Basic Tools of Microwave Engineering
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Lecture - 12
Scattering Parameter: the Second Tool

Once we have defined equivalent voltages and currents. Now we will see the Scattering Parameter.

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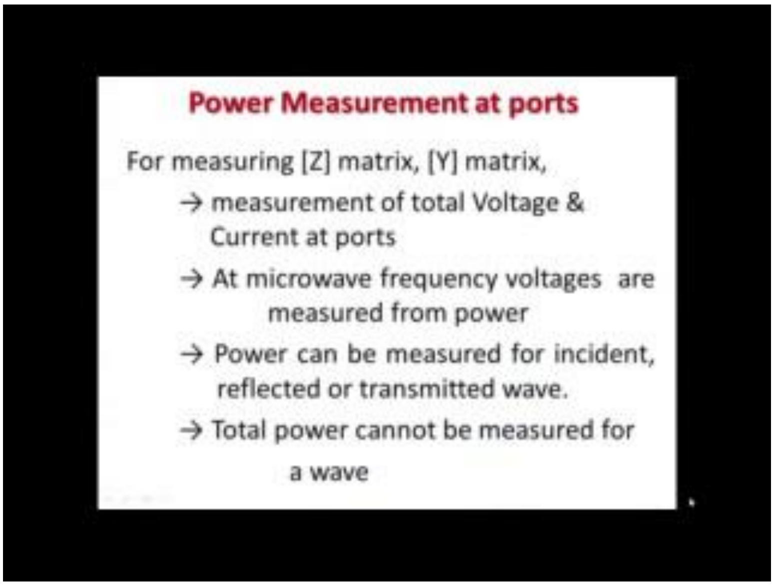

The second tool, we know that at ports we do power measurement because at high frequency is very much necessary that exactly at ports, we need to define powers because at other points the power measurement will be different. Now, for measuring that at 2 port network or any import network, linear network it characterize by Z matrix or Y matrix and for finding Z matrix or Y matrix of an network, we need to terminate properly the ports and measure either voltage and currents.

Now, that voltage and current at high frequencies when the mechanism is through waves incident and reflected waves, basically those voltage and current is actually the total voltage total of the incidental voltage and reflected voltage current means total currents due to the incident current wave and reflected current wave. So, at micro wave frequency the voltages are basically measured from power which is a fundamental quantity. When we introduce measurements, we say that power measurement is another very fundamental being at micro wave frequency. So, measuring from that power the way equivalent voltages, etcetera define you can find out the voltages.

Now, think of that if we try to measure power for at high frequency. Now, power is either flowing with the incident wave, or flowing with the reflected wave, or flowing with the transmitted wave and remember, that super position principle applies for voltages. It does not apply for power that means, power we cannot say that incident power plus reflected power is equal to the total power that is not true super position wise it is true super position principle is applied for voltages, but for power it is not.

So, measurement of power, total power is difficult that is why measurement of total quantities total port quantities at microwave frequency is a difficult job, but separately we can separate out the incident wave reflected wave that we will see in last part of this course that, there are devices available at microwave frequency who can separate incident and reflected or transmitted waves that device is called directional coupler. Now, that is why total power cannot be measured for a wave, we need to measure it in terms of either incident power or reflected power transmitted power as voltage is measured from power.

So, voltage also cannot be measured as total micro wave frequency in low frequency it can be done, whether microwave frequency, there is no point talking about total voltage or total current. We will have to say what is the incident voltage? What is the reflected voltage? What is the transmitted voltage, etcetera, that is why when we try to characterize in microwave network, we cannot characterize it directly in terms of Z Y etcetera.

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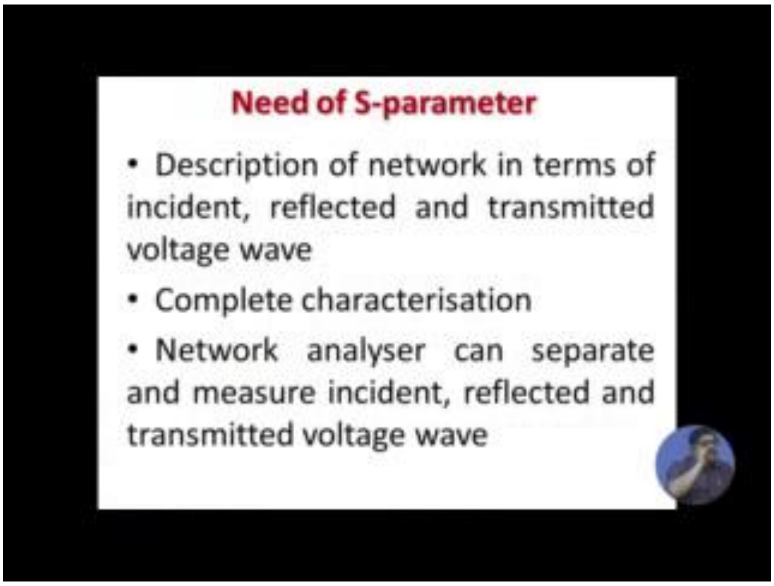

Z Y h, a, b, c, d we still can do indirectly, but if you want to measure this parameters then we need to measure the separate wave quantities and that is why there was need to define a new 2 port parameter that is called scattering parameters.

So, this scattering parameter describes the network not in terms of total voltage and current, but in terms of incident reflected and transmitted voltage wave that is why it solves the problem of measurement. Of these voltages at microwave frequency that is why in microwave frequency this parameter or scattering parameter is quite popular at lower frequency. You have other parameter Z Y for active devices like this transistors H or G for castigating of networks a, b, c, d those are popular.

Now, like other Z Y etcetera this S parameter also completely characterized microwave network and there is an instrument available which is based on the component direction of coupler that is called network analyzer that can separate and measure incident reflected and transmitted voltage waves. We will see in one of the lectures in this wave this network analyzer instrument also, this is parameter we can relate mathematically this S parameter with the existing Z Y a, b, c, d etcetera parameters.

So, we can interchange and ultimately we can characterize a microwave network in terms of Z parameters also a, b, c, d parameters also etcetera then what is the need of S parameter that for measurement this is the way that if you have a microwave network you either measure or estimate the S parameter convert S parameter to other 2 port parameters. So, any of them can be used there is the popularity of S parameter which we are calling the second 2 tool of microwave engineer.

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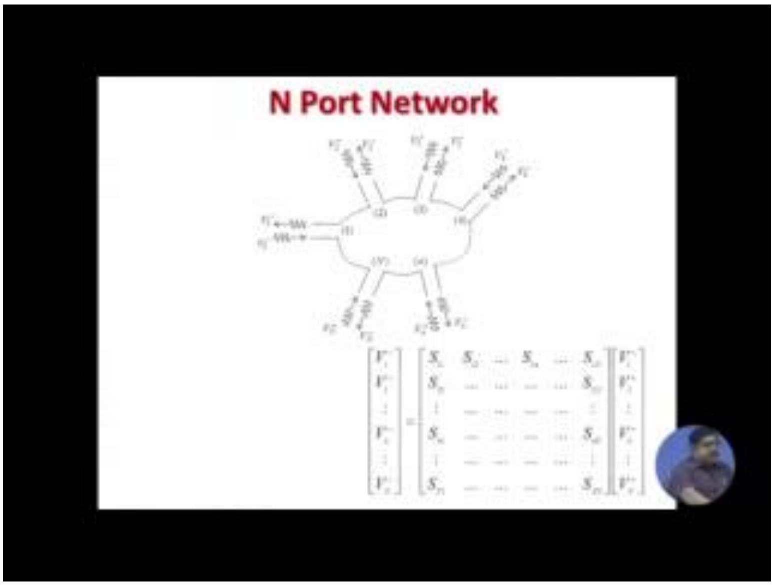

So, let us see, suppose we have a general input network and in this is an N port network. You see 1 port number 1, small nth port capital nth port. So, we are calling that it has total capital n number of ports this is the last port. So, that is why nth port network now. So, in the every port there is 1 incident wave it can come from outside entering the port or due to various things happening in the network that can be a reflected wave, reflected voltage wave V 1 minus tends for reflected last tends for incident. So, you see that you have V 2 plus which is coming inside which is going inside the port 2, V 2 minus going out V 3 plus V 3 minus like that. So, we can represent, since it is linear network.

So, what is V 1 minus what is getting reflected, suppose this V 1 plus is coming, now due to the impedance seeing, some of these may directly come back also whatever V 2 plus is coming some of that come here. So, that can also contribute to V 1 minus something happening in port 3 n, if that power comes here. So, that is why V n minus can be written as a linear combination of all other port incident voltage waves if I expand these it becomes V 1 minus is equal to S 1 plus S 1, 2 V 2 plus S 13 V 3 plus S 1 n V n plus etcetera.

So, any reflected wave at 1 port can be written as linear combinations of incident voltages at all other ports. So, you can write it as the various port reflected voltages this vector is equal to this matrix square matrix n by n matrix and then you have another n length capital n length vector. So, this matrix is called S matrix. So, the same thing in the matrix from, we can write V minus is equal to S V plus these S matrix.

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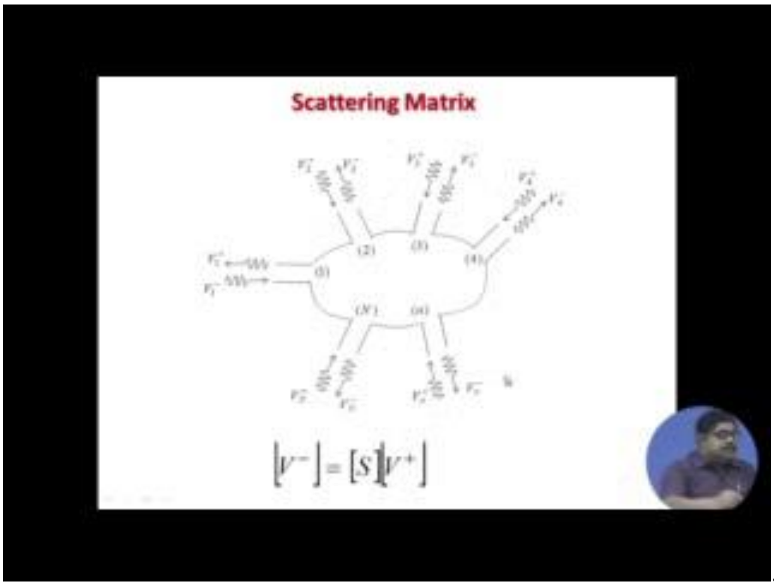

Now, if I want to determine. So how many S parameters are there in an n port network there are n by n that means n square number of S parameters.

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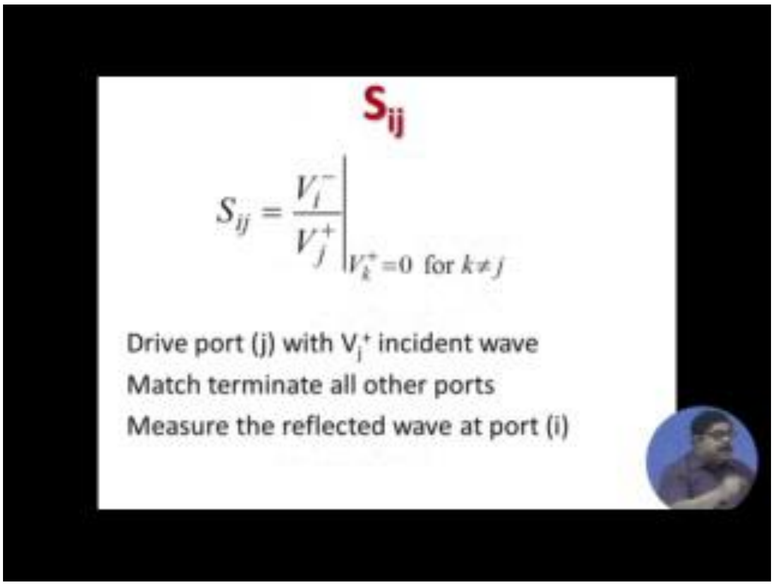

If I want to determine any of them, let us say S i, j, I want to determine. So, you see that S i j will be equal to when we wrote that, suppose I want to determine S 12. So, S 1,2 how can I determine V 1 minus by V 2 plus if I put all other V 1 plus V 3 plus V 4 plus all other 0 that means, only 1 is exciting another collecting at the reflection. So, that is why when we say S i j that means, that I have given the excitation at jth port the second subscript I am collecting the reflection at i th port, except j th port all other ports the excitation is put off.

How I can put the incident voltage at other ports put off that is called match terminate, if I match terminate a port. So, it cannot give rise to any incident wave. So, drive port j when I am trying to find S i j drive port j with v j plus incident wave do not match terminate this port because if you do that you cannot give this V j plus match terminate all other ports match terminating means that means, all other ports V k plus the incident voltage become 0 and measure the reflected wave at port I. So, by this we can do find out the any S parameter. So, this is the measurement thing we put match termination at all other ports except the incident port where we were trying to give incident and measure the reflected port as the designated port.

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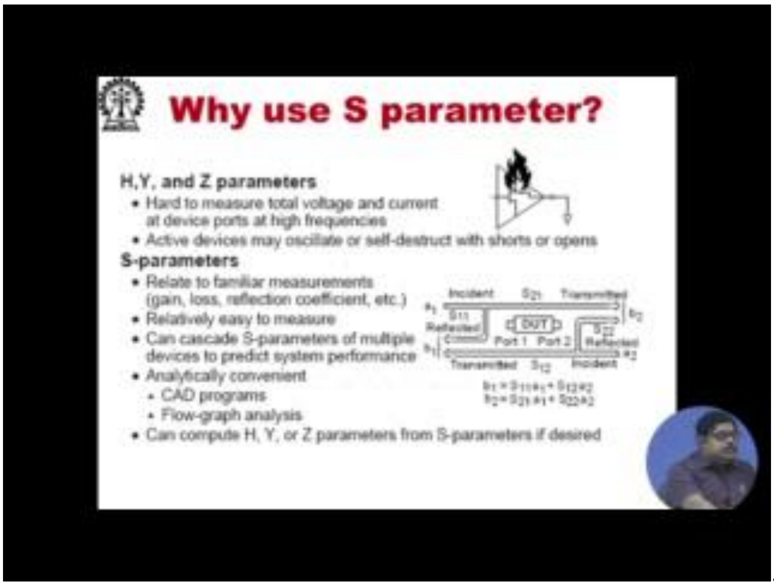

Now, we have told that why we used S parameter, again I am summarizing that there are H Y Z parameters. So, this H is generally, small h the hybrid parameters. So, hard to measure total voltage and current at device ports at high frequencies, I describe the reason why it is. So, and active device may oscillate or self destruct with shorts or open because in case of the other H Y Z parameters; that means, total voltage and current measurement type of things either we open or short a port, but that for active devices at high frequency it may oscillate. So, that is shorting or opening may become dangerous for the devices at actually that was 1 of the reasons why transistor was defined not with Y Z parameter with hybrid parameters. Now, S parameters they relate to familiar measurements like gain means how much voltage gain, power gain, etcetera loss reflection coefficient.

How much reflection taking place from S parameter, we can easily find those things relatively easy to measure cascade S parameters of multiple devices to predict system performance also analytically, it is convenient there are various CAD programs by which you can find out what are those reflection coefficient, transmission coefficient, etcetera also will see flow graph analysis the third tool by which also you can find out then as I said there are interrelation between these parameters. So, if required to calculate H parameter, Y parameter, Z parameter or b, c, d, parameter that can be done from S parameter if desired.

So, you see that some incident wave A 1 is put some of that gets reflected that we measure as S 11 by putting match termination here. Similarly, by A we measure B 1 and find these ratio what about we have said already is written here for 2 ports

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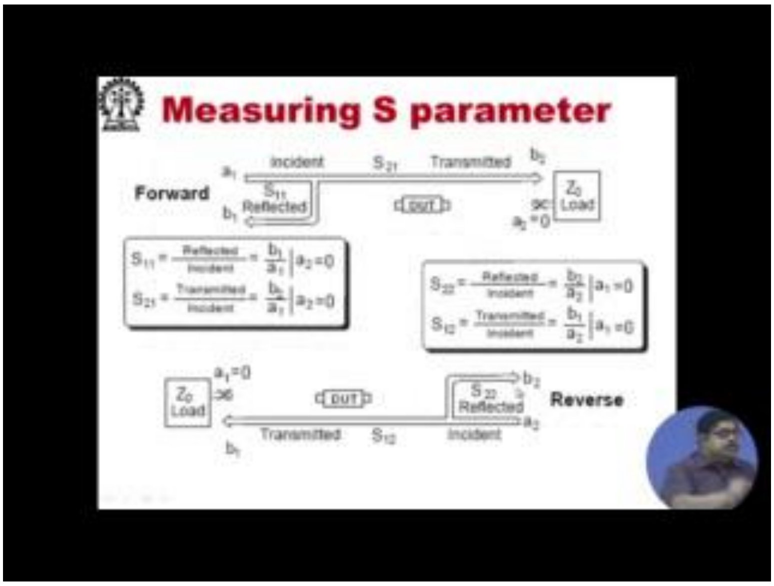

Now, measuring S parameter means now boil down to 2 ports. So, S 11 means what that second port you match, terminate and find these ratio B 1 by A 1 or in our terminology B 1 minus by B 1 plus, similarly S 21 means to match terminate port 2 and find out B 2 minus by B 1 plus. Similarly, if you exude the second port and match, terminate the first port you get the other 2 S 22 and is 12. So, that thing is described here that you have A 2 port network we called device under tease DUT. So, in 1 case we put that A 2 is equal to 0 that means, match terminate this, find out these quantities then you reverse the thing put the excitation in second port, put the match load here and then find out. So, you can measure S parameter.

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Now, this is the device network analyzer that can measure the S parameters. So, in A 2 port network, these are available in 2 port, 4 port etcetera obviously, 4 port is quite costly network analyzer is a quite costly equipment, but now what is its price is coming down in eighties it was invented and nowadays in your lab, you can hopefully see a network analyzer. This is a modern network analyzer looks like this, you have a large display section, then you see the ports it has 2 ports; this is 1 port, this is another port, with these ports you can connect your things.

Now, there is a numeric keypad here then there is 1 nob, which can change the analytical analog way of changing the values and there are various buttons, by pressing buttons you can update. So, this is a network analyzer you can connect with these; this is 1 port, this is another port, with this you connect your devices. Now, this is a closer view of network analyzer where you will see that I think there are some frequencies you can change. Then there are ports, there are stimulus etcetera. We will discuss those things at a later when we will concentrate on this thing you can put some markers there is. So, you see that there are 1 measurement function. So, various measurement S 11 measurements, S 21 measurement at that you can put there.

Then there is a format now format means in each way you want to get the display. So, whether you want the plot as smith chart plot, as a pollard plot, as a rectangular lot that you can do it here which scale you want to use what is scale whether you want log scale dB scale etcetera which type of display as I said then averaging whether you want averaging there is an averaging means suppose when you do any measurement and in presence of noise.

Now, if you repeat that measurement same quantity you measured several times some measurement and take average of that, your S n r will improve averaging, in improving S n r why because signal is a deterministic thing. So, if you repeat several times the same measurement. So, suppose some signal value is 5. So, I am taking several times. So, then when you average more or less I will get the same thing, but noise it is random. So, if I take large number of noise values their average will be equal to the mean of the noise generally our vibration noise they have 0 mean. So, noise will become reduced by a averaging.

That is why network analyzer, they provide various averaging things typically the same assignment is done 1024 times that improves the measurement accuracy then network analyzer need a calibration. We will see when using that if we do calibrate various types of systematic errors which occurs in a measurement that gets reduced then there are stimulus that start as we say that you can a network analyzer, you can see from you want to see the behavior of a network with by changing frequency response of. So, you can select the start and stop, so that you can get frequency.

Similarly, you can sweep, sweep means that frequency thing you can then, you can give trigger this is like other that some event we occur then that time I want to measure that is called trigger then you can put marker. So, that exact measurement values automatically will come, those are called markers. Then the instrument measurement set up that you can store that is called instrument state and then you can get preset some factory level setting cam do and then there is a another 1 is the microwave.

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This is navigation means you can change various values, you can see any other thing. So, you can which is the save recall button so that means, any time you can recall any previous measurement etcetera. So, this is about network analyzer

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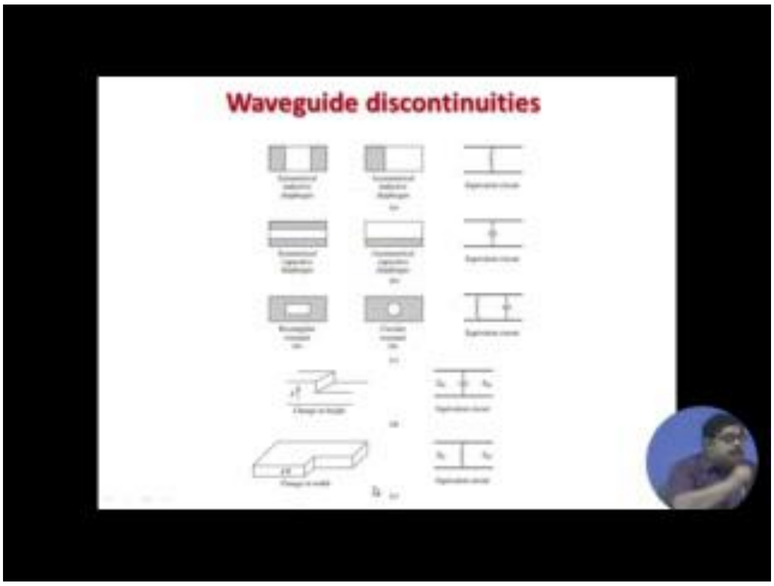

Now, this is in the microwave, things you will see this and an inductor. An inductor is formed by a rectangular wave guide. If you have a diaphragm that means, these positions are metal. So, actually the whole thing was open, but if you block some question of it like this it gives you an inductor this is called a diaphragm, inductive diaphragm. This you see the blocking is in the horizontal strips in this case these are vertical strips. So, this is called capacitive diaphragm, that is why a capacitor can be implemented by wave guide like this is ALC circuit by some rectangle then step.

If n step that means, the in the vertical side of the wave guide your having an step this continuity that is again a capacitance. So, capacitance you can give either by a diaphragm or by escape. Similarly, h plane step here the dimension is changing of the guide that is like an inductance. So, inductance you give by the h plane step or by a inductive diaphragm. Now, these things am showing because these are discontinuities and there we said various higher order modes will come that what we have seen, but net effect of them is producing an ALC in high frequency with cannot fabricate LC, but these are way we fabricate LC at high frequencies and you can measure that their S parameters by network analyzer. So, to give you an idea that microwave, at microwave frequencies these are equivalent of the themes that here, we do not use elements, but these are the distributed element.

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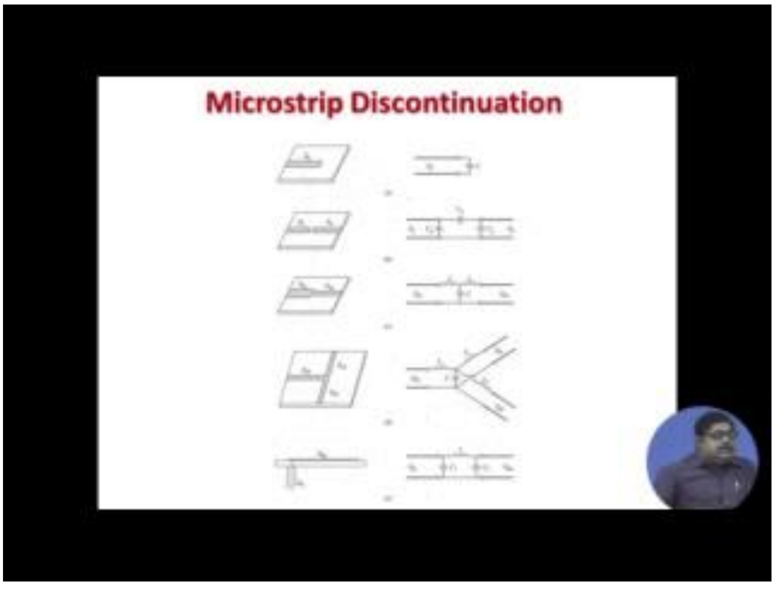

The same thing that was wave guide, this is micro strip technology, micro strip means you know there is sub stead over that there is a metallization. So, that micro strip discontinuity is the same C then LC you can make like this.

So, if you have a single micro strip actually in a normal micro strip line, whole thing should come total, but here we are keeping a gap that given raise to c now 2 tings there in between a gap. So, that gives rise to a pi c network pi capacity of network then if you are constructing this transmission line the materialization that give raise to a t network which 2 series and LC. Similarly A t here that gives you 2 branch cup lards similarly acquires to micro strip line that will give you an LC. So, these are the discontinuities discontinuation micro strip discontinuity that equivalently can be model.

Now, through S parameter you can model these there are ways by which theoretically you can find, also you can measure it through that network analyzer, the result will be comes some timely, this I am showing because in impedance measurement you can use these as your various loads. So, if you want give a capacitor as a load you can give either these micro strip or a capacity of diaphragm, we do that in the lab, we ask the student give that inductive diaphragm and ask him to find out what is the load etcetera. So, with measurement you can do that.

So, with this in the second tool that is scattering parameters. In the next lecture, we will try to find out how what are the properties of the scattering parameters for various microwave networks.