Analog Circuits
Prof. A. N. Chandorkar
Department of Electrical Engineering
Indian Institute of Technology-Bombay

Lecture-20
OPAMP Circuits

However some of the interesting and some of the nonlinear kind of them I would like to discuss or at least show you many of these circuits are given in the books particularly the Smith and Sedra's book. So, you need not have to really write down what I am saying but these are actually taken from the book itself okay. However there are tricks something which I might have added but not much.

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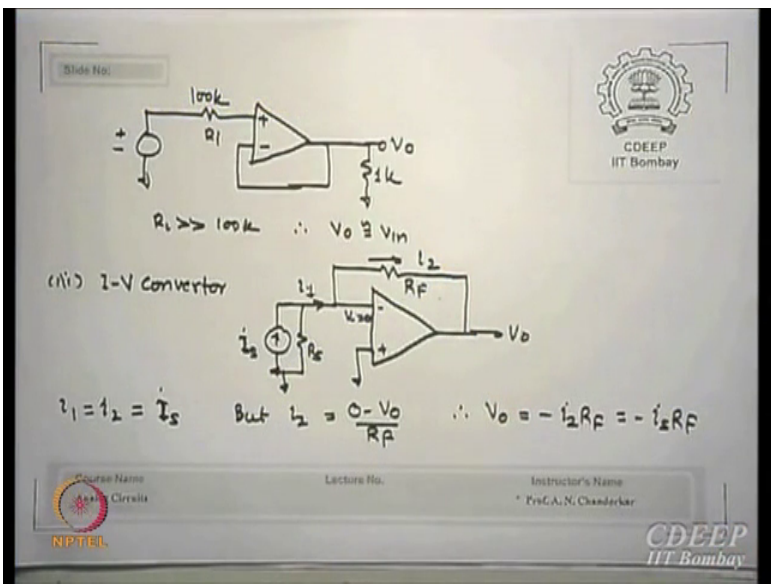

One of the use of a OPAMP is to convert of what I should say V to I converter or I to V converter and see the typical current to voltage converter you have a current source and obviously we know in the OPAMP, if it is in the negative feedback system and the V+ is grounded the current entering here from the current source must enter through RF because no current can enter OPAMP why we say so.

Because input impedance is treated very, very high roughly infinite, in ideal case it is finite. Since, that moves through this so one can write I2which is 0 - V0 by RF = I1 which is nothing but Is so V0 is Is time RF and therefore one can say output voltage is proportional to the input current okay therefore it is called voltage to current converter okay.

If you put a resistor here it will be a normal gain amplifier which can be output multiplied by something more can be actually voltage to voltage converters just to say you that why it is called voltage to current converter. This is very simple most of us uses indirectly or directly but there is something which is of an interest.

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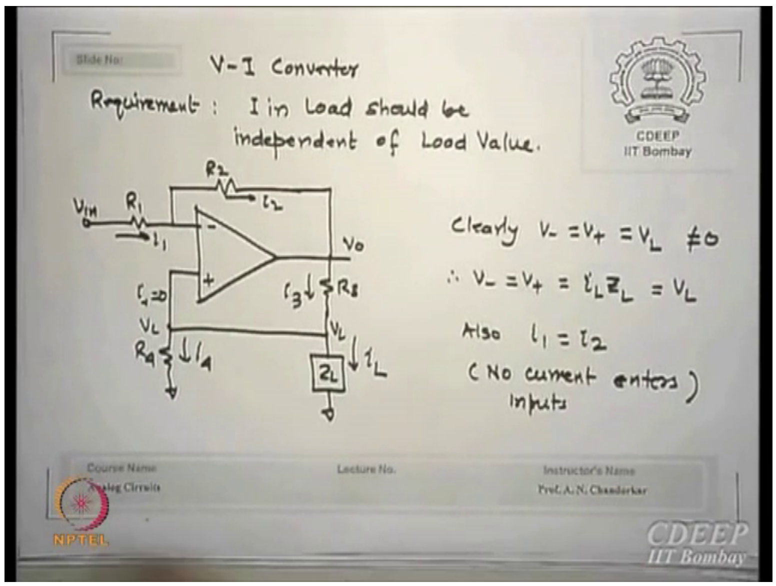

Normally all amplifiers can be voltage to current converter but here is something which is interesting if you want voltage to current converter one of the thing which you are expecting; please remember in this circuit it was I to V but if you are doing V to I, the I will be decided by the load current, how much load you put larger the load currents will be proportional to that actually but what is the good current source at the output.

That current should be independent of the load that is what we are looking. So, here is this modified circuit of normal V2 like any OPAMP the V to I converters that is not a big issue. But here is something a modified V to I converter which shows that the output current is independent of the load, here is my load circuit; here is my normal OPAMP. This is my R1, R2 feedback, input is given here.

Now what I am doing from the output I have a resistor which is connected to the load and this is the current which I am interested in IL, IL is my output current which I want to be proportional to V in is that correct. What is my requirement IL should be proportional to V in and not functions of 0 itself okay, is that point clear. What are we looking for we do not want if I change their help the IL should not change in normal sense it will and we do not want that to happen.

So, I did it I took any feedback from this common point and return it to the+ and put a resistor down they say they are very simple in interesting circuit please remember this is a negative feedback and this is to some extent positive feedback going on we are trying to adjust the net feedback now. We also know V - is V+ okay and not equal to 0 because this potential will not be 0 now okay is that point this V+ will not be 0 now there is a divide or going on.

So, obviously V+ is not and that = the potential VL is that point clear, this VL is same as this and therefore V+ is actually V-, so V- is V+ = VL and not 0 as we normally assume because there we always say V+ is grounded in this case V+ is not grounded. So, we can say on how much is VL is essentially IL times ZL is the voltage drop across ZL, IL times ZL is VL okay, now what I am trying to say that this IL should be independent of ZL that is what I am looking for.

I also know current entering here must enter to the feedback, so I1 is I2 as no current enters OPAMP okay. In what cases current can enter OPAMP, if the Ri not very high and the other resistances are small enough some current may enter OPAMP proportionately but our assumption as of now is we are close to ideal OPAMP's no current or practically 0 current actually flows okay.

This is an assumption in real life there is a modification has to be done because it may not be very, very accurate in most cases. But as I say difference potential will be order of less than a millivolt, so our assumption of V- = V+ which makes Ri close to infinity is not very invalid assumptions okay please look at the circuit if you are drawn keep watching that I all that I did is

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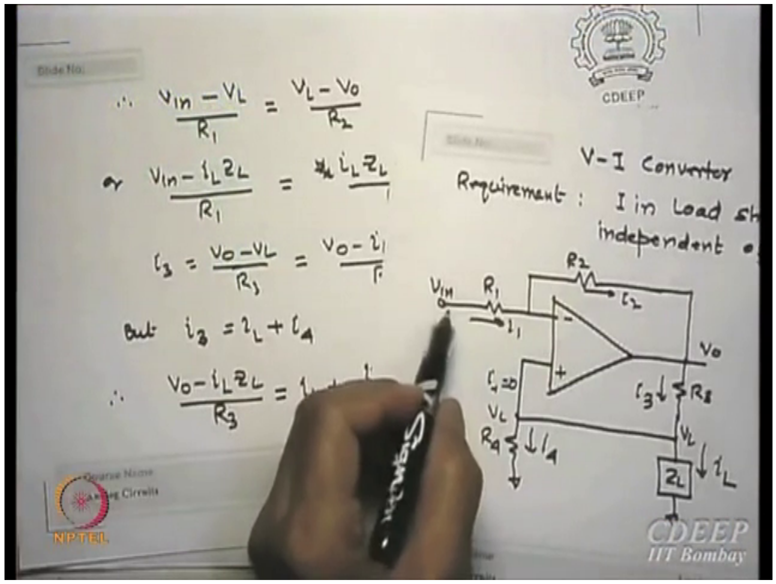

I am now trying to get the current equation V in – VL. Please remember V- is VL, so V in - VL by R1 is VL - V0 by R2 which is the current flowing from this that card I1 and I2 are equal. So, I1 is V in - VL by R1 and I2 is VL - V0 by R2 they are equal.

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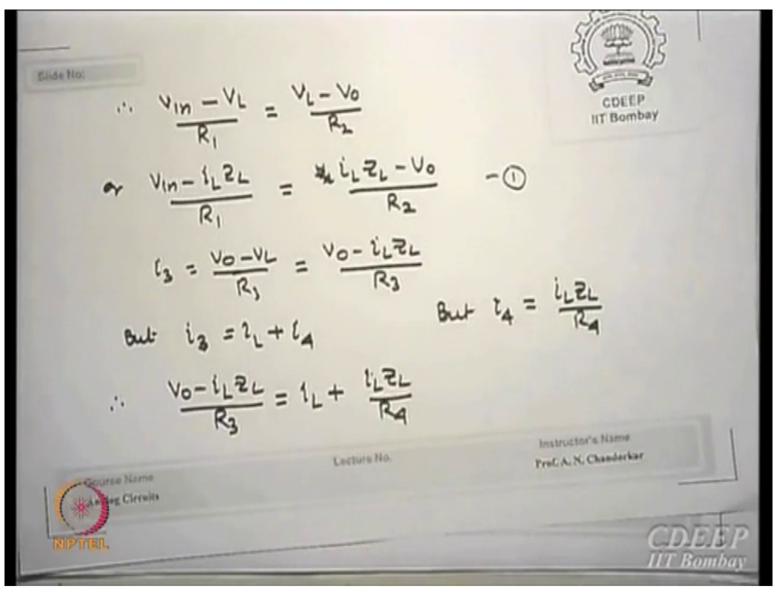

But I know real is IL R1 right now IL is ZL, so VN - IL ZL by R1 is IL ZL - V0 by R2, this is one equation of interest. For example the second equation is not done all that I am doing is substituting VL = IL ZL is that current substituting VL is IL RL my earlier equations substitute VL by ZL RL is that okay no great thing nobody Jackson going on just simple substitutions. Now I am interested in the current entering from feedback side through a resistor R3 and in that current I declare it as I3.

So, I say I3 how much is I3 will be from here in the figure this potential - this potential divided by R3 this potential - this potential divided by the simple Ohm's law nothing great okay. So, I said I3 is V0 - VL by R3 but I again re-substitute VL by V0 – I will read it by R3 this may be my interest of second equation but if you see at this point at this node what are the this node and this node are same is that correct they are connected.

So, what is the; at this node what is the Kirchhoff's law will say at this node currents, current sum should be 0. So, I said okay I3 is Il+ I4 IL+ I4 is I3 okay, but how much is I4 VL by R4 but IL ZL by R4, so I substitute again in this equation third okay which is V0 by iL ZL by R3 = iL+ R4 which is iL ZL by R4. So, if I do this and collect terms now, I am what is the interest I am looking I am looking for a load current in terms of Vin.

And what I am expecting and then it should not be function of their L if I get it I have achieved what I am starting with is that point clear. My ultimate aim is to get iL in terms in in terms of Vin but the term should not have any ZL term okay because if that happens then the source output current is function of the load itself which no one will like because I do not know what I am going to connect latter okay.

So, I want the current output which is only function of input voltage. So, if I do this collect the terms as I did from these three equations.

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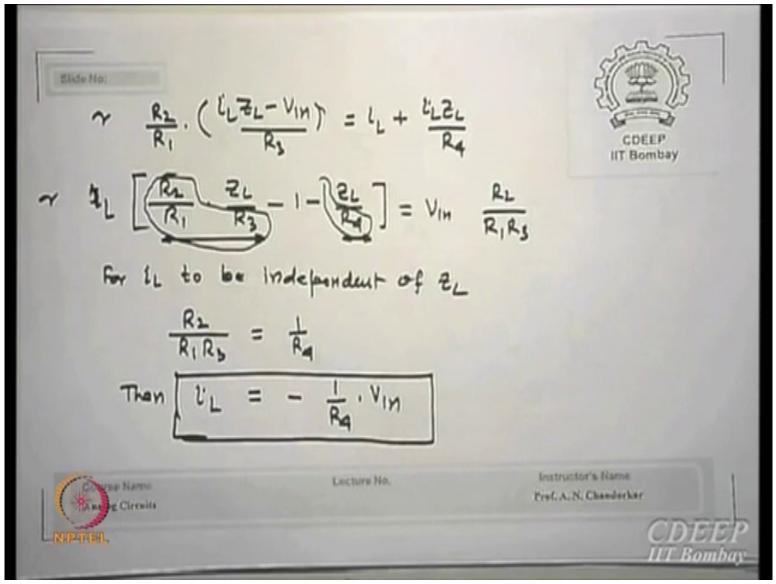

I am going to get iL into R2 by R1 upon 0+ R3 -1 -, I just collected iL terms = Vin upon R2 by R1S, now what is the condition I should have that iL should not be a function of ZL, the upper equation shows there is ZL terms appearing is that correct, ZL terms appearing. If I want iL to be only functions of resistances okay independent of ZL what is the condition I should meet that R2 by R1 R3, R2 upon R1 R3.

What is the term I am talking which is functions of Z4 this term must be equal to; then this terms will cancel, is that clear. If this R2 by R1 R3 =1 upon R4 these two terms will cancel is that correct. So, the condition that iL will not be a function of ZL will be g by R1 R3 =1 upon R4 and if I then substitute here iL is1 upon R4 into V in. This R2 upon R1 R3 has been replaced by1 upon R4, now this R2 upon R1 R3 has been replaced by1 upon R4.

So, we say iL is been by R4 is that correct, so we are now got the output current which is independent of ZL and only a proportional to input voltage but under what condition this was derived that R1 R2 upon R1 R3 must be equal to1 upon R4. If this condition is met the output current will be independent of any load value which; as long as this identity holds this will always be valid is that correct.

So, choice of resistances can make output and proportional to Vin but independent of ZL. This is very simple circuit and has been used almost extensively every other than you want current source to the next stage proportional to the input voltage. In the OPAMP there is no real difference between them okay is that clear. Right yeah that is what I say in OPAMP there is no nothing much because the OPAMP allows all AC, DC inputs. So, is that; so this is a slightly different circuit which is standard V2, I is always known to us just put a OPAMP and it is V to I converters okay.

But here we found out that that term will what the load goes may have a function of that so we just wanted to find a condition in which output currents will be independent of the node itself. This is something slightly additional circuit which we added there to make the point clear is that clear. So, these circuits are also given in books but may be on sites you can see with some websites. But this is a standard circuit which is used extensively on the chip okay.

Therefore I thought I should show you that how do we actually get current sources for the next stage okay is that correct. What should be it called? There is; this is a current source proportion of what voltage, so what is it should be called CS voltage control current source. This is voltage controlled current source VCCS is that point clear. The name is VCCS voltage controlled current source.

By similar logic we can create current controlled voltage sources, current controlled current sources everything is possible by some small tricks here are there, is that clear to you. These are the tricks which we will use whenever we need for the driving something, what we need and what is available as an input we can convert correspondingly to the next stage. Drive you understand what is the word, I keep using right.

When I actually give that output of that stage to the input of the next is called driving okay. I drive it okay is that point clear. There is of course we are not talking any technology here not many good students singing this we have a process called diffusion in the case of making integral circuits. When P-type or N-type impurities are introduced into the other kind of material and the process is called diffusion.

So, what first we put some impurities on the surface and then we call drive-in, drive-in okay impurities get in.

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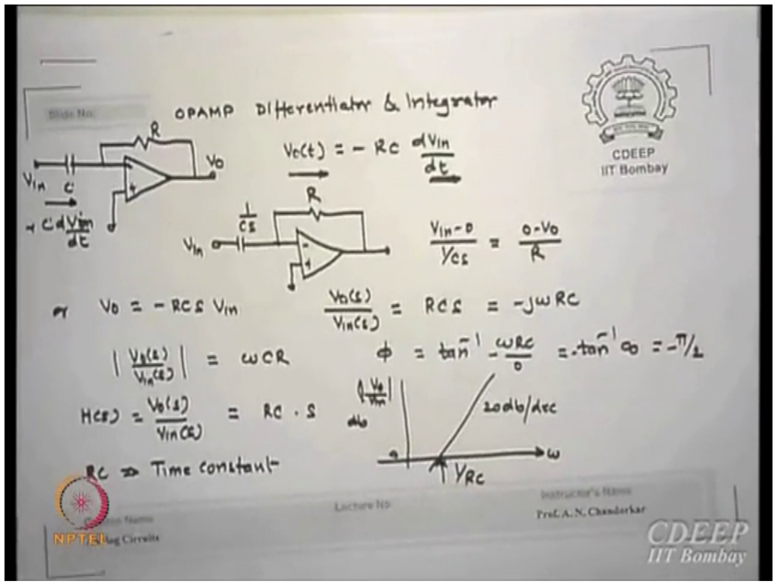

The second two circuits I will not spend much time but you they are very important circuits in our analysis or many circuits these are essentially why I am showing you this because I am going to go for filters and I need these kinds of circuits there. OPAMP can be utilized to create a differentiator as well as an integrator. Can you think if I have a differentiator and I want to convert it to integrator what should be the without thinking much.

Integration is opposite that of differentiation C dc by dt is I so V in1 upon C integral idt this fact that I just have to do opposite of that makes integral integrator convert to differentiator and differentiate are going to integrate. So, we will see both of them quickly if to anoint. This is my capacitor in the series of the input through a feedback resistor R. The current entering capacitor is C dv n by dt.

Now that DC cannot go back once I put a series capacitance I am only talking of time dependent terms. So, c dv n by dt is the current through capacitor must pass through R which is 0 - V0 by R and if I therefore write V0 then V0 is - Rc dv n by dt is that correct. Please look at what is the current in R0 - V0 by R that = cdv n by dt, essentially saying V0 t is - Rc divided by dt, so what I am saying output is proportional to differentiation differential of input is that correct, this is differentiator.

If you look at from the transfer function side put it1 upon CS, here, do all the analysis get a transfer function V0 by Vin S which is Omega CR. If I plot this as the gain function there is a 0 going here at1 upon RC and it will give 20 DB per decade rise, is that correct. So, what why I showed you if there is a capacitor here at the input, at that 0 point, the gain will start 20 DB per decade this is something you should remember.

So, wherever there is a capacitor or a differentiator circuit it is essential in a transfer function would plot saying at that 0, the gain will or transmission magnitude will start rising by how much 20 degree per decade. Can you convert it to octave also what is it equivalent will be, They keep writing many books 60 B per octave (FL) to the base10, to the base 8 (FL) convert it to logarithmic simple okay. From going to1 this to the other so is that point clear what is the point I am saying.

This is what we wanted but this is essentially saying what I am trying to show that whenever I see a capacitor there, in a transfer function of this kind I am as if trying to rise my magnitude by 20 DB per decade after 1 upon RC value okay. This fact I am going to utilize in my filter design is that what clear to you why I am showing you this ultimately my aim is not to use differentiator integral just for the heck of it.

I am going to use them as; can you think about what is let us say per se after somewhere this have occurs like this. So, what kind of filter I am looking for, high pass (FL) is that point clear. If I somehow make ahead of this something like this, so below that nothing is passing beyond that everything will pass. So, a capacitor series (FL) what I am going to do now if I put a series capacitance, this is what you should understand in principle circuit is not really great.

Because there is nothing very great happening in a circuit but what is principle behind is this if I do this, then I am allowing other frequencies. What will I need otherwise, I will also need low pass I also will need low pass, and so what is the low pass will be initially it will pass everything at certain point of frequency it should not pass ahead anything. So, if I want to invert this I should see integrator maybe doing the same thing okay.

Because opposite of this will be a low pass and opposite of differential will be a integrator. So, an integrator essentially will help you to get a low pass system a series capacitance will give you this differentiator will give you like to give you some kind of high pass applications. Can you now mix the two what can you get then, I can get both band pass as well as band reject. Why because then I right now I put both frequency like that if I do this and I can reject it.

So, a general principle of filter is essentially taken from a simple transfer function which is essentially capacitor related is that point why we were all the time worried about that where the poles are, where the poles are because at the end many applications will require some frequencies to pass and some frequencies be stopped okay. This is where the filters are most important in all applications okay.

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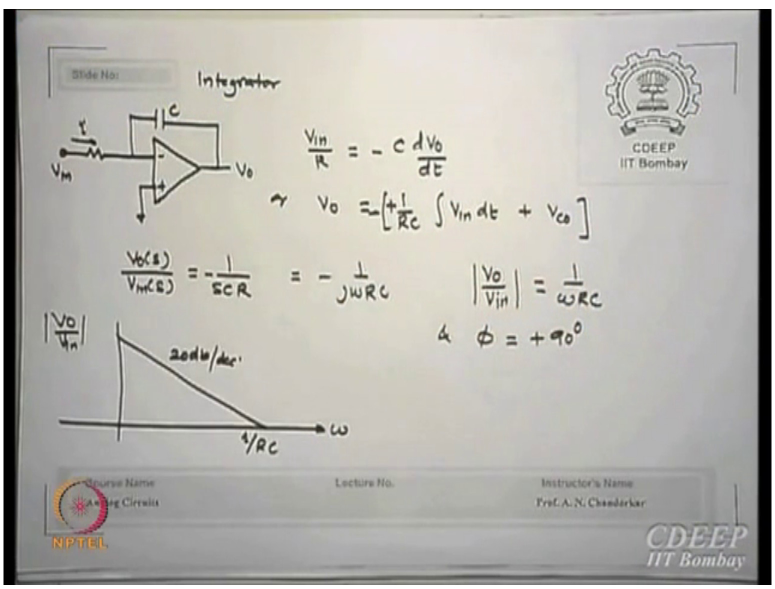

So, without going into much detail for integrator if you see an integrator I have an input register so what do I do an integrator exchange capacitor with a resistor wherever there was a register put a capacitor where ever capacitor put the resistor and it will become inverse V in by R is - c dv0 by dt so V there okay; only thing you should remember in the case of integrator this initial value has to be specified because capacitor may completely charged.

In most cases if I want VCO to be 0 what should I do let us say initial because once you do it, it will get charged. Now for the next application I want VC to be 0 again, what do i do, what should I do (FL) is that correct. So, we will see that whenever we want to discharge a capacitor a parallel path must be provided through a resistance which is switched. Why it is called switched one there because when during the process of integration I do not want that switch to the open.

This switch to a switch to be open when I am doing like this but when I do not want to do this I want to decide the charge put on the capacitor through our resistor is that current. This is something we do almost all integrators is that clear. The charge otherwise what will happen the next time it will pile on that okay, is that correct. So, if I want this term to go 0 every next time then I must actually discharge the capacitor before the next integration is going to be is that correct.

So, there is some resistor with a switch is always connected across the capacitor to remove the charge from that is that correct. This is a technique which is universal in all analog digital or whatever you say this is the standard technique of removal of charge free charge system (FL) so, there is a pole this will go up to from here to here 20 DB per decade and this is essentially saying if initially it was constant at this point this will give me a low pass.

I can adjust these two values where from it should start okay. So, I can say I can create a low pass putting an integrator I can create a high pass using a differentiator will come to filters more detail but this is just a basic principle behind filters.

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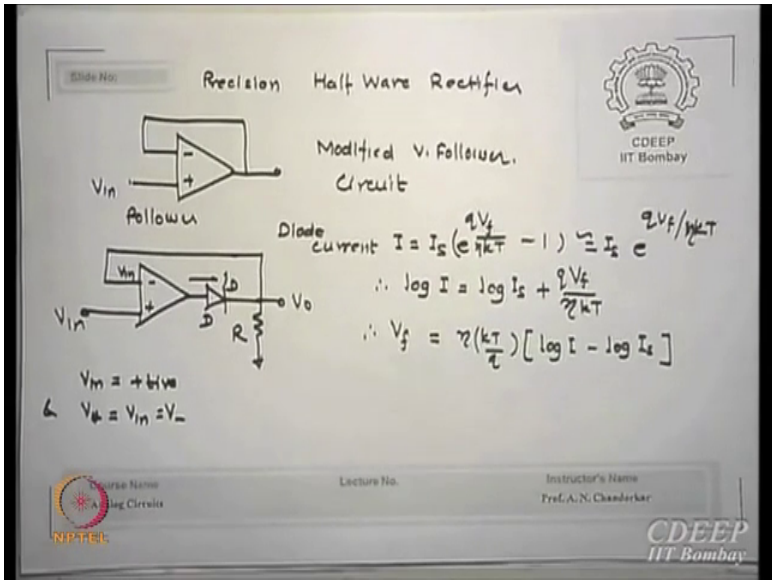

Before we go to filters here is another interesting circuit you have already done halfway rectifiers in your sector first year course. What is the very field rectify anything.

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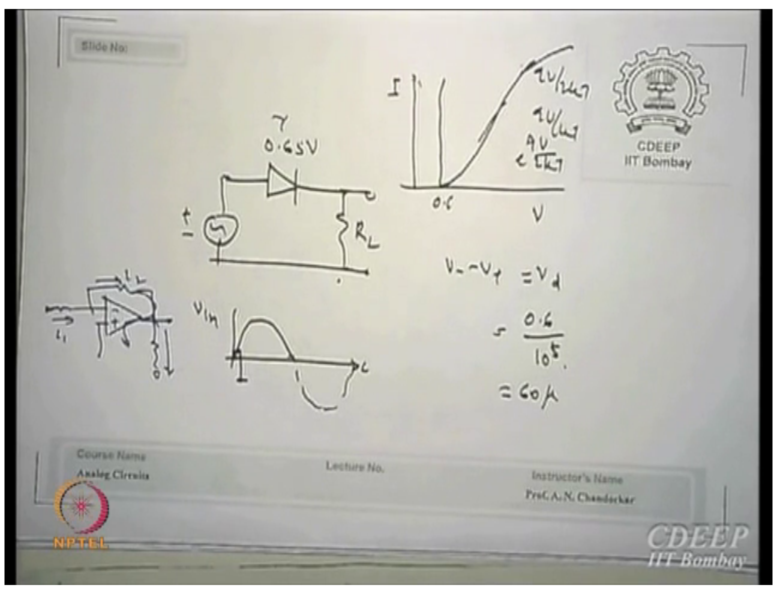

Normally if you have a diode okay load here and a signal here what is the way; say this is a half way rectifier we say so whenever this becomes positive signal the diode conducts okay, diode conducts. So, all of it is transferred to RL okay, whenever this becomes negative now it is reverse biased and no output is seen is that correct. So, we say rectified AC became DC one direction unidirectional.

Now the problem with any diode will require at least 0.65 or 0.6 or called gamma as we say voltage drawn for turning it on okay cutting voltage is roughly 0.6 to 0.65 typically 0.65. So, at least till that happens the device will not turn on, is that clear. Now this fact means that; but I want that means for certain values you cannot strictly switch it on, (FL) is that clear. This is a weakness of this so I want to make a more precision.

I say as close to 0 can I get it or maybe few micro volts 50 micro volts instead of 600 millivolts I want 50 micro volts (FL) though this will be therefore called word precision rectifiers is that correct. Why precision? I want this switch over we are occurring at close to 0 or at least in micro volts okay not in millivolts this is what we are looking for and therefore this circuit is essentially called a rectifier again as I said I will not dwell too much in detail just to the principle behind these.

Circuits are given in work so it is not anything great I am talking I am only trying to explain what is the basic system we are working at. There is a diode in series to the output of a OPAMP we say what is this connection will be called, follower. So, we are using a follower out in between the load and there is a diode and we expect V0 will be then switching on off at very close to 0 or as close to 0 as is possible.

Now think of it, diode has a voltage drop of 0.6 volt okay for cutting what is the typical gain of an OPAMP I mean list if an OPAMP10 to power 4 or 10 to power 5. So, if I see input if output is 0.6 volt what will be input V- V+ is my Vd, how much will be at that .6 divided by10 to power 5 how much is this, this is 60 micro volt okay. So, in 60 micro volt difference the diode will conduct, is that correct or not, conduct 60 micro volt okay it depends on the gain I use ok all right.

So, is that one clear that very small change in V in differential I can make output go high or low I mean this after the rectifier because diode will be switched off at less than .6 is that correct. Anything less than that will switch off. In earlier case it could not because to the .6 voltage drop was required to on and off the switch okay. This fact that I can now switch off or switch on even at a very low differential is something very great.

Because then the output will be immediately 0 going to cut off or going to full signal passing by just small change is that current. So, is that what precision is clear to you why I call precision because small the input can rectify now because the gain is very high the diode drop of .6 is equivalent to in 6 micro volt at the input which means small change here will actually create 60 micro 600 milli volt at the output which will turn it on our turn it off this is why we say it is precision rectifier.

So, the theory behind is a diode current is IS qVf by n KT Eta KT, how much Eta in silicon devices, if I plot IV (FL) e to the power qV by how much (FL) I just told you that some day before you go look at it the normal slope starts with 2KT, 1 upon2 KT then becomes1 upon KT kind and then again become too critical which turns start dominating in the currents okay. Which phenomenons and therefore it is proportional to differently okay.

This is just to show you why it is precision the word was people there is they have not explained in some books okay. So, I thought at least you should know why these are called precision review (FL) this fact you must understand OPAMP is doing great business for you, indirectly. It is not actually participating because (FL) that is why it should be important okay. (FL)

There used to be initially when we started education you know your time at 30, 40y years ago. We used to have a computer those are digital computers have not come okay. We only knew somebody know when we say logic and get (FL) there were other kinds of computing systems which were their thoughts analog of computers we have worked on that, analog computers okay.

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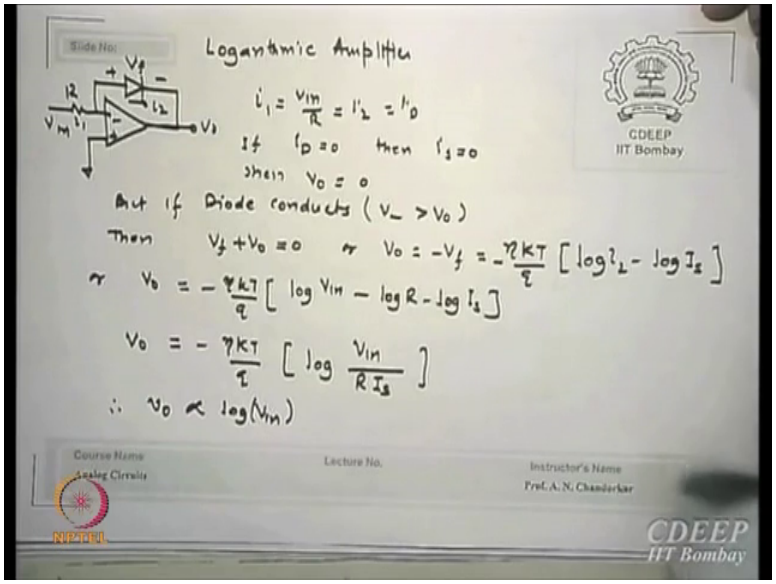

So, analog computers (FL) but we could do lot of games using analog computing (FL) it is normal circuit instead of a register here I put a diode here is that correct I put a diode here. What is the input current V in (FL) is that correct? But that same current must go through this which is the I2 which must be the diode current curve. Please remember diode does not listen anything it only passes as for this diode theory.

I just calculated Id current in the rectifier did you see that current Id, Is e to the power q by KT is the Id current is that diode current. Now please take it if Id is 0, how much is V0, 0 no connection that means if Id 0 that means there must not be any current here why it should not be current here because no current can enter OPAMP. If there is no current here there cannot be current here. If initially there is no capacitor and output is 0, if there is no power current passing through this okay?

So, if Id we can stress that means you can say last voltage but if capacitor it really finally discharged through internal OPAMP okay. So, if this is 0, Vin has to be 0 then there is no current here. But if diode conducts what does that mean this potential must be larger than V0 (FL) diode cannot conduct is that good. If that is so, one can say if this is the voltage drop VF, VF+ V0 must be 0 because this is 0 is that correct.

Which means V0 is -VF and VF (FL) so, V0 is - ETA KT by q log I – log Is (FL) so, V0 is ETA KT by q log I log Vin– log Is or to say ETA KT by q log Vin – log Is V0 is proportional to logarithm of Vin with a constant this is the constant so this is essentially called logarithmic amplifier. If this is 0 no current, if there is no current that is diode is switched off, no current can enter here either okay.

However if the current has to pass this potential has to be 0.65 or this should be at least higher than this. That means this potential + this potential must be this, this+ this some sum of the two that is V0+ VF must be 0 because this point potential is 0 at this node is that correct. Which means V0 must be –VF when the diode conducts correctly. When it is not conducting this potential has to be smaller than that only then not conducting.

Essentially which is not conducting there is no potential here, if there is no potential or there should not be any current coming from. So, there is no 0.65 drop it can create. So, diode is switched off okay (FL). Irrespective the expression which I got whenever diode will conduct it will do logarithmic situation, it has to conduct is that correct. (FL)

Which is essentially given in terms of the values given to me but it is 0.65 anyway. (FL) is that clear. Then only it will conduct, so we say (FL) so it will become a anti log amplifiers exponential (FL);

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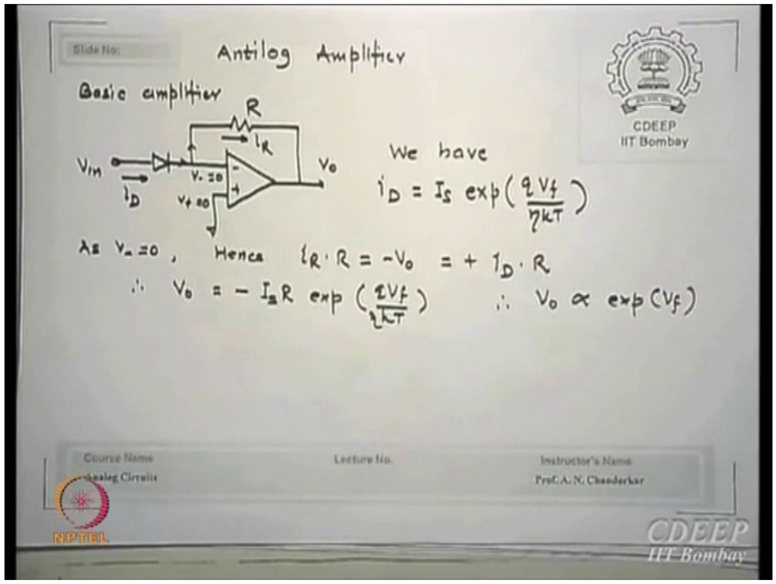

So, is it clear to you there is something mirror is going on. Mirror is something slightly different from copy okay (FL) this is very interesting analog circuit (FL) so there is nothing great time, so I am just repeating OPAMP basic theory current enters here goes through here, if the diode is conducting this will happen if not conducting it will be anyway system okay. (FL) I have V0 is - IR exponential qVf by KT.

So, V0 is proportional to qVF by this essentially exponential of the drop, VF is a function of all Ii whatever you are looking okay, so (FL) exponential R antilog amplifiers. So, you have a log amplifier, anti log amplifiers your precision this; I will ask you now you try maybe you look in the book. There are few more circuits in and along you did in your second year or maybe doing now. There is something called clamp, there is something called limiter use diodes there.

A precision clamp and precision limiter (FL) I repeat you try yourself two circuits, all these circuit (FL) I want to now create a precision clamp, what do you mean the precision clamp? (FL) current should not exceed beyond a given value at any cost okay precision (FL) and see that they are better than without OPAMP circuits okay. (FL) using OPAMP's will be better than without using movements.

Actually do you understand this simple logic (FL) the hoe actually OPAMP does nothing all that we are doing is only this circuit is that clear. So, why OPAMP then because otherwise it is not;

this virtual grounding (FL) that is essentially because of an OPAMP is that correct. So, OPAMP property it directly is not appearing in anywhere here do you see anywhere OPAMP (FL). But you remove OPAMP and everything will be lost is that clear, so, please do not feel that OPAMP does not play any role, OPAMP actually is playing all the role indirectly and that is what you are utilizing those properties.

So, (FL) nothing is happening in the triangle anyway (FL) now that you have quit this is a very trivial query (FL) through an OPAMP the output stage actually sinks it, is that correct. So, the current path is like this is that clear. So, this fact has to be understood that open looks as if it is open circuited but it is not it is essentially providing your path internally is that clear. These are trivial but this makes OPAMP theory much more interesting that how OPAMP is doing all this mischief okay. (FL)

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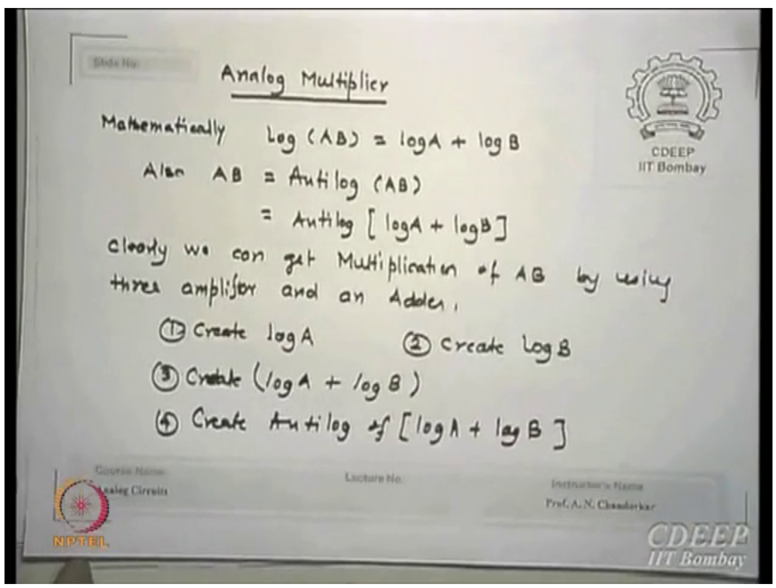

Okay, so there is an amplification sorry there is a multiplier which can be analog. What do you want to multiply? I want to multiply two voltages V1 and V2 okay. So, I say okay, I go back to my simple math's, I say log of AB is log A + log B, log of AB, so AB is my product (FL) AB is which is the product of A and B anti log of log A + log B is that correct, anti log of log A + log B (FL) I should create one logarithmic amplifier to create log A.

Similarly I should create logarithmic amplifier for log B then I must create sum of the two (FL) I create log A, I create log B, I sum them by summed up then I take antilog so that I get AB as multiplier (FL) is that clear. Given two voltages to multiply plus create logarithm of first voltage create logarithm of second voltage then add them. How do you sum? Summer is the easiest circuit which you already know (FL).

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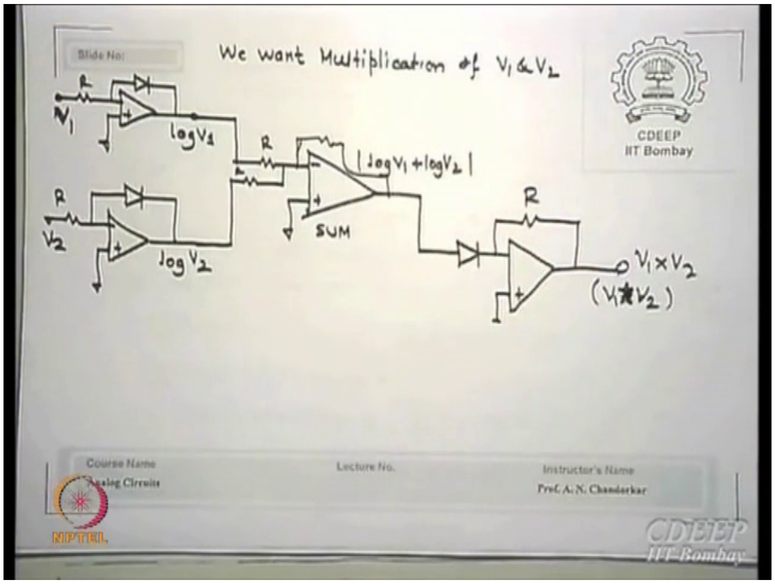

This is my V1, the first block is giving me log V1 this is log V1, this is log V2 what is this summer (FL) is that point clear. So, if you are given a function now you can understand how we were doing in analog computations of arithmetic's you can see how we were doing it. We were trying to use OPAMP's everywhere to create arithmetic is that correct, arithmetic? (FL) by choice of values is that okay. (FL)

Okay, since we are looking for; ultimately what is the importance of my OPAMP, for what I am looking for? I am looking for what we called there is a word in electrical engineering you are also doing a course in that name it is called signal processing is that the word is signal processing. What does signal processing means? There is an input signal on which you do some mischiefs and get some output signal okay.

Now what mischief we do is of different game, which transforms (FL) but there is something processing is done. One of the signal processing requirements is, filtering that means certain part of the signal I want to pass and certain I do not want, is that correct. So, this is first signal conditioning (FL) one of the major components of signal conditioning is filter, is that correct. Now if you want to learn filters you must know bit little bit of Bode plots because only then you know how the filters can be created.

What else you will require in signal conditioning other than filters. (FL) in world is as you are learned by now world is digital like or not like, ninety percent of the chips you use or systems use are digital. But all nature signals are always analog okay. So, what do you do? So, you must convert our analog signal into digital that is also another signal conditioning or signal processing. I am convert an analog signal into a digital signal.

And for some reason I want to display like (FL) I want to display that like in computer also if you see many laptops or this they show a watch which is like running analogue they must be having a digital-to-analog converters is that correct. So, the last part of this course will be analog to digital converters and digital to analog converters. Which ones will be maximum used A to D because you need not require every time display which is not enough. You need only bits.

So, all the processing first thing is many other processing part but actually the two of them which are most crucial for us one is filtering the other is A to D converters.

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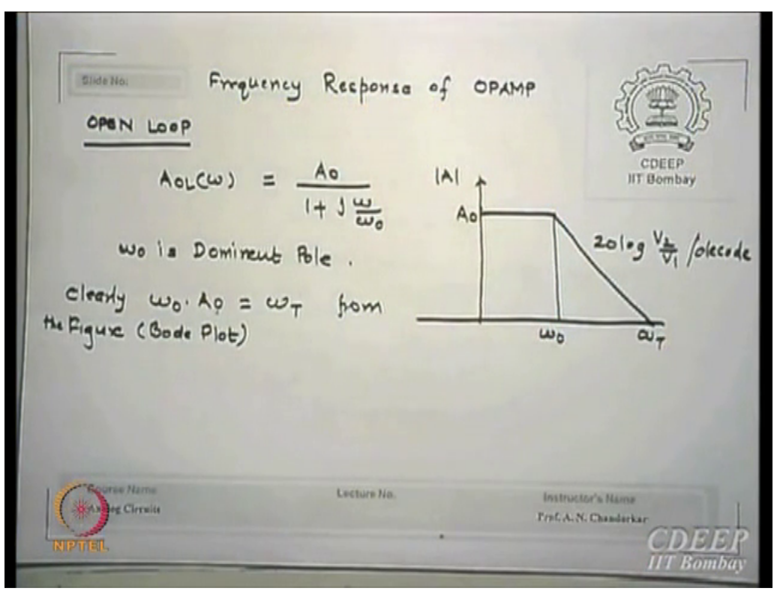

So, we were looking for frequency response which is essentially for any amplifier or any system is interesting. if you have an OPAMP which is an open loop case then the open loop gain is A0 upon1+ j by Omega 0 this is a transfer function for a normal open loop amplifier okay, OPAMP (FL) gain is falling 20 log V2 by V1 after Omega 0 and at 0 the gain is DC gain which is A0, this is the transfer function of open loop OPAMP and therefore Omega 0 is the dominant pole. (FL)

Assuming there is a dominant Pole far away from others what does that mean what is the cry that what it will satisfy automatically. If I have a dominant poles far away from other poles and 0's what does that actually guarantee me. (FL) what will be the phase margin then positive system will be stable enough is that correct system will be stable enough okay. So, right now assumption is there is a dominant pole away from other poles so only we are looking for the first pole okay.

At only; please remember this is an interesting fact you can see Omega 0 to Omega T (FL) because every decade you move on the frequency how much deviate goals 20 DB or 20 log A0 essentially is what you are going down is that correct. So, the (FL) is that correct, let us say10 times, this is10 times, is that correct, 20 log for a decade. We have (FL) is that clear, so what does it trying to tell you it says that if you have a dominant pole approximation valid system is stable Omega 0 into A0 is the unity gain frequency.

Which is essentially saying because unity gain means (FL) gain bandwidth is constant please look at it what I said (FL) A0 Omega 0 gain bandwidth, is that clear okay (FL) you say gain bandwidth product is constant for any amplifier. So, Omega 0 is the bandwidth again is A0 which is constant. Bandwidth no, no the bandwidth is the point at which the gain starts falling that is the first pole is the bandwidth is that correct.

So, A0 into Omega 0 is the gain bandwidth product is constant even here it should be constant so here if omega t is this the unity gain must be achieved. What is this frequency? Gain bandwidth constantly product of gain into (FL) what is omega t how do I define this, A is 1, so what is the multiplier 1 into Omega times gained into frequency but that means this frequency into one must be same as anywhere which wherever you go that is how Omega T was derived in fact.

If you see gm by c was derived on that principle. Please go back and read what we said please read it this equation is always valid, if dominant pole approximation is valid Omega times (FL) this relation is valid for dominant pole approximations.

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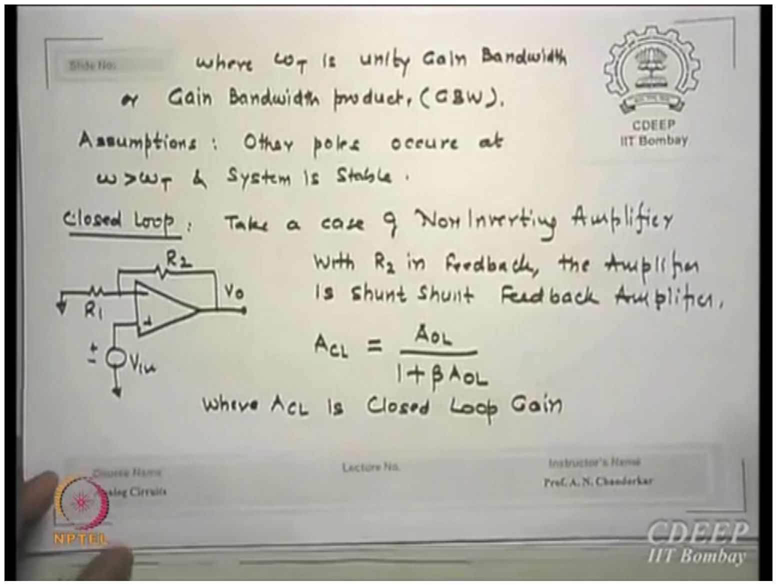

If that is so then Omega T is unit again bandwidth or gain bandwidth product GBW assumptions other poles occur at much higher than Omega greater than Omega T and system is stable this is my assumption which I started. (FL) Now let us say I have an amplifier which has a closed loop system with a feedback of R2 and series of R1 input is that R1input at V which is this kind non-inverting kind same thing can be done for inverting do not worry too much. (FL)

This is which kind of feedback is this output V0 (FL) so voltage is in shunt to that that means the shunt feedback connect (FL) is that clear, shunt-shunt amplifier is that correct okay. So, (FL) actually use OPAMP this non-inverting kind or inverting kind and see that shunt-shunt amplifier (FL) and use feedback and verify whether our theory what we said is valid (FL) so the closed loop gain for this shunt-shunt amplifier is AOL upon1+ beta times AOL.

So, if I give feedback factor beta if I derive open loop gain you help then I can get closed loop gain which is how much is closed loop gain for this1+ R2 by R1 so I must get using this as well one upon R2 by R1 and which is that value will be that will be a DC gain but I am not interested only now in DC gain. I am interested in frequency dependence is that clear. Here AOL is not A0 it is AOL which is the frequency dependent terms.

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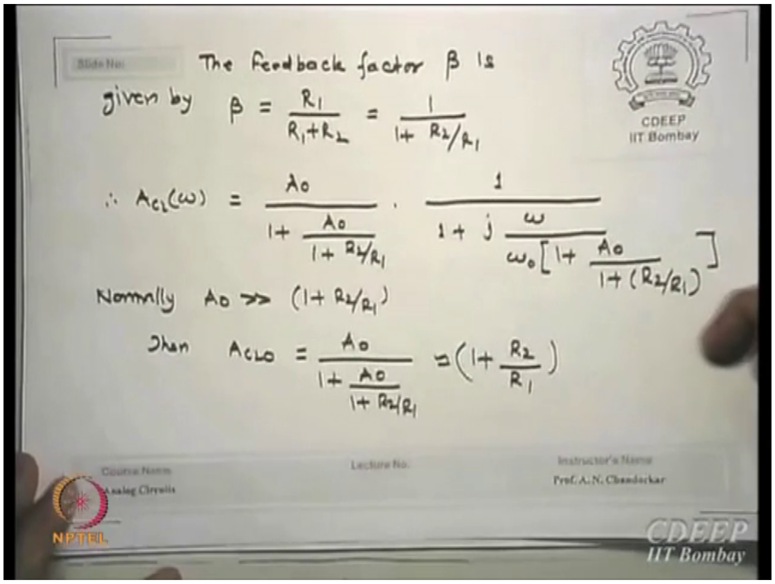

So, now I use this theory from this figure I see the feedback factor is given by R1 upon R1 to R2 or something like this now I write closed loop frequency dependent gain is AOL upon1+ AOL times beta, I collect the terms normally this AOL on open loop (FL) is that term correct to me AOL is much greater than1+ R2 by R1 is the term open loop gain of an OPAMP is very large compared to1+ R2 by R1.

How much is a well even on open loop will be10 to power 4 or10 to power 5. So, our assumption at if that is so I can reduce some terms out of that if this is valid. I will get closed loop gain at DC value is A0 upon 10 A2 upon this which is roughly equal to R1+ R2 so that point clear ACL 0 is1+ R2 by R1 this is the value you got it. Under what condition you got this open loop gain is much larger in deriving that OPAMP normal characteristics also we kept saying that that the AOL is very large, is very large.

So, only the current goes through input to the feedback network this is the condition which we are satisfying there please look at it, what did I say, I substitute (FL) A0 upon1+ A0 upon1+ R2 by R1, if A0 open loop gain of a OPAMP is very, very large DC open loop gain is very, very large this term is A0 upon this can be approximated by1+ R2 by (FL) is that clear divided by A0 1 by A0 is 0 okay, so is that clear the closed loop DC gain. (FL)

Under what conditions we have actually got it A0 is much larger than this value is that correct. So, is now I am clear that using a feedback when I make the same assumption again I get the same gain values which I had got it, so is that now clear that the feedback amplifier theory is more universal and the normal solutions which we get we assume that automatically and solve for it because we say OPAMP is ideal input resistance is higher gains are very high.

This assumption is actually coming from this expressions is that correct that A0 is much larger therefore this is the value which will get is that here then that is why I say that anytime you do feedback it is much more general case you do whatever otherwise is a specific case okay. So, this example which I want to show you is how do I got that time by assumption is now provable that my assumption is this which I can still get the same value okay.

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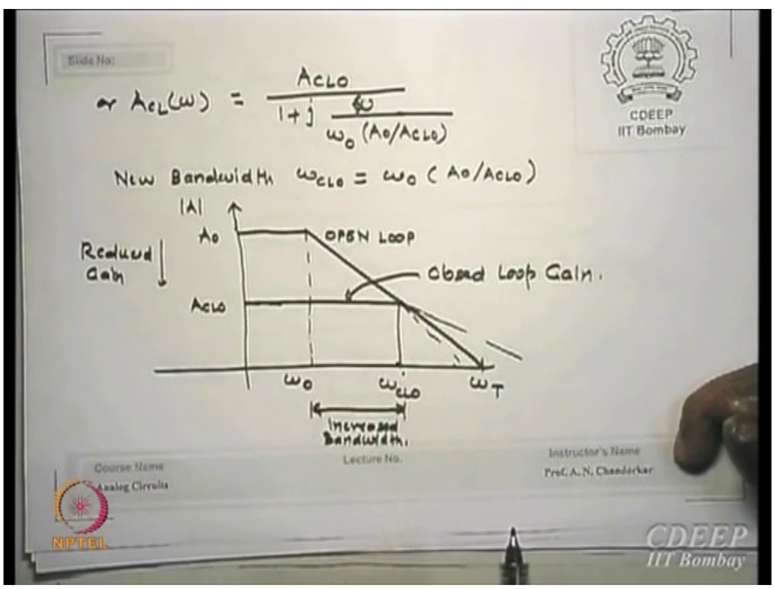

Now if I substitute this back into my closed loop this then this = 1 ACL 0 upon1+ J Omega upon this okay. So, what is the new bandwidth now, we substitute (FL) Omega naught into A0 by ACL 0 (FL) is that correct, let us see what we are done. If you have a open loop this was your amplifier Bode plot is that correct. If I have a closed loop the ACL 0 is the DC gain okay and it has a pole of Omega CL0 which is here Omega 0 times A0 by AC and 0 (FL)

However according to me I say onwards it will still follow the same path to Omega T is that point clear what I said. I could have said (FL) but I say no from beyond this value it will always follow the same path. What does that mean the close loop gain Omega T should be same as Omega T of open loop is that point clear, what is the proof I had to do if it follows like this means Omega T of closed loop must be Omega T of open loop then only it will follow the same path from the same point.

So, now we will prove that both Omega are actually equal is that correct if they are equal (FL) is that correct at the cost what I improved my bandwidth from Omega 0 to Omega CL 0 and unity gain bandwidth remains same now we must prove that unity gain bandwidth of a closed-loop system is same as unity gain bandwidth product for unity bandwidth product for closed loop if we prove it my all assumptions that all that happens (FL)

Can you think now if something else this can also occur (FL) the bandwidth technology so you can go anywhere and you find if I reduce my gain I will improve my bandwidth is that point clear if I improve my decrease my gain I will improve my bandwidth or vice versa if I reduce my bandwidth I can improve my gains. In what case we said gain can still be boosted without loss of this cascade.

What is the penalty we paid there additional power we have to give because all transistors must get saturation VDS (FL) what is the advantage you got we broke this line okay, okay. So, I had done this.

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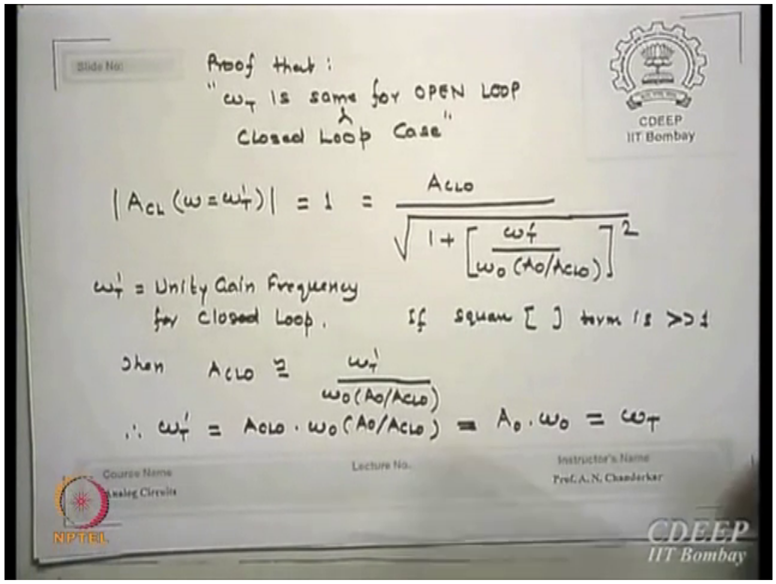

Proof that Omega is same for both open and closed nope ACL at Omega let us say Omega T dash is for closed loop and Omega T is for the open loop. So, ACL at Omega Omega T is how much? Unity is not it. (FL) The unity ACL 0 upon Omega T dash upon Omega 0 - this is a last expression (FL) please remember this expression (FL) Omega is not unity that is the definition I am saying so that =1 is this function.

If square term is much larger than this bracketed term is larger than1 which will be because this term is we can think like them. Then ACL 0 will be Omega T dash upon Omega 0 is A0 upon (FL); If this term is larger than1 then I knew one square terms (FL) so I get omega T dash upon Omega 0 into A0 by is that clear (FL) so I will get this expression so what is Omega T dash, now ACL 0 into Omega 0 into A0 by ACL, ACL at Omega T dash is1 substitute that equal to Omega T dash.

Then I say if the condition is such that this term is much larger than1, then I square under root goes then I say ACL 0 is this. (FL) And if I say that Omega T dash is Omega 0 is 0 by ACL 0 into ACL 0, ACL 0 cancels which is A0 into Omega 0 which is your Omega T, so your Omega T dash, so under what condition this was valid that the Omega dash T by Omega 0 is A0 ACL 0 is much larger than this if it is guarantee then the Omega T dash will be always equal to Omega T is that correct. So, our assumption in our figure and which always normally because ALC will always be lower than that this condition will be always met.

So, onwards then the gain will fall with the same point 20 DB per decade down to Omega T is that correct. So, ever if I have an amplifier I can now think closed loop (FL) is that clear that is what essentially feedback amplifiers okay, is that clear. This is the strongest point of feedback that I have now control over the fall of gains as per I what I am looking for is that clear. (FL) I say in some cases it does not some other cases it will.

So, what is the advantage of feedback it always splits the poles okay (FL) this is the theory of OPAMP frequency response is that correct. So, close new gain (FL) I also explained to you that under what conditions this expression where is that that the gain is valid equal to1+ R2 by R1 only and only if the open loop game is very, very large which all OPAMPS why A0 is always very large the define followed by gain stage gives very large gains is that correct.

So, is that why we are using OPAMPS because this is guaranteed for everything by using an is that point clear. This is an essential feature of OPAMP circuits (FL) DPAMP define because it is just a differential amplifier okay because if there is no feedback then it then it will saturate because as soon as signal V0 exceeds VDD it will saturate to VDD or do non-linearity will start building amplifier will not remain amplified is that point clear.

This is the important factor which we all should consider when you work on OPAMPS. Why OPAMPS why analog people do not want to use single ended amplifiers okay or cascade amplifiers but they want to use OPAMPS. That OPAMP is therefore extraordinarily great device which can do almost everything what you are really looking for is that clear. I got still AM chip it is controllable whatever values you want you can achieve those values very, very accurately that will quit this. But if introduced (FL);

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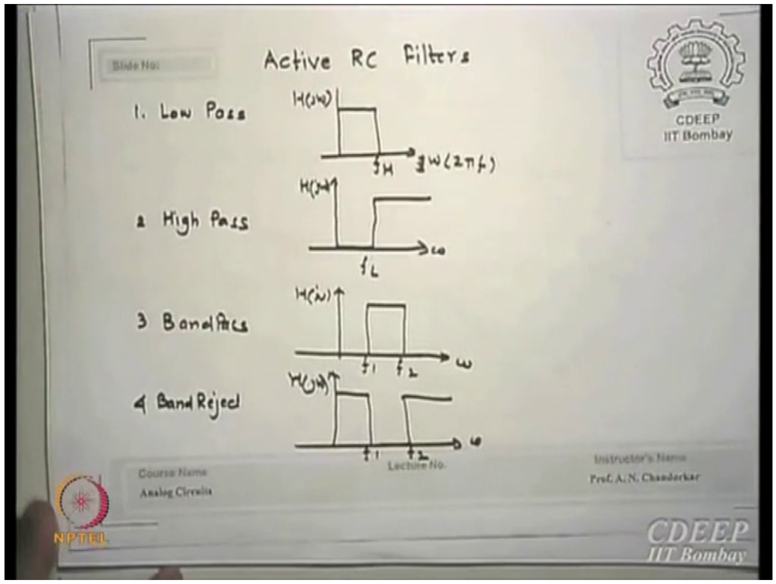

So, next time we are going to start this area for which we are waiting signal conditioning (FL) all they circuit so far shown here what were they were independent functions now I say multiple functions can be used multiplier was multiple functions but otherwise we will start looking use of now OPAMP circuits okay. First thing will you use them as filters okay is that point clear. These are 4 kinds of filters we want to use just for this the low pass filter cutoff (FL);

Why it is called a FH but it is the highest frequency up to which gain or transfer function is one okay. This is the lowest below is it is 0 rest is high okay if I have a band pass between some frequency f1 f2 our gain is the transfer function is1 and if in between there is something in pseudo rest it is1. Then we say it is band reject okay band reject.

So, we will use this all 4, can you think that actually only2 should be sufficient to create other two you square (FL) square is that correct, (FL) you can always get banned pass and band reject so basic to filters concerned low pass and high pass see you then.