Microwave Theory and Techniques
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Module – 04
Lecture – 20
Microwave Couplers – III: Rat race Coupler and Applications

Hello, in the last lecture we had talked about branch line couplers. We had started with a 2 branch line coupler, we actually saw the configuration.

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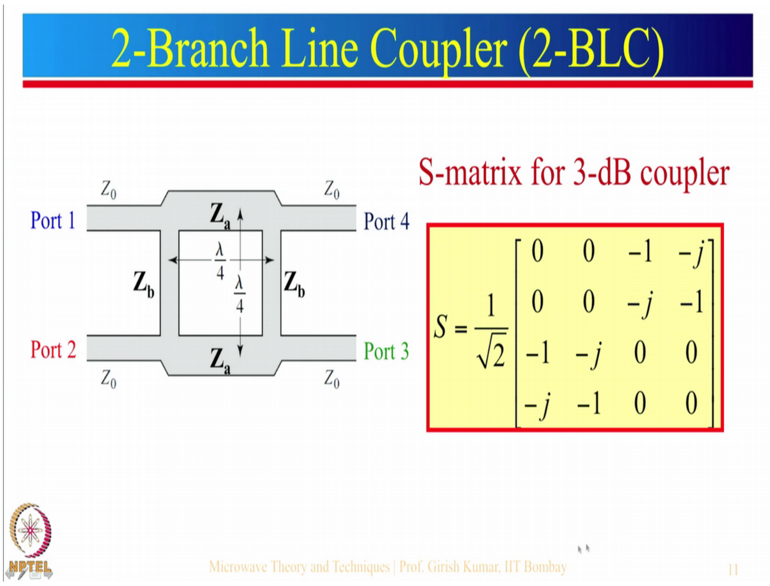

Here the lines are lambda by 4, this main line as well as the branch line; and we had seen: what are the S parameters for this particular branch line coupler.

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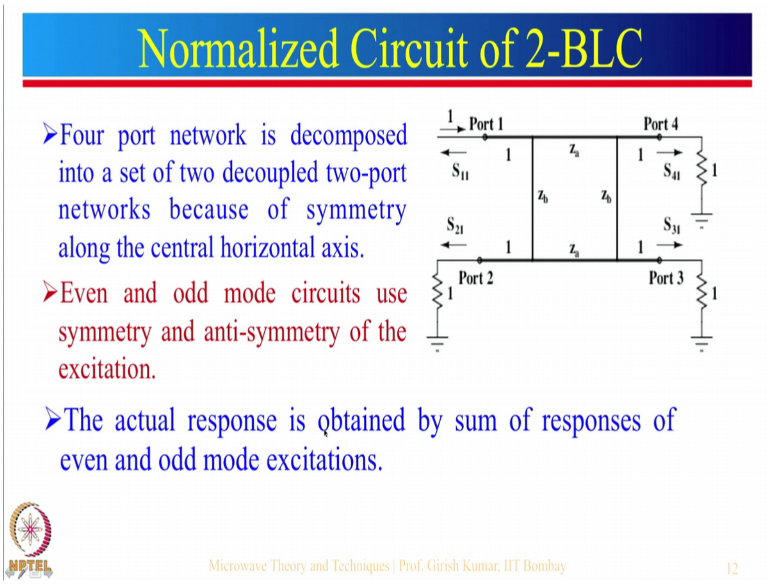

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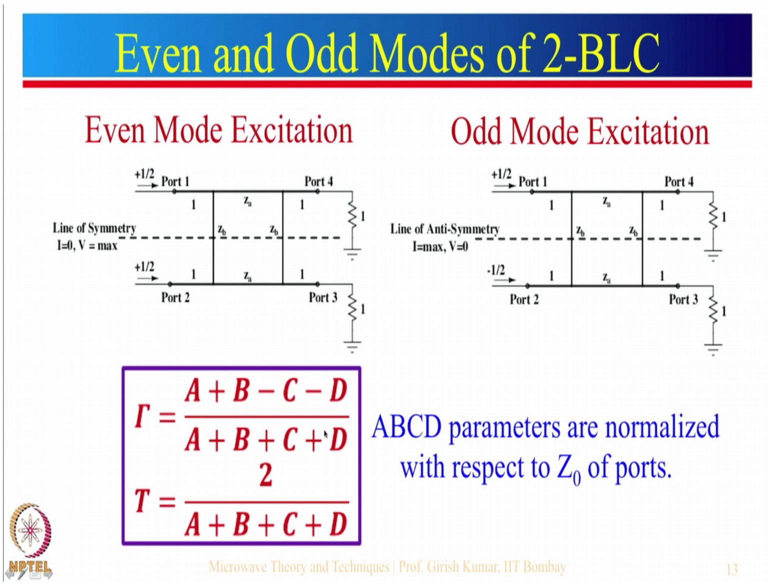

So, from here we had done the analysis by decomposing a 4 port network into 2 even mode as well as odd mode excitation ok.

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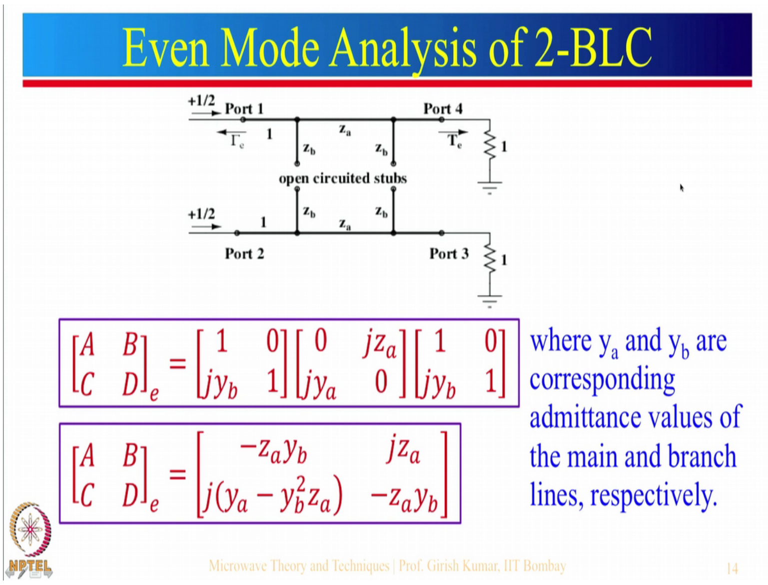

So, for even mode analysis first we find ABCD parameters for even mode and then find out ABCD parameters for odd mode.

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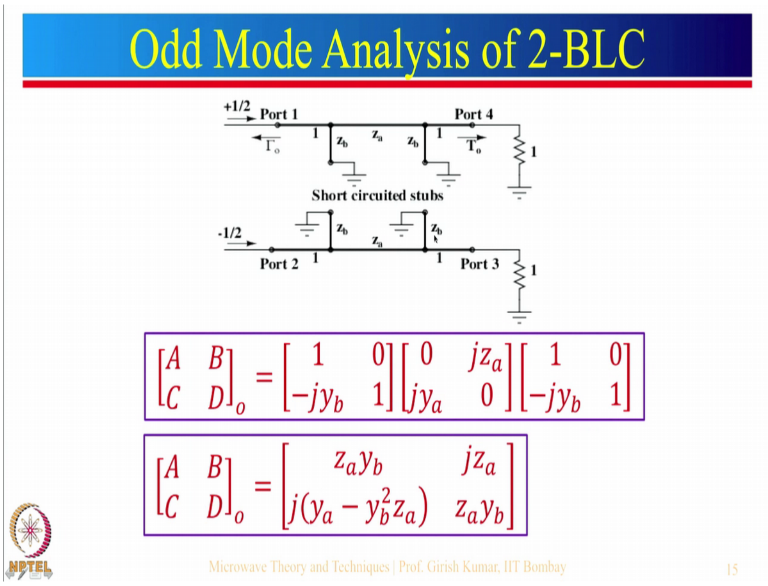

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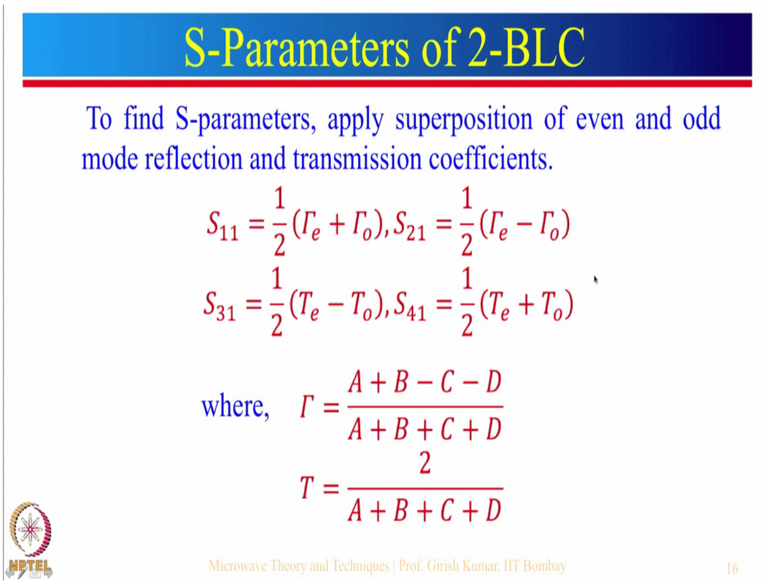

And after that apply the principle of superposition to find out the S parameters, by using ABCD parameter conversion to S parameters.

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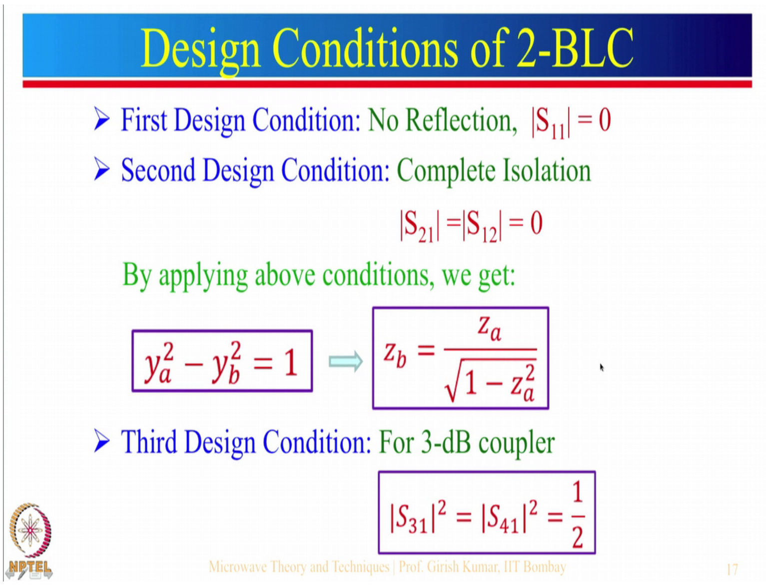

And then we had applied the boundary condition we require S 1 1 equal to 0 isolation to be equal to 0, and for half power to the 2 output ports this was the condition port.

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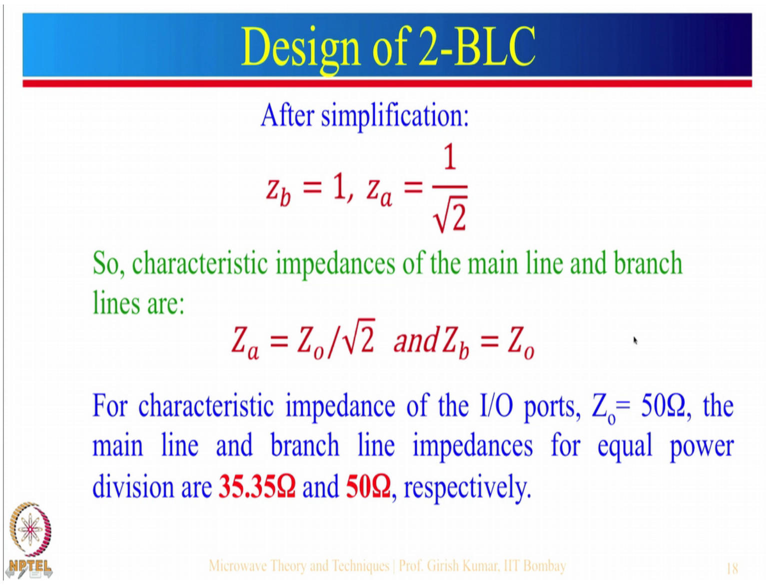

And for that particular condition we have seen that the impedance has come out to be 35.35 ohm and 50 ohm.

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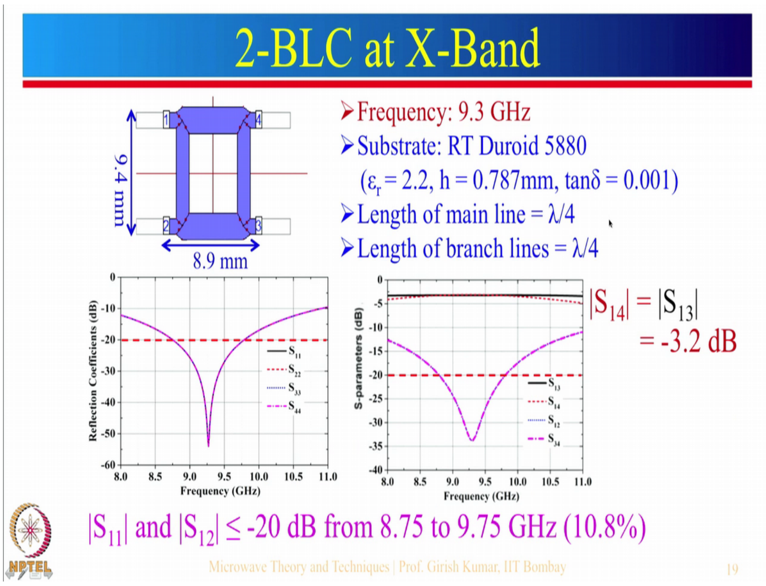

And then we had taken an example at X band and we had seen that the bandwidth is of the order of around 10 percent or so.

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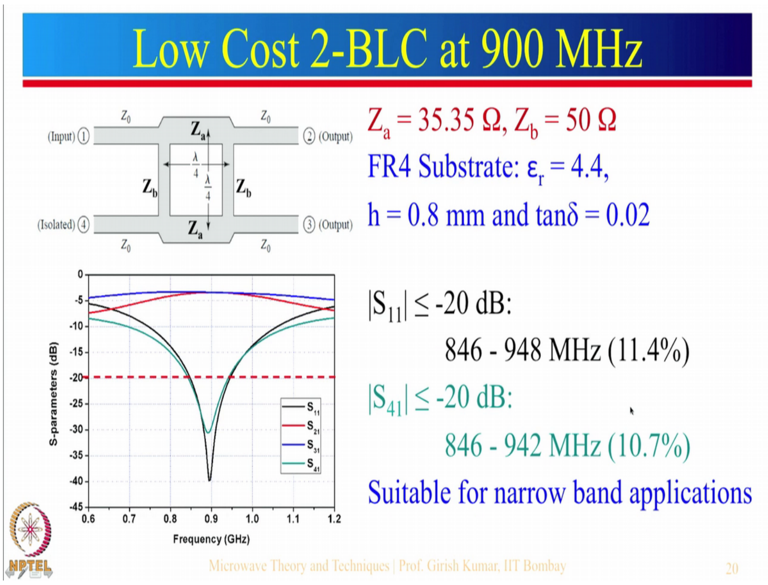

After that we saw a low cost realization using FR4 substrate or a glass epoxy substrate for commercial application. And again here we had seen that the bandwidth is limited to about 10 to 11 percent. So, from two branch we went to 3 branch line coupler.

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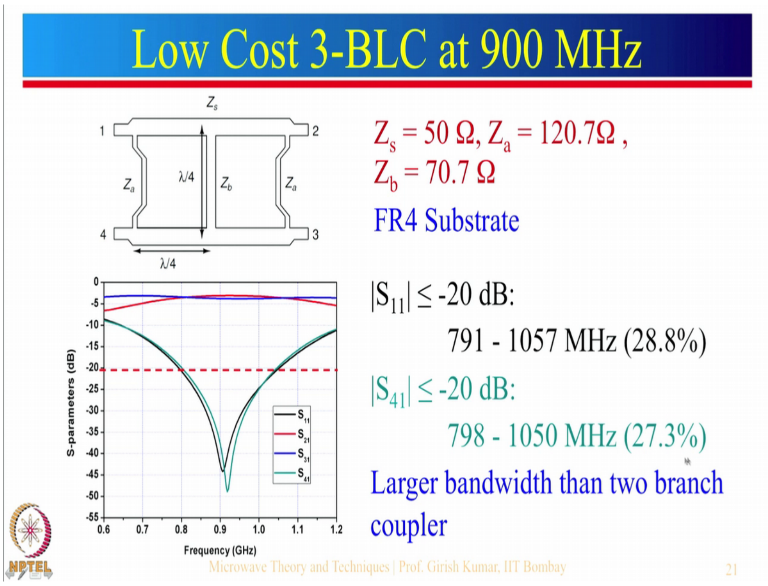

And we had seen that for three branch line coupler, bandwidth increase from 10 11 percent to about 27 to 28 percent for S 1 1 and S 4 1 less than minus 20 dB.

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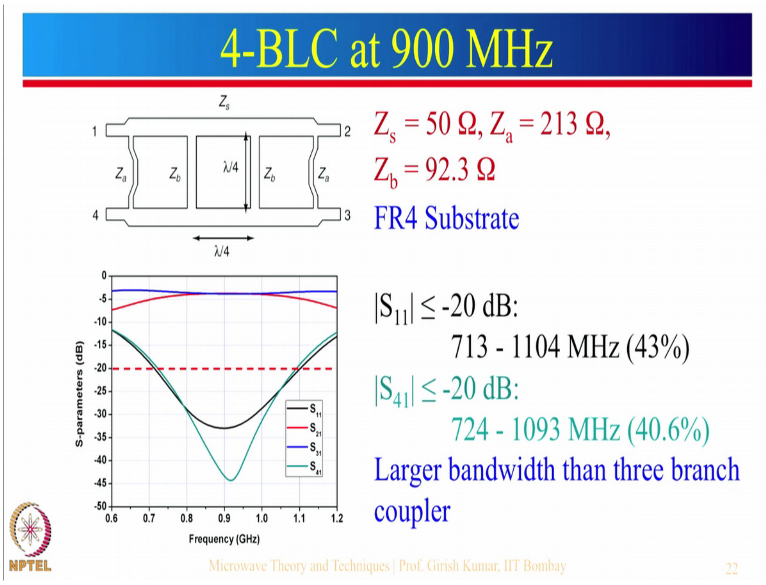

So, after the three branch coupler we went to 4 branch line coupler, and for 4 branch line coupler we had seen that the bandwidth is now much larger 40 percent to 43 percent. However, we had noted that there is a small problem, and the problem is that this impedance Z a is 213 ohm, which is very very high which results into a very thin microstrip line, the width of that may be of the order of 0.1 to 0.2 mm depending upon the substrate parameters. So, this was covered in the last lecture so, today let us see how this problem of very high impedance can be solved. So, here you can see Z s is equal to 50 ohm and most of the literature actually talks about this 50 ohm.

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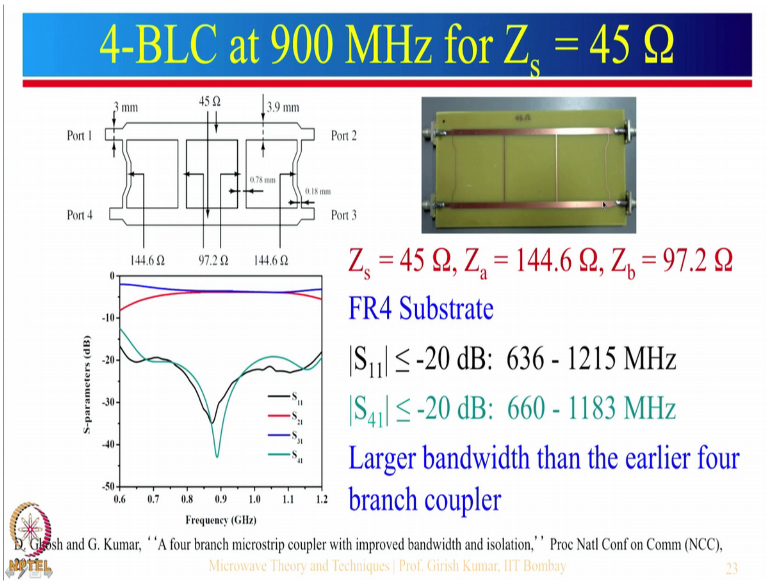

However what we did? We actually designed this whole thing for Z s equal to 45 ohm and when we took Z s equal to 45 ohm, in this particular case now Z a is 144 ohm and Z b is 97.2 ohm and these are realizable ok. So, after doing that we did the simulation, so here is the design for that, you can see the various parameters are shown over here, thicknesses are shown, the various dimensions are shown over here and this is the fabricated thing and these are the now measured results. Again, the fabrication was done on FR4 substrate and let us see what kind of a bandwidth we get over here.

So, here if you see for this particular case we are getting a much larger bandwidth, 636 to 1215 megahertz, this is you can say of the order of close to 600 megahertz or over here, it is more than 500 megahertz bandwidth. So, this bandwidth is much larger than even the earlier 4 branch line coupler. A few other things I just want to mention that here you can see that the total size in this direction is relatively large ok. You can say that this dimension is lambda by 4, but here it is lambda by 4 another lambda by 4 another lambda by 4. So, the total length becomes now 3 lambda by 4 so, by overall size increases. However, you can do a few simple things also which we have also done, and that is instead of using this length as a straight line, you also use this whole thing in the form of a u shape ok.

So, something like that. So, if you use something like a u shape here, and this also can be used like a inverted u shape here and the all these lines can be done. So, then what will happen? The entire dimension along this direction can be reduced ok. So, you can say that instead of now just think about it that, if I just go in this direction then down below and down below. So, we can say that by using a u section, we can actually speaking reduce the overall length of this particular coupler.

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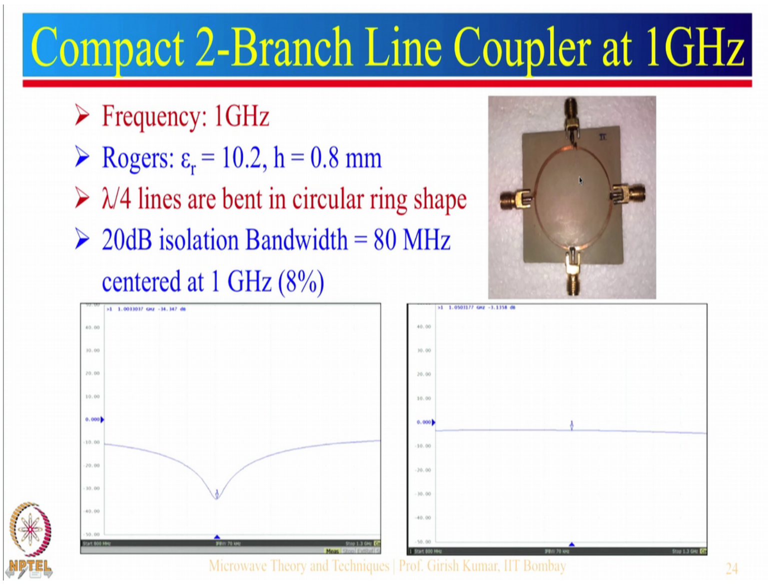

So, here is a another design, where we had actually designed a compact two branch, just to tell you that those four branches which were actually shown earlier as horizontal line, here they are shown in the form of the rings. So, this dimension here is lambda by 4, this is also lambda by 4. I just to tell you there was a requirement where we wanted a compact 2 branch line coupler, but the shape required was a circular shape.

So, this 1 here even though we have used a square substrate, this is just for the testing, but ultimately the whole thing will be actually speaking cut from over here ok. So, this is here circular form and to make it compact, we had used a very high value of epsilon r which is about 10.2. So, by choosing a larger value of the epsilon r, the size is reduced. Of course, you can further do the reduction instead of going lambda by 4 like this; you can go here then go here then go like this.

So, instead of this curved line, you can always use a u shape line and that way the size can be reduced even further. So, in this particular case we can see that lambda by 4 lines are bent in circular ring shape, and the bandwidth obtained is of the order of 80 megahertz, the required bandwidth was only 50 megahertz for this particular application. So, in this particular case now, the if this is the input we take it. So, this is the you can say a direct couple port, this is the coupled port and this is the isolated port.

So, the power going from here to here and here to here you can see that it is relatively constant, and this is the reflection coefficient and which has a similar value for S. So, only one curve has been shown over here.

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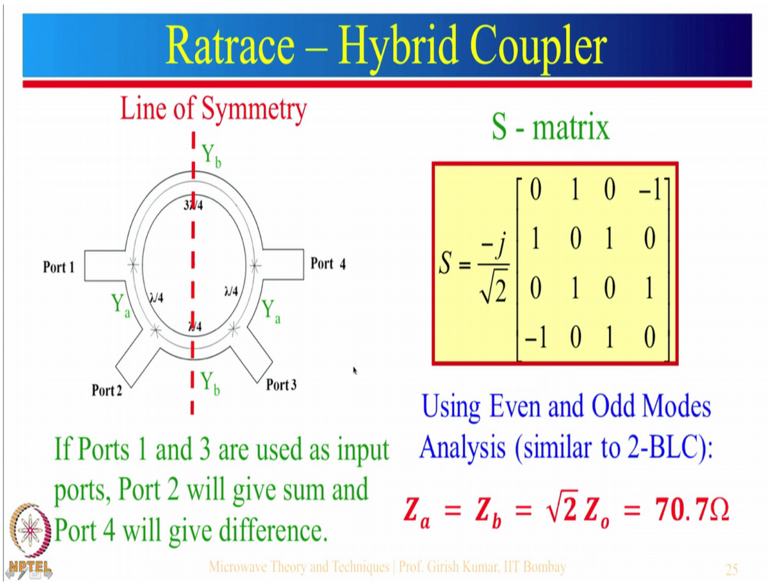

Now, we will go to the another configuration, this is actually known as a hybrid coupler and there is a another name given, which is known as a rat race ok, but this rat race is the special name only given when we designed this whole thing for equal power division. So, why it is called a hybrid coupler? Just recall now in the case of two branch or three branch or four branch couplers, we had seen that the 2 outputs had a phase difference of 90 degree. But in this particular case we can design in such a way that when you give a input at 1 port, let us say port 1 then the output goes to let us say port 2 and port 4, but they are now at a phase difference of 180 degree.

And when we give input at port 3, then the output at port 2 and port 4 are in the same phases. So, let us see what it is and how it really works. So, let just go with a simple thing first. So, port 1 here port 2 port 3 port 4. So, this length is lambda by 4, this is lambda by 4, this is lambda by 4 and this is 3 lambda by 4 ok. So, do not compare with the 2 branches coupler; 2 branch couplers had all the things as lambda by 4 here the difference is this branch length is 3 lambda by 4. Now the general case is that this Y a and Y a these 2 are same and Y b and Y b are same over here. Now, but for a special case I just want to mention for half power going here or half power going here, in that special case Y a actually becomes equal to Y b. But we will see that one by one how do we do the analysis of this particular thing and what are the concept.

As far as the analysis is concerned you can see that along this particular thing, there is a line of symmetry. So, you can see that with this line, you take it on the left side or right side it is symmetrical. So, the analysis of this is let us say if we start from here. So, you can say that there is a port 1. So, from here this length will be now 3 lambda by 8, then there will be a transmission line and this is the port 2 and at port 2 there will be a lambda by 8 line. So, when you do the analysis, it will not be same as for 2 branch coupler, but it will be similar. In case of 2 branch coupler these 2 branches have the exactly same length which were lambda by 8 and lambda by 8. But in case of hybrid coupler or rat race, this branch is now lambda by 8 and this branch here is 3 lambda by 8. So, that is about it so, now, we do the exactly the same thing.

So, for this particular network do the even mode analysis as well as odd mode analysis find out ABCD parameter, from the ABCD parameters find out S parameter and then put the boundary condition that we want a port 1 to be matched and S 1 1 should be equal to 0. And by putting that condition that half power goes here and half power goes here, we get the characteristic impedance to be equal to 70.7 ohm. But now let us just look at the overall concept now. So, when we give input at port 1 so, this one here sees a 90 degree phase delay. So, this will be minus 90 degree.

So, now, from here this is 3 lambda by 4. So, phase delay is 270, then another 90 360 degree which is equivalent to 0 and then 90 degree. So, path from here sees a 90 degree delay, path from here also sees a 90 degree delay; so, this path and this path they will get added up and phase difference will be minus 90 degree. So, from here to here what is the phase delay? Minus 270; from here to here to here to here this is also minus 270 degree; that means, net is plus 90 degree now let us see what happens over here. So, from here to here phase delay is 180 degree, from here to here phase delay is 360 degree. So, they will cancel each other.

So; that means, if we give a input at port 1, no output goes to port 3 and then half power goes here, half power goes here because we have taken Y b equal to Y a or Z a equal to Z b. So, let us first try to complete the first row of this S matrix. So, let us say what is S 1 1, S 1 1 is equal to 0 what is S 2 1? Remember here this minus j is written outside. So, 1 by square root 2 will be corresponding to half power minus j shows minus 90 degree phase difference here.

Then from port 1 to port 3 there is a 0; then from port 1 to port 4 the phase delay is minus 270 degree ok. So, already minus j is out there. So, there will be a another minus here. So, if you multiply the 2 it becomes plus j by square root 2 and minus 270 is equal to plus 90 degree. Now let us just do other way round now, suppose if we give a input at port 3 let us see what happened. Now for port 1 we had seen port 3 is a isolated port, there is a no power going to this. So, when we give a input at port 3 now. So, let us see to port 2 what happened.

So, this delay is minus 90 degree, from here 90, 270, 360 degree which is 0 and then a 90 degree so; that means, this path and this path will add up, and the phase delay will be minus 90 degree. So, from here this is minus 90 degree and this one here is also minus 90 degree. So, they will add up. So, when we give a input at port 3, these 2 outputs are now in same phase and the phase delay at this is minus 90 and minus 90 and what happens here at port 1? Well this is 180 degree this is 360 degree so, the net output will be 0 here. So, now, think about an application, if we give a input at both port 1 as well as port 3 so, what will happen? So, because of the port 1 output here will be minus 90, but because of the port 3 it will be minus 90 so; that means, we will get some of these 2 ports at this one.

But because of the port 1 this is at 270 degree, but this is at minus 90 degree so; that means, output at 4 will be the difference of these 2 port. So in fact, that is what this hybrid coupler is all about; that if we give a input here the 2 outputs are at out of phase. If we give input at this port, the 2 outputs are at the same phase and if we give input at both the ports here, then the 2 outputs will be sum and difference of these 2 input. And you can apply the rest of the symmetry for other thing and build the S matrix yourself ok. So, just you summarize if ports 1 and 3 are used as input ports, then port 2 will give sum and port 4 will give a difference of these 2 inputs.

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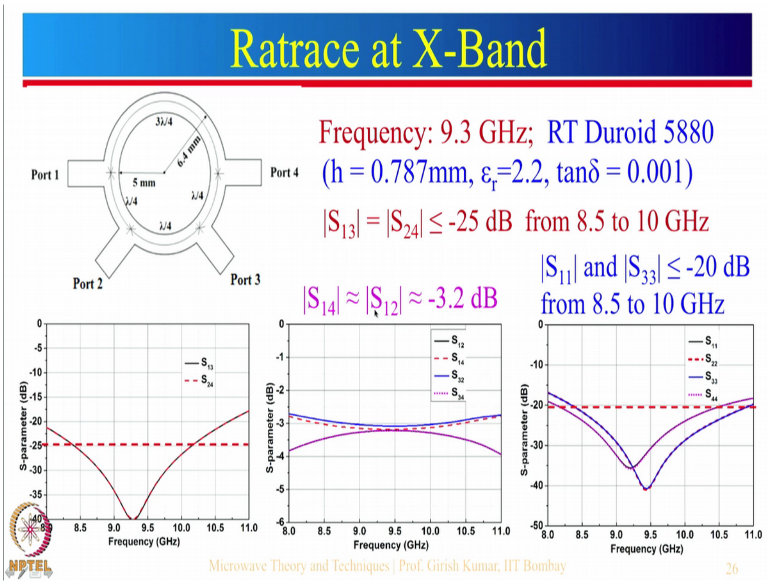

So, now let just look at the design and analysis of this one. So, rat race is designed again at X band. So, that there will be a good comparison. So, earlier we had designed 2 branch coupler, now let us look at the design of a rat race at the same frequency of 9.3 3 gigahertz same substrate has been taken over here. So, let us see the plot over here now. So, when can see 3 different plots over here so, this is the plot which corresponds to S 1 3, S 2 4. You can see that S 1 3, S 2 4 will be same and you can see that they are exactly same. And in this particular case you can see that this line is drawn at minus 25 dB. And for minus 25 dB the bandwidth obtained is from 8.5 to 10 gigahertz of course, if we choose minus 20 dB then bandwidth will be much larger ok.

But it is not that we define bandwidth for just individual thing, we have to look at the overall bandwidth for all the other performance parameter. So, let us see the power divided output at the 2 ports, you can see that one response is going like this other response is going over here, and this is the reason mainly because one path is longer than the other path. So, if you look from here this is the one path, and this is the longer path over here going to this particular side here. So, that is why effectively this is a 90 degree phase delay, effectively this is 180 degree.

So, because of the different path length so, one response is in the opposite direction of the other response. But still if you see right from 9 to 10 gigahertz, the difference between the 2 is very very small and this one here shows S 1 1 and S 3 3 you can see that for less than minus 20 dB bandwidth obtained is from 8.5 to 10 gigahertz ok. So, actually speaking just to tell you in general rat race has a larger bandwidth and 2 branch line coupler. However, this bandwidth is still relatively small compared to 3 branch line coupler or 4 branch line coupler. So in fact, broadband rat race is a very good research topic so, I urge the listeners, you can do little bit of your own search.

In fact, just to give you a little bit of a hint also, instead of using a 4 port there are papers which use 5 ports one of the port is terminated in to match load, and that gives rise to larger bandwidth. There is a another concept what they do in that one they replace this 3 lambda by 4 section by a lambda by 4 coupled line section ok. So, you do a little bit of a research on your own, but this area is wide open. So, you can think about some more innovative design, which will lead to larger bandwidth. So, a quick comparison of branch line coupler and rat race coupler.

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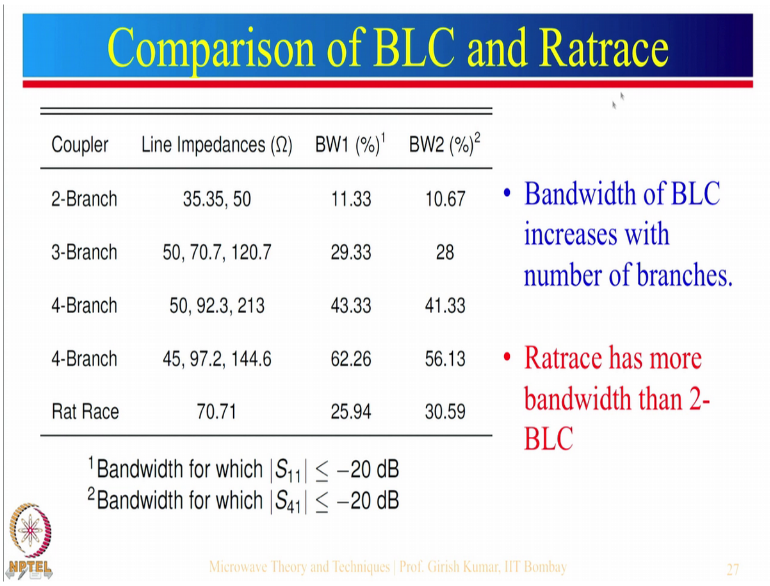

So, here 2 branch 3 branch 4 branch and in 4 branch we have taken two different cases one was series impedance of 50 ohm and another one was 45 ohm. You can see that the 2 bandwidths are defined here, one bandwidth is for S 1 1 less than minus 20 dB, another bandwidth is designed for isolation S 4 1 less than minus 20 dB.

So, you can see that the bandwidth increases from here to here and bandwidth increases from here to here. The comparison of a rat race should not be done with these cases, it should be compared with 2 branch line or maybe say between 3 branch line because of the total size. So, you can see that this bandwidth is more than a two branch line coupler. Let us look at different applications of a rat race also and one of the application which I would like to mention is a mono pulse comparator.

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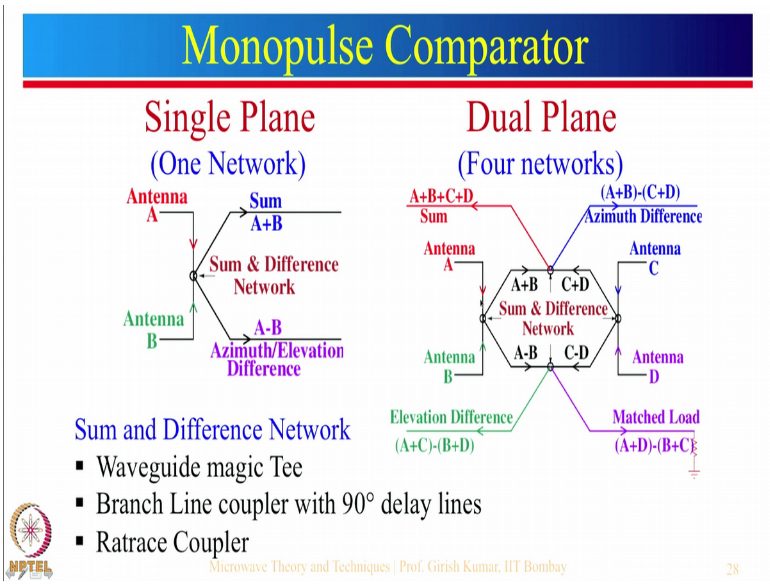

What is really a mono pulse comparator I will go through that one by one, think about first we have 2 antennas; antenna A and antenna B and they are pointing in one particular direction, and let us say we want to track a target. So, what they do? Through these antennas we actually send the same signal, it goes there and from the target the signal reflects back.

Now, that reflected signal what it does? We actually come through these 2 antenna and this 2 antennas come to the sum and difference network, and one will give the sum another one gives the difference ok. So, this way we can track the object in single plane, but if you want to track the object in 2 planes that means, you want to track in this direction as well as in this direction this direction is known as Azimuth plane and this direction is known as Elevation plane.

So, in that particular case we actually need 4 identical antennas. So, what is done over here let us see. So, antenna A antenna B we have a sum and difference network, and we have just covered rat race. So, you know that rat race generates sum and difference network. So, one rat race will do the job of single plane tracking, now here we need actually 4 different rat races let us see why. So, one rat race here will give A plus B and A minus B, now we have 2 other antennas C and D. So, another rat race will give C plus D and C minus D.

Now these 2 signal will go to another rat race, then what we get? A plus B plus C plus D over here. So, that gives us the sum pattern, and over here A plus B minus this that gives the Azimuth difference. And here we have the difference of these 2 difference of these 2 this gives us Elevation difference and this is terminated and matched load it is not required. Of course, instead of using a rat race coupler, one can use other things also one can use branch line coupler with 90 degree delay, but generally it is not very preferable; one can use waveguide magic tee, but generally the size is very large and these are very bulky where a rat race can be printed on a substrate. So, let just look at what is really there now. So, we will just go through one by one now.

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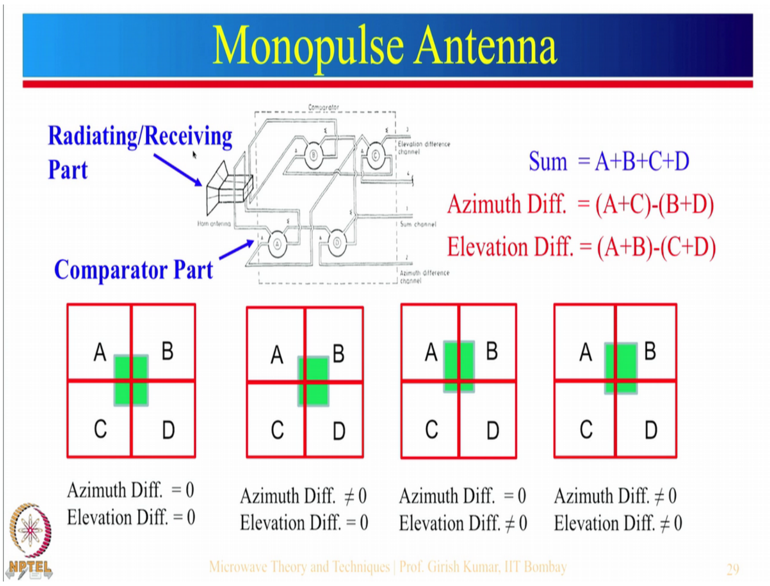

So, here are those 4 antennas you can say radiating or receiving part. So, here 1 2 3 4 of course, this one shows here horn antenna; however, I will show you the results using microstrip antenna, and these are the basically rat race couplers which are put together, but let just first look at the concept point of view. So, let us say this ABCD 4 of these antennas are transmitting signal, and then that signal is reflected back. So; if Azimuth difference as well as Elevation difference both are 0 that means, target is right at the center. Now if Azimuth difference is not 0, Elevation difference is 0 so; that means, target is aligned in the elevation, but it is not aligned in the Azimuth direction. So, you can see that target is shifted here.

If Elevation difference is not 0 then the target is not aligned in Elevation direction and both of them are not equal to 0 then the target is not aligned. So, what happens? Basically this particular output goes to the servo controller, then servo controller will accordingly move in the Azimuth or Elevation direction to track the target properly. So, now, let us see how this thing has been achieved.

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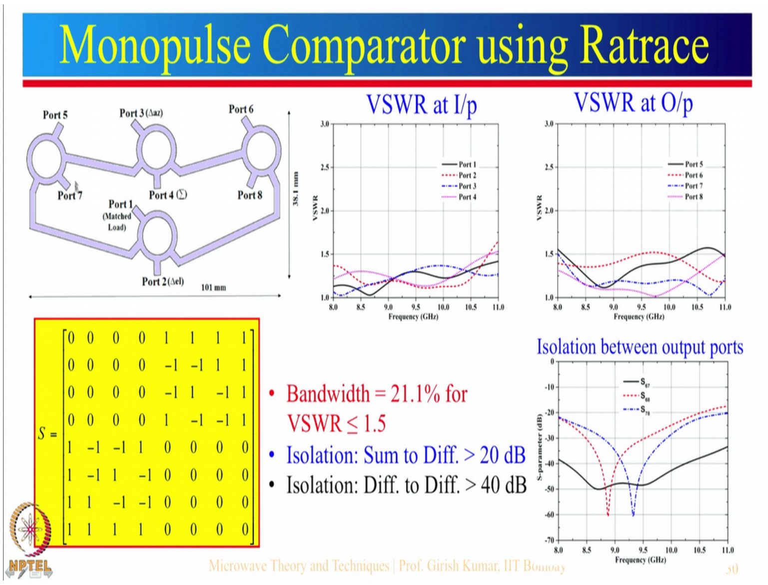

So, here are the 4 rat races you can see over here. So, just to give you a little bit of an idea here. So, that antenna ABCD are connected over here the outputs of the antenna, and here you can see that if you take input at these 2 port, this will be the sum port this will be the difference port. So, from here for these 2 input this will be the sum port and then from here you can generate the sum over here and the difference over here and similarly this one here is put in to match load and this one here is the difference. So, this is the S matrix for 8 port because you can see that there are 4 input ports and 4 output port.

So, these are the simulated results for this particular configuration here. So, we obtained the bandwidth of about 21 percent for VSWR less than 1.5. Now isolation is very important between these ports. So, you can see that the isolation is between sum to differences greater than 20 dB and this is difference to difference is greater than 40 dB.

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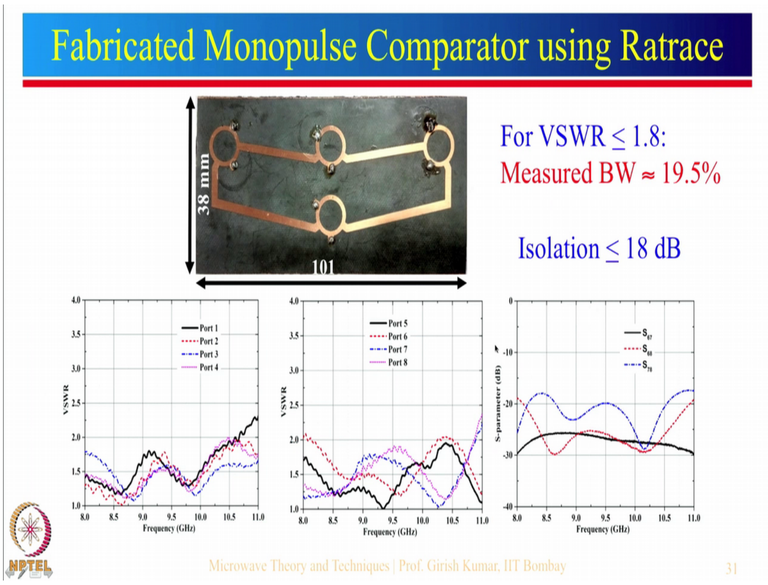

So, we have done the experiment also. So, you can see the fabricated rat race, you can see the dimension here it is just about 101 mm by 38 mm. So, there was a small discrepancy in the measured results and simulated results ok, but still the results were fairly good bandwidth is of the order of 19.5 percent. So, isolation was you can see that greater than 18 dB over this entire bandwidth.

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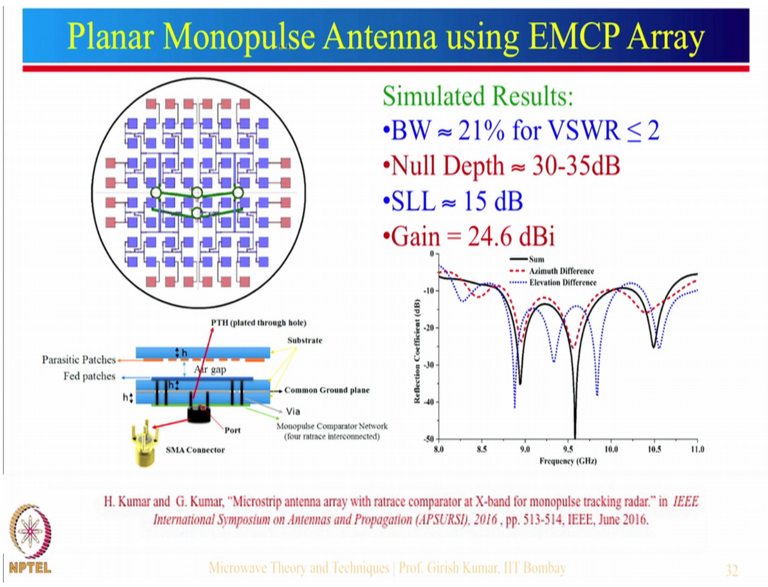

So, this one shows over here planar monopulse antenna using electromagnetically coupled array. So, we are going to discuss this thing in more detail when I talk about microstrip antenna, but here just look at the concept point of view. So, here what you see at this particular level? These are the feed patches along with the power divider network. These are the parasitic patches or we also call them electromagnetically coupled patches. So, there is a no feed network for these things over here. Now the entire array here is on one side of the ground plane which is on the above side, and the ratrace hybrid power divider network is actually speaking on the other side of the ground plane here.

So, the ratrace hybrid over here is shown this is what you see over here, that is printed on the other side so, let us see what are the results we got over here. You can see that the bandwidth obtained here is 21 percent, for VSWR less than 2 what is null depth it will be clear in a short while when I show you other result. So, gain for this particular antenna array is of the order of 24 dB. So, we have first done that design, after that this array has been fabricated.

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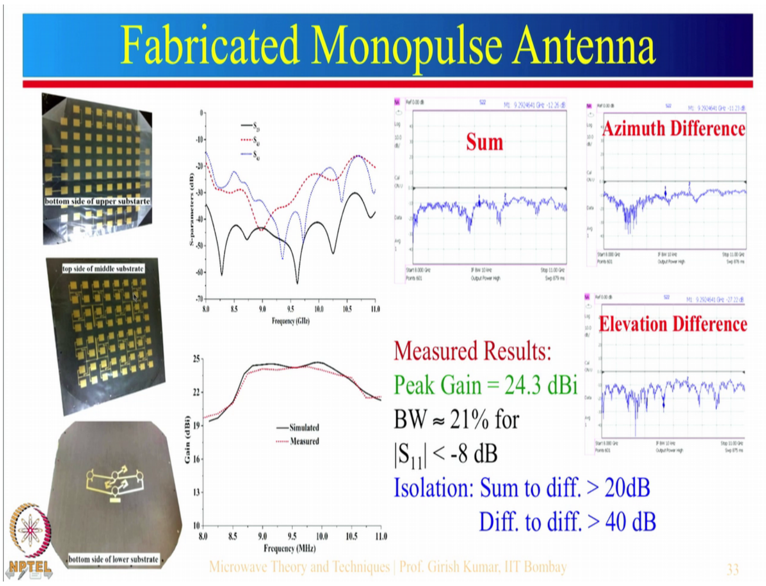

So, these are the different snapshots, this is the backside layer, this is the in between layer and this is the top layer which shows the parasitic patches over here. So, you can see all the results over here. So, measured results let us see peak gain is 24.3 dB whereas; the design was for 24.6 so, which is very very close.

Bandwidth is almost similar except there is a small problem that we had designed it for S 1 1 less than minus 10 dB, but because of the fabrication error it came out to be minus 8 dB. Isolation is as good as we had designed so; the results were pretty good ok. And these are the measurements done at different ports some port and Azimuth difference and Elevation difference ports.

See these are the results which we can say for S parameters, but ultimately what is important is whether we are getting a decent radiation pattern or not and this one here shows the gain. So, you can see that over the bandwidth the gain is fairly flat. So, it is actually a fairly good design, you can see that from 9 to 10 gigahertz almost for 1 gigahertz bandwidth gain is relatively flat, but let us see the performance for sum and difference pattern.

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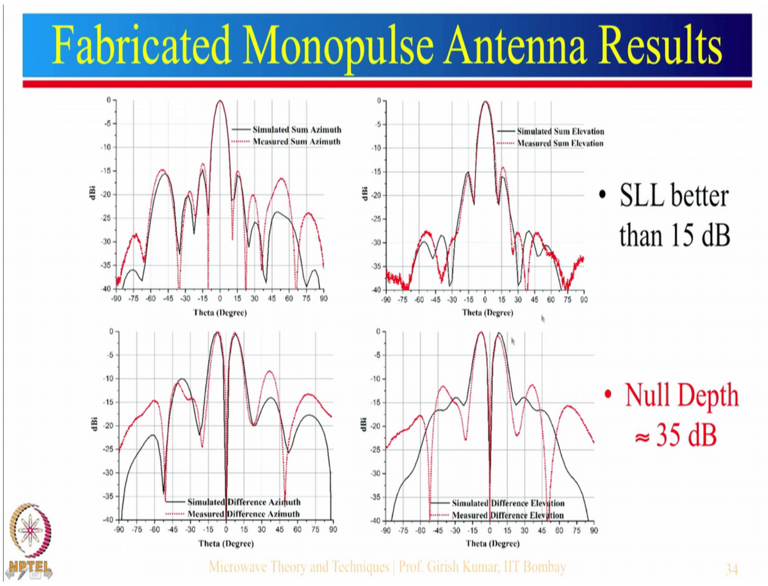

So, here only 2 of these antenna, antenna A and B, and here is the result for some of Elevation in this particular thing and here is the difference. So, where we take that difference? We take the difference in the Azimuth direction of these 2 antenna, and along the Elevation we take the difference in this particular direction.

So, you can see that here the some patterns are almost identical for Azimuth as well as Elevation of course, the net pattern will be sum of these 2 also ok. And SLL is better than 15 dB, you can see that that is a side lobe level which is less than minus 15 dB, but what is really important is the null a depth. In fact, generally better than 20 dB is considered decent, but we got over here less than 35 dB, you can see that compared to here see how sharp the null depth.

Now, sharpness of null depth is very very important, because this tells us whether the target is within the proper region or not, whether the antenna is tracking the target properly or not ok. So, we conclude at this particular point. So, just to summarize so, in the last few lectures we talked about couplers. So, we started with the coupled line directional coupler, which is good for coupling from minus 10 dB to about minus 30 dB, then we talked about two branch line coupler, three branch line couplers, four branch line coupler. And these are generally good for coupling of minus 1 dB to up to about minus 90 dB; and then we talked about a rat race coupler the difference between branch line coupler and rat race is in case of branch line the 2 outputs are at 90 degree phase difference.

But in case of a rat race the 2 outputs can be in the same phase or they can be out of phase depending upon where we are feeding it, and also if we feed at those 2 isolated ports let us say port 1 and port 3, then at port 2 and 4 we can get sum and difference of those 2 signal. And then we saw an application for monopulse comparator, where we looked at an antenna design and then that antenna was fed with these 4 rat race coupler and we saw that fantastic results came for very good null depth ok. So, the null depth was very good, the gain was also similar to what we had designed leading to a very good performance.

Thank you very much.