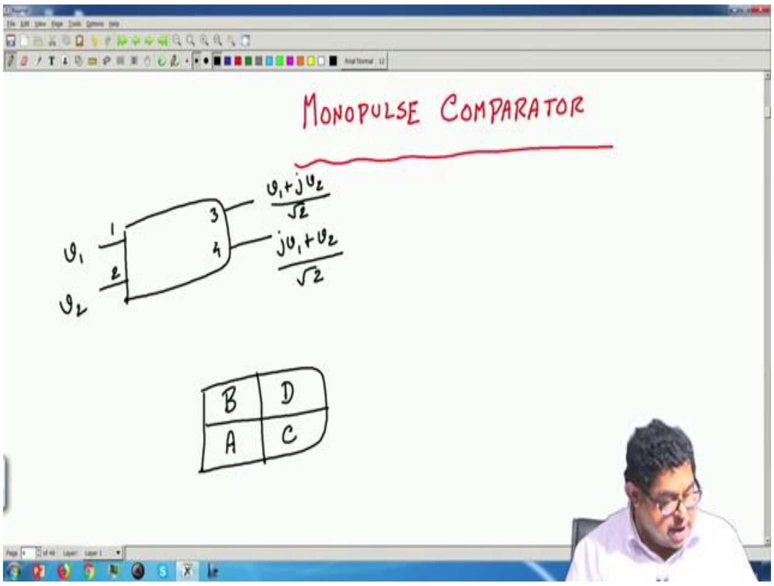
Principles And Techniques Of Modern Radar Systems
Prof. Amitabha Bhattacharya
Department of E & ECE
Indian Institute of Technology, Kharagpur

Lecture - 31
Tracking Radar (Contd.)

Key Concepts: Monopulse comparator, Arrangements of microwave hybrid junctions in constituting a monopulse comparator

Welcome to this NPTEL lecture on Principles and Techniques of Modern Radar Systems. We were discussing the monopulse tracking radar; now in the last class we have seen different types of hybrid that can be used which is familiar to you and to sum up I can say that in last class, we have seen that if we have a top-wall coupler, top-wall 3 dB coupler.

(Refer Slide Time: 00:59)



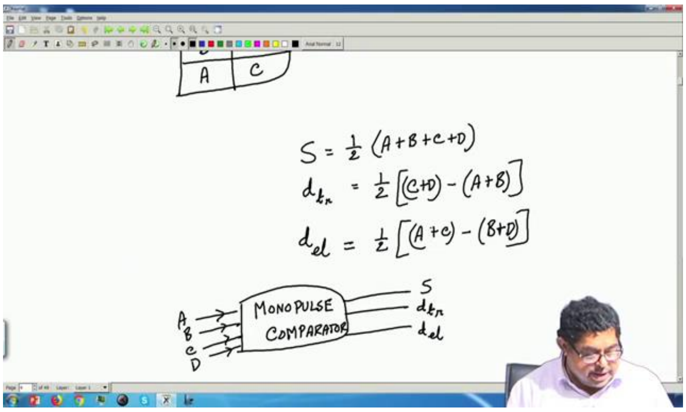
Then I am just for recapitulating this will be required. So, what we have seen that if we have a either hybrid or a coupler that the requirement it should have the port 1 and 2 as a input port and port 3 and 4 as a output port and if we give signal v 1 here if v 2 here and then this 3 that is v 1 plus j v 2 by root 2 I am using a top-wall coupler.

So, that is why I am I have chosen the plus sign and in port 4 it will be j v 1 plus v 2 by root 2. So, this thing we will be using that we have seen in the last class. Today we will discuss the Comparator. Now what is a Comparator; actually comparator does not compare anything, comparator is a actually the name came because it provides means for indirect comparison of the signal from the individual feed horns, four feed horns. So, that is why it means it is not the comparator that we discuss in digital classes it is not that. So, it is actually a whole assembly of hybrids, phase shifters if needed and waveguide section that convert signals from the individual feed horns into a sum and two difference.

So, comparator is the whole assembly of various hybrids, phase shifters, waveguide etcetera. So, that the it can convert the signals RF signals that are received at the four feed horns to one sum and one difference signal ; so that is called comparator. Now in comparator you see that this we require number of hybrids; a single hybrid cannot give us the one sum and two difference because that is our requirement that monopulse comparator should give that from four feed horns we should get the some microwave circuit. So, that at RF level we can get the sum of all those signals and also two differences; one is the traverse difference another is elevation difference.

So, that we will see that single one cannot do. So, what combination can do, that we will see. So, all these hybrids are 3 dB hybrids and quadrature hybrids. So, now to have this comparator thing, I recall that our what is our assumed squint bean patterns; so again I write that, because that will help us to find out. That we have four feed horns A B C D actually these are the feed horns, also A B C D are the received RF complex voltages at the receiving horns; that means, when the echo has come fallen on this four feed horns and let us say depending on the target's position, different amplitudes will be generated in the output of the four feed horns. Let us call them A B C D because this is the arrangement of horn pattern we are assuming.

(Refer Slide Time: 05:21)



Now, I will give you a structure that I need to have one sum pattern. So, what is required, the sum that I will get that should be something like the half A plus B plus C plus D.

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

Then the d traverse, so that should be what half, what is traverse difference; you see I should have let us say C plus D minus A plus B.

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

You see this is traverse that average of this minus average of this that will give me what is the traverse angle, also d elevation that will be half A; so elevation means that A plus C minus B plus D.

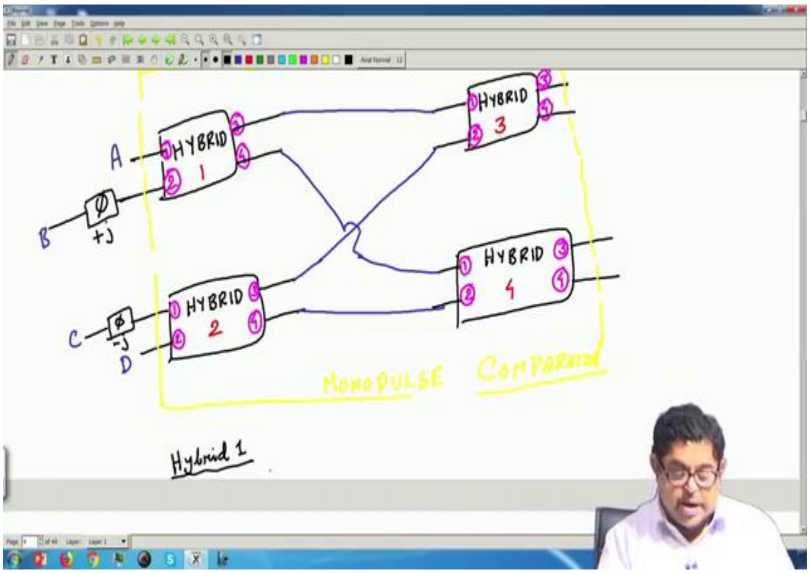
$$d_{el} = \frac{1}{2}\left[(A+C)-(B+D)\right]$$

So, I can now say that what is a monopulse comparator; monopulse comparator inside you may have anything, but what is its input, there will be 4 inputs to it one is A, another is B, another is C and another is D and what will be its output S, d t r, d elevation.

So, if you look at the functional diagram of monopulse radar that time I did not use this term monopulse comparator, but actually the that time I have said microwave combining network. Now you can remove that and say that it is a monopulse comparator; actually since this concept was not discussed I did not use that. So, you can correct in that functional diagram that it is the monopulse comparator. So, that A B C D is the received voltages at four feed horns and monopulse comparator at the hardware it is nothing to do with software, this monopulse comparator will give this.

Now, we will see the what is the arrangement of the monopulse comparator.

(Refer Slide Time: 08:09)



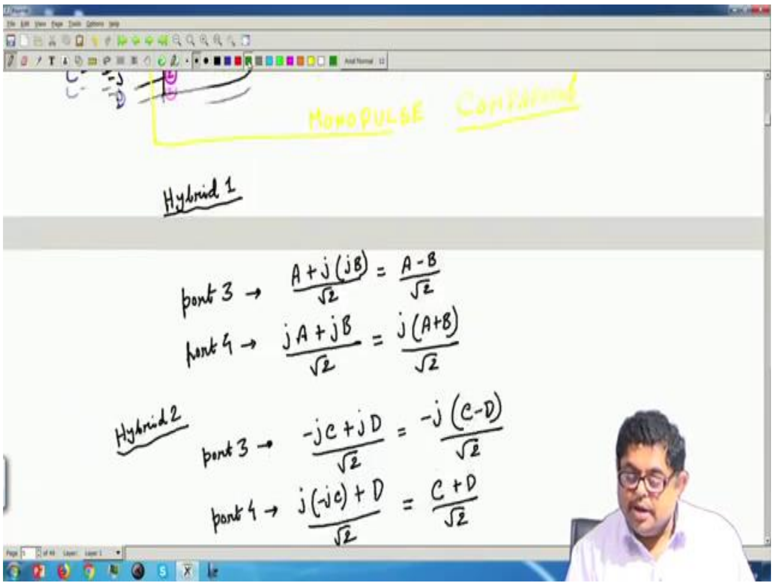
So, actually you require 4 hybrids to have that thing. So, 4 hybrids, let me call this as hybrid 1, hybrid 2, hybrid 3, hybrid 4, okay, and what I will do that I will… Okay. So, also let me write this is port 1 input port, this is another input port. So, let me put some encircling things. So, that you understand this is the port number this is 3, this is 4 then sorry. Okay..

Now, two more things; this is one of the implementation I am assuming that I am having this hybrids are directional couplers, quadrature hybrids, top-wall coupler. So, that my this is the expression if I give input v 1 v 2 I will get the outputs like this. So, with this choice I am showing a implementation of monopulse comparator. So, A B C D the four things, the A B I give 2 hybrid 1 but in the hybrid 1 in the port 2 there is a phase shifter. So, that B is phase shifted by or lagged by 90 degree; similarly C there is a lead phase of minus j. So, C signal is applied to hybrid 2 port 1 with a lead of 90 degree and D is applied here; and what about the interconnection this is like this.

Now, this one is put here, this one is put here and this one. So, you see this arrangement I will prove that will produce I have this in hybrid 3 and hybrid 4 there are two-two so four output ports; I will show that in out of this four ports in three of the ports I will get the desired thing. What is the desired thing; this whole thing is a comparator I should get S, d traverse, d elevation. So, I can now say that this whole arrangement is my monopulse comparator. I am deliberately using a very light color because this is not so important, but this is the whole thing that we will see.

So, first one by one I will write what is the thing. So, again I a that what will be suppose I find hybrid 1. So, hybrid 1, if you recall that my construction is this again I am reminding that v 1 v 2. So, at third port I get v 1 plus j v 2 by root 2 and this port j v 1 plus v 2 by root 2; if we remember this, this is our basic construction all these hybrids follow this. So, at hybrid 1, what will be at port 3?

(Refer Slide Time: 15:25)



I can say at port 3, I can write hybrid 1. So, I can write the port 3 will be that A plus j into j B by root 2. So, this is nothing, but A minus B by root 2.

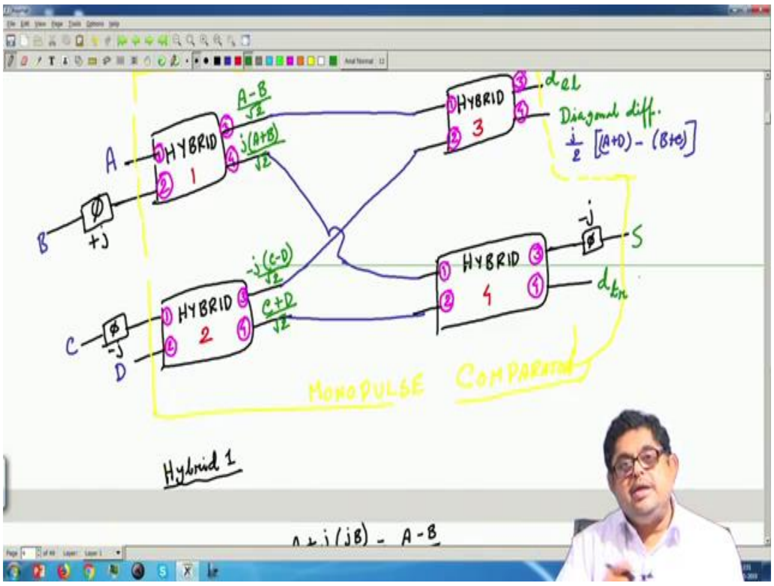
$$\text{port } 3 \rightarrow \frac{A + j(jB)}{\sqrt{2}} = \frac{A - B}{\sqrt{2}}$$

So, I will write that here. So, that I will use a color, I think green is not used, so A minus B by root 2. Now what will be at port 3; port 4, so port 4 will be j into A plus j B by root 2, just the thing only remember the phase shift relative phase shifts I have given. So, it is j A plus B by root 2.

$$\text{port } 4 \rightarrow \frac{jA + jB}{\sqrt{2}} = \frac{j(A+B)}{\sqrt{2}}$$

So, I will fill that up by that green thing that it is j A plus B by root 2. Now let us come to hybrid 2, so hybrid 2, so we can write port 3; port 3 will be minus j C plus j D by root 2.

(Refer Slide Time: 17:51)



So, I can write it as minus j C minus D by root 2.

$$\text{port } 3 \rightarrow \frac{-jC + jD}{\sqrt{2}} = -j\frac{(C-D)}{\sqrt{2}}$$

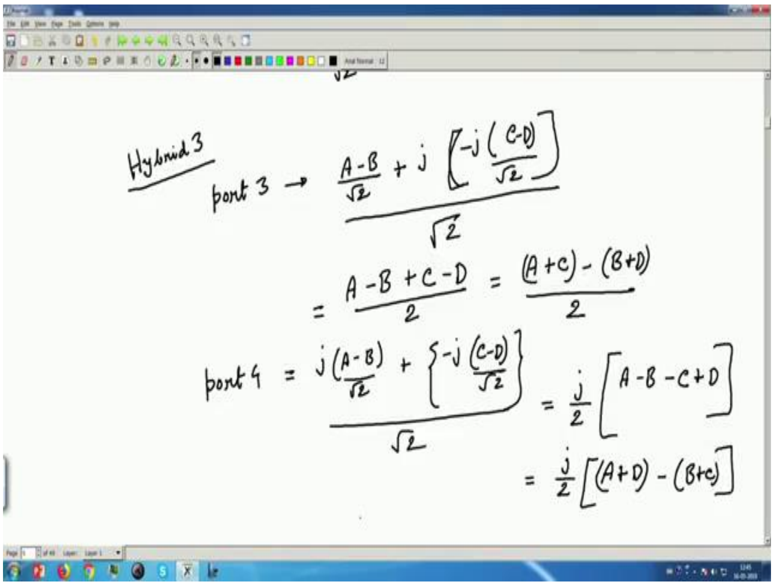
I should fill that up minus j C minus D by root 2; and at port 4 I will have j D plus minus j C is it not j sorry you I can recall this one that this port will be j v 1 plus v 2.

So, j what is v 1 here that minus j C plus D by root 2. So, that will be C plus D by root 2.

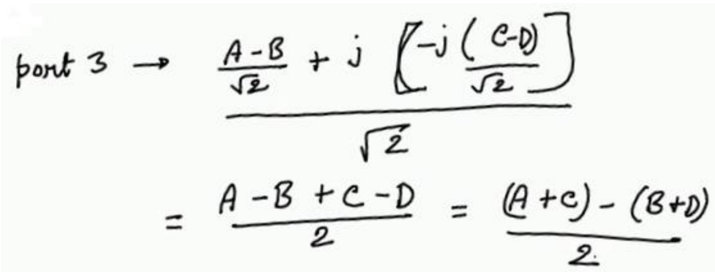
$$\text{port } 4 \rightarrow \frac{j(-jC) + D}{\sqrt{2}} = \frac{C+D}{\sqrt{2}}$$

So, I should fill that up here that C plus D by root 2.

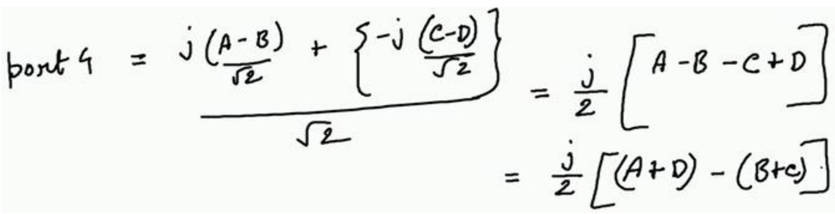
(Refer Slide Time: 19:33)



Now let us come to hybrid 3. So, hybrid 3 will be port 3 that we can write as A minus B by root 2 plus j into minus j sorry C minus D by root 2 the whole thing divided by root 2; so that will be A minus B plus C minus D by 2. So, this I can write as A plus C minus B plus D by 2.



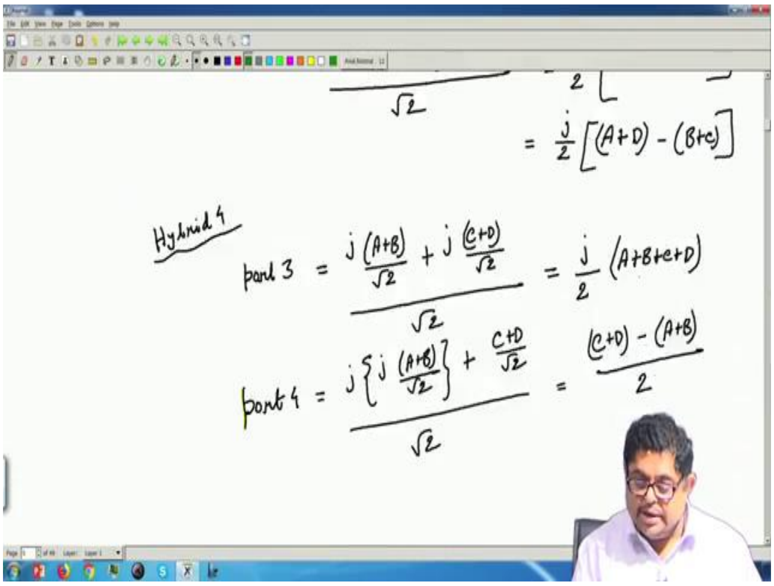
But what it is you see A plus C minus B plus D by 2; that means, d elevation. So, actually here I have got the d elevation here, I have got and what will be at port 4 let us see. Port 4 is, so j v 1 plus v 2 by root 2. So, j into what is v 1; that means, A minus B by root 2 plus v 2, what is v 2 minus j C minus D by root 2 this whole thing root 2. So, if you do this it will be j by 2 and this side is A minus B minus C plus D. So, this I can write as j plus 2 A plus D minus B plus C.



So, what is this let us see the structure where is our A B C D. So, you see that it is not coming in any of these three ratios, but if I look at here the A plus D minus B plus C; that means, I can say that diagonal difference A plus D minus B plus C. So, I will write that that, this is the diagonal difference.

So, this is not wanted, because I said I require from monopulse comparator only three things. This is an extra information, actually sometimes this port is match terminated or some dummy load is put here; but if you want to process this diagonal difference which is actually the expression you should also write, that in a different color let me write j by 2 A plus D minus B plus C now hybrid 4 is remaining. So, let me go to the hybrid 4.

(Refer Slide Time: 24:17)



Hybrid number 4, so what I will get at port 3 again port 3 is v 1 plus j v 2 by root 2.

So, let us look at port hybrid 4 port 3. So, I can write sorry v 1. So, that v 1 is j A plus B by root 2 plus j C plus D by root 2 divided by root 2. So, that if we do we are getting j by 2 A plus B plus C plus D.

$$\text{port } 3 = \frac{j\frac{(A+B)}{\sqrt{2}} + j\frac{(C+D)}{\sqrt{2}}}{\sqrt{2}} = \frac{j}{2}(A+B+C+D)$$

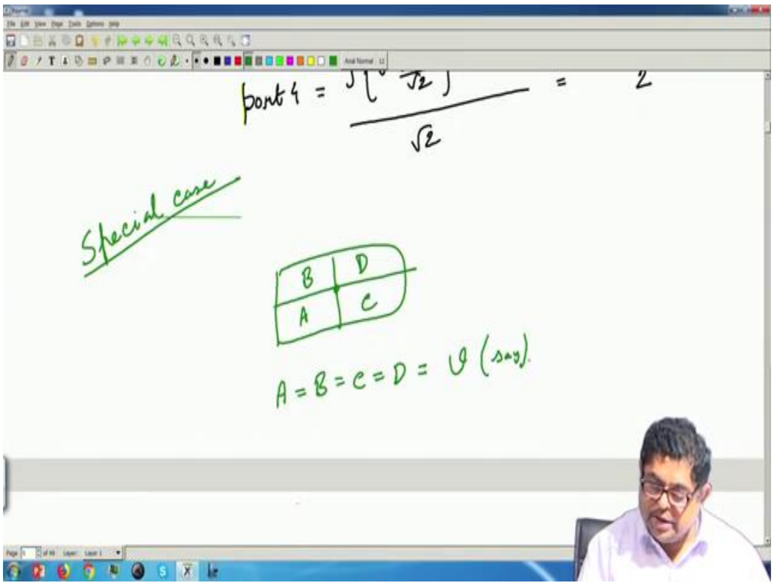
So, what is this, sorry where is the ratios A plus B plus C plus D half, but with a j. So, I will modify the comparator this port 3, actually I will modify and I will put a phase shifter here or phase shifter of minus j.

So, then the output will be S. So, I can write S and actually this sorry first let me erase. So the, this will also be part of monopulse comparator. So, monopulse comparator is this. Now one port remaining and you know that I also have one more a thing, so that should be come in traverse. So, let me write that port 4 is what is port 4, j v 1 plus v 2. So, in this case I can write j then v 1 means again j A plus B by root 2 plus the v 2; so v 2 is C plus D by root 2 and this whole thing by root 2. So, that will give us that directly C plus D minus A plus B by 2.

$$\text{port } 4 = \frac{j\left\{ j \frac{(A+B)}{\sqrt{2}} \right\} + \frac{C+D}{\sqrt{2}}}{\sqrt{2}} = \frac{(C+D) - (A+B)}{2}$$

So, this is nothing but you can see d traverse you see C plus D minus A plus B half. So, I can fill that up by that in this port 4 I am getting d traverse. So, what I was looking for I got, now I have got all these things. So, that will be given to the receivers, so if you look at the functional diagram yesterday we have discussed that. so these informations are given to the, the sum thing is given to the sum receiver, the d elevation information is given to the receiver for traverse the d traverse…. So respective receivers. In the receivers there is a local oscillator, that local oscillator will bring that RF signal to the IF signal and then they will process that. So, because they will have to find that angles. So, they will have to a thing that they will be able to process that thing; so we have got our this thing.

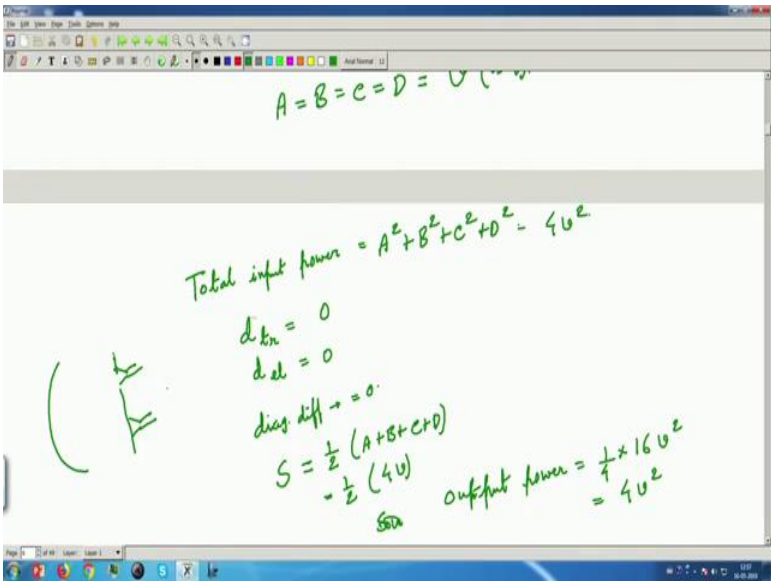
(Refer Slide Time: 29:27)



And let us check that whether my circuit is ok, we can check by giving a special case. What is that special case that let us say; that the target is on the boresight or target is on the monopulse axis. So, if the target is on the monopulse axis; that means, if these are the four feed horns; so, target is here at the center. So, what will be the value of A B C D; we had A B C D.

So, can I say that if the target is here on the monopulse axis; so the four feed horns will get equal voltage. So, A will be equal to B will equal to C will be equal to D and let me call that these voltage is v; v say. So, let us see the power balance. So, what is the total input power?

(Refer Slide Time: 30:25)



Input power is A square because these are voltages A square plus B square plus C square plus D square; that means, 4 v square.

$$\text{Total input power} = A^2 + B^2 + C^2 + D^2 = 4v^2$$

And what is the output, you see in this case what will be d traverse that will be 0, d elevation that will be 0 because target is on the monopulse axis but there will be the sum also the diagonal difference that also will be 0.

$$d_{tr} = 0$$
$$d_{el} = 0$$
$$\text{diag. diff} \rightarrow = 0$$

But sum will be value; what is the sum? Sum will be half A plus B plus C plus D; that means, half 4 v.

$$S = \frac{1}{2}(A+B+C+D)$$
$$= \frac{1}{2}(4v)$$

So, what will be sum power or I can say what is total output power; these three outputs will give 0 but total output power that will be square of this term. So, one-fourth into 16 v square that is 4 v square.

$$\text{output power} = \frac{1}{4} \times 16 v^2 = 4 v^2$$

So, you see total input power is 4 v square, total output power is 4 v square; so the monopulse comparator is a lossless device. So, we are having power balance. So, our expressions are correct and this is a marvelous circuit at RF level, it can give from four feed horns, offset feed horns it is getting four squint beams.

So, it can immediately say what is the position of the target in terms of traverse, in terms of angle and also it can give the transmit thing sum. So, in practice the hybrids are placed together and the comparator is placed closed to the feed horns to form a very single compact assembly. Also the compactness is required to minimize blockage to reflectors because if you remember that we have said these are the feed horns sorry that there were feed horns like this.

Now, this thing actually is blocking the reflector. So, the less it does, the blocking efficiency improves. So, in any reflector system if the feed is placed here; obviously, there are other options that you can put a reflector in a offset position, I am not going into there but this blockage will be minimized if we make it compact.

So, for that you have various design options as I said that whether you will take top-wall coupler or the sidewall coupler all those things and also you should have there will be waveguides. So, these waveguides will have the there will be some space phase introduced by the length of the waveguide. So, that also we should be made short.

So, that the path difference in various paths that should be balanced exactly; otherwise that if there is a relative path difference between any of the two paths then the this calculation of the angles they will be erroneous. So, you should make it as compact as possible. So, that errors in the phase path that does not affect your measurement; also the lightweight is desirable to because actually this feed that is put, the because the feed is actually it is a in space you have this feed, now if the weight is much then the feed may breakdown because of its weight that will be more.

So, because there is a reflector there is a feed system and that is connected to the other receiver circuits etcetera. If the feed weight is there because these are all metallic structure this feed, so their weight if it is heavy then it will break down. So, that would not serve your purpose. So, you want it as a cantilever this feed is there. So, that is why you should have it as small as weight. So, that the receiver this waveguide parts they will be able to hold this together otherwise due to gravity that will fall and that may get tilted or cracked etcetera.

So, we have seen we are closing this discussion on Tracking Radar, this monopulse you see that we have got that nicely with this RF circuits with microwave technology you can have this immediately by sending one pulse and receiving that pulse you can tell what is the azimuth position, what is elevation position of the body and obviously, from here you can extract range and that you can do with an accuracy even upto one-millionth of a beam width that we have shown because of that graph that ratio measurement that d by s that can give you an accuracy of that sort.

Actually this technology this monopulse technique that is making this guidance the precise guidance of missiles, precise guidance of various spacecrafts, the landing, ectetera all these due to this monopulse type of technology; so it is a new thing that you learn in radars all modern radars have these so that our precise angle location of a body gets determined.

Thank you.