CMOS Analog VLSI Design
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Lecture – 22
OTA Operation Trans Conductance Amplifier & Application

So, we I have already discussed the OTA part, as a concept and as also discuss the circuit. Today we shall starts with, some applications. These applications which few of them I will show you as I say there are many, but the major once I will actually like to tell, and the first in an foremost what which OTA is very popular, is realization of active filters. What is the difference between active filter and a passive filter? That if we do not have any device only RC or, R and C circuit we called passive filter.

of course, please do not think that passive filters are bad or something, passive filters are many a times very good actually, but there are their own limitations many times because that the realization on silicon and therefore, it is better to go for active filters. We already done in our second year. Active filters using opamps, certain key kind of blocks, which we say that we can always create using (Refer Time: 02:33) this or maximal flat filters, choosing the whatever you wish to have specks.

We can have second order third order 4th order nth order filter designs, more accuracy can be built. Cutoff can be very sharp can be slow 3 dB down point can be shifted all possibility exists, and if you all aware about the metlabs nothing this is a very trivial job in the case of using metlabs. So, do work in some case the first attempt of any filter design should on metlab so, that you see the response and know what is going on.

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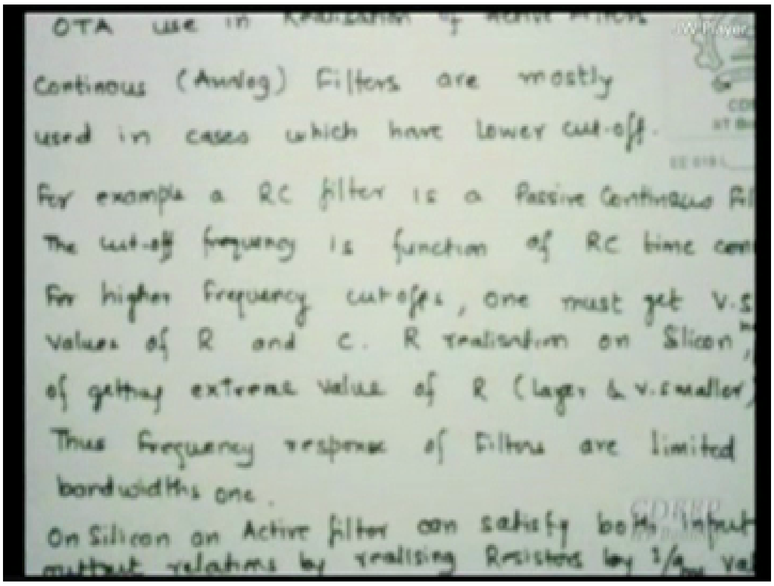

What we are interested more so, in the realization of filters with using OTAs. And one of the problem with most of the filters requires higher frequency cutoffs, that is a bandwidths are required higher and; that means, if you look at normal passive filter it is time constants is 1 upon RC frequencies R 1 omega 1 upon RC, either you reduce C which at best you can create out of a mass transistor, with all parasitics there everything there, that is not very small value as we thing.

So, you can and reduce R, but if you reduce R silicon has a problem that they it is a limited on both sides. We cannot have very high resistance, because the sheet resistance is not very high. So, area it take it is value. If you take a very low, R then the exactness of that R because of the variation in parameters like mobilities is very difficult to get 10 ohm one ohm it is very difficult.

That means one of may become 2 ohms also. On chip there may be many which are varying drastically remember 50 percent variations. And therefore, very low resistance of very high resistances are not greatly realizable on silicon. In circuit we can always one ohm and fair enough, but when I do in silicon I will find I an 100 chips only one worked. So, that that something which I am worried about.

So, active filters try to elevates some of those problems. And therefore, the OTA base filters have become very popular. Essentially what we are doing we are replacing R by 1 upon gm. And we know gm can be by because of feedback system we can make much more accurate gm values compared to passive Rs and much more controllable by bias currents. So, we can have large value of variation on gms, for which or even tunable we can actually tune it back by feedbacks. So, something which is great in the case of active filters we would like to see n.

Is that why a OTAs are and see gm is coming from an OTA output is essentially iout if it is a transconductance amplifier. Let us start with the actual filters. Typical OTA as I have shown here its.

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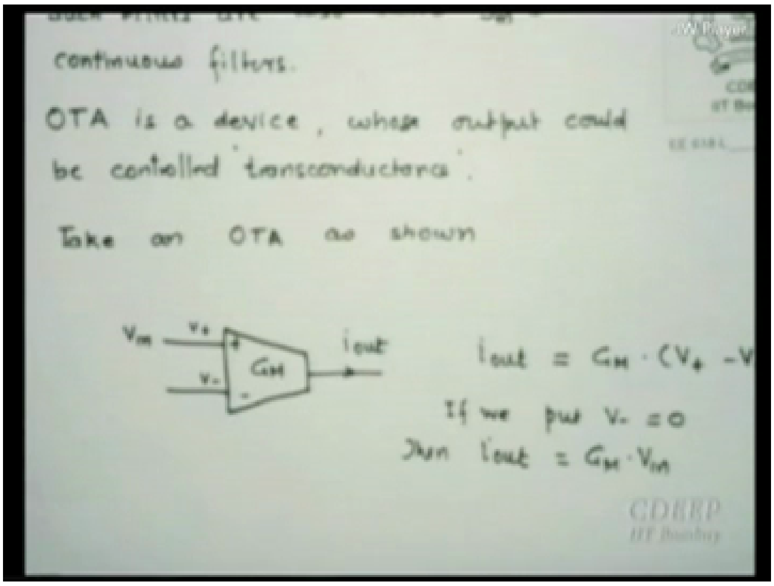

It has a transconductance GM, and in the case of GM we show in actual circuit which I have showed you. If the k the multiplying factor k is used one. Then small gm and capital GM are same otherwise k times small gm, is essentially the capital GM. And there will be said iout current is proportion to GM V plus minus V minus.

So, if we put v minus 0; obviously, which we can do any time so, this is iout is gm times Vin and iout by Vin is therefore, the transconductance. So, iout we have now trying to see, can I have use this block to create a GM circuit, which then can be use in a gmc filters. So, that is the basic idea behind all these choices.,

So, let us see is anyone anything there is much return there is nothing great in figure, all that I am saying, I am trying to use iout to G Vin any is it ok, the kind of thing right now shown here is open loop is right now open loop, but we like to use most of them in close loop configurations.

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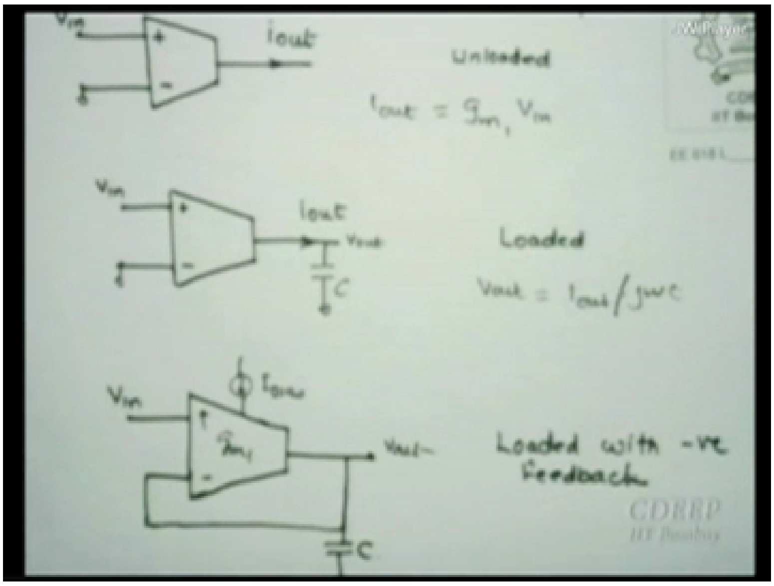

So, let us say this is the this (Refer Time: 05:46) for say, and this is the OTA which you have started with. And then we always said iout is GM let us say right now, GM is equal to gm 1 or whatever if it is one we wish to good one times Vin ok.

Now, if I say if this is the system I load it by a capacitor C. Is that ok? I can load this iout OTA of course, this are still grounded. Of course, they are remove the ground soon, but right now I will kept it in real life what I am going to do this. So now, what will happen the output voltage here, is iout into j omega C oh sorry

Student: (Refer Time: 06:49).

Sorry, sorry iout upon j omega C impedance is 1 upon j omega C.

So, I now figure it out, that iout has something to do be gm, there is some Vin there sitting. So, Vout by Vin has a function of gm by C kind of function, is that correct that something I am seeing it.

So, I said to control it better of course, Ididn’t show you, but you can always say this is my I bias, which is controlling my gm. And now I will do, this is my Vout I actually feed it back, like this and here, I actually put the capacitance. This is loaded and with negative feedback.

Why we normally do not do positive feedback?

Student: (Refer Time: 07:54).

Because it is it will become unstable, because growth will start. So, this is an interesting simple circuits I can solve this now, I will see something few things you just draw it. This is only step by step I am showing you have couldn't directly written this and solve it, but I thought how do we realize this is how we started thinking.

So, my transfer functions for this is Vout by Vin. And if I have look now, for any transfer function of a low pass filter n is it drawn everyone. If you see a low pass filter.

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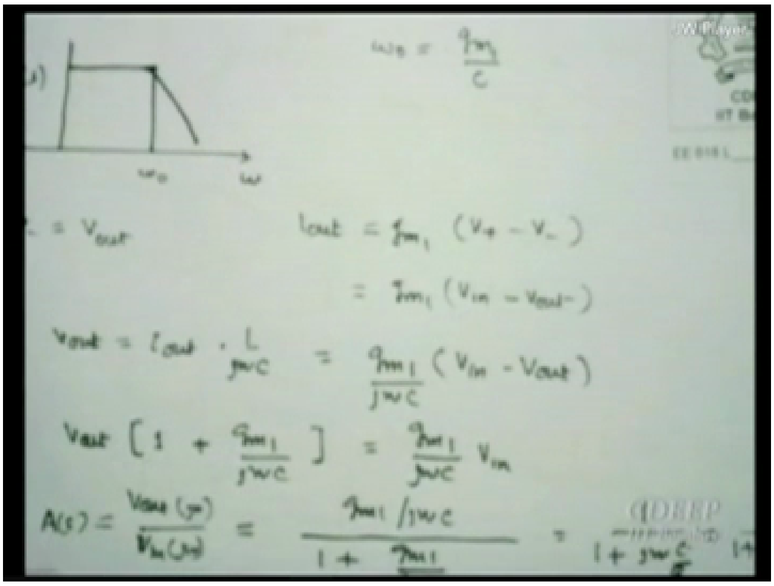

Typically,I am looking for, let us say transfer function what can be this into omega. So, I want ideally, this kind of transfer function sharp fall, but if I say that ok, it fall something like this my cutoff is still the same 3 dB point of a normal gain amplifier kind.

Though, whether you can calculate this much is your requirement, we can decide how many 20 dbs what dB down you want. So, additional poles may be required additional some gains required, but otherwise in normal as omega function or a or j omega omega function, if it has a single dominant pole it looks like a low pass filter. So, that is the idea behind actually finding that v 0 by Vin if we find is a function of omega and we get omega 0 as it is known frequency, which is one of related to Vin and C and I know what is the cutoff of this low pass filter.

So, if I use this last expression. You can see from here this vout is connected to v minus that is vout is v minus. So, for this case vout or rather v minus is vout. We also see one thing for this figure, what is vout essentially iout essentially is iout is gm times v plus minus v minus, or gm 1 times Vin minus v minus which is vout, is that ok? I will just replace v minus by vout, because that is the connection I did. How you will look at this point, this point and this point are same. So, what is essentially vout otherwise I can figured out. There is a iout current flowing in capacitor. So, vout is iout into 1 upon j omega c is that. So, if I right now this iout here I get gm 1 vm minus vout by j omega c is vout.

Collect the term for vout. So, I get vout 1 plus, or rather if I would have done the other way does not matter. 1 plus gm 1 by j omega C is equal to gm 1 upon j omega C into Vin. If I find the transfer function, gain function which is vout yes if we are all omega terms j omega times Vin, which is also a sinusoid then it is equal to gm 1 by j omega C divided by 1 plus gm 1 upon j omega C. I will divide numerator denominator by gm 1 by omega c. So, I get 1 upon 1 plus, please remember I am dividing this is that ok? So, it is j omega C by, if I define gm by C I will define omega 0 as gm 1 by C. So, this function can be written as 1 upon 1 plus j omega by omega 0. Which is like a dominant pole setting at omega equals to omega 0 because of omega equals to omega 0 the gain is 1 upon root 2 magnitude.

So, obviously so I looks very trivial and it is I will just thought that if we will think I will just copy somewhere and can one can always do every time. So, there is nothing great thing happen. So, a transfer function shows me that if I do this, I can always get a low pass filter this. If I want this omega 0 to be larger what should I do? See of course, will be normally decided by availability of Cs. So, I must boost gms. So, what do I boost bias current, k of course, is into if it is 6 once I cannot change maybe 4 at that should me put; that means, I should change the bias currents. So, the low pass filter with variable cutoff, is now possible from v control. So, I will change the v control bias and I have different cutoff for the low pass. So, it is a tunable gmc filter, is that correct? It is tunable gmc filter that is the fun of OTA that OTA allows you to do such tunable it.

Otherwise what will happen for every k it will have to R and C, you have did just you can not change in inside chip you have only pin which is v control outside. So, you have to only play with that and still be able to actually design a filter of your cutoff values, is that clear? Stability somewhere better because there is a single pole, and there is no question and solvage on the left half plane. So, system is inherently stable ok.

Student: The varactor will give a duel level filters.

Yes, but the varactor is a some kind of a single activity bias, because j omega c c is not there is a under root of v it comes 1 upon under root of. Now whenever there is a some kind of such relationship the cv is parabolic; that means, a certain range you cannot a separate the Cs. You understood what I am said? If the curves are sharper like this, somewhere at very view small values the C values that can not be figured out how much. Varactors are normally use when you are actually looking for lot of difference that is in that is in which I will use it actually max min values. So, I will use one value here on the current, one value other side then I have range of this I can use, which is what which V Ci wants voltage control. So, in voltage control oscillators you will use diodes or varactors is that.

But as I say here, that voltage is you as I say is which range is very difficult to control. So, this is much easier to control, just is that ok to you. So, this is what I say that this is a low pass filter which I can create out of a simple OTA by putting. If I want to put the high pass what should I do? Where should I put a capacitor? In the input side. And still keep it negative feedback; please remember system will became unstable as soon as I have remove the negative feedback.

Of course, this is not the course I should talk, please remember that whenever opamps are used we always use this equation in all of our circuit, that v plus is equal to v minus this is very suspect function, some other day we will use this is not true every time. You must verify this statement, and that is why the worries starts.

So, is that low pass filter. So, I also did for the sake of a of course, this I have got it I mean dead ohms. So, that if we as I show the technique.

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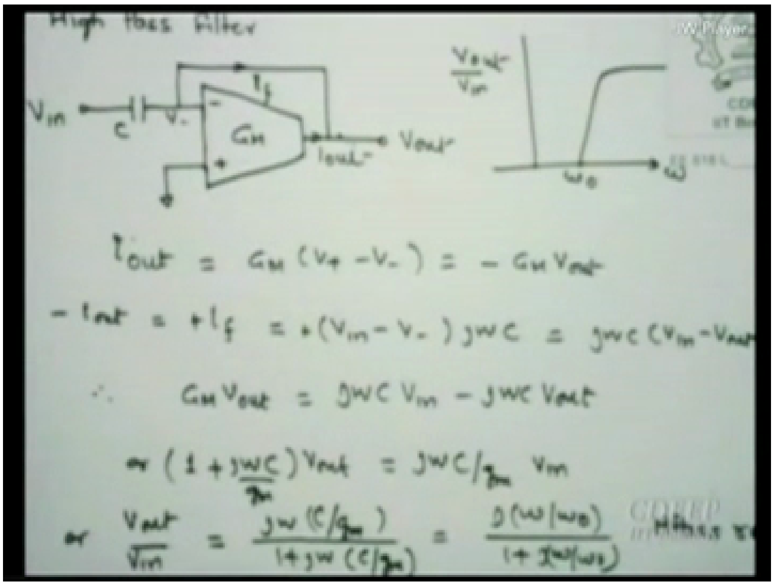

So, this is the technique which I used. I want the high pass filter. So, beyond the frequency of omega 0. I want everything to pass, below that I would not want anything to pass. This is not omega 0 maybe in this is. So, I use same OTA, now I will put v plus s ground I will put capacitor in series with my input, and took a feedback from the minus vout. And then same equations I can use iout is a function of v Vin v minus time this much. Iout into this gm v I just write down these expressions just like Kirchhoff'slaws.

One equation is coming from Vin minus v 5 upon into j omega c is the input current, which is same as the rf current which is opposite of actually iout currents. So, you calculate this and adjust the 2 currents, and figure it out what is v 0 by Vin. You would note down if you see you cannot, but otherwise function I got therefore, is j omega by omega 0 upon 1 plus j omega by omega 0 which is the sim which is the trademark for a high pass filter with cutoff at omega 0, is that okay?

So, now I have got 2 circuits. This is the high pass filter with the capacitance, here in low pass filter where was the capacitance, at the output oh. So now, I have got trick I said I have a low pass, and I have a high pass. And if I properly make the 2 combinations. I can make a band pass to band reject, because depending on the cutoff of which, I can let say if low pass filter cutoff is higher than cutoff of a high pass, it will become a band pass, but if we did the other way it may reject that band between the low pass and the high pass. So, it is only a matter of adjusting cutoff for low pass and cutoff for high pass.

So, what essentially a chip available to use a by quad filter with OTA. Which is general purpose in the sense, all 4 filters can be obtained by using the same block by just putting 3 input terminals different voltages, either 0s or one v one 0 and you can now create out of these blocks any filter a low pass, a high pass a band reject, or a band pass.

Another filter which is require very often in the case of communication in specific is the notch filter. So, you can now think how to the notch you bring omega 0 is very close. And you can create a relatively good notch filters. So, there are the same by quad can actually be implemented for low pass, high pass, notch, bandage reject, band pass. And that is the fun of, this by quad filter designs or is by quad filter chip available this is available chip. So, it is nothing great.

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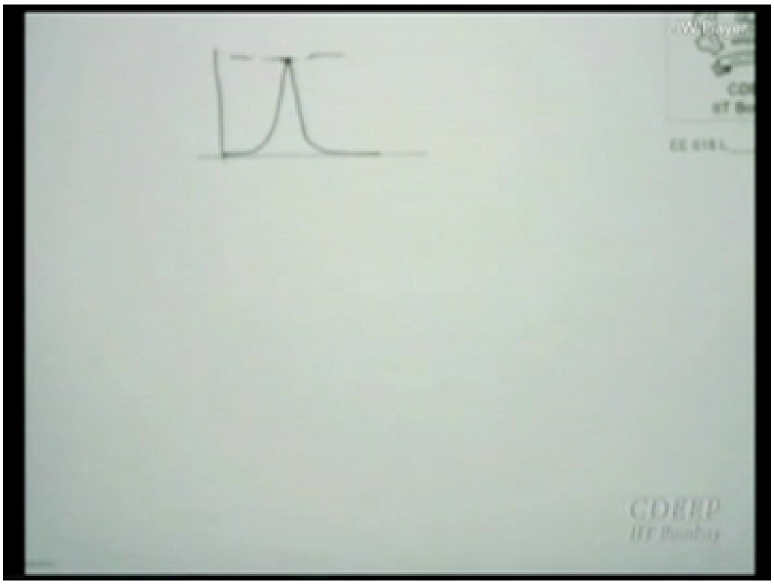

Notch, it is not really the band pass, you can say band pass with 0 here, but since the 3 dB point anyways slopes a down you can adjust the 2 slopes, such that the omega 0 is common. Is that clear?

Student: (Refer Time: 21:10).

It is a band pass, at the one frequency. It is a band pass at one frequency, but there is a noise associated ahead because of the slope down. So, some part of the frequencies are passing, but mean is input directly at that frequencies maximally output.

So, you understood this is omega 0. So, low pass high pass. It is falls down as the one. This is the low pass requirement, this is the high pass requirement. So, you can understand what I am saying; this is like this. This is high pass, this is low pass. Fix it you get a notch. Of course, this is not very easy because to get exactly this value for this 2 gms which cannot be easily adjusted. So, it depends how much notch you have. This notch has very high qs many circuits required very high q1 circuits. So, these are required for high q circuits ok.

So, think of it. So, I am just trying to tell you where simple things which we have can be implemented and realized whatever you are really trying to achieve in your actual hardware. So, where is the circuit? Which is the quad one.

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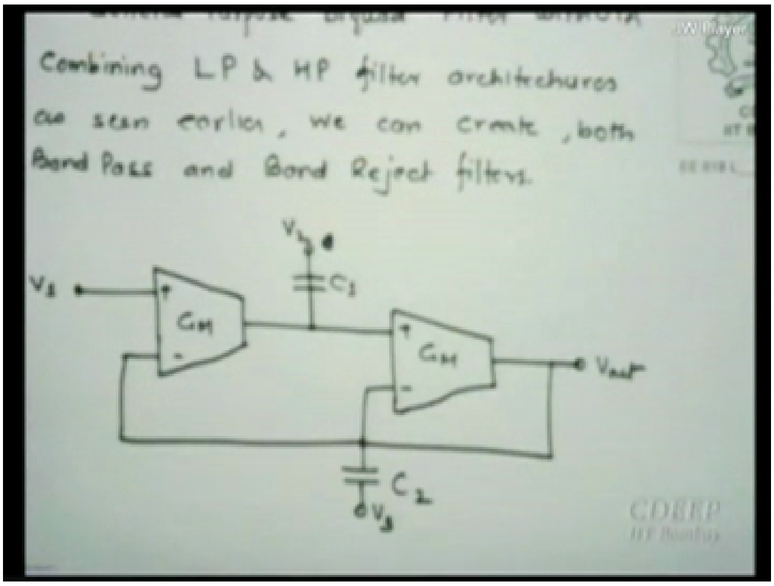

By quad there are 2 OTAs available. Right now, I should not done that there are gm are same. On a silicon chip this is not a very wrong assumption, as clears I can make there properties can be almost identical.

However, on chip there are many chips one can 100 percent guarantee, but one believes at least at that area the 2 gms will equal, this gm may not be same as the other chip gm exactly, but on chip they will be same property can be held actually. Sorry, this capacitor is here this line has come so, please do not draw that line also, because I have Ididn't want to redraw again. So, Ijust interface capacitor there. And this is a typical circuit, which can implement anything that is, a low pass, high pass, band pass, band reject and even notch if omega 0s are adjusted.

Of course, if I only want lp I can do one gm itself only one hp only one gm circuit, but if I have to go 2s 3 such separate chips that much costlier. So, I will give you one chip which makes all of it. So, I will repeat I can certainly I have chip only for low pass only for high pass, but then I will have 3 chips do or 4 chips do each one chips. So, which I am not like.

So, please I have repeat again this is a C 1 in series from this node to the v 2, and there is nothing in between there is no shorting in the capacitor. We say capacitor is shorted like this what is the output impedance.

Student: (Refer Time: 24:25).

Thing wrong I think you have you have you are justified in writing there, I will just since this is goes out faster. So, I thought we should not allow people to see something we as if intentionally we do not now think when putting things so.

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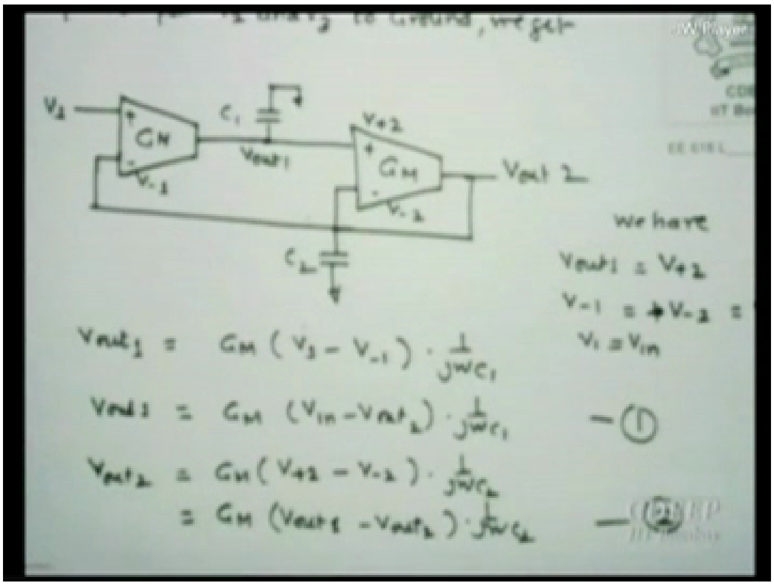

Now in this case, we start with the case let us say first, the first one was low pass. So, can actually a this creates a low pass filter. So, I said v 2 and v 3 voltage we have grounded. V 2 and v 3 voltage are grounded. So, only v 1 is present v 2 and v 3 are grounded. And now we start looking at the identities here. The vout one is essentially v plus 2 isn't it for the second transistor input v plus 2 as I have call is same. V minus 1 is same as v minus 2, and it is same as vout 2 connection there is nothing very great I am talking about. And Vin of course, I have say is my input voltage. So, start writing now for each voltage this small gms sometimes I replaced it by capital gms so, just think right now case one.

So, you know in heavily sometime I will write small gm. So, take it k is one. So, capital GM is small gm incase something happens ahead. So, vout 1 I want to find the output of this it is nothing but the transconductance on this my v plus minus v minus so, v 1 minus v minus into j omega C is the output, this is the current; this is the impedance at this note down. Now please take it this capacitance should be larger than any other capacitance at the input and otherwise, that will get modify it, but still there is parallel so, C may still be little different than the now, but this you have C 2 n which is vout 1 minus vout 2. Please remember v plus 2s vout one. So, vout 1 minus vout 2, v minus 2s vout 2. So, vout 1 minus vout 2 into. Illusions vout one and vout 2, and now I will just pick up this vout one from here and substitute that in 2

So, that why I am interest, I am only interesting vout 2 by Vin that is my interest. So, I will just probably replace vout one from this will equation one and substitute into 2.

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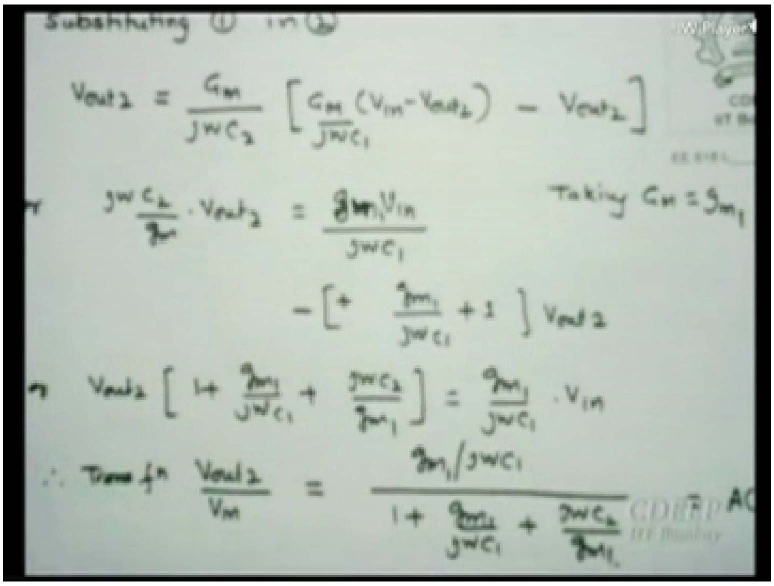

So, substituting my vout one and vout 2, I get vout 2 is gm by j omega C 2 I will substituted v out one from the earlier equation, and collected terms. So, I got vout 2 with this whole I have shifted on the other side. So, jm omega C 2 by gm that is what an happening as I say I started you will see small ones into vout 2 is gm 1 Vin upon j omega c 1 minus of vout 2 which is minus gm 1 j upon say plus into vout 2 collect the terms. Turner all vout 2 terms were collected by me which gives me 1 plus gm g omega c plus j omega C 2 by gm 1 is equal to gm 1 by j omega C 1 into Vin.

So, the transfer function of the gain aj omega is vout 2 by Vin, which gives me this function gm by j omega c 1 upon 1 plus j omega one j omega c 1 plus j omega C 2. If I replace for your standard thinking the j omega is nothing but the S which is what if I go into the S domain or if I am in the frequency domain. Then, kind of function I am going to get. So, if I replace it by a s is a gm by C1

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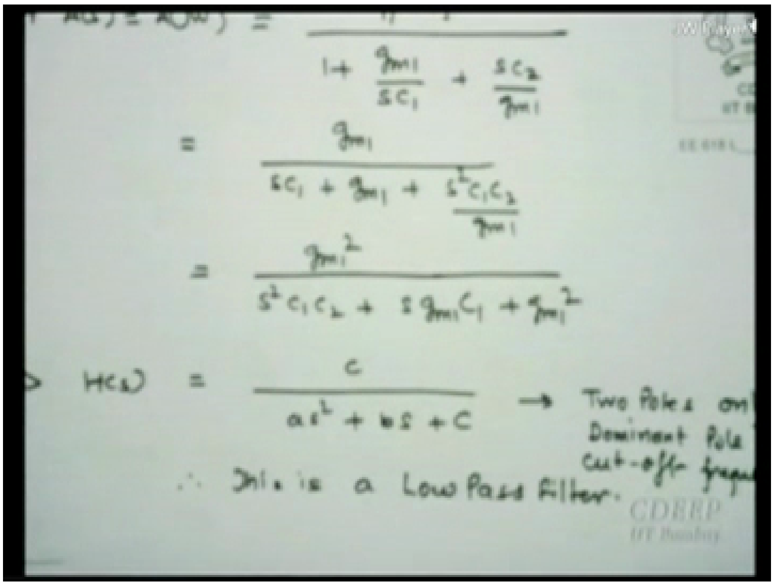

Gm by C1 S C 2 by gm 1, collect the terms now. So, again gm 1 square upon S S square C 1 C 2 plus S g 1 C 1 plus gm 1 square. If I put some constant looking things, then this is C upon as square plus bs plus C C is constant gm is the constant value. So, 2 poles one of them is dominant which is the cutoff frequency for this low pass filter. So, what which was the volt which are the voltage are made 0 v 2 and v 3 I have made it 0, and v one I will put it as Vin and I got the from the same this a transfer function which represents, a low pass filter is that okay? Let us to the next one.

So, this is a what is; obviously, I have 3 voltages. You make in other case other 2 0s and one of them and in the one 4th case what can you do 2 of them you make available you can one of them in make 0. So, it will be the next 4th one. So, we will do one will not do all of it I will just shows the 2 of them then you can repeat the other once. So, is it okay.

So, if I use the same circuit now.

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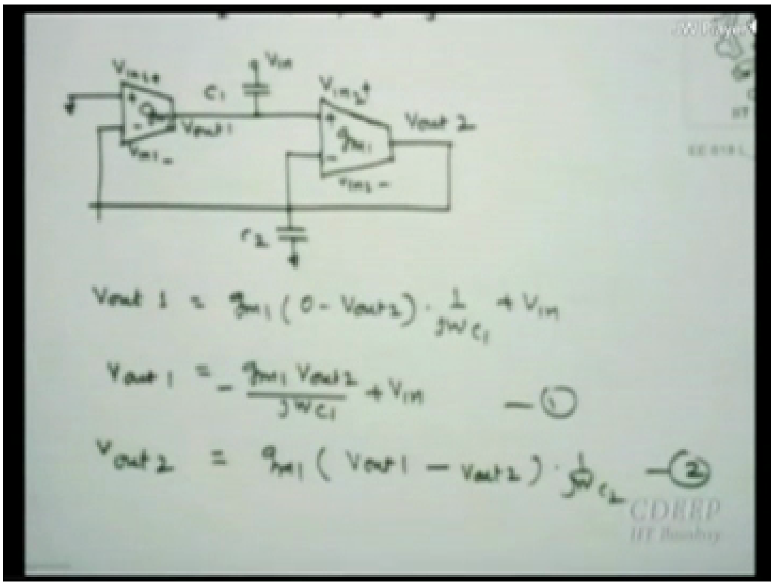

V 2 is Vin, but v 1 v 3 are 0 is that okay? And I believe it should give me high pass I believe it. So, let us see by same method which I have followed just there I will figured out vout 1 I will figured out vout 2 substituted vout 1 into the equation for vout 2, which I will did just now only thing now that is slide change is occurred. This voltage plus Vin is essentially the output, is that clear to you? Whatever iout times this; plus, because that is at above that will be additional term which is appearing, there if this would I have mean grounded this term would I have been seen this is series 2 battery in series.

So, I collected vout term is minus gm 1 vout 2 by g omega c 1 plus Vin. And vout 2 is same as gm 1 vout 1 minus vout 2 upon j omega C 2 is 2 substitute this vout 1 here and shall for vout 2 by Vin. Is that clear? I will repeat substitute vout 1 here and then collect the term for vout 2 and other side we lead the term for Vin vout 2 by Vin is the transfer function. You know many times book do not solve. So, doubt they are the or not. So, I solve and check whether things are, and luckily, they are always right. Once, I will have go to resolve some mistakes which in the newer versions they have corrected.

Every step there is help to know how it is done, but it does not give any physics ahead of it. It only tells you how to substitute arithmetic is may algebra these have been now how it says, but that is that all that.

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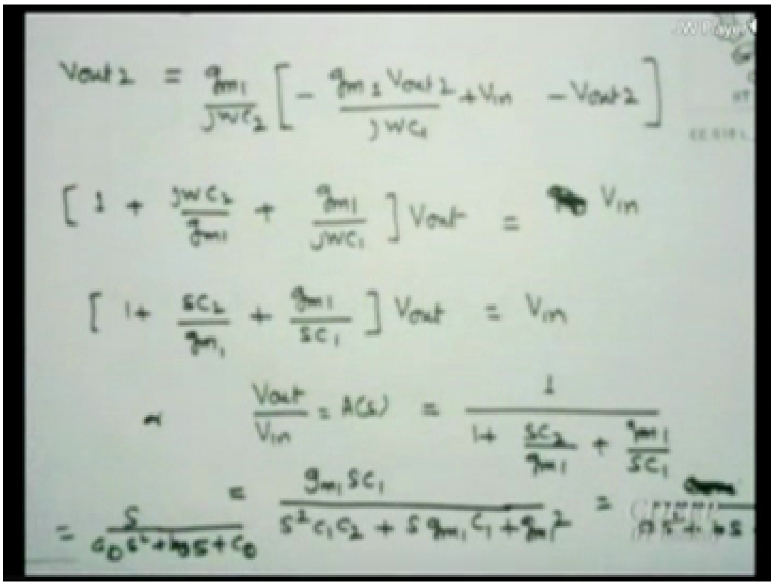

So, if I substitute 1 in 2 I am collect term for vout and Vin in the other side, and I get this terms again and I will get the transfer function, as 1 upon 1 plus S C 2 by gm 1 plus gm 1 by C 1. And if you see, if I take this S C 1 and multiply numerator by gm 1 S C 1. So, is that goes up this, become gm 1 S C 1, this become S C 1, S C 2 into S that is S square C 1 C 2 and this becomes gm 1 square, just multiplying numerator denominator g 1 into S C 1 multiply.

If you get a term which is g 1 and C 1 upon S square C 1 C 2 plus S g 1 C 1 plus gm 1 square. If this is g 1 n S C g 1 g 1 C1 is called constant d. So, d into S upon as square plus bs bs plus C are divide 0 some new other constant s upon a 0 s square plus p 0 S plus C 0 is the transfer function and you know whenever the transfer function s upon s square kinds this is a representing a high pass filter and it is dominant pole will be the cutoff point. Oh sorry, this is S you know it is a band pass. If what would have been high pass s square yeah sorry this is band pass.

So, let us see the 2 frequencies are omega, one omega 2 is essential the band in which outputs are one. Transfer function as of the magnitude of one.

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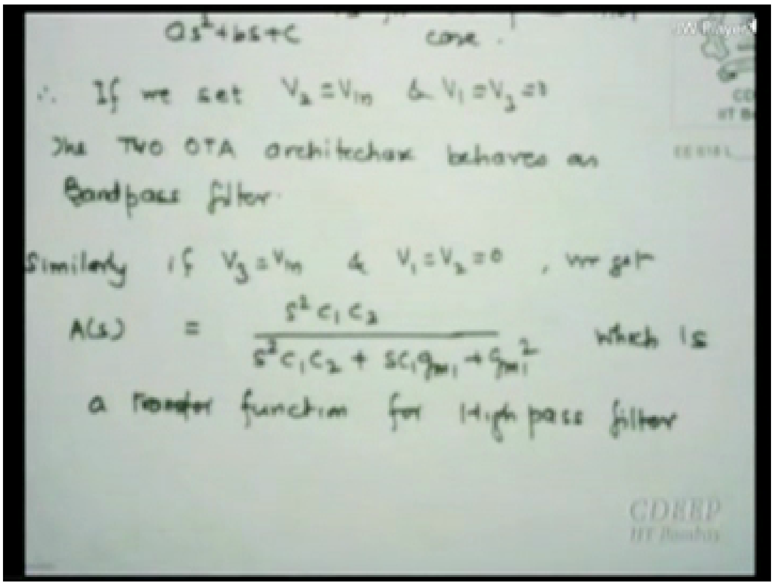

So, this is the band pass filter as I said, you are write by same argument if make v 2 equal to vn and then make v one equal to v 3 equal to 0. They 2 OTA I mean this is what we did right now, 2 OTA architecture behaves like a band pass filter. We can do something interesting now if v 3 is Vin and v one v 2 is 0 by same method which I did I can get a function of S square C 1 C 2 upon S square C 1 C 2 as same gm 1 gm 1 square; which is the transfer function for a high pass filter. Only filter we have not yet done is band reject.

So, band reject we have plus term constant with band pass or band. So, let us if you have seen it denominator for all of them is same S square C 1 C 2 plus S C 1 whatever gm like gm square this is denominator for all 4 of them, the filter is only on the top I mean by the which kind.

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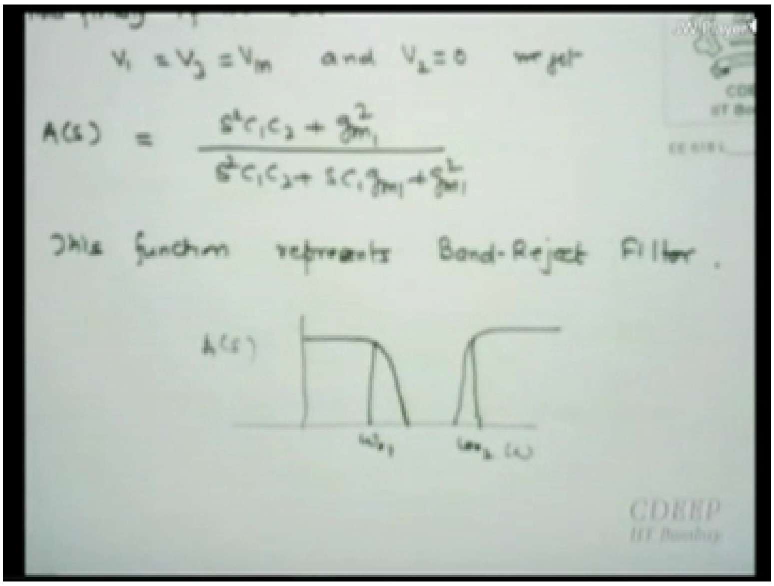

So, if I put the final filter which is v one is equal to v 3 equal to Vin, and V 2 equal to 0 then I will get this transfer function S square C 1 C 2 plus gm 1 square upon the same denominator, and this represents a band reject filter.

I repeatedly I think some someone were we should not be worried about; this essentially is being told. All the times sayings are if omega is 0 1 omega 0 2, I just 2 blocks n and the in between there is nothing and therefore, it is reject in those frequencies in between.

Student: (Refer Time: 37:01) a omega naught one and omega naught 2 will not be simply like gm (Refer Time: 37:05).

But equivalently same it is, the problem is the one loads the other which in this case we have taken care if you have only independent that we do not feel the loading of the other. The reason why I will showed you this was that it takes care of the when you connect, it loads the next stage. So, we now what is happening because the second stage. If you have independently this and when you want to connect in independent design will not take care of load unless, you know what do I have to use there if that happens it is same as what I did is that you have I mean what do you have saying is, I can use 2 blocks, but then I am a not did this just by when you connect the connection makes the difference and that is the circuit I have shown which connects the 2 blocks is that okay. So, this factors to understood that if I 2 stage amplifier I am a design a first stage I must (Refer Time: 38:01) now what is the input stage how input of the next stage that will load my first stage.

So, if you do not take care of that, then your design will be never covered because then actual loading will return at every performance, either first evaluate also we must know the this also loads the one, and this also loads the other. So, both sides the output and input impedance have to be matched and then only power is maximally transferred so, gain is to be played when you connect the things.

And I said to you that, this OTA can also be use that an amplifier. So, let us say if I have a normal amplifier is that okay? This you have done. So, this is something a chip which is available, from ti it is available, from analog device available national chip is available, of course, now national is again ti, but chips has still national number. So, these chips are available.

But I must tell you that there is no chip which takes a whole of a band what they will do there will be still a 8 to 10 chips, which will be because otherwise the gm value will be 2 bands of them. So, they actually adjust band wise filters; that means, from this megahertz, or this kilohertz this much, then this megahertz to this this. So, each has a band of this in which this operate though theoretically 0 to anything is possible from this. So, that is what they can make lot much money, you want this you buy this.

So, here is something last part of my theory. I we have been doing this standard.

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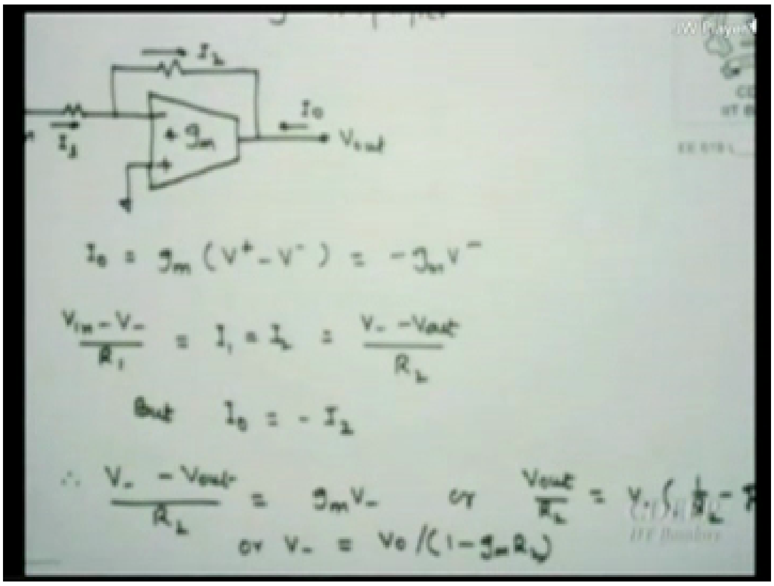

Opamp based amplifier. So, I have actually connect the same OTA, in a opamp feedback kind of thing, instead of you asking me how I solve; the either note down I will not say more than that. I have solve this as I could. The reason why I have put it because, which is v minus minus it is used. So, I will change the sign there, but otherwise its.

So, I will figured out all 0 is minus gm time this much, Vin minus this by R 1 is this current, but this current is. So, in this criteria can the criteria which all of you I should know and that is the one which again I will repeat, and verify yourself in all this analysis we say no current enters the tell me that input of the terminal of OTA opamp the reason to be; that means, the input impedance should be extremely high, and the negative feedback dominants. This is the second condition which allows you to do this. So, if that is not. So, real circuit is solve figure it out if both conditions are met only then these statements are valid statements okay.

So, then I have this minus this this minus this is something r 0 is minus I 2 collect the terms find I one and I 2 gets.

Student: The current (Refer Time: 41:30

The reason is in opamp if you see is the currents are always shown in this direction.

Student: (Refer Time: 41:37).

That it essentially it is minus of the actual current, but opamp if you see currents are always shown in, if you say opamp equal this is for the thing which is equivalent of an opamp. If you see any opamp circuit we show all current in, no this is different case. I am only saying the difference of this into gm is the output current.

Student: (Refer Time: 42:08).

Yeah it is, gm times v plus minus v minus; no, no, no this current which is coming here has no other terminal to go so, the current here in this arm is same this is only a matter of node at that node the current is same actually.

Student: (Refer Time: 42:21).

No, no, no, but please remember the impedance seen from here to here, and here to here is not same. When I said this why at those you can say here, but that is there is no other nodes of this currents will be equal actually. Opposite side that is why I added to added I said with their opposite sign.

Student: (Refer Time: 42:44) points outside.

That is all I say, you that in all opamps we put m side this is. So, I will just equated it. So, think of it yeah second yes, no no because this current essentially is move this and I have shown the direction opposite I put it minus this is only a question of putting minus sign for the equivalence you have doing.

So,I have calculate I 1 and I 2.

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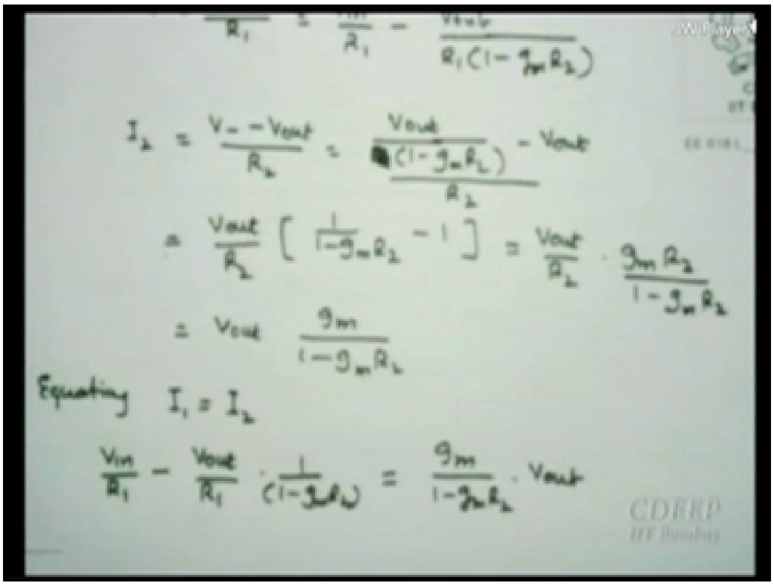

And then equated I 1 I 2 at least that you agree I one is equal to I 2 because there is no current enters the OTA. And I will substitute all these expression here and I will get a very interesting relation, Vin by R 1 minus vout by R 1 upon 1 minus gm R 2 is equal to gm by 1 minus gm R 2 into vout collect the term for vout, and collect the term for Vin, and get a ratio of Vout by Vin note down, because in negative feedback system the output will be v 0 is out of phase of that and therefore, if does not come minus R 2 by R 1 you will start telling me where is minus sign came, now I want to bring this and that is why I should the same direction as opamp uses.

So, yesterday I was telling that, under certain conditions only OTAs behave like a good voltage control voltage sources. So, the condition which now bring it soon. What could be the condition anyone, quickly? Gm R should be very, very high compare to one; which many times you can always attain any OTA that is the purpose of OTA gm is higher. So, if you use do not use very small rs n then gmr will be very large compare to 1 and then equations will be same as an opamp requirements is that okay everyone? Expressions.

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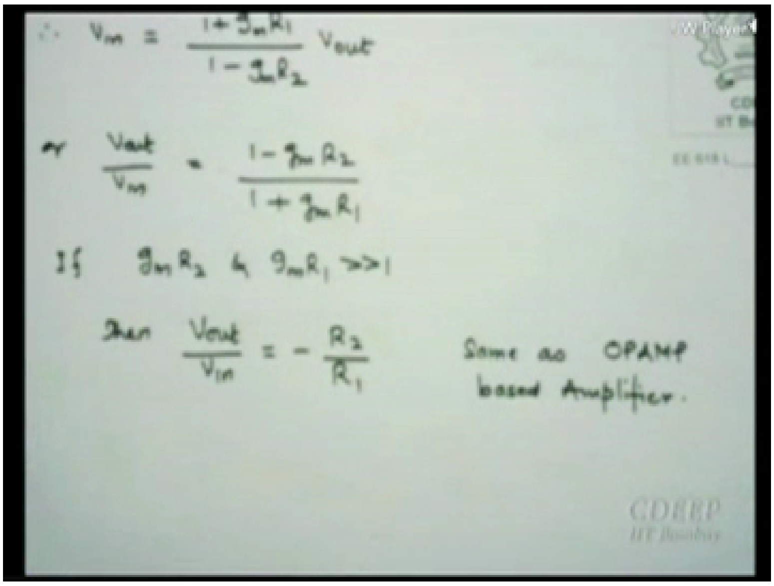

So, I figured out the gain vout the Vin is 1 minus gm R 2 upon 1 plus gm R 1 and. Yes, gm R 2 one gm R 1 as much larger than one vout by Vin is minus R 2 by R 1, which is what an opamp would I have given, say OTA with these conditions behaves like an opamp. Is that correct? So, it is not my this was not necessary to show only I was saying that many a time people believe only OTA are on chip how do they make opamp then, things are possible even using OTAs.

Student: (Refer Time: 45:35).

I agree that, to some extent the load has not been shown to you. So, if I put a load that will take care of this actual impedance going down. Your low point is very correct, if I open ended if I see yes there is an issue, but as soon I have loaded that will be the output resistance. So, in that case it will behave like an opamp output. We have very good point define. It already I have saying that in real life, people use this and say and the do not think, but they get the correct answers say why is a reason I said this is how they get it actually.

The last part of opamp based this, is my one of the last part which I have thought today of course, I will not do all of it I will only show you the basic, but something which is very relevant for those who have per say interest in joining a company which has more interesting mix signal design, like Broadcom, Qualcomm; who are more interested in analog plus digital on chip, and rf as well. These chips require fully differential amplifiers. They require in many applications fully differential, now this fully word was essentially inputs are always differentiate. So, what is. So, fully means even outputs are differential therefore, it is called fully differential.

Some books, some journals only say difference amplifier, but then you know I do not know whether difference at the input or some right difference output amplifiers. Which is also equally good we was telling. I have followed some books which say fully differentiate. I use this terminology nothing very different all that I am saying 2 input 2 outputs. Is that this is okay? So, we start the last part of opamps. As I said there are too many things in real life actually designer should learn to do themselves, but where to do and how to do is whether course is trying to help. I cannot replace everything, I can only tell you why lift this way.

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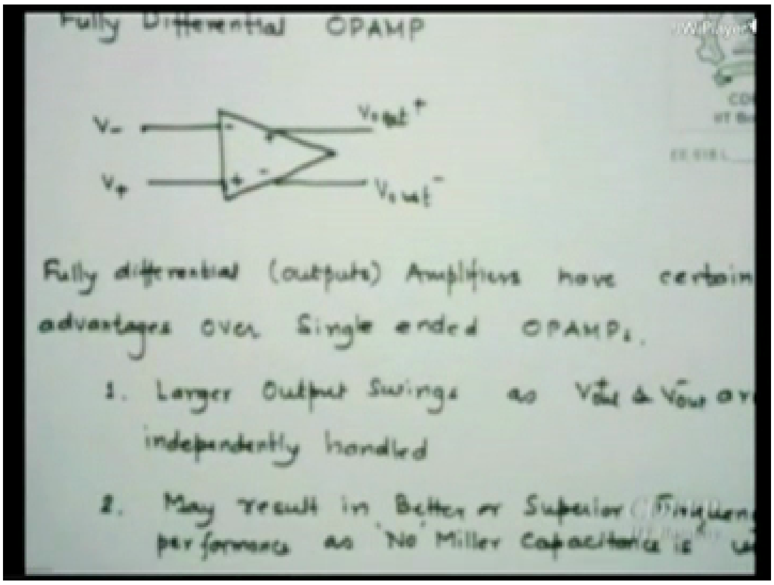

For example now, I will show you how to get somethings which is varying me in this and that is the idea that if there are variations what do I took so, I will show you this later. So, this is a fully differential opamp, which essentially says if I have v minus v plus out inputs vout plus vout minus and they of course, opposite terminals they change. So, this is vout plus this is vout minus, such systems are called fully differential amplifiers or differential output opamps.

So, I will keep telling they are mostly used in mix signal designs. For example, of you want to make an analog multiplier which is essentially a digital requirement. So, you can use such circuits to actually quad multiplications as they called quad multiplier. We can use analog loss to digital functions. So, real R in a adc some of the adcs you require differential outputs. So, these are essentially for mix signal blocks. There are advantages and there are certain whenever things happen good; obviously, there will must not everything must not be good.

One of the thing which is better for 2 ended outputs or double ended output compare to single ended is, since the output and there is limited by the like in the cascode or a buffer vd minus that much, because each is controlled by the same I 5 currents. So, there is an difficult to they have to manage, since this may have much easier way of because you can independent you handle this, and this and swing may be much higher.

It may also have a better frequency response or bandwidth simply because there is no mirror poles here. In the normal stage you put can cc you did stability, but you lost the frequency bandwidth there is no mirror poles here and therefore, a mirror feedbacks therefore, it will have a larger bandwidth requirements. So, in sums this may be before we quit last slide also on the same thing.

The biggest advantage of fully differential system is the rejection of noise.

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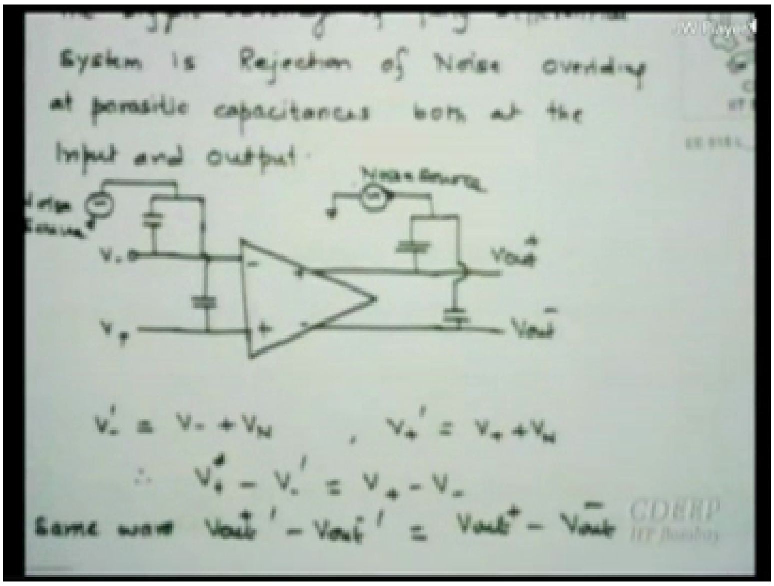

Of course, along with the noise something else we will talk of few minutes we will talk. Let us say this is my fully differential amplifier. And there are 2 parasitics or the 2 inputs, and there are 2 parasitics at the output capacitance. If I now see the noise signal comes at the input, is that okay? And our believes cannot be very observed if is a the noise at the 2 terminal there will be 2 different noises and likely event, I am not say cannot happen, but unlikely event.

So, what will be the actual v minus it will receive? This plus noise which is charging this capacitor. If these parasitics are same because of the symmetry you have, then this noise sitting with this, and this at this terminal noise sitting with the other since both gets noise added to their input the difference will be independent of noise, by same argument if there is a noise coming at the output the difference between vo plus or vout plus 1 vout minus will cancel the noise, if there is a biggest advantages having a fully differential system it rejects all noise is whether at the input or at the output.

we I want actually I should have said, but I think some word finally, I am a say is another problem in diffamps opamps, the word we never talked we talked about cmrrs, but we did not talked about psrrs. So, this power supply rejection ratio is essentially, because power supplies non-constant all the time.

The output varies and we believe that that should not vary, it should be even is how much power supply goes output should not vary with the change in power supply voltage. This is equivalent of that. If there is a change the difference will cancel it. So, ps arrive is very high 100 dv plus in the case of differential systems. Get in 65 to 80 dbs ps arrive in the case of normal opamps is stuff, but in the case of diff amp this differential systems they cancels any variation is they can care. So, indirectly not saying there, but it also improves your ps arrives, because it does not alive you any variation at the difference actually.

Only assumption is the variation in vdd is same as variation in cases, if that does not occur there will be some ps arrives value which may not be very large, but still better than normal system. So, is that point clear to you that why differential system are prefered in certain stages and a what is the difficult with them because the difficult is now going to be shown to you few minutes, and then next time you will solve the difficulty. Is that okay? So, the fully differential systems reject noise as much as possible and it also does one more thing, can you think another noise kind of thing is something related to what we call of sets offset is also what is an offset of an opamp, that is the input are made 0 output should go 0 and if it does not we actually some way adjust v minus or v plus. So, that the for that the output go 0.

Here it cancels because any change will both difference is also cancelled out. So, in every sense, differential amplifier seems to be very good, but if you see one this do you think it is actually 2 opamps I am using to create a differential amplifier. So, I am essentially using equivalently saying 2 opamps together equivalently saying. And one trying to cancel the that part of the other that is the one part in this if that ok.

So, we will see one what is the major worry soon and next time that is the circuit I solve for you. There is an issue which will say the common mode voltage as it called.

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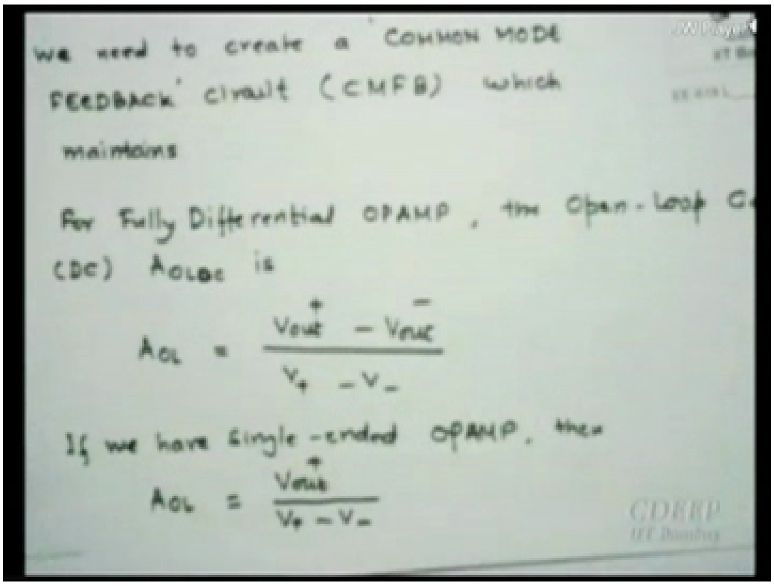

For cm I have to be have the 1. The 2 devices should be as identical has possible on diff amp gm 1 gm 2 everything that by everything should be, and we figure out than the cmrr will be infinity everything is fine delta gm is 0 denominator, but that does not occur gm 1 minus gm 2 occurs, and how close they are that decides a cmnrs.

Now, in this case that common word voltage is not a constant quantity at all, will show you next time and if that happens at different this it will show you different cmnrs operations. And we will like to hold that common mode voltage, and that is call common mode feedback circuit. So, additional circuit is required or fully differential system which is called cm cm fb circuit which is very important in any real design. The first into the ask people to design is cmfb circuit, because that will then wave this common mode to evaluate. Will see that little later.

Just go back to the open circuit and closed loop gain phenomenal differential system. If I see the open loop gain of a differential, fully differential circuit. It is nothing but v out plus minus v out minus upon v plus minus v minus. Is you make a single ended, make one of the output 0 order consider it. So, v out plus upon say is nothing but I cannot make a single ended you one output divided by difference is still have a single ended output. So, it is not this that this cannot be as a single ended it can always used as single ended, but then the major advantage of noise everything is lost then why do we use double you can as well as single ended. Which is much more stable everything is. So, good actually.

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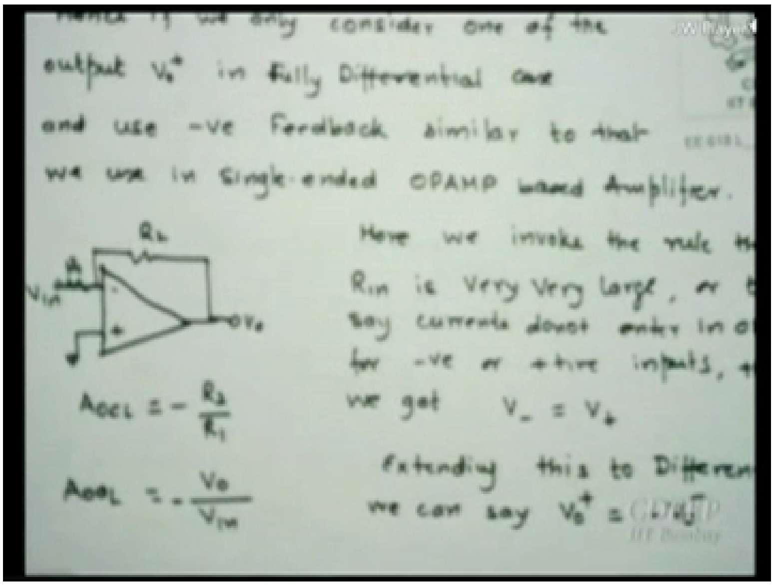

So, if you consider one of the output is fully differential case and use negative feedback similar to that of a single ended opamp, as shown here. Here the in ware the rule that R 1 is very, very large or to say current do not enter a opamp or negative or positive inputs, then only we say v minus is v plus this is we are invoking proof you are done earlier somewhere.

So, a closed loop gain bandwidth will be minus r 2 by R 1 open loop of course, v 0 by vn whatever it is; external this 2 a differential case, than the vo plus is the opposite of v minus if I extend this 2 base it will be opposite of that. Once also this is like this, now yes if I am now telling and it has a 2-diff amp there 2 opamp there you will lead note down this and I will show the equivalent of that. Please do not think I actually put 2 diff amp opamps there I am trying to say equivalent of this is what is inside. So, fully differential amplifier can we realize from 2 single ended differential systems differential amplifiers. So, as if 2 systems are going on is that clear to you? Same inputs one outputs same input as our output. So, as if though system.

This is the last slide for the day and we will start next time will cm fb circuits and why it is needed more. Last slide, for the day not last.

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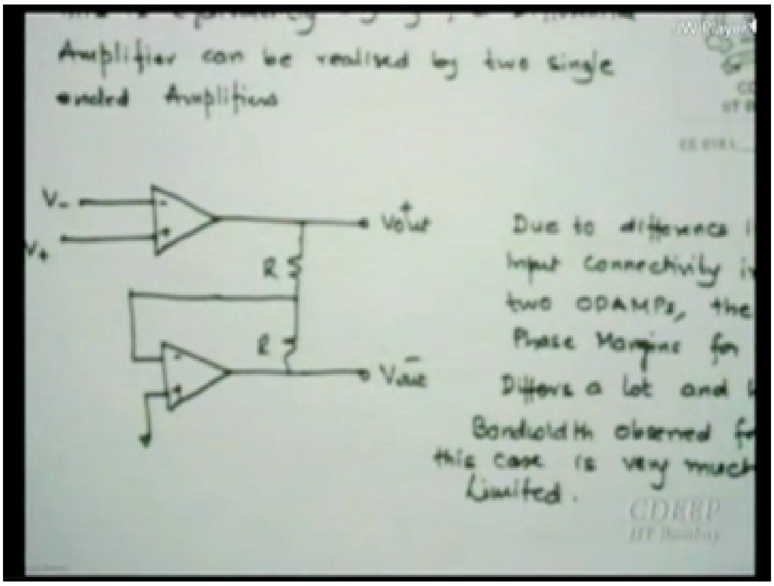

this is equivalently, same there is a differential amplifier can be fully differential amplifier can be created by using 2 single ended normal amplifiers diff amps. At the way it is you have one diff amp is input are v minus mp plus the output is, and the other one input is grounded the other is a taken as a part of this resistive network will talk about this later next time and will say now these 2 2 system together actually gives you vo plus v out which are equal in, but in opposite phase this is given in bias and bakers book.

So, what is the problem with this system which is I wrote down which is why will have to do something more about it. Please, do not think that this is how I am implementing I am just trying to see the principle of fully differential system is essentially equivalent of this, you can see from here the difference voltage is divided equally, and that is being fail here which makes this opposite. R upon R plus 2 is stoop R ratio is adjusted. So, that this actually gives equal and opposite in science.

. So, this is the gain which we are playing there, but just rate next time. The catch word here I essentially because the 2 diff amps do not have identical inputs. So, if you use all year's stability criteria system there, the phase margin is initiated with 2 systems are not identical and if you connect then the worse will come. And therefore, essentially what will happen that the bandwidth will get hurt maximum on this they. We started with saying that fully differential system has higher bandwidth, but if you realize it, like this and you may find your bandwidth your loosing actually; that means, something I must hold greatly correct. So, that my bandwidth is not affected. This is the catch what is that is common mode feedback cm cm fb does every time.

Essentially what is common mode voltage v out plus plus v out minus of this divided by 2 average value of that, I want to hold it, but if you have changes than how do I hold it; that means, adding subtracting out of max must be same as adding togethers. So, that average value remains constantly. That is the what common and common mode feedback that it holds that value and if it holds than much of your problems are solved.

So, next time is that point clear. So, this will be first 30 forty minute I will stop finish this year may be which is as I says is very, very important. All those in real system will use everywhere, you may be circuit will be there and this start with noise next time.