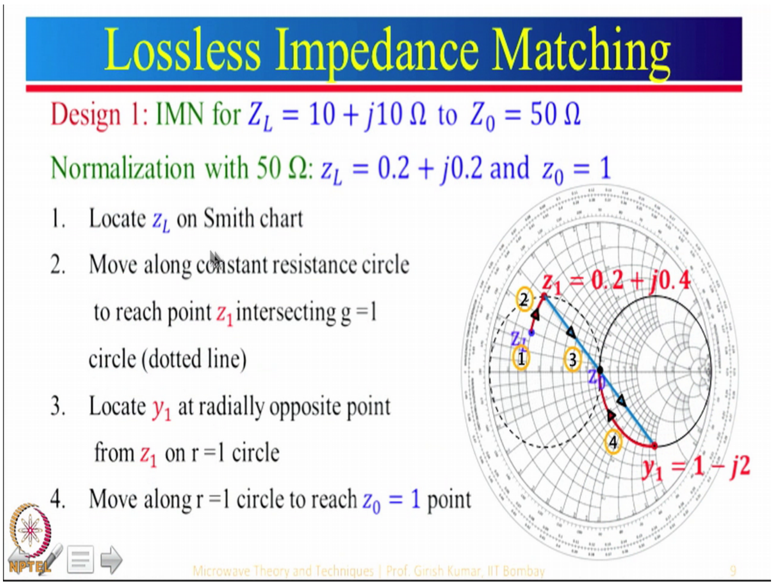
Microwave Theory and Techniques
Prof. Girish Kumar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Module - 03
Lecture - 13
Smith Chart and Impedance Matching – III: using Short and Open Circuited Stubs

Hello and welcome to today's lecture. We will continue our discussion on lossless impedance matching network. So, let us have a little bit review of the previous lecture.

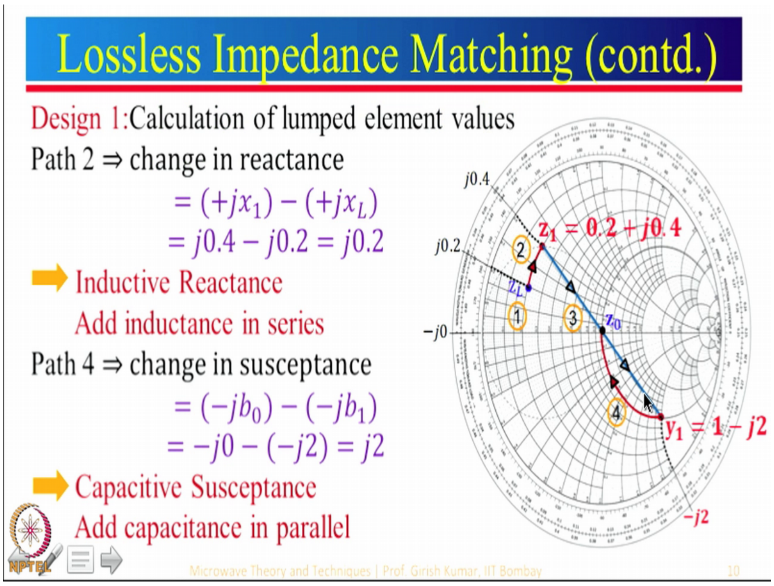
(Refer Slide Time: 00:31)



So, in the previous lecture we had taken Z L equal to 10 plus j 10 ohm and that we had located that on the smith chart. One of the important thing I want to mention that any impedance value inside this particular circle, you can use this particular technique where what should do you locate the impedance value here, you can go up or you can go down the point can be here or here or here or here ok. So, you can go either up or down and then from here take the reflection and then reach to the center point which I always call bull's eye. Think about this you know that you are targeting something so, you reach to this thing. So, what you need to do then? You need to correction from here to here so that the losses are minimal and maximum power transfer takes place.

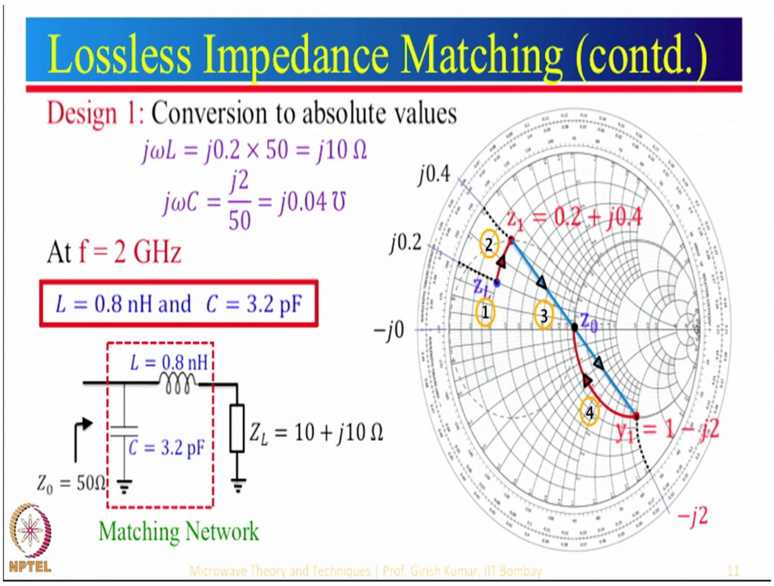
So, or in a game of a band what happens? You get less marks here and you get maximum marks here. So, there you try to maximize your marks here we try to maximize that power transfer. So, any impedance value with in this particular circle this approach can be used.

(Refer Slide Time: 01:42)



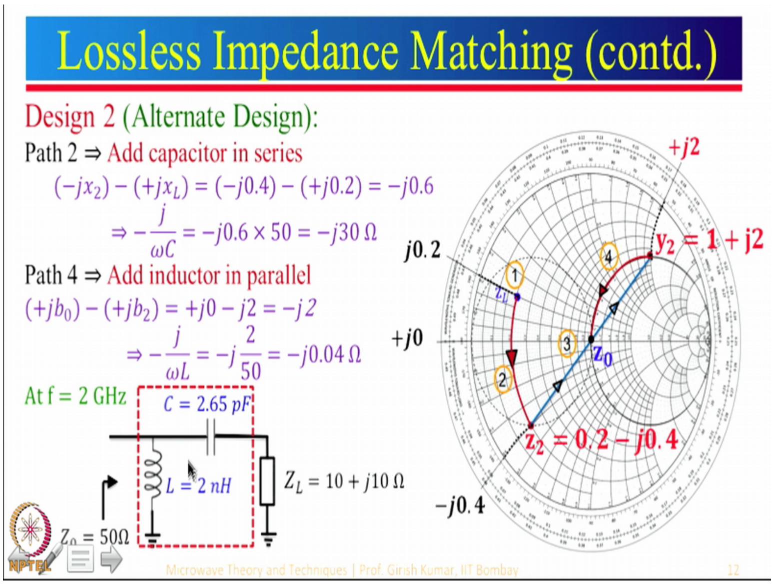
Then we had seen two possible design in one case we had gone up and we realize this particular network.

(Refer Slide Time: 01:47)

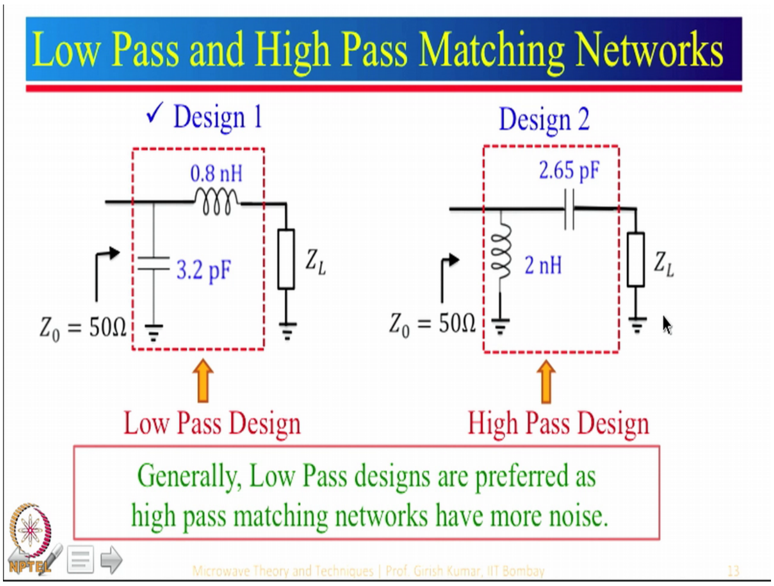


In the other case we had gone down and realize this particular network.

(Refer Slide Time: 01:51)

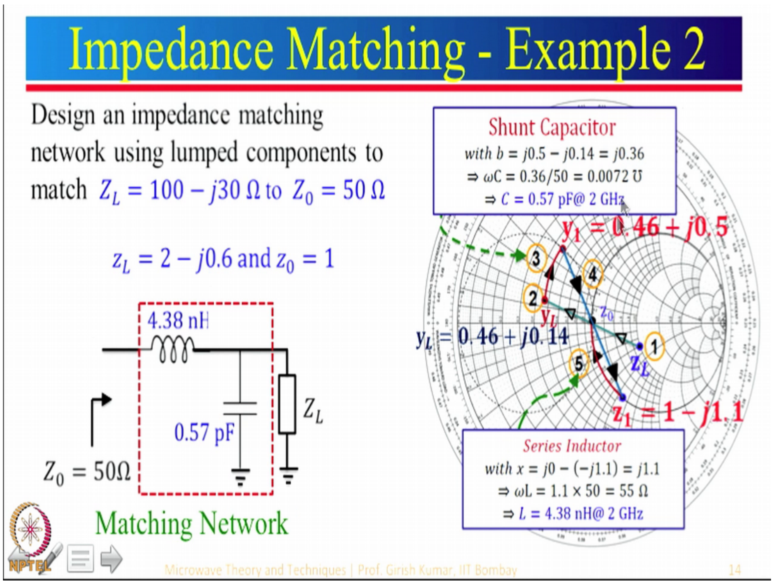


(Refer Slide Time: 01:56)



And then we had looked at the comparison low pass design versus high pass design and I had mention that low pass design is generally preferable then the high pass design.

(Refer Slide Time: 02:07)



Then we took another example two in this particular case now impedance was not here impedance actually within this particular circle. So, when the impedance in this particular circle now I am taking an example Z L which is 100 minus j 30, but you can have any other impedance value in this particular region this particular concept will be applicable. So, from Z L you cannot move in this here because you are not in this particular circle. So, take a reflection through the central point reach to point 2, at point 2 read the corresponding value of y L which is given by this particular value here.

Then now you move along this particular constant circle and when you move along this here you can read the new value which is y 1 remember real part will be same as this imaginary part will only change. So, what we need to do? We need to add something in y. So, anything which needs to be added in y has to be in shunt.

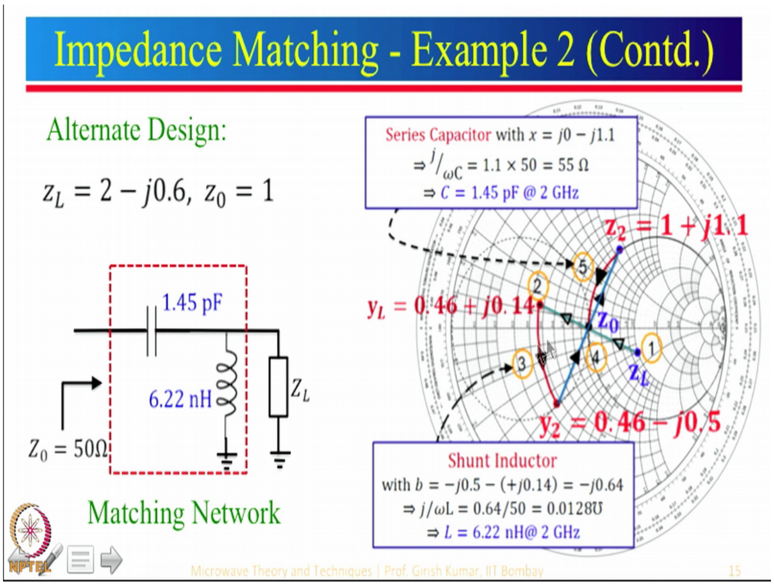
So, what we need to add from 0.14 to 0.5. So, what will be the difference? Difference will be 0.36, and in y we want to add plus 0.36 and in y it is always capacitance so that will be the capacitance I have shown the step here. So, the shunt capacitance you can see that b value will be 0.36 and we can say that j omega C or j is omitted from both the side. So, omega C will be 0.36 divided by 50 that is the denormalized value and then from here we can calculate the value of C at 2 gigahertz. So, this is the value of the capacitance which has to be put a shunt.

So, now from y 1 we took the reflection went to Z 1. Now, the real part of Z 1 has to be one otherwise you have made a mistake. Now, read the imaginary value which is minus j 1.1 we need to add plus j 1.1. So, we need to add plus j 1.1 and we have to add in impedance. And anything in impedance to be added it should be in series and plus j value will imply omega L or j omega L j will be here also and that is comes out to be 55 ohm and from here we can find the value of inductance and this is in series.

So, this one here completes the design ok. So, what we have Z L in parallel with capacitance and then in series with inductor. Now, you can see that these values are very small and which does happen, that is why we do not generally recommend lumped impedance matching beyond 1 or 2 gigahertz because these component values become very small these are good designs at lower frequency.

So, generally what do we do at higher frequency? I will tell you that little later on, but let us just look at the alternate design for this also.

(Refer Slide Time: 05:31)



And this time what we have done? This Z L go to here instead of going up we are going down. So, if you are going down this was plus j 0.14 you read this value so that means, now we have to add minus j 0.64 you have to add that and since we are adding in y and negative value it will be a shunt inductor. And from here you can calculate the value of inductor which is given by this. And then from here go through the central point reach to point Z 2 it is very important.

Whenever you are trying to do this impedance matching please remember one thing locate the numbers in the title itself ok. For example, number 1 you write Z L; number 2 write y L, you are moving this write y 2 from here you have taken a reflection write Z 2. And then now at this point we have to add minus j 1.1. So, minus j 1.1 will be capacitors and it will be in series so that is a series capacitance which we have to add and this is the capacitance value. And this relatively completes a design, these values are more readily available compared to the previous value, but again this design is not a very good design in a sense that this is more like a high pass filter whereas, a previous one was low pass filter.

So, so far we have taken two different design using lumped element in one design we had the Z L value inside this particular circle. In the another design we had to the load impedance inside this particular circle. So, now, suppose what happens in the impedance is somewhere here or somewhere here ok, in that case you can actually use either of these two approaches ok. So, what were that these two approaches? Suppose if the load impedance was in this particular circle generally what we did we added something in series and then we took that reflection and then y was in parallel. In this case what happened? We took the reflection, we reach to y and then we added something in y which was shunt.

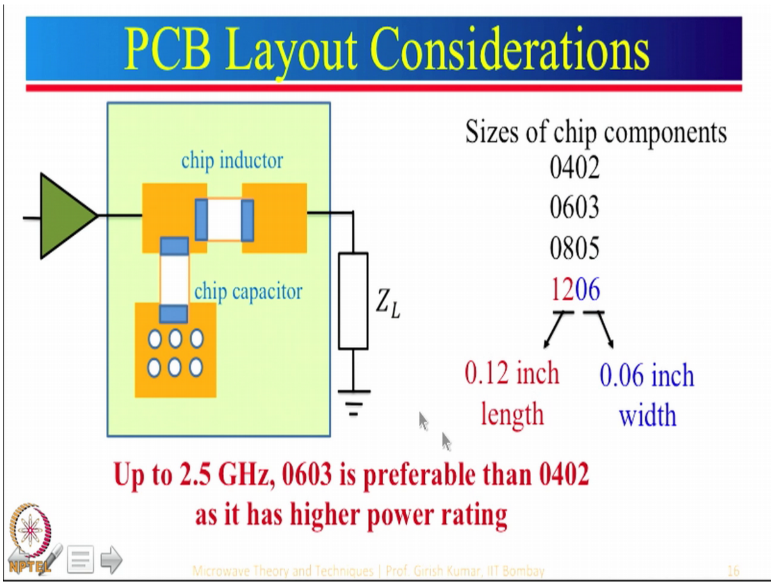
So, suppose if the point is somewhere here that at this particular point, what you do? You add something in series at and reach to this particular point from here take the reflection come to this point and this will be y equal to 1 minus j b you add plus j b to the y and that will be a capacitance you will reach to the center point.

Suppose the point was somewhere here then what you can do? You can again add something in series and then reach to this point take care reflection come back over here. However, from here you can also do another thing instead of going in series like this you can actually take a reflection go to y and then you can add something in shunt and then reach over here then you add something in series. So, there are multiple ways to solve the problems when the impedances are neither in this circle or in this particular circle here.

So, you always have the option when the impedances are here or else here you can add first component and series then in shunt or the first component can be in shunt or second component can be in series ok.

Now, once that design is complete now we have to design a PCB. PCB is Printed Circuit Board. So, let us see how do we do that.

(Refer Slide Time: 09:20)



So, here let us look at this is the load. So, from the load we have to add let us say a chip inductor this is the previous design, this is that a low pass filter design, but it can be chip capacitor this can be chip inductor depending upon whatever the case may be.

So, now we are going to add a chip inductor. So, this is what is the PCB layout that is an amplifier. In fact, it can be part of the same PCB after the amplifier has been designed you actually use the same substrate. So, what we need to do? Generally this is used as a 50 ohm line. So, you calculate 50 ohm line width corresponding to whatever the substrate you have taken and I have given you the formula for micro strip line because this is 50 ohms it is better to use this 50 ohm. So, this width will be same and now we put the chip inductor and now we have to put a chip capacitor here.

Now, grounding in the micro strip line as I had told you can use a PTH which is known as Plated Through Hole. But however, if you see I have not just used a single PTH I have used multiple PTH over here. So, what is the reason for putting multiple PTH or plated through hole. Now just to tell you, so what are we doing? Suppose if you use only one particular PTH instead of using 6 shown over here if you use only one so what will happen. Let us say this is the upper part of the substrate and the lower part of the substrate is all ground and basically this capacitor is to be grounded.

So, what you do? You put a plated through hole and through this hole what happens and what is the plated through hole technology, basically you can give it to the PCB manufacturer who will fabricate PCB for you and you actually have to put the plated through hole. So, basically in that hole the copper is actually speaking put around that. So, the top connection is connection to the ground connection.

But now there is a certain height of the substrate. So, this particular single hole actually speaking adds inductance from this point to the ground point ok. So, in a reality if you put only one what the circuit will see a chip capacitor in series with the inductor from here to the ground. And I just want to tell you that this inductor can be of the order of 0.5 nanohenry to 1 nanohenry and at very high frequency, that can be very detrimental in the design.

So, what we have done here by putting 6 of these. So, what happened? So, from here to ground there will be 1 inductor this will have another inductor and all that. So, we have now 6 inductors in parallel and inductors in parallel there inductor value will reduce and if the inductor value reduces Z equal to j omega will reduce and that will be closer to the short circuit.

Now, these chip components whether it is a chip resistor or chip inductor capacitor they come in different sizes, ok. So, you will actually see that many a times you see it says 0402 or 0603, 0805, 1206 and so on. Now these are basically not like a normal resistor or a normal inductor you would have seen a normal resistor if you see that is you know a resistor is like this and there are two leads are there or inductor you would have seen a inductor which is wrapped around those are very large inductor values. Here we need very small values of inductors and capacitors and they are available in the form of the chip. And what these numbers really say actually speaking these numbers signify their size.

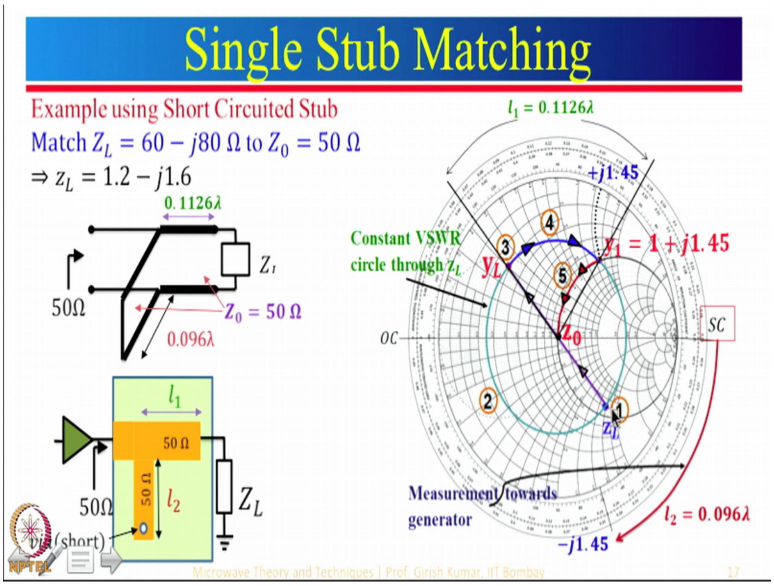
So, what you see? The first two digits; the first two digits basically are equivalent to you put a point before here. So, this if this is the number this is 0.12 inches length. If this is the number 0.04 inches is the length. Now, just to tell you 0.04 inches will correspond to 1 mm ok, 0.06 inches will correspond to about 1.5 mm. And then the last two digits basically correspond to the width of this particular chip component.

So, if it is 0 2 that means, 0.02 inch or 0.03 inch or 0.06 inch and you can multiply this with 25.4 to get the value in millimeter. So just to tell you now up to what frequency which one is preferable and how. So, generally speaking 0402 is preferable at higher frequency little bit lower and lower and lower.

So, if you are designing at a high frequency I have written the comment also here that up to 2.5 gigahertz 0603 is preferable then 0402 as it has higher power rating. So, in general this one will work at a higher frequency this one little lower this will lower, but still these are all good even in the gigahertz frequency range but the power dissipation rating is very small.

So, typically these values of 0402 or 0603 they can handle only about 0.1 watt. But do not be afraid most of the time when we are dealing with the microwave circuits if you are not looking at the output power sight if you are looking at the input power most of the power levels may be of the order of 1 milliwatt or even 10 milliwatt, except at the last stage high power amplifier which can be 1 watt or 10 watt or 100 watt. So, their definitely please do not use these components for impedance matching.

(Refer Slide Time: 15:44)



So, now we look into the another scheme which is known as single stub matching. So, the examples are here we are using a short circuited stub I just want to mention here that in the micro strip technique we do not use series stub matching. You might have studied in your electromagnetic wave course series stub matching or shunt stub matching, well in micro step we do not use series step we actually use a shunt stub matching also it is much easier to realize you can see here this is all the impedance matching technique is it does not require any inductor or any capacitor, but let us see step by step how we can do that.

So, here let us say the example is that Z L is 60 minus j 80 ohm and that has to be normalized with Z 0 equal to 50 ohm. So, the normalized value is 60 by 50, 1.2; 80 by 50 is 1.6, now you locate this value on the smith chart. So, this value 1.2 you locate here you have 2 minus Z you go down and that is value is over here Z L. Now, here all the techniques which we have discussed well lumped impedance matching or not at all applicable. So, please do not get confused between the two techniques. So, here you locate Z L. Now, take this as a center point and this as here radius you draw this particular circle, ok. So, that is the step two that you draw the circle, ok. So, from here now thus next step is you take the diagonally opposite point which will be y L. So, that is a step number 3.

Now, this y L at this particular point what you do? We need to do the single stub matching. So, at this point this is what it is which is Z L and now we have reached to y L and why we did that it is not same as before that you have to go to the constant r circle or constant g equal to one circle nothing like that over here, ok. So, here we simply go to this and now on the smith chart you will actually see that it is also written that this is a measurement toward generator or this point here it will be measurement towards load. So, from the load we are moving towards generator or we are moving towards amplifier.

So, at this particular point just on this circle itself you keep moving till you come to this particular circle which you know it is a r equal to 1 circle. So, come to this particular point. So, from here to here we have to add the line length. How do we measure or calculate the line length, what you do? From here you draw the line up to this here wherever it is cutting from the center, you put it over here and then you can measure the length from here to here all these things are actually mentioned on the smith chart.

So, just to tell you suppose this is the point you can see over here I have shown here this particular point as open circuit and this point as short circuit. Why I have done that? Because we are doing all the matching using shunt stub. So, in shunt if we are adding that shunt we can add only when it is in y. So, in y, y equal to 0 implies open circuit, y equal to infinity implied short circuit and from here also I want to mention. So, if you look at this scale here it will actually show you 0, 0.25 lambda and comes back here which is 0.5 lambda. So, from here to here half will be something like 0.125 lambda. So, this you can just see read this value, read this value take the difference and that comes out to be L 1 equal to 0.1126 lambda.

So, what you do at the load? We are moving along the generator. So, you move along this. Now, remember these are all 50 ohm like you move along this particular thing. So, that length is 0.1126 lambda and we have reached at this particular point.

Now, remember right now everything is in y ok. So, y 1 is equal to what 1 plus j 1.45. Please ensure this has to be 1 ok, if it is not 1 again you have done something wrong. Now, you read the corresponding value which is plus j 1.45. Now, what is our objective? Our objective is to reach bull's eye which is the central point. So, from here we have to move along this particular thing, but we can also do the same thing using it transmission line let us see how we can do that. So, this is a plus j 1.45.

So, we have to add minus j 1.45 to this and that minus addition has to be done in shunt because we are adding something in y. So, what you do? You locate minus j 1.45 on smith chart not 1 plus, but minus j a 0 minus j because 1 you do not have to add anything. So, minus j 1.45 actually all this thing will be at the outer of the circle. So, you locate this point here which is minus j 1.45.

And then what you do? You draw the line from here and if it is a short circuit line you take this thing from here to this because this is a short circuit point. I will also give you the design for open circuit stub here also. So, if you have decided to take this particular thing as a short circuited because I have taken example using short circuited stub. So, from the short circuit which is this point here we are moving towards generator. So, if we move towards generator we stop at this particular point which will be minus j 1.45. Read this length again you can read the length from here to here and that length is l 2 which you locate here.

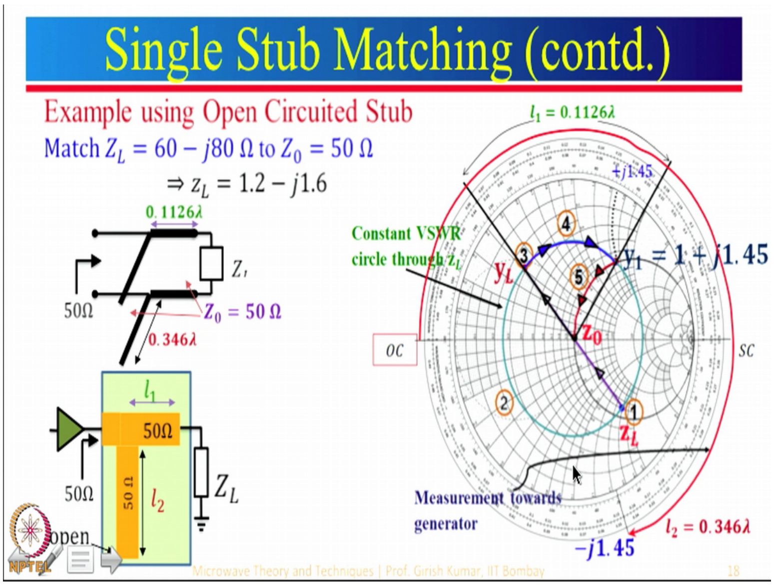
So, now this is the length l 2 which is 0.096 and that is a short here. So, this is the length l 2. So, how do we realize the short circuit? Again short circuit can be realized using a via now I have shown here only single via, but you can actually use even two shorted via or two PTH here also and that length will be nothing but equal to l 2.

So, let us just look at the design, what we have here is a unknown impedance. From this unknown impedance we took the reflection along this particular circle the radius of that is given by this so you go to this opposite point. So, till now we have reached from 1 to 2 to 3 then from y L you move along the same circle till you reach this particular circle, read the value of y 1 which is this and by doing this particular thing from here we have come to this particular point here.

At this particular point the value is 1 plus j 1.45 and from here we are looking at this particular point. So, input impedance we have to look for here or you can say input admittance we have to look from here and the value of that, what we have to do we have to add minus j 1.45. So, from short circuit starting point we reach to this particular point here. So, that basically completes the design ok.

Now, we will take another example of this whole thing except that instead of a short circuited line. This time we will take the open circuited line and then will also look at what are the variations possible.

(Refer Slide Time: 23:55)



So, let us just take example using open circuited I have taken exactly the same problem. So, Z L is same as before Z 0 same normalize 1.2 minus j 1.6. So, let us see the step wise they are very similar step. So, this part also looks very similar. So, Z L locate on the smith chart using this particular distance as a radius draw the circle which is step 2 then take the diagonal point which is 3 the y L from y L, you move along this you reach to y 1.

Now, till this point this everything is same as in the previous case. So, there is a no change at all ok, but now the change is that we have to add what we have to add we have to add at this particular point minus j 1.45. So, you locate minus j 1.45 as before, but now we have a open circuited stub where is a open circuited stub point this is the open circuit point, ok.

So, from here do not move in this direction because this is a movement towards load we have to move towards generator. So, from here you actually move along this and this and this and this length comes out to be 0.346 lambda, ok. So, by putting this particular thing here the design is actually complete, ok.

So, you might now wonder that which one to be used when. In fact, for this particular design I do not recommend this particular solution it is better to use shorted stub. Why? The reason for that is that this length is very large this is now 0.346 lambda in the previous case that length was 0.25 lambda smaller. So, depending upon you should always see what is the problem and accordingly you choose the solution. So, the better solution instead of using an open circuited stub it is better to use short circuited stub because the length of that short circuited stub will be 0.25 lambda smaller than this over here.

Let us take a different example instead of Z L over here suppose if the Z L was somewhere here ok, then what will you do ok. So, let us just look into this thing. So, Z L is here instead of here, ok. So, we locate the Z L over here then what we do? We draw the circle like this it will be little bigger circle now. So, from their Z L you are going to take a diagonal opposite point and that will be over here at this particular point.

So, now, from here you have to move in this direction because you have to move towards the generator design. So, from here you move till you cross the circle. So, you do not have to go all the way to cross at this point, even crossing at this particular point is actually acceptable anywhere on this circle you cross.

So, from here we moved along that circle only we reach to this particular point now again everything is y. So, we can say that y 2 will be 1 and now the value will be minus. So, this will be 1 minus j b let us say, where b is the corresponding imaginary part. So, this is 1 minus j b. So, you locate plus j b on the smith chart. So, plus j b on the smith chart will be somewhere here. So, now, plus j b we have to add, ok.

So, now you have to see which one is a better thing, it is better that you start from open circuit you because you have to move to this point. So, this length will be relatively shorter compared to if you take a short set get stub then you will have to move all the way around. So, for this particular problem where let us say Z L is somewhere here, then these two this point move over here, stop at this point read the value locate the point over here and then you can use open circuit stub.

So, for this particular problem this is not a good solution because it uses a larger length, a short circuited thing is better option, but the design which I just showed you that would be better for a open circuit stub because that will use a smaller length.

In the last few lectures we talked about various lossless impedance matching network using smith chart. Using lumped elements we talked about two configurations one was low pass network another one was high pass network. I also mentioned about what are the advantages and disadvantages of these two approaches. After that I talked about single stub matching technique in which a shunt stub is placed along with the transmission line to do the impedance matching.

So, in the next lecture I will talk about a b c d and s parameters followed by various applications of microwave circuit. So, till then bye, enjoy yourself work hard. See you in the next lecture; bye.