Basic Tools of Microwave Engineering
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Lecture – 08
Distributed Impedance Matching Design by Smith Chart

In this lecture, we will see the distributed impedance matching network design that means, as I said that as we go higher in frequency particularly after 1 giga hertz, it is difficult to rely on inductors, capacitors, and etcetera. Also in this high frequency circuits fabricating this LC they are also difficult. So, we need to design a transmission lines or wave guides for realising L and C of that.

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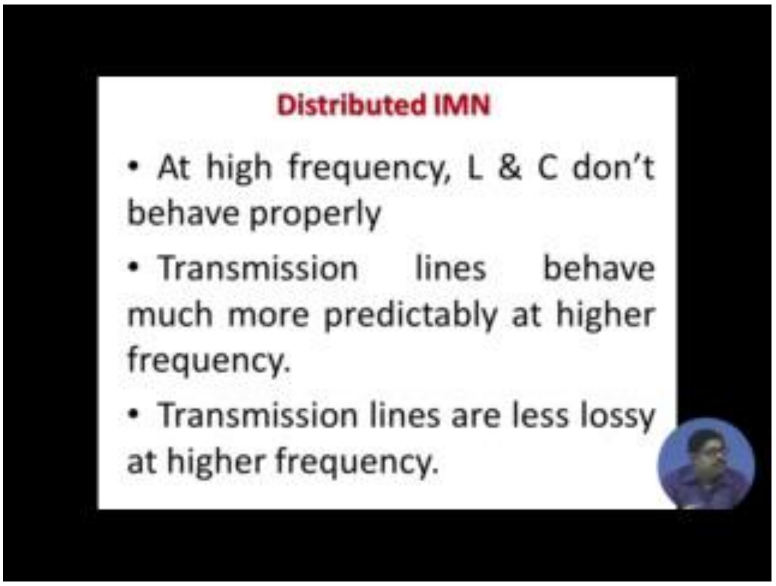

So, that design is called distributed impedance matching network. Transmission lines are less lossy at higher frequency. So, they are used for this impedance matching network.

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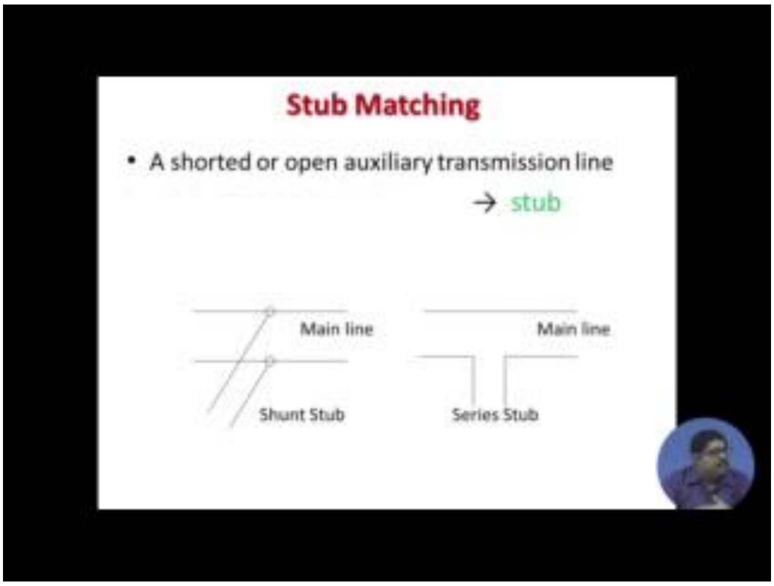

Now, the impedance matching network if there is a power transport going on in the main line that is called main line, and for impedance matching we use some auxiliary transmission lines. Now, that transmission line may be shorted or opened that are called stub. So, I can have an open stub or I can have a short stub. Now, as you see that there is a main line from that the stub can be connected either in shunt that topology is shown or it can be a series stub also.

Now, depending on which technology you are using, the series and shunt connections they are preferred like in sometimes series or shunt or short or open in various technologies like whether you are having micro strip technology, or you are having strip line technology or you are having wave guide technology, based on that it is chosen because in some cases fabricating a short or open is easier because you will have to make some not through via holes are needed.

Also in some cases, if you have large openings radiation may takes place. So, based on that you need to modify, but a microwave engineer once he can design any stub he can change, open stub to a short stub, etcetera. If he knows smith chart well that we will see today. So, you see this is the open stub and short stub open stub means finally, the stub at 1 end it is connected to the transmission line either in shunt or series fashion.

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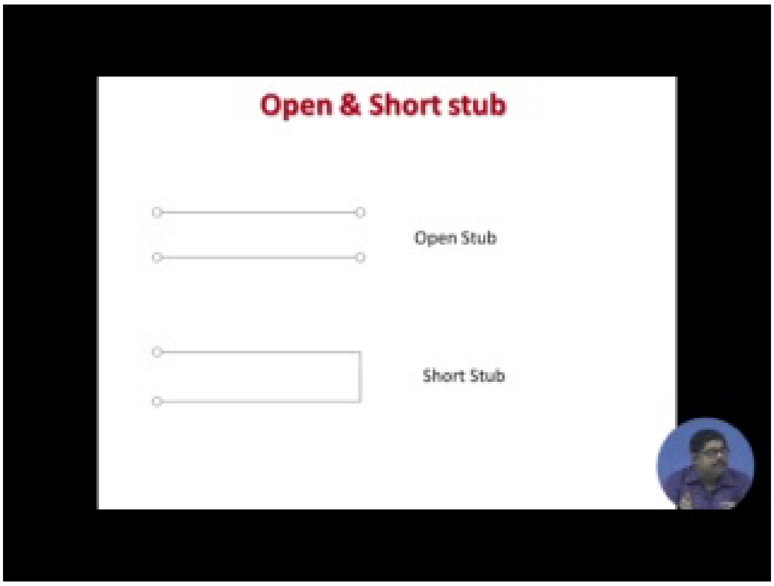

The other end is left open whereas, a short stub the end which is not connected to the transmission line that 1 is shorted then it is called a short stub

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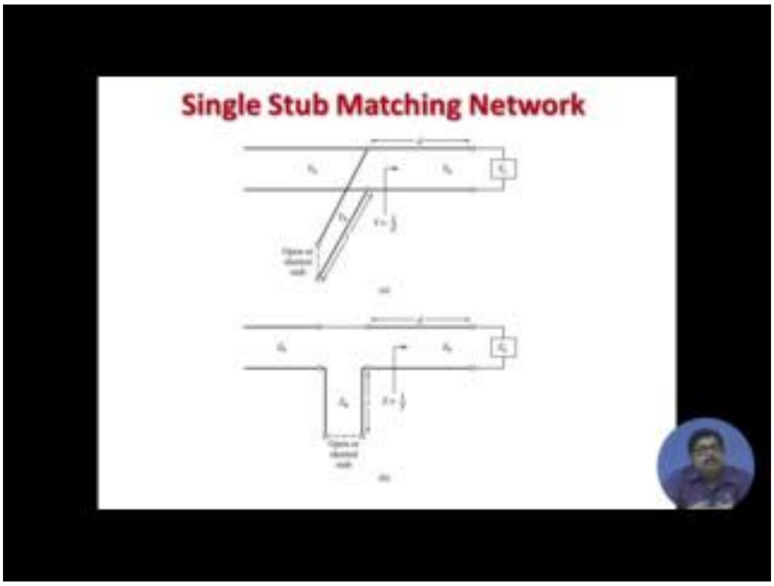

Now, this is the single stub matching network, you can see that single stub matching have the load. Then you have a transmission line portion of length d and then here you can have after that d, either a shunt or a series stub that stub may be open or short that stub length is L and, if you consider that you have a transmission line. So, the load in case of shunt stub generally we carry the analysis in admittance plane because load impedance after coming to transmission line you come to a new admittance which we are calling Y and then you are adding the shunts admittance to that and then finally, after you cross the stub from the left end you can see it should look at a characteristic admittance. So, that it becomes matched.

Single stub matching network will look like this that Y l is matched to Y naught after the stub and the transmission line is connected whereas, in case of the series stub generally we try to do the analysis in the impedance plane. So, the load is considered as Z l and then after traversing a distance d in the transmission line, it becomes a new impedance Z and then with the series stub you change that Z to Z naught. So, that from the transmission line in the left or source side you see a Z naught thing.

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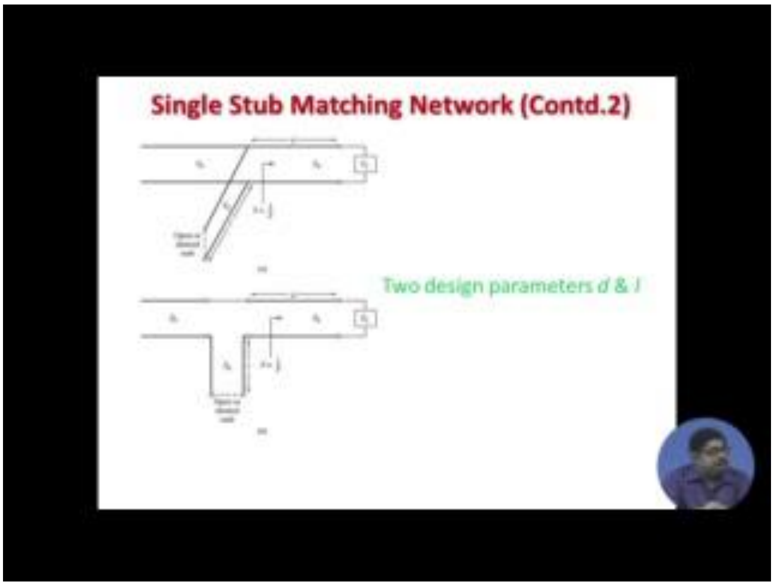

Now, here in both these cases single stub matching network. So, here you have only a single stub and the location of that stub these are the 2 designed parameters. So, d that means, where you are placing the stub, how far is it from the load that is called d and then link of the stub that is called l, these are the 2 things that you need to design and the stubs characteristic impedance stub is a auxiliary part transmission line that characteristic impedance, and the main line characteristic impedance. They are generally taken as same because generally with a when you have either coaxial line or wave guides a particular type of guide element is available. So, characteristic impedance generally do not change there, overview of stub matching, the single stub matching.

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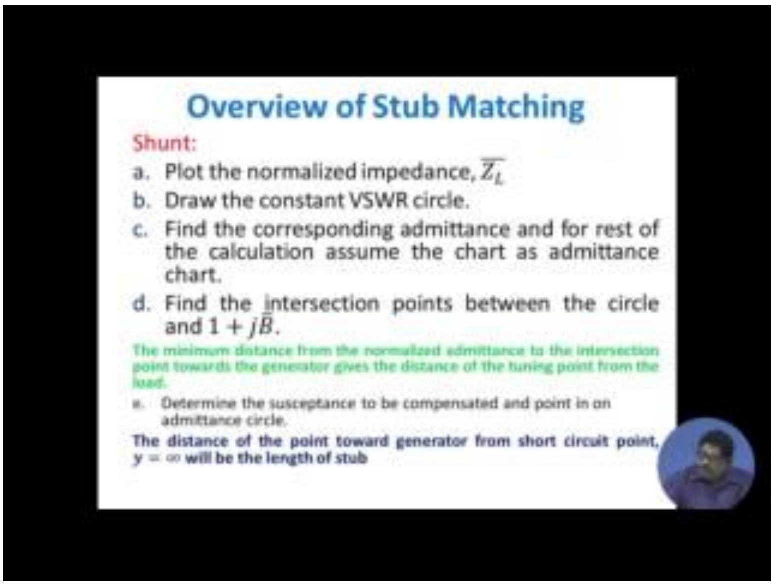

Now, if you have the shunt type of thing. So, first you will have to plot the impedance or admittance. In case of shunt, it is admittance then you are moving on a transmission line. So, better draw a VSWR circle that if we can plot a load then we can draw the VSWR circle by connecting with the centre. We have seen that actually moving on the transmission line means you are moving on that VSWR circle. So, then find the corresponding admittance and for rest of the calculation assume the chart as admittance chart.

As I said it is a shunt drawing shunt design, then find the intersection points between the circle that VSWR circle and 1 plus j beta circle, the minimum distance from the normalised admittance to the intersection points to as the generator gives the distance of the turning point from the that means, what we mean is suppose this is our smith chart.

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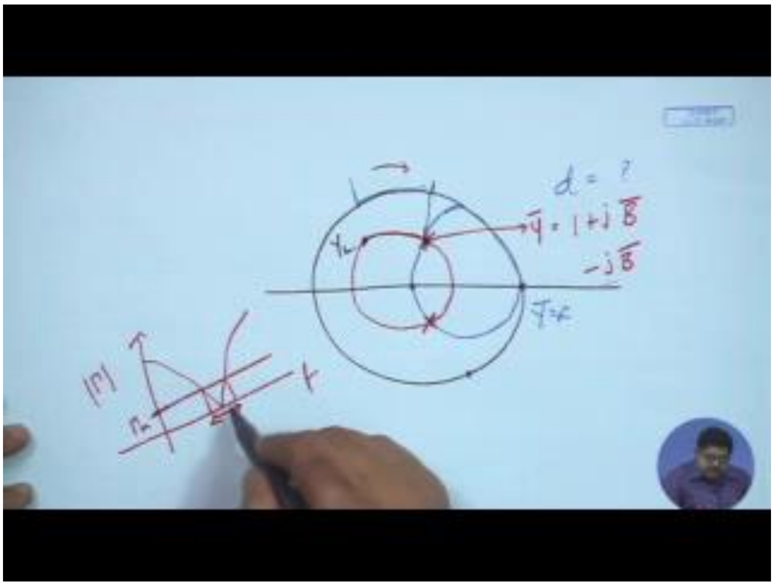

Now, in that smith chart, suppose I have located up to these you are familiar, suppose this is my load. Now, I can always draw the constant VSWR circle and then towards generator in the smith chart periphery, I can find that towards generator is this. So, I will move and try to come to this. This is the constant conductance circle; let us say in the smith chart. So, there I can come. So, here I can either come to this point or I can continue and come to this point. So, these are the 2 solutions, in 1 case I will come like this, I am sorry, in 1 case like this, in another case like this.

Now, it is up to the designer because frequency response of these 2 solutions will be different. So, from frequency response you can decide which 1 you will take also sometimes construction difficulty etcetera can tell you. Now, after coming here what happens that means, this part is given by the d portion of the transmission line that transmission line portion of the between the load and the stub that changes this. So, the change in the transmission line, how much transmission line link that you will read from here because this 1 has a chart here in the lambda scale, this 1 also has a chart in the lambda scale. So, from that you can find out, what is the distance you have travelled and from that you can find out what is the d is how many lambda?

Now, after this you know that after coming here you will have to come to the centre of the chart to match it that is done by the susceptance. So, from here you find out that this point is what is the value obviously, it is susceptance, the admittance seen here that will be 1 plus some j b value. So, you choose shunt susceptance to be negative of that; that means, minus j b bar and. So, you choose a stub whose susceptance is minus j b bar. So, that you can do now how you can do that minus j b bar means if you have a let us say short stub.

So, short means what in admittance 1 that in impedance smith chart, this is your short circuit in admittance 1, this is your Y is equal to Y bar is equal to infinity, this is your short circuit from here. Now, find out where is your minus j b? So, this much this length again reading from the periphery you can find out what is the length of the stub. So, all those steps are given here just whatever we have learnt from the smith chart from that you can just follow this step.

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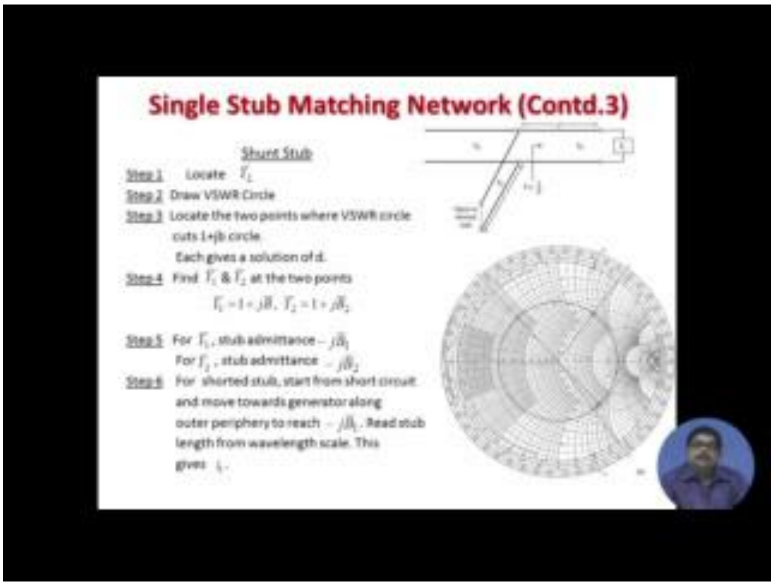

So, here you can see this whole thing that first step is locate the Y l bar point draw the VSWR circle locate that 2 points where the VSWR circle cuts 1 plus j b circle each gives a solution of d take anyone obviously, later we will see that you can from frequency response you can find out then find these values Y one. So, you know there are j b 1 and j b two. So, the stub susceptance, we have either minus j b 1 or minus j b 2 for shortest stub start from short circuit and move towards generator along outer periphery to reach minus j b 1, etcetera. So, please go through, you will understand whatever we have discussed in smith chart based on that.

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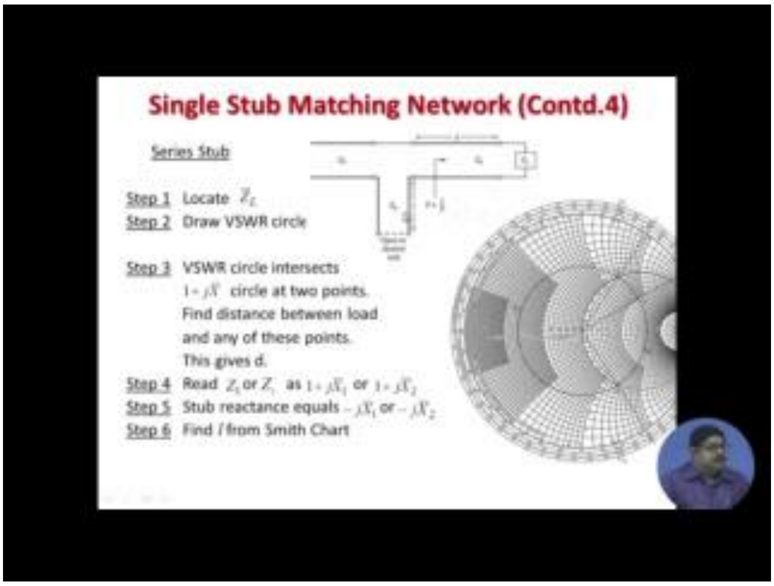

This is for series stub, here in you need not go to the admittance plane here first you locate your load impedance then you draw that constant VSWR circle as you see they are in the smith chart the after locating the Z l after locating the Z l here then you have drawn the VSWR circle then this VSWR circle intersecting this 1 plus j x circle at 2 points 1 point is this another point is this so that means, from your load towards generator means you can come here or you can come to here. So, there will be 2 solutions for this length because all these means this length Z l you are moving up to here if you come then from outer periphery you find out how much you have come that will be your d.

Now, you are either here or here you take any solution. So, suppose you have taken this solution here. Now, you find out what is your reactance value? That reactance value will be you can read from the scale that this is obviously, here it is the reactance is negative. So, minus some value so; that means, suspect this stub its susceptance its reactance i will take as positive value whatever I have got here reactance negative of that I will take here and for short this if is it an open stub open means at the right end portion. So, from this right, end I will now in the outer periphery. I will have to move at the desired susceptance point all these, we will see in the examples because without examples it is difficult, but the steps are given here. So, you note down the steps and from smith chart you then know, what is this length? So, you can find it from smith chart this is all about single stub matching.

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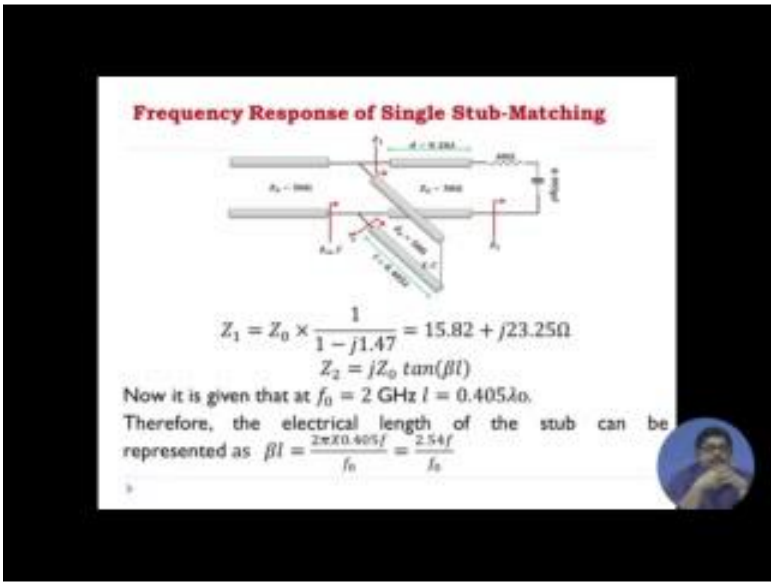

Now, this frequency response of the single stub matching you see this same design, let us say that we have taken some values that d is 0.26 lambda, d means the position of the stub from the load. So, a load is that is resistive part is 60 ohm and another let us say that some capacitance is there. So, the load is 15.82 plus something now that when it is converted here this is called Z 1. So, Z 1 is given now Z 2 the stub part that is you know a shorted transmission line shorted transmission line its impedance is j Z naught ten beta l now ten beta l obviously, this l.

So, let us say that design has been carried out at a certain frequency. So, we have a particular lambda that we call lambda naught. So, 2 giga let us say, in this case if we specify that the design is done at 2 giga hertz, 2 giga hertz means it is the 15 centimetre is the lambda. So, all our lambda naught is 15 centimetre. So, when we are saying that d is equal to 0.26 lambda. So, our length will be actually 0.26 into 15 centimetre, but at other frequencies it is not 0.26 lambda it is some other thing. So, if in at other frequency signal if we give to this impedance network there will be some reflections there will be reflection coefficient that is not 0 that is some non 0 value.

So, that we can find out that we express this Z 2 which is in terms of beta l beta l is a electrical length of the transmission line that beta l can be beta you know it is a phase constant of the transmission line that is 2 pi by lambda. So, we call it 2 pi by lambda and l is some fraction of that lambda. So, beta l can be expressed as f by f naught. So, when f is equal to f naught that means that design frequency if the actual frequency is also that then it is simply beta l is 2.54 otherwise it.

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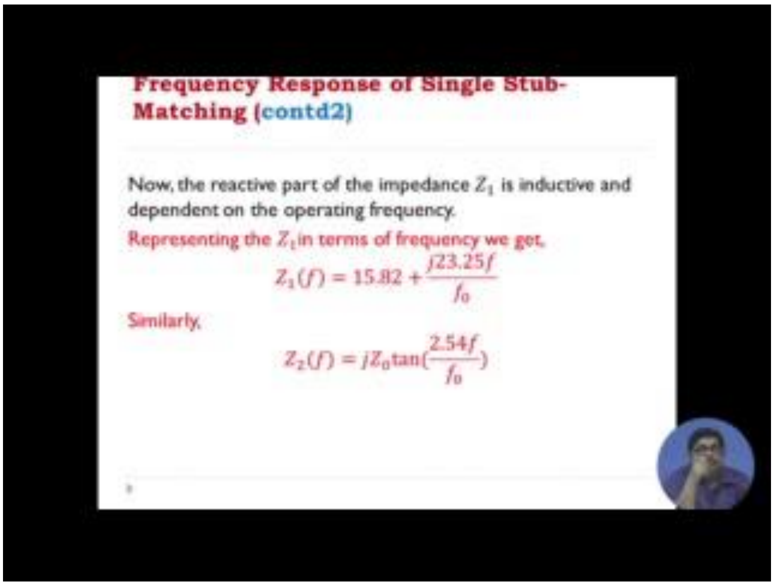

So, now you can represent your Z 1 and Z 2 in terms of that, now in the shunt case the total Z in is this.

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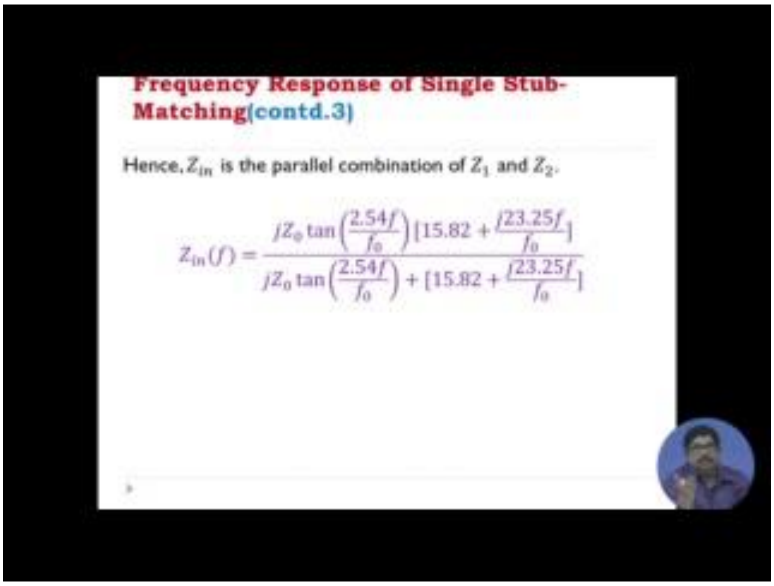

Now, this at f is equal to f naught, this is Z in is equal to Z naught, but at other there will be some other Z in naught equal to exactly Z naught. So, there will be reflection that you can plot.

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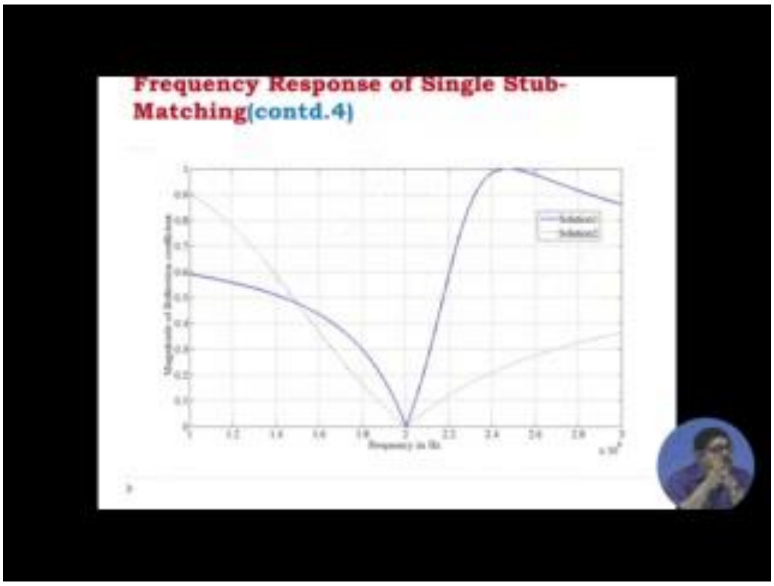

So, we have plotted that in a particular problem as we have seen 2 solutions. So, you can plot and you see that solution 1 and solution 2, you remember that either you are coming here or here. Similarly, how much is the your susceptance depending on these 2 both the d and susceptance they are different. So, you can plot and from this you can see that the suppose I fix that my tolerable you see at design frequency 2 giga hertz the reflection coefficient is 0 for both the solution, but when I am nearby there are some reflection coefficients.

So, there will be some mismatch, there some power loss, there now depending on application you can that how much power loss you can you are ready to suffer. So, that you can see that based on that you can draw a horizontal line suppose from this.

Suppose this is your frequency response the graph is like this now here this is your reflection coefficient magnitude you can find out i will fix that this is my maximum. So, my usable bandwidth for which impedance is valid; that means, reflection coefficient is not going beyond this; that means, power loss is not beyond a certain level that this is bandwidth. So, here you see based on where you are putting your acceptable or tolerable reflection coefficient the bandwidth is different now obviously, we will prefer a wider bandwidth 111.

So, in this case suppose if we say that point 1 is our maximum tolerable reflection coefficient magnitude; obviously, I will choose the solution 2 whereas, if someone says no the 0.5 is my tolerable bandwidth then also I will choose solution 2 because you see the its second part it is going very low. So, based on these designer will have to decide whether he wants to how much wider bandwidth he is getting from which solution that solution he prefers.

Another distinction point is what is the size of the stubs etcetera he is getting because these 2 solution will have different links of transmission lines different length of stubs now getting larger may be problematic getting very small also may be problematic because of mechanical construction etcetera. So, that time based on other criteria you will have to do, but you have this scientific analysis behind you.

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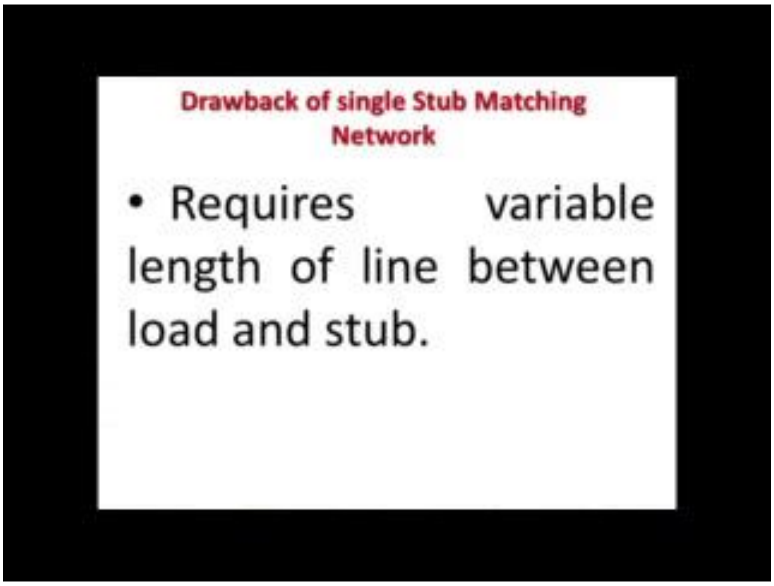

Now, what is the drawback of single stub matching. So, you see that if the load is changed then the stub to be redesigned particularly the position of the stub is to be redesigned; that means, that d will vary because in the smith chart because in the smith chart instead of this point in the smith chart instead of this point if suppose I am at this point then; obviously, my coming here will be different. So, that d will be different. So, changing this problem that from the load that stub position if it is variable then you cannot have a single tuner to tune various loads. So, that is the drawbacks of single stub matching.

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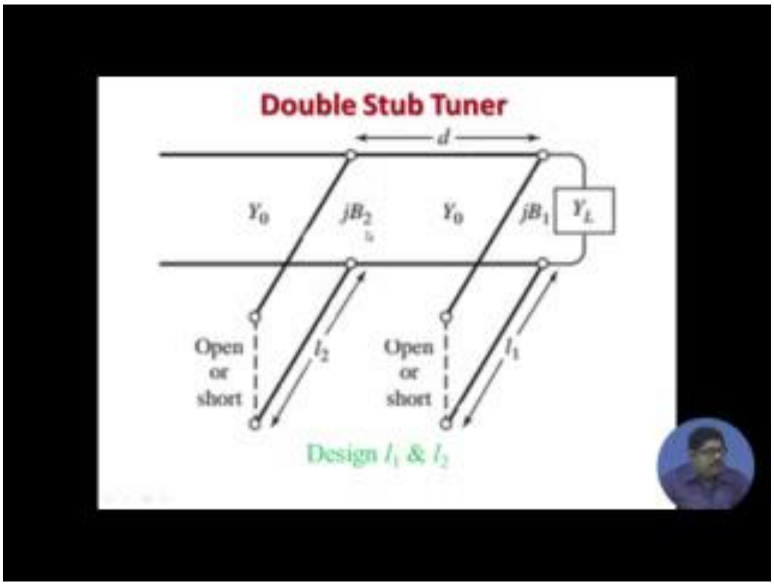

So, people come up with a double stub tuning where the 2 stubs are used not 1 stub, but the distance between the stubs that is called d that is fixed this 1 is fixed. So, stub positions are fixed load immediately connected to the first half then there is d that also fixed connected to second stub. So, what is the design? Design is what is the lengths of these stubs. So, that from here you see a matched design.

Now, here we have taken shunt stubs. So, you see that we have taken instead of Z l, we can represent the load as Y l from Y l after adding these things. So, here I will get this Y l bar plus j b 1 bar will be the admittance here. Then I will have to move in a transmission line by a distance d and come here.

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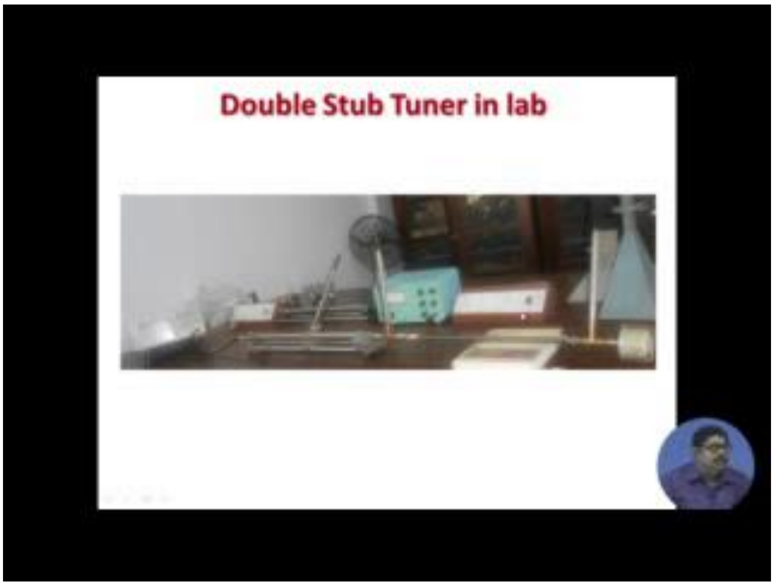

Now, you see how this is a double stub tuner in our lab. You can see that this is 1 stub this is another stub this is the load. So, load we are connecting and this too and this side we are giving the source this is the carriage that you have seen this is the meter where you can observe the whole thing and this stub this stubs their lengths, you can change actually they are foldable. So, you can change the lengths. So, those are the 2 things that you can vary in this I think in your lab also you have this.

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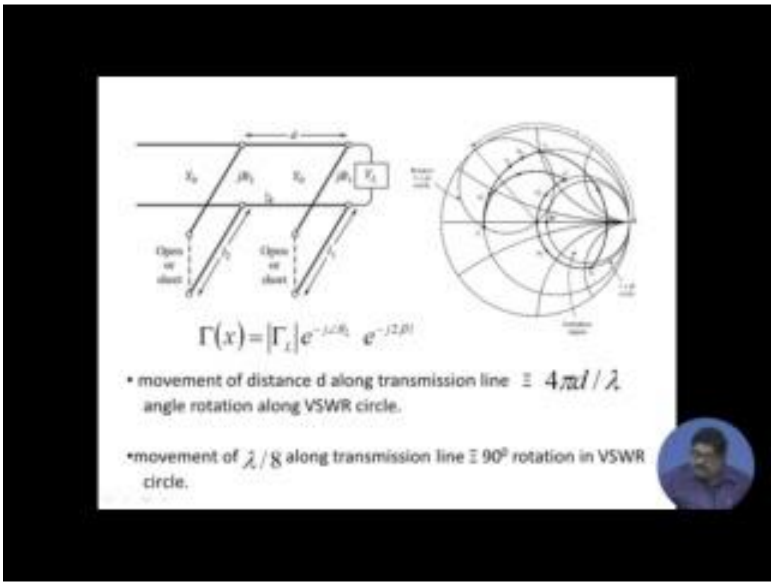

Now, let us see that what is done we know this thing this is a transmission line equation this we use that gamma x is equal to gamma l this. So, a movement of distance d along transmission line means from here you can find out this b is equal to 2 pi by lambda. So, if you put that that movement of distance d along transmission line means a 4 pi d by lambda angle rotation along VSWR circle we have already seen that moving along transmission line same transmission line means moving along a VSWR circle. So, if this distance d is lambda by 2 then transmission line movement 90 degree, if this movement of 2 lambda by 2, this is 180 degree 3 lambda by 83 degree. Why I am saying this that means, that when these ds are fixed generally, they are taken like this lambda by 8 or 3, lambda by 8 so that means, 90 degree or 270 degrees.

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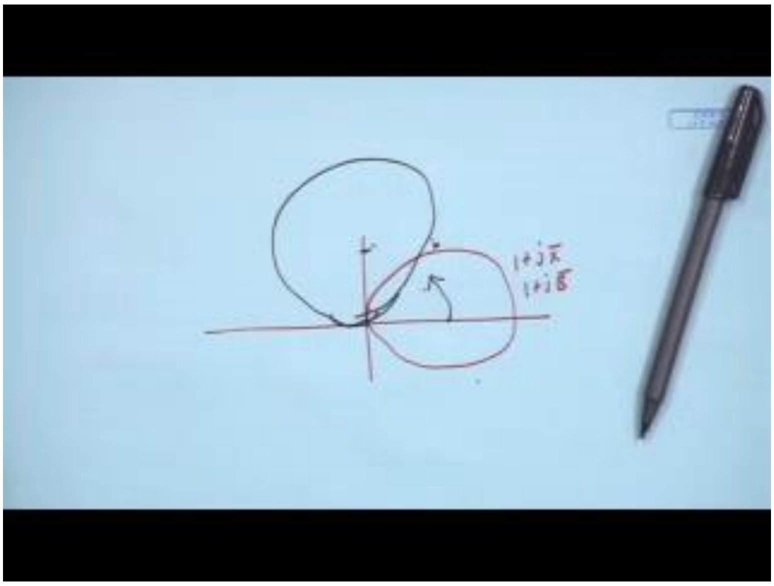

Now, you see the beauty that suppose, I have in a smith chart a constant. This is you know 1 plus j x circle or 1 plus j beta circle whatever you call, now 90 degree rotation of of this will be the same circle is here a reflection 90 degree which side; that means, this 1 I have this centre, I have changed to this centre. So, I have gone here this is called towards load reflection now what is the beauty of this. So, here suppose something I was at this point. Now, if I move here then I will be where. So, suppose I am on this circle. So, basically this movement is towards generator towards generator I am moving because this side is generator. So, from here a movement of d means I will come ninety degree here.

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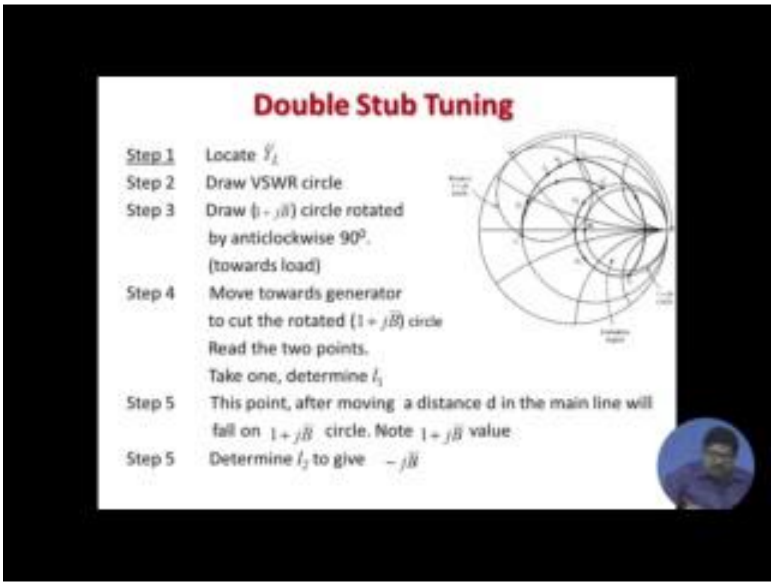

With this you see the procedure for double stub tuning, you locate your Y l dash that you are now familiar, that locate the admittance load admittance draw the constant VSWR circle.

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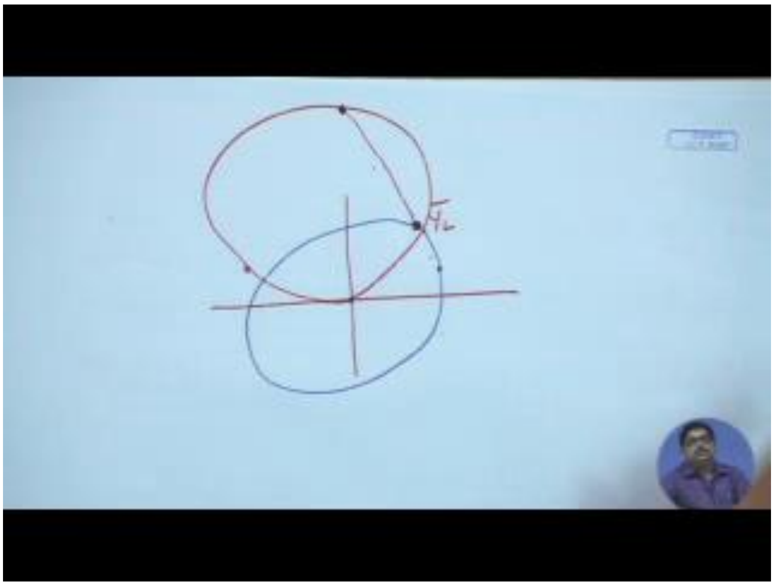

So, what we do in the smith chart we locate let us say this is our Y l bar then I can always draw the constant VSWR circle as a circle like this centre here. Now, depending on if your d is equal to lambda by 8, that means, distance between 2 stubs lambda by 8, you make it 90 degree rotation that will be something like this move towards generator to cut the rotated circle. So, from your load point you move towards generator to cut the rotated 1 plus j b circle. So, from this actually from the from here you should be on the constant conductance circle and see that you change to cut some point that means, you are on a constant resistance circle while move and come to either this point, or you can also if you proceed you can come at some other point take any of that.

Now, the beauty is when you will be transported by a distance d towards generator you will come to this point 1 plus j b point. So, what we have done read the 2 points take 1 determine l 1 this point after moving a distance d in the main line will fall on 1 plus j b circle note 1 plus j b value. So, your second stub that will be compensation of this j b; that means, that susceptance will be minus j b. So, depending on whether it is short or open, you now find again from smith chart, locate the if it is shorted locate the short point and from short you find out how much to go. So, that I get a susceptance of minus j b, that you can get the l 2.

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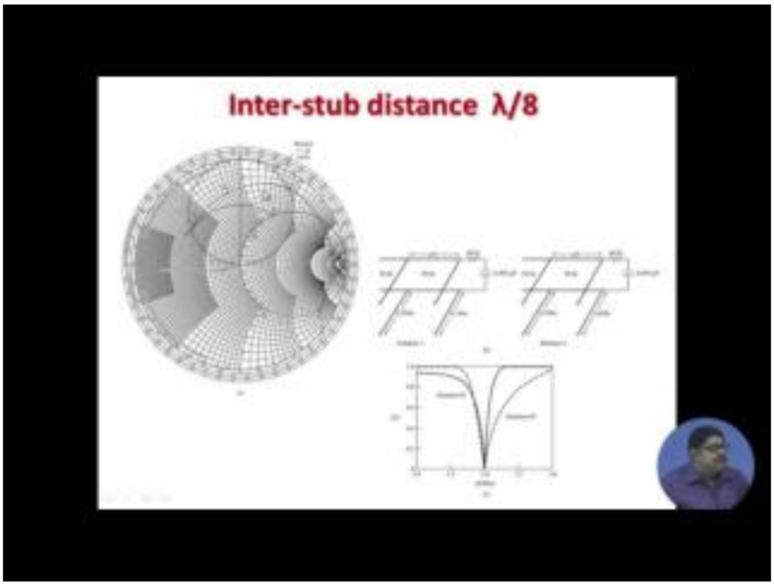

So, this is inter stub distance you see this is the ninety degree rotation of the 1 plus j b circle or 1 plus j b circle is this a lambda by 2 separated 2 stubs. So, this circle after reflection becomes this. So, you try to come on this circle. So, that you know that after this movement of lambda by 2 you will come to this circle and then from there you it is a change of susceptance which will bring you to the centre.

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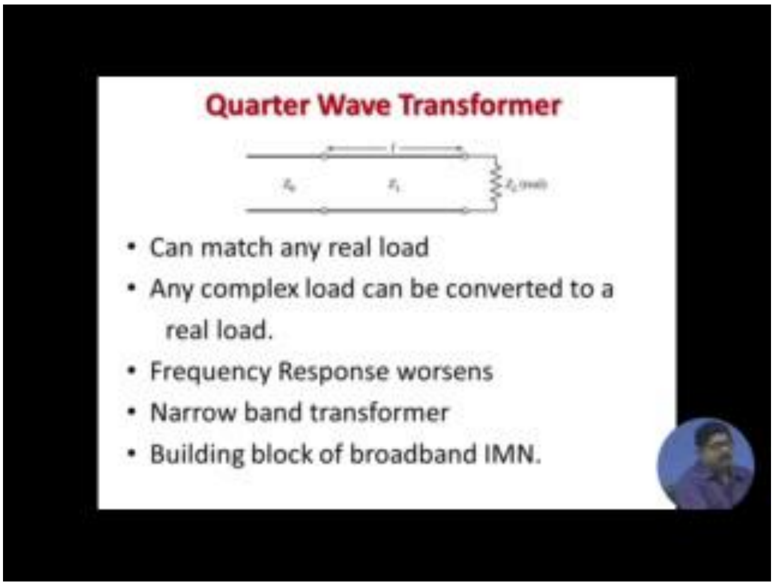

Now, again solution wise you can see there are 2 solutions. So, that is all about at any load any load any complex load you can match to any real load by this then we will see there is another thing it is not an impedance matching thing, but it is an impedance converter it is called quarter wave transformer quarter wave transformer mean a section of transmission line which is placed between a load and any other transmission line of characteristic impedance Z naught now the thing is it can at the input of this quarter wave transformer you get a transmission match.

So, it can match any real load, but it cannot match any complex load, but you do not have any problem because you know by those stub matching you can make complex load can be converted to real load. So, what is the beauty of this that suppose between 2 parts of the network you have 2 different impedances they are matched, but they have difference suppose 1 is at 50 ohm and another is at 100 ohm they may be matched

Now, quarter wave transformer can bring this impedance levels together it is a impedance transformer it is not a matching thing now any complex it can match any real load now its frequency response is not good it is a very narrow band converter narrow band transformer, but with this we can build various broadband impedance matching designs.

So, we will see that next in your next ones that with this quarter wave transformer we will start that those impedance matching network that we have designed distributed ones there they have a frequency response and that frequency response is narrow band means it is not more than 15 percent bandwidth, but if we want that we have a signal which is having more 15 percent more in today's world that is coming up with ultra wide band technology your signal will be having much more bandwidth much larger than 15 percent 500 mega hertz bandwidth etcetera. So, there you need that impedance matching network also should be having wide band, but these designs cannot give you. So, that how to design broadband design that will be topic of our next talk.

Thank you.