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

Module - 7
Lecture - 34
Microwave Amplifiers - III: Design Example

Hello everyone. In the last 2 lectures, we have been talking about Microwave Amplifier and in the last lecture we talked about 3 different types of the gain.

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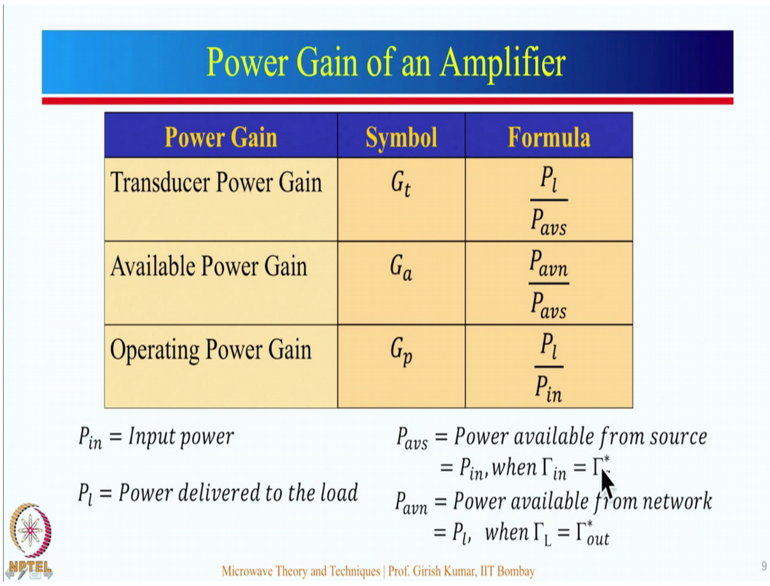

We had started with G p which is operating power gain defined by P l divided by P in, then we talked about G t which is transducer power gain that is P l divided by P available from the source. And then, we talked about G a available power gain and this is given by P available from the network divided by P available from the source and this condition will be satisfied when both input and output side are matched. So, we have to have the condition that gamma in is equal to gamma S conjugate and gamma L is equal to gamma out conjugate. Then, after that we had looked at the derivation and then, we talked about 3 different cases.

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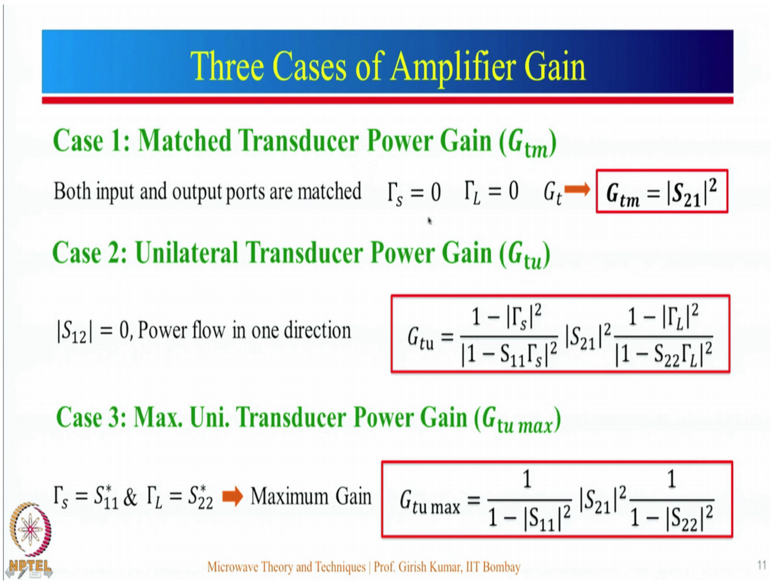

Case number 1 was matched transducer power gain, where gamma S is equal to 0, gamma l is equal to 0. These two conditions will be obtained when input and output are terminated with 50 ohm load. In that particular case G tm is given by S 21 square, then we talked about unilateral transducer power gain where S 12 is equal to 0. And then, we looked at when we will get maximum unilateral transducer power gain and this condition will happen when gamma S is S 11 conjugate and gamma L is equal to S 22 conjugate. So, this is the expression for G tu max.

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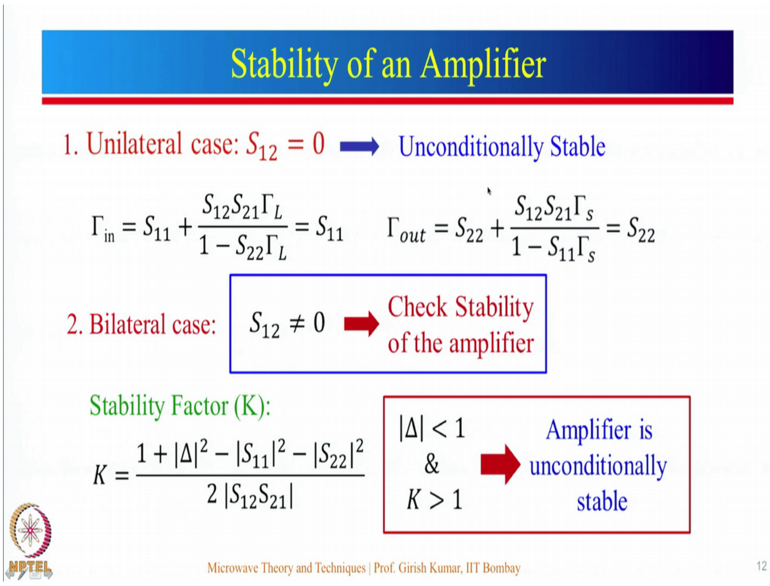

Now, amplifier has to be stable. If amplifier is not stable, then in that case it can become an oscillator. When we talk about oscillator, then we will talk about unstable amplifier, but here we talked about unilateral case in that case S 12 is equal to 0 that would be unconditionally stable. Second cases bilateral case where S 12 is not equal to 0, then we have to check stability of the amplifier and had told you this expression for K. Today I will tell you how this expression of K is derived.

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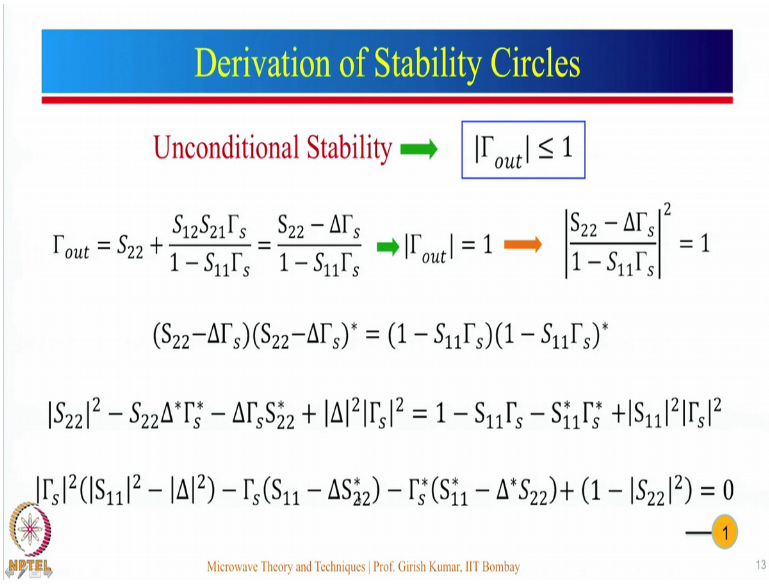

After that we looked at derivation of the stability circles.

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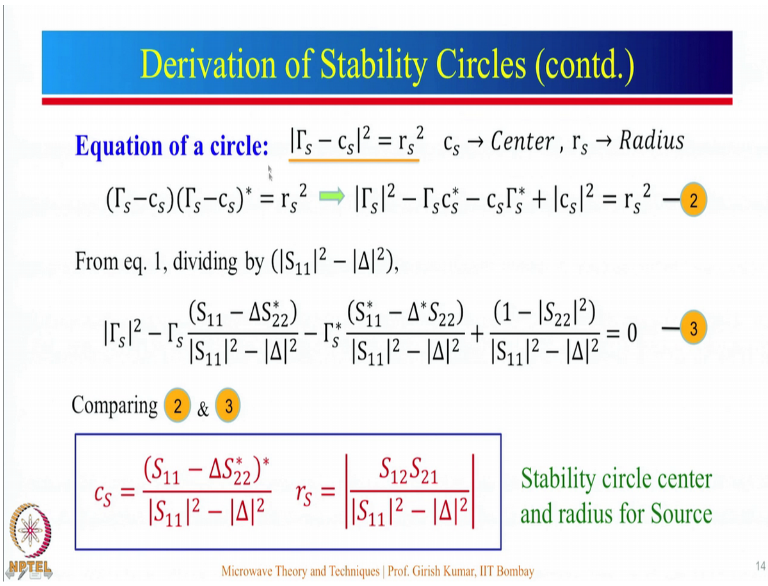

And, we had written the equation of the circle.

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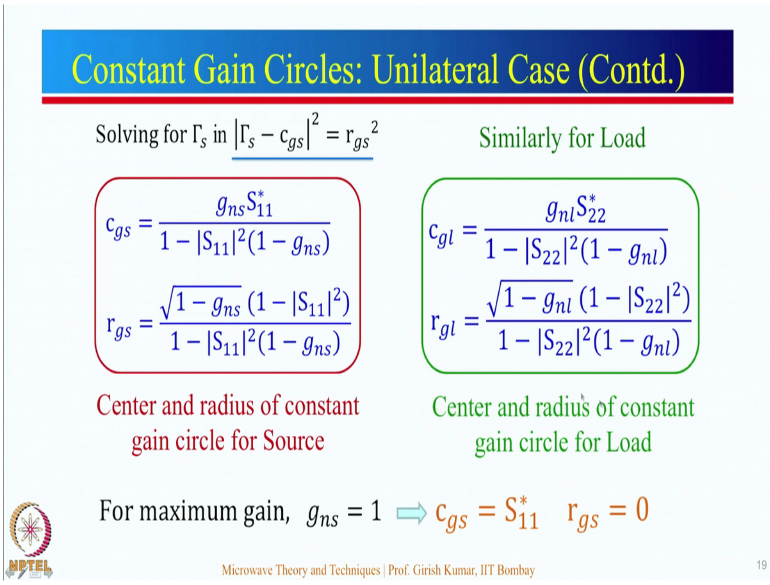

Then, we found out equation of a circle for both source and load.

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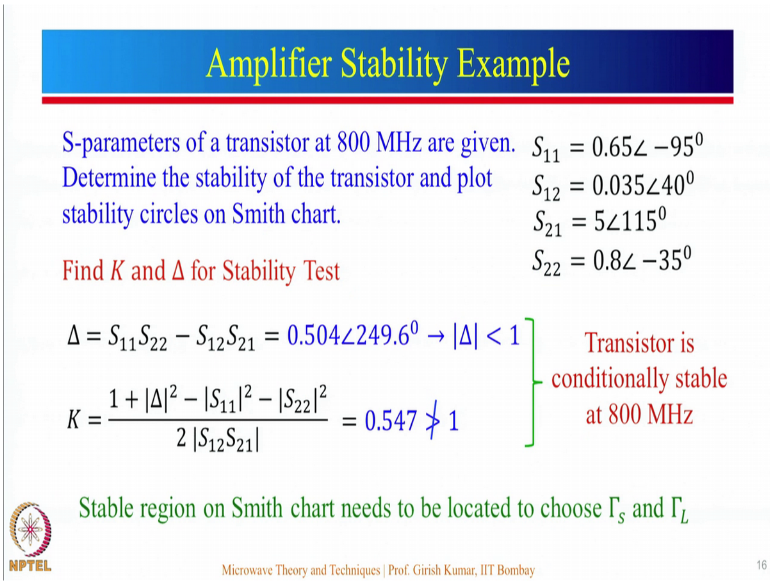

After that we started with an example. For that example S-parameters were given at 800 mega hertz and we found out that this particular transistor is unstable or we call it conditionally stable at 800 mega hertz. The reason for that is delta is less than 1, but K is not greater than 1. In this case, K was less than 1.

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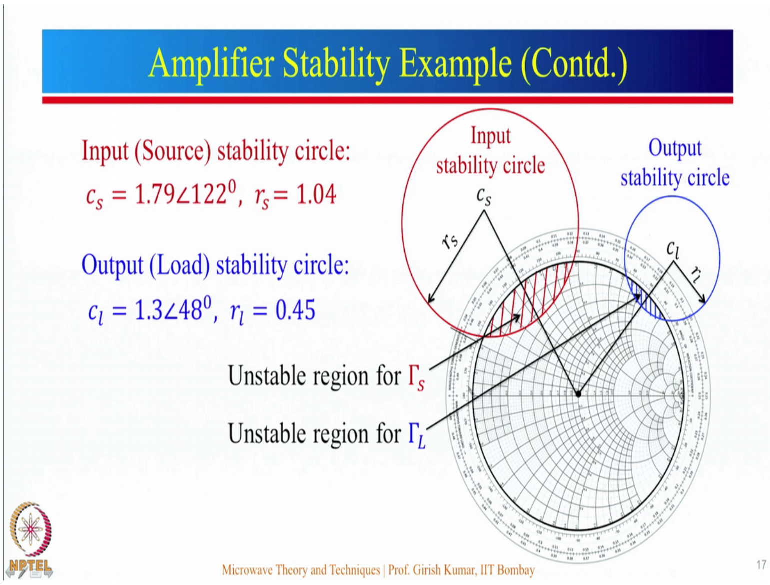

Then, we had plotted input stability circle and output stability circle. So, here I want to mention how K is defined. So, we know that amplifier will be stable when it is satisfy for all the load conditions. If you see in this particular case, this is the portion for which it is unstable. So, if we put the condition that magnitude of c s minus r s is greater than 1, then in that case there will be no intersection on the Smith chart. So, by putting the condition that magnitude of c s minus r s greater than or equal to 1, that condition gives us the expression for K which is stability factor same thing can be done for c l and r l.

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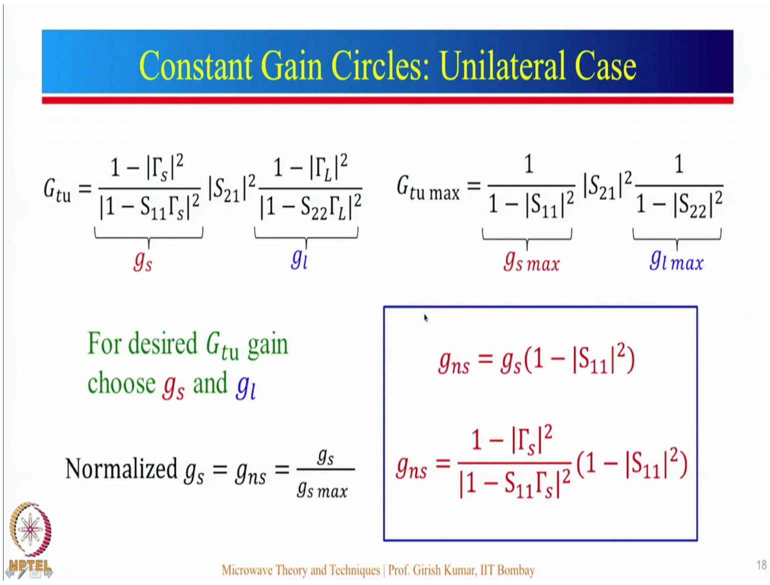

After that we looked at constant gain circle. We started with unilateral case. So, this was the expression for G tu. This was the expression for G tu max and then, I had mentioned that what desire G tu gain, the values of g s and g l should be chosen such a way that they are less than g s max and g l max respectively. So, this was the expression for g ns which was further obtained by substituting this value of g s over here and here, then we have to solve gamma S and by solving gamma S.

These are the expressions for centre of the constant gain circle and this is the radius of the constant gain circle. Similarly for the load we can obtain c gl and r gl and for maximum gain we know that g ns is equal to 1 and if you put g ns equal to 1, we get c gs equal to S 11 conjugate and r gs is equal to 0. However, all this while we have done the derivation assuming it is a unilateral case, however practically S 12 may be small, but may not be equal to 0. So, then what happens? So, let us see what happens if S 12 is not equal to 0.

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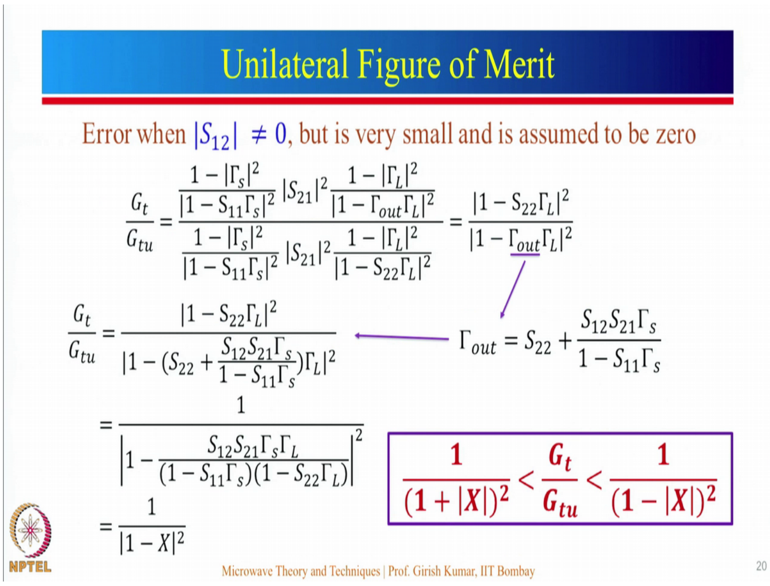

So, when S 12 is not equal to 0, but it is small; so, what do we do? We take the ratio of G t divided by G tu. G tu is transducer gain for unilateral case. This is G t when S 12 is not equal to 0. So, take the ratio, substitute the values, do some simplification and then, we get this particular expression over here. However, most of the time we do not use this particular expression; what we do? We take the maximum possible error and that will be obtained not for G tu, but for G tu max. So, this particular expression can be simplified for the maximum value of G tu max.

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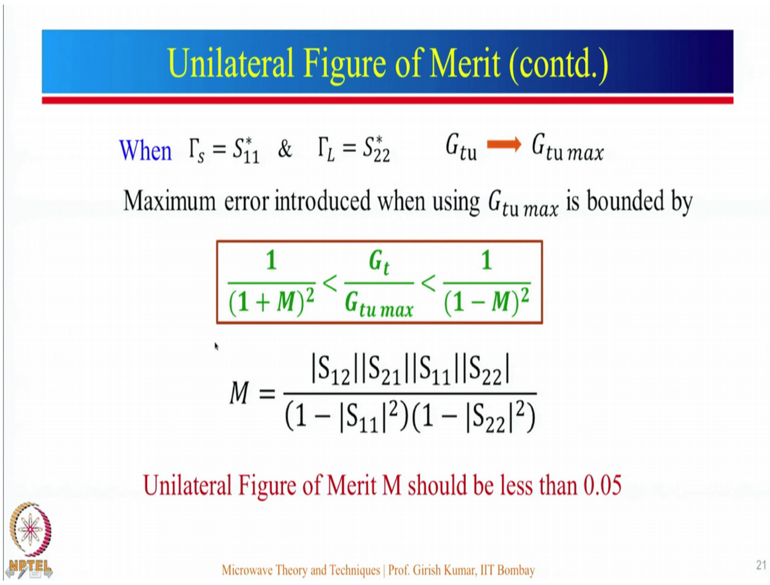

Then, we get this particular range for G t divided by G tu max and when we obtain this, when we substitute gamma S is equal to S 11 conjugate and gamma l is equal to S 22 conjugate where the expression for M is given by this particular terms over here, what you can see over here all these things are magnitude now and also these are only S parameter. So, there is no gamma S or gamma L coming into picture. Why? It is because we have assumed this particular condition.

So, this will be the worst possible error which can occur if S 12 is not equal to 0, but we are proceeding with the design using the concept of unilateral. These things will be clear when we take an example. I just want to mention that unilateral figure of merit M should be less than 0.05. There are some books. They do mention this should be less than 0.03, but most of the time I have seen 0.05 is a fairly good criteria.

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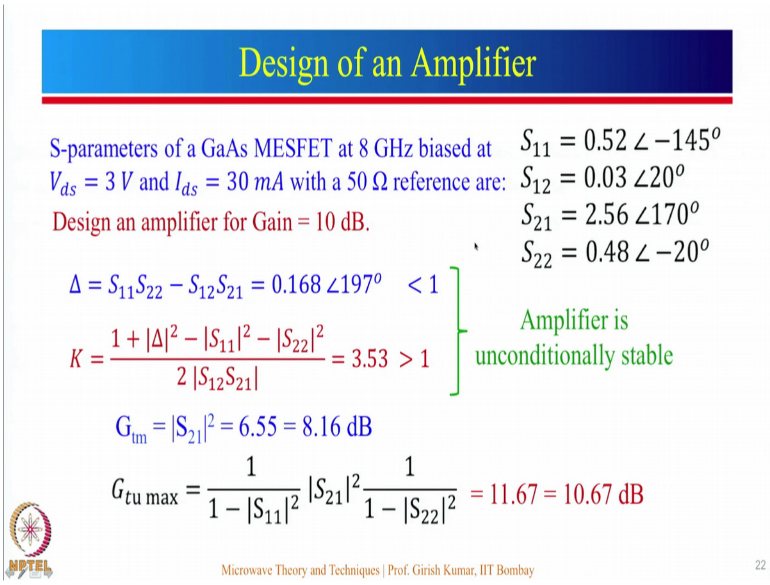

Now, we are going to take complete design of an amplifier S parameters of a gallium arsenide MOSFET at 8 giga hertz are given as follows and these are for biasing condition of V ds equal to 3 volt and I ds equal to 30 milliampere and our objective is to design an amplifier for gain equal to 10 dB. So, do not start the design immediately. First of all you must always check whether the amplifier is stable or not, ok. So, what we do first stub would be that first find out the value of delta which is given by the determinant of S paramete. By substituting these values of S parameters, we can find out the value of delta which is given by these numbers and that is less than 1. Now, we find the value of K. You substitute all these values and that comes out to be 3.53 which is greater than 1. So, that means amplifier is unconditionally stable.

So, I just want to mention that when the amplifier is unconditionally stable, there is no need for drawing the stability circle for input side and output side because amplifier is unconditionally stable, ok. So, now the next stub is we need to find out what is the maximum possible gain which can be obtained for these S parameters. So, first we find out G tm which is nothing, but S 21 square. So, we substitute the value of S 21 which is 2.56 square that comes out to be 6.55 equal to 8.16 dB. Now, you find out G tu max. By substituting these values, we can actually find out G tu max that comes out to be 11.67 which is 10.67 dB.

Now, please recall what I had mentioned earlier that we get some value of S 21 that will give us some gain, however because S 11 and S 22 are not equal to 0, part of the power gets reflected back. So, we must design a proper matching network, so that better gain can be obtained. So, in this particular case we can get maximum gain of 10.67 dB and since, 10.67 dB is more than 10 dB, that means this particular design is feasible. So, let us proceed for design of the amplifier, but before that again let us find out what the maximum gain error is.

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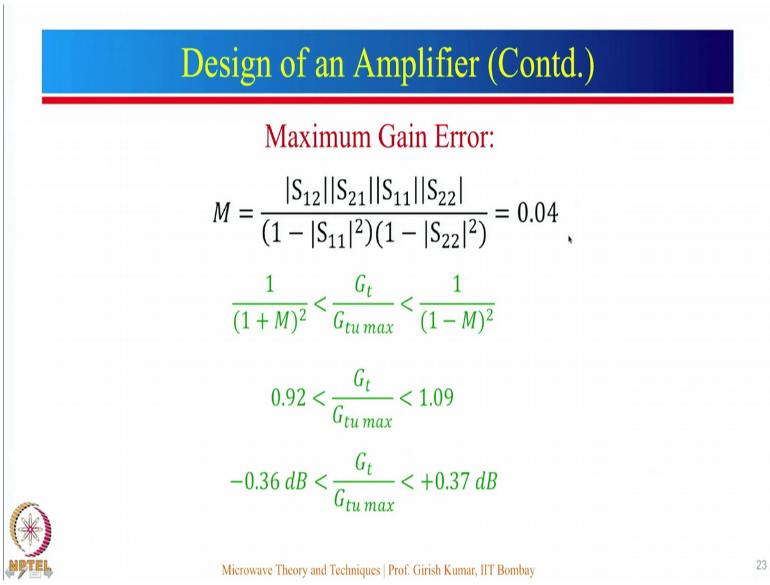

So, we must find the value of M and the value of M comes out to be 0.04. So, let us see what the extreme error in the gain is. So, we substitute the value of M over. Here simplify this thing, it comes out to be in the range of 0.92 and 1 09. We take the 10 log of these values. So, that means the gain error can be between minus 0.36 dB to plus 0.37 dB. If we proceed with unilateral design, now in comparison with 10 dB which is the required gain 0.36 or 0.37 that is relatively small number. So, we can proceed with the unilateral design.

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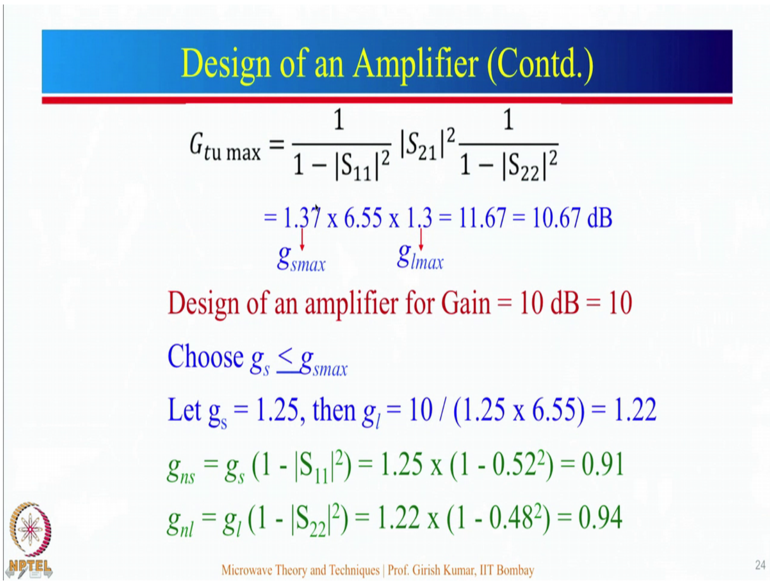

So, now we have already seen G tu max expression. So, this is the expression for G tu max. I have shown this thing one more time. So, let us substitute the values of S 11 S 21 S 22. I have written these values separately. So, you can see that this particular term which belongs to the input site gives us g s max of 1.37. S 21 square is given over here and this term here which corresponds to the output site that gives us maximum value of g l max as 1.3.

So, now we have to design an amplifier for gain equal to 10 dB. The numeric value of 10 dB is equal to 10. So, now we have to choose g s. We must choose this value of g s to be less than or equal to g s max. No one can see over here g s max is 1.37. So, let us choose g s equal to 1.25. You can choose g s as 1.2 or 1.3. It does not matter you can choose any value of g s as long as we get a gain equal to 10. So, if we choose g s equal to 1.25, then we can calculate g l.

So, g l comes out to be 10 divided by these values over here that comes out to be 1.22. You must check that g l must be less than g l max and in this particular case, g l max is equal to 1.3. That means, g l is less than 1.3. So, now find out the normalized values of g ns and g nl and that comes out to be 0.91 and 0.94. So, this is another check. These values must be less than 1. If any one of these values is greater than 1, please restart this whole thing of choosing a different value of g s.

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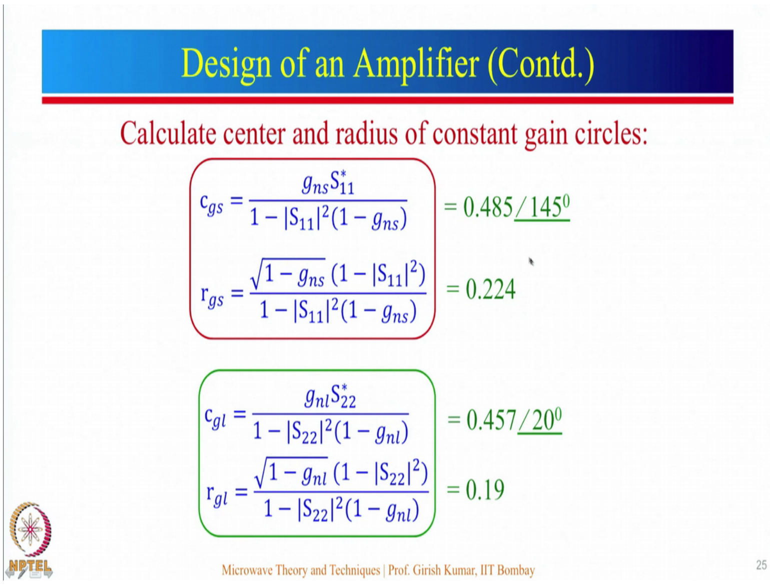

Now, we calculate centre and radius of constant gain circle. So, the expressions are given over here. So, substitute various values for g ns, S 11 we can find out the value of c gs to be equal to this r gs is given by this value. Similarly we find out the values of c gl and r gl. Next stub would be to plot these things on the Smith chart.

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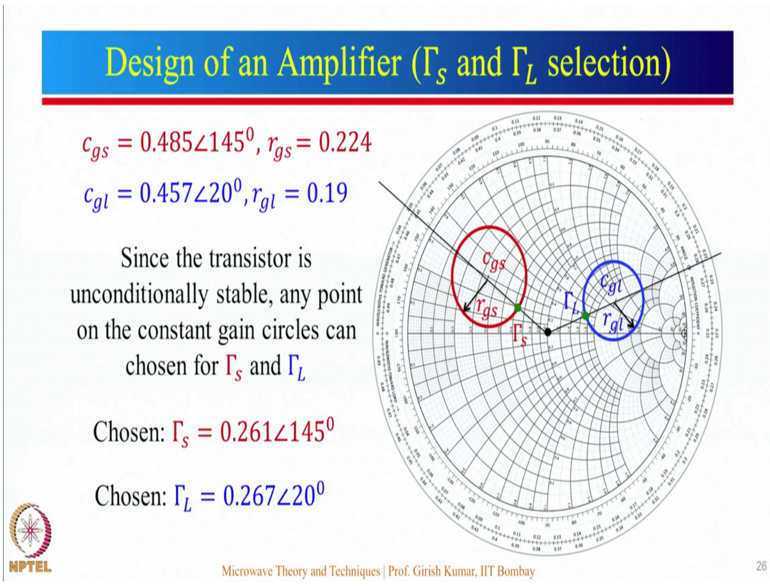

So, now we have to plot the constant gain circle. So, let us see for the source site c gs is 0.485 angle 145 degree. So, you draw a line like this which is at an angle of 145 degree and then, choose 0.485. As I mentioned if you assume this distance is approximately 10 centimeter which corresponds to 1, then 0.485 will be equal to 4.85 centimeter. So, you look at this particular point which will be c gs, then 0.224 is the radius. So, you draw a circle with the radius of 0.224. So, this is the constant gain circle for the input side and similarly plot for constant gain circle for the output side.

So, here c gl is given by 0.457 angle 20 degree. So, again draw a line at an angle of 20 degree, choose point c gl at 0.457 value. So, that is the centre, then draw the circle. So, this is the circle for that. So, that means now any value on this particular circle would be good value for Gamma, as any value on this particular circle would be good value for Gamma l to achieve the desired gain equal to 10. So, now the question is which value of gamma I should choose. So, again let me ask you people just think about this thing.

So, shall I choose gamma s over here? Shall I choose gamma s over here? Shall I choose gamma s here or shall I choose gamma s over here? All these are valid points, but I have chosen here gamma s equal to this value over here which is closest to the central point. See remember ultimately we have to do the matching from this point to this point or from here to here depending upon from which direction you are looking at it.

So, we should always choose a point which is closest to the point, where you would like to travel to see. Remember if I have to go from point a to b, it is better that we take the shortest path rather than taking the longest path. If you take this particular point, then from here we have to move to this particular point, ok. Similarly for gamma l choose a point which is closest to the central point. Now, what we have to do once we have chosen the value of gamma s and gamma l? Now, we have to design the impedance matching network.

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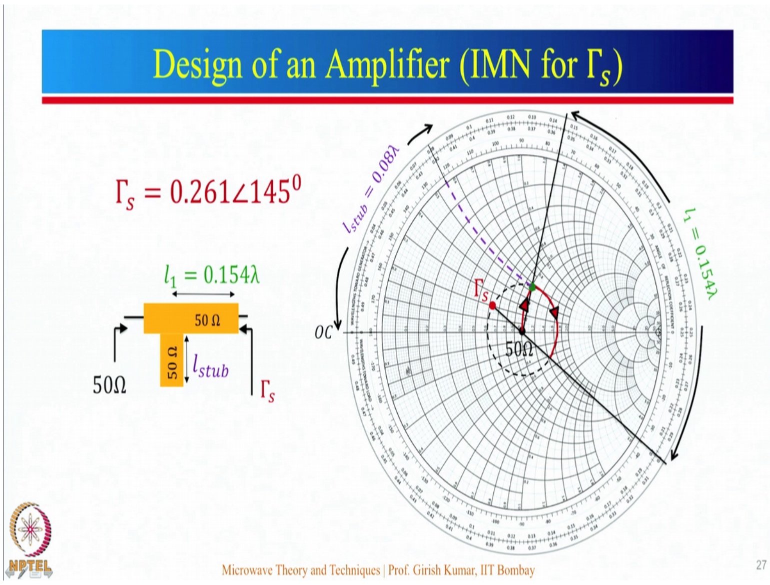

So, we have proposed here to use single stub matching, so design of the amplifier for gamma s. So, I am going to show you impedance matching network for gamma s. Now, recall impedance matching techniques which we had discussed a few lectures earlier. Not there what we had done, I just want to mention slightly things that different over here. Earlier what we were generally doing, we were generally taking an unknown load and that unknown load was match to 50 ohm. Over here things are slightly different.

Here we have 50 ohm where source is connected and we want this thing to be gamma s. That means, from 50 ohm we have to move to gamma s, but still you can think about the previous concept which we had done for single stub matching and I will tell you how things to be done differently. So, first objective will be to locate gamma s on the Smith chart. You can see that gamma s is at angle of 145 degree. So, you draw a line at 145 degree angle and this is 0.261, you locate over here.

Then, what you do is you take the opposite point of that see gamma s represent z s opposite to that will represent y s. Why we do with y s? It is because recall for single stub matching stub is added in shunt and in y only we can add shunt. So, now instead of moving from here to here, what we need to do? We have to move from 50 ohm to this particular point. So, from 50 ohm you move along this particular r equal to 1 circle. You stop at the point where the circle is cutting this particular r equal to one circle. So, at this particular point, this is the point which actually gives rise to the value of l stuff and that comes out to be 0.8 lambda.

Then, from here now you move in this particular circle and this distance from here to here will be the length of the line. So, that is the length of the line which is equal to 0.154 lambda. So, by using this particular configuration, we can transform the impedance of 50 ohm to gamma s value. Similar thing we do it for gamma l.

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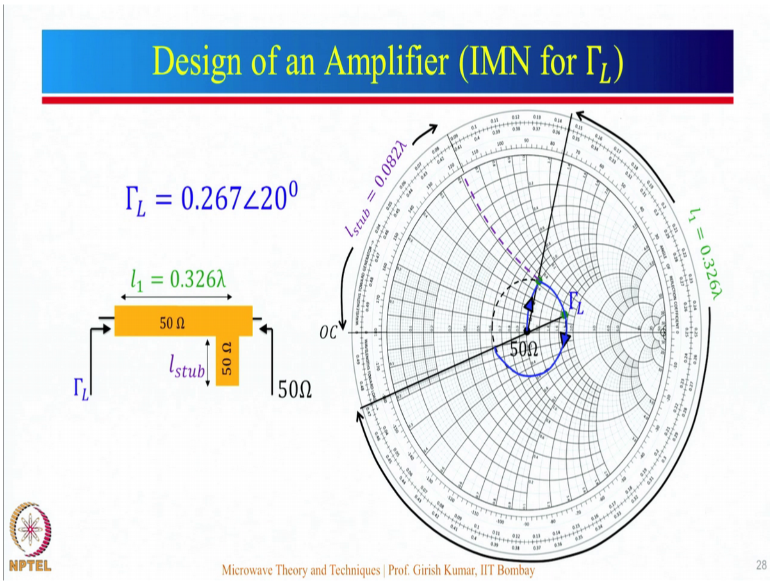

So, now gamma l is given by 0.267 angle 20 degrees. So, again we draw a line at an angle of 20 degree, locate this point over here which is gamma l at 0.267 distance. Again draw the circle, take the opposite point over here, ok again gamma l represents z l. This will be y l, ok. Now, again we have to start from 50 ohm.

Remember now we have 50 ohm termination, but we want gamma l over here, so that higher gain can be transmitted to the final load. So, we have to go from 50 ohm to gamma l. So, from 50 ohm you again move along this r equal to one circle stop at a point. So, at this particular point you can stop and then, this particular thing over here will give us the value of l stub, then from here move in the clockwise direction. So, this distance will give us the length of the transmission line. So, now let me show you the complete circuit.

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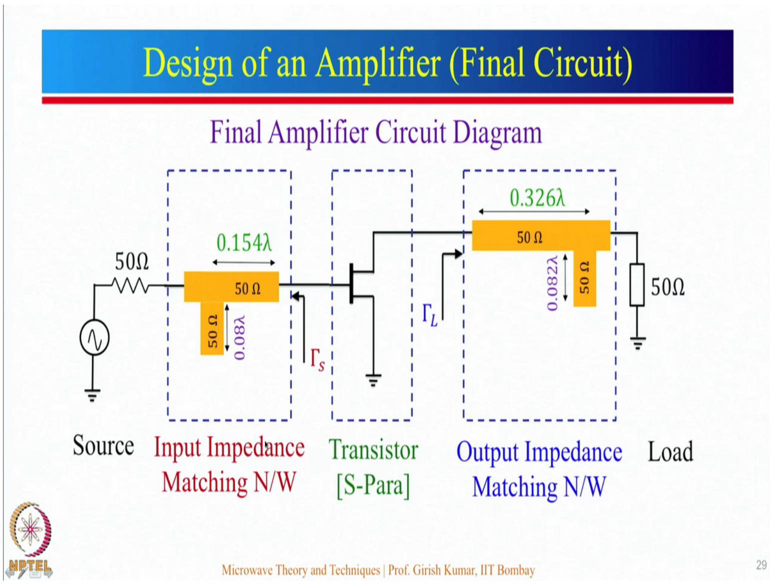

So, this is the complete design of an amplifier final circuit. You can see that this is the device for which s parameters were given. So, we started with the s parameters, we found out all the gain values, then we found out the value of gamma s and gamma l and then, designed impedance matching network input side as well as output side. So, this is now the complete circuit. You can see here source is there source has that 50 ohm resistance, but I just want to tell you most of the time it is not a physical resistance you put over there.

So, do not get confused that you are going to put 50 ohm resistor. This 50 ohm corresponds to the output impedance of the source, ok. So, you do not physically put any 50 ohm resistor. Similarly over here this is the output load which is connected at the output of the amplifier. So, now I am going to show you the simulation of this particular circuit.

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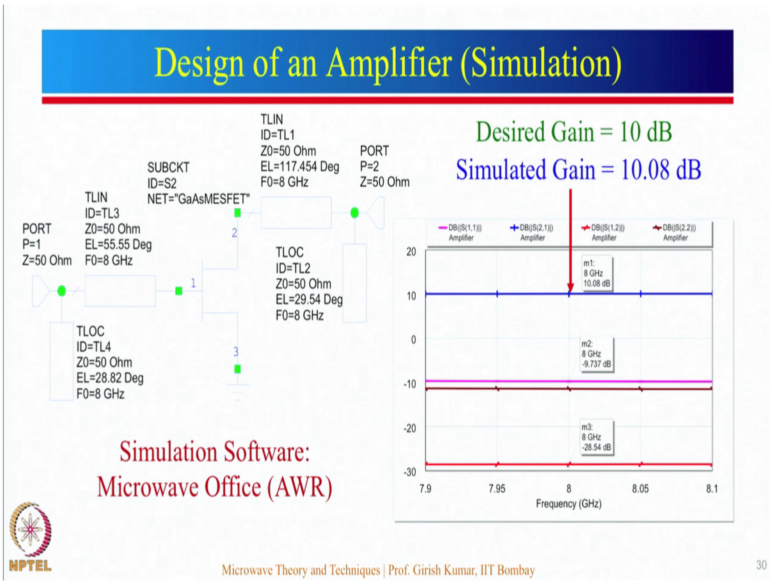

So, we have used microwave office software and we have done the simulation of this particular amplifier. You can see that these are the various simulated parameters. So, this is the device over here, this is that transmission line, this is that stub over here, then the transmission line stub, ok.

So, for this particular amplifier, analysis has been done and these are the various s parameter. So, let us see this one here shows the gain of the amplifier. Desired gain was 10 dB, simulated gain is 10.08 dB. So, you can see that this number is very close to that desired value of 10 dB. So, hence you can say our design is good. Now, these are the two plots. These are for S 11 and S 22. You can see that these values are around minus 10 dB, ok. Here I just want to mention we have taken a very small frequency range from 7.9 to 8.1, because our desired frequency is 8 giga hertz. This is the plot for S 12.

So, we know that S 12 should be small for an amplifier because amplifier should amplify the signal in one direction and not amplify in the other direction. So, you can see that this value is around minus 3 dB. So, if you give an input from this particular side, then the output on this side will be about minus 30 dB which is about 1000 times less than the input over here whereas, if you give a input here, we get a gain of 10 dB which will be 10 times. Now, one thing also I want to mention you can see here there is a no perfect match for S 11 and S 22.

The reason for that is we had optimized for the gain equal to 10 dB. We did not optimize for maximum power transfer from the source side and from the load side, ok. So, I will just show you another example where we actually optimize for maximum power transfer and in that case, we can realize a better gain. So, if you recall G tu max was about 10.67 dB. So, now let us see if we optimize for the maximum power transfer, what happens?

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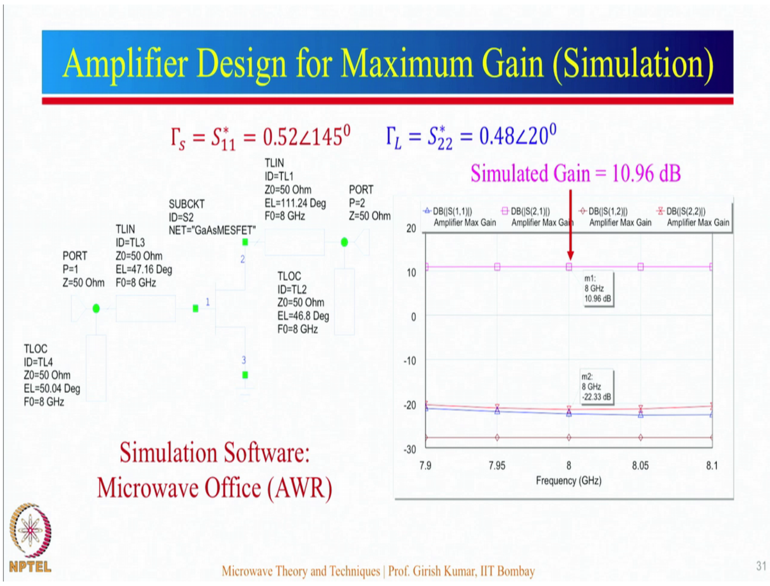

So, in this particular case now we have chosen gamma s as S 11 conjugate gamma l as S 22 conjugate. I just want to mention over here that we have not taken the real value of gamma s which actually is equal to S 11 plus S 12; S 12 gamma l divided by 1 minus S 22 gamma l. We have still assumed S 12 to be approximately equal to 0 which is not really the case, but I just want to mention what happens if you do the design using unilateral process and what is the realized gain for complete bilateral case when S 12 is not equal to 0.

Gamma s and gamma l are chosen in such a way that it assumes S 12 is equal to 0. In reality, it is not equal to 0. So, let us see what do we get here in this particular, this is S 12 plot. So, simulated gain is 10.97 dB. Now, if you recall G tu max was 10.67 dB, we are getting slightly more than G tu max. How that is possible? This is possible because of the reason we had S 12 not equal to 0. We had calculated the value of M and we had seen that G t divided by G tu max had a range from minus 0.36 dB to plus 0.37 dB, ok

So, we can have that particular error. So, you can see that this particular number is within that particular error. So, we can get in reality simulated gain equal to 10.96 dB. For this particular device, you can see over here that reflection coefficient here comes out to be around minus 20 dB. It is not minus 30 dB or minus 40 dB which is generally expected if you do a perfect design again. The reason is that we have designed for gamma s equal to S 11 conjugate and not for S 11 plus S 12 S 21 gamma l divided by 1 minus S 22 gamma l. So, this design is actually done assuming S 12 equal to 0, but you can see that even if you assume S 12 equal to 0, matching is very good over this particular frequency range.

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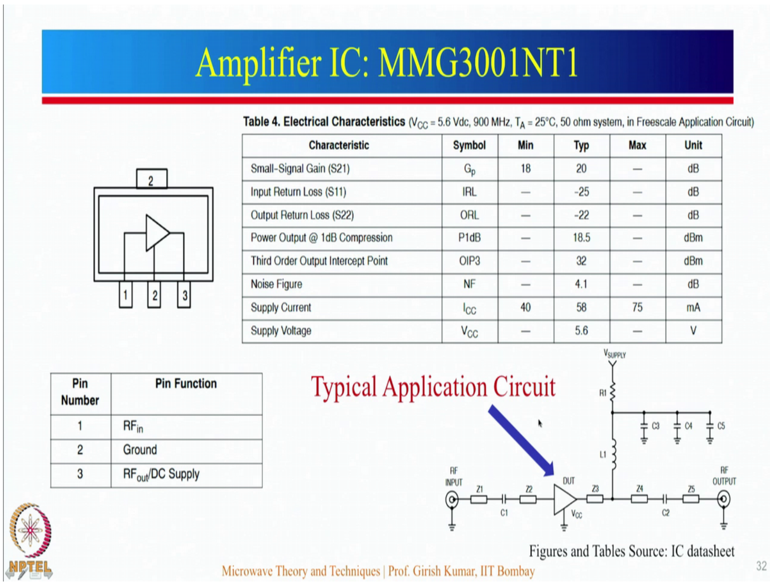

I am actually going to show you one another amplifier example. This is MMG3001NT1. So, this particular amplifier is available commercially and this is the typical pin out over here and you will see that how simple it is sometimes to design an amplifier using commercially available IC. So, just to tell you quickly here you can see here 1 is RF input, 2 is ground and 3 is nothing, but RF out and also, it is to be connected to DC supply. You can see that there is another 2 over here these two must be connected together to provide proper grounding to this particular amplifier.

Not the various parameters are given over here. I just want to mention power output is about 18.5 dBm, ok. So, this is 1 dB compression point. Saturated power output of this is approximately 20 dBm which is equal to 0.1 watt power. So, this is the typical application circuit given by the manufacturer. So, just to show you here what we have over here. So, this is a small transmission line, then coupling capacitor small transmission line, another small transmission line, transmission line coupling capacitor. Coupling capacitors are required to block DC current flowing through the input or output side. Now, as I had mention this is also to be connected to DC supply. You can see hear that there is an inductor and then, a resistor connected to the supply of few capacitors have been used. These capacitors are mainly for suppressing the ripples as well as suppressing the transient.

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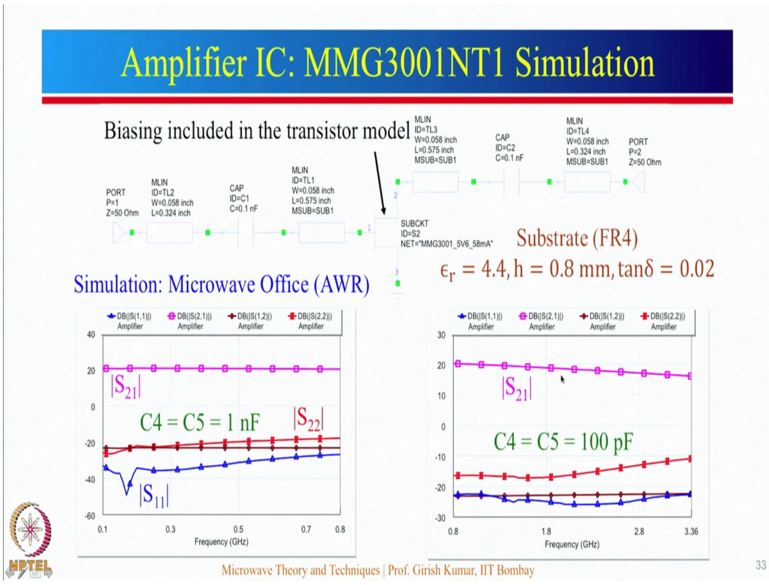

We have simulated this particular circuit using microwave office. So, this is the simulated circuit. So, this particular circuit has been simulated for two different sets of frequency. This is from 0.1 to 0.8 gigahertz and this is from 0.8 gigahertz to more than 3 gigahertz. I just want to mention here the coupling capacitors are taken different in these two cases.

Here we have taken coupling capacitance values to be equal to 1 nanofarad which is for the lower frequency region and here we have taken coupling capacitor value to be equal to 100 picofarad for higher frequency region. So, please remember that for lower frequency, you should take higher value of capacitance and for higher frequency; you should take lower value of capacitance. Ultimate goal is that z equal to 1 by j omega c should be small.

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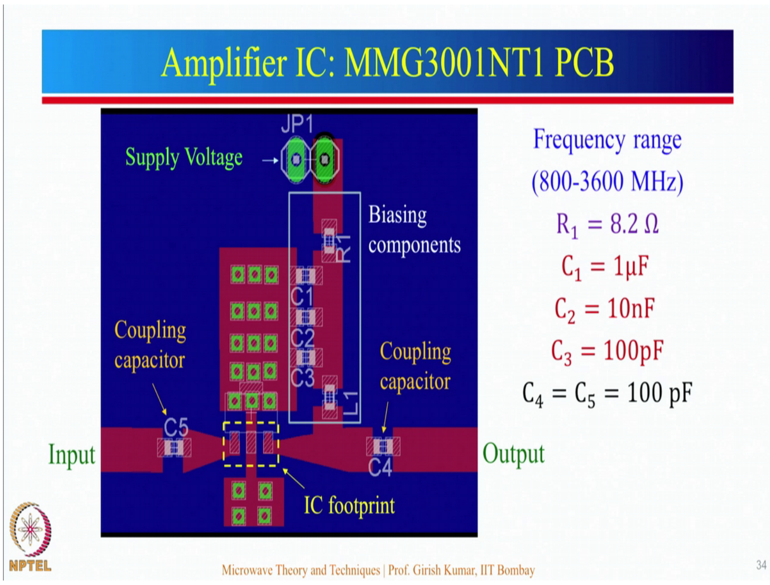

So, this is PCB for that particular amplifier. So, you can see here this is the transmission line, transmission line coupling capacitor connected over here coupling capacitor connected over here. You can see that these two things are connected together and we have put multiples of pth. That means multiple plated through hole, so that there is an effective grounding provided for this particular IC. So, from here you can see that this is the inductor which is connected over here. 3 different capacitors are connected and then, there is this resistor which controls the current flowing through this particular device and there is a power supply.

So, we have designed this particular thing for frequency of operation from 800 mega hertz to 3600 mega hertz. The value of r 1 is 8.2 ohm c 1 c 2 c 3 which are connected over here. You can see that we have used different values of capacitance over here; 1 micro farad, 10 nanofarad, 100 picofarad. 1 microfarad is actually good for suppressing the ripple or you can say to reduce the ripple. This particular capacitance is good for suppressing the transients and this is in between think any noise which comes and that will be blocked by this particular capacitance and we have taken coupling capacitors as 100 picofarad. So, let us see: what are the major results for this particular amplifier.

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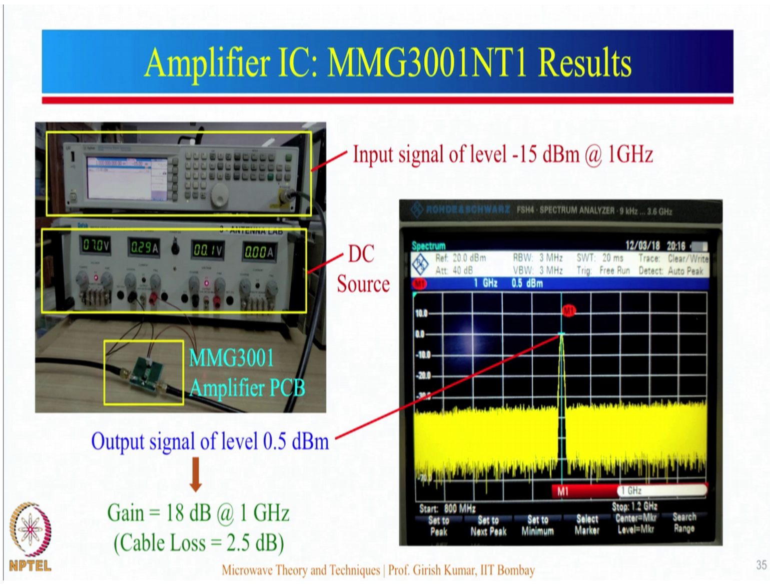

So, here is that amplifier. You can see how small it is and this amplifier input is given from a microwave generator input signal level of minus 15 dBm is given at 1 giga hertz. This is the DC source which gives voltage and current of course and the output of this generator is given as input to the amplifier and output of the amplifier goes to the spectrum analyzer which is not shown in this particular picture.

So, this is the response which appears on the spectrum analyzer. So, if you look at this value here, this value is approximately equal to 0.5 dBm. We gave a input of about minus 15 dBm and the output is 0.5 dBm, however there is 2.5 dB cable lose as you can see that cable is connected from here to here and then, this cable is connected to the spectrum analyzer. So, you must account for these cable losses. So, if we add all these numbers from minus 15, we get 0.5. So, that will 15.5 plus 2.5 equals 18 dB. So, the gain of this particular device comes out to be 18 dB at 1 gigahertz. So, with that I can conclude the session on microwave amplifier.

In the next lecture, I talk about low noise amplifier. Low noise amplifier is one of the very important block in the receiver chain. We must have the first amplifier in the receiver chain as a low noise amplifier. So, in the next lecture we will talk about how to design low noise amplifier.

Thank you very much. Bye.