Analog Circuits
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Lecture-23
Oscillators

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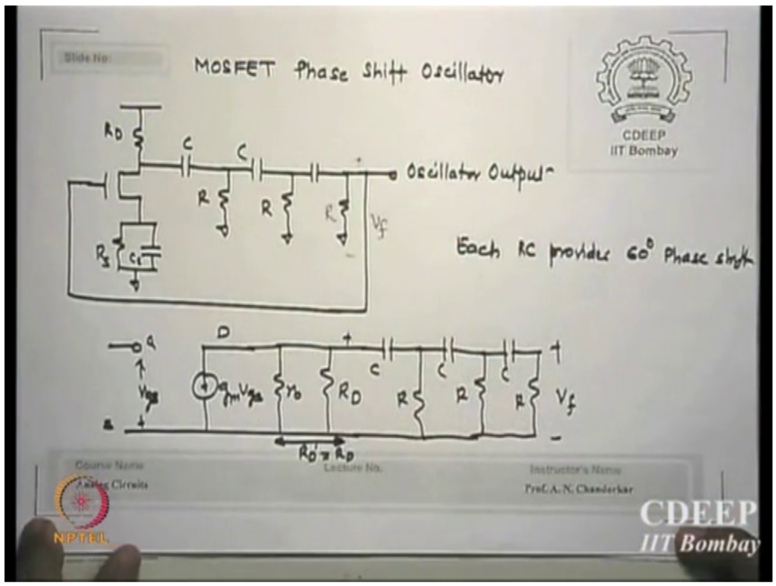

So, we start with the oscillators quickly today last time I was talking of in oscillations and I gave an criteria which is called Barkhausen criterion. It says the loop gain should have a value equal to 1 either it should have a magnitude equal to 1 and phase accordingly or phase imaginary quantity may be 0 and only real TJ Omega may be only real value if that occurs we say that oscillations will start or sustained.

The first of that version I said that you have a phase shift oscillator basically you want 180 degree phase shift from the network feedback Network and we need 180 will come from the transistor. So, this is the first of the series of oscillators which we use this is for discrete transistor. This RS CS is of course a bias Network so just forget about it this is the load and I have 3 RC ladders Network kept here and the output of the final on CR is fed back to the gate of the transistor.

So, obviously you can see the voltage drop across this R which is nothing but this is remember this is my V0 and this is my VF the whatever is voltage here is returned to this. Now the criteria for oscillation should be that this RC, CR, CR, CR should each should give you 60 degree phase shift that correct. so, three of them will give how much 180 degree phase shift 180 will come from transistor so total feedback will be 360 degree in phase is that correct, in phase.

So, if I want if the return is in phase modulation bits and that is what the circuit is about. Please remember drop across this R is VF, so this is the equivalent circuit gmvgs, vgs is the gate and right now I assume which is very pair in case of MOSFET that the input impedance of MOSFET is infinite. So, it is not really infinite but it is good enough for infinite. R0 is the output resistance RD is the load which I kept and I call it R this is given inside Sedra Smith.

So nothing great about R0 parallel RS the guy I call RD - and then this is a phase shift network. How do I adjust 60 degrees for NECR network the impedance of SCR is how much 1 upon CS + R the tan inverse imagining by real value is the phase. So, adjust your RC value so that it gives you up is off 60 degree is that okay. The point just simple RC and you find that it will give you a phase of imaginary tan inverse or tan inverse real.

And if I put R secretly I can get at a frequency of oscillation this value should be equal to 60 degree and if that 60, 60, 60 the 10 is 180 will be the, this. So, I put an equivalent circuit of this which is very simple nothing great we are done N times okay so you do not need me to say how it is done.

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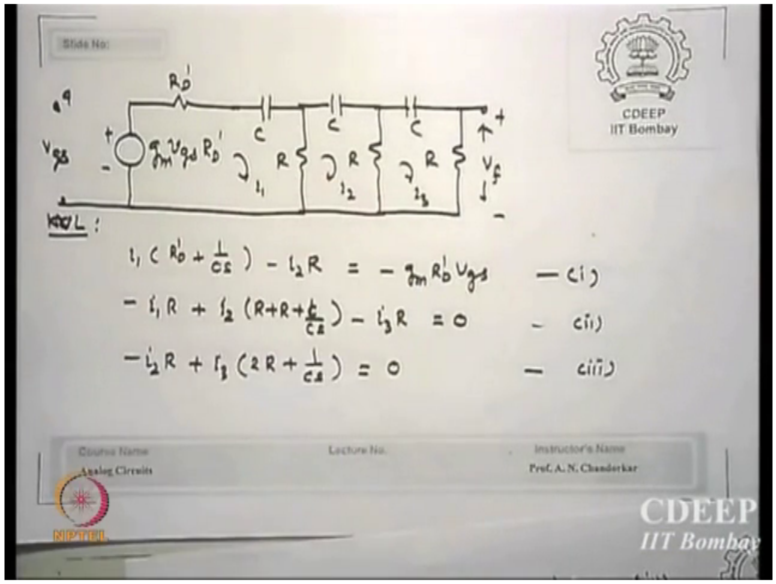

And I solve this without I will not show you all of it I use Kirchhoff's law I1current in this loop I2 in this I3 in this wrote three equations for three loops okay. For this I1 times RD - + 1 upon CS - I - R is gm RD - we get the - sign this is first for this loop then for the second loop this equation then for the third loop this equation that okay. Simple Kirchhoff's law nothing very serious this is a KVL going to be done.

At every move currents are shown we write three equations; please remember I1 flows in this but I2 flows in this opposite direction that is why the signs this you are done in your basic circuit courses, so there is nothing great about. As I say there is no source resistance there is that okay. So, if I write these three equations and you need not it is given inside Sedra Smith you can always and this is a trivial network at the end of the course if you cannot solve this network we will have a problem of the course itself okay.

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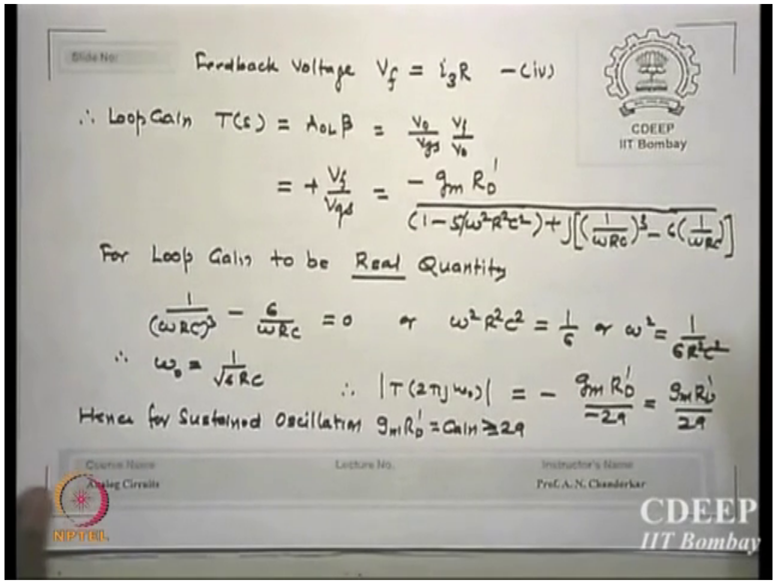

Then the feedback voltage as I already said the drop across the final R you can see from this circuit sorry. The current in this I3 R is essentially the feedback I3 R essentially is the feedback voltage. So, it is I3 R is VF we also know the loop gain this is a feedback circuit. So, loop gain is AOL times beta which can be written as V0 by Vgs into VF by V0 or essentially it is VF by Vgs I substituted all that equation 3, 4 equations which are used for 4 equations are gave you.

Find values corresponding to all this and you get this you get this which can write. Now the loop gain Ts loop gain is also called return ratio okay, some books. So, it is VF by Vgs which is - gm RD - upon Phi 1 - something sum + J time on upon Omega RC cube - 6 times 1 upon Omega RC and I have substitute Re S = j omega substituted s = j omega. Now what is the Barkhausen criterion we said that the real value being 1 it satisfy all of it okay.

So, what does mean if the real value has to be 1 the imaginary quantity must be 0 is that correct. The real part is magnitude wise one so the other part must be 0 and if that occurs the condition of under that condition to oscillate 1 upon this term should be 0 which gives me a value of Omega 0 as 1 upon root 6 RC. So, can I now fix my frequency by a proper choice of RC, I have my oscillating frequency which is 1 upon root 6 1 into RC.

Now if I take the magnitude which has to be how much 1, so I use the magnitude part gm upon RD - and substitute this Omega 0 back in this I get a term gm RD - upon 29 substitute Omega 0 here and get transfer function value at Omega 0 magnitude is gm RD - by - 29 substitute here Omega 0 and get transfer value at Omega 0 by RC 6 will come from here so you will get 29. Now this; so what is the condition of oscillations to start that gain should be larger than gmRD dash is actually a physical gain of an amplifier.

So, that should be larger than 29 or equal to 29 slightly about 29, so isolation can start and be sustained that okay, is that ok; how do I adjust my gm by choice of bias current okay the DC or I can also if I am on the integrated circuit I can also choose W by L, I can choose the size of the transistors. In this specific case we say only bias current can. So, I just your DC Network forget whatever gm you want loads also you can adjust because you know RD dash will decide the gain okay so you can adjust that value.

As long as this value meets 29 choice of current what do you do you may be given RD dash for example from there you will calculate gm and for that gm find what is the bias current and go back and bias it properly is that okay, the method of design opposite. Given cache in it this must meet this go back and find gm and therefore I, that and then given that RC's you choose this will be your facility is that okay.

So, this is the basic phase shift oscillator which is normally only used in discrete why I say not used so much in the their circuits but I once said realizing a R on a silicon is large area problem okay. So, no one wants to use RC networks as far as possible I do not say never use it as far as possible. So, these are the issues which you all should know what we are talking about there are other oscillators of interest will quickly go through some of them.

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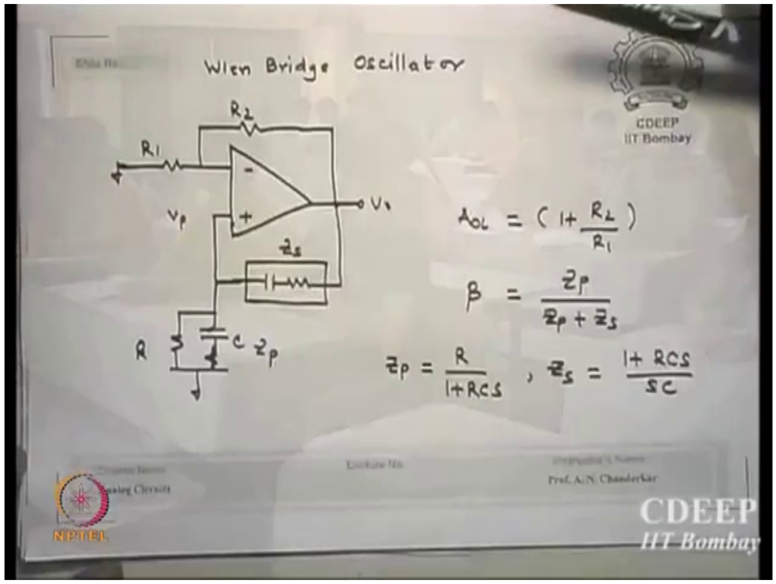

The very famous oscillator credited to Mr. Wien which is the Wien Bridge Oscillator it consists of an OPAMP and what is this part is called R1 R2 part which feedback is this negative feedback. So, please remember one important factor which are not stated very obviously to you they are both possible feedbacks are available negative as well as positive and the balance of the two will decide whether it will grow or it will done.

If were stronger and negative feedback what will happen it will damp out or fix a value okay if it is otherwise it may grow and if you have both of them together we may I just went to a select that is exactly what being tried here. I have a R1 R2 as the open loop gain is 1 upon; since it is a non-inverting amplifier kind. So, AOL is 1 upon R2 by R1 and the return voltage is something here okay which is written to be +.

So, how so that are you how do you calculate let us say there is two impedance as shown here one is called series resistor a series impedance R and C in series the other is parallel impedance which is R parallel C okay straight for this is in series this is in parallel. So, ZP upon ZP + ZS is essentially VP while V0 which is your feedback factor is that okay. This voltage by this voltage is essentially the ratio of this upon this + this.

So, how much is ZP parallel combination of the R and C so R upon 1 + RCS this is series so ZS is 1 + RCS by S is that okay. I can substitute this in the beta factor is that ok, what I am going to do; what is the condition I am looking for that the imaginary value be 0 and the real value be 1 to get a Barkhausen criterion satisfied. So, I now substitute this here get AO beta what is the AO beta the loop gain. And in the loop gain I will find real, real value and I know it would be real one at that frequency and phase imaginary quantity be 0 same procedures is always followed.

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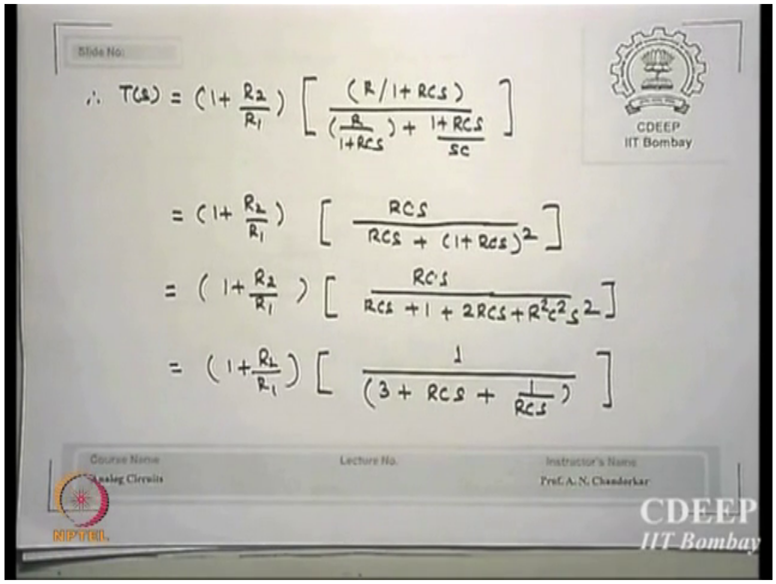

So, I substituted this ZP upon ZP + S into 1 + R2 by R1 (FL) I write so many steps you can write final step please remember I write because I actually keep solving on the paper I do not actual copy from anywhere. So, I just have to do steps rather I cannot get this expedition. So, when I substituted all of this correctly RCS to RCS, I get a term and if I divide by RCS I get four sorry that function in 1 upon 3 RCS + 1 upon R seems very straightforward function is obtained.

Then what do I do calculate TJ Omega and then make imaginary quantity 0 and the magnitude at that frequency where this is 0, I get the TJ Omega 0 is unity and fall for both of them that is what I did, do not fall; I mean there is nothing really great I did all that I substituted and got the value.

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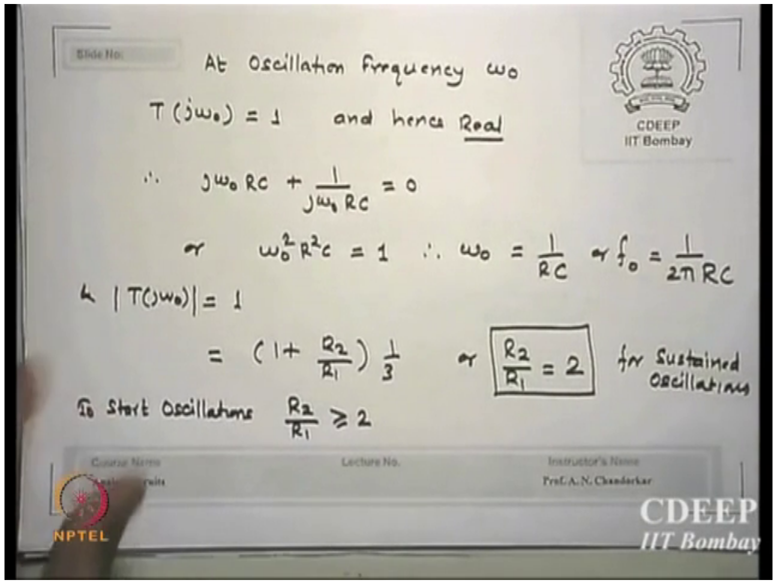

From Barkhausen criteria 3jOmega should be 1 and hence real and they imagined be 0, so j Omega 0 RC upon + 1 upon j omega 0 RC = 0 or Omega 0 square RC R square C square = 1, so Omega 0 is 1 upon RC or the frequency of oscillation is 1 upon 2 Pi RC is that ok so adjusting R and C I can adjust the frequency is that okay. An integrated circuit how could I have realized GR by what method. I just did last time there is a filter I created using; any time I want a pole is 1 upon RC put in OPAMPS.

But how do I get that by getting gm 1 upon R is gm and gm can be attained by what way operational transconductance amplifier OTAs, OTAs give you constant gm for a proportional to current. So, use this is again same gm upon C. So, it is like same thing which we did if I am realizing on a chip I will prefer to use OTA there to create gm vandals okay. So, if I substitute this Omega 0 the RC in this function.

I get 1 + R2 by R1 1 upon 3 = 1 which gives me a condition that R2 by R1 should be equal to 1 to start it should be slightly more than 1 because initially noise or some extra value has to be provided. So, choose value of R2 by R1 that is what is the gain I am talking 3 that is the non-inverting game is A value is 3, if I adjust that I will get oscillations at what frequency 1 upon 2 Pi RC. So, it is a procedure is identical look for a circuit find it is Tj Omega by AOL and beta that is why we did enough work on feedback.

Why I spend so much time because that is the way all circuits can be easily implemented. I also yes phase is 180 degree see what I say at what is Barkhausen two criteria one is it should be -1 as a value which means magnitude 1 and phase 1 it is that clear, if you look at that your initial Barkhausen criteria we said the magnitude be 1 and phase be 1, it because Tj Omega - 1 we wanted but I alternately I suggest if the real value exists at that frequency the imagination be 0 that will give the same value.

So, at that frequency yes the impedance is real value that is exactly oscillations are all imaginary quantities do not leave the; and lead to oscillations. This is the only procedure I showed you either this or that Barkhausen criterion it satisfies I am using the second criteria most of the time okay. (FL) So, we are now beam bridge oscillator we are then phase shift or senators another oscillator yes yeah this is all serious idle oscillators yeah but just think of it the oscillators which we are right now talking are all sinusoidal oscillators.

Yeah yes you are perfect you are actually employing this circuit and give a small noise signal of any frequency okay and then you verify that fundamental frequency will come as 1 upon RC is that correct. What I said, so it is not that I am talking because I wish to talk these are sinusoidal oscillators and they will give means insights. Any noise which is random which may have one fundamental out of that we will actually lead to that value at that point clear.

You want to see non sinusoidal yes they will be coming soon you are interested in both yes we will be interested in where do we interest we are get interest in where do we interested in digital hardware I am looking for square waves okay. So, yes I really like to see what is the sinusoidal to non sinusoidal conversions very good.

Another factor which is of interest other than the RCO see what is the problem with RC oscillator I say if I want to increase very high frequencies what should be a constraint on RN C they should be very small higher the frequency if you are using your discrete oscillator or discrete functions in the lab to get a very low value of R have you any times its tolerance. You see go and look for say less than a ohm register probably our lab does not have a resistor which are typical than ohms.

Now these tolerances are not less than 10 okay so the reasonable value of tolerance less than 1 percent it is very good and therefore one will not like to use normal RC oscillators for higher frequencies is that clear to you. It is not that I cannot I can certainly reduce our and get higher frequencies but one of the biggest thing what RC oscillators were giving me I have a range of RNC products okay and I can have number of frequency range I can attain.

For example just to given that idea C can be a variable, how can make C variables variable capacitor how do I get it (FL)

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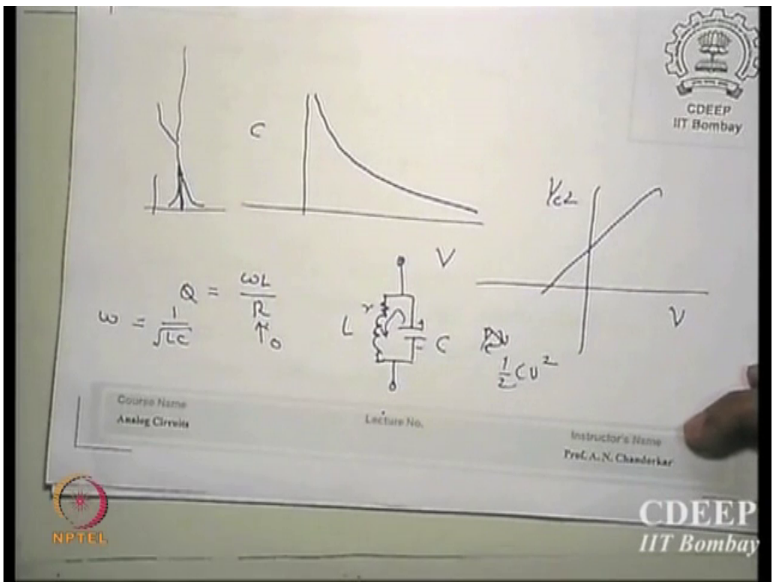

So, it acts like a variable capacitor, so if I have a R and variable capacitor their only guarantee you must say that it please you have a small capacitance already existing and add to this variable capacitor (FL) no explanation given to you at no time circuit or same way R should always be broken into two parts okay. Let us say does not shot anytime any circuit okay (FL) is that clear to you. So, there are caches in lab which probably you do not use because you realize that; (FL)

So, that is the way life is but anyway so I can use varieties of characters and can get a range of RC's. What will be these oscillators called? If I have C variable with voltage and frequency will be decided by 1 upon RC, C variable V (FL) voltage, these are called voltage controlled oscillators VCO's okay. So, these are essentially will come back to be VCO better. That is what I am finding so.

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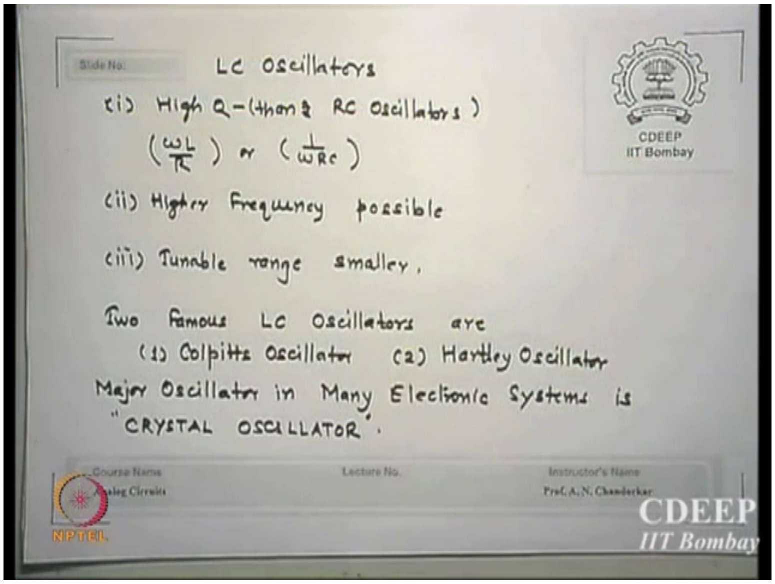

This event we are always thinking R and R and R so why not look for else. So, we say we can use inductor capacitor combination to realize an oscillator and these are called LC oscillator. There are few things which are relevant to them compared to RC oscillators, LC oscillators are higher Q (FL) quality factor in terms of math's (FL) Omega L by R, R is the series resistance of inductor is that correct.

This is something we are saying okay before we go ahead let me show you what I am really talking about. This is essentially called a tank circuit or a resonant circuit inductance parallel to a capacitor acts like a resonator or tank circuit. How does it work if inductance is ideal and capacitor is ideal? Initially let us say it has some noise or something picks up something charged on this that half CV square sorry half CV square will be the energy stored.

If I apply some voltage across this half CV square energy will be stored on the capacitor, remove the voltage then it will discharge it through inductor and it will be C half Li square energy here and since it is no dissipation going on this energy will be dissipated back into capacitor and keep doing this infinite times okay. This is therefore called resonant resonance and the frequency by creating pendants for this get 1 upon LC root LC is the frequency at which this will resonant.

Now in real life there is nothing called ideal inductance? So, if there is a small r situated in series to an inductor then IR will be able to some drop potential drop across which means there will be loss of energy dissipated in the resistor. So, what will happen every time you charge it back some energy will be lost for as if oscillation may start damping down okay? So, our; I this is essentially we say energy dissipation factor is called the quality.

And therefore if R is 0 which is ideal how much is the Q for this, infinite so larger the Q better is the time circuit that means the frequency response will be something like this sharper response at a given frequency is that correct I really where it should be you go to infinite ok at that frequency only it should have value other places no matter. But that may not occur in your life it may have some narrow band in which to rise and fall okay.

And the maximum will occur at does not hit in frequency, so is that point clear to you. So, if LC tank circuit or LC resonator circuit is the best way to create oscillations the only problem as I said that since going to lose some energy it must be replenished all that we are saying is replenish, replenishment of lost energy. And if that happens oscillation will be sustained is that clear oscillations will be sustained. (FL) is that clear to you.

This is the trick which we following all LC oscillators. So, that is what I was saying to you it has a very high Q 1 upon Omega RC Omega L by odd and therefore since inductance worth varies from very small to very high. Inductance can be as low as femto henries' or at least nano henries are below the Cohen entries (FL) what should be the type of inductance I should use type means inductance is generally wire bound okay.

So, wire (FL) thicker wire, is that correct. So, if you are using a thicker wire area is higher obviously it is resistance is lower. So, if you are seen a transformer you see how the wires they actually wound okay because of very low inductance if they want their okay. So, because inductance values can be minimized and capacitance for a diode or any other can be redo at least go to femto farad we are seen in mass transistors how much capacitance I could go down up to femtofarad .

So, I have very large frequency operation possible with LC oscillators. So, is that clear why not RC people always ask this question that when RC was doing so great a job, so simple a job, why are we looking for an NC Network at all. The reason is obviously at much higher frequency of operation the problem is low dissipations and very high frequency operation. The only difficulty it will give it at one frequency it will operate tank circuit.

Which what it means is bandwidth related react we are up to which it can give frequency will be limited in RC your wide range of frequencies attendance is that clear that is the advantage which RC's provide over LC therefore we said tunability is very small but other than matter. It gives a very high frequency performance where do you think we need high proficiencies mobiles we are working on say whatever 2G, 3G or what I 890 megahertz and above.

If you are working on Bluetooth we are working on 2 to 4 gigahertz C bands. So, if you are working on higher people now looking for something C Guard satellite phones. So, we are really looking for very high frequency generations. These are not the only generating different other generators RF4 should teach you what our course. But right now we should say any LC oscillator is therefore used only for constant frequencies, very short frequencies and much higher frequency okay.

There are two very famous LC oscillators in literature they were first made if you are I do not know that you recollect very first talk I showed you some diodes made out of vacuum tubes lee deforest vacuum diode huge 6-inch tube. First oscillator was made using a big tube so it is not that it is present. But let us see which are these two Colpitts and Hartley oscillator and hardly a very famous oscillator last 70-80 years these are popular.

The other oscillator which is the most important oscillator in every work where we are working right now is a crystal oscillator so is that clear why I am clubbing this with NZ obviously I believe that crystal equivalence is like a LC network this is my assumption which I can clue but not in this course okay.

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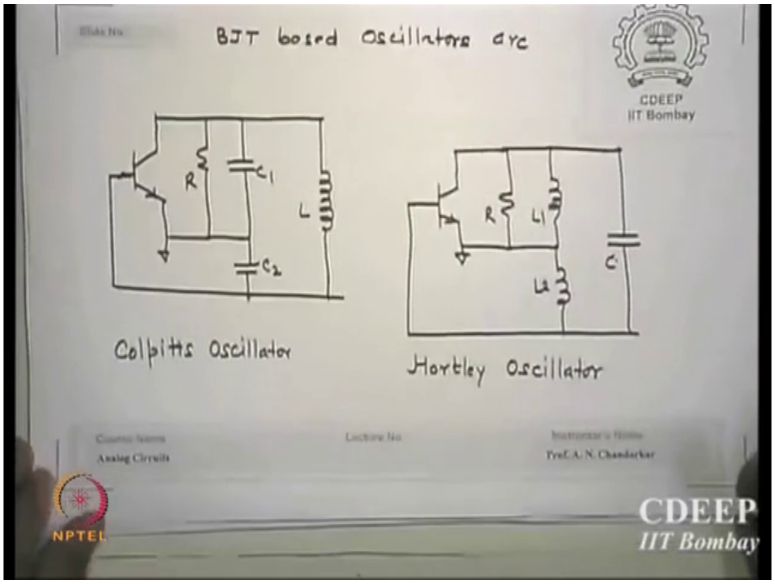

So, let us say typical BJT based oscillator and then I will show you an equivalent of masculinity I just show you the circuit diagram what is Colpitts it is say okay you have a transistor how much phase it will give me 180 degree. This is my load across this is a AC equivalent huh please remember this R is essentially the load is that clear to you R is essential to the load. Then I put a tank circuit across this but I did machine there.

I divided this net capacitance into two parts the center when I ground it and I put this C. So, what is the purpose of this ground in between and what is essentially it is trying to give you, what is this voltage across this we going where (FL) so, this thing too is essentially creating a feedback for you is that okay. This is the net output voltage divided by this is the divider this is the ground potential stick to upon this + this is essentially giving me the feedback factor okay.

So, I am now looking into a transistor + LC network with a load here with a divider to make this I can do just the opposite of Colpitt, what is opposite means (FL) Turing circuit replace L by C this circuit is called Hartley oscillator. You know it is like a derived circuit. (FL) that is what all this circuit is about but that is what you are thinking is okay. If this, work the other should corollary must work for it corresponding system must work for you.

So, a duality here that here have you heard any time this word duality in your physics quotes. So, whole nature is in duality right now matter or waves you know you have your problem duality is there gain in the light okay. (FL)

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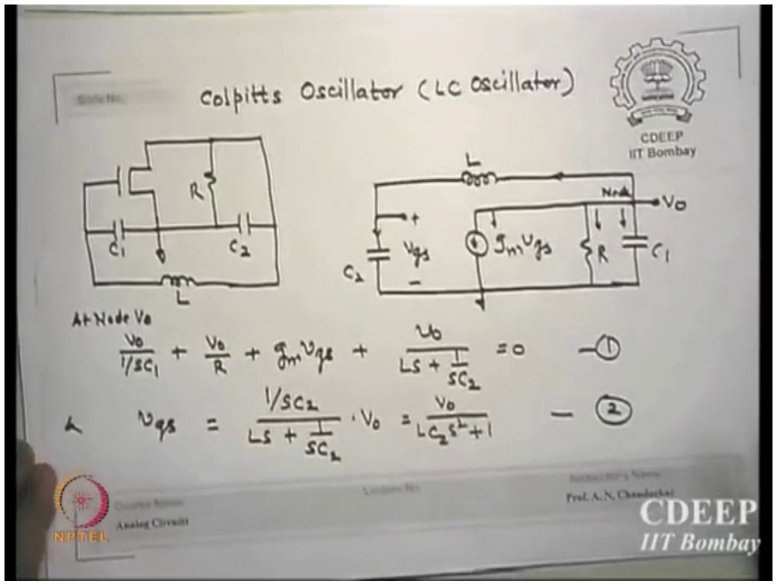

Do not feel very sad about (FL) there is no difference this terminal is same as this terminal so, (FL) please look at it I am now seeing currents at this known V0, gm v gs current in same direction okay V0 upon 1 upon s c1 is another third current or fourth current (FL) is that clear (FL) if you say this then it is V0 upon LS + 1 upon SC2 is the fourth current. All currents should sum up to 0 like it Kirchhoff's law.

So, this is equation one if I want to calculate vgs (FL) this upon LS + 1 upon LC (FL) I think I must be right this should be C2 correct. So, 1 upon SC2 upon LS into V0 is 4 (FL) is that okay substitute this Vgs in the equation 1 and then all terms will be in what V0 terms all terms will be V0 terms okay.

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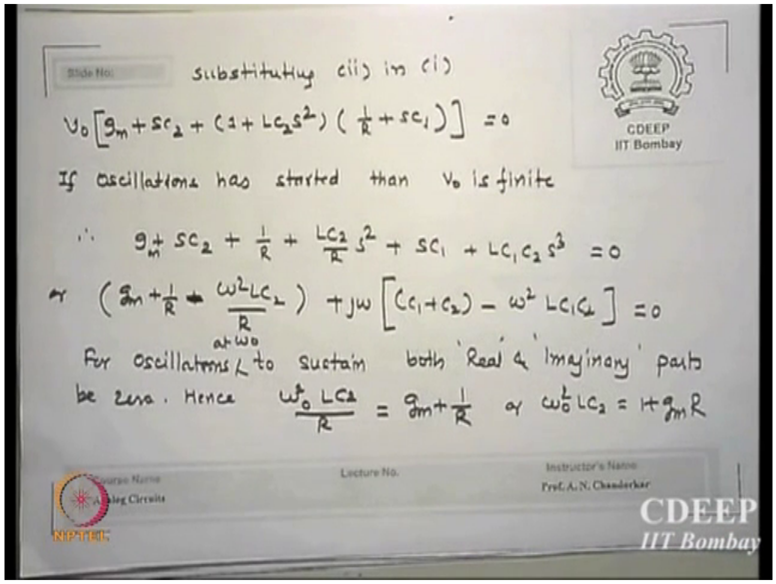

If V0 I just collected the term gm + SC 2 + 1 + LC 2 S square into 1 upon yes they of course you write down I had no objection but I just want to say you these are now quite trivial they are quite trivial because we are just solving Kirchhoff's law and nothing great. You can ask her why (FL) I have to solve to get that expression okay that is the way I am. So, if you collect of course this is given in Sedra Smith book.

So it is nothing really great I just checked latter (FL) now if our solution is to sustain or start V0 (FL) yes if V0 is 0 there are no oscillations in that output 0 (FL) no oscillation. So, if V0 has to be finite then and if this equation has to be correct then the term inside the bracket must be 0 okay, if I substitute again substitute S = j omega real value + imaginary value 0 (FL) real value should be 1 and imaginary value be equal to 0 okay (FL)

So, I got Omega 0 square LC 2 upon R = sorry (FL) or this all this will give me Omega 0 (FL) so, gm + 1 upon R is Omega 0 Square and C2 by R or to say Omega 0 (FL) we will substitute here this = 1 ok real value should be equal to 1. This is my real value okay (FL) how to get frequency Omega 0 by equating imaginary quantity to; I just made this 0 and this 1 for Barkhausen criterion I do not make a 0 okay. At oscillating frequency the magnet real part should be 1 an imaginary part be 0 sustained oscillation gamma (FL)

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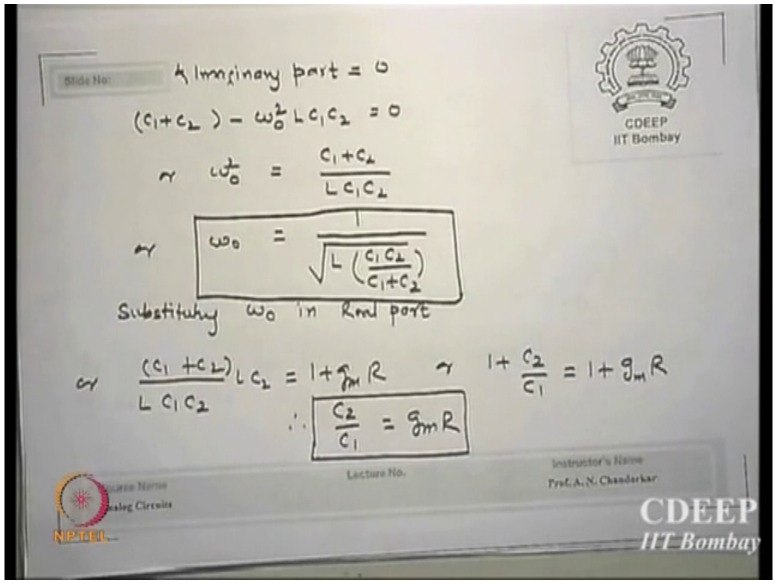

1 upon root L C1 C2 upon C1 + C2 is omega 0 (FL) last function may substitute (FL) so I got a ratio of C2 by C1 = gmR as long as your gmR has a value of C2 by C1 okay slightly greater than C2 by C1 that oscillator Colpitts oscillator will oscillate at 1 upon root L C1 C2 upon C1 + C2 (FL) C2 by C1 you are going to adjust you are going to get a frequency from here a value of C2 by C1.

Assume one capacitor and get the second one substitute here and you can get frequency of oscillation (FL) given operating frequency get the ratio of C1 C2 from here come back substitute here and say okay what should be gm to sustain this remains is that clear. This is design why it is called design I am not interested in gm value R value I am interested should oscillate at 100 megahertz or 800 megahertz that is what I will say.

So, what do I get I go this expression evaluate C1 by C2 come here and find what gm R I should use to have our solutions, gm I will adjust my miles is that okay is the design clear I am always telling you what is the design? Design is just the opposite in that sense output will be told to you this is what I want come back and find what should lead to this. This is how we do in designs. (FL) inductance has to assume or I will be giving you typically inductance as per higher frequency should be less than 1 nano Henry less than a typical value.

But the why should less than 1 nano henry can you think of it (FL) I think inductance should be less than in a nano henries typically 0.8, 0.6 nano henries are used even lower can be used for higher frequencies, is that correct. So, length typically inductances are decided in chip by the wire which wire the bonding (FL) we do not even put an inductance okay. This is what the game is all for our design (FL)

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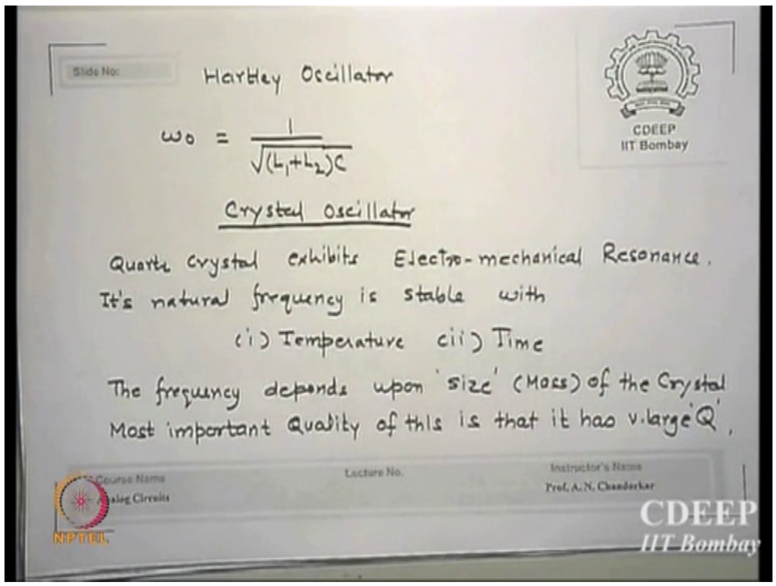

1 upon L1 + L2 C under root of that will be the Hartley frequency is that point clear to you (FL) okay so, we already said that popular LC oscillators are discussed one using Hartley technique or one using Colpitts method the other is using this (FL) which are essentially RC oscillators okay. (FL) we all use and I think all of you have used. The last oscillator which we use very often from this kind you see litters is called Crystal oscillators.

Normally crystals which we use are quartz crystal (FL) the frequency depends on the mass of the crystal or the size of the crystal. Larger mass (FL) what is the property of crystal it follows a electronic mechanical resonance (FL) say piezoelectric effect if you apply electric field to such materials then it provides mechanical vibrations or vice versa this is also doable piezoelectricity is the word which we use there.

So, what they do is let me pick up a quartz crystal with solder contacts on that and advantage of this crystal oscillator see this is temperature independent to great extent it is not correct all (FL) but normal operating range is 150 degree to - 55 degree centigrade (FL) so this is temperature independent. Time stable means (FL) so it is time stable so that is why it is used extensively but what is the difficulty with this it is non tunable in its specific frequency oscillator (FL) now funny part the crystal which are focused on a certain I am going to show you now does not really work the way we thought okay.

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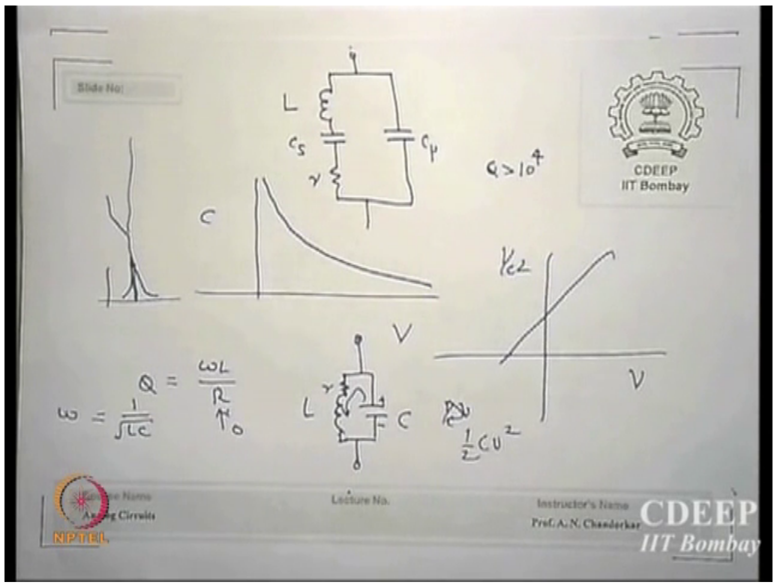

Crystal oscillator is like a tank circuit okay the only difference between this circuit and the equivalence is something different it has an inductance it has a series capacitance CS it has a small series resistance R and it has a parallel capacitance LCF is this is equivalent circuit of a custom; I will come back to it but just to show you. So, this is the resistance so Q (FL) typically crystal scale Q (FL) what does that mean R is practically.

You know Omega L by R is 10 to power 4 which means R is very, very small or negligible. So, tank circuit (FL) LCS shunted by CP is the equivalent circuits of a crystal are is present but as I said normally queues of all quartz crystals are more than 10 to power 4. So, R is neglected in all analysis problem (FL) okay. So, if I say, but before I come, the frequency depends on size most important quality of this quartz crystal is it has a very large Q and Q is greater than 10 to power 4 our above okay.

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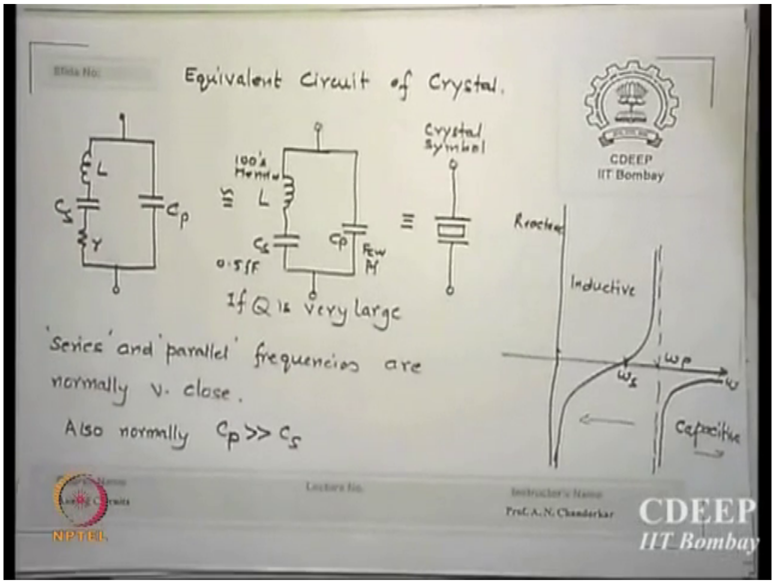

So, equivalent circuit of a crystal (FL) typical R is less than milliohms we just get it the inductance of quartz crystal equivalence is around 100 Henri's the series capacitance is around 0.5 femto farad's and the parallel capacitance is of the order of Q with pico farads is that okay. L, CS are parallel CP is the equivalent circuit of a crystal. So, R (FL) this is the symbol this is the symbol of a crystal.

Can you think what is the CP value is coming from (FL) what is CS could be this is because of the diner what is called dipole moment of the ionize material kept there, which is an inductee series to that. So, that is yes which is typically less than come to collapse (FL) and if I plot it versus frequency (FL) so I figure out that at Omega = Omega S which I call series frequency of this Omega S. (FL) is that okay to you.

Omega S if the series between series resonant frequency Omega is parallel resonant frequencies series and parallel resonant frequencies are called Omega S, Omega P. Please remember tank circuit in series LC circuit is also a tank circuit and it has only 1 upon LC is this frequency is that kind is called series frequency. (FL) The reason why it is different will be obvious when I show you that.

Now as I said CP is very large compared to CS what does that essentially means if CP's are much that means Omega S (FL) If they are very close to each other what does that mean that means anything less than this frequency the crystal will act like what capacitor. Anything slightly larger and Omega S but limited by Omega P what will then act like inductor. So, crystal oscillator on a low (FL)

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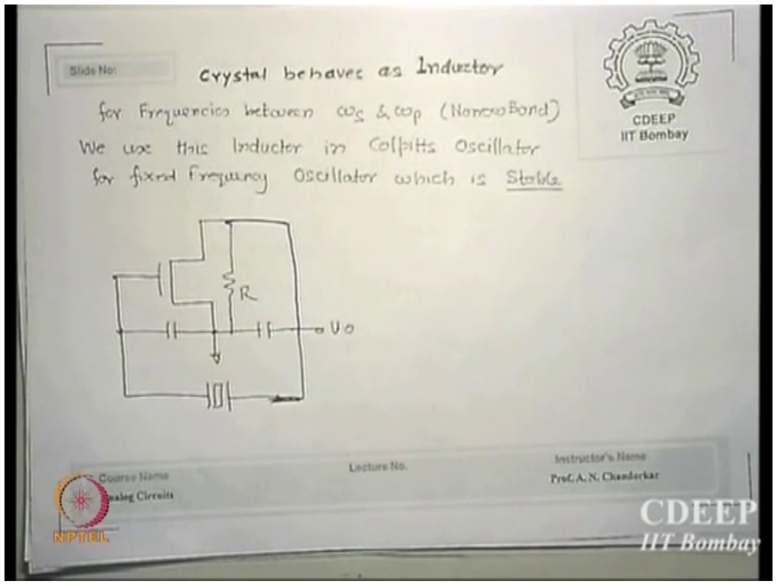

And up to what frequency at what frequency it will always give you inductive between Omega S and Omega P that is why it is called tuned its narrowband (FL) the inductance value will come from the crystal is that okay. So, this is how crystal oscillators are actually used. Crystal oscillators moment really gives own oscillation per se directly. They fit into a Colpitts combination and you replace your inductance by a crystal okay.

And the voltage here should be such that and the frequency appear operating should be touched and this behaves like conductor that those frequency this Colpitts oscillator will oscillate between Omega S and Omega P and if C1 is much larger whatever the value I give larger or smaller. If CP is much larger than CS then Omega S and Omega P very close to each other and which means at that frequency this will oscillate. (FL)

It is stable because crystal and its temperature independent is that (FL) why it will be much less (FL) so this system is perfectly usable in any system where you are looking for oscillations of constant frequency independent of time and temperature that this is called crystal indicator. There are some other version OPAMP (FL) how do I use it crystal in any oscillating systems

Omega P is because of L and CP it has an equivalent see the piezoelectric effect if I apply voltage the natural frequency the equivalent of putting this time something.

It is a piezoelectric theory which I am not solving you are sure right now equivalent circuit is this how many I's cannot be later because CVS (FL) idea rides Edith and find them that okay which I have not done it but I just showed you what to do sorry (FL) I am sorry but essentially what I was saying that you just use a crystal in place of inductance rest Colpitts remains simple. (FL)

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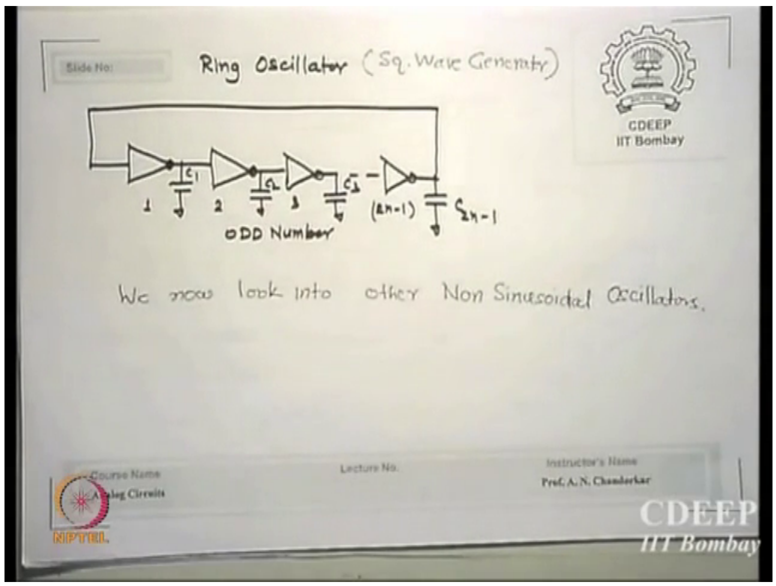

Here is a circuit which is used for ring oscillator. What is ring means? It is a ring these are standard inverters okay (FL) sorry they are all inverting inverters the word I used have you heard of this word non-inverting inverters.

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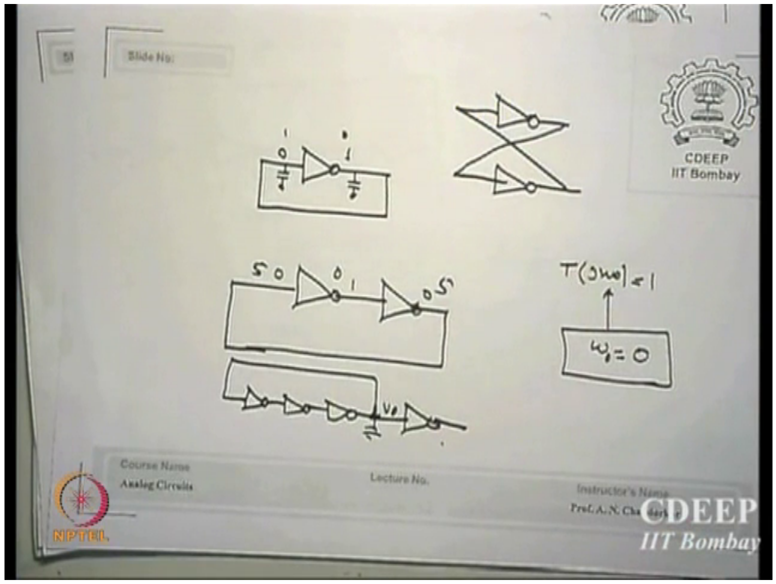

Purpose the idea is simple I have an inverter let us say the capacitance here and a load capacitance here this was storing 0, so this will store 1 okay. But next time (FL) depending on the delay it will keep changing so at any given time I do not know whether output is 1 or 0. (FL) So, this cannot oscillate it cannot sustain in frequency. (FL) Omega 0 where it can become unity is only 0 what does 0 means DC.

So, this sale oscillate for DC yes anyone (FL) so it is a DC oscillator which is not oscillate (FL) it is still an oscillator for a DC but DC oscillator is not called a oscillator. So, essentially two inverters though it gives phase value correctly it does it does satisfy a Barkhausen only at 0 frequency. Therefore it does not really oscillate. (FL) Is that clear to you? By more than two otherwise will never oscillate. (FL)

Very relevant why two inverters do not actually OC okay, so in the odd inverters (FL) so any odd number will actually give you 180 and network will give you another 180 like a phase shift so it will start giving you square regeneration. (FL) when you start monitoring oscillations here (FL) the last capacitor will change the phase will not remain one it is that clear to you. So, the buffer essentially takes you out of that probe business is that correct.

Then real life (FL) is that clear to you okay. So, let us so we want to see some kind of a square wave generation or even triangle or any saw tooth (FL)

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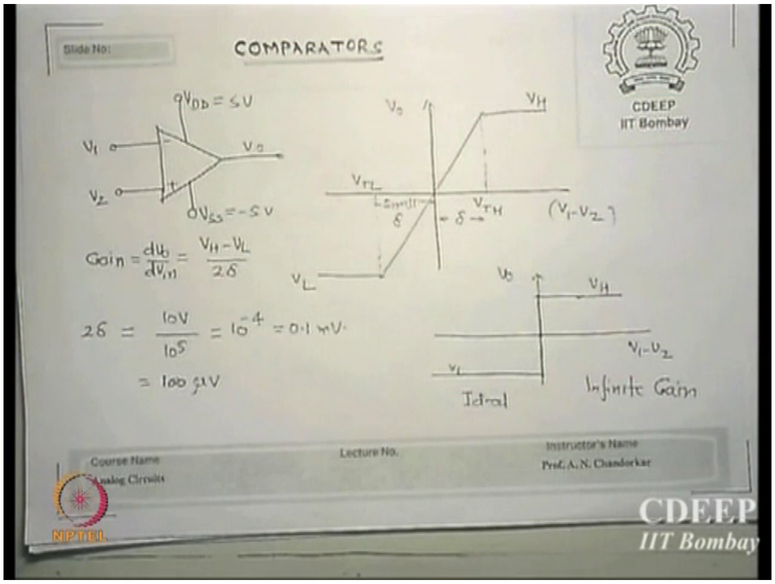

Okay, you are right, (FL) no feedback you are two inputs V1 and V2 your power supplies are VDD and VSS that is a 5 and – 5, 2.5 - 2 whatever values you put and you are a V0. (FL) so, A times feeding with a - sign is the Vd is that clear, Vd is the difference signal V1 – V2 A time this (FL) if I plot this same thing on a sheet on a graph V0 versus depression I see some small less value of say this is V1 - V2 at 0 if there is no upset output is 0 okay.

If V1 - V2 is positive or rather it should be opposite sign because they – sign. (FL) It should rather than as simple as that, if it is - the output will go high and it is + output will go – VSS (FL) what is the gain function dV0 by dV in is the gain of any amplifier which is in this case VH - VL by point this the X value Delta, Delta equal (FL) item. So, if I substitute this 5 volt 5 volt and let us say the gain is 10 to power 5 for open loop gain for this OPAMP I use or DPAMP.

Then 2Delta is .1 millivolt is that clear, .1 millivolt (FL) so this characteristics can then look Delta will become close to 0, if this value is very, very high then tends to infinity let us say Delta will tends to 0. So, what will the ideal OPAMP gain (FL) at V2 - V1 (FL) is that correct (FL) switch, so a comparator with a high gain creates like a switch (FL) On-Off okay. So, now you can think that if I have a comparator I should be able to create on-off situations which means square wave is that point clear. (FL)

So, a comparator other than comparison itself either one another advantage it has it will also give me equivalent of a On-Off switch okay and that I can utilize to create square, triangle (FL) is that correct this is essentially what the non-sinusoidal oscillators do using comparators but pure comparator (FL) the kind of comparator I am going to use is called Schmitt Trigger next time we start with Schmitt Trigger.