Basics Tools of Microwave Engineering
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Lecture – 19
Understanding Network Analyser Calibration
With the Help of Signal Flow Graph

Welcome to this lecture, 19th lecture. We will Network Analyser Calibration with the help of Signal Flow Graph.

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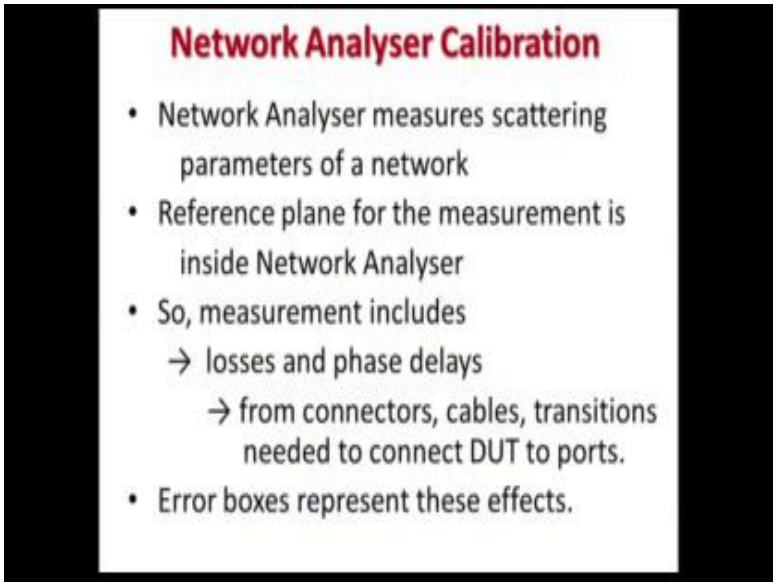

Now, network analyser we have introduced in this course that it measures scattering parameters of a network that is why it is a very important instrument in measurement. Now in network analyser when you discuss its architecture we have seen there the measurement of scattering parameters that is difference plane dependent. If you change the reference plane, the network analyser this parameter gets changed.

Now in the measurement network analyser its reference plane is quite inside the instrument that is not accessible to outside, but in outside to connect the duty from the ports we connect some connectors, we connect some transition, we connect some tables etcetera and then the device that we want to taste that is (Refer Time: 01:40). So, this

extra thing that shifts the, this extra connections, connectors cables that shifts the reference plane and that is why the measurement includes those loss and phase delays that are obviously, present in any cable connector etcetera. So, there is some error in the measurement.

Now as network analyser is when we preside measurement. So, these errors become significant. Now in microwave bench etcetera the measurement itself is not so precised that is why they are even this errors cause due to that change in reference plane does not come in to such prominence, but here in network analyser since it is a very precising instrumentation. So, these needs to be corrected that is done by putting all these errors etcetera errors (Refer Time: 02:44) etcetera into a box that is called Error Box.

So, error box represent all these losses or error effects. Now that error box is characterized by S parameters. So, if we were aware that there is an error we can characterized that error that will see how it is done and in that finding that error box is S parameter these are assumptions made.

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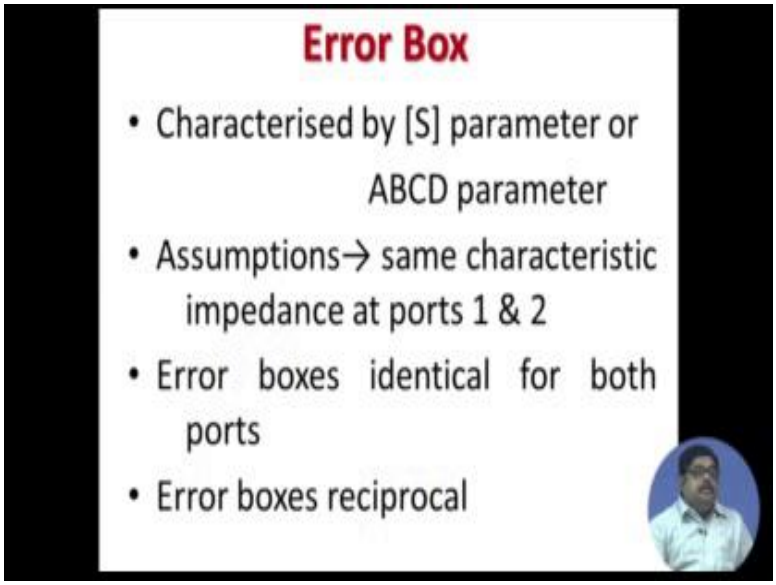

But it can be always, if the assumption are not valid you can (Refer Time: 03:23) that at the two ports whatever extra thing you connect that error causing connectors etcetera they are symmetric and their having same characteristic impedance. Now if not you know how to handle different characteristic impedance in the generalized S parameter we have shown you that. Also we have assume error boxes identical for both ports now that means, the both port there are identical connection, if not you need to change some of the formulation and also error boxes are reciprocal that means, we are not using anything in that connections and transition etcetera which is non reciprocal, so error box also a reciprocal.

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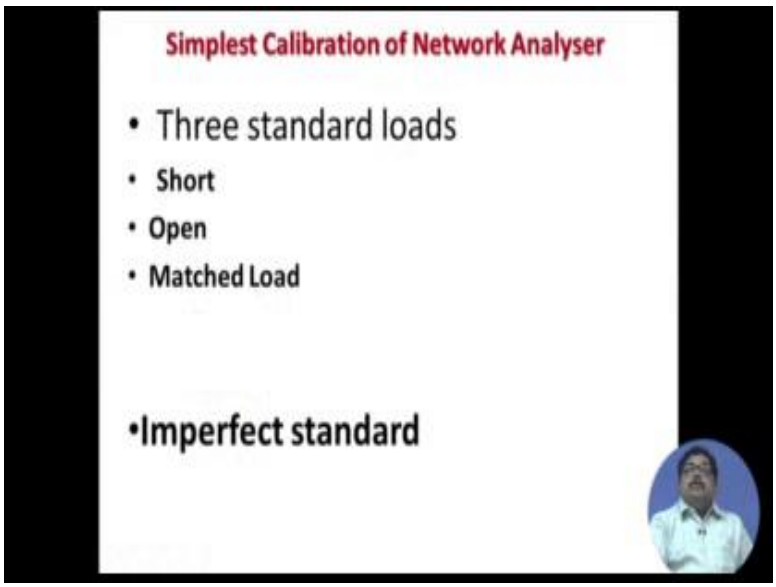

Now, calibration of network analyser the simplest way which in earlier days used to be done that if you have 3 standard loads one was short, one was open, another is matched load, you know that what is their behavior, what is there reflection coefficient at the loads, short will have a minus 1 open will have a plus 1 matched load will have a 0. So, by that you can found, but getting these standard loads you see I can design a short I can say that reflection coefficient is minus 1. But in reality if you one to fabricate a short it is a metal plate, now that has a thickness, now whatever you see that it should not absorbed anything, but generally some waves going inside, so complete reflection

you do not get. Also the reflected waves phase is 180 degree opposite to the incident waves phase that is not always true, so that are some imperfection.

Now making a open is quite a problematic thing you know there is a transmission line by which actually convert a short to an open and now that thing is very precise at a particular frequency, always it is not same and match load also that we except it is a absorbing the whole thing, whole power nothing is coming out, but in reality something comes out. So, any standard like that is imperfect; obviously, it is very that imperfection is small, but there is some imperfection. So, later people come up with the things that we need those some loads, but they a not so correct standard loads that calibration procedure which is a modern calibration procedure nowadays used that is called TRL calibration.

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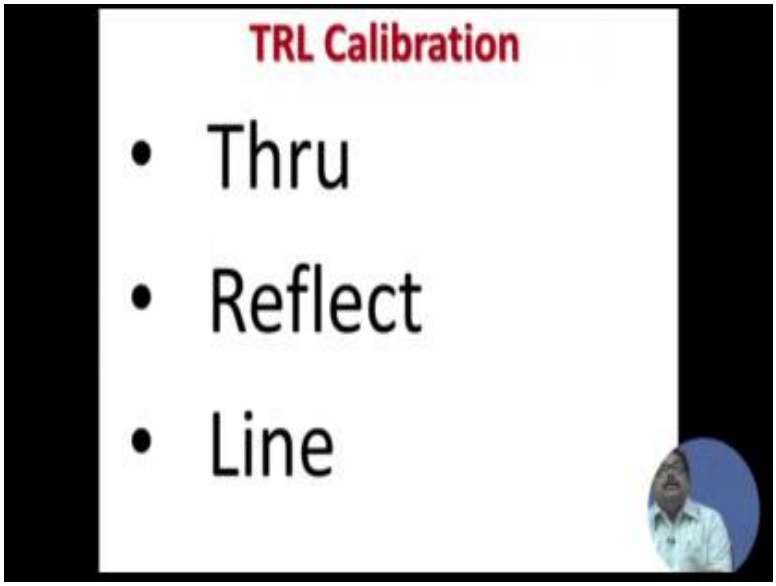

Now, TRL - T stands for Thru, Thru means a Thru line as we are showing in a direction coupler that thru line. So, Thru Reflect is line in; now what is Thru? Thru means just connecting port 1 and port 2 instead of connecting that duty if you just connect the accessible port 1 accessible port 2 of the network analyser directly together that is called Thru connection. Obviously, the male female matching will be there that is why there is some something there, but Thru.

Then Reflect means you use a high reflected load, what is the high reflected load? Either an open or short both gives high reflection both values are near 1, 1 is minus 1 another is plus 1. So, you take any and it need not be exactly minus 1 or exactly plus 1 that is why it is called Reflect, not short nor open. That it is a high value of reflection coefficient and that value also need not know that what is the reflection coefficient of that it should be high so that you get good amount of reflected signal. But its value actually as a byproduct of this calibration it comes out that what was that gamma L value.

Similarly, what is a Line? It is some length of transmission line. So, since the ports at generally (Refer Time: 08:30), so it is some form of (Refer Time: 08:34) line, but in web guide calibration is it can be some length of web guide line. Now here also what is the line length you need not know or what is the propagation constant of that line that also need not know. The line need not be lossless also the whole gamma; that means, the propagation constant into L that thing comes out of as a byproduct of the calibration. So, TRL calibration is so good that this loads or other things and not so perfect but it is not required to be perfect also, but it finds out those values in the whole process this is called TRL calibration.

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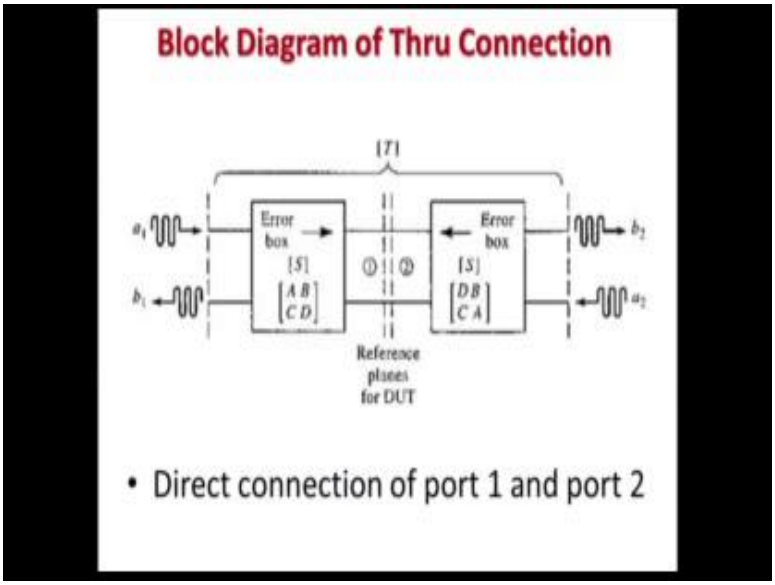

Now, first let us see the block diagram of a Thru connection. Now you see that port 1 and port 2 they are put together. Now obviously, this is your actual inside difference plane of the network analyser which is its ports inside and these are sincere connected something, so there is an error box is as we said that in both side we have assumed error box same phase also due to the nature of connection you see, instead of S you can also have transmission parameters both sides and you see that if you call this side A B C D this side you should call D B C A because the things are here coming from one side here from another side. So, direct connection of port 1 to port 2 that is called Thru connection.

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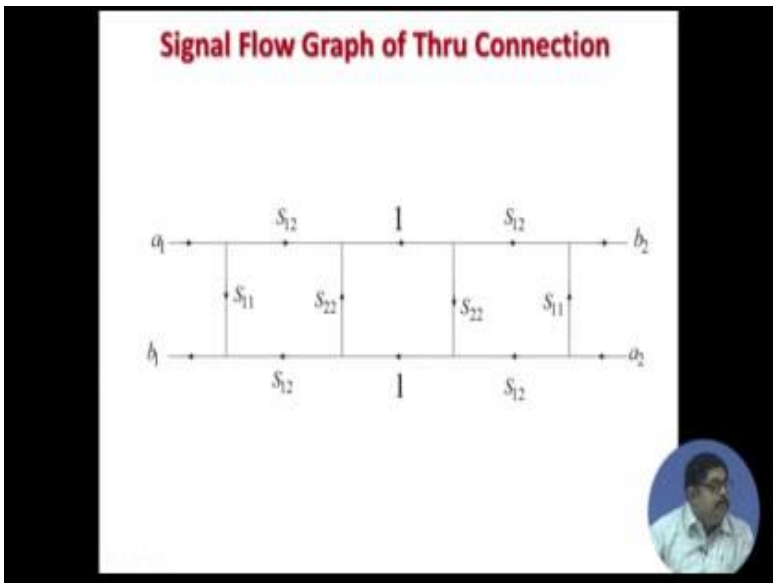

Now, in the signal flow graph what will be these? So, you see that you have this S matrix we know this is a error box S matrix where assuming same S matrix here, only thing is a 2, b 2 this is a 1, this is a 2, this is b 2, this is b 1, that is why these direction etcetera they got 3. And inside you see Thru, Thru means directly that transmission from this point to this point is 1, this point to this is 1, there is no transmission line also it is just 2 that is why these two n's are connected by 1; of these two connection.

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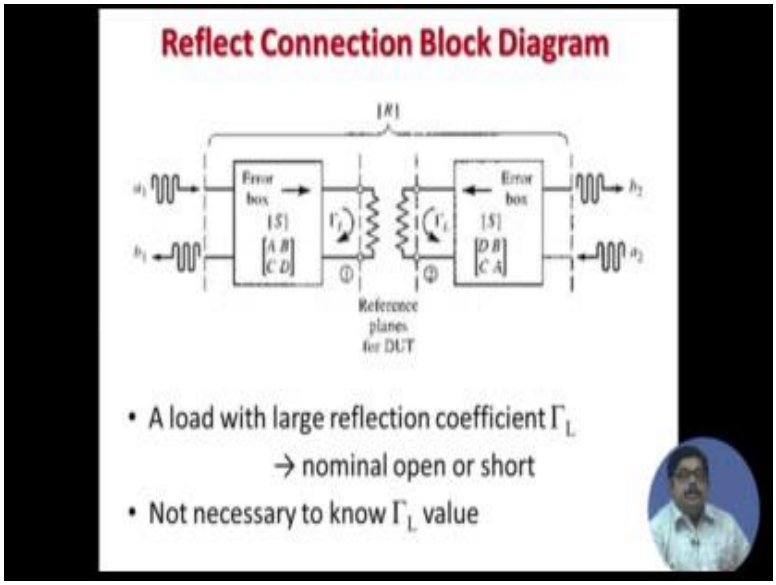

Now, reflect connection you see that you have the high reflection load that is why port 1, port 1 is getting high reflection coefficient. Similarly in port 2 you connect high reflection coefficient. So, a road with large reflection coefficient as I said nominal open and short will do, not necessary to know our gamma L value. Now this part we are calling it as R matrix this reflect, so r. So, this error box is they will now we are R matrixes, like in the previous case this one when you are connecting T that we are calling this whole error box and this connection everything we are calling T matrix here in the reflect case this whole thing we are calling R matrix.

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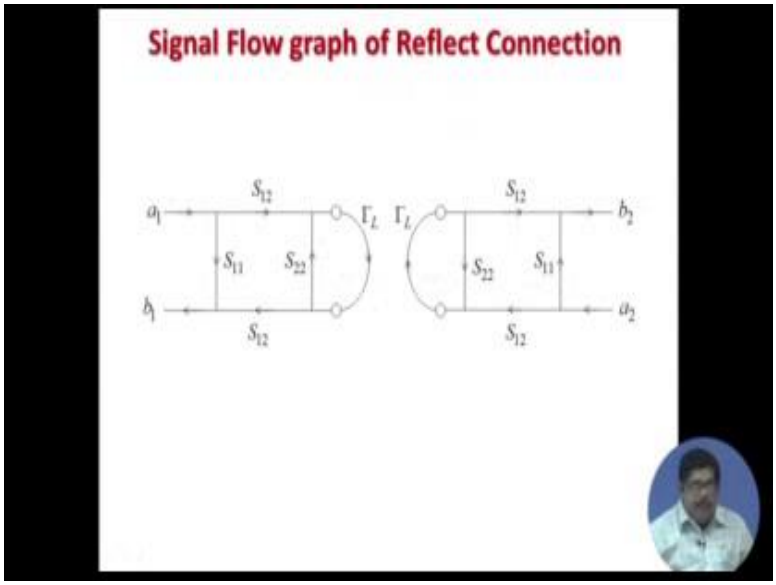

This is the signal flow graph that port 1 site, port 2 site and gamma l in between. So, this is the two disjoined graphs here because of the reflection connection that the port 1 that is getting fully on its own similarly port 2 is getting on its own.

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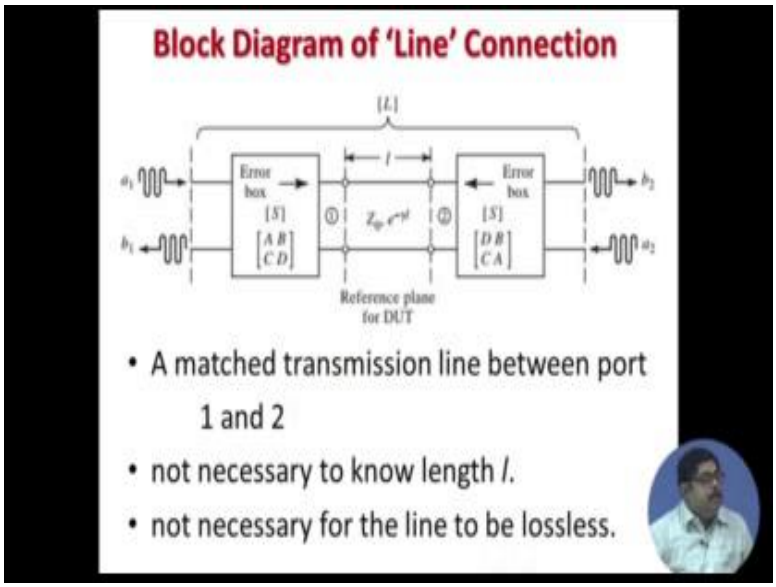

Now, this is block diagram of line connection. So, line means using a transmission lime we are assuming not beta it is gamma. So, loss is allowed it is a length L. So, you see line connection a match transmission line between port 1 and port 2, as I said not necessary to know length and not necessary to be lossless also. This whole, this two error box is and this line together that we are will designate as an L matrix. So, if we know the T R and L matrix then we can find this error box completely that will show now.

And this the signal flow graph of line connection, we get the two port networks between them these line.

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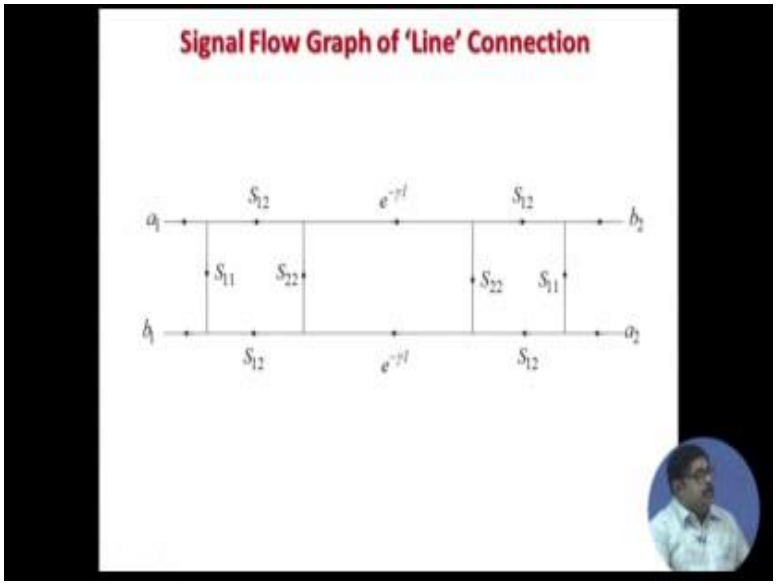

Now, come to the T matrix.

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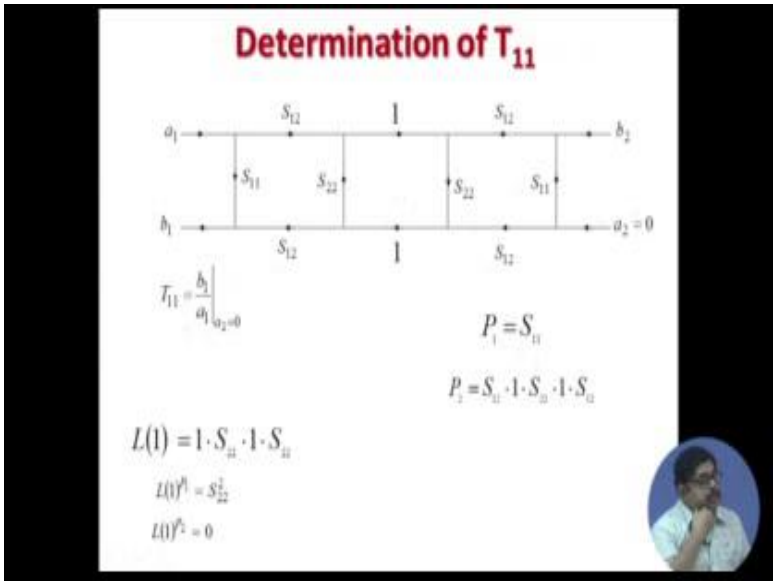

This was the signal flow graph here will apply the machines formula. So, what we are trying to find when we are trying to find the T matrix, basically this T matrix all are something S matrix - scattering parameter, it is together scattering parameter of the error box is two side and then the two connection. So, this T 11 will be b 1 by a 1 when a 2 is equal to 0; that means, this I side match then how much you are getting. That means, I will have to connect come from this independent variable to this dependent variable. So, what are the paths by which I can do - one path is definitely this one that we are calling P 1 and that value this path is S 11.

Another path is this one, this one, then I can come back. So, this is another path that we are calling S 12, 1, S 22, 1, S 12 all products. Is there any other path can I come like this? But there is no coming, but can I come like this? That we have already done, but this one - we cannot come. So, only there are two paths for coming from this side to this side.

Now is there any loop. So, see this is not a loop because I cannot come here, this is a loop. So, this is a loop again, this is not a loop now. So, there is only one first order loop that is 1 S 22, 1 S 22 that we have written L 1 is this. Now obviously, since there is only one L 1 then there is no L 2, L 3 etcetera. Now let us also see whether L 1 is P 1;

that means, first order loop non-touching P 1. P 1 is this part and this is first (Refer Time: 16:37) loop, so obviously they are non-touching. So, what is a value that? That will be the loop, its value as this. So, L 1 P 1 will be S 22 square the value of this loop and L 1 P 2, P 2 is this path, but this loop is touching that path that is why L 1 P 2 is 0. So, with this you can put T 1 values (Refer Time: 17:12) formula that P 1 is S 11 into 1 minus L 1 P 1 that is S 22 plus P 2 1 minus L 1 P 2 that was 0.

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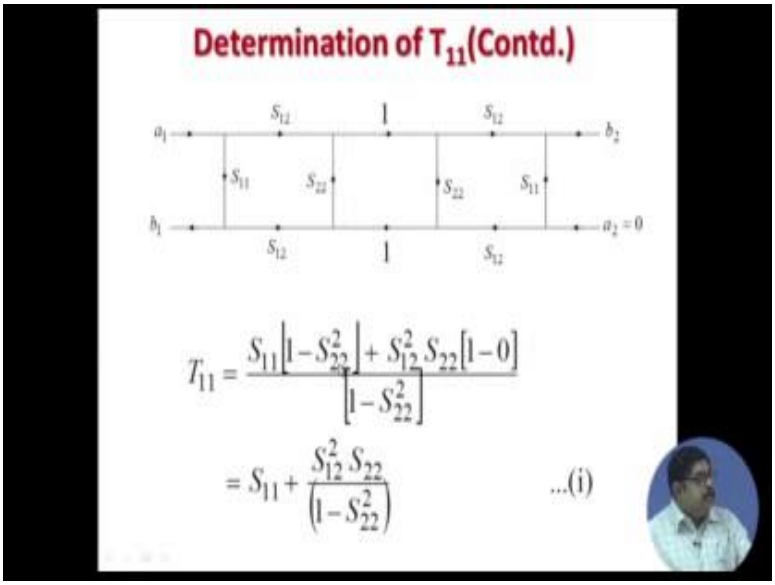

And here 1 minus sigma L 1 there are L 2, L 3 etcetera. So, that why this thing, this becomes your T 11 in terms of this. This we are calling first equation.

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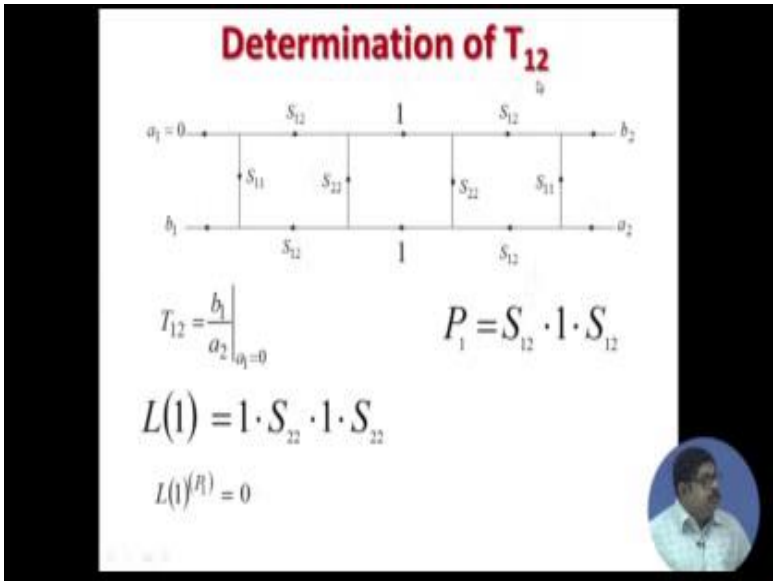

Then determination of T 12, T 12 what is a definition a 1 should be now 0. So, we are putting a 1 0 and will have find b 1 by a 2 b 1 is this, a 2 is this. So, from a 2 to b 1 how we can come one path I am seeing directly, so P 1 is S 12 1 S 12; is there any other path? Can I go here, no - this is blocked, then this is, then it is blocked. So, there are no other path only one path where coming from here to here. Is there any loop? Yes, that old loop that value I know, but my path and this loop they are touching. So, L 1 P 1 is 0 and obviously, there are no L 2, L 3 etcetera.

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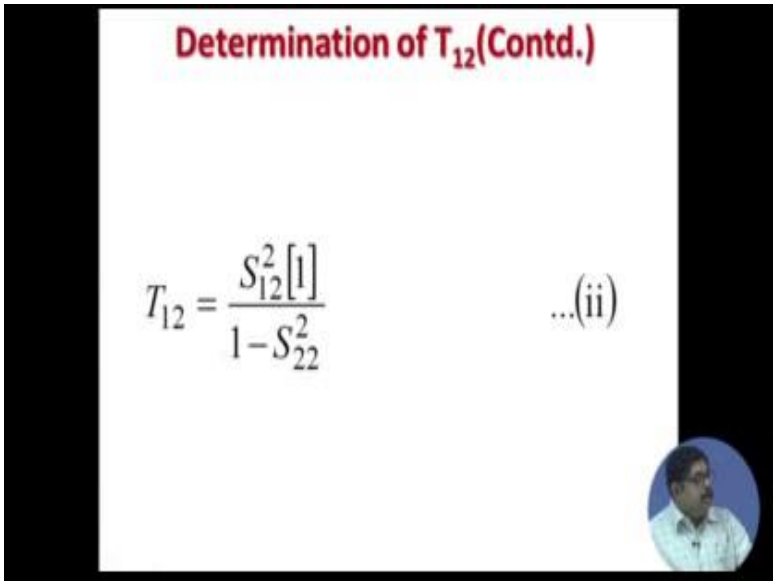

So, you can put this value S 12 square, 1 minus that L 1 P 1 that is 0. So, this we are calling second equation.

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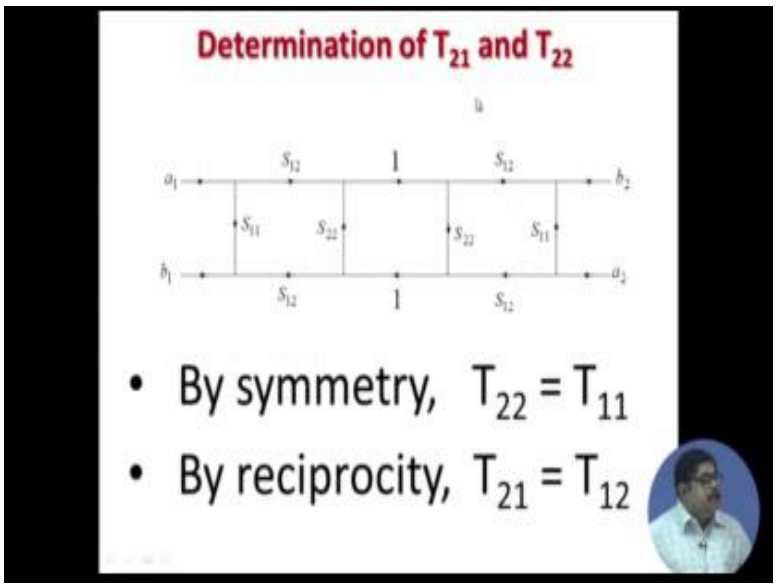

Then T 1 and T 22 you see the signal flow graph the by symmetry we can say that T 22 is equal to T 11 and by reciprocity, the whole thing is reciprocal error box is also be

assumed to be reciprocal; obviously, Thru connection is reciprocal, by reciprocity T 21 in T 12. So, no extra information coming from this, but we know now T matrix completely. T hat means, Thru when you make through this T in terms of this is parameters, we know.

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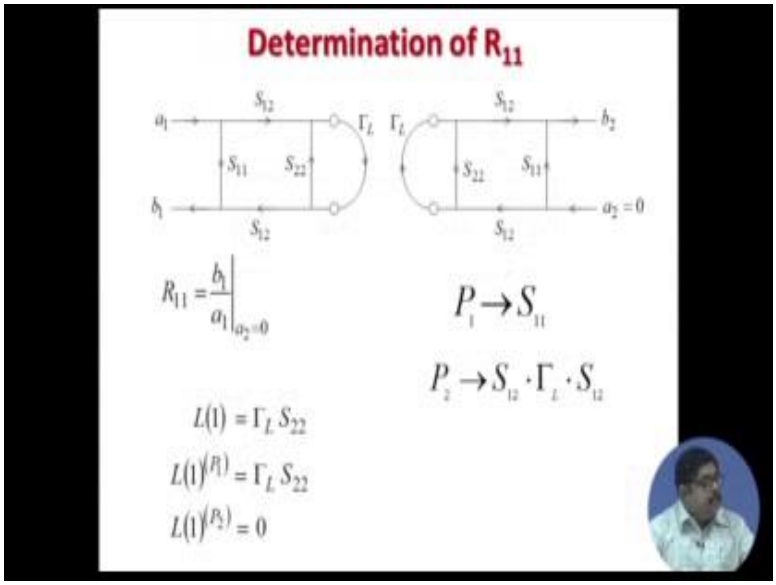

Now, T matrix we can measure. Now you see this determination of R 11 the reflect case. So, there this is the signal flow graph, now R 11 is b 1 by a 1 that means, I will have to come from here to here. One path is directly this, so P 1 is S 11 another path is this you see S 12 gamma L S 12 P 2. Now loop, where is L 1? Is there any L 1? Yes, this is the loop, you see this is the loop there are no other loops. So, gamma L S 22 and L 1 P 1 does it cut S 11 S 11 is this loop is this they are not cutting, so L 1 P 1 will be this L 1 value, L 1 P 2 - what is P 2? These, these, these, the loop are these. So, they are touching that L 1 P 2 is 0.

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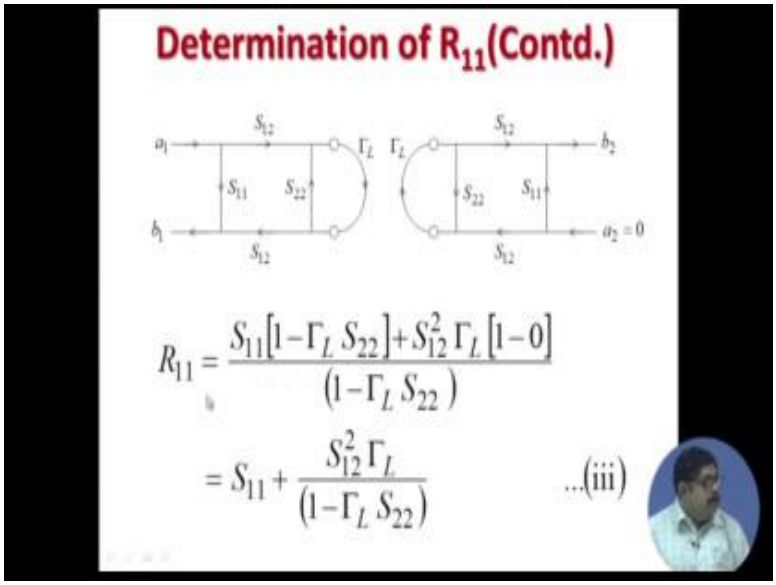

Now, with this you can put it inventions formula R 11 will be this that will give you these equation, gamma 3.

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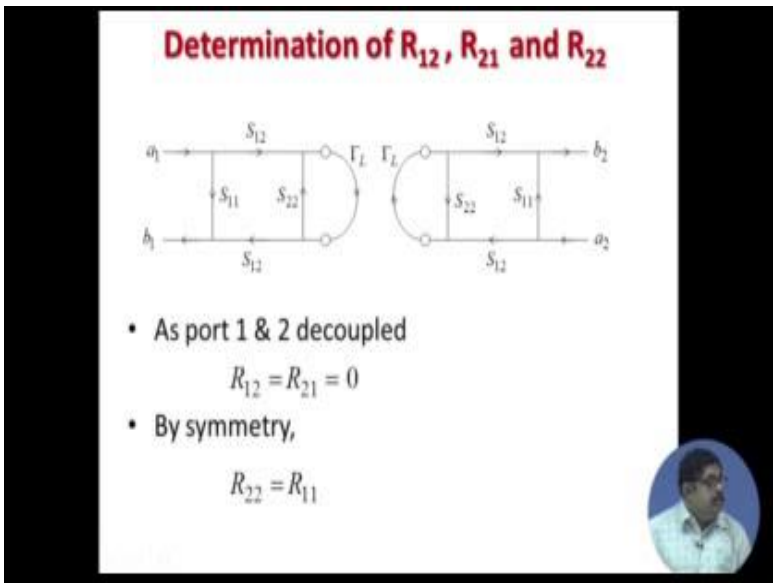

Then as port 1 and 2 decoupled, so obviously, we can say R 12 and R 21 they are 0, because signal flow graph itself is cut, so no signal can come from 1 to 2 or 2 to 1. So,

R 12 and R 21 will be 0 and the whole thing is symmetric, so you can say R 22 is R 11. But, that does not this determines the complete R matrix, scattering matrix for R connections but that does not give us any extra information, extra equation.

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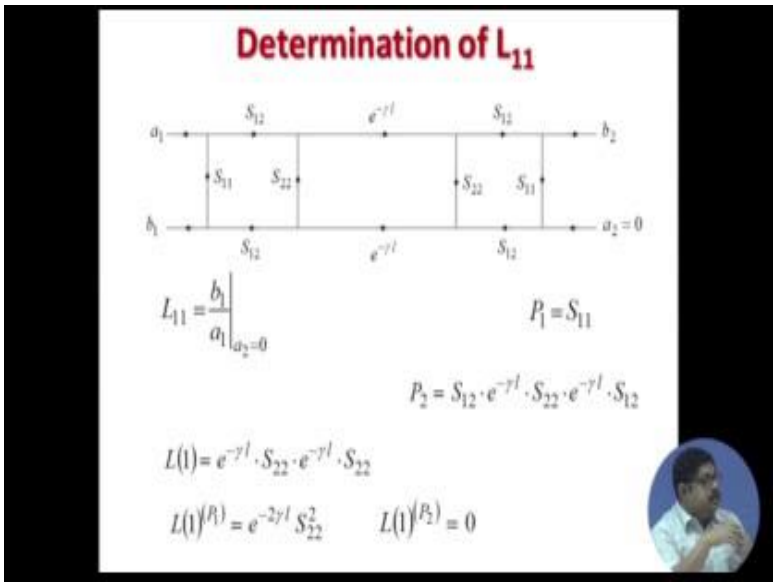

Then the last one - L 11, they are again L 11 means b 1 by a 1. So, a 1 to b 1, one path is b 1 another path is these, these, these, these, these S 12 e to the power minus gamma L S 22 then e to the power minus gamma L S 12. So, there are two paths is there any third part, I can go here now because this is not allowed. So, there are two paths. Now is there any loop? Obviously, this is a loop we are. So, e to the power minus gamma L this e to the power minus gamma L into S 22 this is a loop, any other loop? You see this is not a loop, this is not a loop no S parameter can be a loop, 2 port S square meter.

Now, L 1 is it touching with P 1, this loop is not touching with 1. So, L 1 P 1 value will be this loop value that is e to the power minus gamma 2 gamma L in S 22 square. Now this one L 1 p 2, but L 1 P 2 is this and this is the loop, so they are touching so L 1 P 2 is also 0.

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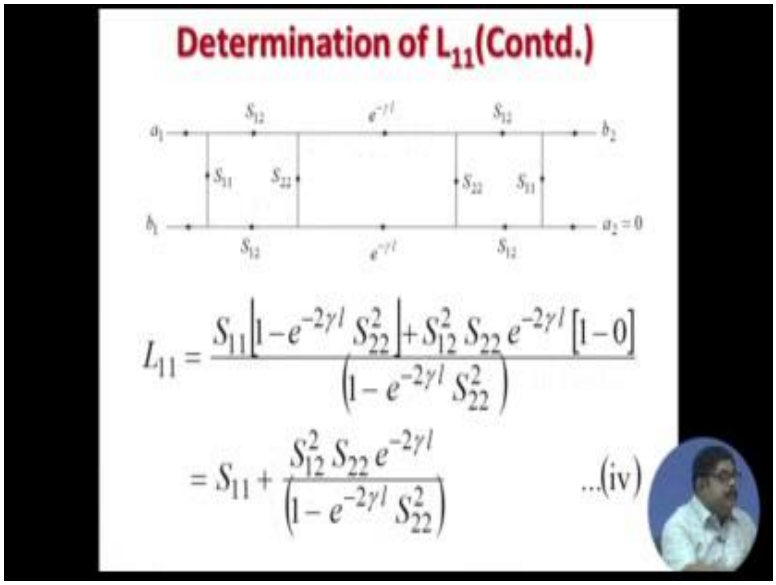

Now, you can put it the values. The values will be something like this that gives us 4th equation.

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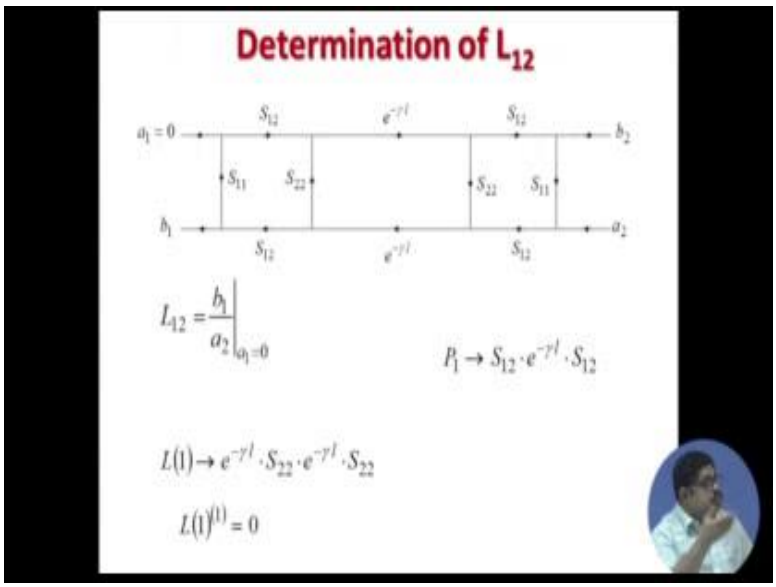

L 12, L 12 determination, L 12 is what? b 1 by a 2, b 1 by a 2, so there is direct path is there P 1 S 12 e to the power minus gamma L S 12. Is there any other path? You can go

here, but then it will track; I can go here I will get start. So, there is no other path and is there any loop? Obviously, this loop last time also we have seen L 1 is there, but L 1 is touching this loop, so in this case L 11 will be 0.

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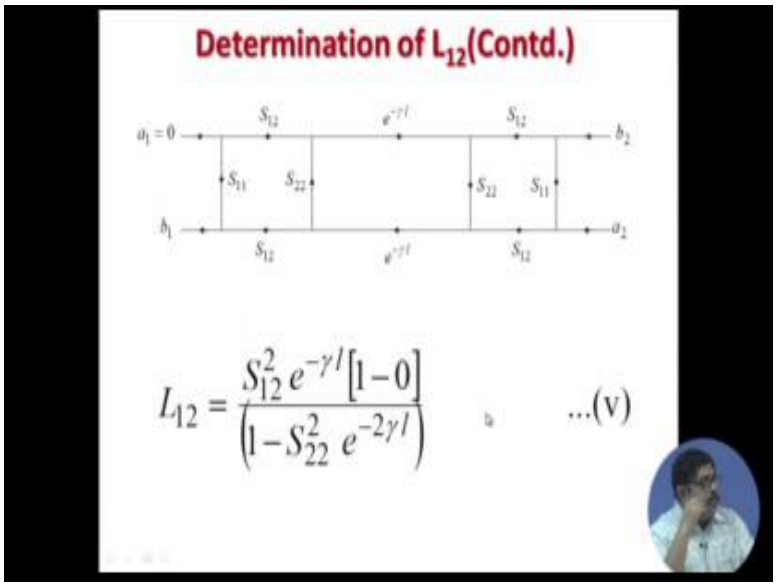

So, this is our value of L 12, so 5 equations. So, you have got you see this in terms of the error boxes S 12, S 11, S 22 etcetera we have got this 5 equations. Now when you see in all this cases the network analyzer is measuring these L matrix for line connection, R matrix R connection and T matrix T connection it is measuring because these are its internal planes. So, this whole thing it is measuring. So, we have found that from that measurement it will find T 11 is in terms of S 11 S 1 S 22. So, S parameters are 4 S parameters and we have 5 such equations, we have 5 such equations. So, they can solved by symmetric by reciprocal.

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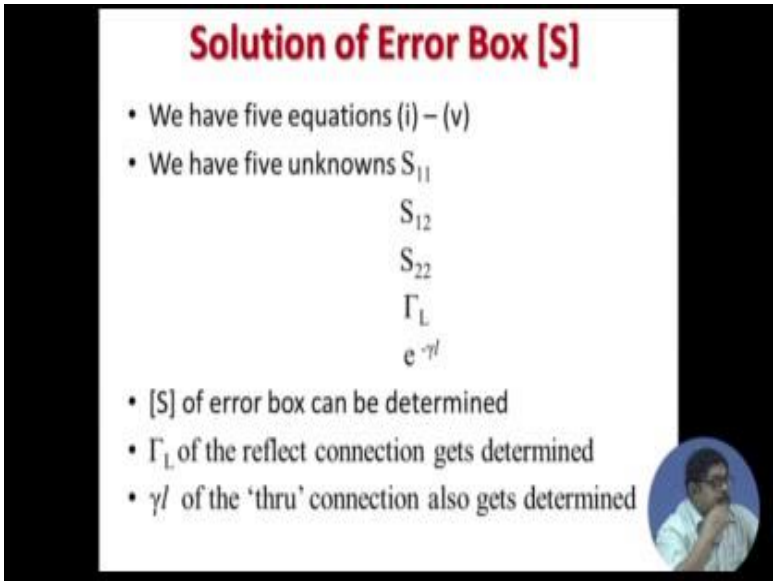

We have 5 equations, we have 5 unknowns S 11, S 12, S 22, so due to the error box reciprocity we know S 12 and S 21 will be same. So, S 21 is not shown here, so S 11, S 12, SS 22 - 3 unknowns. Gamma L is an unknown; that means, a load that we are connected in case of that reflect connection it is reflection coefficient and in case of line the gamma l. So, 5 unknowns, are there 5 equations we can be solved I am not going in to that have to solve 5 unknowns 5 equations by proper manipulation. That manipulation is long one, but you can solve it. So, by that you can determine this if you determine this 3, basically you are determining the complete symmetric of the error box.

So, you know error boxes. So, you can find out form that error boxes what is the actual when you will do actual measurements you know that with you duty you will have that error boxes. So, you find those error boxes and also in the process gamma L of reflect connection gets determined that was not your objective, but you see that what type of load you are using suppose that load is not very good because if the signal coming low then there are the sensitivity problems come. So, that you can check also you can get your Thru connection what is the gamma L of that.

So, you see such a nice procedure that you measure by 3 such TRL connections the S parameter you measure, networks analysis measure then it finds out that S by these mathematics and then it now know error box is. So, actual measurement time it can correct that for those error. So, I thing that is you see this type of complicated things with the help of signal flow graph it got very simplifier that is why it is a very elegant and useful tool for micro designers.

With this we complete all the lectures except the last tutorial. So, here we have seen 3 main tools switch charts, scattering parameter, signal flow graph, but we have seen lot of applications of that, we have seen impedance matching techniques, we have seen the network analyzer, measurement, micro (Refer Time: 29:12) measurement, network analyzer, we have seen network analyzer calibration also and also we have seen some useful devices, their scattering parameter like directional coupler and magic Tee which are used heavily in microwave securities. So, with that this theoretical part is completed next will have tutorial to exemplify these signals flow graphs and some of these parameters.