Microwave Integrated Circuits.
Professor Jayanta Mukherhee.
Department of Electrical Engineering.
Indian Institute of Technology Bombay.
Lecture -23.
Impedance Matching Circuits for Amplifiers.

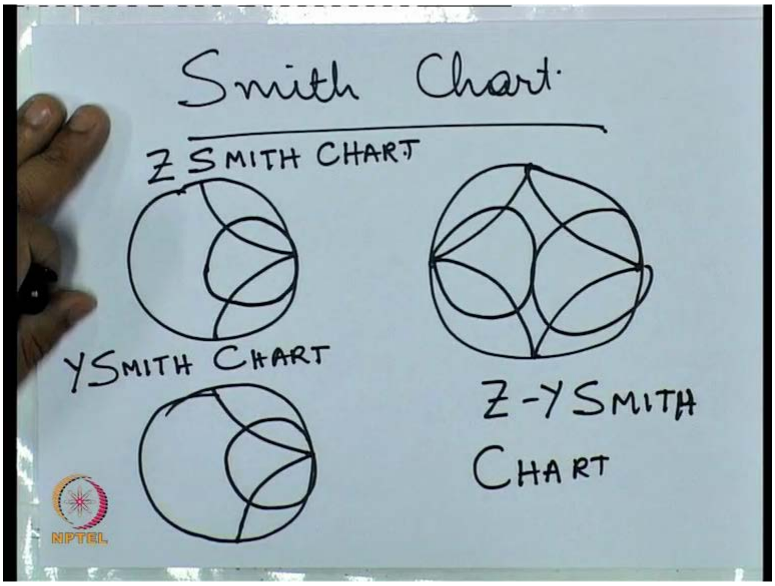
Welcome to another module of this course microwave integrated circuits, we are now in week 6 of this course, so far all the circuits that we had considered were basically passive circuits. So, passive circuits are one which do not produce or circuits where the output power or rather I should say passive circuits are the ones which do not require external power supply whatever power they need for their operation come from the input itself. So they do not need an external DC source for their operation.

Then the active circuits are ones which for their operation separately need a power supply it can be a DC bias circuit or it can be directly device can be directly connected to power supply. Now active circuits, some common examples of these active circuits are amplifiers, mixers and various other active circuits that are used. So when active circuits, when we are considering active circuits for microwave engineering, there is often the problem of impedance matching i.e. we make a device but it have to be properly input and output matched to minimise the reflection.

How do we do this, so in this module, we will be studying about how these impedance matching networks are designed. You may be wondering why impedance matching is so important, it is important because impedance matching is the main determiner of how much power is being, how much power will flow through an active device. It is true that there are other intricacies within the device for example the biasing and how the active device should be acting within a circuit. But most of the circuits, for example if you are designing an amplifier circuit for microwave engineering, it might be a simple say NPN or your PMOS or NMOS type circuits.

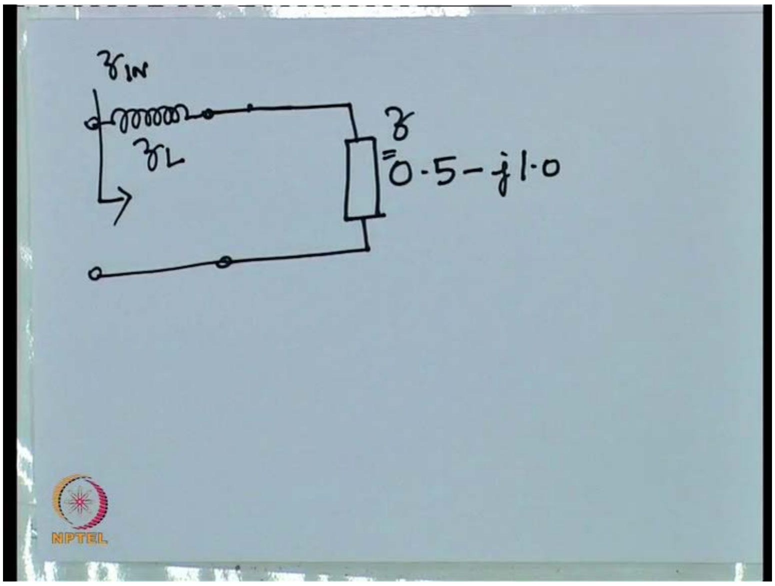
And once the circuit topology is fixed, all that is left to be designed is the input and output load in the circuit. So, let us consider how to do this design of this input and output matching circuits for active devices, specifically 2 port amplifiers.

(Refer Slide Time: 3:05)



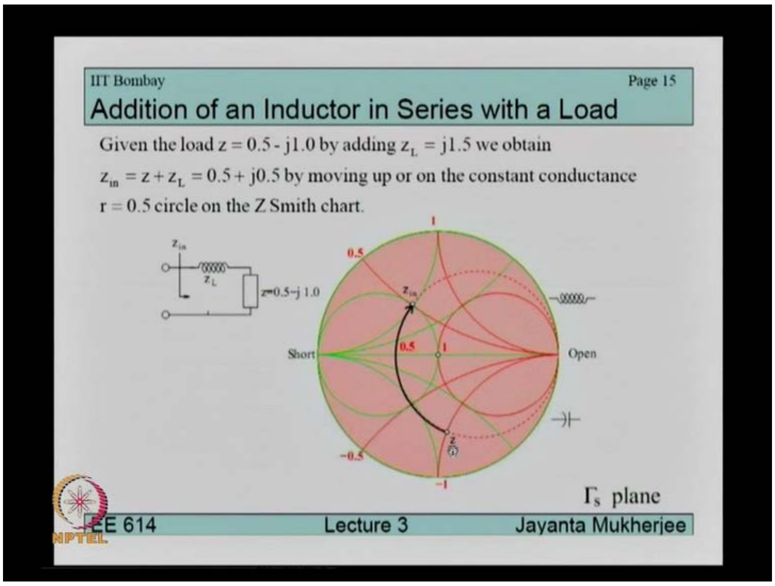
So let us consider 1st, we have already studied our Smith chart in the previous lectures. Just to review it once again, we have 2 types of Smith chart, one is the Z Smith chart, then there is a Y Smith chart and then when we combine both, we get what is called as ZY Smith chart.

(Refer Slide Time: 4:42)



Now suppose we have a load connected let us consider a simple load Z and say it is normalised impedance is this, so this small z is equal to this. And we now connect an inductor in series like this. So, this is an inductor having a normalised impedance zl. So, when we connect this zl, how does the input impedance change.

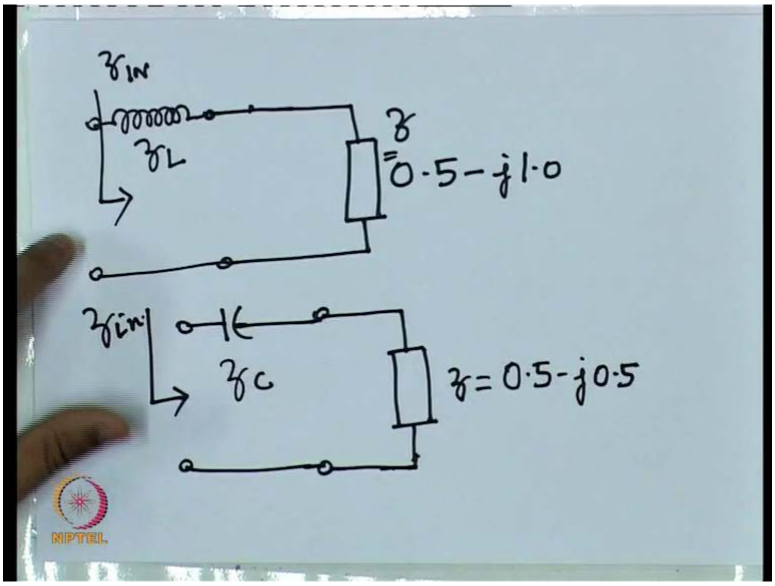
(Refer Slide Time: 5:45)



So, if we go to the slides on the screen this point, this point here represents our impedance Z given by 0.5 - J1.0 and we have connected an inductor in series with this impedance as shown. Now we recall now recall that when we connect an inductor in series, then we will be moving in a clockwise direction from on the Smith chart if we connect capacitance in series, then also we will be moving in a clockwise direction however we will be moving towards the bottom side of the Z Smith chart, whereas for an inductive zl, we will be moving upwards.

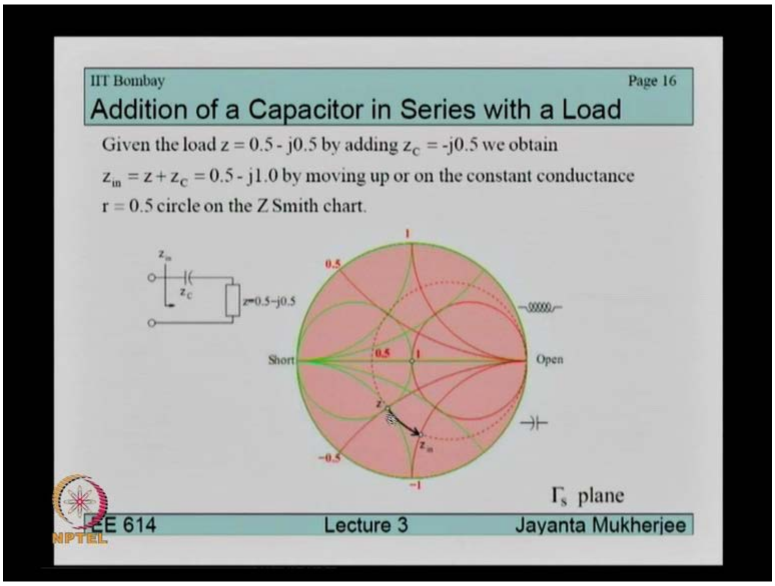
So, this is the point where we started initially, z. On connecting impedance and reactants zl in series, what happens is this point traverses a constant resistance circuit, since we are not changing the resistance and it will appear at this point Z.

(Refer Slide Time: 7:11)



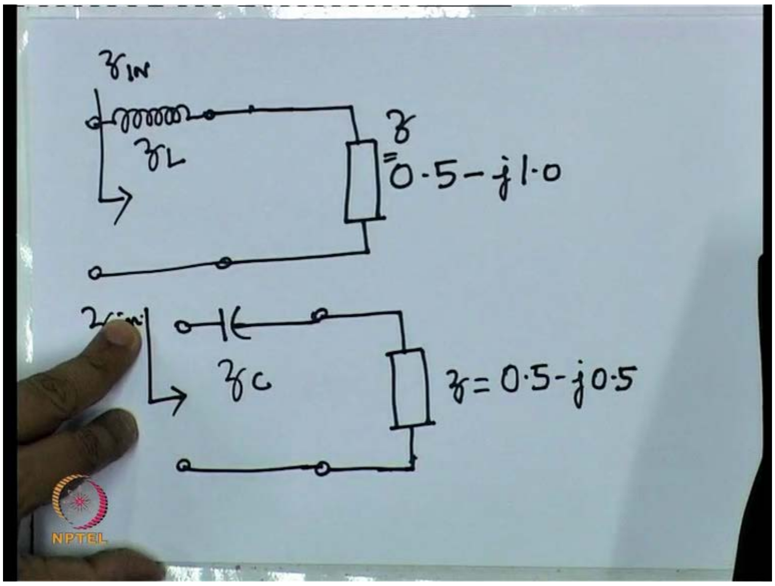
Now see now consider the other case, suppose we have the same load Z but now instead of the inductor, we have a capacitance in series. Then what happens, suppose this load is, this is zc.

(Refer Slide Time: 8:00)



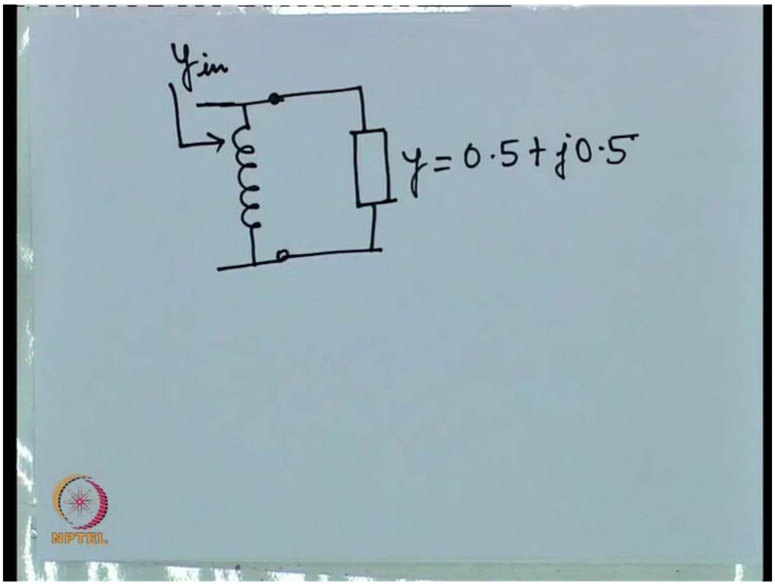
If we go to the slides on screen, we see that this is the initial Z that we had, just like in the previous slide but then on connecting a capacitance in series what happens is that this Z travels and becomes a new value Zin and the locus that we travel when we move from Z to Zin is along a constant resistance circle and in a downward direction.

(Refer Slide Time: 8:42)



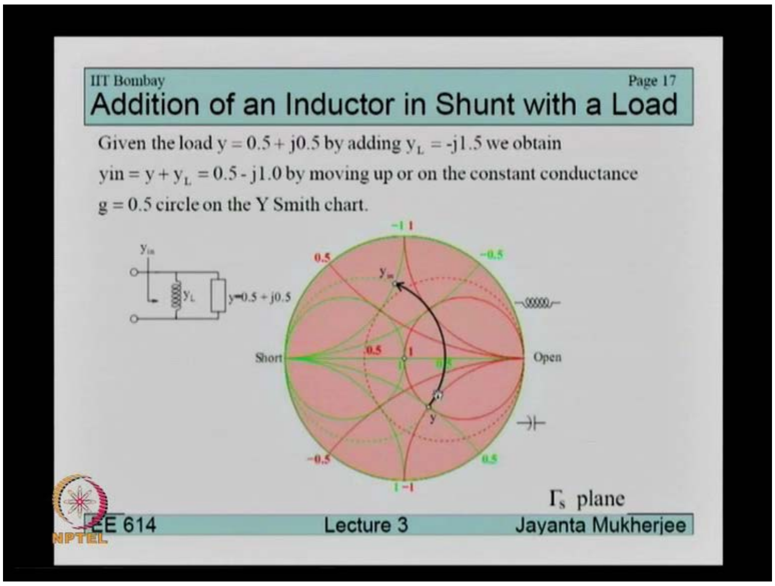
So, when we have an inductor in series, then we move in a clockwise direction upwards. And when we have a capacitance in series, we move in anticlockwise downwards, direction downwards. Let us now consider the case when we have an inductor in, in shunt with the load.

(Refer Slide Time: 9:15)



If we have an inductor in shunt, suppose we again have a load Y equal to 0.5+ J0.5 and we connect an inductor in shunt as shown. Then what happens. So, let us go back to our slides on the monitor.

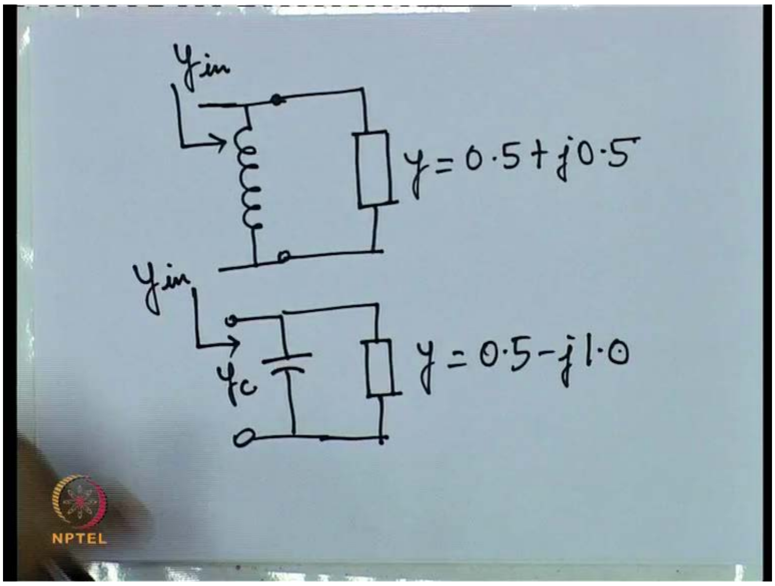
(Refer Slide Time: 9:49)



Now this is the ZY Smith chart, the red lines belong to the Z Smith chart and green lines belong to the Y Smith chart and I had mentioned earlier that in a ZY Smith chart, if you plot a particular impedance with respect to the Z Smith chart, then it will also be the correct position with respect to the Y Smith chart.

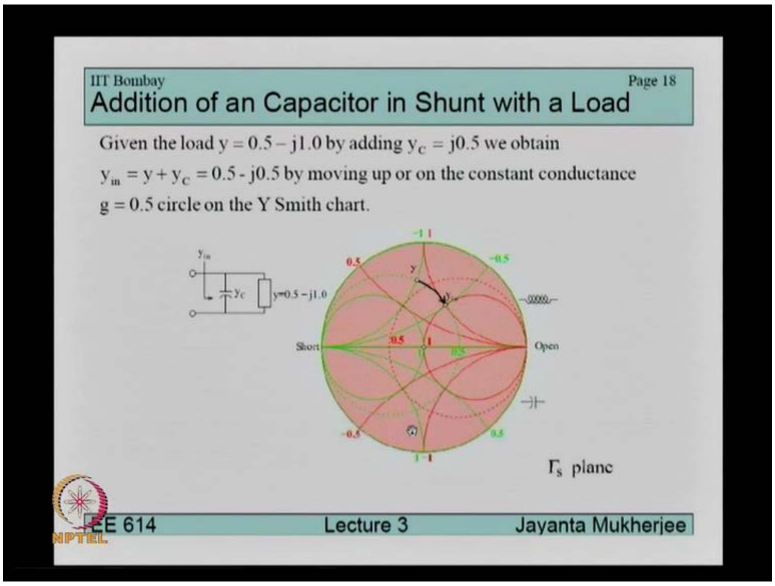
Here we have this impedance or admittance Y and on connecting inductor in shunt, the locus of this point which moves along a constant conductance circle till it reaches this point YN.

(Refer Slide Time: 10:36)



And finally let us consider the case when we have a capacitor in shunt with the load. So, say our Y is equal to 0.5 - J1.0 and this is YC what will YN be.

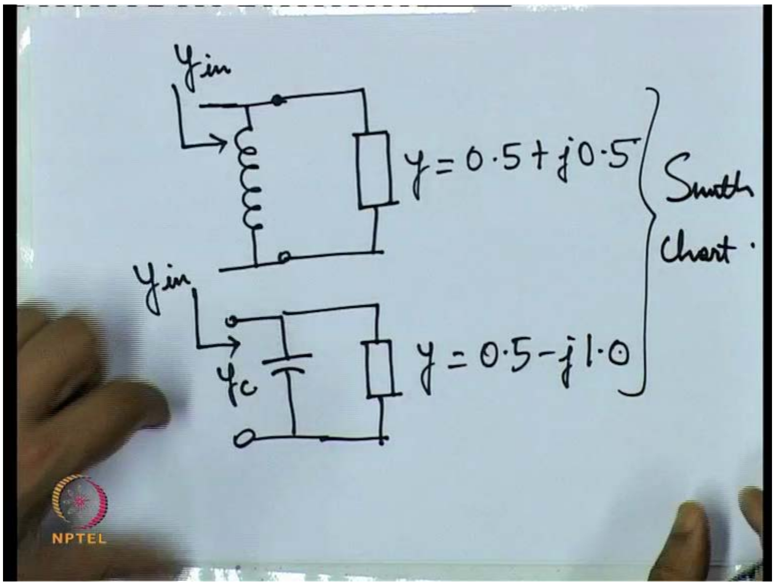
(Refer Slide Time: 11:05)



For this again we go to our slides on the monitor and we see that on connecting a capacitance in shunt Y traverses in the anticlockwise direction along constant conductance circle till it reaches the point YN.

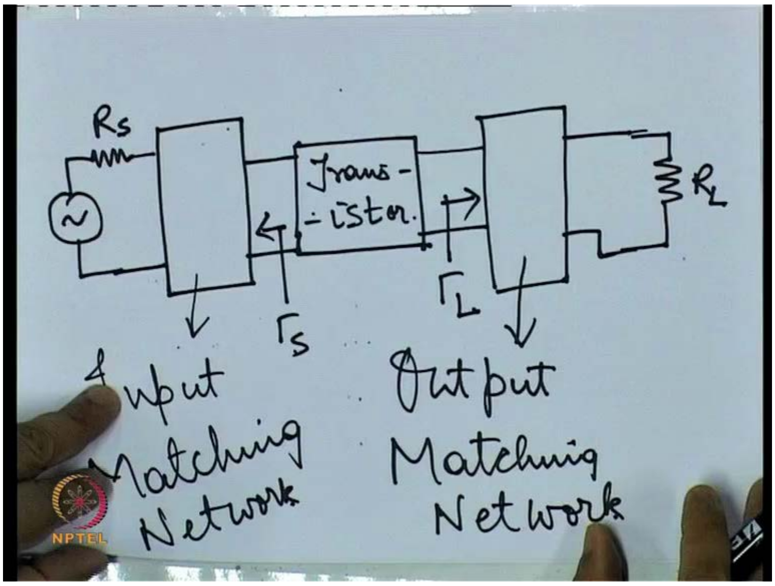
So, essentially what I would like you to understand is that when we have a capacitive load, whether in shunt or in series will always move onwards and when we have inductor, inductive load whether in shunt or in series will always move upwards.

(Refer Slide Time: 11:52)



So, that was, so this is the way we move along the Smith chart.

(Refer Slide Time: 12:02)

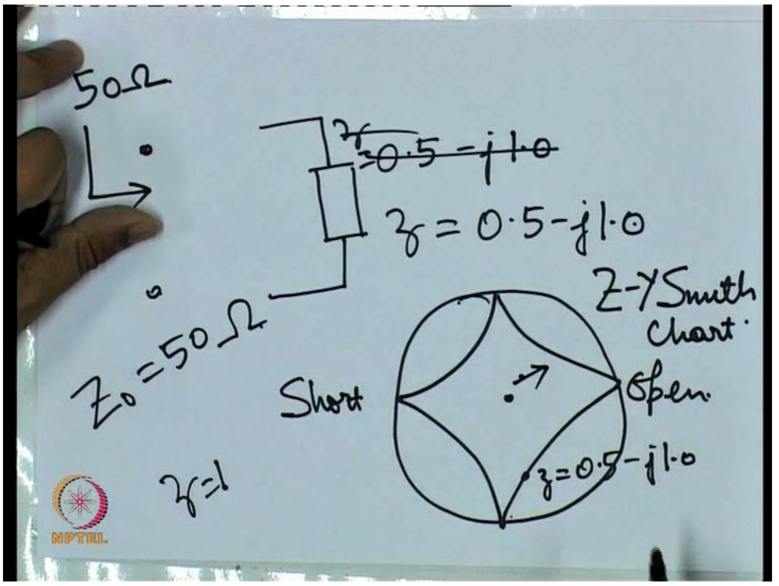


Now when it comes to designing matching networks for amplifiers, let us suppose our amplifier is like this, state has a transistor, some transistor inside it, now your generator will have certain input impedance RS and there will be some load RL.

Here the transistor needs to be properly matched at the input as well as at the output. Now, at the input, therefore we need some kind of network to act as an interface between the generator and the transistor and similarly at the output of the transistor also, we need a network which will act as an interface between the load and the transistor. Now this network that is that between the transistor and the load is called the output matching network.

And this network which is there between the generator and the transistor is called the input matching network. Now say so our input and output matching networks have to be properly designed so that the output impedance that we see here is converted to this generator source input. Similarly here also my output matching network has to be designed in such a way so that my at the output of the transistor whatever impedance exists, that is the output impedance of the transistor is converted to the load impedance. Now, how do we do that?

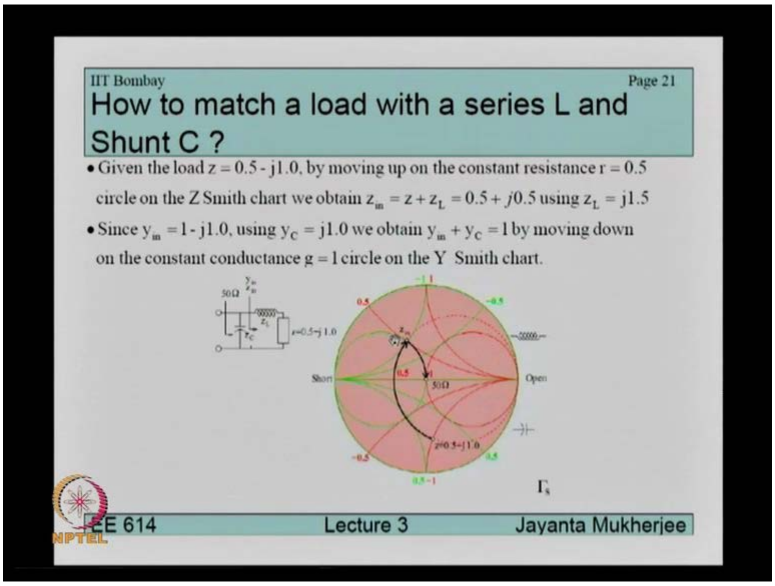
(Refer Slide Time: 14:22)



Now to understand the way in which we can do this, let us see again an example. So, we already saw that when we have an inductor in series or shunt, we can shift our impedance or admittance and they will be shifted upwards in a ZY Smith chart when we have a capacitor in series or shunt, the impedance or admittance will be shifted downwards in the ZY Smith chart. Therefore let us consider that we have an impedance, here of course all the impedances and admittances that we are considering are normalised impedances and admittances.

Let us suppose we have an impedance Z given by (let me write it properly) and we want to realise we are to have some network in between so that we finally realise 50 ohms impedance at the input of this network. Now to do this, let us consider our Smith chart, our Z equal to 0.5 - J1 .0 is somewhere here on this ZY Smith chart. This is of course open, this is short, this is a ZY Smith chart. So, from here we will have to bring it to the centre because this is the point corresponding to Z equal to 1, this is a normalised impedance. And normalised impedance corresponds to whatever our characteristic impedance is. In this case suppose our Z0 is equal to 50 ohms, then this point will correspond to Z equal to 1 or the 50 ohms point.

(Refer Slide Time: 16:50)

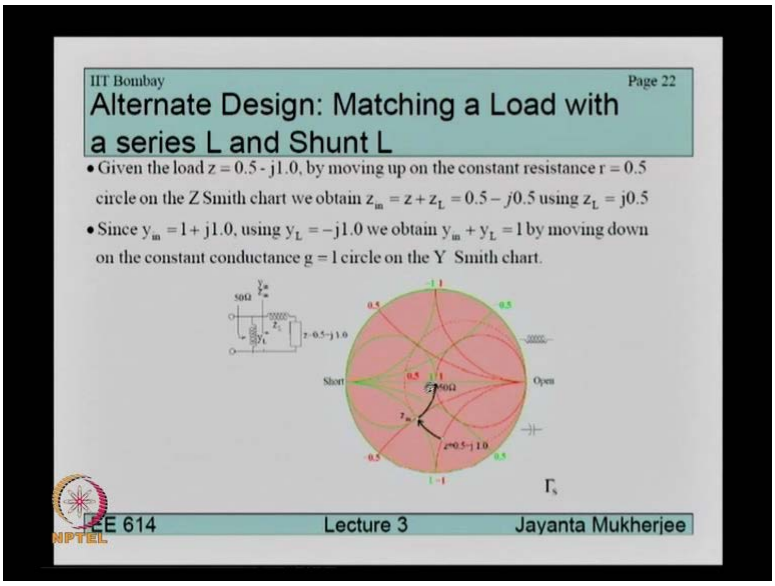


So, let us see now how this is… If we can go to the slides on the monitor, so this is where we were starting from, this is Z equal to 0.5 - J1 .0 and then if we connect an inductor in series then as I had mentioned before that it will be moving upwards because the upward part of the ZY Smith chart is inductive and the lower part is capacitive, we will be moving upwards along a constant resistance circle till we reach this point say Zin at this point the input impedance is Zin or Yin, if we consider the Y Smith chart in the ZY Smith chart. And after that once we go from here to this point, we have to come back to this point at the origin. So, to come back we need to move in a clockwise direction once again but then we need to go downwards.

To do this, as we have learned earlier, to go downwards, we can use a shunt capacitance, then this shunt capacitance will move downwards along this constant conductance circle. Now how much inductance do we need so that we go from here to here and which constant conductance circle we will choose you. We choose that conductance constant conductance circle that responds to the real part of Y being one was the G equals to 1 circle. So, we connect that much inductance in series so that this Z go up till this edge of G equals to 1 is green circle, the conductance is one.

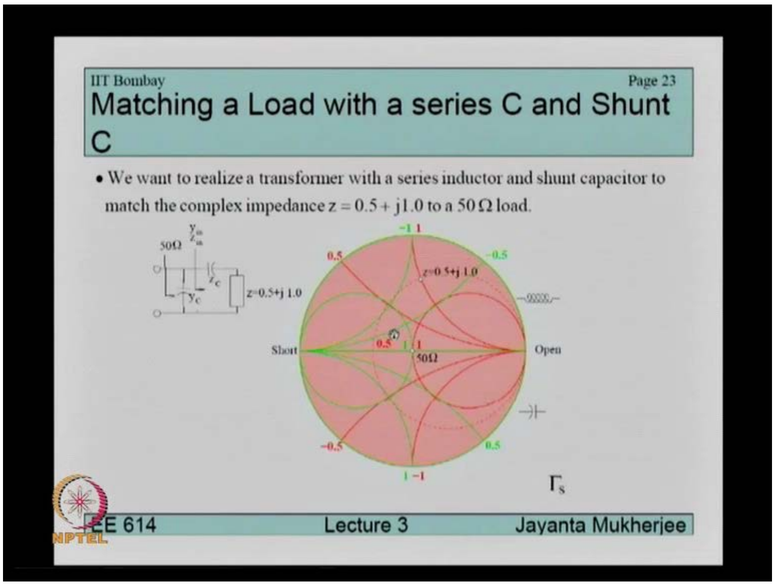
And then we connect another capacitance in shunt so that we go along a constant resistance circle, I beg your pardon, we will go along a constant conductance circle till we reach the origin. So, how much capacitance should be connected in shunt, we should connect that much capacitance that will cause the locus to move from this point Zin to the origin. Now you might have asked me why restrict ourselves to this path, there can be other paths also and absolutely. In this slide we saw that we are going like this and then coming like this to the origin.

(Refer Slide Time: 19:30)



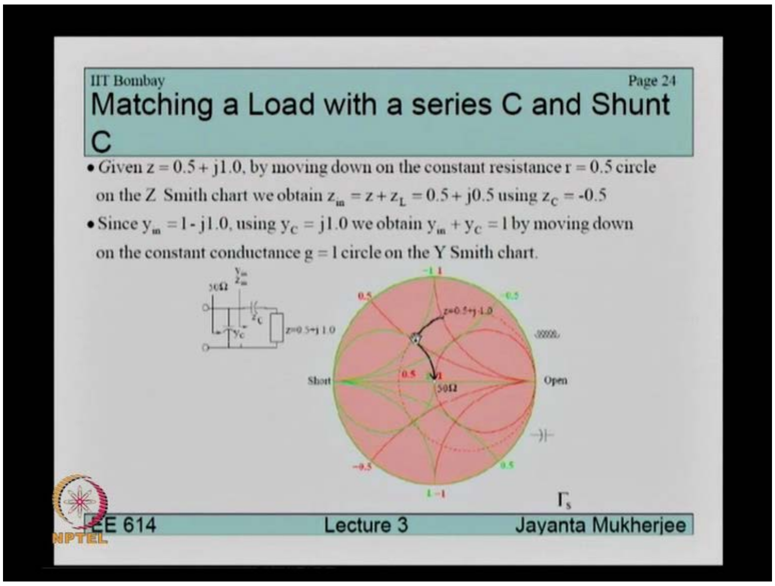
In this slide we will show another path we are 1st going along a constant resistance circle like in the previous case but then instead of touching G equal to 1 circle at this point, here we touch at this point. And from here we see that we can also, we have a path along this constant conductance circle where G equal to 1 to the origin. So, for going from this point to this point, we connect a series inductance as we did previously but then for going from Zin this point to the 50 ohm point, we have to travel along a constant, along a G equal to one circle but then upwards.Upwards means that we have to connect an inductor in shunt and that is what we have done.

(Refer Slide Time: 20:39)



Now let us see another example, we have a load 0.5+ J1 .0 as shown and again we have to match this impedance or admittance to the origin, so this is the basic set, this is our Smith chart, this is where we start from and this is our destination.

(Refer Slide Time: 21:10)

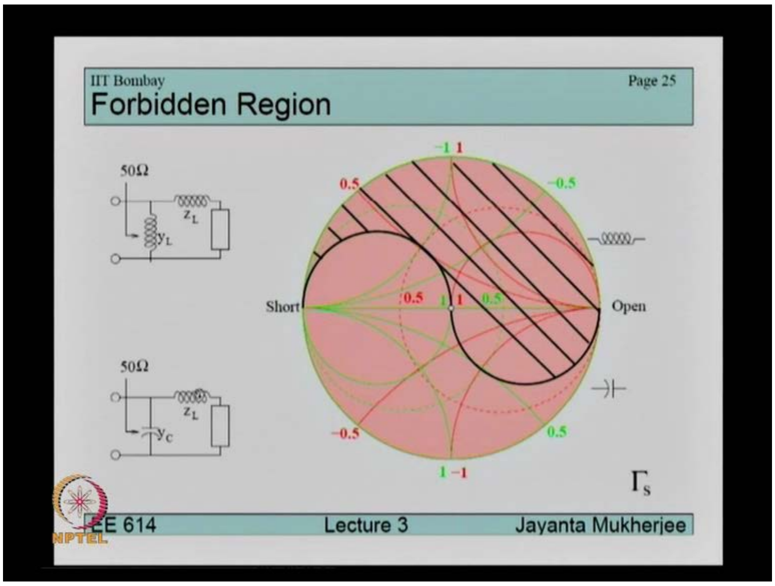


So, at 1st we travel along a constant resistance circle and this point is upwards than the origin, so we have to go downward. So, 1st what we will do is that will go downwards along a constant resistance circle and then touch the G equals to 1 circle at this point once we touch G equals to 1 circle at this point, we note that if we go along this G equals to 1 circle, we can reach the origin.

So, if we are going downwards, that means that we have to connect a capacitance in series and then once we are going downwards along a constant conductance circle we again have to connect a capacitance but in shunt. So, that is how it is shown. Now what with the values of these capacitance can easily be computed from this constant reactance and constant susceptance line. For example the capacitance value here is that… We start from a constant reactance circle of 1 and reach a constant reactance circle of 0.5 and so the capacitance capacitance value will be the difference between the 2.

So, we need YC of 0.5 ohms for this series for implementing the series impedance and then here we go from -1 susceptance to -0.5 susceptance. So, again here we need a YC I beg your pardon, here we go from -1 YC susceptance to 0 susceptance, so we need around 1 ohms of capacitance of susceptance to be present in shunt.

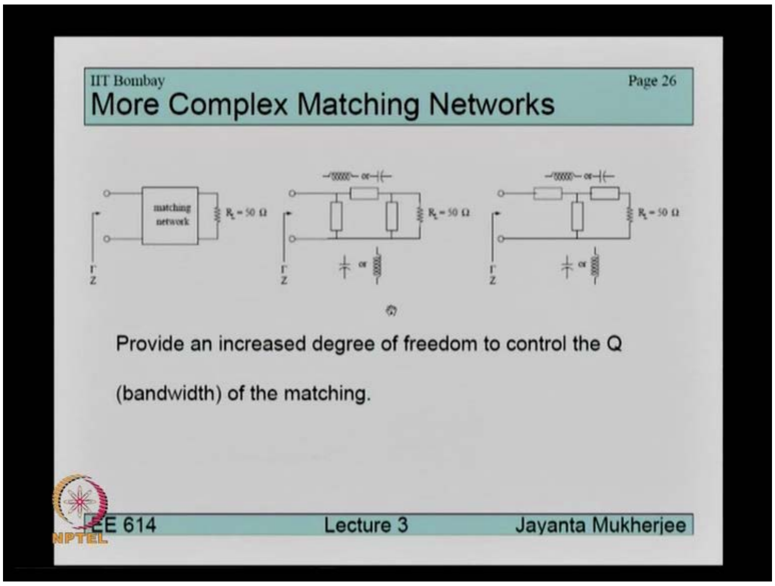
(Refer Slide Time: 23:26)



Now it is not always possible to obtain a solution. For example, if we have, if we have a load when we would like to connect a matching network like this that is an inductor in series and an inductor in shunt after that, then is that load is in this region shown by this shading mark, then we see that no value of this load can be obtained on matching network.

Because see if we connect, if we have an inductor in series, that means that we have to travel along a constant resistance circle 1st and then we have to come down via constant conductance circle which is not possible. Similarly if we have this kind of matching network where we 1st have inductor in series and capacitor and shunt after that and that is also not possible if we have our load anywhere in this shaded region. Now there can be more complex types of networks.

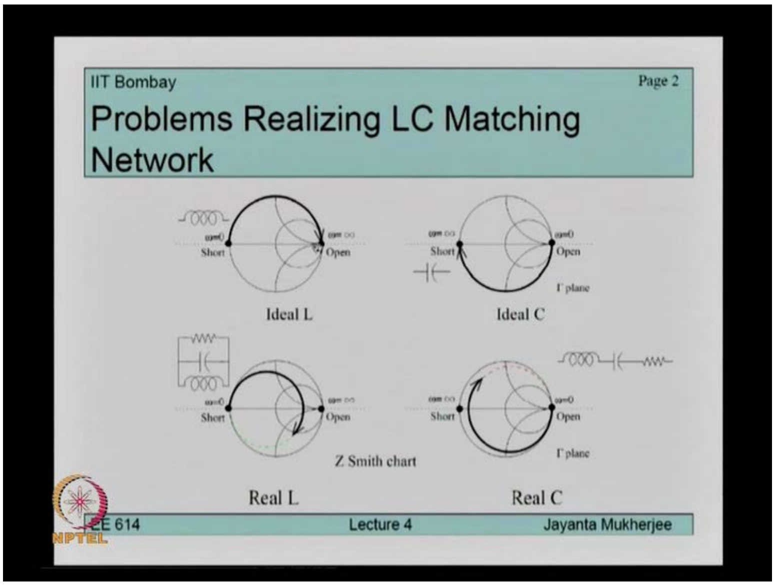
(Refer Slide Time: 24:40)



In all the cases we have seen, we had only 2 elements for satisfying our matching networks but that is not necessary. We can have more than 2 elements as shown to you. And in fact having more number of elements will give us more freedom over controlling the matching network. But then the problem with adding more number of elements is that the noise of the circuits increases and so not desirable. So, in summary, what we see is that there are various ways of implementing a matching network and we can use the Smith chart that is the ZY Smith chart to know the correct values of the elements that are required for implementing a matching network.

Now of course all the networks that we have showed so far are based on lumped element networks. So, how do we go from lumped elements to microstrip or distributed elements which we have to use when we are in the microwave domain.

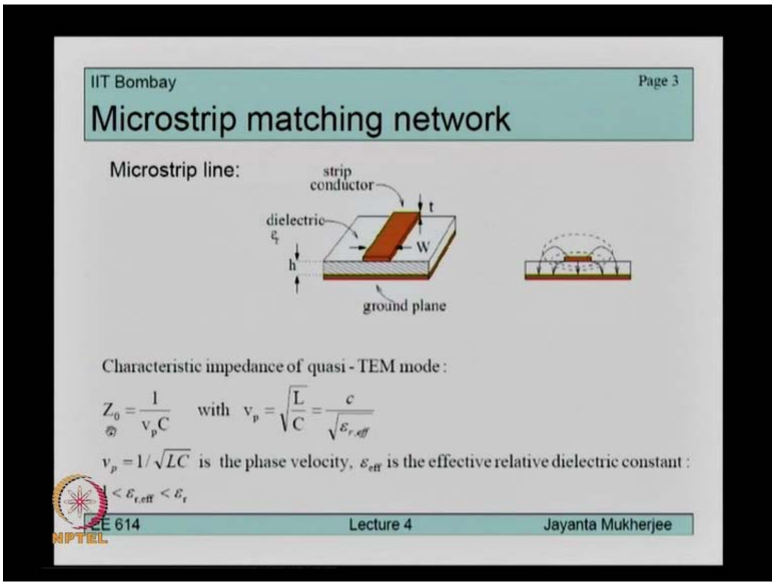
(Refer Slide Time: 26:04)



So, let us see this example, so one problem in realising you see all the inductors and capacitors that we have discussed so far, we have considered them to be ideal. If we have an ideal inductor in series, then we see that we can go along in clockwise direction along the Z Smith chart. And if we have an ideal C in shunt, then we can also go a long clockwise direction in the Y Smith chart.

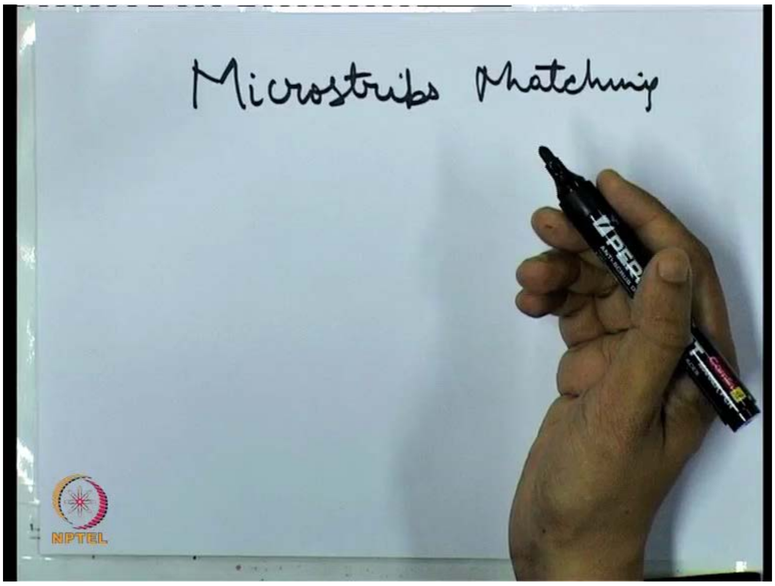
But in case of real elements, what happens is that there is often a lot of resistance associated, so instead of getting a response like this, we end up getting a response like this.

(Refer Slide Time: 26:53)



Now microstrip matching network is an example of of of a transmission line where the Z0 and BP are given like this. Microstrips are often used for implementing these matching networks.

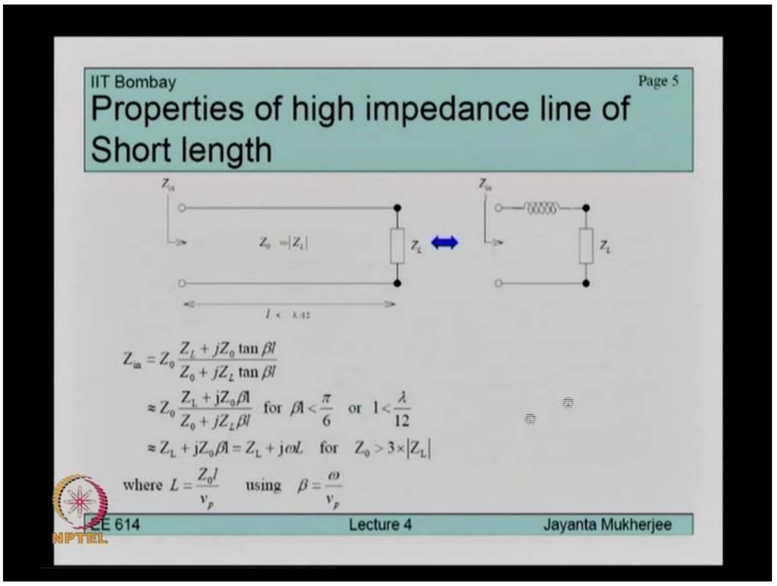
(Refer Slide Time: 27:20)



So, let us see how to do matching using a microstrip line because microstrips are the as we have discussed are a very popular method of realising transmission lines, there really to fabricate and there also simple to understand because they have a direct relationship with the…

For example the longer the transmission line, longer electric transmission line translates to a longer length in a microstrip line. Then the characteristic impedance of a microstrip line is related to the weight of a of a width of the microstrip line is related to its characteristic impedance i.e. if it is wider, then it has lower characteristic impedance, if it is thinner, then it has higher characteristic impedance.

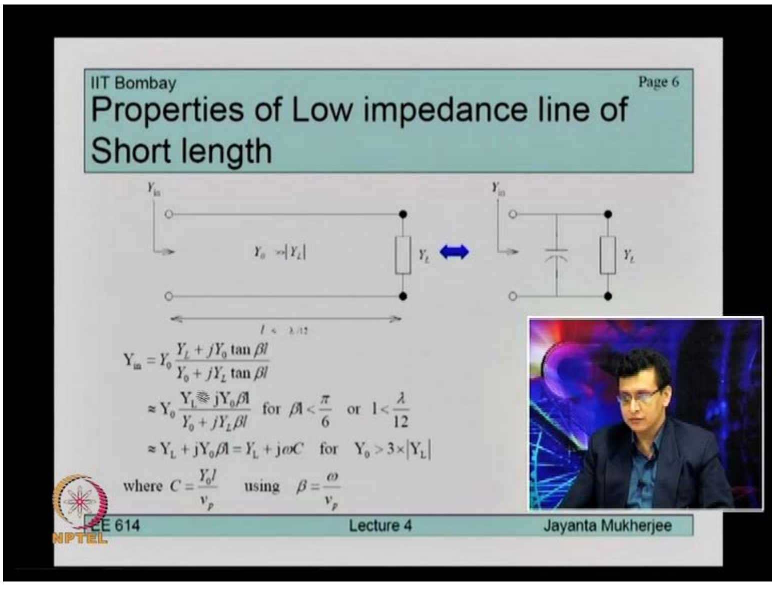
(Refer Slide Time: 28:16)



Now if we go once again back to the slides on the monitor, then one common way of implementing a microstrip line would be… Or if we choose a high impedance line of short length, then it can act as an inductor.

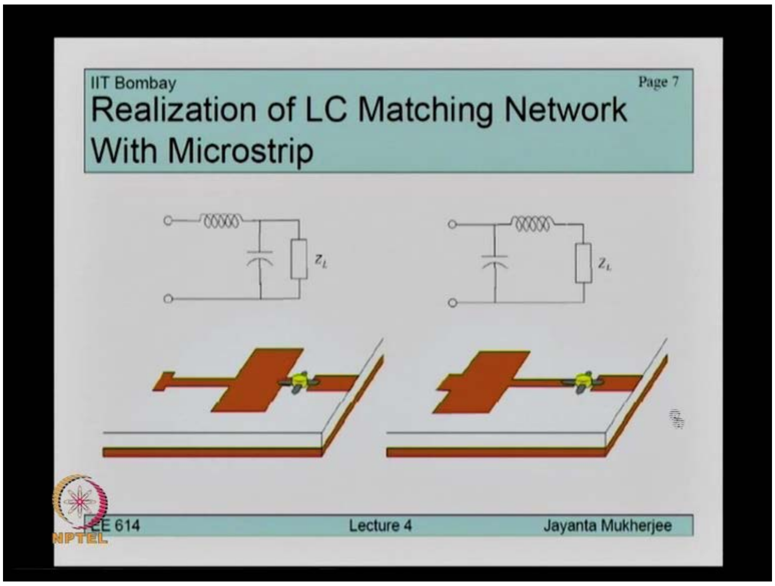
Starting from this equation, length, the electrical length Beta L is less than pie upon 6, then we can show that Zin will be equal to this value. So, this is one way of achieving impedance, achieving inductor that we have discussed few minutes ago.

(Refer Slide Time: 29:01)



Or if we use lower impedance line i.e. the one that has low value of Z0, then also they can show that it will act as a capacitance because for low value of beta L that is when beta L is less than pie by 6 for Yin, say we reduce it to this value which is like having a capacitance in shunt with the load.

(Refer Slide Time: 29:37)



So, this entire line becomes equivalent to our this and this is one diagram of how microstrips are used commonly. Now in this module, what we discussed were how we can use a microstrip to realise a lumped L and lumped C that we discussed, that we saw are necessary for realising an impedance matching network. And we also said that high impedance, short length of high impedance line can act as in that and we can substitute that for inductor. Or a short length of low impedance line can act as a capacitor and it can be substitute it for the capacitance.

But then, that is not all, in the next module we will see that how purely from a transmission line perspective rather than substituting L and C with short lengths of microstrip lines, whether we can use a normal, i.e. a microstrip line which has the same characteristic impedance as that of the input, I that required for impedance, as that required for input and output impedance matching but it is length, by varying its length we can achieve the same impedance matching. Thank you.