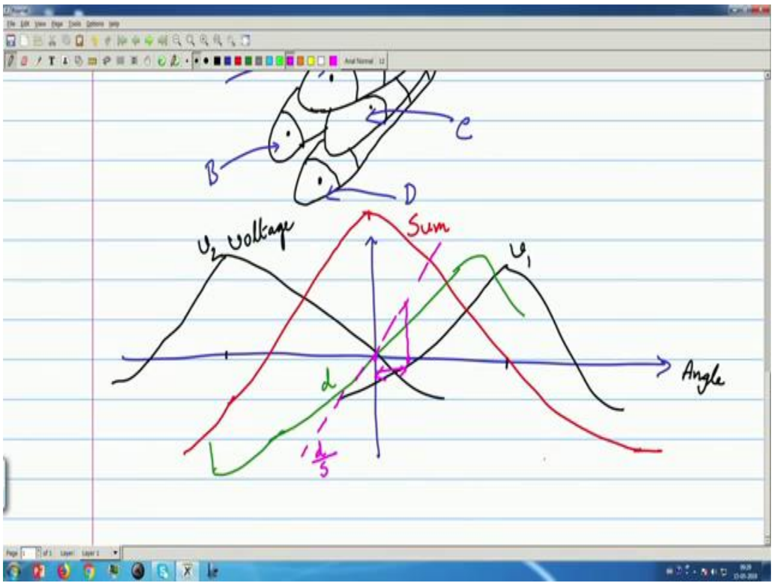

So, for that what we do we now make a graph that, because you see till now we do not know how to measure angles? Because any angle detector or any detector should be the measuring quantity should be linearly proportional to the angle or the quantity; that means, the response should be linearly proportional then only we can have that okay what is the I think. So, this linear operation is needed, but if we look at, that suppose we are putting the patterns.

So, let us say that or let me take this. So, suppose the squint beams so, this is the angle first I am doing, later I will modify this. So, angle and this is the voltage received voltage by the A so, the pattern basically voltage radiation pattern. So, let us say that it is squint at an angle similarly here the squint so, roughly. I can say that these are the 2 points, but you see that. So, from any target at any point I will get these 2 voltages, let me call this is v 1 voltage this is v 2. Now, I am in 2 dimensions; that means, only or I want only one let us say either azimuth or elevation any one angle.

So, this thing we have seen that when we saw the necessity of the squint. So, I got that, but here the deviation from that, I can find out whether v 1 received voltage v 1 is greater or not, because if the target is here then v 2 will be larger than v 1. If, the target is in this zone then v 1 will be larger than v 2, but how much is the angular separation from the axis, that we cannot say here. But, you see because these patterns and actually these patterns, if we see these are generally exponential type of pattern. So, there is no linear detection possible with these, but if we do a sum of this two things. So, let us say that I am summing v 1 and v 2 and to make the comparison similar I am dividing it by square root 2. So, that power can be done.

So, v 1 plus; that means, average of these two, if I take that gives us a remarkable thing that it; obviously, at this point it will be a. So, it becomes something like this. And that means, if I call this is sum pattern. So, sum pattern of two offset things that is the peak is at the axis, but still you see that the we have not got the linear region, it is sum of this two, but what happens to the difference, if we take the difference surprisingly the difference is linear, but the difference again has a peak here difference has a peak.

So, in this zone you see there is a d is the linear region, but there are in these zones it is not linear. Now, people have found out that if we make a ratio of sum by difference; that means or difference by sum d by s ratio. If, I make a d by s ratio that is exactly a linear and it is proportional to the angle. So, if I get all these returns v 1 and v 2, I can form the sum I can form the difference and I can take this ratio all this things can be done by processer.

And processer will be able to immediately say, that from the axis this is the axis point from the reference point, how much is shifted suppose it is here it will be able to say that this is the angle by way it is off to this v 1 side. So, in this terminology it will suppose you are making v and d, then it will be able to say whether it is to D side or B side and by how much angle. So, everything can be done.

So, this is a important thing very fundamentally new thing that angle detection is possible, if you make the d by s sum. So, with this knowledge actually we will see that actually this graph we can plot.

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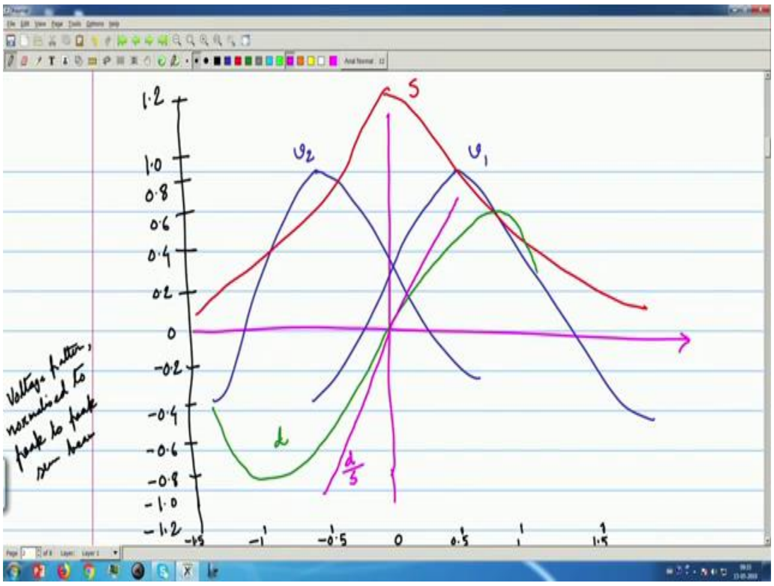

Actually people have plotted the same graph and that gives you some other consideration. So, I will draw that graph again and this side actually now I will make the scales. So, this is 0 and let us say this is 1, this is 1.2 and then 0. So, 0.2, 0.4, 0.6, 0.8 minus 0.2, minus 0.4, minus 0.6, minus 0.8, minus 1.0, minus 1.2. Similarly, here this one I am calling 0 and this is minus 1.5 this side it is plus 1.5. Now, here is minus 1 here is minus 0.5, here is plus 0.5, here is 1 here is 1.5.

And, what I am actually facing this I am calling off axis angle normalized to sum pattern beam width, some normalization. And, this side I am saying voltage pattern, normalized to peak to peak sum beam. So, if we do that and then we can have let us say that, the squint is at 0.5 and so, I will have 2 beams 0.5 1 side something like this is the v 1 pattern similarly, the v 2 pattern is something like this. And, the sum pattern will be that, this is sum and the difference pattern is something like this. This is difference, and the most important why I have used that colour let me change that, d by s that is this is our d by s.

So, this is the more a thing and here you can see the this is more or less a more accurate representation, you can make it in your thing actually you can make a Gaussian approximation to v 1 v 2 and plot it in MATLAB it will come like this. Now, we will say some thing about all this things and some definitions will come. So, actually it can be proved that instead of 4 beams if you have 3 beams, 2 in the any 2 coordinate either azimuth or elevation and 1 on top.

So, you are getting the all this information, but generally for symmetry point of view this 4 beams are used for taking advantage of the symmetrical design. Now, please note this A B C D thing. So, we can find out that.

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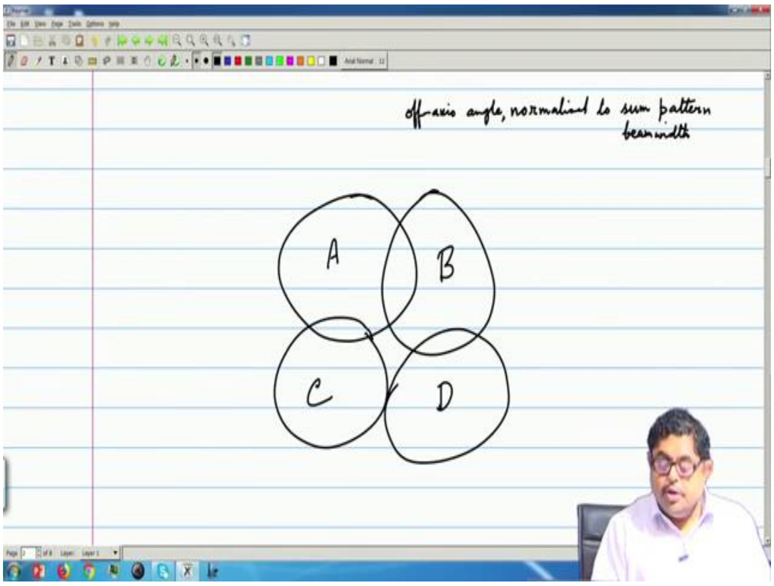

The received voltages we can draw like this that, if this is our A voltage, then there will be the B voltage will this, and C voltage will be something like this, C and D voltage will be something like this. So, let from the 4 squint beams their received voltages now we are calling A B C D. Previously we were denoting them by A B C D, now instead of calling everytime VA, VB, VC, VD we can say A B C D. So, what we can do now we will need to put the sum and ratio.

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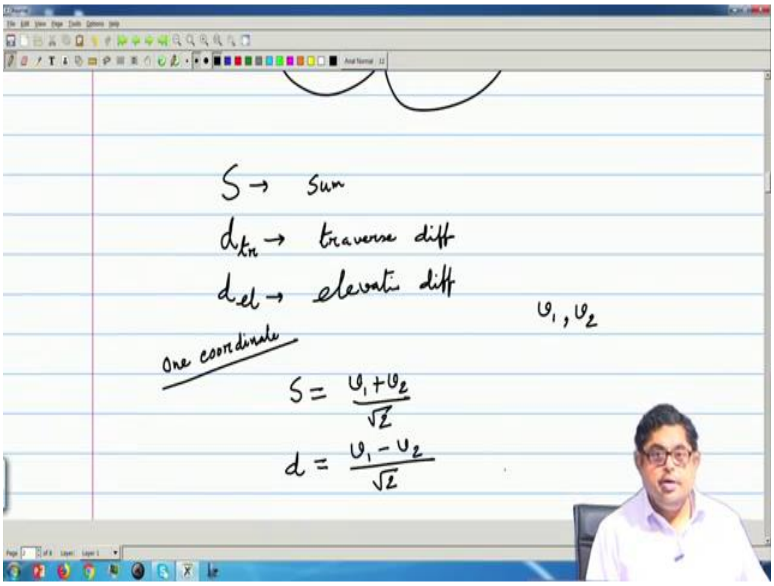

Now sum is so, s is the sum of all 4 we can take in d actually we will have to take differences. Now, differences so, in actually both elevation and azimuth we need to find out or both traverse and the elevation we need to find out. So, there will be one d t r traverse another d elevation. The graphs will be similar, because in for with 2 squint beams whatever I said the same picture is there for all.

So, what we need to do you see that this involves actually the change in the amplitude, that we will see that is due to the complex ratio. Because all these are r f signals, r f signals you know can be represented by actually it is a band pass signal, r f band pass signal. So, they can be represented by complex envelop I think in communication you have learned this concept. Complex envelop then they becomes low pass signal complex envelops are low pass.

So, it is a complex ratio. So, there is a phase of the ratio also we cannot throw it. So, at r f label or at I F label without changing the phase we will have to take this ratio. So, that is the main a thing and this ratio if we take, we have seen that it is beneficial for the angle detection because that ratio gives directly the a linear variation with angle, also we will see later that the that ratio is invariant to the drifts.

So, actually that was people initially when the monopulse was introduced people did not understand, but later they found out that, that ratio is invariant to drift we will later prove that point. So, even if the receivers, oscillators reference oscillator that drifts there is no problem all the values this d t r, d elevation, s they will change. Because drift will make that complex numbers change, complex voltages are these patterns they will change, but the ratio is invariant to drift.

So, that is the beauty that is why it becomes so precise. Actually, the same concept is there for network analyser measurements also, you will see that in measuring S parameters in network analyser, that time the ratio actually that ratio is invariant to all this drifts that are possible in the electronic circuits. So, that is why ratioed measurements always are a qualitatively order of magnitudes better than the a thing the non-ratioed measurements. So, we have this is the S we will call sum the traverse difference and elevation difference.

Now, for making the sum; that means, combining taking differences we need to do it at r f level. So, we will see those hardwares that how you can do that? So, r f combining devices should be used and now let us give a quantitative thing of what is the sum? So, if suppose we are taking any one coordinate at a time.

So, suppose we are interested in any one coordinate. So, if v 1 and v 2 are 2 voltages, then what will be S S we can write as v 1 plus v 2 by root 2, you see why we are writing root 2 because it is a voltage addition so, root 2. So, that power is we are assuming all these additions etcetera that r f circuitry they are loss less. So, power balance is there for that this and what is difference? Difference is v 1 minus v 2 by root 2.

$$S = \frac{v_1 + v_2}{\sqrt{2}}$$

$$d = \frac{v_1 - v_2}{\sqrt{2}}$$

Now, we it is time for a definition that, what is the monopulse axis, monopulse axis.

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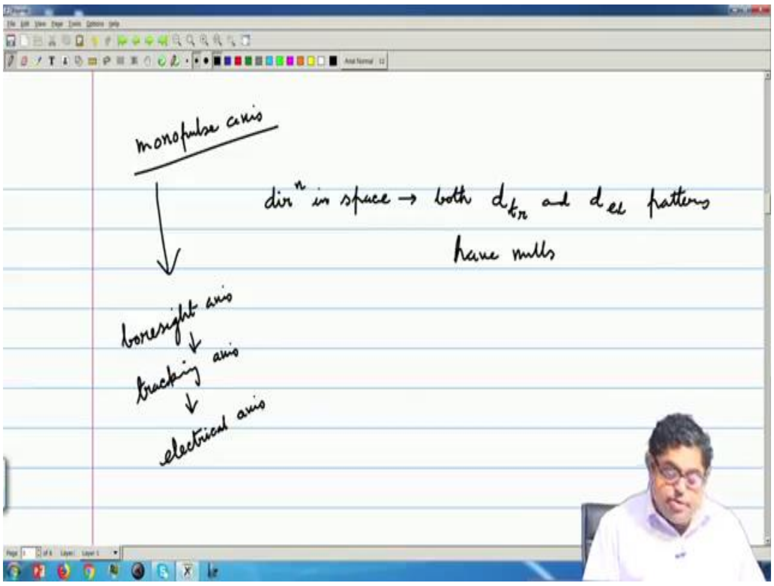

So, it is the direction in space; it is the direction in space where both the d t r and d elevation; that means, traverse difference and elevation difference patterns, they have they are nulls you can. So, you can see in our diagram that this is the difference this green one is the difference pattern and that has a null here.

So, that is the definition actually in case of both elevation and azimuth; that means, two coordinates, two angular coordinates, they are there will be one such graph d t r, another such graph d elevation, both have their nulls at the point of the reference. And, that is the actually axis, monopulse axis. So, this is the definition of the monopulse axis that is direction in space where both d t r and d elevation patterns have nulls.

Now, monopulse axis has got several names in literature, sometimes it is called boresight axis, sometimes it is called tracking axis, sometimes it is called electrical axis. Because, all this patterns etcetera they are electrically we measure the voltages in it. So, now ideally the geometric paraboloids the geometric axis the parabola axis of the parabola, that an electrical axis should be identical, but in the imperfections in the design etcetera that makes them slightly differ.

So, in the calibration or for antennas people call it collimation that time it is taken care of whatever slight difference is there in the read out that is adjusted. So, that process is called collimation of antenna. Now, now as we have seen that sum pattern let us again see the sum pattern, actually the sum pattern is narrower than either of v 1 and v 2. So, sum is a pencil beam. So, sum pattern is a pen pencil beam and the important thing is its peak is on monopulse axis.

So, sum pattern is a pencil beam its peak on monopulse axis and what is the bandwidth of the monopulse antenna, because every antenna we should define its bandwidth. Actually the bandwidth of the monopulse antenna is the same as the bandwidth of the sum pattern. So, beam width of a monopulse antenna is the half power beam width of sum pattern. So, we know from our antenna knowledge that, it is the beam width of any antenna is defined as angular interval between the points, where the voltage pattern goes to 1 by root 2 times the peak.

So, beam width of a that is why you see that this angle is given as sum pattern beam width so; that means, where it is 1; that means, at this 0.1 the sum pattern is going to 1 by root 2 of it is peak. And, you see here also the voltage pattern is normalized to peak to peak sum beam, we will see why this is there.

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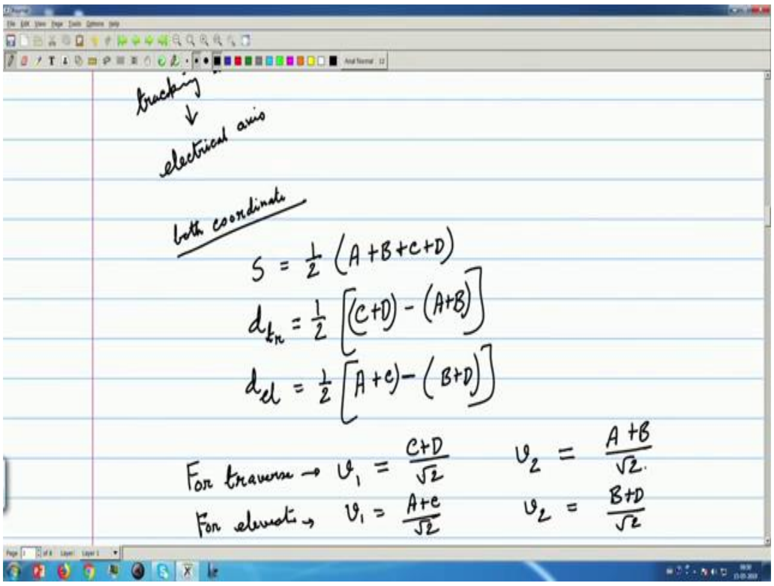

And, now we can one coordinate we have defined this now in both the coordinates; that means, both coordinate we can define S will be half into A plus B plus C plus D.

$$S = \frac{1}{2}(A + B + C + D)$$

A is the received voltage by one of the end beam that we have shown B like that. And, half is for again power balance and what will be d t r. In this case you can again look at this point that traverse difference you see this is our beams. So, traverse means the we need to have this side and this side; that means, A C side and B D side, they are difference. So, the definition of d t r is half into C plus D minus A plus B.

$$d_{tr} = \frac{1}{2}\left[(C+D) - (A+B)\right]$$

Again, let us check C plus D minus A plus B. So, C plus D and A plus B and what will be the elevation difference, d elevation that from that same diagram you can find that half A plus C A plus C minus B plus D.

$$d_{el} = \frac{1}{2}\left[(A+C) - (B+D)\right]$$

Sorry this diagram should be A B and this is C, I will correct it then it will come C and D.

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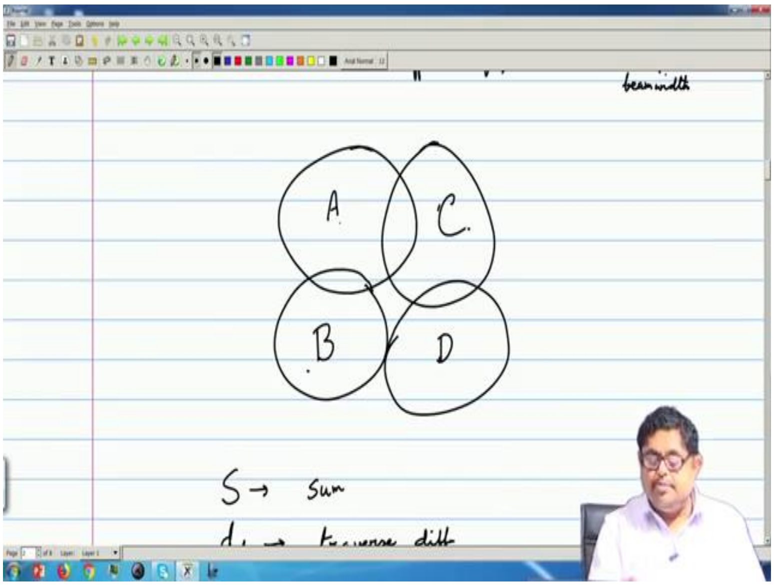

Then you see what will happen to traverse that, this side and this side because traverse is in the azimuth sort of thing horizontal azimuth thing. So, half of C plus D minus half of A plus B. Please correct it. Previously it was and this elevation will be half of A plus C minus B plus D. So, we are taking the difference. So, at the same traverse are same elevation that portion should be taken. So, we will work with these definition and with respect to that arrangement, and then further we will see that what is the so, in terms of what is our v 1 v 2 voltage patterns of squinted beams.

So, we can write that for traverse what is v 1 for traverse you see v 1 is we can call C plus D by root 2 and v 2; that means, this is to make compatible with our previous v 1 v 2 thing and what will be v 2; v 2 will be A plus B by root 2.

$$\text{For traverse} \rightarrow v_1 = \frac{C+D}{\sqrt{2}} \qquad v_2 = \frac{A+B}{\sqrt{2}}$$

And, for elevation things what is our v 1 v 1 will be A plus C by root 2 and v 2 will be B plus D by root 2.

$$\text{For elevation} \rightarrow v_1 = \frac{A+C}{\sqrt{2}} \qquad v_2 = \frac{B+D}{\sqrt{2}}$$

So, the same channel that is that forms the sum channel, that is used for both reception and transmission via duplexer.

So, transmitting pattern so; that means, actually the sum pattern is transmitted by the monopulse, it gets return from the target. Now, that is by 4 squinted beams because the offsets are the horns are placed offset twice. So, 4 squint beams will be coming then we will have a microwave r f circuit which will form this s, d t r, d elevation and that will process and processor will say what is the thing.

So, we will next see that functional diagram in the next class. That, how functions, what hardware is used in the actual combiner circuit.

Thank you.