CMOS Analog VLSI Design
Prof. A N Chandorkar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Lecture – 28
Oscillators

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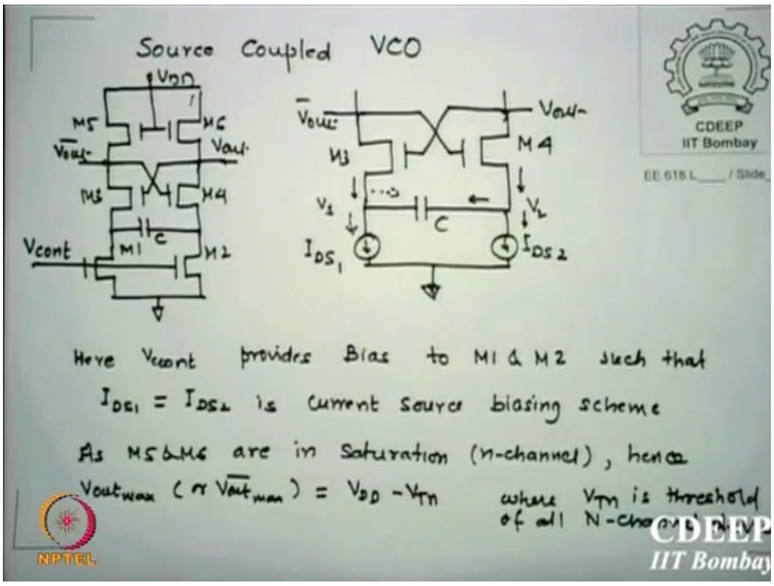

We start with the thing which we just left before lunch. A source coupled VCO and I said I can have either n channel or devices or the upper transistors could be p channel to make it CMOS. Let us say since these are 2 n channel devices, the basically if M5 and M6 are in saturation. These 2 voltage initially will be VDD minus V T is that correct? There in saturation these are like a pause gates and you put VDD here so, they will give one V T drop across this source drain and there are VDD minus V T at both ends. If you have VDD minus V T it should remain permanently that is called metastable position on the cliff ball is sitting on the top nothing happens, but if there is a noise the ball may fall left or right from the cliff. This is called metastable to stable by stable states.

So, any one which may pick up noise little more than the other may bring this little higher than this or this little higher than this, and then M3 M4 has been have been connected in latch form. So, one will start pulling it up the other will start pulling it down, is that point clear?. So, let us start the with this definition what will happen, if you say now at some point of time when you start measuring that this M3 is not conducting.

If we say that M3 is not conducting or M4 is conducting; obviously, this potential should be such that if this is driven, this potential must be lower to switch it off is that point clear? I repeat if M3 is to be turned off and M4 to be turned on Vgs minus, let us say initially when V1 must be equal to V2 and it starts. So, this Vgs must minus V T must be larger enough for M4 to conduct and this should be less than V T not to conduct.

So, if that so, this potentially let us say it is Vgs minus V T and this potential at least should be Vgs minus 2 V T. So, that this transistor turns off. That is why you say the levels of out and out bar will be actually seen, is that clear? If you say this is conducting this potential to be switched off or this has to switch off out must be v something lower than this. So, that this conducts and this does not conduct.

So, if I plug this now which.

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This should be VDD minus 2 V T this should be VDD minus V T. So, this is conducting V DS minus VDD minus V T is larger than VDD minus 2 V T. So, this will be switched off because this is my VDD minus 2 V T, this is VDD minus V T. So, this turns on this turns off; by one V T shift is of it at the edge, but we can say it switches off. V out is VDD minus 2 V T and VDD v out bar is VDD minus V T.

Student: Sature in saturation.

edge of it will switch off, because this minus this and this minus this does not support a let us V T.

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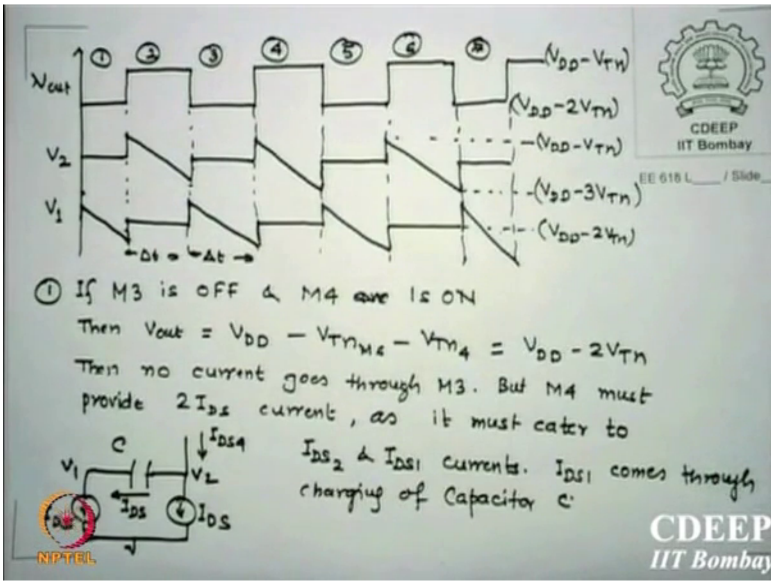

So, that happens I have a figure you can draw that; I do not I can keep this you have the figure I do not have, but I can keep like this. So, I am interested to know these 3 potentials here, here and here. V1 V2 and v out, v out bar is the bar of that. So, that we can just see the otherwise; think of it, if this potential should be at least and they are equal if this device has to be switched off it should be at least one V T below.

So, that is the 2 V T minus 2 V T I will remove that much voltage equivalently. Actually, one dilemma at the start how it works, but that is how one thinks that noise could have actually done this kind of in a oscillator there is no input signal so; obviously, something must start in a way it can.

So, let us say initially since we said M3 is off and M4 is on so; obviously, one may say v out is VDD minus VTn 5 minus VTn 4 or at least 2 VTn. There is no current goes through M3. Please look at your there is no current goes through M3. So, M4 must provide you 2 IDS current.

So, that one goes towards the 2 and the other M1 has to receive a current off same IDS assuming M1 M2 are identical; that means, capacitor would be charged through what current 1 IDS current, is that correct? 1 IDS current this capacitor will be charged. This is what I have shown IDS 4 it provides same current and therefore, and there is no current coming from M3 is that clear M3 is switched off no current is coming from M3.

So, if IDS 2 IDS 1 where same as we did here; that means, one IDS goes here the other IDS must supply to charge this capacitance. So, that this potential and this potential or plus minus now. Is that clear? This potential and this potential are VX, call it is a I have given the name V2 V1 this is V2 this is V1. So, if you look at V2, let us say V2 was given by me this is my V2 this is my V1.

So, what we see initially let us say it was VDD minus V T and it is sorry the top portion at this point it is VDD minus 2 V T that is where device was switched off, and as long as this remains V2 remains VDD minus 2 V T so, that M3 remains switched off all the time and m M4 conducts all the time. During this charge once occur no changes will occur because capacitor will not then allow any current to flow further.

At that instant since V2 has gone to other higher this potential and V1 please remember will not look into V1 will see it is a complementary to that V1 and V2 are complementary to each other so, we will right now not to show you can see from here every cycle it just follows the V1.

So, when this occurs the when m the next stage case 2 will see will come back and come back to see figure again, if M3 is on and M4 is off.

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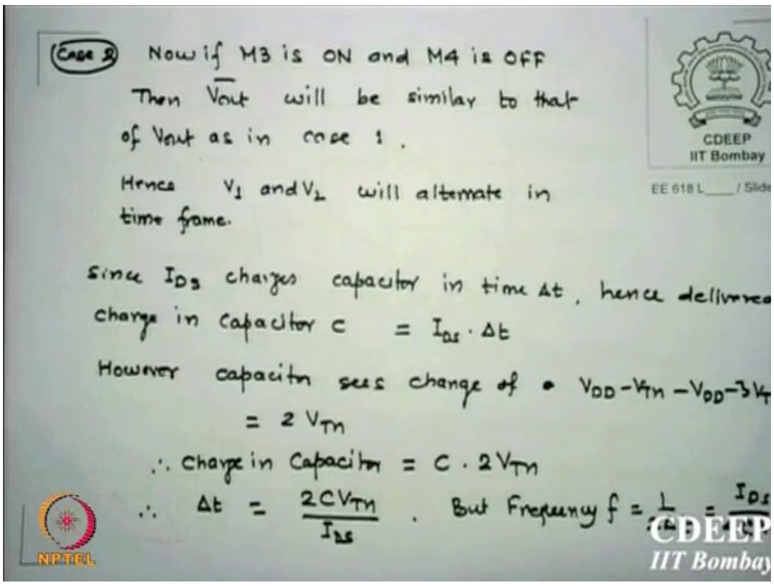

Let us say if M3 is on. So, the inverse should occur, is that clear? Now M3 should conduct and M4 should not conduct now it is the complementary case of V1 V2 and that is why I say

V1 V2 will actually every clock cycle they will switch over the they will follow the each other, the time taken for time to charge the capacitor let us say is delta t. So, what is the current we have IDS. So, what is the charge dumped on the capacitor IDS into t delta t.

However, what is the potential through which it is going through VDD minus VTn and VDD minus 3 VTn that is it shift through a voltage of 2 VTn. So, they what is the charge because of 2 VTn on the capacitor C into 2 VTn they must be same. So, IDS delta t is C times to delta VTn or delta t is 2 C VTn by IDS in the frequency is 2 t delta t repeats again you can say it is IDS upon 4 C VTn.

So, frequency of this multi vibrator or this VCO source coupled VCO, is decided by what? Is decided by IDS; IDS coming from where please look at it IDS is decided by whom v control. So, I have now I have voltage control I wanted. So, adjusted v control. So, that I decide my IDS. Capacitance I have put it. So, this will give me the range what is I range you are looking for threshold of course, the process technology which you are working at, is that clear to you?

So, by do adjusting the control voltage, as well as the capacitance value, I can have a voltage control oscillator which gives me pulses at the output, is that clear? Now, the only thing why this may be it has advantage we shall see little later, one of the advantage of this source couple VCO is, it is comparatively low power, because it does not require huge power depend of course, see how much you want to charge. Typically, it is having a relatively compared to the other one which I will discussed is a low power circuit, but it has a very bad feature in the sense the other one which I am going to show you does not require external capacitor it uses it is own capacitance, ring oscillator uses it is own capacitances, is that clear to you?

So, because of this and now please remember capacitance take. Firstly, larger areas, and Secondly, it requires what kind of process? Either I will have to create an mim capacitor between 2 metal layers or I should create a poly double poly process, this means I need additional process to have these kind of specialized capacitors made available to you. Let us say the thickness is very small for you or thickness is larger for you, than you have one kind of capacitor then you want to change the capacitance.

So, you must have more than one capacitor in series or in parallel to adjust the desired value of see so, it require little larger area to make the capacitance of your choice, is that point clear? You have one-unit area you know this much. So, you want larger or smaller depends on you make 4 or 5 rate and parallel series whatever combinations you do, you can adjust c value and if you do. So, you will best not best actually you will use larger area of silicon for one capacitor. This is something problem, it requires technology different technology and it requires at times larger areas just even to reduce it you will have to put in series of them.

So, it is not that it is a parallel every time you can even series them and change the capacitance values. So, all VCO source couple VCO that they are called are good because comparatively to the other ring oscillator circuit. One finds that they are low power relatively, but requires new process or rather different analog process and also it requires area additionally, this is a weakness the other is may be some advantage.

So, if you are looking for relatively lower frequency circuits then you may have a problem, because then you have to actually put large C if you are very large frequency then your minimum C should be sufficient enough to go there. So, there are issues which are not very easy to handle. So, it limits your performance in most cases, but is the easiest way of making a oscillator this is therefore, very popular in many circuits if you see actual circuits in chips you will find many have the use source coupled we use. The second one which I said you is called ring oscillator.

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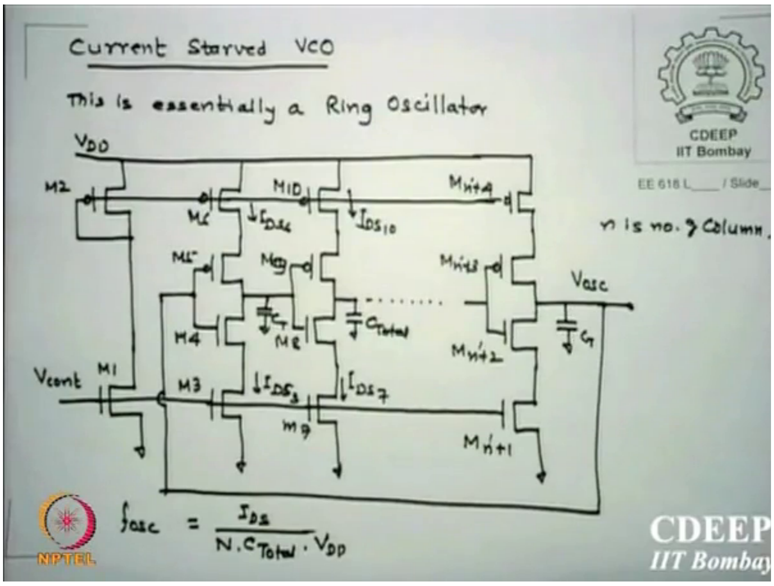

Now, it is also called current starved VCO. This M1 M2 essentially forms a mirror kind of input side. So, and that is controlled by V control. So, if I have on M1 if I decide my V control I decide the current in M1, and since it is made on that wherever I connect the same current can be proportionately size if I use, I can passing the other arms you can see through this p channel I am going on number of vertical inverter changes.

Each column is the inverter change or other one inverter plus additional something in between 4 transistor inverter has been shown here. The method is here is they decide the current, this decides the current this is decided from M1 and M2 will decide the current in M6 M10 whatever the this side; depending on the sizes I can have different values I may have same also if I put same size correctly then I can ask this current and this current maybe identical, but to show it right now I am showing you as this current is 6 and this current is 5 or rather 3 I should say IDS 3 they are not same, but they may be normally I will make it same.

In between these 2 this is an inverter sitting here, m 5 and M4 forms an inverter change inverter this the output has a capacitance which is essentially the output capacitance of this inverter at this node; plus, the input capacitance of the next stage which it is driving. You know ring oscillator is inverter driving the next inverter so; obviously, I know w into l is the area for n channel and p channel into cox from the input side and from cdb and these also are functions of areas. So, one will be able to calculate the net capacitance which will be area dependent for both omega n I mean n channel area and p channel areas ok.

So, this capacitance which is self-created, is that clear to you? It is self-created I do not put external capacitance here; I put natural capacitance which are available to me now the way it happens, that I have a chain of such inverter of course, odd number as I said we already said odd is to be there to make it. So, satisfy the barkhausen criteria and the last one for example, is feedback here.

So, that it forms the chain now why it is called starved is the following; the current here and current here way it will happen, depending on the output here one or 0 either n channel will turn on or p channel will turn on, say p channel turns on this IDS 6 will go through a idea whatever current id 5 can take, only this much current it can push in. Your sizes may be decided by the Rc time constant you are looking, but the currents are coming from current sources and current syncs, is that clear to you?

So, it may be able to take larger currents, but is supplied lower current from the top for the case of this p channel. So, it is called M5 is starved of current it can drive larger currents, but it cannot because the current is provided from and why it has to be done because this current is control through the VCO sorry v control. So, this is deciding how much current this arm can have.

So, this charges the capacitor this and the opposite this capacitor discharges through M4 M3, this is like a normal inverter having a load of capacitor which charges through p channel and discharges through n channel. The only difference what is happening here is the currents in this are not just decided the w by of this, but also decided by the control voltage which should be stronger than the capacitance effect coming from w by else of this, is that clear to you? That is what this is called current starved VCO. If of course, this oscillator frequencies IDS upon n is odd number n is odd number please take it I am not written it, but n is odd numbers 1 2 3 4 5 n is odd c total what they all please remember what is c total I repeat the capacitance output of this and input of the next stage. That is the total capacitance at every node.

Even here this is the output, this is the input. So, it is universally true now this for the secondary students are third year may do some experiment. Normally, if you see in our lab we put additional inverter here to monitor the frequency, do you know why? If I do not do this then this will start during this the last stage will have a different you base you are a probe which probe has a much larger capacitance. So, normally the last is the buffer stage through which you actually pick up the outputs in the lab. So, please check it there I have if my sheet old sheets are still running I am told 92 last analog lab I took and I think I see the other day the same experiments are still sitting there which is lot for me. So, is that clear?

So, this is the another VCO which is like a ring oscillator please remember this is no different from ring oscillator, the only difference what we did we ordered a control part on this and by doing this I can now make currents available for an inverter of my choice which is proportional to control voltage.

Student: The IDS 4 and IDS 3 will be matched.

Generally, IDS 5, 6 and 3 will be matched in size we generally 90 percent the way it is shown it is correct. This current and this current are same, but you can have a different duty cycles by adjusting different currents in the 2 arms; charging current will be different discharge current can be different. That is what a normal CMOS inverters we keep it equal, but it need not be I can have a duty cycle of 30 percent 40 maybe 50 which is equal. So, I can always do whatever currents I push I can always adjust it duty cycles.

So, this is also a very popular in ring oscillator because it allows you to convert your normal ring oscillator into a VCO, is that clear? Why it is becoming popular because ring oscillator we use very often. So, here additional circuits if you do it can convert itself into a voltage control. This is one class of oscillator we saw today there another class and I keep saying you this answer I may give it the end maybe or you should think, there are circuits in which we only use Rc networks or Rc components to make a oscillations most of the feedback circuit will looked earlier have only Rnc, but there are another class of circuits which requires LC combinations instead of Rcs.

So, Firstly, think of it why LC can do what Rc cannot, and if initially Rcs were doing why LCs were not use them either way at certain bandwidth a frequencies we always use Rcs and at much higher frequency prefer to go for LC circuits. So, why complementary to each other was not tried let us think of it, this is an issue which is not very true every time, but yes there are issues with Rc is the advantage sometimes LC is the advantage.

So, we look into second class of oscillators which are essentially called LC oscillators inductance capacitance their basic principle lies in the is called tank circuit.

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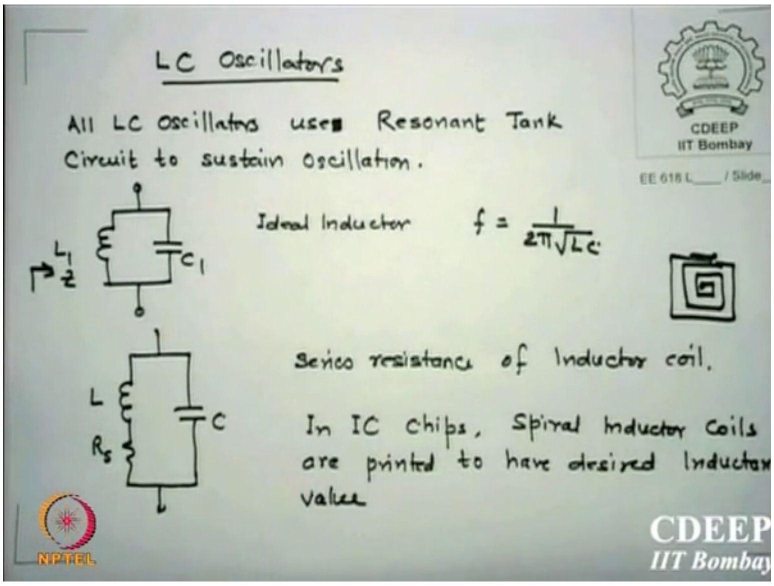

An inductor in parallel to capacitance let us say, both inductors and capacitors are. In fact, actually capacitors also are leaky to some extent. So, in real life if the capacitance are used a different dielectric is standard it has to be figured out and the resistive part even there can occur though 99 percent we never show that we are seen inductance we show, but capacitance in real life even c can actually create additional resistance there, but okay.

In ideal case if I see this circuit, if I monitor the capacitance on this side at a frequency which I call it f is equal to 1 upon 2 pi root LC which is called the resonant frequency of this tank circuit is called resonant tank circuit. Now if we find out this frequency for monitor z what is the impedance do you expect this to happen how much at this frequency when it resonates.

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What essentially, I am saying that the j omega l at this frequency is equal to opposite 1 upon j omega see for this they are equal and opposite, is that correct? And because of that the current in this arm is 0 and therefore, the impedance scene is infinite, but any other frequency they may not be equal and therefore, they will be decreasing z as you move away from resonant frequency.

Now, this fact is very interesting that infinite whenever tank occurs it gives you infinite z. This can be understood very easily the problem starts like this if let us say capacitor is charged and there is no dissipation. So, it discharges through the inductance ldi by dt this see inductors source energy that energy is discharged through a capacitor and it will keep happening and times. So, will get oscillation charge discharge charge discharge, but that is essentially saying that there is no dissipation.

So, in real life there is no such thing like ideal tank circuit, or ideal resonant circuit inductance being always metallic wire it always have some small series resistance associated is that clear to you? And as soon as now you say r is there some IR drop will keep coming. So, one time we see may be full, but next time it will go down because that is heated out heat out.

So, you will not have infinite impedance essentially equivalently saying it will be some finite impedance and the name which essentially says dissipation factor is called Q the Q of the tank circuit which is essentially given by omega l by r; that means, there is a finite Q in normal case ideally what Q should have been infinite, in most CMOS or NMOS technologies the Q which will get maybe 3 to 4 or 5 or attempt to get higher Qs actually have much more trouble some other day in designs.

So, since we typical inductance are made out of wires or metal lines printed on the silicon substrate or other silicon dioxide areas. It is something like a spiral we create you can have, this is have inductance are printed. The gap the tells they decide net inductance of this spiral which we create. Why we do not create circular that is ideal, but circular this on a graphic terminal is very difficult. So, easier stage cartesian xy. So, all spirals are normally xy spirals, but they could be circular by some tricks, but it requires better graphic and longer time to do this which does not help you great anyway in some sense.

So, if you now say it has some finite resistance. So, let us see what is the z now availability because you say this now z will be different from the infinite value which we created at that frequency.

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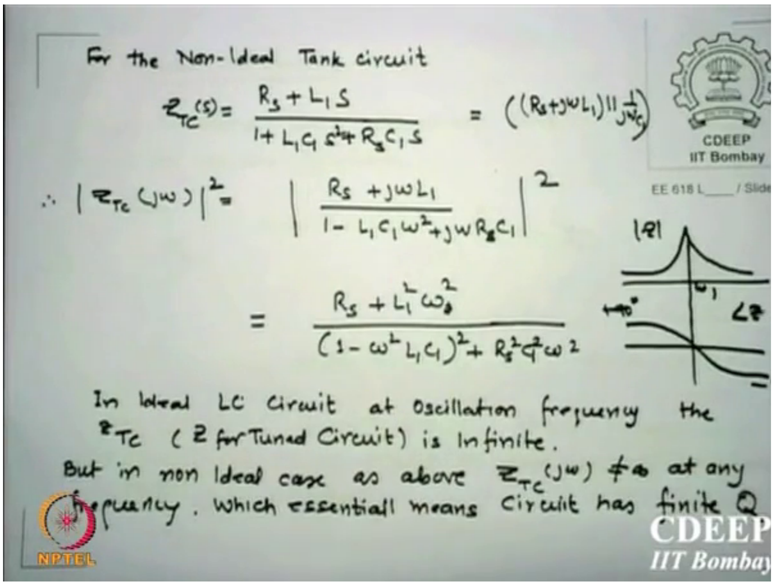

So, I calculate it RS plus L1 S upon 1 plus L1 C1 S square plus RS C1 j omega l and RS are in series and parallel is a capacitor. So, if I do this this is what essentially RS plus j omega l, parallel to 1 upon j omega see if you expand this I get this terms and if I evaluate the value of this at square. So, I can say magnitude of this can be RS L1 square omega square 1 minus omega square L1 C1 square this is a complex quantity magnitude were real magnitude wise this value will appear.

So, now you can again check this if RS is 0 what will happen this is 0 this is 0. So, what will happen? At omega equal to L1 C1 upon L1 C1, 1 minus 1 is 0 and impedance goes to infinite. So, as long as our basic condition initially idle situation is still available if RS is 0. At the frequency of omega equal to 1 upon root L1 C1 this still gives you infinite impedance, but says RS is present.

So, this turn is not becoming 0. So, there will be finite resistance even at resonant frequency. Typically, if you plot it will be something like this. You can see the denominator parts. So, it will start decreasing from it is peak value and if you plot it is angle; at omega one there is no imaginary quantity and we say that is that is why it is please remember expand this make imaginary quantity 0 then you say at that point phase it 0. On what is the tank principle that the impedance is match at that frequency.

So, the imaginary part as it goes away. So, the net phase this is angle z is 0 at resonant frequency that is what resonant word means, beyond which what is the kind of impedance on this side and what is the impedance on this side.

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This is inductive the other is capacitive lead and lag whichever way you look at it. So, since only at the resonance it has much larger z which is essentially replicable trying to say there is a Q finite though is not infinite, but larger Q is certainly available which may be as I see in ICs typically is 4 5 best of times 10.

So, if we say now that I have this RS is going to be there whether I like and I do not like. If I want to use this. So, I must survive through this Q availability how much Q larger Q is better, but larger is how much. So, that will see and will take care of that Q in our design. So, that the system is always still oscillating at we are not very, very much because the phase goes to 0 anyway at resonant frequency even if Q is not infinite. That part is this LC circuit tank circuit always provides.

So, the first advantage of tank circuit over any RC circuit with active device is there is no question of barkhausen criteria has to be satisfied. I am independently going anyway do what you do; and that is the fun part in LC circuits this is one example advantage I told you over r is that okay? So, in real life as I said there will be, but I want to have some better way of representing LC circuit which is called the parallel representation of this resonant circuit with RS has the series resistance.

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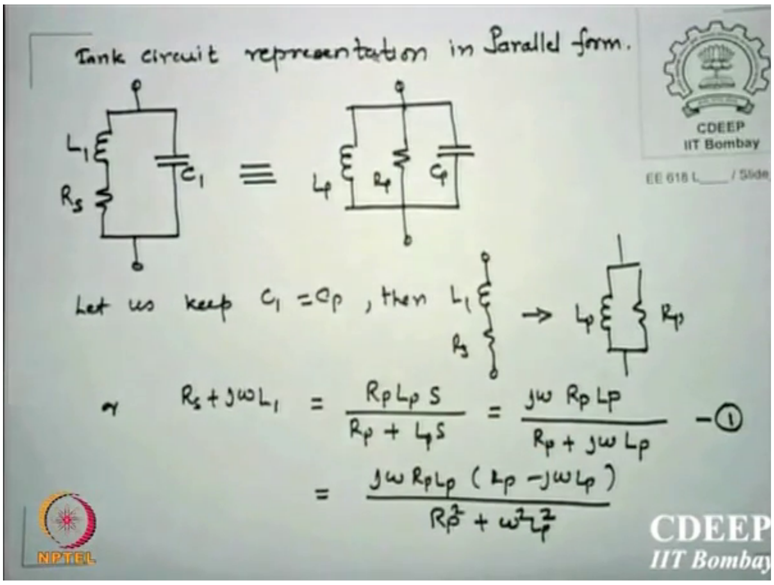

So, also if is LRS series tank this is therefore, sometimes called series tank circuit. Actually, it is also parallel, but all component I want to be in parallel. So, as a LP parallel RP parallel CP is equal to this identically, equal to this. So, what is the method you have to do it calculate impedance of this, calculate impedance of this real values on the left must be equal to real values on the right imaginary values on the left must be right imaginary values on the right. So, we are 2 equations will get and those condition relationship between LP L1 RS all can be figured out is that method clear? Find therefore, this find therefore, this equate real part equal imaginary part equal and solve this.

So, RS plus j omega L1 is this and on this first equation is if I do that RP LP s upon RP LPs is equal to j omega s if I substitute j omega RP LP is equal to RS plus j omega L, and then please remember I am saying, capacitors are identical they may not be you can choose different and then you are long difficult situation to get I assume CP is the same as C1 then I separate them. So, whatever is this parallel combination must be equal to this if I solve this this is the equation I get I get lot of equation solving.

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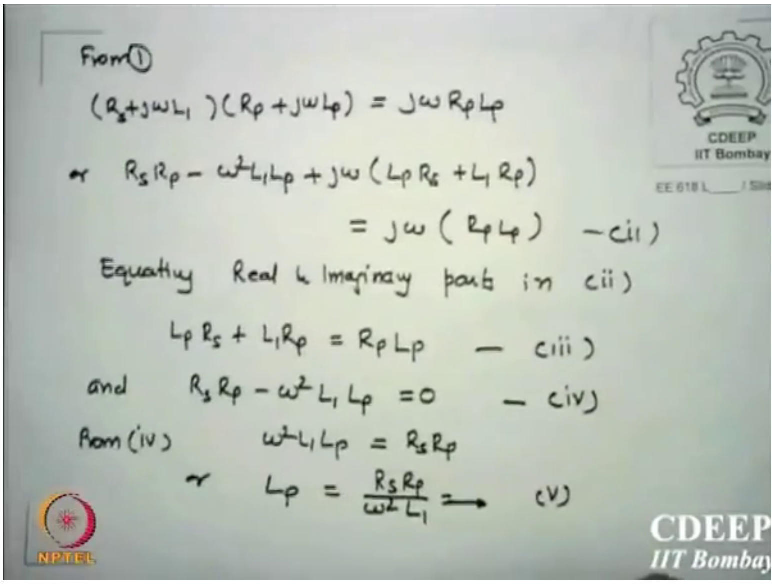

I actually put this equation into one I write RS please look at it the way I am now doing RS into j omega L into RP into this if I get it then that is equal to j omega RP this is 1 equation. As say write z for left, write z for right equate the real imaginary terms and I get 2 equations I think the first part I just showed you in case you do not want to use it then you actually write z for left z for right equate the real and imaginary.

So, I get LP RS plus L1 RP is RP LP when I equate real values and RS RP minus omega square L1 LP equal to 0 from the imaginary side from here I can write omega square L1 LP is RS RP from here. So, LP is RS RP upon omega square L1 LP by this. So, I actually what is the value I want to find? RP, I want to find the equivalent RP corresponding to LNS on the series side (Refer Time: 34:21) on this equation, I get omega square L1 LP is equal to RS RP.

So, RP is equal to omega square L1 LP upon RS. So, I got one expression for RP in terms of L1 LP and RS. That I will used now in the other equation substitute there I replace RP is by the term which I am going to get and then solve again to get what relationship between LP and L1, I am interested in 2 terms I am interested in LP related to L1 and RP related to RS, is that correct? These are equivalence I want to see.

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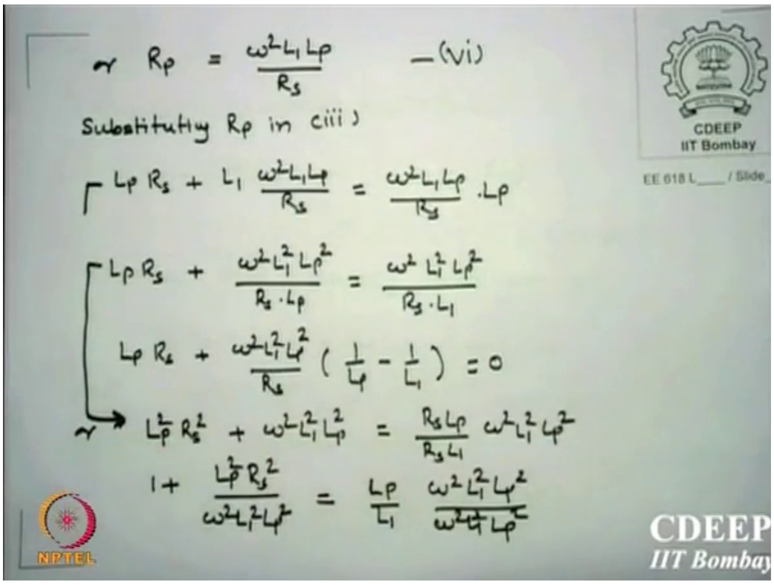

So, if I get RP is omega square L1 LP by RS substitute in the earlier equation 3 which is this and then you expand that. And at the end of the day you forget those term may directly. I multiplied by RS from here and I get LP square RS square omega square L1 square LP square RS LP RS L1 omega square L1 LP square, from here I can directly get this then I realize and need not have done this from here you come here maybe from here you can come here trick Q term what is Q omega 1 L1 by RS is the Q is that correct? Omega one L1 by RS is the Q.

So, if I look at these terms omega square cancels, this cancels. So, only get LP by L1 and on this side what cancels are LP square cancels. So, 1 plus RS square upon omega square L1 square is LP by L1 term. So, that to get that expression what I was looking for, is that point clear? Readjust l square p square divide and then I get term 1 plus LP square r square upon omega square this is terms divide.

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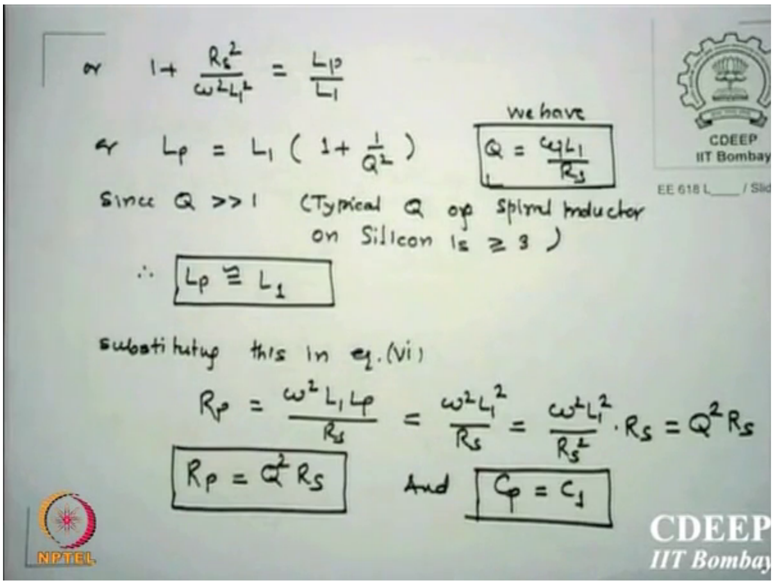

If I do this, I get an expression 1 plus RS square omega square L1 square is LP by L1, but Q is nothing but omega 1 L1 by RS.

So, then I can write LP by L1 that is LP is equal to n 1 times 1 plus 1 upon Q square, is that correct? Normally, Q is much larger than 3 or 4 or 5. So, 1 upon 3 will be or 1 upon 4 square 1 upon 5 square will be 1 by 20, 1 by 9, 1 by 25 or larger number. So, typically LP is very close to L1 larger the Q or as much closer smaller the Q you will be you will have to use this expression, is that clear? If Q is smaller this term may not be small and then you have to find the actual value. Normally Qs are larger than 3 at least even on silicon. So, one may say one point one I can say one and I say LP is L1. I substitute it back here and then I solve for this RP is equal to Q square RS.

So, RP is equal to please remember RP is omega square L1 LP by RS I just calculated earlier; where you are seen that expression RP is omega square L1 LP by RS I say L1 is equal to LP is that okay? L1 is equal to LP. So, omega square L1 square by RS omega square L1 square by RS square into RS which is Q square into RS. So, RP is Q square times the RS. Now the way I did it capacitance I have separated anyway. So, CP is C1. So now, I know from the series circuit I can go to equivalent parallel circuit why I am doing it because if I see in real life when I make a oscillator I am going to play this game very nicely.

So, I have now RS in series now all 3 are in parallel and they are connected to Q square RS is RP CP is C1 and LP is if you want exactly this otherwise LP is close to L1. Now again, if you at that frequency of omega square is 1 upon LC L1 C1 essentially or LP CP, because ln L1

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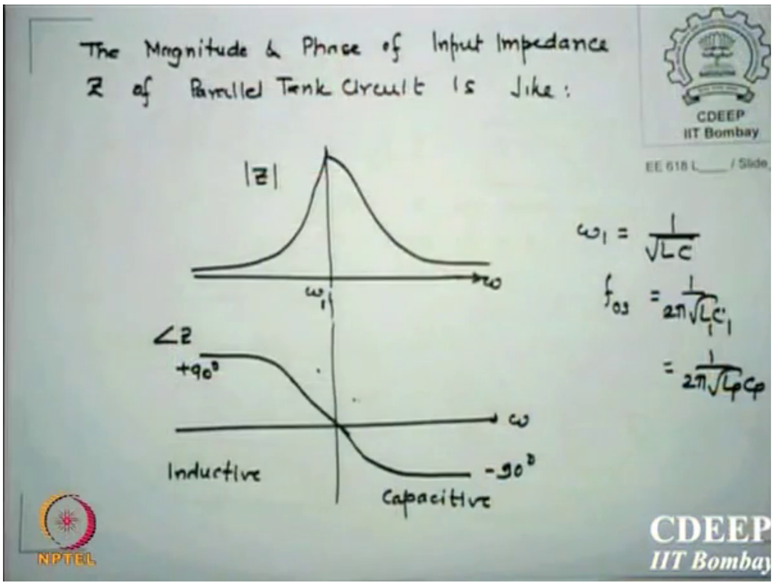

And L2 are same. So, LP is are same. So, again say z is peak at maximum value occurs at resonant frequency maybe call it omega 1 or omega whatever we and the phase correspondingly is 90 minus 90.

So, this is the principal of a tank circuit. I know that when it resonants it gives you large impedance; large mean this should be much order higher order not infinite, but much higher order and at that point phase is both L and C phase will cancel and therefore, it will be 0 phase. So, based on this principle of time circuit I can make my first cross coupled oscillators, is that clear? I have now start using this principle I know now how tank circuit works I can use now tank circuit with a transistors to tank circuits and cross couple them. Is it okay? Figure z is same as what I said earlier. So, even for parallel circuit they are same simply because I have made equivalence of that.

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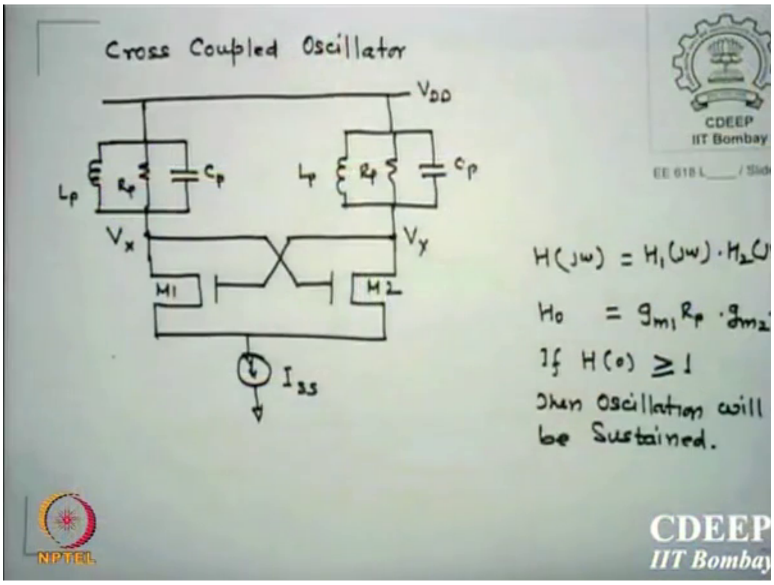

So, the first cross coupled oscillator; any now tell me, if I want to make a vc out of it from where I can make a vc out of it.

Student: Iss.

Iss I can control the ISS from my v control I can also do something else capacitor. So, I have 2 ways I can look into it to convert it in to it is VCO operation. You can see here this is essentially trying to say at a time, circuit or circuit. At one time let us say it is at fixed value when this is operating the other time when this is operating this is at a fixed value these are 2 transfer functions 1 due to this 1 due to this.

So, what is the net transfer function will be if H1 omega is transfer function of this H2 omega is for this, since they are feedback please remember this the way shown here this output is going to the gate of this this output is going to the gate of this, is that point clear to? You says these are equivalent like a large situation if this voltage changes the currents here will change here and therefore, change the voltage across this is that clear? This is what the cross coupled word means.

So, we say at when close to resonant frequencies are at dc value of that what is the gain of each stage when they are in resonant L and C goes away only what remains there RP, RP. So, gm Rp and gm Rp if they are separate gm1 Rp and gm2 Rp are the gains. So, the net gain is product of the 2 which is; because one is feeding the other. So, gm square RP square is the actual gain of this stage.

So, I can use this cross-couple oscillator and what is the frequency at which it will operate, as longer please remember this is like the latch situation, but why it is not latching now what is the value I am here looking RPs are extremely small RPs the equivalent of a series resistance which is the less than ohms is that correct? So, gm times RP is very, very small compared to gm times r 0 in the case of the large action we said there a 0 when to beyond to in no time and therefore, at only at dc when the capacitance has no phase to inverters could give 360 phase out and therefore, the latch to a 1 0 1 0 outputs whereas, here it is identical to that, but now the games are actual when where this will happen only at frequencies off this interest.

So, only when the resonant at omega equal to 1 upon root LC then or root LP or CP then only at that time the gain is much smaller and therefore, one can say it will act like a oscillator of course, that condition must be that that should be slightly greater it should be positive otherwise need any feedback will occur.

So, it should be positive, but should not be very large positive and this will help you to oscillate at a frequency of 2 pi 1 upon 2 pi root LP CP or L1 C1 which is same, is that correct? So, this is called cross coupled LC times circuit-based oscillator which is often used and as some of you said I can either change CP by voltage and will see later or I can change the ISS value, why ISS because ISS will decide gm1 gm2 and therefore, it will decide the point at which oscillations can have that.

Colpitt they are 2 names very famous colpitt oscillator and the other is Hartley. What they did will not solve full of it, but may be quickly will show you.

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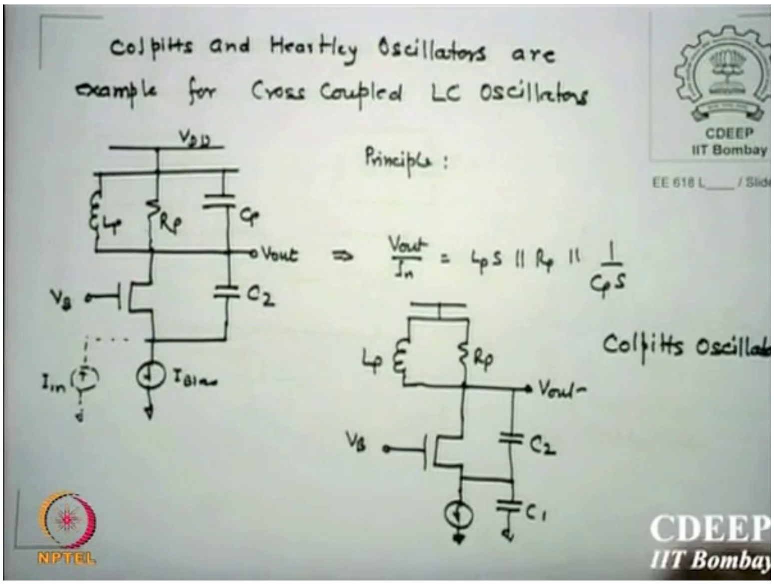

I have one transistor here I have one CP across the tank circuit and I have another capacitance between output to this and please remember here, what is this transistor is working like?

Student: (Refer Time: 45:57).

No not negative, what is this? Common gate is not correct and the input which is noise is actually available to at the source of this transistor, is that clear? Source of this transistor. Which is shown here as colpitt oscillators, can you think what will be is oscillating frequency roughly?

Student: (Refer Slide Time: 46:26).

How much is c at this node? These are grounds so, this is also grounds.

Student: (Refer Slide Time: 46:27).

These are in series, C1 C2 upon C1 plus C2 is essentially the capacitance which is coming at this node, is that clear? So, L1 into C1 C2 upon LP means LP upon C1 C2 upon C1 plus C2 1 upon of course, that is the omega square term for this CP, CP capacitance CP plus and that is what you was said CP plus C1 C2 upon C1 plus C2 will be the new capacitance if I also hold this capacitance here, is that clear?

So, essentially it will be decided by what values LP and the series combination of C1 and C2 will decide the frequency analysis quickly solve book quickly, you have done this figure equal, I am right now not using CP, but later all adds please remember CP is only paroling there. So, add additional capacitors if I need that, the reason why I removed this CP from here, because the actual colpitt oscillator did not have a CP there that is why actually it was not used we can add that to C equivalent of other network, but since in actual colpitt there was no CP here. The only thing is they have no transistor then it was a vacuum try which was used in those cases the first colpitt oscillator was used with vacuum device. At least 4 to 5 inches long, at least 2 inches in dia pilamentre a grid plate or the other (Refer Time: 48:37) equivalent circuit, explain we all done this equivalents end times this is the common gate amplifier.

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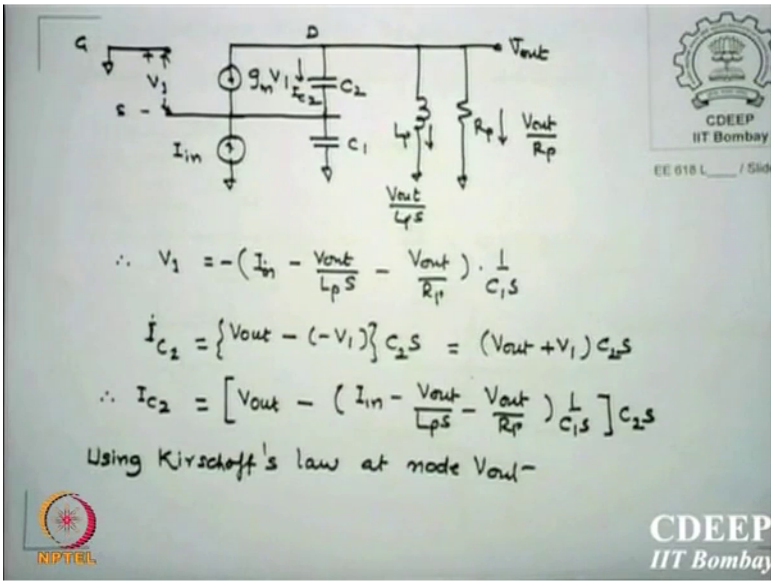

So, I in noise voltage at because oscillation cannot start unless there is some signal comes.

So, we assume I in is the noise voltage and please remember this is the source end of the transistor. So, source current source transistor Vgs please remember the gate is grounded in common gate gates are grounded fixed value. So, that is grounded and between source and the gate let say the potential is V1 which gives me a output current of gm V1 then there is a capacitance C1 and C2. So, part of the current goes through C2 there is also current in C1 then this is your LP RP and this is your output voltage.

So, how much current actually how many at a given node of this how much current you can see this current this current this current and this current is that clear output current. So, will do that. So, V1 if I want to find this voltage this is ground. So, I have I am trying to find this voltage. So, I in ground I in minus this current minus this current minus because opposite sign minus sign I in minus v out by LPs minus v out by RP into this capacitance 1, because this is current into 1 upon C1 S is V1 drop across C1 is V1 minus of course, because it is the opposite polarity there. So, I can calculate this voltage V1. So, gm times V1 is known to me is that clear? I want to calculate current in this arm how much is that this is v out minus of minus V1 into C2 s is the current in this gv or v out plus V1 into C2 s.

So, IC 2 is and then I substitute V1 from this here. So, I got v out minus I in minus v out by this into this into C2 s. So, I got IC 2 as the current in this arm I know gm V1 because gm times this current is also known to me, I know this current, I know this current. So, some total current should be 0 at node. So, I is that current node 0 sum of them are 0. So, I calculate this current, I calculate this current, I know this current, I know this current add 4 currents and equate them to 0 is that written down.

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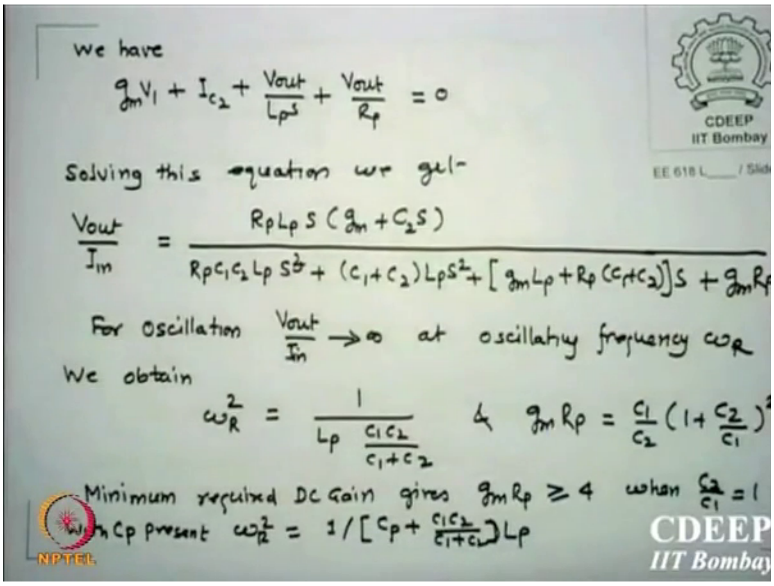

So, to say gm V1 plus IC to v out by ps v out by RP is 0 or substitute v out by I in expression left calculate finally, what is the condition of oscillation we said? The impedance should tend to infinite. So, v out by I in should tend to infinity oscillation I have to occur at frequency of omega r which is called resonant frequency.

So, 0 denominator omega square R is 1 upon LP times C1 C2 upon C1 plus and the second part from the this gm RP real and imaginary part. So, gm RP is C1 C2 upon 1 plus C2 by C1 square, if I use C2 by C1 one that is C1 same as this gm RP 4. So, at least the minimum dc gain you expect is 4 slightly more because it should sustain it, and if you know C1 C2 here this is C1 square upon 2 C1. So, just LP C1 by 2 is the frequency available for you at the resonance for this and colpitts circuit CP capacitance add parallel.

So, I can calculate the resonant frequency of a colpitt oscillator by deciding and gm is decided what? The bias current I will put RP of course, is not in my hand it is inductance whatever Q I have I will decide on that Q square RS is RP ok. So, oscillator colpitt capacitor or inductance capacitor inductance circuit Hartley oscillator, that will become Hartley oscillator. Please remember Hartley came later then many old book the always start with Hartley oscillator and they show colpitt later, but I may tell you again colpitt oscillator was made first and Hartley was a modification.

Do you know what kind of capacitances we have? We used to use in those cases variable capacitance we have known diodes as such who with variable what do kind of capacitors we used? Anyone as seen? You must have seen metallic plate or metallic plate, gang condenser hum plates distance you change the capacitance by knob plates, plates change gang condenser.

So, actually radio receiver tuner actually gang condenser tuner plate that is the used tune the different bands times are change.

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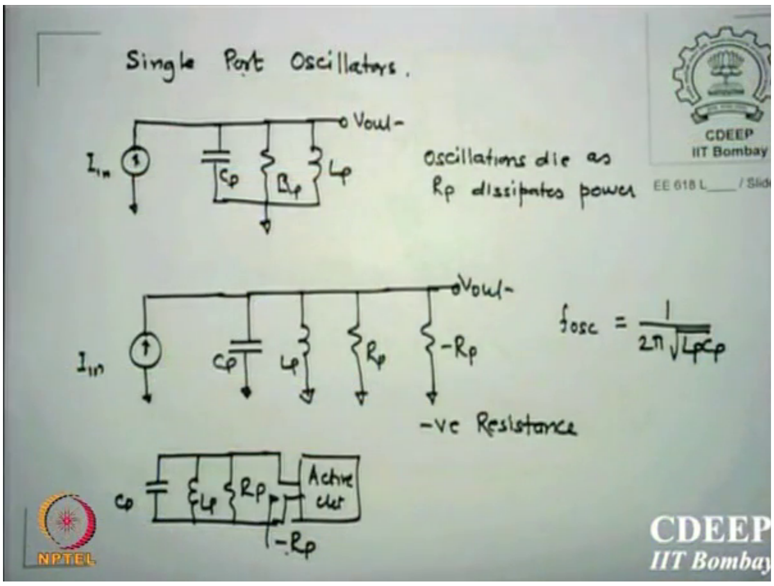

So, here is the another kind of this is only fun part in that there are other kinds of oscillators before we quit for the day this may be the last. This is very interesting someone earlier in between said that though now will show you that. A typical noise source is shown here is fed to a tank circuit a CP RP LP, because if you give a noise it will died on after some time because all p will dissipate out die ideal tank. Let us say if this RP minus RP then it will act like a ideal time circuit and then it should oscillate even with the small noise signal it should start oscillating.

So, the game was, that you are a tank circuit and you connect it with a some active circuit such that the input of that is equivalent of minus RP. So, it is called negative impedance converter or generator. If I can create minus RP out of this active circuit then I will be able to cancel this RP, RP and minus RP and therefore, we may say that I have a ideal tank circuit till oscillate and you does not required than any other this only you have an active device, but in fact, actually you are using only one time one starts it starts; however, this circuit should maintain minus RP all that time.

So, you mean that you know it is not something like, is that point clear? One simple negative impedance to the generator circuit is shown here now and based on this we will show you oscillator this is also as I say gm oscillator as it is called transconductance oscillator, is figure clear? RP cancels the minus RP is minus RP active circuit input impedance is minus RP and the fun part there is it independent of frequency, resonant frequency minus RP minus RP that is a it will once you provide that it will always oscillate there is nothing to worry about, is that okay? This is negative impedance generator.

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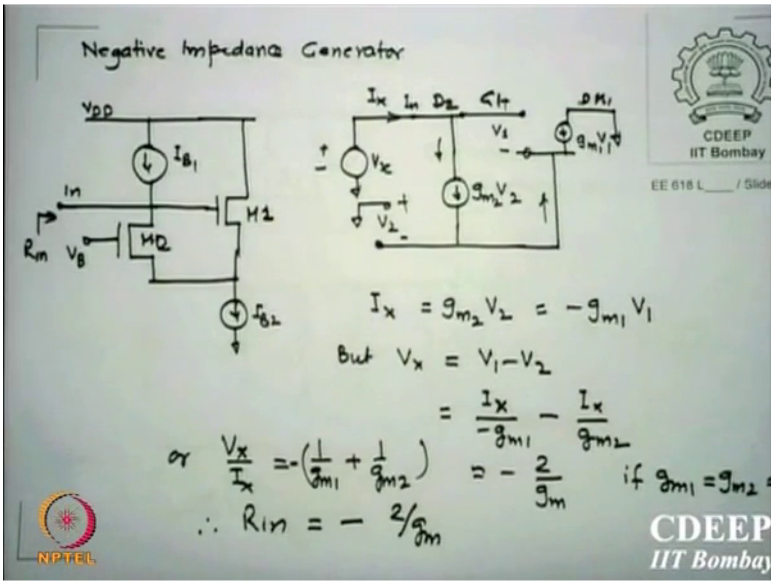

I have 2 transistor M1 M2 this is a common gate circuit this is common base common source circuit and input terminal this is bias through a IB 1, this is bias through a IB 2 or call it IB 1 also it is immaterial it is biased same or different if it is different than gms are different please remember if you bias it differently there gm are different, but if you assume same then gm should be same of equivalent, what is the equivalent of this? How do I calculate impedance I apply a voltage VX at that terminal and find the current they also VX by Ix is the r there or z there.

So, I have a source VX at this terminal please remember where I am calculating r in is that. So, this VX is supplied by me and I am monitoring this current Ix at this node is input current ac part. So, if look at it since it is going to this is M1 and this is M2, from VX drain M2 M2 drain M2 current flow gm 2 V2 what is V2? else see, but gm 2 V2 a drain M1 gate. So, M1 gate I repeat this is d 2 and this is g1.

So now from g 1 that must be some Vgs V1 which is creating current in M1 which is gm V1, but this is going to VDD for ac it is ground. So, ac it is ground. So, this is the drain of M1 and this is the source of M1 from source of M1 to g one must be some potential V1 which is cause in this current to flow that this source is connected to the source of source same or voltage Vgs otherwise there is no M2 conduction.

So, they should be a potential V2 and this is ground. So, this is ground is that equivalent clear to you? All of you I start with this go supply source of VX and I want to monitor Ix the d 2 of this there is a gm 2 V2 and since this is same as g1 I have a separate voltage which is Vgs for M1. So, that is gives me V1 which gives me a current source of gm V1 in this, but the other end is grounded. So, the is grounded and this source of this end source of these are connected. So, source of these end source of these are connected.

Now, we see if I see Ix this is the current Ix, but if you see opposite of this this is going to the ground this side which essentially means Ix is also equal to minus gm one V1, but what is VX? You can see from here this is VX and this is V1. So, V1 minus V2 is nothing but VX, VX ground or V1 V2. So, V1 or subtract that is the VX. So, VX is V1 minus V2, but Ix is gm 2 V2 mi[nus]- or equal to minus gm one V1 V2 substitute.

So, VX is equal to Ix upon minus gm 1 minus Ix upon gm 2 let us say IB's are same. So, you may say 1 upon gm 1 plus same as 2 by gm. So, minus 2 by gm. So, input see in from this terminal is minus 2 by gm. So, negative impedance now adjust this gm value by what RS current or even size is to some extent you can adjust w by l as well and the get the value of r in which is equal to RP and as you tune it you will actually get oscillation sustained oscillation. This is very interesting and the actual use of this negative impedance terminal last oscillator for this side is that is that mam clear?

So, trivial it looks, but very powerful negative impedance generator you know a similar negative impedance generator can be use generation is being tried in opamps or defames what is it called? Gladiator, a negative impedance generator with op amps is called gladiator. So, gladiator popular circuit equivalent gladiator is shown here with 2 transistors connected in this fashion you can create negative impedances, and gm decides the value for your RP your choosing. At time this please remember RP is are very small RP is are very small 10 RS or 20 RS, RS is ohms less than a ohm.

Now, this gm should be very high and this higher gm means power. So, to create this we will pump power whereas, circuit person first think frequency power equivalent sustainable circuit cross coupled oscillator.

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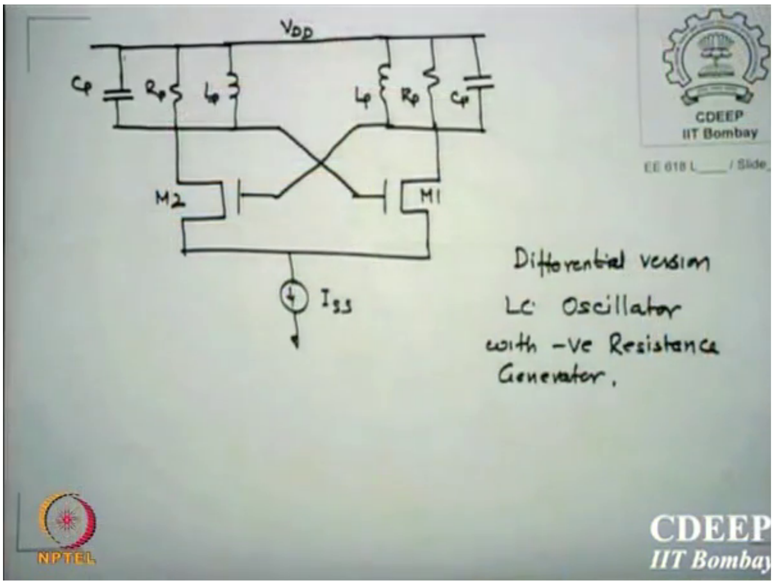

But you can see from here these and these 2 transistors are. So, connected the actually are providing negative impedance at these 2 terminals 1 by 1 think of it.

So, adjust gm of the here you will get RP and minus RP across this and they will be sustained oscillation from this generators this is essentially negative impedance-based LC oscillators is that clear? That is very they are know this essentially requirements. This RP is are canceled please look at it or circuit all that is a ISS, but essentially ISS by 2 is provided to each of them and therefore, it will act like a same circuit which I showed.

At this node it is minus RP for this at this it is minus RP for this and it can you can now say this is sustainable oscillator which is used this is negative gm oscillators is that clear? Negative gm oscillators, and these are also very popular modified version negative CP adjust that will be the one which VCO we are going to often use in real life circuits is that okay?

The problem I said in this morning that there are issues of drifts available irrespective to what? And you want to retain that change in frequency are change in time which is called jitter and phase noise. So, how to get rid of them and the circuit we use is pll. pll will not be part of this exam codes, but I will tell you what is pll because that is something you all should know because I do not know your mix circuit signal circuit people if at all you take that course whether they believe that is actually pll is a sudo.

So, it can be a mix signal or it can be a analog which you look at it like phase detectors are essentially digital parts digital confusion, but I will show you in a essentially appear, and may be a time permutable also show you very interesting what is the switch circuits are which is again make signal should talk about. So, see you till Friday.