Microwave Theory and Techniques
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Module - 04
Lecture - 17
Power Dividers – II: Unequal, Broadband and Compact Power Dividers

In the previous lecture we had discussed about power dividers and combiners. So, we are stared with the 2-Way equal Power Divider and then we had finally derived its S matrix.

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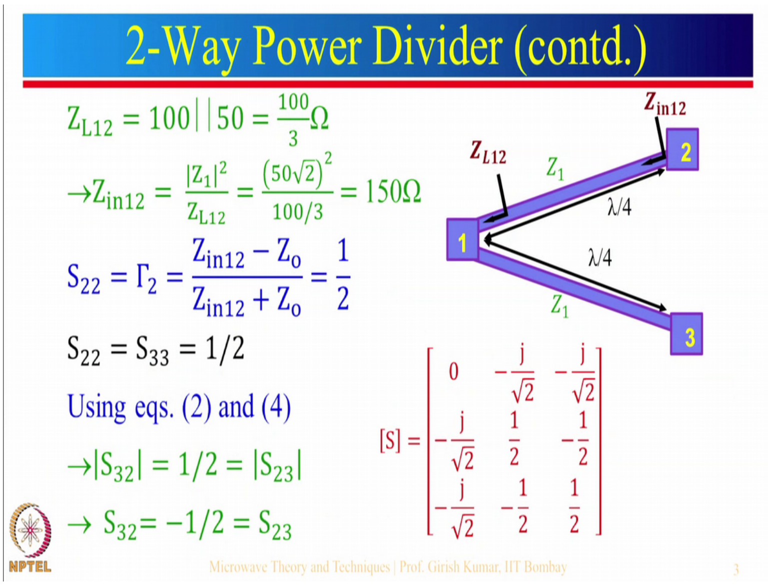

And we had actually seen that this is a good power divider, but not a good power combiner because if we give a input at port 2, then one-fourth of the power reflects back, one-fourth of the power goes to port 3 and half power goes to port 1, ok. So that means, the reflection coefficient is not good and also coupling between the two port is there which means that isolation between these two ports is not very good.

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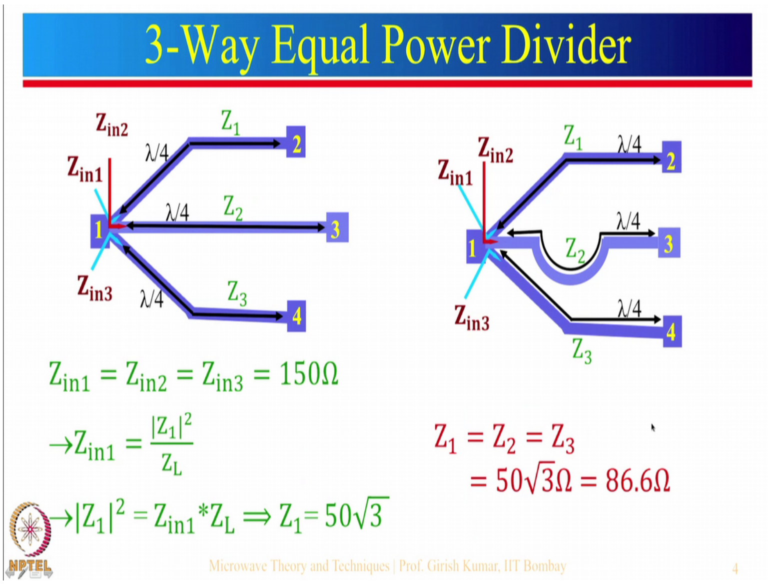

But after 2-way we had looked into 3-way and we had actually seen that for 3-way Z 1 equal to Z 2 equal to Z 3 should be 86.6 ohm.

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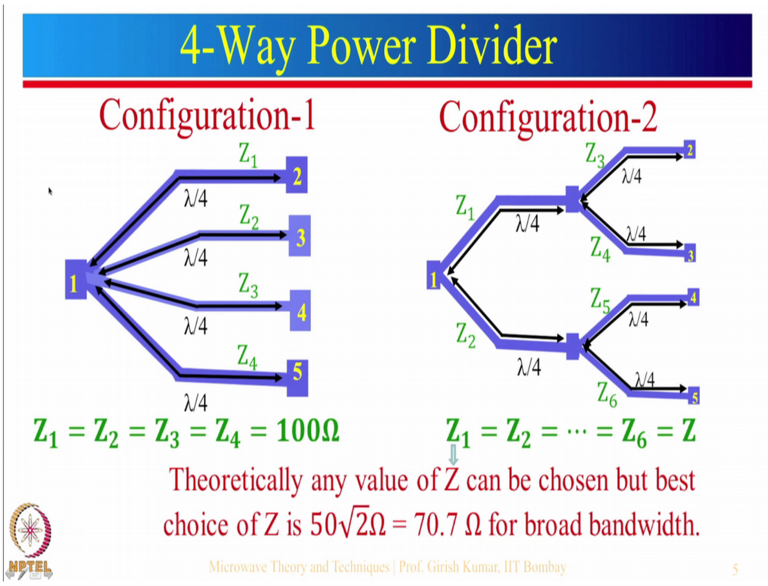

We had looked at two different configurations for 4 way power divider, one configuration had only single lambda by 4 section, second configuration had 2 lambda by 4 section. In general this particular design will have a more bandwidth compare to this particular section.

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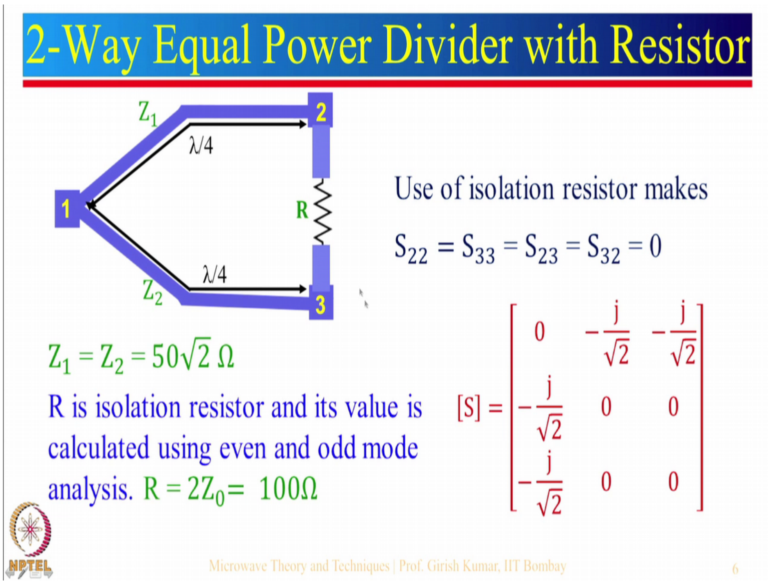

And then we looked at the equal power divider with resistor and basically the resistor value is equal to 100 ohm. And in fact, when we discuss about even and odd mode analysis then you will understand how this value comes into picture so you have to wait for one or two more lectures.

So, by choosing this isolation resistance we can actually see that S 22 also becomes 0, S 33 also becomes 0, and also the coupling from port 2 to port 3 is 0 that means, the isolation between ports 2 and 3 is very good. Then we also discussed about when we use as a power combiner, so let us say if we put one watt here, one watt here you have to ensure that the 2 input powers have equal phase, ok. So, they should have equal amplitude as well as equal phase.

If they do not have equal amplitude even then the current will flow. Suppose if you give one watt here and 0.8 watt here. So, whatever is the corresponding V 2 will not be same as V 3. So, if the two voltages are not same then the current will flow through the resistor and there will be dissipation in the resistor. And I had mentioned also that how the phase cancels from here to here this is a 180 degree, and from here to here the phase difference is approximately 0 assuming this is negligibly and then the output here will be 0.

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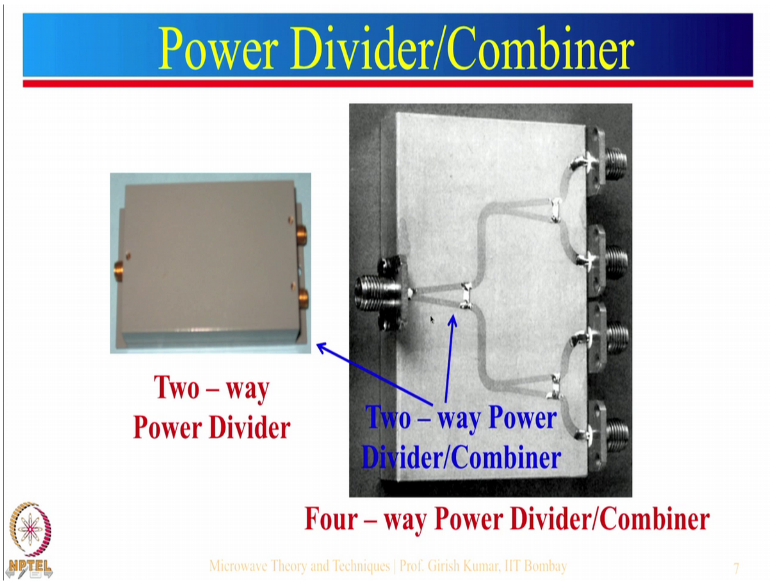

Now, after that we looked at the example. So, this is the fabricated one and this is the inside PCB layout for 4-way. I just want to mention over here, this is not necessary that you always put the ports on this side only. So, just to give you a little bit of a different idea, suppose it is if it is acceptable that the port 2 ports can be even this side and 2 ports can be even this side then what will happen. So, from here only this section is actually not required from here only you can actually use power divider like this, and from here you can use a power divider like this and then you can have a connector right here.

So in fact, the overall PCB size will be only now this much. So, depending upon the requirement if people want or if the application requires all the 4 port should be on the same side this is one of the solution. But if the 2 ports can be on this side and 2 ports can be on this side that will result in to a relatively smaller PCB, and smaller PCB would also mean smaller box size also, and that would also mean smaller cost also.

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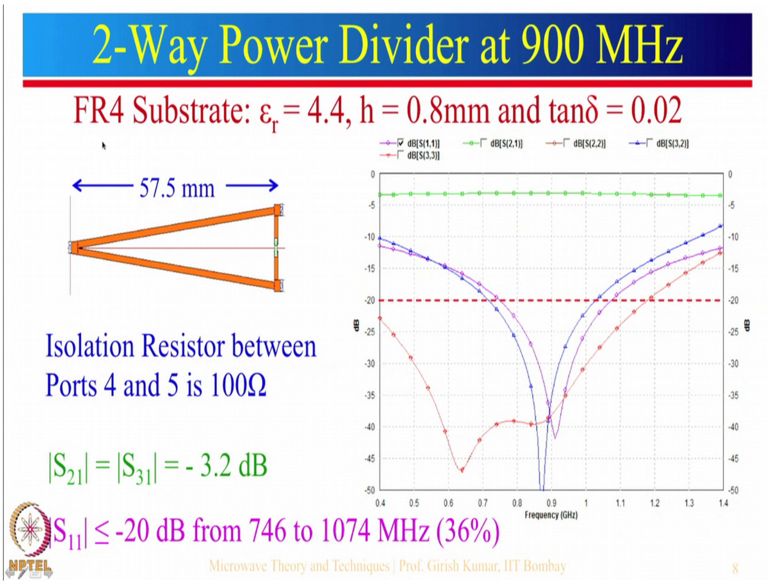

So, let us just now look at the practical realization of these power divider. So, we have actually taken an example of FR4 substrate, this is a normal glass epoxy substrate which is generally used for PCB manufacturing or all those your mobile phones or laptop generally use this FR4 substrate these are readily available, and they are relatively very cheap.

So, epsilon R equal to 4.4 we have taken the in reality epsilon R can be from 4 to 4.6. So, please check before you know you start using this particular thing. Here we have used thickness of the substrate has 0.8 mm and this particular substrate has a tan delta of 0.02. Just to also mention that there are many FR4 substrates their tan delta may vary from 0.01 to 0.025 also.

So, here this particular simulation we have done using IE3D software. So, let us see what we have here; here is a port 1 define, this is a port 2, and port 3 over here. And you can see that there are 2 ports are defined over here there are port 4 and 5. These are basically to put a isolation resistance. In fact, in IE3D you actually have two different thing first thing is you use m grid which is for layout and simulation later on you can do the processing of the simulator results. So, that is known as modwa. And then in modwa you can go replace these ports 4 and 5 and connect a resistor 100 ohm over here. So, let us see what result we get here.

So, just to tell you epsilon R is 4.4 and we had designed this particular thing around 900 megahertz. So, we know that what is the wavelength at 900 megahertz it is approximately, 33 centimeter divide that by 4, so let us say approximately 8 centimeter, divide that by square root of epsilon effective and you actually see that including this port termination also the total length here is about 57.5 mm, ok. So, that you can say it is slightly more than 2 inches.

So, now let us see the simulator result. So, you can see from here input is 1. So, port 2 and port 3. So, that is S 21, S 31 shown by the green color over here this is minus 3.2 dB. Ideally it should have been minus 3 dB and minus 3 dB but because we have used a lossy substrate some losses do happen and that is why instead of minus 3 it is coming out to be minus 3.2 dB.

Now, let us look at the reflection coefficient. So, reflection coefficient plot is shown by this purple color write over here and I have mentioned here the bandwidth for minus 20 dB. S 11 less than minus 20 dB actually imply 1 percent reflected power. So, that is why also these values become little lesser also. So, 1 percent power is reflected rest is transmitted.

So, you can see from here you can read the value from here to here I have drawn this horizontal line at minus 20 dB and one can see that the bandwidth obtained is about 36 percent. So, just to tell you this bandwidth is actually sufficient to cover let us say 900 megahertz. Why we chose 900 let me also tell you. So, we have a band of GSM 900 which is from 890 to 960. We also have CDMA which is from 820 to 890, so if you really see this band covers right from 820 to 960 which covers both CDMA as well as GSM 900 band and we have sufficient margin also.

Now, let us see what is the isolation between this and this. So, you can see that this is the isolation curve and you can actually see that this isolation curve is slightly shifted compared to what is the minima of the reflection coefficient curve. The reason for that is that this particular length is not 0 it has a finite length, ok. So, what is happening let us say this is a 180 degree, ok, at let us say this particular frequency but this is not 0. So, what is happening? That is why perfect cancellation is not taking place at this particular frequency but it takes at a slightly different frequency.

So, I just have shown you this particular thing mainly that what this particular dimension can do, it can actually shift the thing. But let us see also what are S 22 and S 33, S 22 and S 33 are actually fairly good you can actually see that here, if I look at a just say minus 20 dB bandwidth then these are much below that, so that means, S 22, S 33 if I actually look at minus 20 dB this bandwidth is huge, ok. So, matching at the output ports is actually pretty good matching at input port or even this isolation is fairly decent over the desire 890 to 960 megahertz.

So, now the layout of these micro strip lines is very very important. Here we have shown you the layout where these are more like a straight line.

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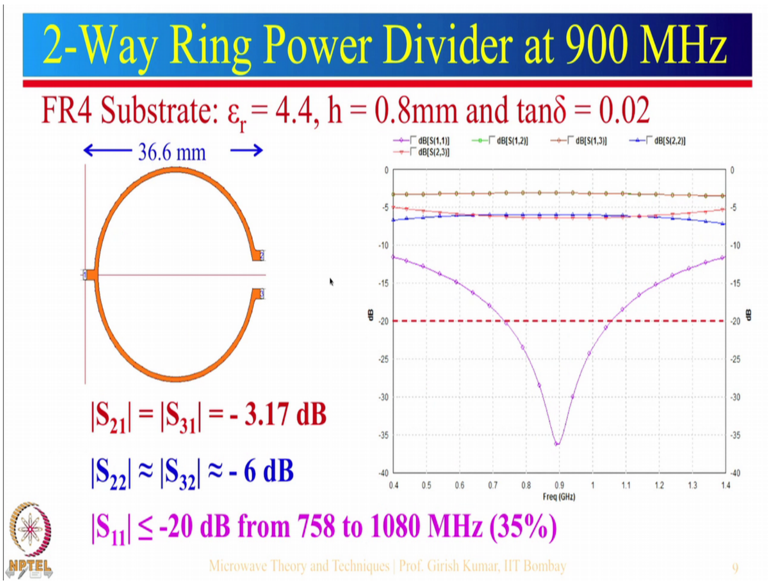

Let us see if it use different type of layout what happens. Here instead of using a straight line like this we have actually use a we can say more like a circular ring which is of course, certain portion is removed from here.

So, if you use a circular ring now this is that length is lambda by 4. So, we can see that now the total length has been reduced from, if you remember the previous case the length was 57.5 and now it is 36.6 so that means, the size is reduced. You can say that yes this size is slightly increased, but then connectors have to be connected over here and that will occupy certain space, ok. So, one can realize the little bit compact at least in this particular direction.

Now, this simulation is done without the isolation resistance, you can see that there is a no isolation resistant. This is just to show you what happens if you do not put isolation resistant. So, in this case you can see S 21 is equal to S 31 which is minus 3.17, earlier it was minus 3.2 dB. So, the performance is almost similar.

Now, you can see that S 22 is approximately equal to S 32. You can see the curve from here these are the curves for that and that is equal to minus 6 dB. So, minus 6 dB implies one-fourth power is reflected back and one-fourth power is going over here. So, now let us see what happens.

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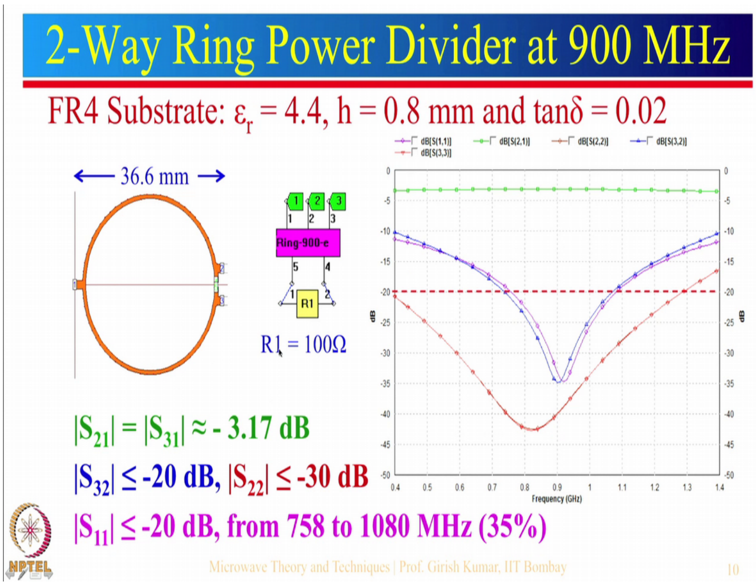

If you put isolation resistance we can see that in the same ring now we have defined 2 ports in between here and then in modwa we move these two ports and we put a resistance. You can see here this is the modwa part of the IE3D software. So, you can see that port 1, 2, 3 are shown over here put 4 and 5 which are over here, we have deleted that and substituted the value of resistor R 1 which is equal to 100 ohm.

So, let us see now what is the performance. They can see that S 21, S 31 they remain same as before which is minus 3.17 dB. Let us see now S 32, you can see S 32 is this curve here which I have shown as a blue, S 22 is over here, you can see that S 22 is very good over this entire bandwidth. And what is S 11 less than 2? That is again this bandwidth is almost similar as in the previous case because by adding isolation resistance nothing really happen.

But what has been improved? S 22 has been improved, S 32 has been improved, ok, and also now since this particular length has been reduced compared to that tapered section which we had taken, so we can see that now the 2 bottom peaks are very very close to each other. You can see that the frequency shift is very very small. So, if we can make ideally this to be close to 0 even little more smaller these two will become almost closer to each other.

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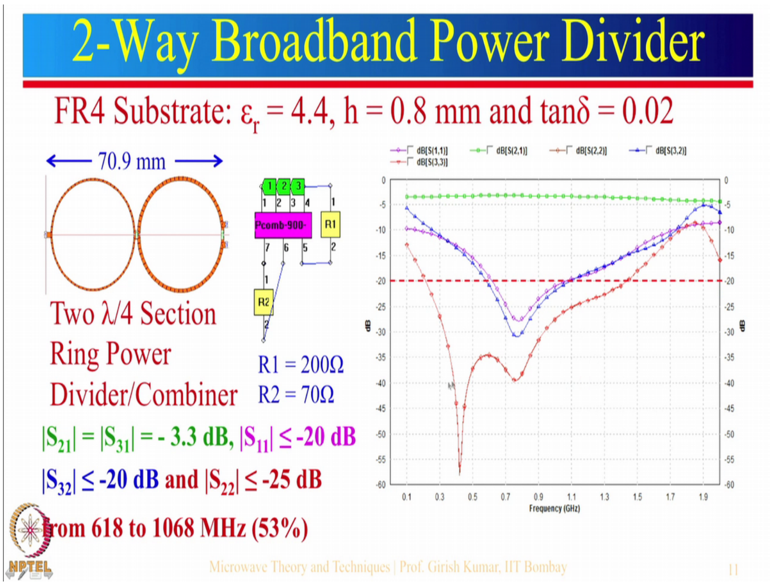

Now, let us just look at another design which is a 2-way broadband power divider. So, we have still use the same FR4 substrates, so that is same. But now you instead of using 1 lambda by 4 section we have actually use 2 lambda by 4 section of ring power divider and I have added the term combiner because of the isolation resistances we have put here.

Now, we have to define two different things here. So, this is here you can see that these are the ports here and these are the ports in between over here and here you can see that port 1, this is port 2, port 3. So, between port 4 and 5 which is right over here we have a put a resistance of 200 ohm, over here it is 70.7 ohm. So, this is basically to improve the bandwidth using two section for power divider, these two isolation resistance are required to improve the bandwidth for power combiner.

So, let us see now what is S 21, S 31, this is now minus 3.3 dB if you recall earlier one of this ring had given 3.17. So, now, we have a additional thing. So, we have a little more loss. So, that is why path loss had increased. So, that is why it is minus 3.3 dB.

Now, let us see S 11 less than minus 20 dB. This is actually a much broader frequency scale compare to what we had shown over here. So, you should see what is the scale, but I have given the numbers here. So, for S 11 less than minus 20 dB you can see over here this is that isolation which is actually fairly good now, it is even broader than S 11. So, S 32 less than minus 20 and S 22 is less than even 25 dB over this entire range. And you can now see that this particular thing is giving as from 618 to 1068.

So, if you can calculate the percentage bandwidth it comes out to be 53 percent. How do we calculate percentage bandwidth? It is actually simple, percentage bandwidth is nothing but bandwidth divided by f 0 multiplied by 100. So, to calculate the bandwidth take the difference of these two and f 0 will be the center frequency of these two thing and center frequency can be obtained as sum of these two divided by 2. So, that comes out to be 53 percent.

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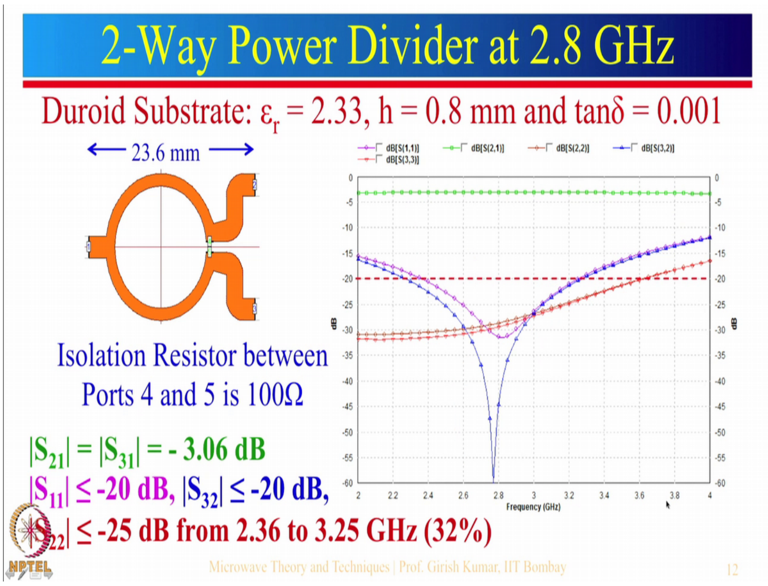

So, just to tell you that not all the time we have to design glass epoxy substrate which is a lossy substrate, there are application which do require good quality substrate for better performance. So, just to tell you here design example of 2.8 gigahertz in fact, this particular thing was the requirement from one of the defense organization. So, we had use a duroid substrate here which has a very low tan delta as you can see this is 0.001 epsilon r is 2.33 we took substrate thickness same as before which is 0.8 mm, ok.

So, now because epsilon r has reduced so that would actually increase the width of the 50 ohm line compare to when epsilon R is equal to 4.4. So, again isolation resistance has been put over here which is 100 ohm as before. So, you can see that we have used this circular ring. So, let us just see the results. So, this is the simulated result that designed frequency is around 2.8 gigahertz.

So, let us see what we have got here. S 21, S 31 is minus 3.06 dB, ok. So, instead of minus 3 dB we are getting 3.06 dB because there are some losses do happen which are going from here to here, there are Frinching Felix are there which may also amount to small radiation losses also, ok. So, but still ideal is minus 3 this is 3.06.

Now, if you compare this with the lossy substrate for that case instead 3.06 we got 3.17. So, really speaking the differences only about 0.1 dB. So, one can still use low cost and just to also mention whenever we design things for let us say defense organization or for satellite communication their performance is very very important, cost is not that important. Whereas, when we design for commercial application which could be for telecom operator band CDMA, GSM, 900, 1800, 3G or 4G or for Wi-Fi band generally we use low cost substrate for that particular case.

So, now you have a little idea about what really happens. So, in this case again you can see S 11 less than minus 2, so this is the S 11. And S 32 is the plot over here you can see that matching has been done properly you can see that the size over here is very very small and then S 22 again is fairly large. So, the bandwidth obtained here for all these parameters is from 2.36 to 3.25 and that is about 32 percent, so which is fairly large bandwidth, ok.

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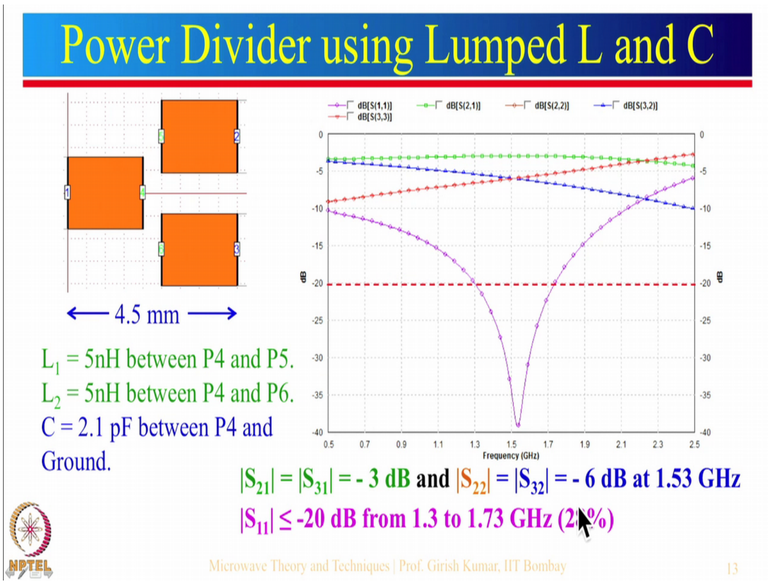

So, now, instead of using these quarter wave transformer sometimes we can use lumped L and C components also, ok. And this is generally done when size is really of important consideration. And also suppose you want to design something at let us say 100 megahertz, at 100 megahertz, what will be the wavelength? That will be 3 meter. What will be lambda by 4? That will be 75 centimeter. And even if you use a very high dielectric constant substrate the size is going to be very large.

So, at some of those applications it is better to use lumped L and C elements which will give us the required performance. But, nevertheless here I have actually shown you the example of a design at 1.5 gigahertz so that is the central frequency. Let us see what this whole thing is and how do we do it, ok.

So, let us say this is 50 ohm, this is 50 ohm, this is also 50 ohm. If we connect directly this and this it is not good idea because 50 in parallel with 50 will give me 25 ohm and then the input impedance seen here will be 25 ohm that will give me a VSWR equal to 2, ok. Means 11.1 percent power will be reflected back. So, that is not a good solution. So, what is this here? Lumped L and C.

So, just to show you first since it is an equal power divider you can see that a inductor L 1 is connected from here to here, next inductor L 2 is connected from here to here. This is now same 5 a nano Henry; you can actually see that between this port and this port and this port and this port we have connected inductor.

Now, form where this inductor comes? Now, you have to recall we did mention about impedance matching technique, ok. So, in the impedance matching technique just imagine now what we have to do. We have to transfer this impedance of 50 ohm to 100 ohm, ok. So, what you do? Now, my Z 0 at this point required is even though we say Z input, but for the Smith Chart you think about at this point we want the impedance to be 100 ohm and this is 50. So, 50 has to be transfered to 100.

So, what you do? You normalize 50 with 100 now. So, 50 will be equal to 0 0.5 locate 0 0.5 on the smith chart, now recall the lumped impedance matching. So, what you do? This is the normal circle and then you draw a dotted circle. So, 0.5 will be on the real access you go up that means, you are adding a inductor in series take a reflection then add capacitance in shunt. So, this is what has been done.

So, inductance has been added in series and the capacitance. So, one inductor from here, another inductor from here, now you can actually see we have added only one capacitance because there will be one capacitance from here to ground, one capacitance for this from here to ground, but the 2 capacitances add now in parallel that can be replaced by a single capacitor, ok. So, this capacitor will be from here to ground. By using these values now let us see what we have got, ok.

So, this is the reflection coefficient plot you can see that the bandwidth obtained is from 1.3 to 1.73 so that is about 28 percent bandwidth. Now, recall when we had used the quarter wave transformer we were getting slightly more bandwidth and this, but even this bandwidth is sufficiently good for majority of the application.

Now, few other things I want to mentions you can see S 21 equal to S 31 that is equal to minus 3 dB. In fact, it is actually better than that other results because in the other cases we had a longer transmission line. So, longer transmission line means there will be losses. Here the total size of the whole thing is just about 4 0.5 mm. So, you can really see it is a very tiny small power divider, ok. So, this is minus 3 dB and by the way all these designs have done again on glass epoxy substrate. So, it is not at all a lossy substrate.

Now, since there is a no isolation resistance over here. So, you can see that S 22 is equal to S 32 it is equal to minus 6 dB at center frequency which is right over here, otherwise you can see that blue is this is S 32 and this color here is this one here, but at the center frequency they are about minus 6 dB.

So, this is the simple way you can make a compact thing. Now, just to tell you now instead of 5 nano Henry and this is 5 nano Henry. If you increase the value of inductances let us say 5 becomes 10. So, what will happen? And also correspondingly you have to change the value of the C this whole thing can be shifted to the lower frequency also.

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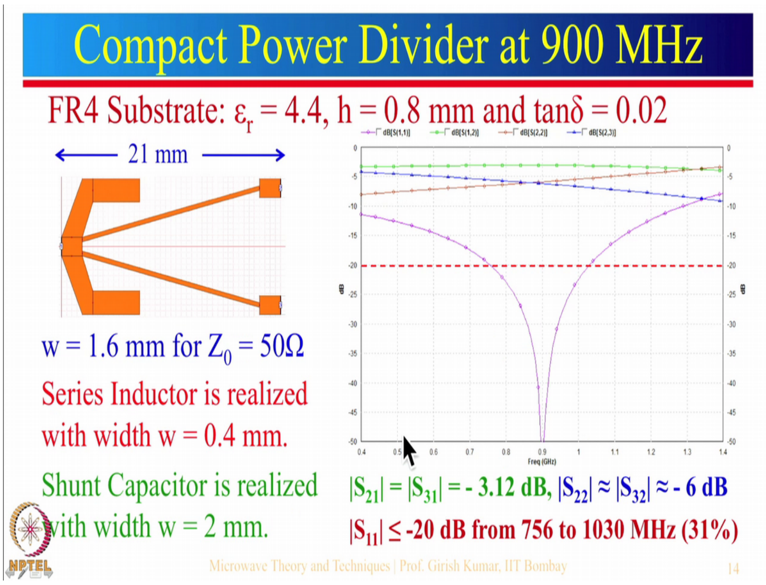

Now, let us just look at alternate way of doing. So, we had seen that in the previous case we can use inductor and capacitor. Here I have shown you a compact power divider design at 900 megahertz. Again we have use the low cost substrate and what has been done over here. So, this is a 50 ohm, 50 ohm, that is a 50 ohm.

Now, here that series inductor has been realized by this thin line and that is the series inductor realized here and the capacitance is realized by using this thing here. You have to actually now recall the transmission line concept. So, open small line will act as a capacitance and open small line will act as a capacitances, ok.

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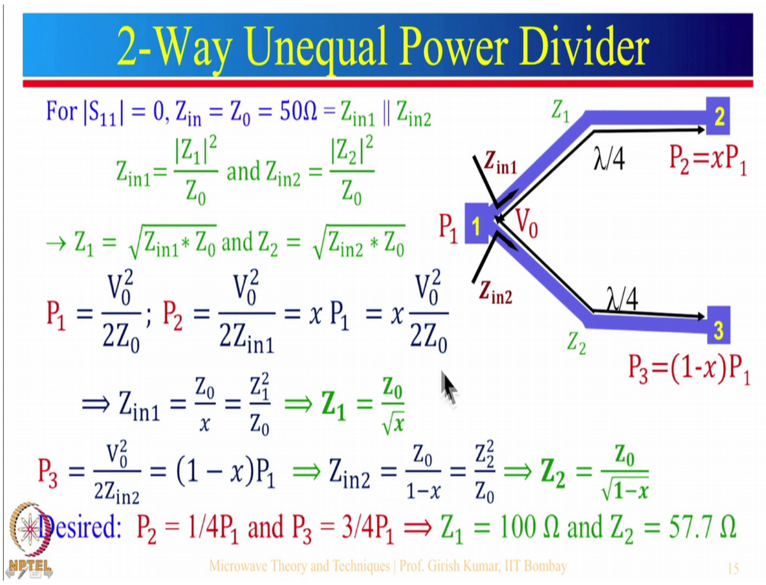

So, here series inductor is realize with width of 0.4 mm which is 0.4 mm here and shunt capacitance is realize with width equal to 2 mm. You can see now the overall size is 21 mm only, and even if the smaller size is required one can actually use a little bend over here and a little bend over there, so then you can reduce the size also.

Let us look at the performance of this particular thing. So, we can see that this is the S 11 plot we are getting about 31 percent bandwidth you can see that this bandwidth is comparable to lambda by 4 transformer, just slightly smaller. S 21 and S 31 you can actually see is minus 3 point 1 2 which is actually smaller than what we were getting for a lambda by 4 transformer which was 3.3, and S 22 S 33 approximately minus 6 dB at center frequency because we have not put isolation resistance over here.

So, now let us just look at 2-way and equal power divider, ok. Now, I have given all these steps, but what I just want to tell you here conceptually that let us say we are giving a input power P 1 over here. Then what we want P 2 is equal to x P 1 and P 3 should be equal to 1 minus x P 1. So, if you add the two you will get P 1 that means, we do not want anything to be reflected back and we want the power loss in this particular transmission line network to be as small as possible.

So, our objective for this is that S 11 should be equal to 0 so that means, what we want input impedance at this point should be 50 ohm and that input impedance is given by Z in 1 in parallel with Z in 2. So, what is Z in 1? That is Z 1 square divided by Z 0. What is Z in 2? That will be Z 2 square divided by Z 0.

So, we have to put those values and now we have to also write in the form of the voltages. So, let us say what is P 1 if we define this voltage as V 0, P 1 will be V 0 square divided by 2 Z 0. What will be P 2? We can calculate from here, so if this is a lossless line and if this is also a lossless line. So, we can define P 2 at this point will be V 0 square divided by 2 times Z input 1. What will be P 3? V 0 square divided by 2 Z input 2, and you put this as 1 minus x P 1 you put this as x P 1, simplify this you will get an expression for Z 1 as Z 0 divided by square root x, Z 2 you will get as Z 0 divided by square root 1 minus x.

So, I have given a problem statement here desired is that one-fourth of the power should go here, three-fourth of the power should go over here. You substitute these values, what we can see that now, Z 1 is equal to 100 ohm Z 2 is 57.7 ohm which is here. Now, you should be little careful here just to check S one-fourth power means lesser power is going here. So, less power is going here that means, this impedance is high impedance high means width is small. So, smaller the width lesser power will go, here impedance is small width will be larger, so more power will go.

You can actually think about this whole power flow as a power going through the two pipes. So, if the width of the pipe is small here or the diameter of the pipe is small then lesser water will go, diameter of this pipe will be more; more water will go. So, the same thing here, if the width of the line for Z 1 is small less power will go.

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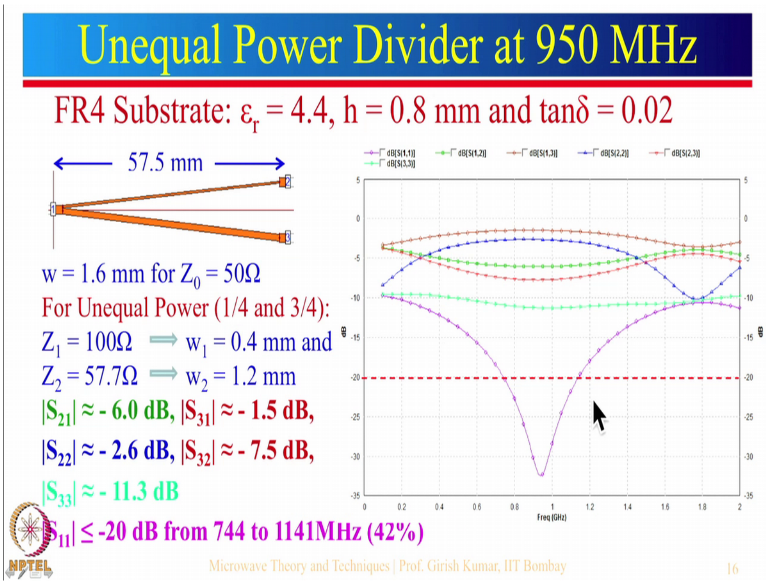

So, you can practice these things, but I also want to show you now the simulated results. So, corresponding to the same design one-fourth and three-fourth we have done the simulation of that. So, corresponding to 100 ohm width 1 comes out to be 0.4 and for this it is 1.2 mm, you can see this is 0.4, this is 1.2. One-fourth of the power is approximately minus 6 dB and three-fourth of power is approximately this here. You can see that the matching has been obtained and the bandwidth obtained here is about 42 percent.

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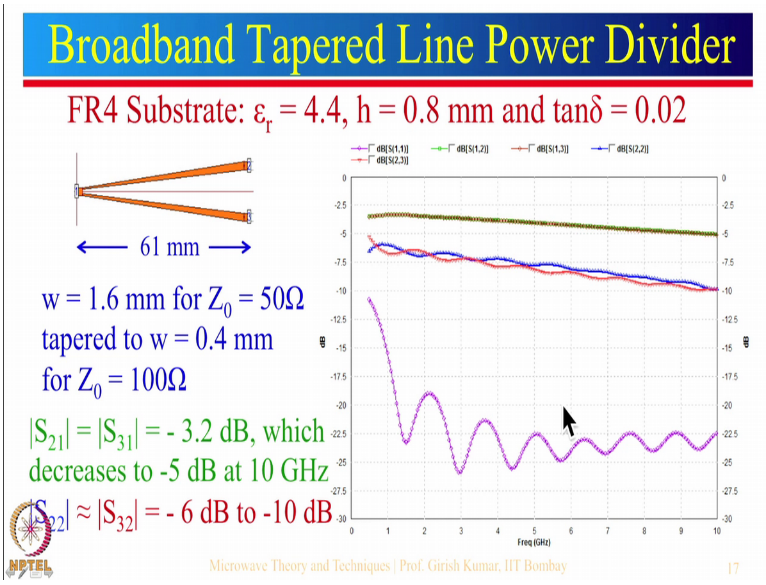

We can also show you some broad band tapered line power divider thing. So, what you do concept is very simple. So, this is a 50 ohm and desired here is 100 ohm. So, take a micro strip line which has a width here belonging to 100 ohm impedance, width here corresponding to 50 ohm. So, you can see here what we have done. So, w is equal to 1.6 mm for 50 ohm tapered to 0.4 mm. So, that is all, this is the linear tapered line and let us see what do we get over here.

So, for this particular case you can see S 21 is equal to S 31 minus 3.2 dB over here, but this here shows from 0 to 10 gigahertz that is a very large frequency range. So, that is what you can see it is decreasing to this particular value here which is minus 5 dB each. Now, S 22 equal to S 32 because we have not put any isolation resistance. So, you can see that at this point it is minus 6 dB which decreases to about minus 10 dB.

Just want to mention here because this whole thing is decreasing significantly the reason for that is we have taken a lossy FR4 substrate, which has a very high tan delta. In fact, one should never be using this particular substrate at this particular frequency, ok.

So, generally FR4 substrate I do not recommend that you should use it beyond 2.5 gigahertz. So, if one uses good quality substrate this decrease will be relatively smaller. But what you see here S 11 you can see that S 11 if we take minus 17.5 dB line you can say everything is less than that value up to even 10 gigahertz. Even if I see 20 you can see here that except for this small thing this whole thing is less than minus 20 dB.

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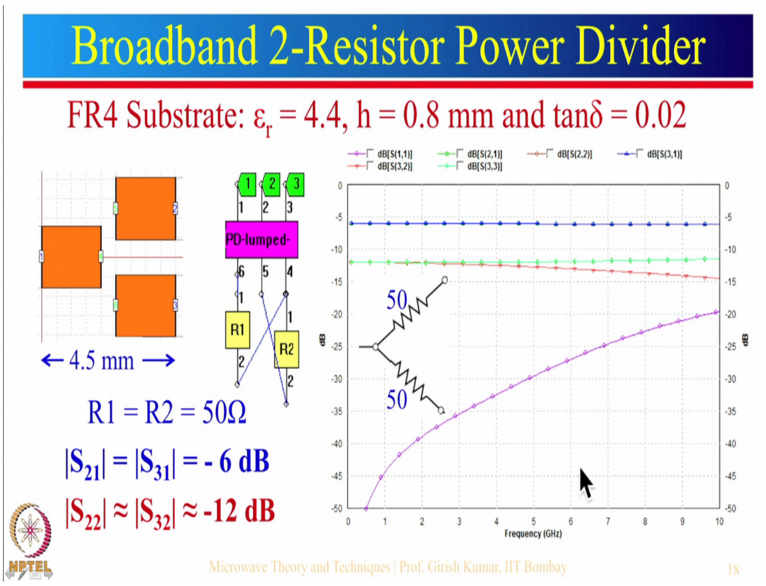

I will also show you quickly 2 ultra broadband resistor power divider also. What are these two ultra broadband power divider? So, here actually speaking if you just put a 50 ohm resistor here and a 50 ohm resistor here. So, what we will happen? This is 50 plus 50 will be 100, 50 plus 50 will be 100, 100 in parallel with 100 will give me 50. So, that is the circuit.

Now, if you look at the response of this same 0 to 10 gigahertz, you can see that S 11 is less than minus 20 dB in this entire frequency range. See the size, very very small. So, now, the question is then why do not we use it. The reason for that is and if you use 50 ohm resistor, 50 ohm resistance, then half the power will be lost here; half the power will be lost here ok. So, the total let us say then one-fourth will go here, one-fourth will go there, half of this part which is one-fourth and one-fourth so that means, if you look at totality total half power will be lost in the resistances over here. One-fourth will be delivered, one-fourth will be deliver, and that is why you see that S 21 is equal to S 31 is equal to minus 6 dB, ok. So that means, one-fourth is going, one-fourth is going over here, ok.

So, only in some situation where you do not mind extra power loss you cannot use this kind of a configuration, ok. So, for lab purposes these things are very simple to use. And you can also see what is the cost of this particular thing. It is very very small. A typical 50 ohm lumped resistor may not even cost 1 rupee. So, it is a 1 rupee, another 1 rupee, this is a small PCB which will not even cost you more than few 10s of rupees. So, the entire thing cost very little money, but the same thing if you want to import from other countries, it may cost you somewhere of the order of 50 dollar or even more and that is very high.

So, that is why you know I emphasize that please start doing design in India. If you do design in India then only we can do make in India, and you can get all these things at a very low costs price.

Thank you very much.