Microwave Theory and Techniques
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Module – 9
Lecture – 42
Microwave Oscillators – II

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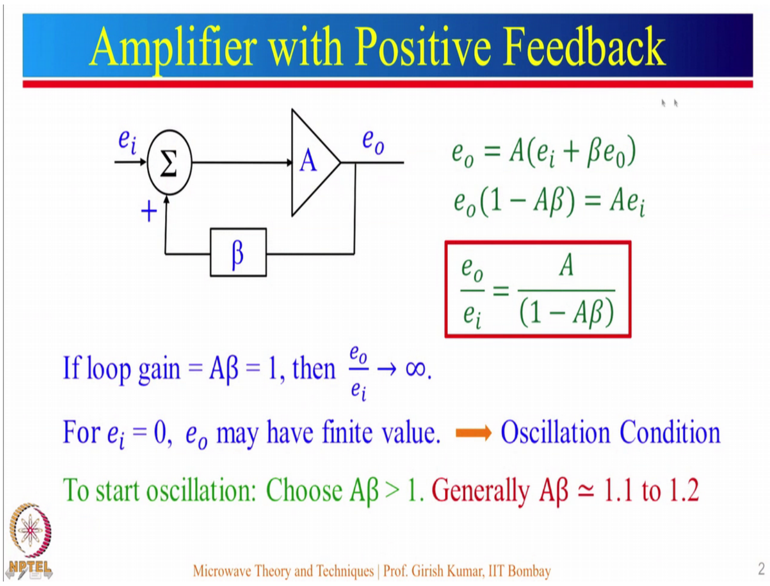

Hello and welcome to the second lecture on Microwave Oscillator. In the previous lecture, I started with amplifier with positive feedback. And we had seen that oscillation condition occurs, when loop gain A beta is equal to 1, and I had recommended that choose A beta around 1.1 to 1.2 to start the oscillation.

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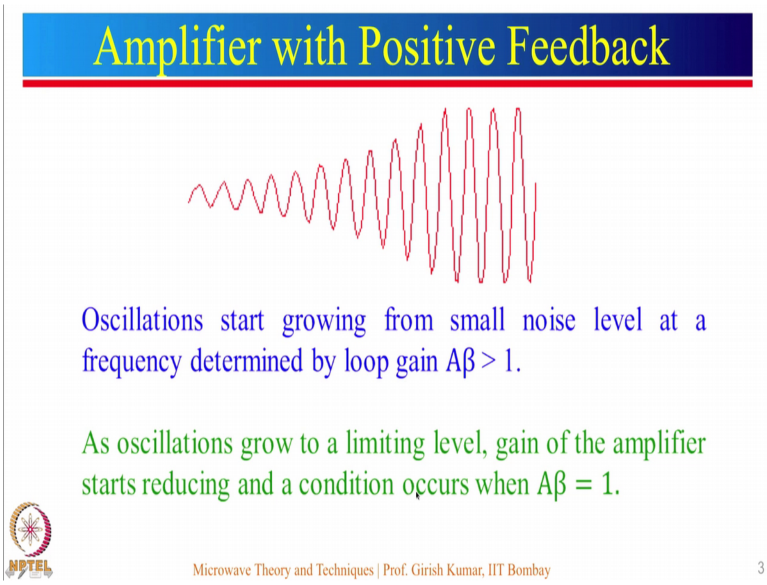

The reason for that is that if you choose larger value of A beta, then there will be clipping of the sinusoidal waveform at the output. And if you take smaller value than 1.1, there are chances that oscillation may never start because of the tolerances in the network which may make the device itself stable.

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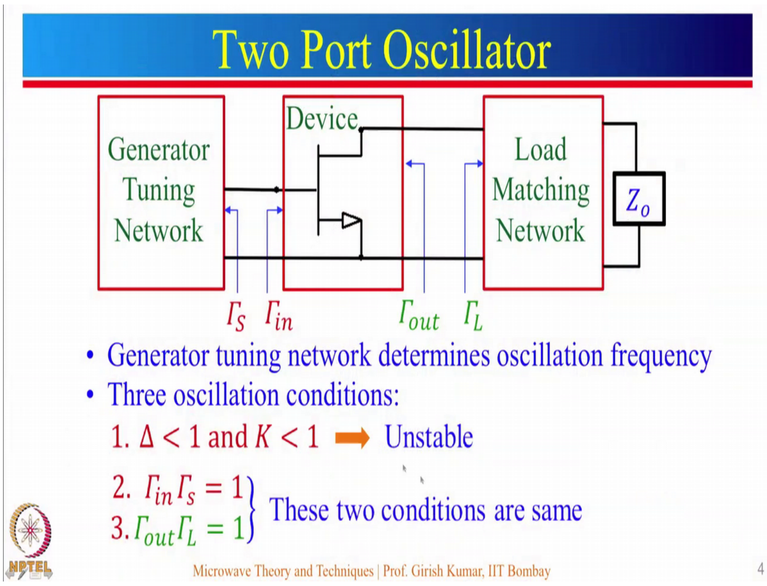

Then we started with the two port oscillator configuration, where we started with the unstable design when delta is less than 1 and K is less than 1. And we had seen oscillation conditions will happen, when this loop gain is equal to 1 that is gamma n multiplied by gamma s equal to 1 and gamma l multiplied by gamma out equal to 1; if this condition is satisfied, this will be automatically satisfied.

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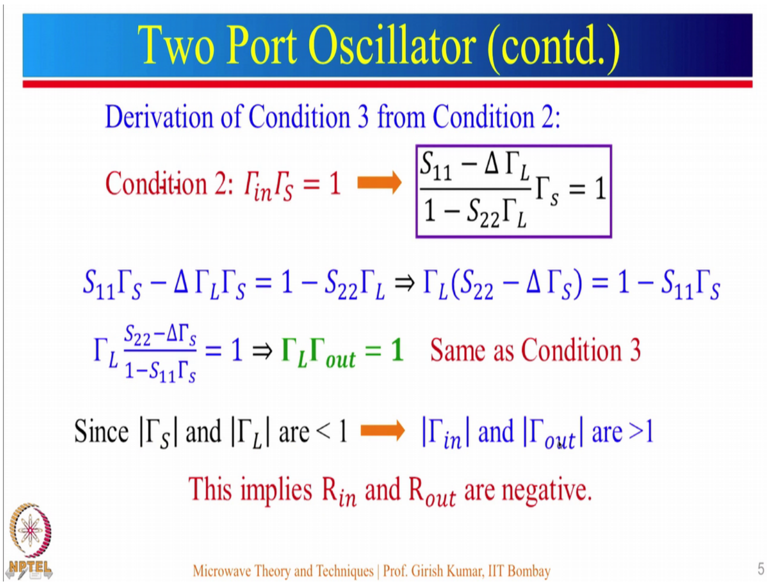

And we had seen that derivation also, we started with condition 3, we reached to condition 2. We had seen that since gamma S and gamma L are always going to be less than 1 for any physical impedance which can be let us say resistance plus inductance or capacitance. So, this will be always less than 1, so gamma in and gamma out will always be greater than 1 which implies R in and R out are negative.

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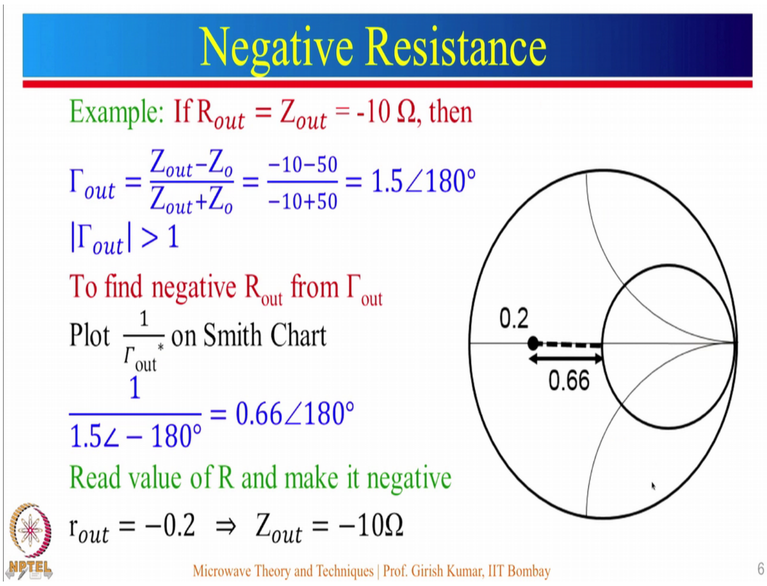

And we had use Smith chart to find out the value of R out for a given value of gamma out, we had seen that when R out was minus 10 gamma out was equal to 1.5 angle 180 degree we had plotted 1 by gamma out conjugate on Smith chart, and from that we read the value of Z out equal to minus 10 ohm which is same as this here.

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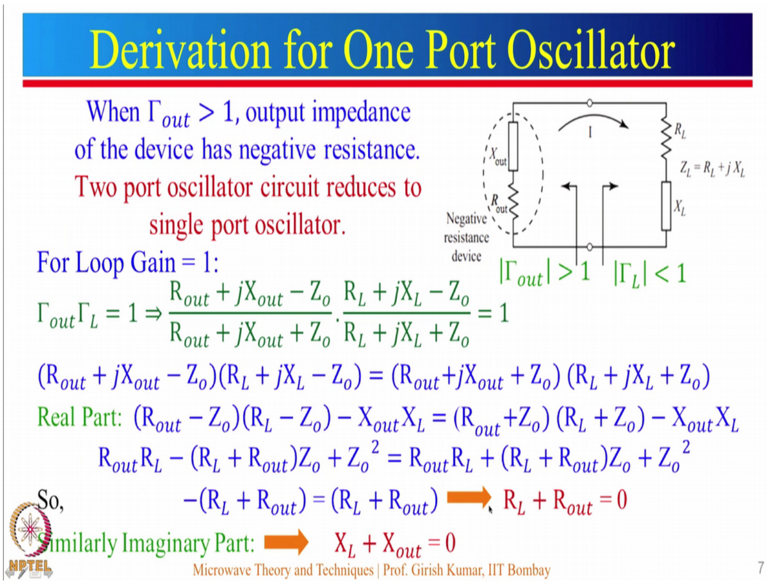

After that we will looked at the derivation for one port oscillator why, because a two port problem was reduced to a one port problem, because we were not looking at only at the output side of the device. We saw the condition that R L plus R out should be equal to 0; and since R out is negative, R L will be positive. Similarly for imaginary part, we saw X L plus X out equal to 0. So, if X out is inductive, this will be capacitive; if this is capacitive, this will become inductive.

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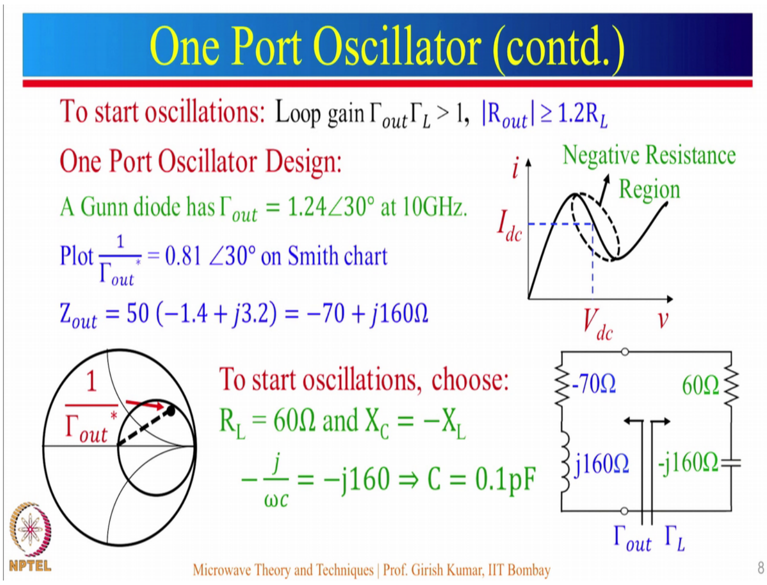

Then we will looked at the design of Gunn diode. A Gunn diode which had gamma out given by this particular value at 10 gigahertz and this particular thing happens, because i v characteristic of Gunn diode is like this. So, we have to bias in this particular negative region. I just want to mention here, even though we took example of Gunn diode, but similar negative resistance region or they are for impart diode, tunnel diode.

And even low frequency components you might have read about SCR Silicon Controlled Rectifier or triode, so that means, you can bias these devices in their negative R region, and then the process will remain same for all those cases. So, what you do, for the given biasing condition find out what is the value of gamma out, then you plot 1 by gamma out conjugate on the Smith chart, find the corresponding value of Z out and then choose the value of R L which is smaller than the magnitude of R out, but X C should be chosen as minus X L.

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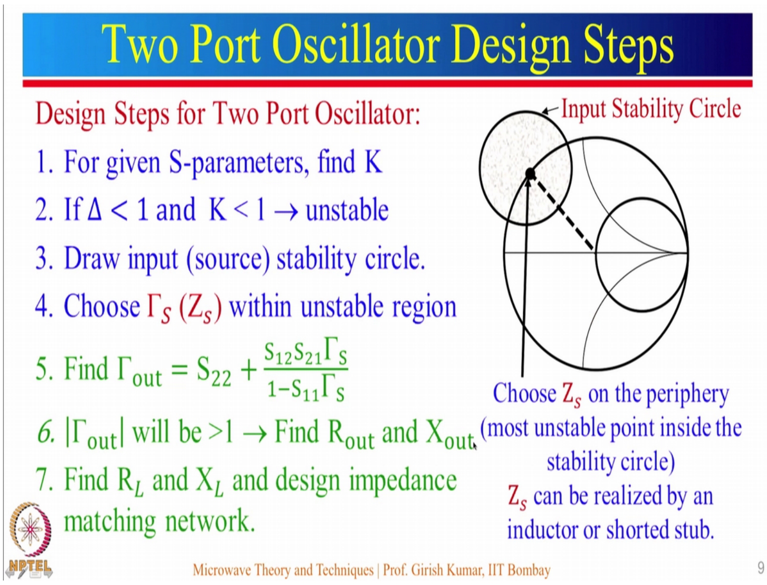

After this, we looked that two port oscillator design; I had shown you 7 different steps let us just go through it one more time, because oscillator design is crucial for many applications. So, let us say S parameters are known to us at a given frequency and for given biasing conditions. So, for given values of S parameter find the value of K; if delta is less than 1 and K is less than 1 that means device is unstable, if K is greater than 1 then the device will be stable. And in the next slide, I am going to tell you what to do when the device is stable. So, right now let us go with the steps when the device is unstable.

So, in this particular case draw input stability circle. So, this is the input stability circle and choose a point which is deep inside this particular unstable region, do not choose this point; or this point; or this point; or points which are close to this, choose a point which is deeply inside this. So, this is the point, which is deep inside the input stability circle that means, this is the most unstable point. So, corresponding to this particular point now we can say gamma S or Z S is chosen, and since we have taken this particular point this can be very easily realized by an inductor or a shorted stub. Suppose if this curve was somewhere here, then that point over here can be realized by a simple capacitance.

So, now once gamma S is chosen, find the value of gamma out which is given by this particular expression and please check magnitude of gamma out has to be greater than 1; if it is not greater than 1, you have made a mistake. So, once gamma out is greater than 1 find R out and X out; R out has to be now negative. So, once R out and X out are known find the value of R L which has to be smaller than the magnitude of R out, but X L should be same as X out with the negative sign. And after that design impedance matching network which will transfer 50 ohm impedance corresponding to these values of R L and X L.

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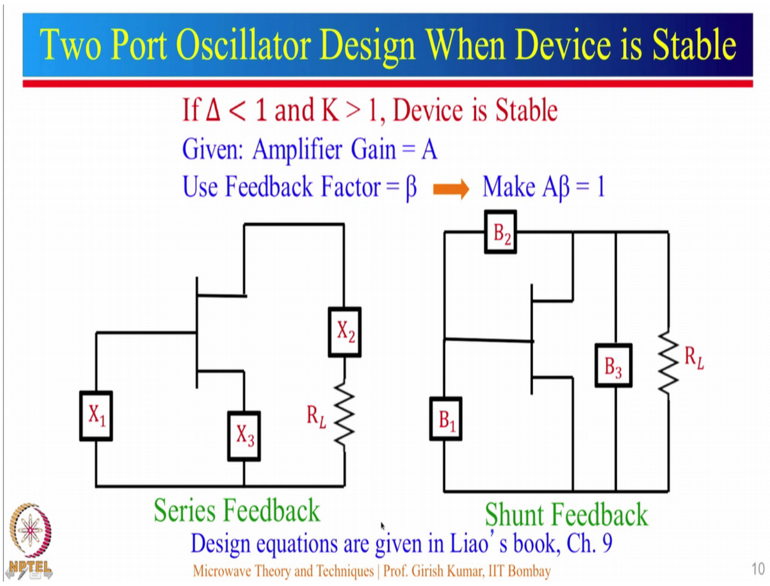

Now, let us just take an example, when the device is stable so if the device is stable that means, delta is less than 1 and K is greater than 1; for the stable device what you do, the first step would be is that you design an amplifier with the gain equal to let say A. And then use feedback factor beta and that would make A beta equal to 1, and in this particular case again you must choose A beta greater than 1 as I recommended earlier choose A beta as 1.1 to 1.2.

So, here is that device which is stable, now in this particular case you can see that this particular thing is connected to the input side, this portion over here corresponds to the load side and this is the series feedback. You can see that this particular X 3 is common to the input side; it is also common to the output side. In your analogue circuits course, you might have designed something like a common emitter amplifier or you can say common source amplifier, there one uses resistance over here to stabilize the amplifier, but over here this is X 3 it is not resistance, so this can be inductance or capacitance. So, this is series feedback.

Let just look an alternate configuration where shunt feedback is used, you can again see this is the source side, this is the load side and this is the feedback from the output to the input side. So, now the next part is to determine the values of X 1, X 2, X 3; if you use series feedback network or determine the values of B 1, B 2, B3; if we are using shunt feedback. I just want to mention that design equations for both these circuits are given in Liao's book chapter 9. So, I have not reproduce it over here in my slides, so please see the Liao's book, you can actually see the expressions for X 1, X 2, X 3 and B 1, B 2, B3, but I just tell you what are the steps involved.

So, what has been done S parameters of this particular device are known then these S parameters are converted to Z parameters, since these elements are in series, in series Z parameters get added. One finds the equivalent Z parameters of this particular entire network, then one uses conversion from Z parameter to S parameter ok. Then those S parameters are found for these particular conditions ok.

So, there are several steps are there, so please see this particular book and then you can actually get the expressions for X 1, X 2, X 3. In this particular case what is done, actually S parameters are converted into Y parameter, and Y parameters in shunt get added up. So, find the equivalent Y parameter then from Y parameter converted to S parameters, apply these conditions and then complete the design. All those things have been done by our earlier researchers. So, I am not going to repeat that they are all basically equation. So, please see the book and then you will be able to design the amplifier accordingly.

Now, I am going to talk about one very very important thing and that is what about the value of A and how this value of A affects the output. So, to start the oscillation we make A beta greater than 1; and when oscillations are sustained A beta equal to 1, but let me ask you a simple question first. So, let us say if I start A equal to 2 or I start with A equal to 10 or maybe a equal to 20 correspondingly we can choose the value of beta, will the output amplitude be same in all these cases. In fact, the answer is not really. So, actually speaking when you are designing an oscillator, please choose some decent value of the gain. So, how we do that, what is the effect of that; so let us look at the derivation of output power of two port oscillator.

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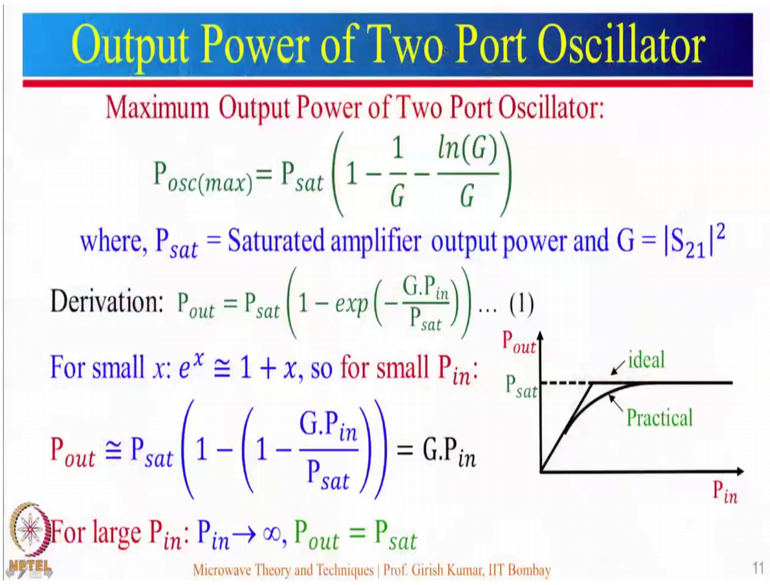

So, maximum output power of two port oscillator is given by this particular expression; now, do not worry I am going to show you the derivation of this particular expression in a short while, but let us first define what are the different terms over here P saturated is the saturated value of any amplifier and G is the gain of the amplifier this is just ln of G. So, let us just first look at this particular response of any amplifier where as P input increases P output increases you can see over here. So, the ideal response is generally it increases linearly and then saturates. The saturated output power is denoted by P sat; however, this is the ideal characteristic, but this is the practical characteristics ok. So, now this particular exponential term can be represented in this particular form here. So, P out is given by this particular expression.

Let me take a few cases just to show that this particular equation is right. So, when P input is small in this particular region, so let us see what happens in this particular region. So, we can say that for small x e to the power x is given by approximately 1 plus x. So, now let us simplify this particular thing for small p input. So, P out comes as it is this is p saturated 1 minus so exponential which is e to the power x is now equal to 1 plus x. So, this exponential term now comes out to be 1 minus x which is this particular term over here. So, you can see that 1 minus 1 will get cancel and P sat, P sat will get cancel this comes out to be G times P input. And this is obvious in the sense that this is P input, this is P output over here, as P input increases, P output increases linearly with the gain of G.

Let us see what happens in the extreme case when P in is very large. So, for very large P in let us say P in tending towards infinity what will happen e to the power this term is getting towards infinity. So, e to the power minus infinity is equal to 0. So, 1 minus 0 will be 1. So, P out is equal to P saturated. So, I have just confirmed this particular expression for two extreme cases; when P in is very small and when P in is very large.

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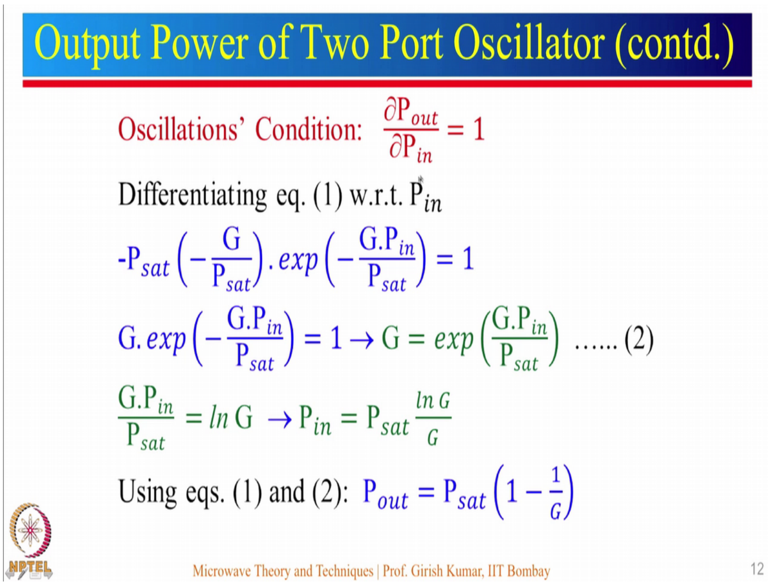

Now, let us see how we can do the derivation for oscillation condition. So, what is the oscillation condition, this is rate of change of the output divided by rate of change in the input should be equal to 1. Now, you might wonder from where this particular thing has come, we talked about A beta equal to 1. In reality just think about, let us say we have a this particular oscillator block. So, what happens whatever is the P out and then let us a part of that is going as a P input.

So, what is important is for sustained oscillation, the rate of change in the P output should be same as rate of change in the P input. So, we put this oscillation condition to do the derivation. So, let us differentiate equation 1 with respect to P input. So, let just look at the expression over here if we do the derivation with respect to P input over here, you can say this is the constant term and this is the term which is coming over here. So, the derivation of that is given by the term over here.

So, you can see minus P sat comes as it is, this is the term which corresponds to the coefficient of P input and this is coming as it is ok. So, this should be equal to 1. Now, we need to simplify this particular expression. So, just follow these steps we will get equation 2 G is given by this particular expression and then we simplify further to find the expression for P in and then using equations 1 and 2, we can find out the expression of P out equal to P saturated multiplied by 1 minus 1 G, so from here now you want to find out what is the maximum oscillator power output.

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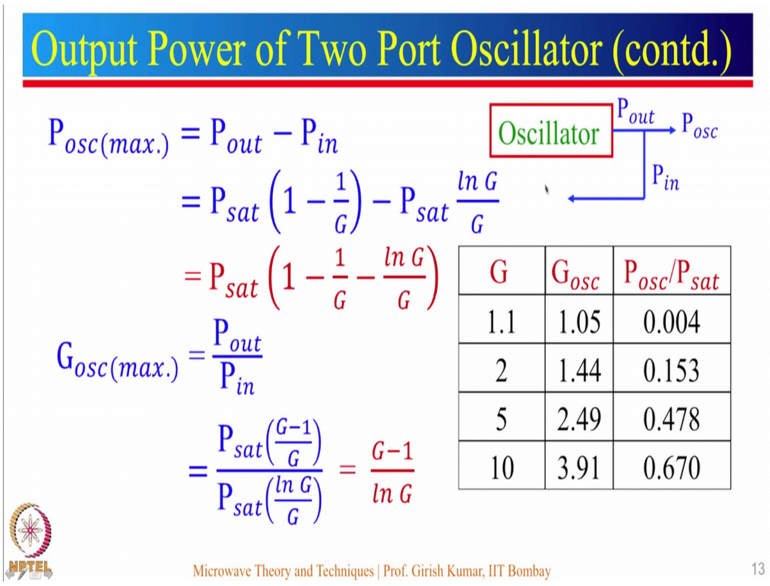

So, oscillator is shown in the block over here. So, this is the P out of the oscillator, but part of that is going back as P input. So, this is the net oscillator power output which can be written as P out minus P in. So, P oscillator maximum is P out minus P in why I have put the term maximum over here, because we are doing the derivation for the situation when loop gain has become equal to 1; that means, rate of change of P out with respect to P in has become equal to 1.

So, we substitute the different values of P out and P in over here and then simplify. So, this is the expression for P oscillator maximum, this is the same expression as I had shown in the beginning; from here lets also find out what is the value of G oscillator maximum, please remember this value will always be less than G, why in the beginning loop gain is greater than 1, since loop gain is greater than 1 signal amplitude is increasing, but as the amplitude increases gain starts reducing a condition comes when output becomes constant.

So, we are trying to find out what is the gain at that particular point when the oscillations are sustained. So, G oscillator maximum is now given by P out divided by P in. So, we substitute the values of P out and P in this is the expression for G oscillator maximum. So, I have actually taken a few cases of G, so 1.1, 2, 5, 10 then let us find out G oscillator value using this particular equation. So, one can actually see that corresponding to 1.1 this is 1.05 G oscillator is increasing. So, for G equal to 10 it comes out to be 3.91.

Now let us see: what is the value of P oscillator. So, P oscillator divided by P saturated is given by this particular expression and these are the values. Now, you can see that if gain is just equal to 1.1: what is the oscillator power output it is very very small, it is just 0.004 of P saturated value. Suppose if the amplifier has a saturated value of let us say 10 dBm, you can say that this is very very small number. If gain is equal to 10, in that particular case you can see that this is almost two-third of the P saturated value. Of course, if you take gain equal to 20, you will get a larger value of P oscillator. So, you do the calculation and find out what will be the maximum oscillator power.

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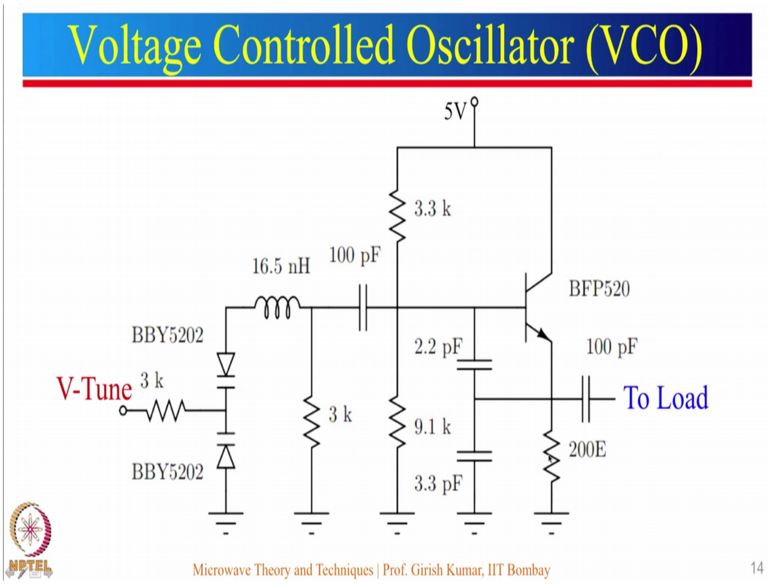

Now, let me give you a practical example of oscillator, here I have shown you a voltage controlled oscillator. So, what is voltage controlled oscillator basically you can control the output frequency by varying the input voltage. So, let me go step by step. So, here is the V-Tune, so by changing this particular voltage, we can change the output frequency, but now let us see step by step. So, first please look at only this particular portion ok, this is actually a DC biasing circuit for this particular transistor and the transistor which we have used here is BFP 520 corresponding to this dc voltage you can find out what is the voltage at this particular point.

And then you can approximately assume this drop to be about 0.3 volt, so that will give the dc voltage over here. I just want to mention the resistor values are 3.3 kilo ohm, 9.1 kilo ohm and this is actually 200 ohm, so that sets the biasing condition ok. Now, these are basically the coupling capacitor, so for this particular amplifier this acts as a biasing network. You just think about from here to here, this is an amplifier and part of the output is fed back to the input side.

Now, you can see that we have used the capacitors over here and not resistors; if you use resistors, it will never ever become oscillator. So, this feedback ratio ensures that A beta is greater than 1 to start the oscillation. Now, let just move to this side here. So, what we have we have an inductor and then these are varactor diodes. Why we have used varactor diodes, basically we have used varactor diodes for the property that as the biasing voltage in this case tune voltage changes, their effective capacitance changes. And by changing the effective capacitance, we can change the resonance frequency of the oscillator.

So, now let us see how the oscillation frequency can be determined. So, now when can see that this is a DC voltage; so, for AC signal this will act as a short circuit 3 k resistor is large, so we can assume this is to be approximately open circuited, similarly this resistor is also large. Now, let us see what is the equivalent capacitance seen by this particular inductor. So, you can see that equivalent capacitance seen by this inductor is series capacitance of this varactor diode then series capacitance of this varactor diode, ground over here is common to this particular thing, then another series capacitance over here, another series capacitance over here.

Here an approximation is being made that we are neglecting the current over here and neglecting the current over here; however, there will be a small effect of that, but we can approximately find out the resonance frequency of this particular circuit as omega 0 equal to 1 by square root L C, L is 16.5 nano Henry over here; and C equivalent will be this capacitance, in series with this capacitance, in series with this capacitance, in series with this particular capacitance and that will give you approximate value of the resonance frequency. There may be small error in calculating the resonance frequency using this approximation, but you will see that it is within a few percentage. So, now by changing this particular voltage one changes the capacitance hence equivalent capacitance changes at that results in to change in the output frequency. So, let us see the response of this particular circuit.

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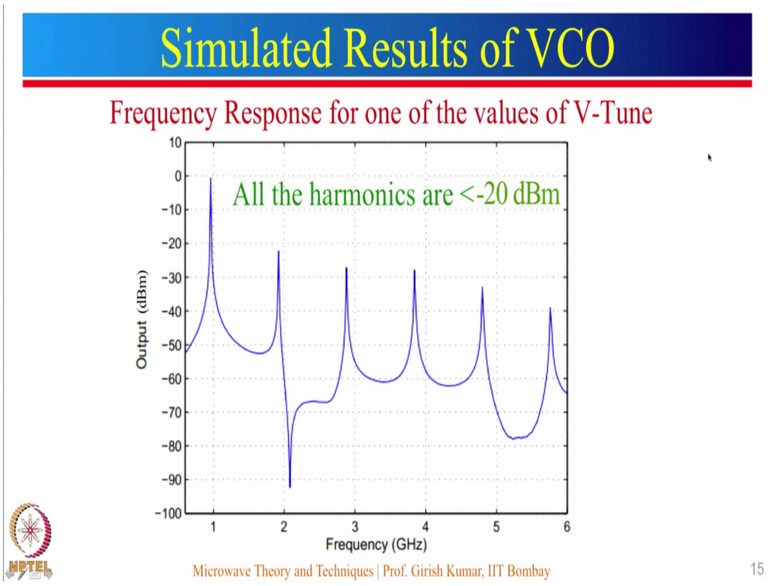

So, we have done the simulation for one of the values of V-Tune, you can say that the resonance frequency is slightly less than 1 gigahertz, just to tell you that we had used this particular circuit to design different types of oscillators ok, we had actually designed these things for jamming mobile phones. So, we designed it for CDMA jamming or you can say GSM 900 jamming or even GSM 800 jamming even Wi-Fi jamming also.

So, what you do it is simply change the values of inductor and for higher frequency we also reduce the value of the feedback capacitor; so that higher frequency can be realized, but let us see now for this particular circuit, you can see the output here is slightly less than 1 gigahertz and these are all the harmonics. So, this you can say is second harmonic, third harmonic, fourth harmonic, fifth harmonic, sixth harmonic, but what is important is all the harmonics are less than 20 db. So, you can see that corresponding to this normalize value of 0 dBm, all these are less than minus 20 dBm which will give rise to very small distortion in the output sinusoidal waveform.

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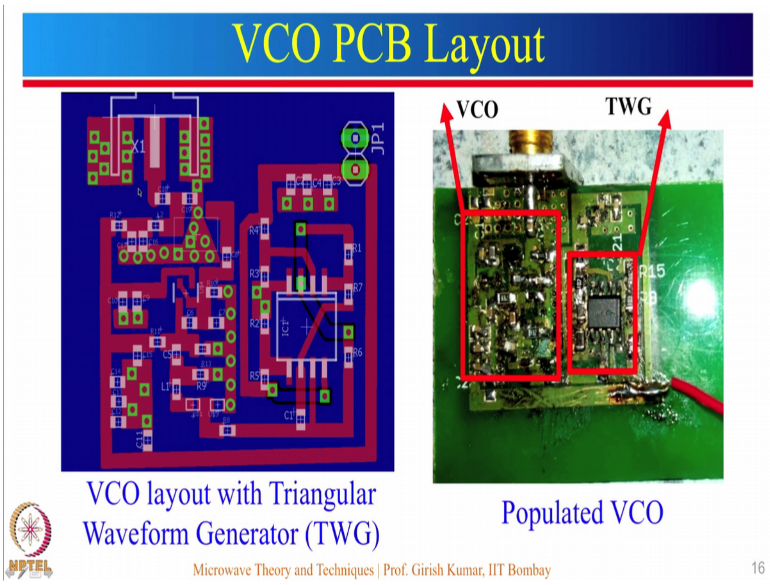

So, let me now show you the realized PCB, so this is that VCO circuit which I had shown you, this is the V-tuned circuit or you can say triangular waveform generator. Triangular waveform generation can be realized either using by triple five timer or by using Op-amp circuit. So, this is the populated circuits. So, you can see that all the components have been soldered over here, but I just want to mention over here quick things. So, this is where the connector you can see connected over here; so that is the centre pin, so basically this is the output, and this entire circuit represents the VCO design at this entire particular portion is for the triangular waveform generator circuit.

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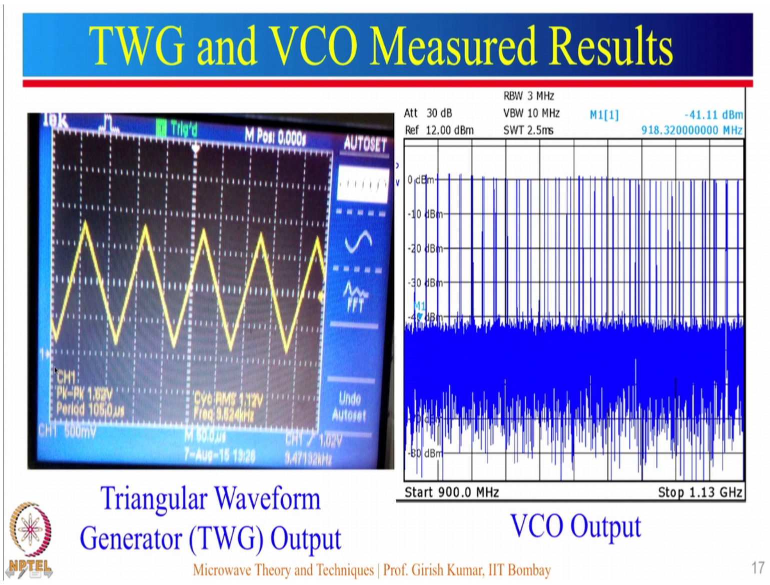

So, this is the response of the triangular waveform generator, you can see that there is a nice triangular waveform output. This is the response of the VCO output, since the input voltage is changing in the triangular fashion, you can see that the output frequency is also changing, this is the response shown on the spectrum analyzer, you can see that various signals are there which correspond to different amplitudes of the triangular input waveform. You can see over here that this level is very small; it is of the order of 0 dBm. So, in the next slide I am going to show you where we have integrated an amplifier.

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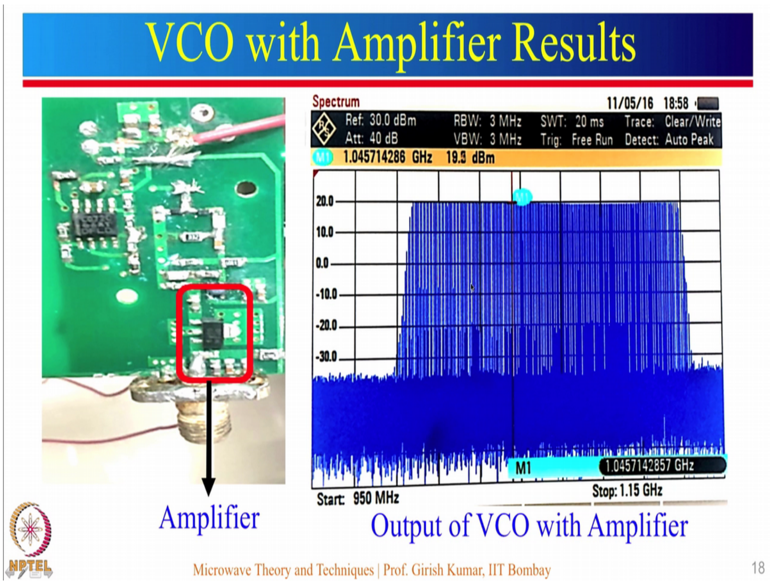

So, an amplifier has been integrated in that particular VCO circuit. So, now you can see the net output of VCO with amplifier you can say that the response is fairly stable and output is about 20 dBm and you can see very nice response of the VCO over this particular band.

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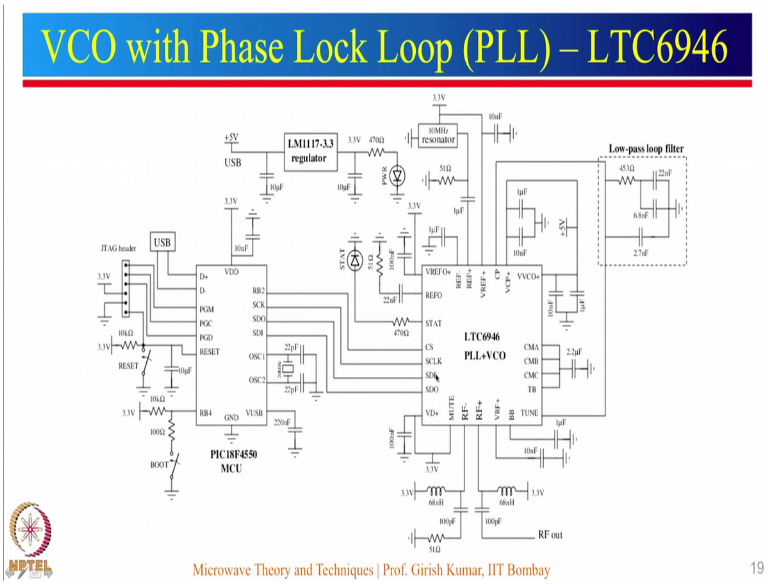

Now, let me show you VCO with phase lock loop and the IC which we have use is LTC6946. In fact, this particular IC has PLL plus VCO built into it ok. In fact, there are many things in this particular IC, so I do recommend that please see the data sheet of this particular IC and this IC is driven by a microcontroller. Of course, here we have used pic microcontroller, but you can use any other microcontroller.

So, basically microcontroller will give input to this particular device, so that you can change the output frequency. In fact, we have used this particular circuit to design a VCO which works from 700 megahertz till 2600 megahertz. So, it is a very broadband VCO from 700 megahertz to 2600 megahertz. Of course, you can design for larger frequency values also ok.

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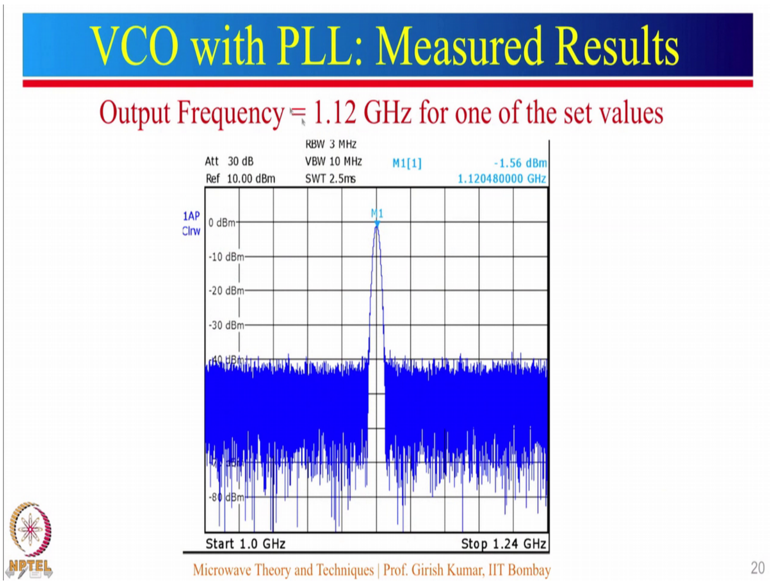

So, let me show you the response for one of the settings. So, output frequency is approximately 1.12 gigahertz for one of the set value. You can see that this is the response shown on the spectrum analyzer. You can see that the output has a magnitude of 0 dBm just to refresh your memory 0 dBm corresponds to 1 milliwatt of power. And this is nothing, but noise floor the simple IC can be designed to generate desired frequency output.

Just to summarize we saw different configurations for oscillator when the devices un stable, in that particular case your draw the input stability circle and do the design. If the device is stable in that particular case we use either series feed network or shunt feed network. After that I took a practical example of a VCO which use varactor diodes and transistor. And we use capacitive feed network to design the VCO. So, we had use that VCO for different bands of mobile phone. After that we look at a broadband VCO design using PLL. In the next lecture, we will see application of oscillator for the design of mixer. Next few lectures on mixer will be taken by my Ph.D., student Vinay.

So, thank you very much. Bye.