Design Principles of RF and Microwave Filters and Amplifiers

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Module No # 3
Lecture No # 12
Stability Analysis of Microwave Amplifiers

Welcome to this twelfth lecture in earlier lecture we have seen various power definitions power gain definitions and we have related the power various at various points in the microwave amplifier network. Now also we introduces these three power gains now is the time to find the expressions for that power gain. So G we know that G = PL by Pin if we put those expressions that we derived then we can write it as S21 square, 1 – gamma L square by 1 – 1 gamma in square 1 – S22 gamma n square.

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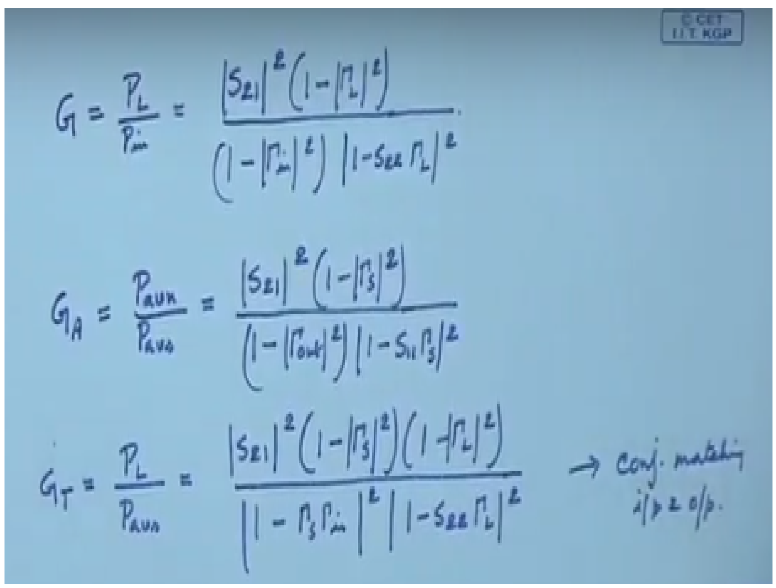

S you see that power gain it depends on load as we already said that it is independent of source that is why you see the source reflection coefficient gamma is does not come here it is S parameter of active device and various load conditions also from the network if we look that in just a after Zs. If we look Z gamma in that will also independent of Z2 that is why you get the expression also we get this. Similarly we can find out what is the available power gain. That we know is Pavn by pavs so it will be independent of ZL gamma L.

This is again S21 square 1 – gamma S square divided by 1 – gamma out square into 1 – gamma S square you see the similarity that gamma L is changes to gamma S gamma in to gamma out S22 S11gamma L to this. And from already derived ones we can now write the transducer power gain that will be S21 square. I said you see this transducer power gain is dependent on both and source impedance that is why it depends on gamma S and gamma L gamma in everything is included here.

Now you see that sometimes this is this the maximum gain possible but for this we require so GT is the maximum gain possible for a particular gamma L gamma S which is conjugately match with the input and out impedances this is a maximum that we can achieve and so please remember that this is for conjugate matching input and output one sorry both.

But always we do not do such stringent ones because always we need to know the loading conditions source impedance and load impedance to do this conjugate matching sometime instead a easier one is done that is just simple matching this we can say simple matching that means what we to that we choose that Zs is simple equal to Z0.

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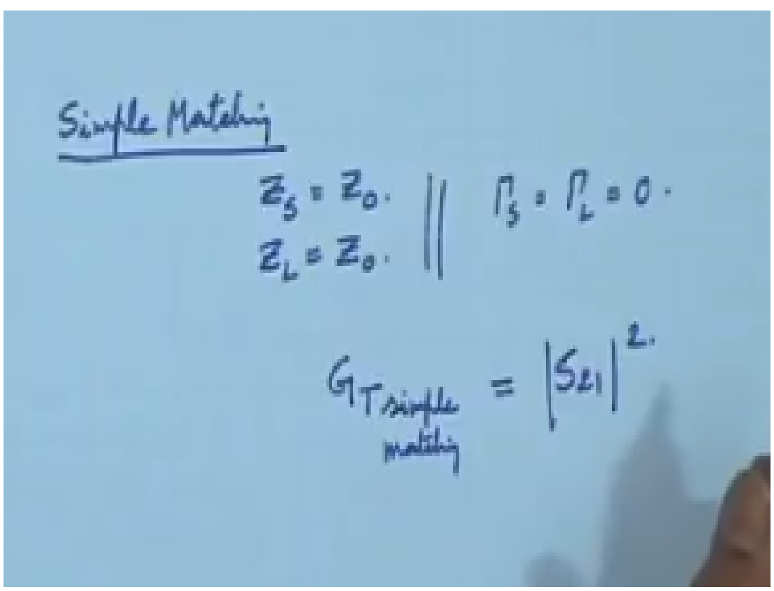

You see Z0 is generally a real quantity so Zs and ZL we choose real instead of that complex thing actual four com conjugate matching we require that Zs should be chosen as Zin star ZL should be chosen as Z out star but simple matching is this but if you look at the expression of gamma S and gamma L that we have done so if I have Zs = Z0 gamma s will become zero reflection coefficient there wont be any reflection in the source there wont be any reflection in the load.

But that does not ensure maximum power transfer that ensure less that maximum power transfer but sometimes we do that reflection we just need to cut we are not so bothered about maximum power transfer. So in this case these implies gamma s = gamma L = 0 and then what happens to these you can say GT simple matching this will be what is the expression just now okay I have done so here if you see if put gamma S and gamma L 0 it becomes simply S21 square.

So by simple matching what we can achieve whatever the transistor is giving me whatever as we device it is giving me I can achieve that. So let us see this first graph yes so you see that here I am not taking advantage of this graph. So I am a good RF engineer but this is sufficient that ok whatever device transistor is giving I want transducer gain to to be that I can do that simply by simple matching.

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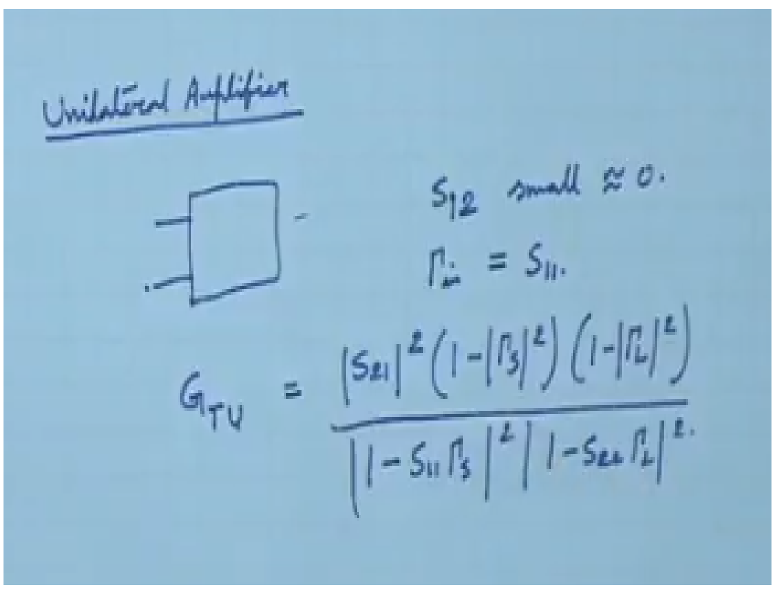

Another important case is called in many practical transistors microwave transistor we have unilateral amplifier. What is the meaning of obviously in an amplifier the S21 please remember that in a 2 port network S21 means whatever am giving here how is coming here so this by this is S21. What is S12 that if something is reflected how much is coming here in many of the practical amplifier this S2 value is very small practically I can all it zero.

Sometimes it is not very not exactly zero but very small compared to S21 it is quite small so if we consider it to be zero. So in that case let us look at our that this expression you see that from signal flow graph I said that you can find out this gamma in is S11 plus this now here S12 becomes 0 then gamma even though you do not have a matching at the output gamma in becomes practically S11.

Similarly if you write the expression for gamma out that will be S22 so under this case we get that gamma in s11 and then the this transducer gain for unilateral case will turn out to be S21 square 1 – gamma S square into 1 – gamma L square 1 – S11 gamma S square 1 – S22 gamma L square. How it is different from a transducer power gain for a non-unilateral that means in general one you see the GT expression here there is the presence of this input reflection coefficient and output load reflection coefficient.

This two this input reflection coefficient now here that is absent that means input reflection coefficient means I need to know what is loading. Here it is independent and it can be much simpler design can be attempted to this. So this is another special case that we will see in the gain definition but for unilateral amplifiers this simplification can be made. Now let us generalize that we are in a position for simplify our whole microwave transistor design.

I can say that instead if this design instead of please look at these two figures where is the transducer power gain that three power gains not this. So this was my actual circuit and this is the transducer power gain in the most generalized sense. Now here you see that this is a total design that means I need to find out gamma S gamma in etc. But now this whole thing I can attempt like this that I have a source VS here I have an input matching network.

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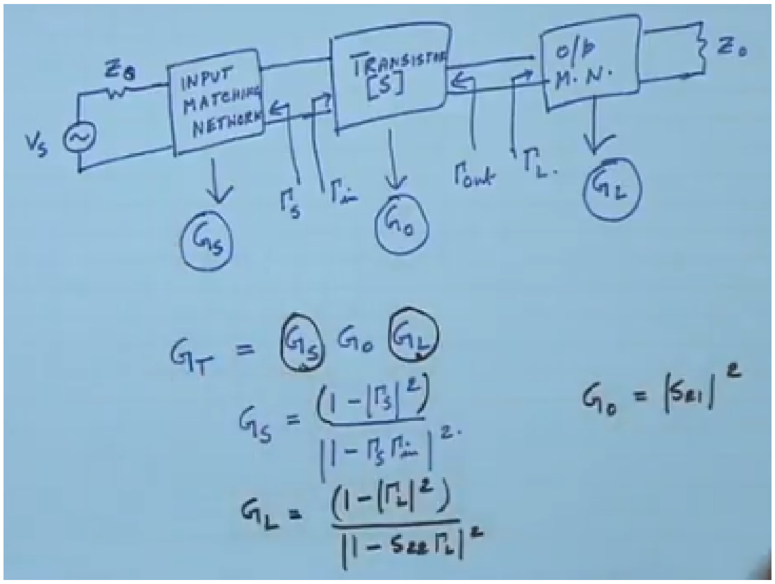

So basically I have a Zs but with a input matching here will have an input matching network this will be based on conjugate matching and then I can say that with this input matching network that job of it is to bring the this to an impedance level Z0 and then let us call this or that I will do later now then I have the transistor S and then I have this there also will be output matching network and then due to this output matching network instead of ZL I will say that I will terminate by Z0 and so here I have that gamma S here.

I will have the gamma in here I will have that gamma out and here I will have that gamma L. So these two are equivalent things here I has ZL Zs etc but that with input matching network and output matching network I can do it and if we look here I will say that this part will give me a gain of Z0 this part will give me the gain of source side again from this input matching network and this I will get a GL load side input matching network and I will say my total GT is nothing but GS, G0, GL.

As you see that I have various products so if we group it together can I now say that what is GS ? GS is equal to 1 minus you see this by this because source is coming here only so 1 – gamma S square source impedance, source matching they are coming here only. GS I will have a GL = 1 – gamma L square by 1 - S22 gamma L square and the active part is G0 is s211 square.

So you see that simple matching people they we have already found that simple matching GT simple matching is S21 square but if I do conjugate matching actually I have three parts so this is like simple matching but i have two more degrees of freedom here one is the input source matching another is output side matching. So by this if I design properties two network I can get this additional gains because here due to conjugate matching I will make maximum power transfer and by that I can increase the gain.

So basically you see when a transistor you have already chosen ok obviously while choosing will choose a transistor which will suit out purpose our impedance level etc and we will try to maximize this but once it is chosen there is not much role for a designer to play. But his role is basically to design here that means if I want to have a high gain I need to play with these two basically so microwave amplifier design is playing with this input matching network and output matching network.

So that GS and GL can be made higher and higher. Obviously there is interconnection between them independently this two cannot be done but we will do something we will see the techniques by which this can be done. But there is another problem here that when I am trying to make this gain maximize I should also understand that I can playing with an active device.

So for certain loading condition because input matching network output matching network design means I will have to choose proper leave my Zs and Zl levels. But to do that sometimes it the whole active device become unstable what is unstability that for finite input it is giving infinite output. We know that condition is basically it can start oscillating etc., I do not want amplifier to oscillate because that will start generating new more frequencies also its level etc that will start going up.

So that we do not want from an amplifier so we want to do a stability check for that . Now what is the so the next part before designing these finally we will design these two that will be our base main aim but before that we want to do a stability check for a particular load and source condition. We want to see that what is the stability of the amplifier because many times it happens in students project that suppose you are asked to design an amplifier you see that finally you have loaded it such that it becomes an oscillator.

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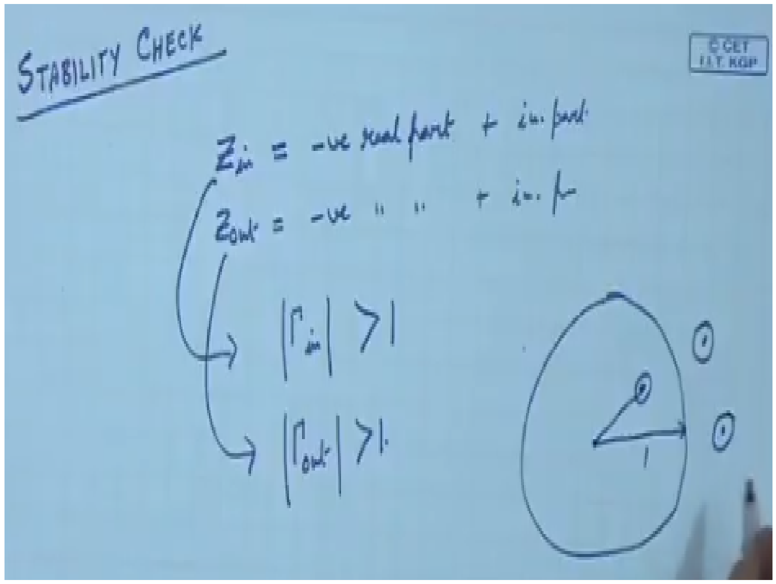

So that means you have not given proper attention to stability. So if we do that stability check so what is the stability criteria that basically Zin. If we see this that this input impedance Zin and also form this side I have output impedance Z out now Zin if it has a negative real part that means instead of resistive if it has a negative resistance also Z out as a negative real part, obviously it is having an imaginary part plus this is a reactive part.

But if either Zin or Z out or both they have negative real part then I will start getting oscillation it is obvious because then whatever I am giving suppose if Zin is more than it as a negative part whatever signal am given the signal will start building up and then it will be starts oscillating. Similarly in the Z out whatever reflection coming that will start picking up and the device will start oscillating.

So the if Zin is having a negative real part I can say basically that time the gamma in because what is Zin we know what is the relation between gamma in and Zin, gamma in is Zin minus Z0 by gamma by Zin plus Z0. So Zin if it as a negative real part then I know that gamma in is greater than 1 this you know form your smith chart knowledge also that in smith chart every point that represents either an impedance or a corresponding reflecting coefficient.

Now if Zin you know in the normal smith mart that we use there the all we consider is passive impedances so they are the real part is never negative real part of any impedance is never negative it is zero to infinity any value it goes. So what is the, when Zin have a negative real part basically the point goes out of our normal unit circle smith chart and that time gamma N becomes one similarly Z out is here gamma out its magnitude that will be 1.

Because in the smith chart that suppose this is the point this is the magnitude of gamma. Now if the generally this radius is one if gamma N greater than one means this point instead of here it is going here or here it is going here like this. So that means it is going out of the passive smith chart of unit circle. So what is the stability check we can check this conditions that gamma in, if gamma in is greater than one magnitude of gamma in is greater than one for certain or for any ZL and Zs combination.

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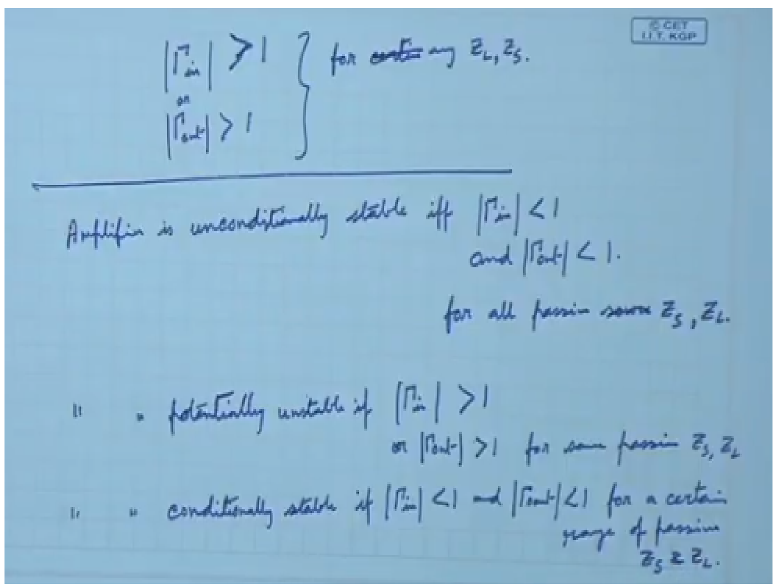

Then we say that device is potentially unstable or I should say or gamma out is greater than one so gamma in greater than one the gamma out is greater than one for it any choice of ZL any particular combination of ZL, ZS then we say that device is potentially unstable. So the whole stability problem we break into these that I what is my this amplifier is unconditionally stable IF and only if gamma in is less than one and gamma out both of this should satisfy gamma out is less than one for all passive source Zs and ZL.

So amplifier is unconditionally stable if for all passive because generally we are talking of passive source and load impedances but this amplifier should be unconditionally stable. Now we have seen this gamma in and gamma out values they depends on S parameters of the device and also load and source conditions. So we can find out this. So we can find out some criteria or we can find on the smith chart that whether this is taking place or not.

Similarly, amplifier is potentially unstable if gamma in is greater than one or gamma out here not and because this was unconditionally stable it is potential unstable If either these or this gamma out is greater than one for some passive ZS ZL not for all even if or one then will say it is potential unstable. Now we can make an amplifier conditionally stable that means though it is potentially unstable will avoid that combination of Zs and ZL.

And then say that if I avoid this set, this particular choices of ZS Zl then I will make say that it is conditionally stable. If gamma in is less than one and again you see and gamma out is less than one for a certain range of passive ZS and ZL. So this is important because first we will see whether we can find out whether it is unconditionally stable.

If the network is that unconditionally stable that means what about the ZL ZS I choose still it is always stable then no problem I will go ahead I will start concentrating my effort on design the input and output matching networks so that we achieve the particular gain or maximum gain or other things. But if it is not if I say that no there is a potential unstability then first I will have to determine what is the range of ZS and ZL that I can choose so that the amplifier becomes in the stable region.

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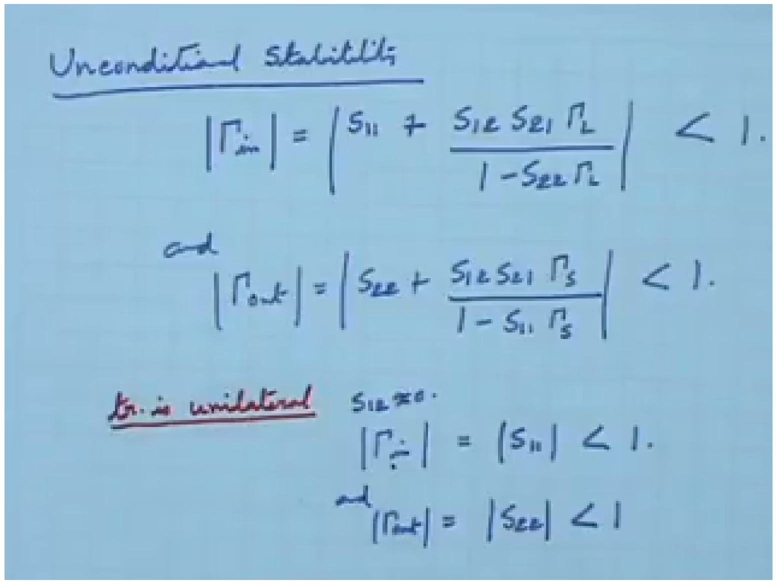

So based on this we can say that unconditional stability implies that gamma in magnitude which we have already seen in earlier NPTEL classes that it is S11 + S12 S21 gamma L by 1 – S22 gamma L that should be less than one and gamma out = S22 + S12 S21 gamma S by 1 – S11 gamma S that also to be less than one. Now if we have if the transistor is unilateral which we already discussed that many practical transistors is unilateral.

Then this condition become simplified that gamma in becomes unilateral means S12 is 0, so gamma 1 is S11 less than 1 and gamma out S22 less than 1. So for a unilateral transistor I can always check because manufacturer always gives me the S parameter or I can measure the S parameter by modern devices network analyzer that we have already seen in earlier classes. So and if I find that ok the device is unilateral it says S12 is equal to 0 this is means S12 is 0 or approximately 0.

And then I see that S11 magnitude is less than 1 S22 magnitude is also less than 1 then I know that is input reflection coefficient output reflection coefficient also will be less than 1 so I will be happy I will go on designing the actual thing. If it is not then or if I can also fine that S11 is greater than 1 or S22 is greater than 1 then I will be worried and I will have to do some more thing.

That some more thing is called the stability circle. I need to get a smith chart and out some stability circles on that so that will be doing in the next class that will be seeing that how when I have a potentially when the next class will be saying that in potentially unstable cases how to make conditionally stable amplifier.

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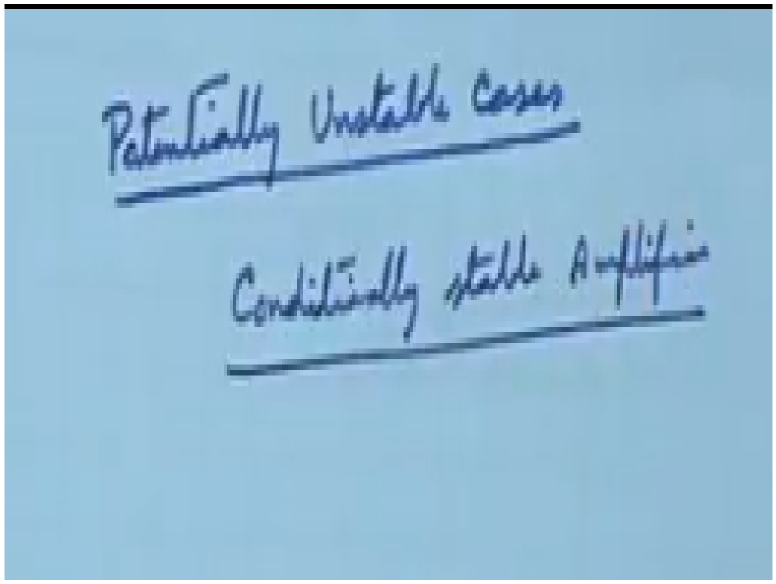

So we need to demarcate some zone of ZL ZS etc so that we wont touch that and will also demarcate the zone where we can choose ZL ZS from those are stability circle drawing and determining the region where it can have conditionally stable thing. So this is something like whatever you have learnt in circuit classes that a any network that when it is become unstable you can find that conditionally how to make it stable we will also see that in the next lecture.