Microwave Integrated Circuits
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Mod 06, Lec 25
Amplifier gain stability

Welcome to another module of this course 'Microwave Integrated circuits'. As you must be must have noted for the past few modules we have been discussing about active circuit design. In the previous modules we were discussing about impedance matching as related to an amplifier especially the input and Output impedance matching. Now, what is the goal of this matching that is the first thing that has to be established? There are various goals while we design an active circuit like an amplifier. Let us list the goals.

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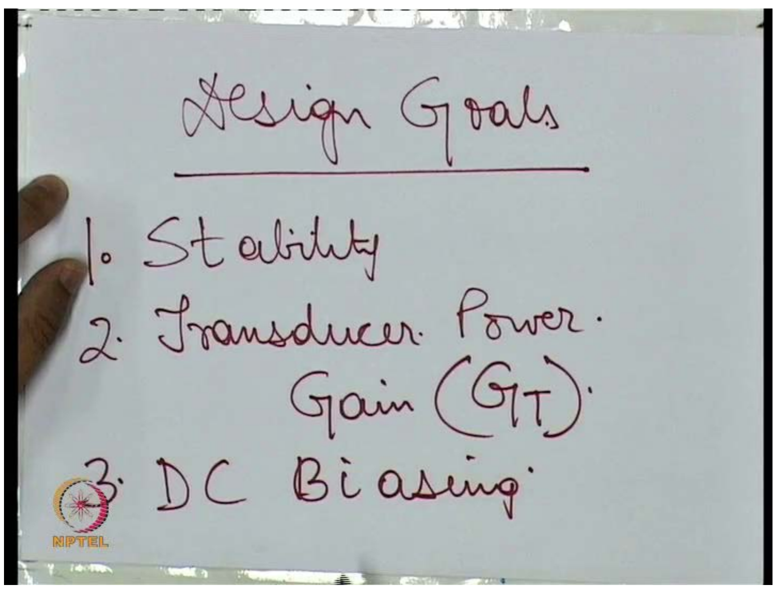

So one first there are various goals that you need to first of all the circuit should be stable. So stability, then something called transducer power gain we shall see in a moment in the next few slides may be, what is this transducer power gain and this is represented by the symbol G. Then DC biasing that is another important because all active devices need to have a proper DC for the supply for them to work unlike passive devices where they simply work on the input power active, device needs a separate DC wires.

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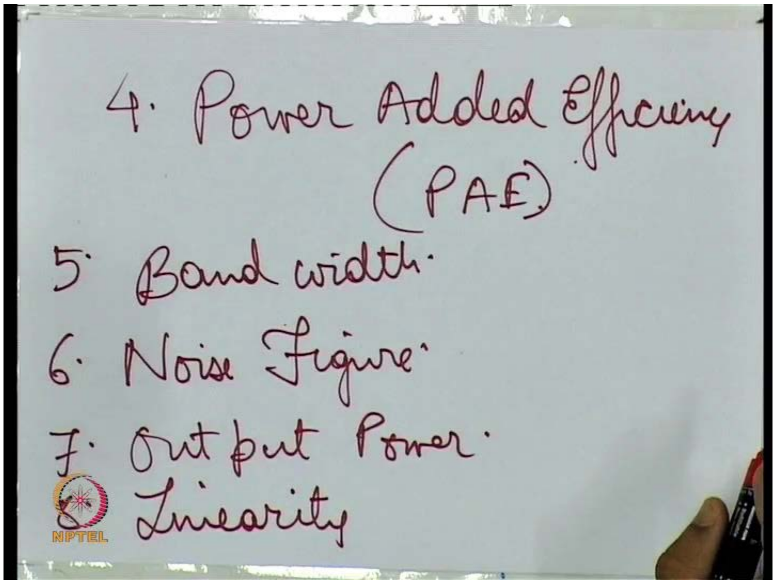

Then there are other design goals as well like Power Added Efficiency or PAE. Then we have band with. Then we have noise or as we call Noise figure. We shall all we shall take up these aspects one by one when we discuss the amplifier design. Then output power we may because that is also an important figure of medit, how much power not just the efficiency or the band with or how much DC power it takes but also how much output power it gives and finally the linearity.

This is another very important aspect of the amplifier design how linear it is that is how close the input output relationship of the amplifier are towards are to a linear relationship that is output should be proportional to the input. So let us let us take up these things one by one but before going there we would like to define some of the, so let us let us see…

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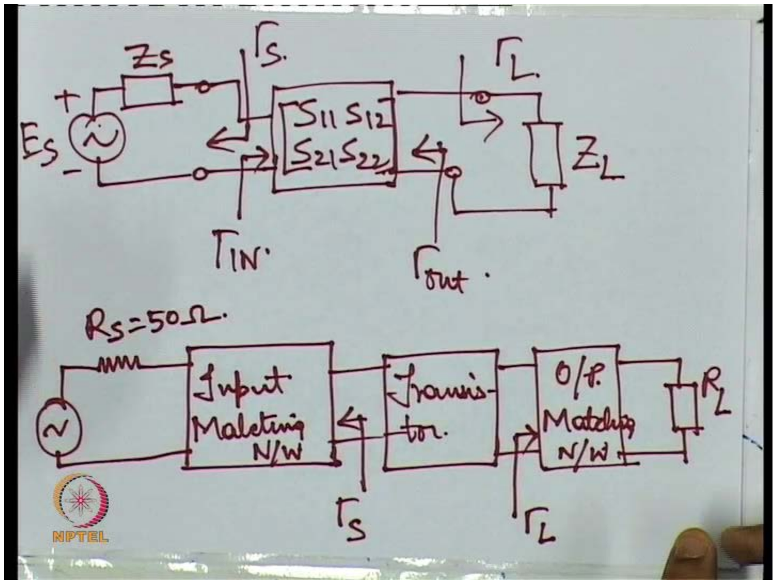

So we have our amplifier with a certain X parameter matrix then we have a load ZL and a source ES and as I said earlier the reflection co-efficient of the load and of the source and the load are given by gamma S and gamma L respectively. And the input reflection coefficient and the output reflection coefficient of the amplifier are given gamma in and gamma OUT and then I had also mentioned this earlier that for proper input matching we need to place something called input matching network between the source and the amplifier input of the (ampli) of the transistor or the active device that you are working.

So let's call that transistor and then we also need an output matching network which will be between the output load and the output of the transistor. So this is my RL so this is more or less the design you know this input matching and output matching and what the purpose of this input and output matching networks is to obtain an appropriate gamma S and gamma L that will satisfy the conditions the various you know input matching and output power noise and all those criteria that I mentioned earlier earlier in the lecture today.

So how to select question is how to what should we select because there are so many design codes so you know one value of gamma S might give you impedance matching one another value might give you output power added efficiency. How do you select optimum gamma S and gamma L and the and mind you when I say how do you select since you know one value of gamma S or one value of gamma L may not be able to satisfy all the design parameters it may be that if I have a single goal say stability.

Then there may be more than one values of gamma S or gamma L that can satisfy the stability criteria if I have more than one values of gamma S and gamma L for satisfying the stability criteria then that allow gives us some allowance in choosing the gamma S and gamma L to satisfy the other criteria like the noise or say the gain…

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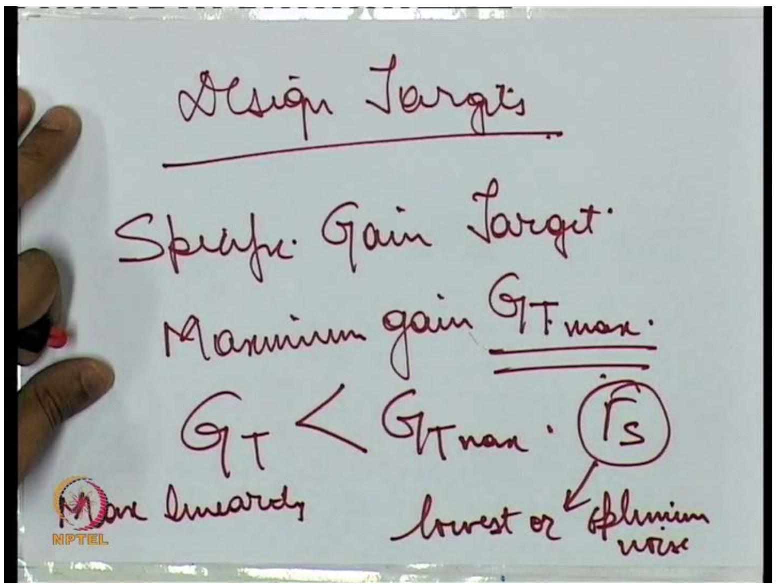

So say the design targets that we have specific gain target say maximum gain GT there might be a maximum gain for GT possibly again let if you are not clear what is GT is for now just take it that this is the most correct definition of power gain in an amplifier the most useful value of power gain even though it is the most useful it may not be the easiest to compute or easiest to design as we shall see later.

So there might be a maximum gain GT max and all other gain will be lesser than GT max other possible is that say a particular gamma S which gives lowest noise or optimum noise as we call it or say it might give the maximum linearity. So let us first concentrate we’ll see how we can achieve all these targets this noise stability and gain but first let us suppose we are concentrating on the gain aspect so if I want to achieve the maximum gain then what should it be?

Now the preliminary answer can be given by common knowledge which is that gamma S should be the conjugate of gamma IN and gamma L should be the conjugate of gamma OUT.

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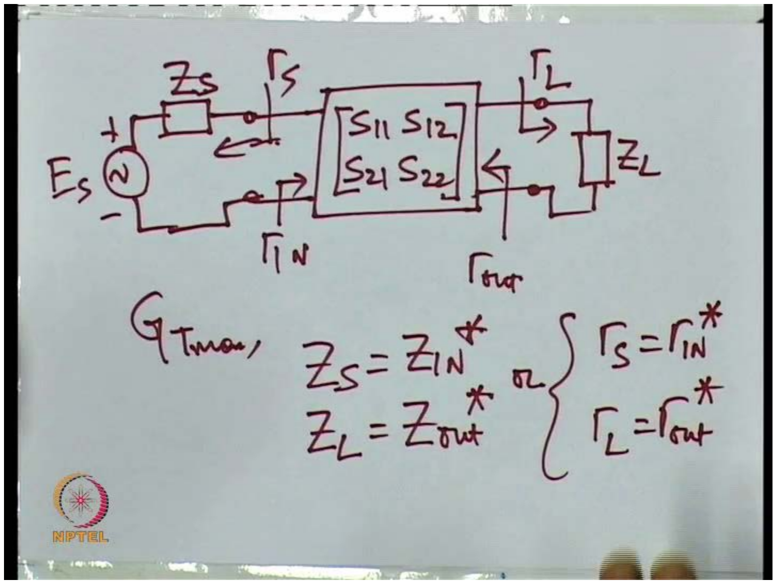

In other words suppose we have an amplifier like this so preliminary answer for maximum transducer power gain GT max will be ZS should be equal to Z in star and ZL should be equal to Z OUT star or gamma S should be equal to gamma in star and gamma L should be equal to gamma OUT star that is the preliminary answer based on this not based on this as I said I had said earlier that I would give you a number of definitions about these power gains so let us now one one one by one see the various definitions.

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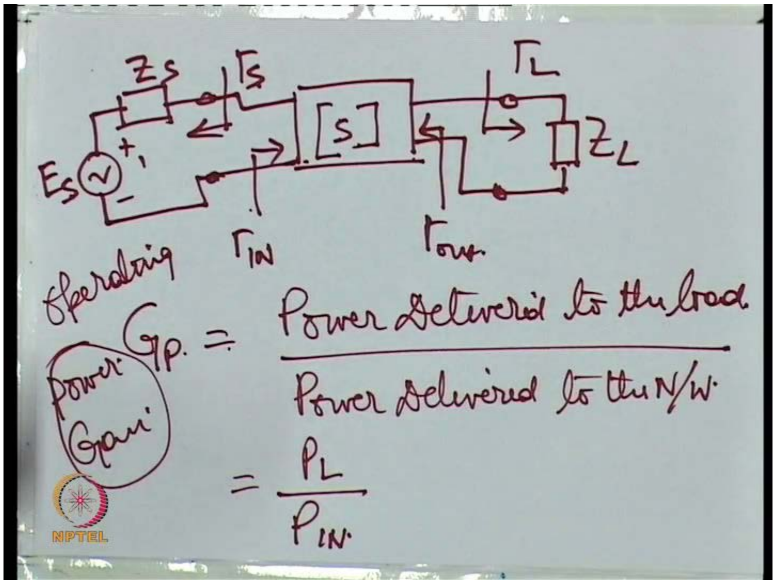

First so again let me just draw my amplifier once again the first type of power definition is GP this is quite simply known as power gain or alternatively as operating power gain. I can call this as operating power gain or simply power gain GP is equal to power delivered to the load upon power delivered to the network. So what it means is that this numerator here, I can write it like this also that is PL upon P in so PL is the total power reaching the load ok that is the incident power minus the reflected power.

The net power that is reaching the load and P in is the net power that is reaching the network it means that at the input of this network or at the input of this amplifier. I have an incident power and a reflected power that incident power minus the reflected power is the net power that is going inside the network and that is represented by Pin so this is the definition of GP.

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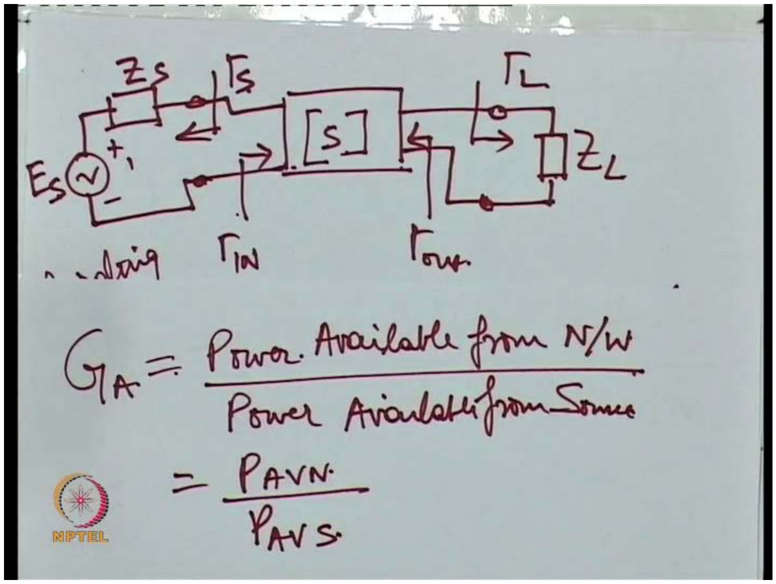

Then I have another definition which is called GA which is so this is my once again this is my network in the top GA is given as power available from the network upon power available from source so this is equal to PAVN upon PAVS. So PAVN is the power available from the network it basically means the maximum power that can be supplied by the network to the load. And PAVS is the power available from the source it basically means the maximum power that can be obtained from the source.

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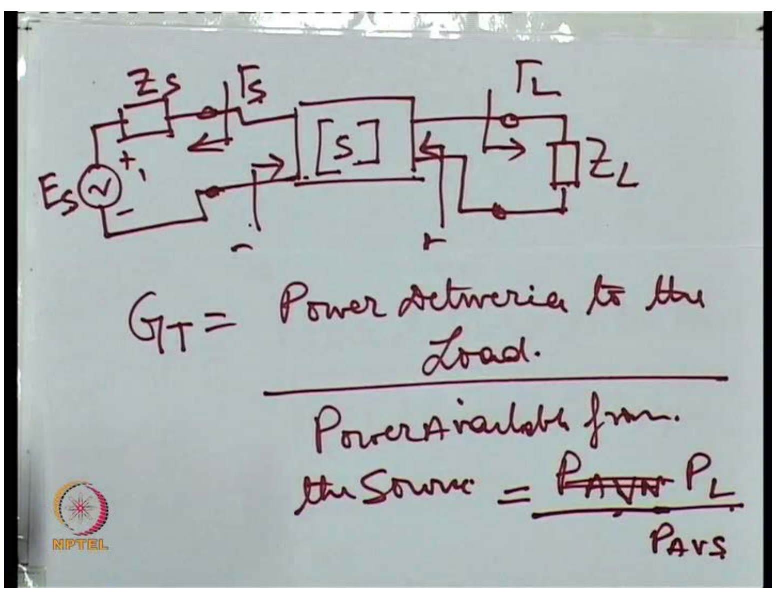

And finally the GT which I have been mentioning more than once previously is power delivered to the load upon power available from the source. So this is sometimes this is can be written as PAVN, sorry this is PL upon PAVS. And this is the gain actually that matters the most because see gain when we when we mention the term gain it basically means what is the total power delivered to the load which is PL upon the total power that can be supplied to the source that is what we care for.

If we have a source and load then we measure how much power has actually gone to the load and how much power was originally available from the source and that's why this is the most practical and most useful definition of power gain. But then the problem as we shall see when we derive the expression for this GT it contains some terms which make the design of a network with pure GT difficult and therefore we will actually design with GT in mind but with some simplifications we shall see this later.

Now these power gain equations can be obtained from the signal flow graph because these are nothing that for example PL is nothing but the incident power minus the reflected power (())(16:06) so these can be analyzed in the same way that we analyzed in the previous module using signal flow graphs. And I I, you can do that as an exercise or you can refer to the book by Gonzalez which is mentioned in this the syllabus for this course the book by Microwave Transistor Amplifiers by Guillermo Gonzalez (())(16:33) check the latest edition.

And there you will find the derivations for all these gain terms I am just giving you the final result if you could go to the slides on the monitor.

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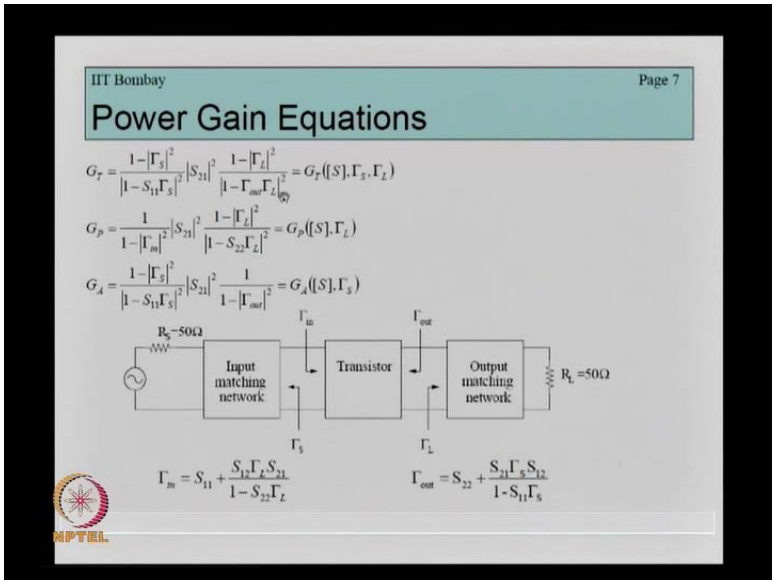

So this GT is given by this expression GP is given by this expression and GA or the available power gain is given by this expression Now you might ask me what is the problem with GT see GT if you notice carefully it has it is a function of this gamma OUT this term But then gamma OUT itself is a function of gamma S isn't it here for example here I have written the expression for gamma OUT as we can see gamma OUT is a function of gamma S. So suppose we design we have a given suppose we have been given some value of GT that we have to achieve then we design our gamma L and then we design our gamma S fine.

Now once I design gamma S I fix my gamma OUT if I fix my gamma OUT then notice here I also have to satisfy the condition that gamma OUT should be equal to the conjugate of gamma L for maximum power transfer that is not possible I if I fix gamma S then I am fixing gamma OUT and then I have to fix gamma L based on the value of gamma OUT I can't independently fix gamma S and gamma L. That is the main problem of this GT expression.

Now there is an alternative expression for GT where I have instead of gamma OUT I have gamma IN and instead of gamma L I have gamma S and instead of gamma S I have gamma L, an analogous expression in terms of gamma IN there also if we fix gamma IN then we are fixing (gam) we are fixing RL or this impedance we are fixing and once we fix gamma IN we have to for matching we have to have gamma S equal to conjugate of gamma IN.

On the other hand the expression for GP, you see that GP is purely a function of gamma IN and gamma L. Now gamma IN itself is a function of gamma L therefore this GP is entirely a function of gamma L. And since it is purely a function of gamma L we have no restrictions on gamma S or RS. Similarly is the case for GA where just the converse of this GP takes place that is this is an expression in terms of gamma OUT gamma OUT depends on gamma S, since only gamma S and gamma OUT is present in the expression for GA this is GA is purely a function of gamma S and therefore we have no restrictions on RL. So we can independently fix RL and ZS.

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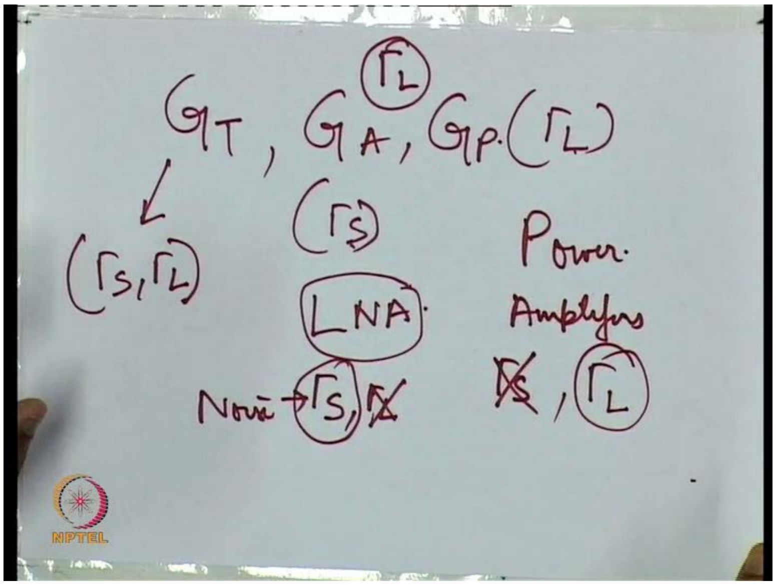

So we saw that we have 3 terms GA GT GA and GP we saw that GP is purely a function of gamma L GA is purely a function of gamma S and GT is function of both gamma S and gamma L. In fact GA is suitable for designing those amplifiers whose source impedance is already fixed for example low noise amplifiers and GP is, I beg your pardon GA is useful for designing those amplifiers whose load impedance is fixed but we are free to modify gamma S to obtain appropriate design parameters.

For example in low noise amplifiers noise depends mostly on gamma S rather than gamma L so noise depends mostly on gamma S. Here the gamma L that is the Output impedance of the amplifier is already fixed but to (con) obtain the optimum noise figure we can modify gamma S. On the other hand if we consider power amplifiers for these amplifiers the source is already fixed so we can’t change anything in the source gamma S but gamma L cab be designed to obtain the appropriate power gain.

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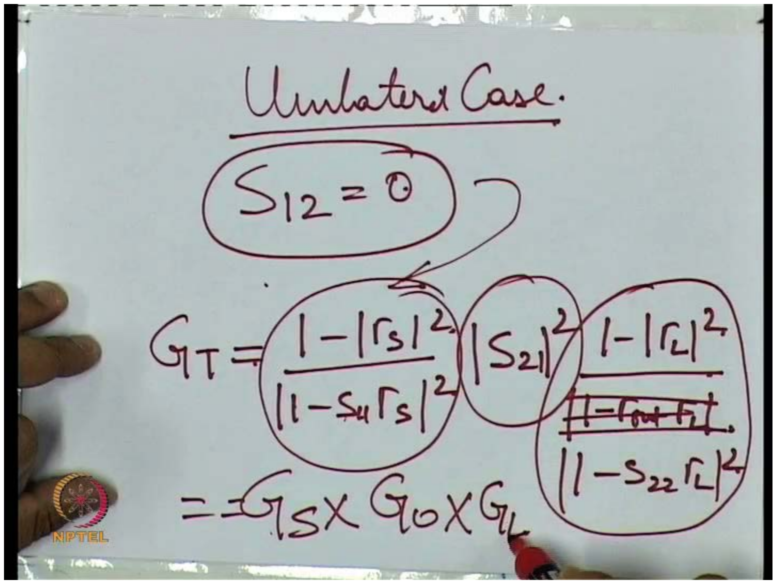

Now let us consider the case as I said even though GT is not useful for designing an amplifier we can consider some special cases one of them is what is known as the unilateral case. Unilateral case means S12 is equal to 0 and this assumption is not that par to S because most amplifiers the reverse transmission coefficient is indeed very low it has to be low otherwise power will keep flowing back we don’t want that we want power to always flow from input to Output.

We don’t want the power to flow back from the Output to the input so this is a somewhat valid somewhat valid assumption though in most amplifiers it is not so low it is not 0 but it is a low value. But then by making this assumption we get some very it makes our life of the designer much easier, how does it make it easier. Because see now the expression for GT becomes 1 minus S22 gamma SL whole square.

As you can see it is now there is no gamma OUT or gamma IN term here it is purely a function of gamma S and gamma L and so these terms are can be considered as gain term. If you want in fact we can write it like this this is equal to GS multiplied by G0 multiplied by GL so his GS is the source gain gain due to the source network S21 is the gain due to the inherent or this S parameters of the network and GL is the gain due to the load network.

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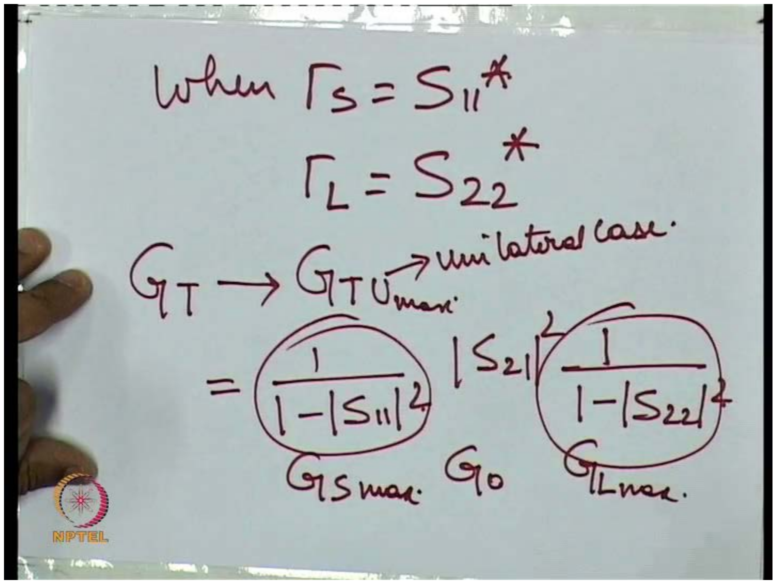

We see that when gamma S is equal to S11 conjugate and gamma L is equal to S22 conjugate then this GT which is its maximum value which I call GTU max. This U represents unilateral so this comes equal to I upon 1 minus S11 whole square, S21 whole square. So this is GS max and G Smax is equal to this value and GLmax is equal to this value.

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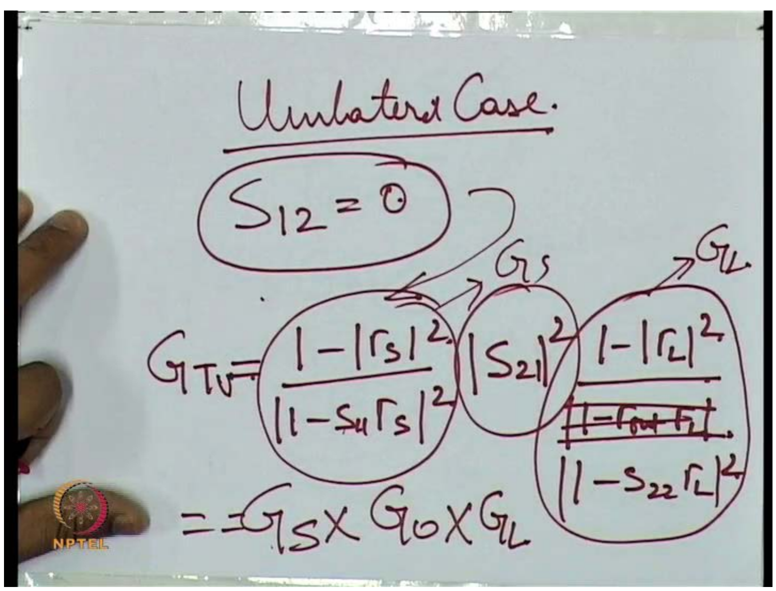

So this is the unilateral design case and as we shall see later when we discuss about gain circles that we the locus of a (lo) of (G) of gamma S or gamma L which gives a constant value of this GS or GL will be circles so this is the equation that we just discussed GTU or unilateral gain and the locus of gamma S that gives a constant value of this GS is the circles similarly the locus of gamma L which gives the constant value of this GL will also be a circle. We shall discuss this when we are when we discuss about the amplifier gain circles.

For now let us discuss let us start about the stability aspect of an amplifier so what do you mean by stability a circuit see when I say stability it means that if you give an input the output should be bound in other words for bounded input output should be bound if you give an input and then the output amplifies itself to such an extent that it reaches its saturation value then the circuit is not stable. Similarly if you give an input and output becomes so low that it no longer sustains itself the output that is also an unstable circuit.

So stable circuit will be one that when you (con) give a continuous input to that circuit, the output should also be continuous and stable it should not either glow up neither it should dim down. As you know passive if an element is passive that is if there is some real resistance to it if the real part of its impedance is positive, then such a device will always be stable because such a device is a passive device.

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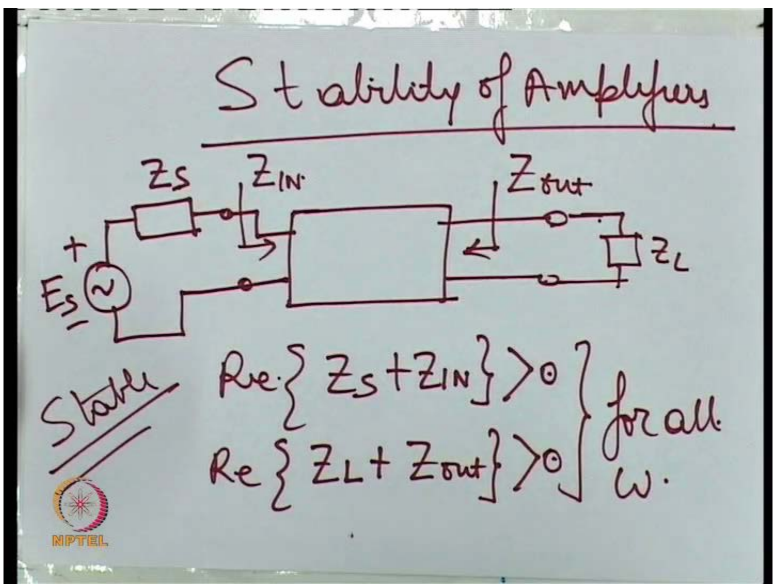

So then the if we have an say an amplifier with load ZL then if we have real part of ZS plus Z IN greater than 0 and real part of ZL plus Z OUT greater than 0 for all frequencies then such a such a (cond) circuit is said to be unconditionally stable or such a.. I beg your pardon such a circuit is said to be stable we shall come to the condition of unconditional stability in a moment.

If these conditions that is you have some ZIN but then due to ZS say ZIN itself has a negative real part or Z OUT itself has a negative real part but then on adding ZS and ZL the real part of the sum of ZS and ZIN becomes 0 becomes greater than 0 then such a circuit is said to be stable How to ensure that a circuit is always stable irrespective of what the value of ZS or ZL is so such a circuit which is stable irrespective of the value of ZS or ZL is said to be unconditionally stable.

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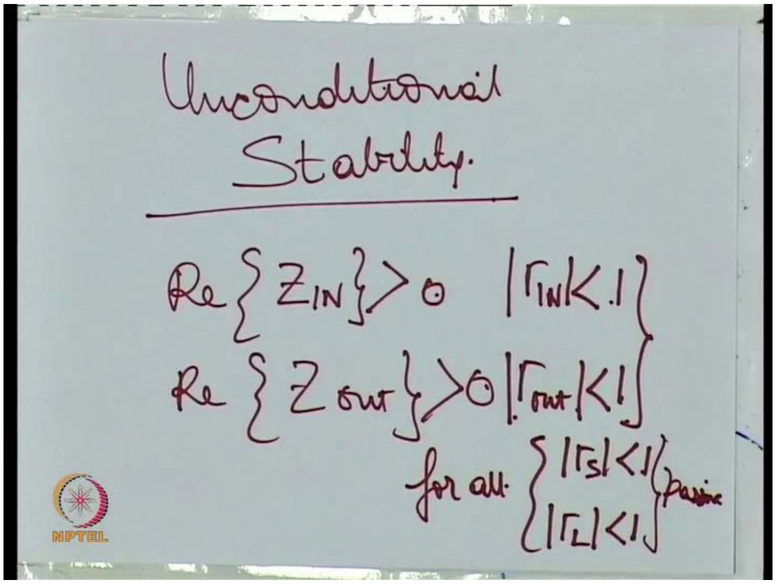

So unconditional stability that will be the case when we have the ZIN itself being passive or Z OUT itself being passive now this same thing in terms of reflection coefficients is expressed as so for all gamma S lesser than 1 or gamma modulus gamma S less or modulus gamma L lesser than 1 it this basically means for passive values of gamma L and gamma S. If gamma N modulus and gamma OUT modulus is lesser than 1 then the circuit is unconditionally stable unconditionally stable I beg your pardon.

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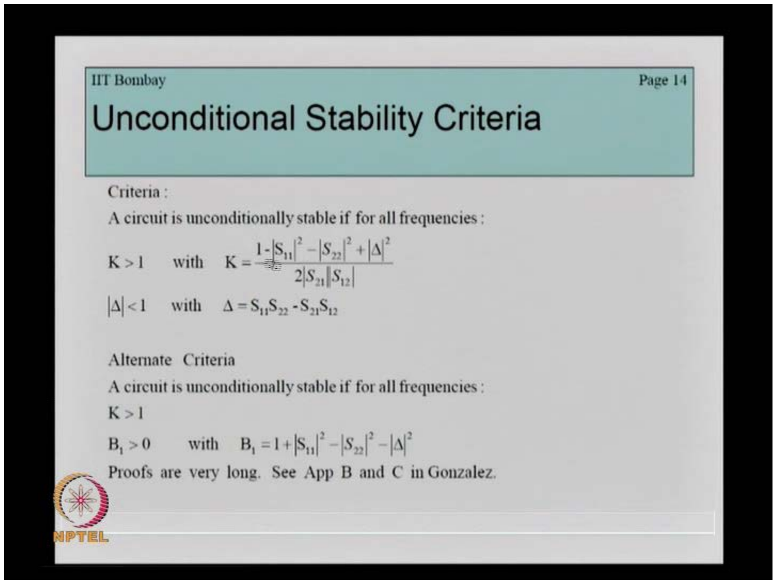

If you turn to the notes on the slides on the monitor mathematically if you are given the S parameters of an amplifier or a transistor and you want to know whether it is unconditionally stable then of course you can find OUT Z IN like I said in the previous slide. But in terms of the S parameters there is a specific there is a specific parameter this K and delta.

If you compute this value of K from this equation and the value of delta from this equation then if K is greater than 1 and the modulus of delta is lesser than 1 then the circuit will be unconditionally stable. So (())(32:18) given the S parameters of a circuit you simply evaluate K and delta and check whether K is greater than 1 or delta modulus is lesser than 1 then straight away you can say that the circuit is unconditionally stable.

An alternate criteria is this that the K greater than 1 and B1 greater than 0. Here B1 is given by this equation. Now if you want a proof of these equations it is given again in the book by Guillermo Gonzales, I would recommend you refer to that book that is the primary text for this course for these active devices the passive devices it was Microwave Integrated Circuits by Pozar this part the active circuits part is the one by G Gonzalez.

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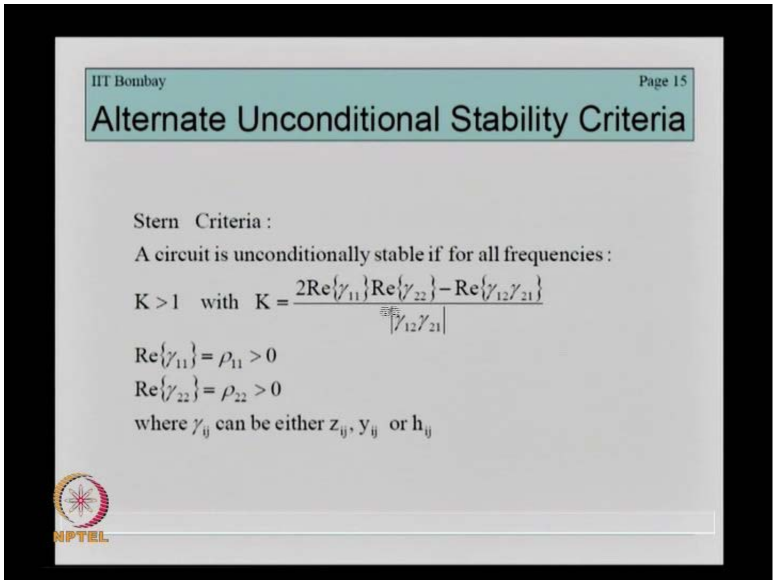

An alternate stability criteria is given like this here K is defined by this term where this gammas would be anyone of Z parameters or (())(33:27) parameters or hybrid parameters we have not covered hybrid parameters for now you can take it that Z and Y parameters this gamma represents Z and Y parameters. Now if the real values here of course we have to ensure that the this Z say your if gamma represents said then Z11 and Z22 have positive real parts. If you simply calculate the value of K and see that it is greater than 1 then we can say that the circuit is unconditionally stable.

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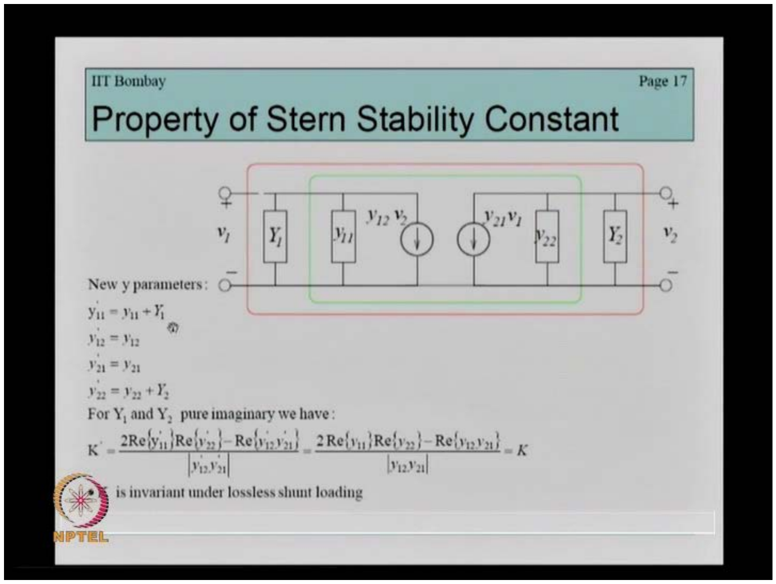

A new condition was given in the year 1992now this condition states that if you simply find OUT this value of mue given by this equation and if the value of mue is greater than 1 then the circuit is unconditionally stable Mue also has a dual instead of this equation you can also write it in terms of 1 minus S22 modulus being on the numerator.

So in this module we covered the basic definitions about the various power gains and also we just introduced we just discussed the beginning of stability. Now mind you one thing that it is not necessary always to for the circuit to be unconditionally stable the circuit has to be stable for the operating frequencies or the operating powers that it is designed for. It is not necessary to make it unconditionally stable that is an over because if you spend if you design for unconditional stability then it might lead to loss or gain or increase noise figure which is undesired.

On the other hand say just at the operating frequency if you can make the circuit stable and stable being the condition that ZS plus Z IN or Z OUT plus Z IN Z OUT plus ZL is passive. If just at the operating point of the circuit you can ensure that the circuit is stable then that is enough and in fact in the next module we shall be discussing how potentially unstable circuit can be made stable.

Thank you.