Microwave Integrated Circuits

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Lecture No 34

Oscillator Design

Hello, welcome to another module of this course Microwave Integrated Circuit. this will be our last module in this course it will primarily deal with Oscillator design. So oscillators are special circuits in any field whether in microwave frequencies or at lower frequencies. In that they are autonomous systems, whereas the amplifiers while discussing amplifier design, we had seen there is an input and output.

In an oscillator, there is no input as such there is only an output. So we will we saw from our discussion of stability that for a system to be stable, for a bounded input it should produce a bounded output. But then as I mentioned, when we are talking about oscillators, it produces an output without any input.

So it is a fundamentally unstable system, at the same time it has to produce a constant, it has to produce an output of constant amplitude or at least the amplitude that we should be able to control. So it cannot either you know that little cannot go down to 0, neither can it expo. So there is an aspect of stability also involved in oscillator design. So all those things we shall discuss in this module.

So the first thing is to discuss about oscillators, we need to go back to our feedback model. So recall that diagram that I had used.

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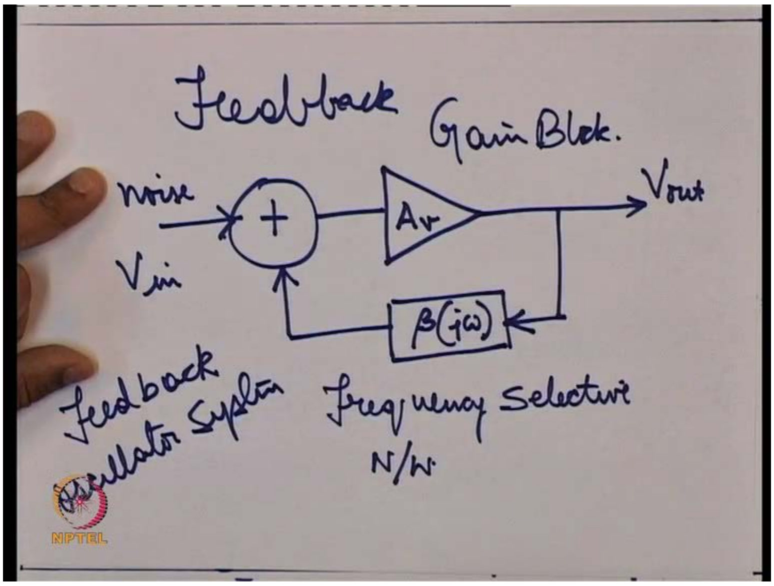

Here everything is same except instead of a negative sign, it is all positive here. So the signal, the feedback signal is positively added to the input signal and so this is a frequently selective network, this is our gain block, this is our input voltage. For now let us assume that input voltage is noise.

So this is what we call a feedback oscillator system. In this system, even if there is no input or if there is just a disturbance at the beginning, then an output V output will be produced which is self sustain. An alternate way from the circuit point of view you know the from the reflection coefficient point of view can also be given for this oscillator.

Suppose, you have an input network like this.

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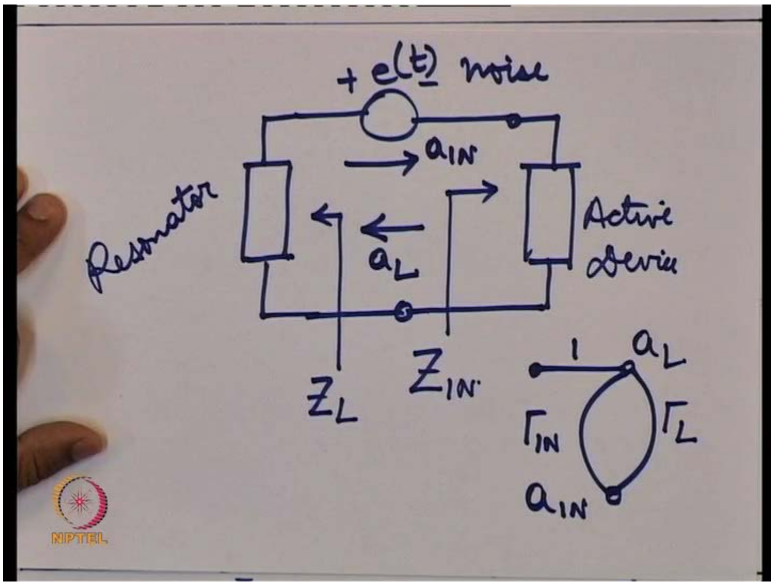

Suppose there is a small noise voltage V t, this is the noise voltage. And suppose we have an active device like this. This is a resonator suppose this is the incident wave in this direction and this is the A l is my incident in the opposite direction and the signal flow graph diagram for this circuit will be something like this.

Signal flow diagram I am drawing from the discussion that we had many modules ago. So once we you know once we draw this signal flow diagram what happens is that at the point of oscillation what happens at the point of oscillation, at the point of oscillation this Z in, which is primarily a function of the amplitude of oscillation should be equal and opposite or negative of the impedance offered by the resonator.

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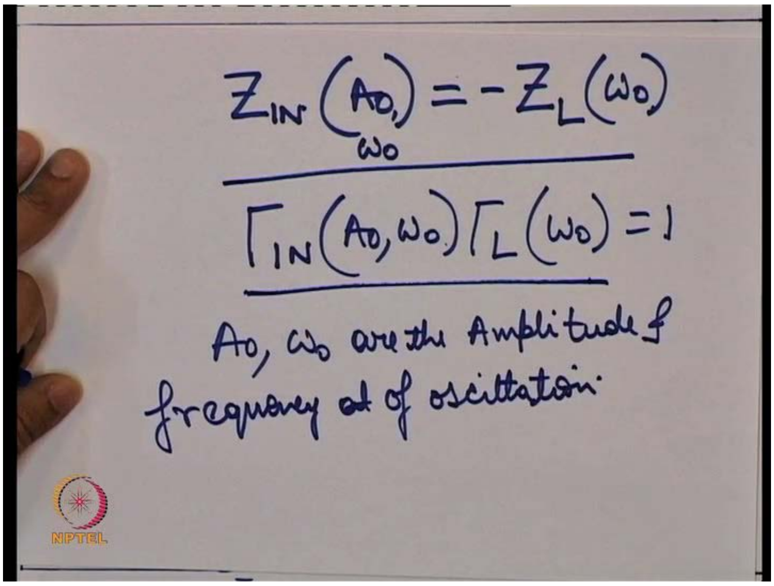

In terms of reflection coefficient you can show that this condition can also… Actually I should have put Omega 0, Z in might also be a function of Omega 0 that is the frequency of oscillation. Now see this A 0 and Omega 0 are the amplitude and frequency at of oscillation. So this is the amplitude and frequency at the oscillation point where there is a where this condition this condition is satisfied.

Proceeding from the model that I had drawn previously, this model.

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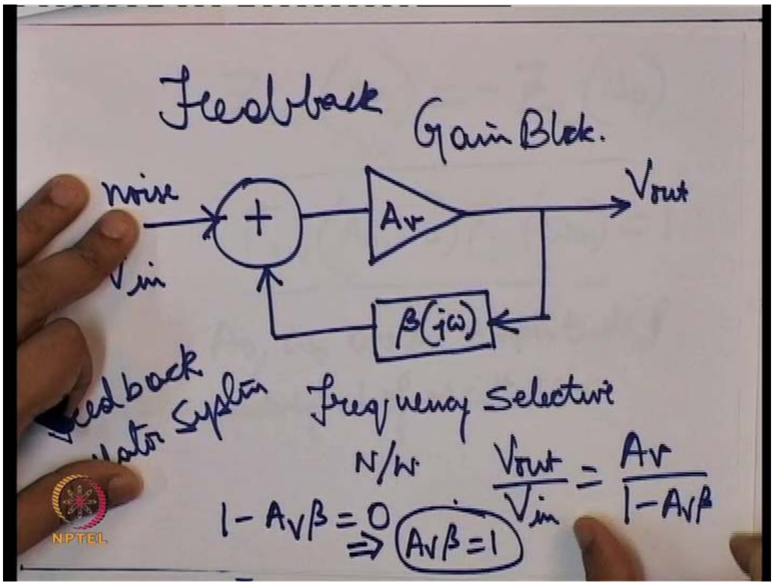

You know that V out over V in can also be written as A V upon 1 - AV Beta. Now V out is produced, V out will produce even when V in is 0. For that to happen we should have 1 - A V Beta is equal to 0, this in turn implies A V Beta should be equal to 1. This condition let me use a fresh page for this.

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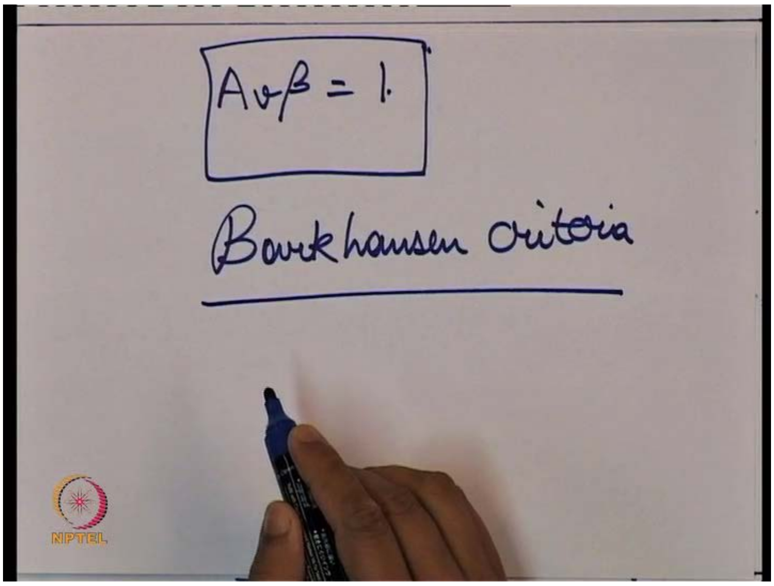

This condition that you know this A V Beta is equal to 1 is also known as Barkhausen criteria. So this in turn means if we go back to if we go back to that feedback diagram.

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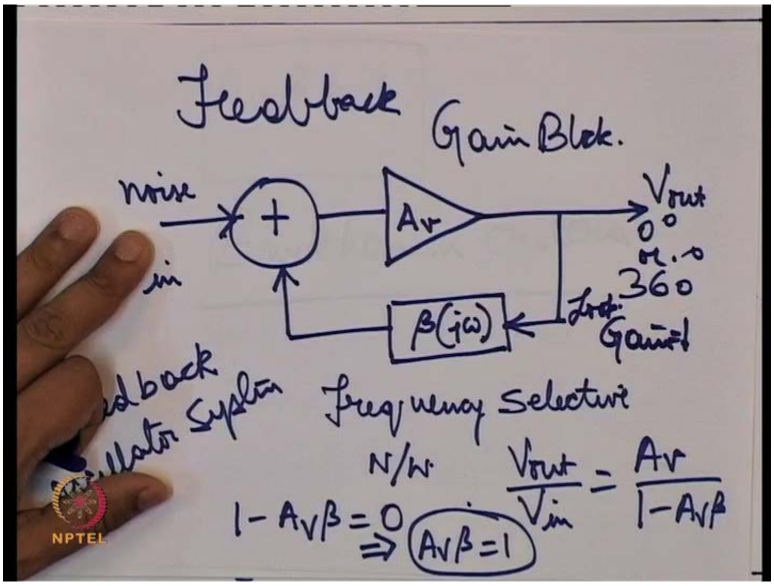

It means that the total phase change over this entire feedback path should be zero or 360 degree and the total gain starting from this point all the way to through the other end then back should be 1.

So this gain is also known as by the term called Loop Gain that is, Loop gain should be equal to 1 and the loop, total phase change over the loop should be equal to 0 or 360 degree. Now proceeding with this definition, now let us see what else we can um we can find.

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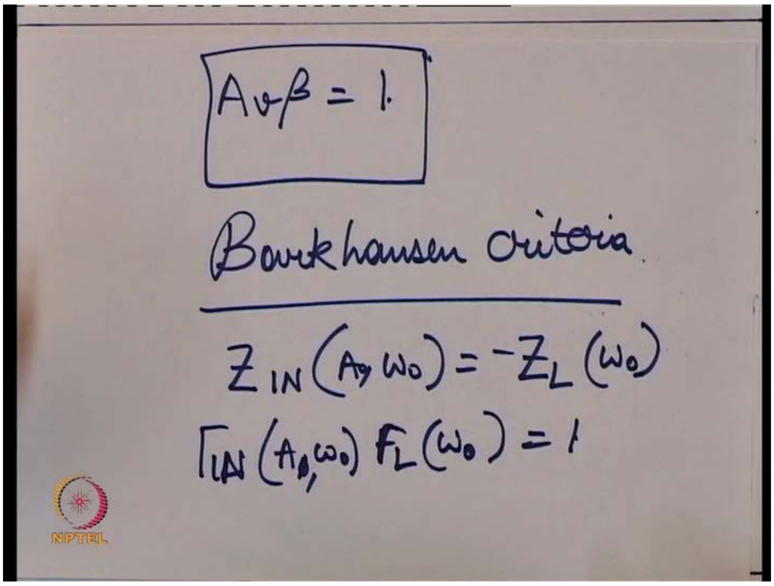

So first we saw that our Z in which is the function of A 0 and Omega 0 should be equal and opposite to Z L and this in turn can be further reduced to 1.

But note one thing that this condition is applicable only at the point of oscillation. Now at the point of oscillation, no input needs to be provided to this feedback system. But for it to start oscillation that is for its amplitude to go from its 0 value the system has to be fundamentally unstable. So at the start of the oscillation, we have to have an instability, how do we introduce that instability?

So for this we go back to the condition for stability that we have studied earlier.

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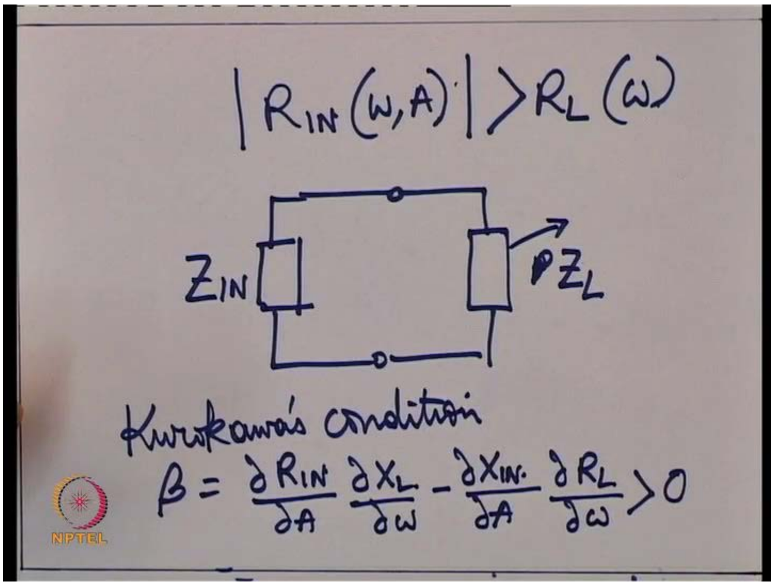

That is that at the start of oscillation, our modular of R in Omega A. Note that here I'm not using the terms Omega 0 and A 0 because this is at the start not at the steady state. It should be greater than R L of Omega, okay. So here R in is the real part of my Z in and R L is the resonator part.

Here we are assuming that this oscillator can be divided into two parts; one which is strongly dependent, whose value is strongly dependent on amplitude and to a lesser extent on frequency. And another purely frequency dependent part Z L. Now it can be shown you know so once so the oscillation has started and say the point of oscillation has been reached.

Um at the point of oscillation however, in order to insure stability there is a condition called Kurokawar condition which states that Beta… If this condition is satisfied, here note this R in and X in our real and imaginary parts of Z in. X L and R L and X L are real and imaginary parts of Z L. If this condition is satisfied then we can safely say that the oscillation is stable. That is oscillation will continue at constant amplitude.

Graphically this is shown here.

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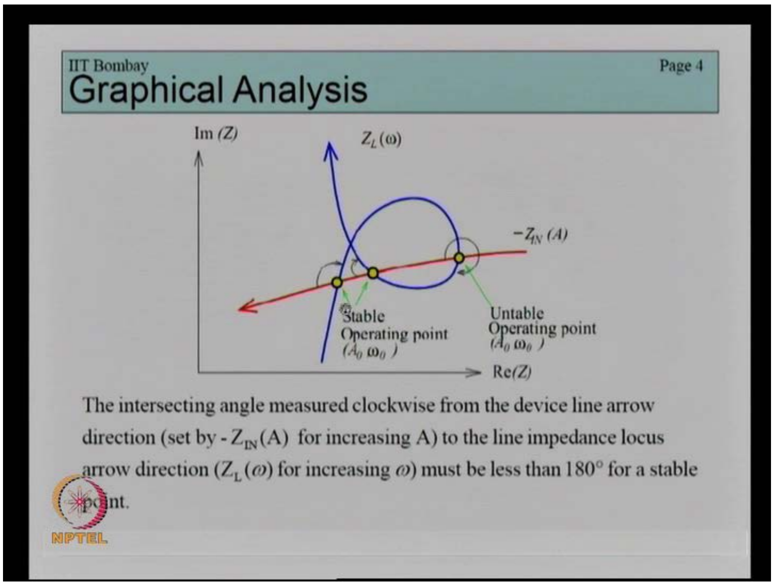

This blue graph is a plot of Z L, this is this plain is the Z plain that is Y axis the imaginary value of Z and X axis is the real value of that. This blue curve represents the variation of Z L with frequency and this red curve represents the variation of Z in - Z in with amplitude.

Now the points where these two meet that is the point where Z L is equal to - Z in A at the potential solution points. But then there is no guarantee that even though they are potential oscillation points we are not sure whether they are stable oscillation points. so the way to so the condition for oscillation was given by that equation which was shown previously. But then what does it mean graphically.

What it means graphically is that if the angle between the two lines. Suppose with increasing A, the red cure is moving like this and with increasing Omega the blue curve moves like this, then the angle between the tangents to the two curves at the point of intersection okay. Suppose I draw a tangent here a tangent that is blue line, the angle between the two will determine whether the oscillation is stable or not.

If the angle between the tangents of the two curves at the point of intersection is less than 180 degree, then the oscillation is stable. If the angle is greater than 180°, then the oscillation is unstable. So for example, for this particular point, you see that the angle between the red line and the blue line, the angle by the way has to be between the -, first it has to start from the tangent of the -Z in A curve and in the tangent of the Z L curve.

So in this case the angle is lesser than 180°, therefore this point represents a stable oscillation point. In this case also the point of oscillation at the point of oscillation angle between the tangent of this -Z in A curve is and the tangent to the Z L curve is lesser than 180° therefore, this point also represents a point of stable oscillation.

However, at this point as you can see the angle between the red line and the blue line, that is the tangents to the red line and the blue line is greater than 180°, therefore this point does not represents a stable point of oscillation. This is an unstable, either the either the amplitude will blow up become very large or it will die down. So how do we design an oscillator?

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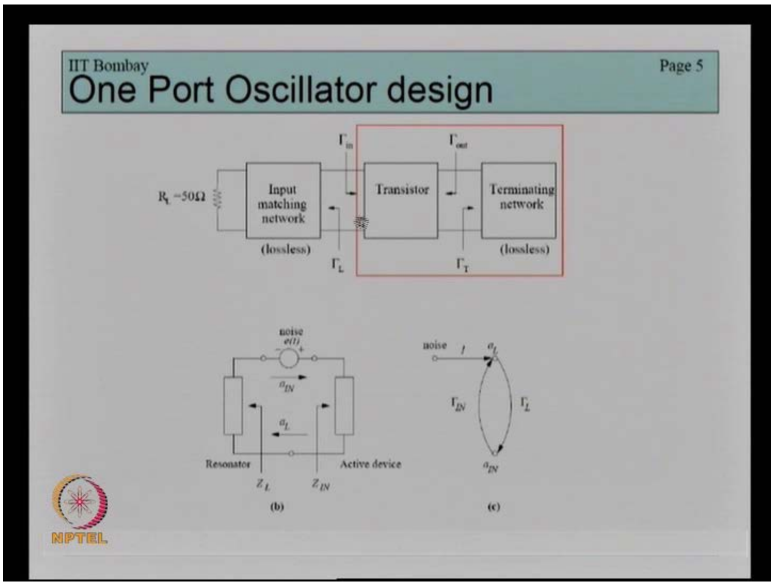

So to design it, you know you have your transistor. If your transistor is this, then at the point of oscillation you should have this Gamma L multiplied by Gamma in should be equal to 1. So what you can do is you know suppose we assume that your transistor has its own termination network which produces a given Gamma in. Then only you have to do is simply make an input matching network which has input reflection coefficient Gamma L such that Gamma L multiplied by Gamma in is unity.

Of course, here first we have to first start oscillation.

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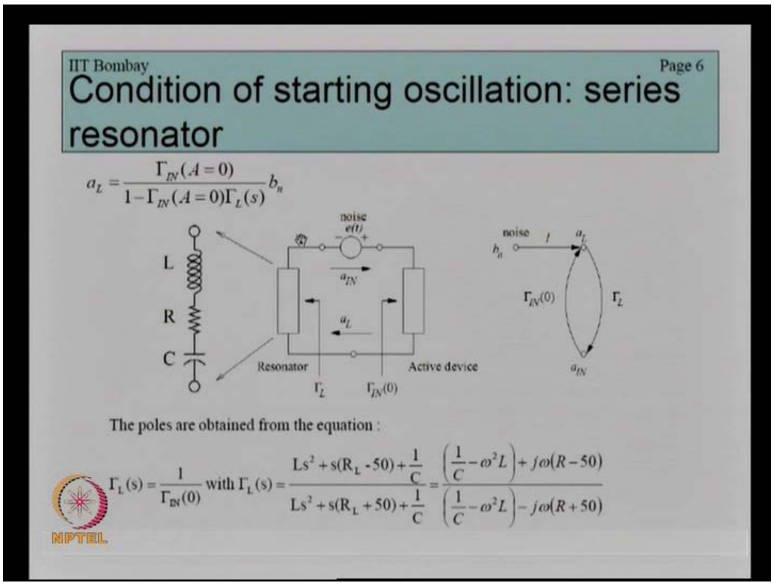

So here suppose you assume your resonator, this resonator to be a simple series R L C network. Then Gamma L will be given like this okay. If you just a simple Laplace transform of the input impedance of this Laplace I mean this is this expression for the reflection coefficient is obtained from Z L which can be simply calculated.

And this you know at the point of oscillation you have to have your R in a modulus of R in greater than R L. After some mathematical manipulation it can be shown that that condition reduces to this.

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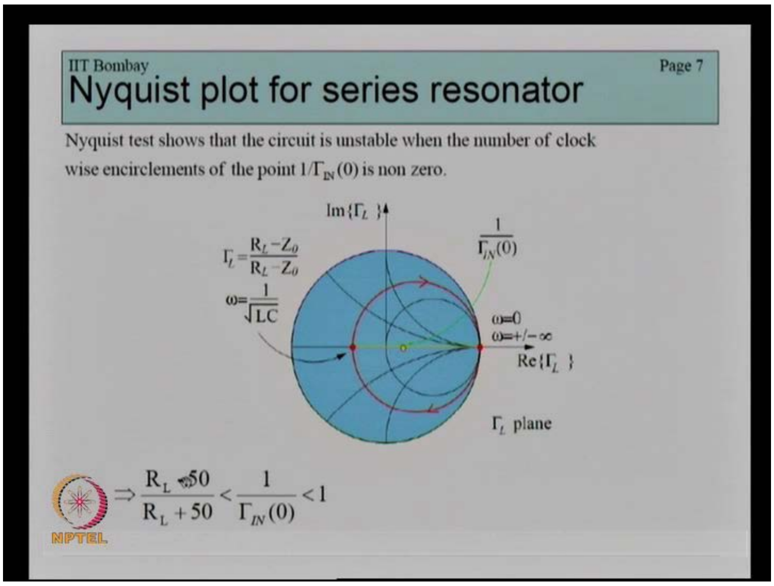

So your input the R L of the resonator should be such that it satisfies the condition. So in summary oscillators as we as I mentioned you know little different from other amplifier circuits that we have studied so far.

In that they have no input, only output. Inputs I mean no AC input, there can be DC input of code, but no AC input. And their design is bit different from that of amplifier in the sense that there is no gain involved, gain term involved or linearity term involved. Oscillators first of all they need to be started, because starting they need to be unstable at the start-up of oscillations and by this example of a series resonator, I just gave you an idea that how you can design your resonator, so that your oscillator circuit is unstable at the start-up.

And also at the point of [osc] and also okay that is first part because the start-up of oscillation is first important. The second important thing is that it should have a stable oscillating point that is there should be a point where this -Z in A curve meets the Z L curve that is the second part. And third, this point where these two curves meet should also be stable according to the Kurokawa theorem.

The Kurokawa theory which I gave by this equation reduces to a graphical form like this.

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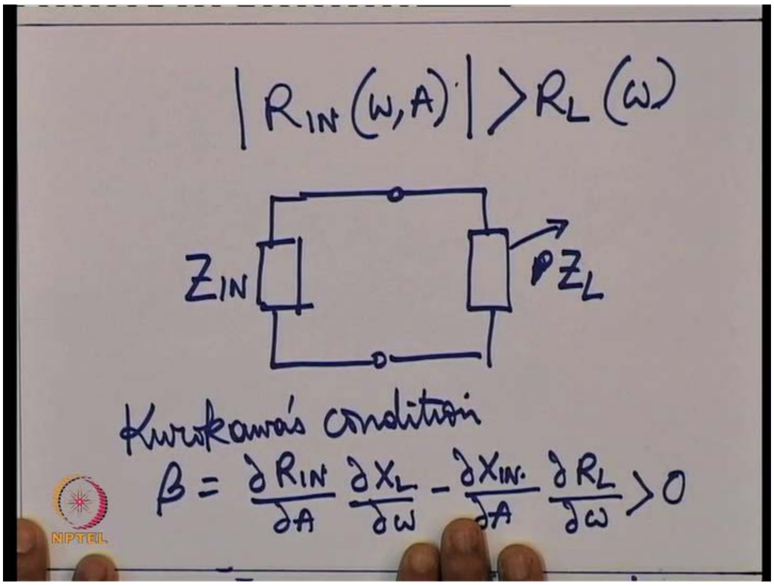

If you could shift to the curve on the monitor please. Yeah this curve.

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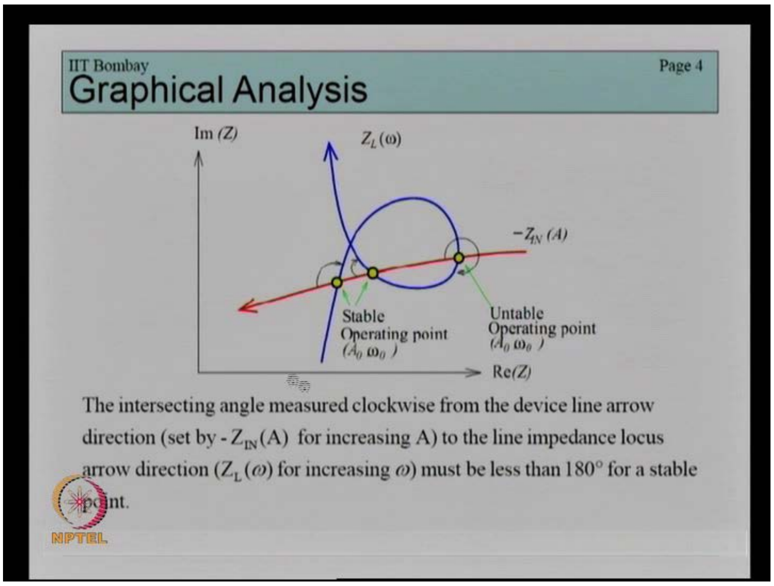

That equation which I showed previously reduces to this, it can be shown that that the question is equivalent to this graphical analysis where the intersection point angle between the two tangents between of two lines at the point of intersection should be lesser than 180°. So I hope, so this is we have come now to the end of this course um, this is the last topic of this course and I hope you like this course.

There will be an exam as per the schedule given on the web page, I hope many of you take this take that exam and do well in um. Please join the forum and ask in question, I will try as much as I can. In case you do not reach me in the forum, please send me an email to my email ID, also you can talk with Pas, there are always…

And thank you for participating in this course and I hope you found some truthful information on this course and you will be able to use this knowledge in your future endeavor. Thank you.

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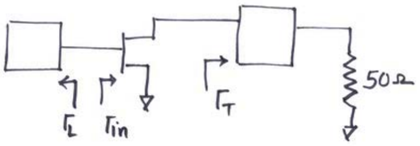
Week-8

Problem: Design an Oscillator at 6 GHz using an FET in a common source configuration driving a 50Ω load on drain.
S parameters are ($Z_0 = 50\Omega$): $S_{11} = 0.9\angle -150°$, $S_{21} = 2.6\angle 50°$, $S_{12} = 0.2\angle -15°$, $S_{22} = 0.5\angle -105°$.
Calculate output stability circle, choose Γ_T for $|\Gamma_{in}| >> 1$. Design load and terminating network.

Solution



Output stability circle is

$$C_T = \frac{(S_{22} - \Delta S_{11}^*)^*}{|S_{22}|^2 - |\Delta|^2}$$

$$R_T = \left| \frac{S_{12} \cdot S_{21}}{|S_{22}|^2 - |\Delta|^2} \right|$$

where $\Delta = (S_{11} \cdot S_{22} - S_{12} \cdot S_{21})$

Putting all S-parameter values

$$C_T = 8.09\angle -15° \quad \& \quad R_T = 8.28$$

Γ_T should be choosen such a way that $|\Gamma_T| < 1$ and Γ_{in} is large. Thus we select $\Gamma_T = 0.9\angle 130°$

Now
$$\Gamma_{in} = S_{11} + \frac{S_{12} \cdot S_{21}\Gamma_T}{1 - S_{22}\Gamma_T}$$

or
$$\Gamma_{in} = 0.9\angle 150° + \frac{(0.2\angle -15°)\cdot(2.6\angle 50°)(0.9\angle 130°)}{1 - (0.5\angle -105°)(0.9\angle 130°)}$$

$$\Gamma_{in} = 1.61\angle -162°$$

Now
$$Z_{in} = Z_0\left(\frac{1+\Gamma_{in}}{1-\Gamma_{in}}\right) = -12 - j\,7.5\ \Omega$$
$$= R_{in} + j\,X_{in}$$

So
$$Z_L = -\tfrac{1}{3}R_{in} - j\,X_{in}$$

using $\frac{1}{3}R_{in}$ ensure instability for startup.

$$Z_L = (4 + j\,7.5)\,\Omega = (0.08 + j\,0.15)\cdot Z_0$$

where $Z_0 = 50\,\Omega$

Now matching network designed using Smith chart. Series and shunt stubs of 50Ω characteristic impedance used for matching network. Final design shown below