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

Lecture - 09
Types of MOSFET Amplifier

About the cascode there are some issues which may somehow brought to my notice, in advertently or advertently and might has a wrong or right. I already said a 6 page problem about what is the bandwidth issue in cascode which is now available on website should be yesterday night I sent to TS they put it on the website and also maybe on model depends on them.

So, please look for issues about the maybe there is an issue which I did not see quickly or maybe I said it wrongly either way, in any case whenever gain increases the bandwidth will go down. So, there is no issue on that what I was trying to only say that if I have a cascode then the change in bandwidth reduction or say from the simple cascode will be not that is large compare to the increase in the gains is that point final word is clear.

That you may have enhance gain and you will not have in the same ratio reduction in bandwidth is that clear that is the all that cascode does. There is no issue in saying that cascode has the same bandwidth if I said it per say I do not think I have I have many times said bandwidth is not same, but in case I have said it I stand correct it.

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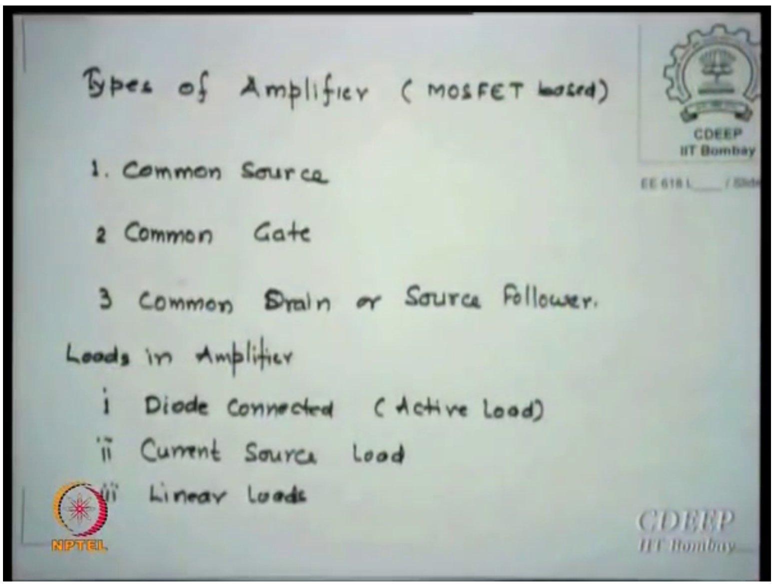

So, we start for cascode. So, I already given there. So, you can read that, maybe a other class I will do today let me finish my because I has I will like to do something up today is class and tomorrow is the Fridays for the test. So, 3 of the common amplifiers which all of us use in variety of applications, as common source, common gate, common drain, or what we are essentially now popularly known as source followers .

So, today we shall like to do common source normal amplifier they already done day 1 they have been doing that often that I am not do it, but I will use 1 of the interesting common source amplifier which is very interesting because it gives you lot of understanding as well as it has a lot of features which will just talk to you. There are 3 types of loads which we can use in the amplifiers of course; fourth 1 I have not written in the sense that resistor is always possible. So, I am talking of non-resistive loads that is active device which is acting like a load, there are 3 kinds 1 is called diode connected, the other is called current source loads and the finally, 1 can have a linear load. Essentially we are trying to replace resistor by transistor in different modes of operations that is the basic idea each kind of load has some advantages and some disadvantages.

So, we will see at least few of them at time permit today or at least on Friday these are very relevant because we also will like to at the end of this all 3 gate all these amplifiers, why do really need the difference amplifier at all if everything was so good with all of them. So, why did we look for difference amplifier or diffamps. So, I will at the end hit these all amplified some way and say that they are not good enough in many applications or most applications and therefore, we are looking for the differential amplifier.

So, I am not trying to say these amplifier will never be use I may show some applications, but generally why diffamps are used why it will be obvious if I limit them oh this is does not give this is not good enough. So, look for something which all in all can I get little better is 1 and that is the diffamp.

So, all this applications or a all this amplifier I am talking because I want to show that they are also gain stage stages, but they have their own limitations and they must be overcome if you want a good amplifier and that is the way we will come to it. So, this is the pedagogy of this why I am looking into this many of you are done this. So, there is nothing new in that and you rush sometimes if you have someone does not follow stop me, but otherwise there is nothing extraordinarily I am talking about which you have done earlier for example, 1 of the thing which I may show at the end of this which this particular part may not show, if the major worry was biasing in most of this amplifiers which we normally never talk.

So, I will show you that why this biasing is an issue for us and why diff amp actually solves that problem. So, the kind of thing which I am trying to show in an integrated circuit what are my problems if I use this and what will be solution if I use diff amps. So, that is why I am looking in such a pedagogy fashion.

So, let us start with the first and the foremost amplifier common source normal amplifier I have discussed.

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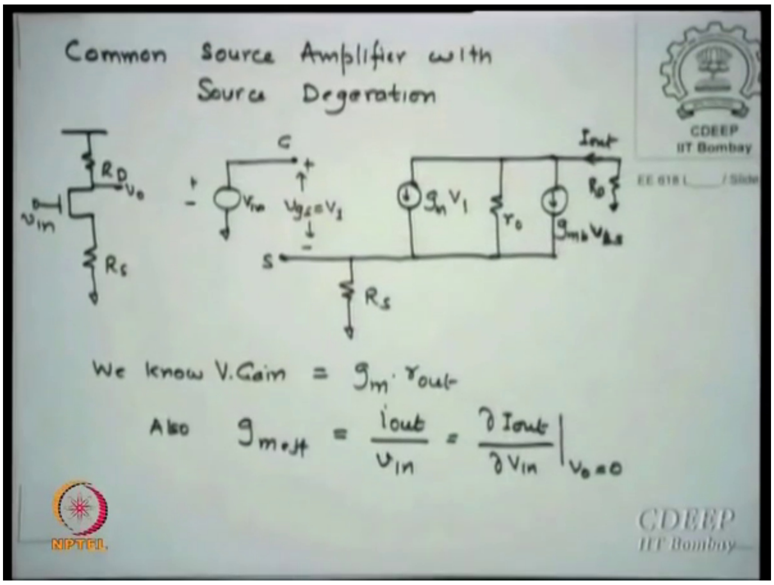

This is an interesting amplifier which shows that there is a resistance in the source and it is very popularly known as source degeneration. Now why this is relevant at times may be shown when the output appears for this amplifier, this is the kind of equivalent circuit which I draw from the razavis book this is not mine.

But this is what taken from razavis book method I do not mean this specific, but razavis technique and I like that technique simply because it explains from each node to each node what is happening in real circuit, that actually explains it very well and because of that I thought is razavis technique of putting an equivalent circuit, it is far superior than many other book in which people just say equivalent of this book replace by this I do not like that, this is a straightforward equivalent circuit of a mass transistor along with other resisters and nothing great about. So, here what I am doing is I have a load RD which I say will replace later with active loads, but right now keeping RD there then there is the series resistance R s to the source and of course, in this case also there are issue which may be at the end I may show you normally for all simple solutions.

We say there is source resistance is 0, the input source cannot be without source resistance. So, if there is a source resistance it may create problem not at the low frequencies, but at higher frequencies. So, right now since I am more worried about the gain low frequency gains I am not showing you R s values or some what is called R with the source itself, but otherwise that will also appear in circuits, Now I am assuming that there are all effects of capacitance only come at very relatively larger frequency, I am not looking into those frequencies, I am in a mid-band low frequency area where gains are independent of frequencies this is my assumption you will see where it starts. So, that is what our frequency response when we do for this we will them merging.

So, the way the razavi defines you have an input voltage V in to the gate to the gate between gate and the source there is a VGS which is essentially he defines V 1 as the voltage across gate 2 source and from source to the ground there is a source resistance RS, at the output side drain side equivalent current source due to the input signal is g m V 1 shunted by r 0 and shunted by the body bias effect g m g m V times Vbs. Finally, there is a V 0 output here, I should have said this is a V 0 output across RD and please remember source is not grounded. So, RD should not come into parallel to r 0 or any of the current sources this fact is clear RD is not in across r 0 or sources it is to the ground.

So, essentially it is if at all I should complete this circuit because that is what is essentially the way I have shown you is that clear. So, please that is that is the only difference from earlier work in this work. Now if I want to figure out the gain I know gain is nothing, but gm times the output resistance and so we will figure out gm effective for this circuit, which is I out divided by V in which is delta if we are looking into delta kinds of the earlier analysis, which we showed in another simple method I showed you I is equal to gm V in plus go V out if you use that then it is I out by delta V in is essentially same as gm. Now if this method what I am what razavi does or I like to do is we figure out gm effective for this circuit.

We figure out r out for this circuit, you can need not do all that also, but this also gives you a feature that how much gm is changing and what parameters gm is actually getting influenced by, because of the designer I want to know if I want to do something what parameter is in my hand and that is something which this kind of analysis that is why I say I like razavi not because of course, he is a prolific writer great analog circuit man.

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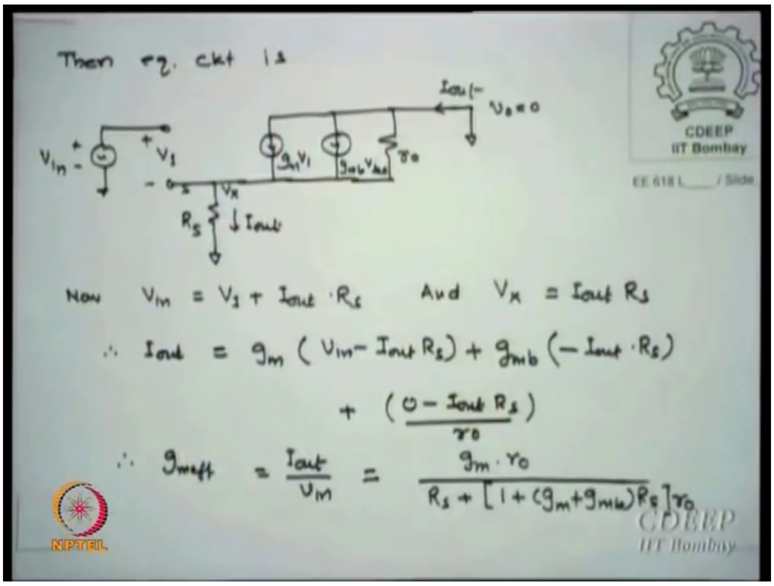

So, first thing we do is we want to find gm effective. So, we will make V 0 0 and put V in and find I out by V in that is the standard technique to find gm. So, I put V 0 equal to 0 is that correct I is equal to g m Vn plus go ro go V out itn is equal to I by V in is that what we said it. So, I make V 0 0. So, I ground this output is that clear as soon as I ground output there is no current in the RD. So, I just forget about RD. So, I have gm 1 V 1 gm V 2 Vbs plus r 0.

So, now I look at the relationship between input side V in V 1 and V, since this current I out how much the I out will be current through r 0 plus current into the body bias current source little this source. So, this plus current source appearing due to dependent gm V 1 these 3 currents must be summing to I out, but the same current say this is open circuited the same current must flow through R s move to the ground there is no other path once the current comes through this there is no way it can go there. So, it has to go through this. So, essentially drop output current is flowing through even the source resistor.

Which is true in a normal amplifier anyway current goes through the drain to source. So, this is not really great; however, if you can see since there is a R s here and there is a current here there is a voltage drop here that we called V x. So, we write what is V x the drop across R s therefore, it is Vx is equal to I out R s is that the drop across R s is ix R s which is nothing, but my V x signs are correct because current I have now chosen is downwards. So, this assumption of plus minus is fair enough because I am putting current downwards is that. So, V x therefore, it is not mine if I would have chosen this outer I out like this then I would have put a minus sign on this right now. So, you can choose either way it is not it is a matter of only your choice.

I have put I out in you may I out also. So, it does not really matter very much because if I out is outside iro RD finally, which will come will be taken positive, but I outside will come minus somewhere. So, minus gm RD will come finally. So, it does not matter if I choose either direction of currents these other things will take care, but this current sources must go from drain to source there is no other direction for them. So, this is what it is gm V 1 into gm Vbs will r 0. So, if I write this this is the expression if you see V in and if you see this loop starting from this ground to this ground what is the way we raviz telling you go from this ground though this is a loop.

So, drop plus this plus with signs whatever it is this plus this plus this must sum out to be 0 with proper signs n in a mesh that net voltage is 0. So, we write then V in is equal to V 1 plus because this is I use this plus minus plus minus of the add. So, V in is equal to V 1 plus I out or s V x is I out or s I out I substitute this values in I out gm V in minus I am replacing V 1 from here what is V 1 V in minus I out R s is V 1 will be V 1 is V in minus I out R s I just substitute that gm V 1 is gm into V in minus I out R s that is gm V 1 plus gm V which is minus I out Rs, because Vbs source to bulk and we are looking from bulk to source, but bulk is grounded.

So, opposite polarity is that source is at positive and this, but we want the opposite. So, it is minus signs. So, minus I out R s is Vsb how much is the current through r 0 0 minus Vx divided by r 0 and what is Vx I out R s. So, 0 minus I out R s by r 0 this is Kirchhoff law and nothing very great going on and this why I do this as I say I like I since I say I like all 3 books as much all 4 books, but this method is very straightforward there is no assumption, there is nothing we are missing in term some terms are going to be smaller or large this automatically numerically will I mean reduce that term to small value.

So, you do not have to worry wish term is stronger or term is, but as a designer it will show you that this is not the ideal way every time because then you solve everything. So, from there you will try to reduce that if this means what.

And then during design will use our conceptual thinking for that. So, first to get that I think we should do analysis. So, if I find out g effective from this I get gm r 0 R s plus 1 plus gm plus gmb times R s into r 0, just collect the terms and figure out gm defective as I out by V in I repeat collect the terms of I out collect the terms of V in divide and you get your gm effective. So, this is the expression I got it. Now I start looking at this terms if you say R s is not very large a few kilo Ohm s even then this term is of the order of 10 or 1 to 10 even if R ss is in kilo Ohm s increase at least between 10 or something this may be 1 case fine, but this into r 0; that means, if this denominator is now getting 10 times r 0 value equivalently.

So, if I just do R s r 0 cancels I also say right now larger than gm which so I neglect that. So, why I got it is actually gm upon gm R s which is 1 upon R s is that correct equivalently saying it is just 1 upon R s; that means, the value of R s essentially is going to decide the gain how much is my R s value is that point and this is very important for us is that. So, this is how you should look having seen an expression which terms dominate and gm is decided by what currents, but right now what I am getting is essentially gm effective is not very much strong functions of gm itself it is only a function of the load I going to put there or so these generation value which I am going to put there.

This makes something interesting because; that means, if gm effective is not a function of technology parameters like thresholds or environmental parameters like temperatures I am getting an gm, which is very very much constant and to my value fix R s and I get much in. So, that is designers thinking. So, I want to fix my gm which is relatively constant relative what has to be thought we will see why , but otherwise say relatively constant for most parameters of working then I say I got a good this gm value, which I can fix now.

So, their designer now I say this degeneration help me to get something a constant value for my choice that is designers output from this expression as such otherwise there is nothing great in this expression. So, as a designer I started looking r is only R s strong function. So, R s is my value which I must decide in my designs is that clear. So, this is the learning part of that the first part is just deriving the second part is to learn what is that I got out of this expression that is the design issue. So, designing she says fix gm by R s that is simple.

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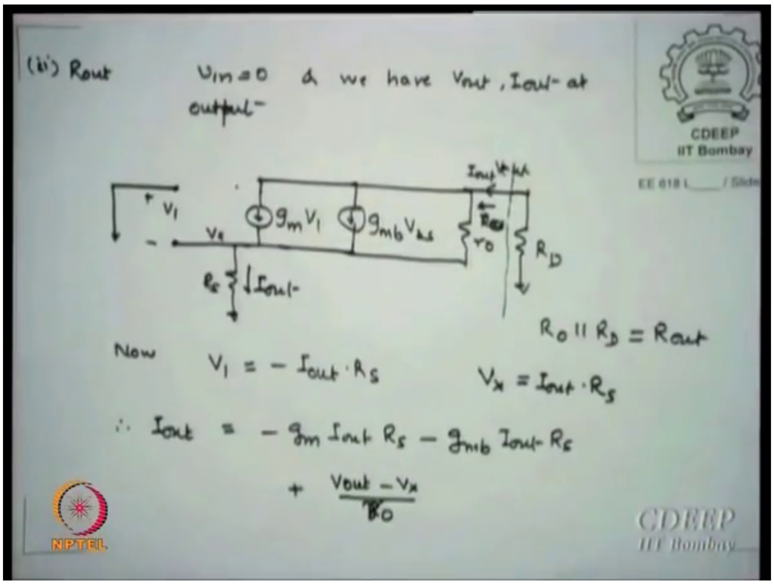

The second term in the gain function was r out and please remember our route is essentially the net output resistance, but right now we first calculate the output resistance other than the load because as seen from the drain side. So, we calculate R o from here, what is the condition there to calculate output resistance put a voltage source at the output and short all independent sources the standard technique of Kirchhoff circuit analysis short all in independent sources.

Please short means if the current source is there it should be opened voltage source it should be shorted. So, do not try to show me some sir I shorted something and got funny with me. So, in my case I say V in is 0. So, from the same circuit I used the actually I will never change my circuit because the I just want to say I do not want to go out of circuit from which I started with. So, I grounded this I still believe since I am putting a V out here V out by I out is essentially what I will call as output resistance seen from the drain end or by transistor. So, I say what is V 1 then since in this case this is grounded V a please take it this is ground this is ground. So, what is the condition you are saying V 1 plus V x is 0 V 1 plus V x is 0 or to say V 1 is minus V x or to say V 1 is minus I out R s is that this opposite of this this is grounded now you bring this terminal ground. So, it is minus I out R s yes.

Student: (Refer Time: 20:52).

V out is at the drain terminal.

Student: (Refer Time: 20:54).

Whenever you calculate the output impedance or of resistance short independent sources at the input or anywhere. In fact, then actually apply a voltage source at the output which I am calling V out which is entering a current I out, then the resistance see in there is V out by I out or why should called resistance if they have a capacitance it will call impedance of that. Now RD I RD is outside see this is the output resistance seen into the device the error you can see, then I will shunted you see next line the actual output resistance is R o parallel RD because why I do not want RD to be part of my calculations because RD is an external parameter it has nothing to do with device per say or circuit I am designing initially that can be decided by the next system is well. So, I do not want to apply decide what is RD. So, whatever it will come I will put it anyway there. So, right now I say I am only calculate is that for you clear now. So, R o is seen in the device at the drain side. So, V x is I out R s V 1 is minus to I out R s.

So, I out again same current this current this then this is V x which is V x minus V out we have to now remember the current is going from V out minus V x divided by r 0, what is the current in r 0 V out minus V x divided by r 0 substitute all of this here V out minus V x by r 0 is the current through r 0 minus gm I out all are minus I taken it because I can understand actually there is plus all are same. This current is some of this plus this plus this, but the minus sign I am trying to say is because can you tell me why because in real life the phase out will come. So, I initially added that minus, but you need not put you can put it plus here and still solve and there is nothing goes wrong about it.

So, having done this I did all analysis and finally, I get r o which is r 0 plus 1 plus gm plus gmb times R s plus R s by r correct terms of V 0 V out and io and divide and you get the output resistance r 0 which is this.

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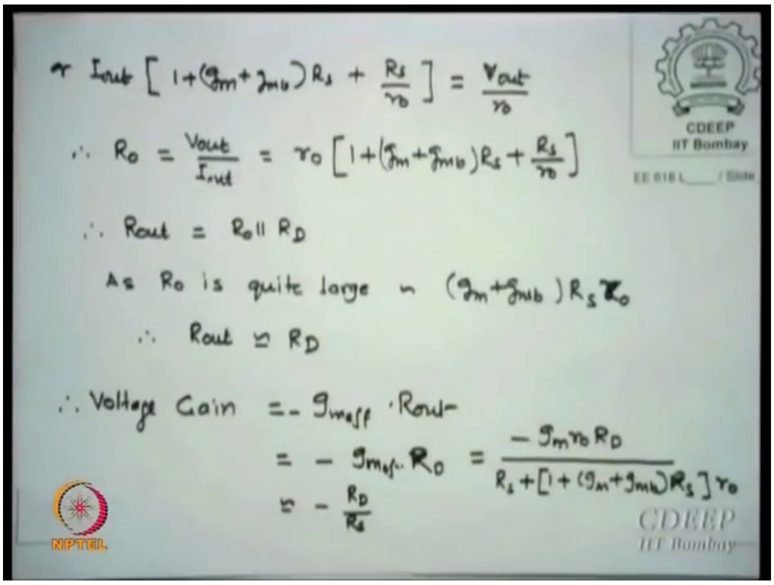

And the final are out as I say is this output resistance R 0 shunted by RD, no because that I out see the problem I am what I removed is the I will come back to it, but let me first finish this talking. This minus sign I would did not put initially. So, I just took it this minus sign which I am going to get. So, I initially itself I used it. So, that a finally, I will get a minus sign, but then I kept using to make it that plus with an additional minus sign, but gain is gm minus gm r out and there I started to plus gm r out I just thought I will make I out the other directions it will automatically defuse out.

Student: (Refer Time: 24:12)

Just come to it just wait I have point I understood your point. So, just let the major feature in that R 0 is quite large why do I say. So, because again gm plus gmb R s is larger than 1 if R s is kilo Ohm s maybe tense; R s is normally much smaller than R 0. So, that this term is negligible. So, what I am this is larger than 1. So, this is around 10 let us say. So, 10 times the R 0. So, output resistance is much higher right now. So, if you shunt it with the load and if the load is smaller than R o then it is there is RD itself because whichever is smaller that will dominate; however, in some cases RD may be larger than R o which will be this case current source or cascode for example, if I use the current source for the cascade at the load end that will be even larger gain larger than this gain because there are it is gm times ro times other R o. So, that time the RD value equivalent will be even larger than gm ro this gm ro. Will be an additional R o coming in the cascode or in the current switch there and therefore, at that time instead of RD what will be the R out whatever is the R 0 got R o you got that will be your output resistor. So, please take it do not always use RD as the smaller or larger RD could be larger.

If it is a current source which is replacing RD if it is normal resistance or RD can be smaller in transistors also when if I use transistor as a resistance and I say RD is small. So, which is the value which way I can get 1 of the active load I said if the device is in linier mode or non-saturated mode the resistance is very small 10 to less than k. So, in that case RD will be always smaller. So, the bias how you did it how do you put an active good on that it may decide RD smaller or larger than R o and corresponding parallel combination 1 or the other may in case they are equal will have half of it, but otherwise 1 or the other will start dominating.

So, typical value if I write gm R R o effective all that here I get this expression and now I again do the same thing which terms is smaller which term is larger gm this is larger this is smaller this this cancels. So, I figure it out roughly this becomes gain is equal to minus RD by R s. Now this ratio has very interesting features what is the importance of a ratio, any parameter which changes the resistance like temperature. Let us say it has a positive thermal coefficient TCR is plus positive, but since both are resistances made out of same silicon there TCR should be same. So, if of course, in some sense you cannot say ratio will has same you know R plus D x is same not necessarily the same R s because it is depend on the value itself also.

But to some great extent we since say it will be always temperature independent. It is independent of all transistor parameters, nowhere W bias will appeared; nowhere beta dash appeared mu I am not even looking at it is that to you. So, essentially now I have a gain of an amplifier which is controllable by me independent of the device. So, this fat has to be remembered that whenever you are looking for a good amplifier, which is temperature independent or device parameter independent we should and what is the limitation I got out of this typically RD can be few kilo Ohm s 100, 20 kilo 30 kilo Ohm s because larger I cannot put that silicon into it 10 will this may be 1 to 5 kilo Ohm s.

So, what is the kind of gain I am looking for is 10 20 30. So, for all the advantages I got I saw that my actual gains have come down heavily. So, at the cost of leaving gains I have now achieved constant seeing gain is that. So, if your requirement in a circuit is that at any cost I want gain should not change for anything, whether it is sensor based device which is in some involvement audio systems, where back noise is too high you prefer that gain should be independent of all other inputs and that case this may help, but the idea is game is smaller. So, do not put this as a stage in this 1000 above gains are expected it never gives that, the first amplifier which we discuss was common source amplifier and that is the word degeneration.

Do you get the point why it is called degeneration the gain has degenerated from it is high value, gm R this to a lower value now and make it as constant as possible and therefore, is called source degeneration and that is a 1 of the major stabilizing factor in any amplifier is that point clear. So, anytime I put a resistance in source I am stabilizing something. Now this issue will use it in the feedback systems where actually we will does this gives you a feedback it does, essentially it is the first feature of a feedback. So, series feedback and we will see this stabilizes things in stability criteria's the poles will move away and then you say system is becoming more and more stable this is the feature we want to now bring to you that why R s in series of source is that clear. So, these are we have learned all this, but start looking from the design perspective if I am given this what should I choose and that is how I am trying to explain.

Student: Sir.

So, second amplifier of my choice stay common gate stage amplifier.

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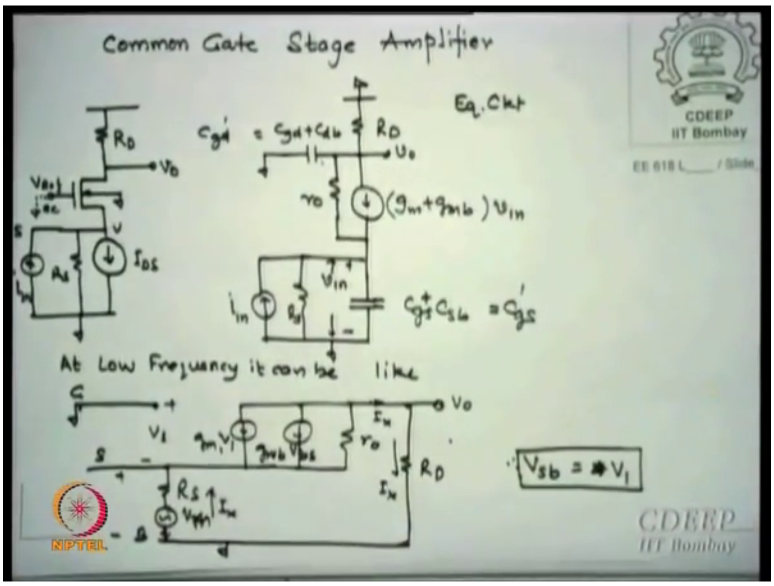

Now, this amplifier we already looked into somewhere where did we look into in cascode the upper transistor was acting like a common gate. So, let us do it as this now this is first time I am trying to show you if I use other people is like bias or Valkyries book there is some time show very different kinds of equivalent circuit . So, I just thought I should copy from them and show this is also one way of putting the advantage of this circuit is it actually mimics the drawn by way normally our equivalent circuit looks like horizontal. So, we do not mimic the kind of circuit we are drawn the way they feel it and that is why I showed you that this circuit actually mimics the way you drawn is that point nothing great it is only to show you that it looks like this. So, here why I am showing you this because in layouts when I do chip layouts for the transistors and everything.

I actually mimic this and therefore, if I have this I have much easier to layout. So, I just showed you why such straight circuits are many times shown simply because the that is the way I will actually implement on chip during layouts. So, just for the heck of it is very great where is a this amplifier whose gate is grounded; grounded S just draw it and of course, as I say I will go back to my standard without this equivalent, because it is much easier to solve with that kind of thing, but I just thought I should show you in some books the equivalent circuit could be shown in this fashion. This includes all capacitances this I in R s is essentially like a V in R s is that correct equivalent in say it is a if you converted from Thevenins to Norton on or Norton to Thevenins I in parallel R s is equal to equivalent in voltages V in series to R s some other R s not same series resistance.

Student: (Refer Time: 33:07).

Gate is AC grounded.

Student: (Refer Time: 33:11).

Ac grounded d dc value you have to put for bias, you have to keep it in saturation, but for AC I think I have made it clear that dot dot AC AC ground. So, if I now put if you are drawn please do.

Student: (Refer Time: 33:28).

Yeah that is what I said this is a current source.

Student: Sir (Refer Time: 33:32) DC ground (Refer Time: 33:33).

No No No, which is DC there is no DC. So, it is all AC.

Student: Ids.

How that is just to show bias.

Student: (Refer Time: 33:41).

That you see this.

Student: Yes sir.

These are current input current source your input V in series R s I can Thevenence convert to Norton and say it is I in parallel to of course, this R s and that R s is not same. So, slight maybe right yes. So, gate is grounded. So, look for the lower actually razavi technique I have gate grounded AC wise, there is a potential between gate and source which I called V 1 there is a so instead of this I used as because razavi as used this. So, I will used a V in please remember this R s and this R s and this R s are not same current source output resistance is very high compared to this series resistance of the voltage source which is comparatively very low 100 Ohm 500 Ohm s. So, do not confuse the same R s.

So, this is a current input through series resistance R s this is V 1 this is the output current gmn V 1 gmb vbs r 0 shunted RD which is RD is down to the ground. Now I assume ix the current at the output which flows through RD is that your sign is taken care now, but the same ix can now in a circuit it can go only like this is that. So, we if current is moving like this it should may up so; that means, this voltage ix R s is any way negative is that correct. So, that sign which you are telling is taken care through the sign of ix; see earlier case do you remember I used ix entering now I have use ix coming out. So, if I use this equations this have you drawn the circuit equivalent.

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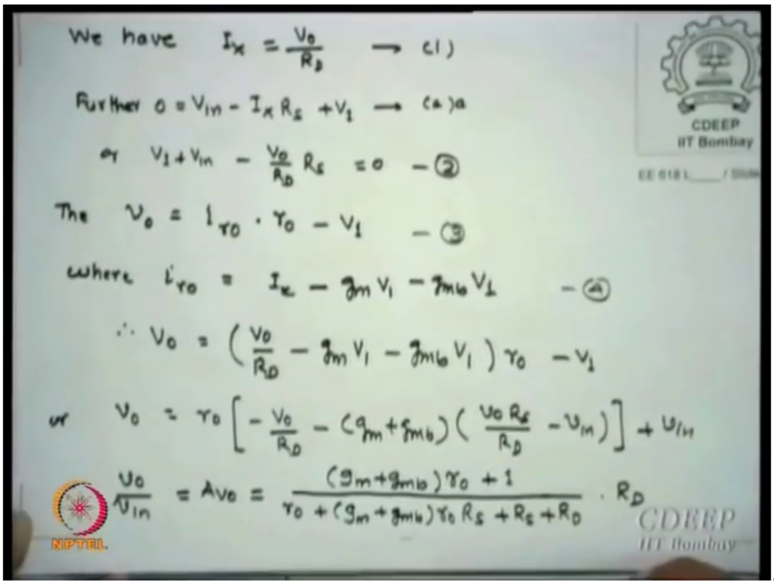

So, let us do maths which is trivial what is ix actually this is grounded, this is v 0. So, V 0 by RD this is ix.

So, the first equation is ix is V 0 by RD please check it sometimes because you know I do not check it myself when I am writing I just come here and show the side at times I may miss sign wrongfully. So, be please bring as he said we will also check again.

Student: (Refer Time: 36:21).

Yeah essentially I am trying to say current source is still downwards this is minus source to bulk that is exactly is the value which I am looking for, but the vsb is always taken like this source 2 this is minus this is vbs. So, essentially it is opposite direction it goes down.

Student: (Refer Time: 36:45) minus (Refer Time: 36:46).

You are ta I am showing as far a sign is concerned I am correct on the sign. So, if I use the please do not write before this, if I use this loop input loop ground V 1 and this then I say 0 is equal to V in minus ix R s plus V 1 is 0 is that just take a mesh from gate ground to the ground through the R s, V in minus ix R s plus V 1 is 0. Why I want to do this because from this I can write V 1 plus V in minus V 0 by I replace this ix by r this R s with 0, I also see V I v 0 just a minute ha I will come back. This voltage please remember what I am looking for is the drop across this which mesh I am looking I am going from here to here, which loop I am looking I am going like this is that ok.

Student: (Refer Time: 38:06).

M common point na. So, if I substitute this if I use this V in drop across let us say I r 0 is the current in r 0. So, which is I r 0 r 0 minus V 1 must be 0 because that loop is completed to the gate ground is that clear drop across r 0 is I r 0 times r 0 minus V 1 must be V 0. Which may and now what is ir 0 ir 0 is this current minus these 2 currents because these 3 current must sum up to ix is that correct.

So, this current must be this current minus this current. So, if I do that I substitute this here, I substitute this back here and then figure out the relationship between V 0 and V in keep substituting nothing very great. What is our aim to get the gain which is V 0 by V in all that I have done it I removed all ix terms, all V 1 terms to get a relationship between V x and V v in and vo this is that expression at any given node the net current must be 0 is that clear Raj at any node net currants.

So, whatever Kirchhoff's law says put signs accordingly. So, having done this all analysis I get the expression of gain which is V 0 or V in gm plus gmb.into r 0 plus 1 r 0 plus gm plus gmb r 0 R s plus R s plus RD into RD why this is what is RD that the output voltage gm times RD. Now if this expressions you see very carefully this term R s and RD they are smaller than R 0 is that R s plus RD s are always smaller than r 0.

So, I leave them gm times R 0 this is anyway more than gm R s is more than 10. So, 10 r 0 maybe you are add if you wish, but even that term I can neglect I neglect 1 from here. So, I cancel it here it is RD by R s is all that I get. So, even in common gate I want really achieved any gain. In fact, it is ah it is very close to 1 only as that common gate amplifier show.

Not voltage gain voltage gain can be ratio of RD and R s, but the current gain is how much in common gate what is the current gain always unity source and drain currents are always equal independent of what you do is that clear. So, it is always unity gain for currents, but the output impedances and input impedances can be separate. So, the gains can be different for, different loads is that clear; because currents are same. So, input current drops will be different and output current drops will be different and therefore, the gains voltage gains can be hire, but current gain always will be unity that is the importance of this; however, as I say this is not very frequently used so much as a good amplifier.

What did wise talk about common gate as an advantage that it acts like a good current source. So, what parameter I should figure out for this amplifier output resistance, because that is what I am right now looking for. So, what is the method I should follow for output resistance evaluation short all input sources independent sources, put a output some in source of the out of vx, entering current let us I out or x vx by ix or V out by r out is the same method which we apply for anything we should keep using the same techniques.

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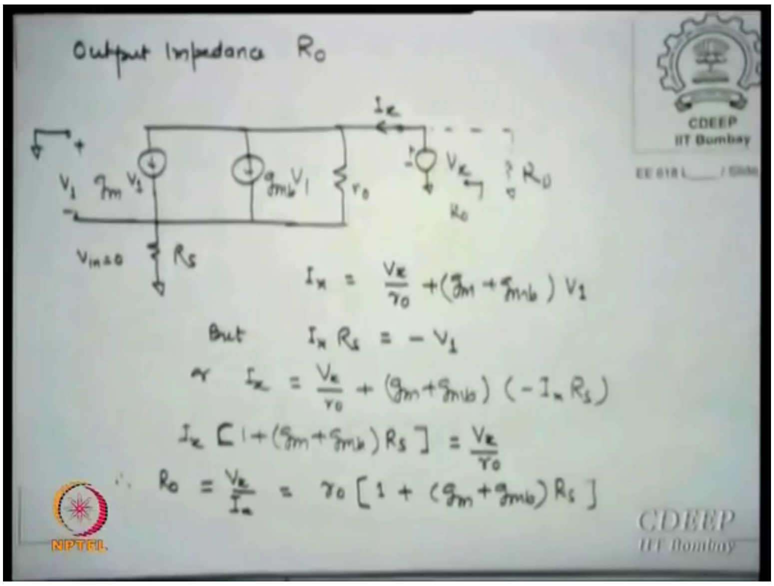

Now, if I do our 0 what is the method I suggest short V in, but what is this case looks like if I short only V in this is like evaluating for a common source amplifier with degenerated R s degenerating source. So, I solve this again and I get same expressions which I did earlier.

Which is r 0 into 1 plus gm gmb times R s, this is the same analysis which we did earlier it is repeats here. Now if I get this r o what is r out again, this r 0 shunted by RD just write down and then is it larger our smaller anything multiplied by this factor to r 0 the output resistance is higher that is what cascode we are trying know the output resistance I want to boost. So, the common gate what did it do boosted the output resistance what is the requirement of a good current source the sources shunting resistance should be as high as pos preferably infinite. What is the third parameter I should look into gain I have looked into output resistance and which is the third 1 I should look for an amplifier.

Student: (Refer Time: 43:50).

The input resistance do believe it will be higher or lower.

Student: Lower.

Lower that is the fun part in that we will calculate. So, what is it trying to do a transform a circuit which has low output resistance, we have higher output resistance. So, it is like a pseudo buffers that you are having a connecting at the lower input resistance this, but putting to the higher output for the next stage. So, that the next stage does not get loads get loaded by this. So, this is interesting, but of course, I repeat if RD is smaller the output resistance will not be very high, it may be few kilo Ohm s tens of kilo Ohm s 20 Ohm 20 kilo Ohm thirty kilo Ohm s , but RD can be smaller also or larger than ro also if I use current sources.

Is that expressions are everyone. So, same expression same statements if R 0 greater than RD less than RD are out is either R 0 or RD.

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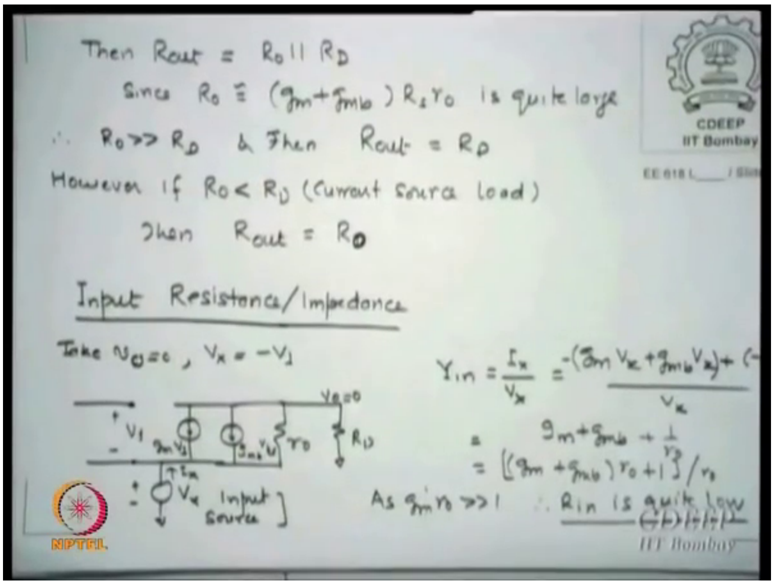

Now, the next parameter of interest to me is the input impedance input, impedance is seen from the input side which is the if I x is the current here and vx is the voltage, I actually calculated conductance ix by V x I x already I can find from here gm V x gm V bx minus V x by R 0, which is gm plus gm V by 1 upon R 0. Since let us call this gm dash. So, if gm dash R 0 is greater than 1, 1 can see this value is larger than 1 this is by divided by r 0. So, R n is effectively very low [FL] because no R s is external.

Student: External (Refer Time: 45:56)

This has to be always understood this is whenever we calculate any input or output resistances or impedances it is seen in the device output from the drain side if it is a output at the R drain and seen from the drain side input always seen from the gate or source side, but the additional resistances we will actually modify that when the correspondingly, but if this is very low even if R s it will further reduce it down. So, it does not really math required. So, what is the advantage of common gate amplifier that is input impedance it is very low.

Impedance word is not clear because there are no capacitance are used, but I will come back to it this is the issue where in frequency response, that capacitance when they come which will have a dominant pole may decide from whether R is lower or higher because 1 by R C. So, this understanding that R is lower more may help to even see oh this may be dominative kind of thing is that clear dominating that yeah. So, observation based on what we are evaluated is that. So, I keeps a I just now said the current gain in the case of this is always I x by I x.

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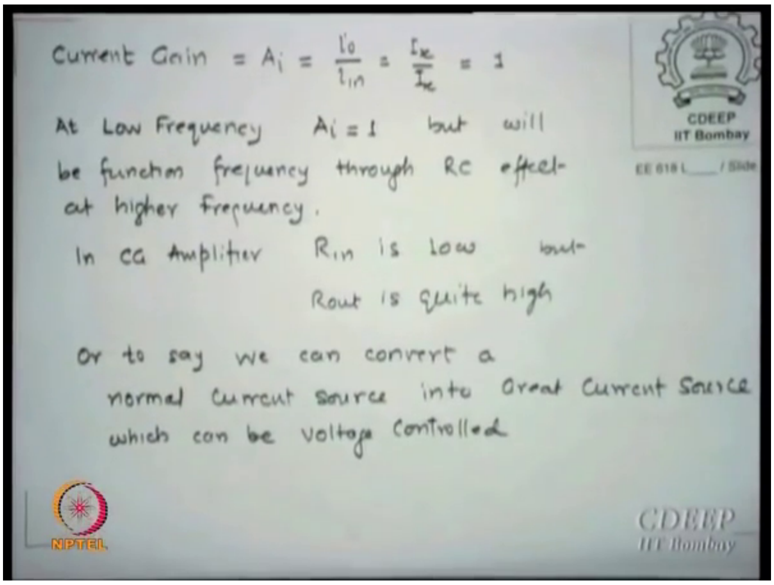

Therefore unity I 0 I in now 1 interesting feature which I did not say. This was all under assumption of low frequency said have equivalent circuits, it will remain unity for very a large frequency and our thinking was that even up to ft should remain 1, but in real life it does not remain 1 at till ft. So, maybe some other day or some other time what frequencies actually it will not be 1 we will see that, but as of now you can say for almost all frequencies the current gain is unit almost and this you must put in course almost not necessarily all times. So, in a CG Amplifier r in is low, but r out is high or to say we can convert a normal current source in to a descent or great current source which is also voltage controllable.

Because if you change V in current value changes. So, it is good to BCVS BCCS, now let us do the mast amplifier among them never is last, but last, but one you may say is that this part anyone, but this is what you should last part is important for us in last amplifier of my interest is common drain .

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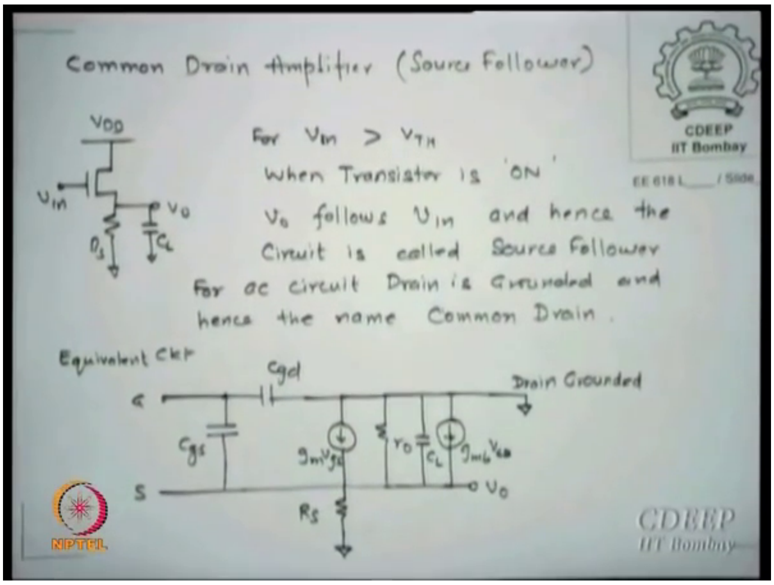

Which is popularly known as source follower there is little difference between common emitter follower and source follower bipolars source followers are different in some sense to the.

Student: (Refer Time: 48:56)

MOS source followers sorry common emitter; emitter followers in BJT are not identical to common source followers of MOS transistor how much they differ and wider differs leave it to you, what is source follower word came from it was found that if V in and VGS of this transistor is such that V in means V capital V in so that V D a VGS plus input signal, if that exceeds threshold voltage the transistor is on and once that transistor is on the current is flowing the through the R s and drop across R s is the output voltage is that correct the word source follower. So, input current is proportional to input and that current flows through R s. So, output voltage is directly proportional to input. So, source follows gate or inputs.

However one can say common drain because drain in this case is grounded there is no V D D RD there since drain is grounded. So, all voltages are reference from the drain point that is ground point. So, therefore, it is also called common drain the drain is grounded means reference voltage has gone to the drain. So, everything is measured from drain ground potential therefore, it was also named common drain amplifier.

If you are looking for all capacitive mode equivalent circuit as shown here gate to source cgs gate to drain cgd cdb plus external load is cl gm VGS is this is the VGS across cgs. So, gm VGS is the current source gmb vsb is the another current source back bias if it is r 0 is the output resistance please remember R s is the load across, which V 0 has been picked up and drain is grounded we will remove this capacitor next time before we start the differential amplifier I will like to maybe if time permit.

No not permit today I will see that whenever I have a series component in an amplifier which is connecting output to input I can put into 2 parts input side outputs side using millers theorem vannas miller theorem valid.

Student: (Refer Time: 51:31)

That is very important you cannot use miller theorem randomly there are limitations or there are compulsions with which miller theorem is valid, because that we will use again in the case of diff amp designs. So, we will like to show you what is the limitations in millers theorem is that equivalent circuit clear. So, first thing what we will do is as usual remove all capacitances and solve for low frequency I am going to do 1 or 2 frequency response for the all these amplifiers 1 time and then the same procedure can be and 1 of the technique, which I taught this batch of second year which is 0 time constant value or open circuit 0 current constant systems.

I will be able to show you which poles are dominant. So, you do not have to evaluate all of them you can figure it out which is the dominant pole which decides the bandwidth, because once I know the bandwidth I do not care much of the otherwise. So, I must know my bandwidth so which need not solve all of it all the time.

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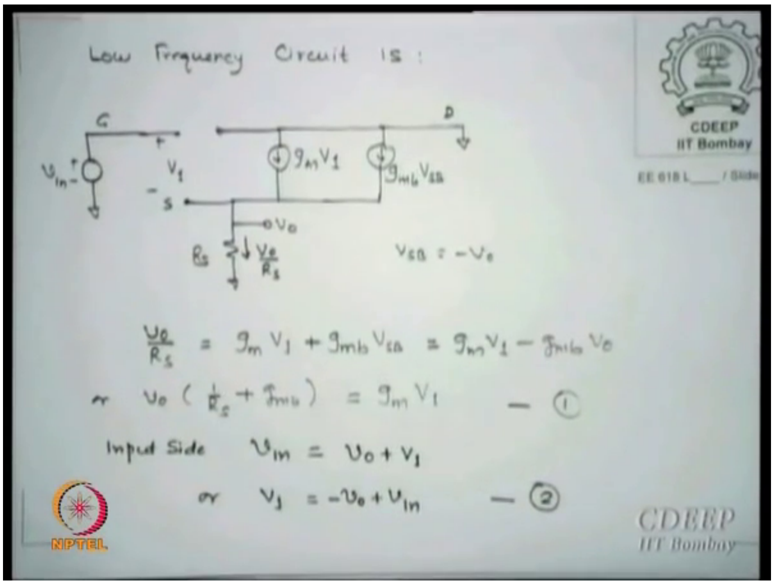

So, typical low frequency circuit is remove all capacitances put an equivalent circuit V in input voltage at the gate same gate to source voltage V 1 this V 1 what as I say I am using it from razavis book, if you want to put some other VGS value or something it is fine I know with objection I repeat I am saying this I have using prom razavis I like this razavis technique. So, I am I normally have been using his terms this is my source drain is grounded now in this case I assume that R 0 is very high and I just forgot about it.

Let us say see this is my V 0 the current in R s is V 0 by R s there is nothing there is nothing else if this is my v0. So, V 0 by R s is my current in R s since this is downwards this voltage with reference to will become now minus V 0 and then I substitute as usual all the terms V 0 by R s is the current which is gm V 1 gmb vsb substitute them again here and solve .

Student: Sir.

You that is writing symbols is yours I think what I meant is the current source going down in series in parallel to V in gmp I think I made a mistake writing sometimes vba sometimes vsb please keep it as if the direction shown corresponding to that vsb this vsb is minus vbs in real terms. So, I at time this sign probably gets into wrong mood. So, please always assume whatever sign I am showing you assuming correct signs I am pushing the current down now. So, if I get first equation is V 0 1 upon R s plus gmb gmb

1 my method like razavis look for input side this is my input side is that correct this is V in this is va v 1.

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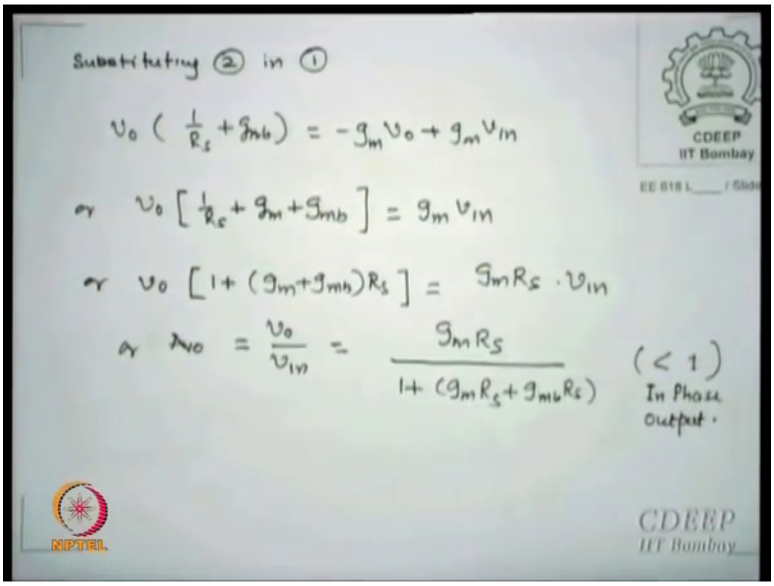

This is v 0 is that correct this technique is very simple [FL] ground [FL] voltage sum [FL]. So, you get v in is equal to v 0 plus v 1 or v 1 is minus v 0 plus v in then this 2 v 1 I substitute here I repeat what is the method first I actually look for these current sources going into this then I look from this side input side I say V in must be equal to this is that clear this is my v in this must be equal to this. So, nothing very mischief done only voltage here at the same node same voltage must appear. So, if I write that I get this plus this is equal to this survi is this is equal to this plus this both ground [FL] load [FL] sum must be this same equation I wrote.

From there v 1 is minus v 0 plus v in substitute v 1 here I get v 0 1 upon R s gmb minus gmb 0 gm v in then collect the term for v 0 collect the term for V in and I get v 0 1 plus gm gm vrs is equal to gm R s v in or gain is v 0 by V in which is gm R s divided by 1 plus gm R s plus gm vrs 2 things you must remember denominator is always larger than the numerator marginally larger because the other terms are smaller you can say the numerator is marginally smaller than the denominator. So, the voltage gain of a source follower will be always less than 1 if there is no back gate bias then you may you may say is very very close to the.

So, what is the importance of back gate bias this is what I want to bring to it why have actually use this can you think, if there is no back gate bias what will be what is the gain will become then even close to 1 because gm R s by 1 plus gm R s is very close to 1, but as soon as I add the term gmb R s I am actually increasing the denominator, but; that means, gain will further go down because of back gate bias is that point clear. So, please remember why spice does not show your initial values because if you are not using the back gate bias your analysis it shows you are slightly away from your actual result. So, this is why also an important fact you must remember that the gain is positive in the sense.

The output and input are in phase because in that loop current in than the same sense from input to output and therefore, it is always in phase outputs and therefore, it is always plus.

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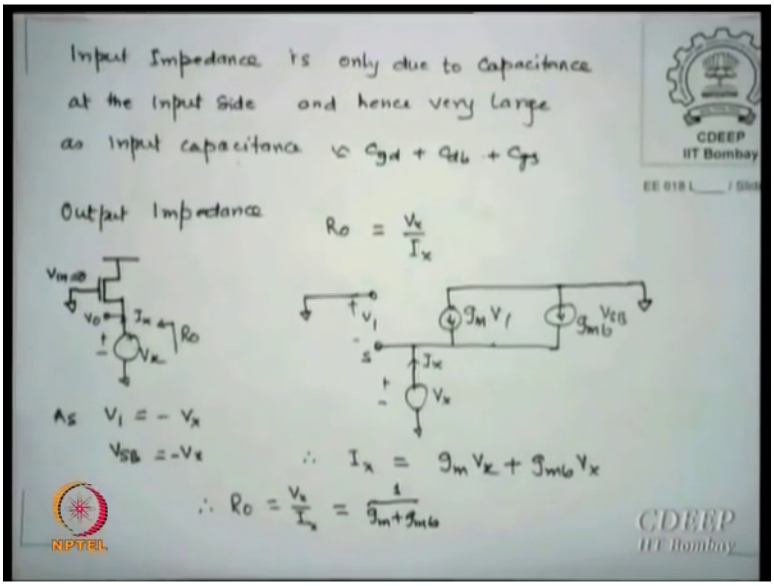

If you look at the input impedance of such amplifiers it is almost infinite except if there is no capacitance is open circuit, if there is a capacitance it is decided by the capacitances. Typically input capacitance is very low cgs plus cgb these values are very low. So, unless it is because 1 upon omega c unless omega is very high the input impedance will be always very high at very high frequencies it may not be because then 1 upon omega c may not be that high and then it will start shunting and that will be some kind of a pole it will start coming to. So, I am not worries too much worried about input impedance in the case of output impedance what is the technique we use remove the R s remove V in.

Put V x there put I x going through there evaluate V x by I x all input sources are grounded V in wherever V in was there that I have grounded.

Student: (Refer Time: 59:05).

So, R s is external impedance is always measured in the device at the output I never took RD.

Student: RD (Refer Time: 59:15).

So, [FL] R s RD [FL].

Student: (Refer Time: 59:18).

Is that load is not my hand is that that word was used there because in the source it was there, but essentially it said output load. So, if I solve this simple this currents are same currents here this, I can say sign taken properly then R 0 is 1 upon gm plus gmb what does this time to say R 0 is higher or lower 1 upon gm plus gmb gmb is same as gm 1.6 or 1.6 gm gm [FL] roughly.

Student: (Refer Time: 59:56).

Milli mauls Milli Siemens so R o [FL].

Student: (Refer Time: 60:02).

Few kilo Ohm s are lower because if number is little more Milli Mauls then it will be even newer. So, the output resistance of a emitter follower is.

Student: (Refer Time: 60:15).

Very low or lower and input impedance is or input resistance is.

Student: (Refer Time: 60:20).

Very high. So, where do you think it can be used?

Student: (Refer Time: 60:26).

In a buffer stage where input impedance you want to be infinite or very high and you want to match the load which is a load value therefore, output impedance should be match able to that what is why it should be match able what is the purpose of matched loads?

Student: Power Transfer.

Power Transfer is Maximum. So, I want to put equivalent there. So, that I get maximum power transfers is that I have drawn, this is very trivial nothing very serious anyone who feels that I have done misuse something please go ahead into razavis book and correct your signs or otherwise.

Student: (Refer Time: 60:61).

No I have not copied from razavi, but since I have taught razavi for 10 years now.

Student: (Refer Time: 61:08).

I almost know the way I must have done. So, since I do not keep books any time.

Student: (Refer Time: 61:14).

So, there may be a sign in case you feel it please look into razavis book this is their technique. So, it must be correctly there quickly I will show you and then finish this this is something we should now remember and note.

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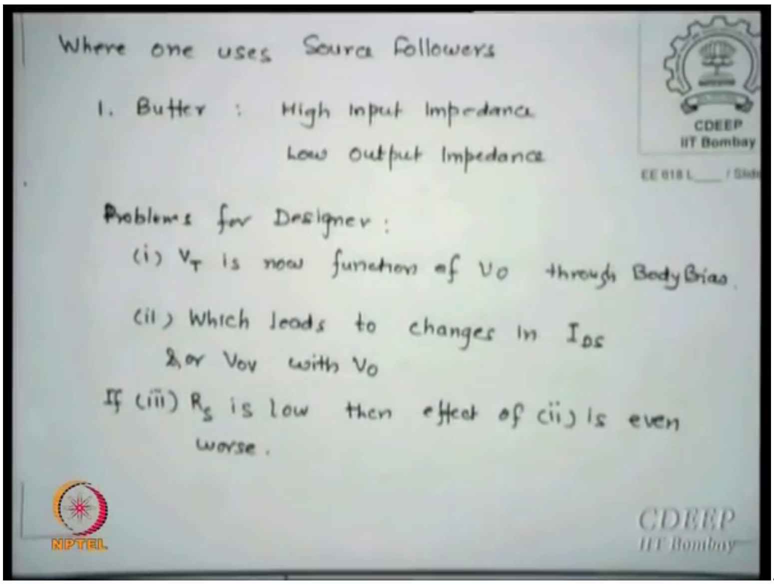

Where do you want to use source followers? So, first thing I just now said if you need a system in which high input impedance and low output impedance, then you should use buffers source followers as buffers. Now here is an issue here is a designer problem [FL] part [FL] circuit issue [FL] circuit analysis [FL] what did we learn we learn the of problems now since vsb is related to V 0 is that clear vsb is related to v 0.

Vsb also changes vt we know vt is equal to vt 0 to 5 half plus vsb to the power half minus 2 5; that means, if we 0 changes vt change if vt changes gm changes. So, vt is now a function of output through this body bias, now if vt changes which current will change if current changes or vo will change either way, which means gm is change the worse may come if this series resistance R s is even low think of it why I say it is not tomorrow I will tell on Friday if R s is lower the effects are even worse. So, at least reasonable R s [FL] source followers may not be that bad, but if the R s values are too small then it will create this say ids variation or vov variation very strongly and then all purpose of good buffer may not be actually seen.

This is first issue which common sources source for.

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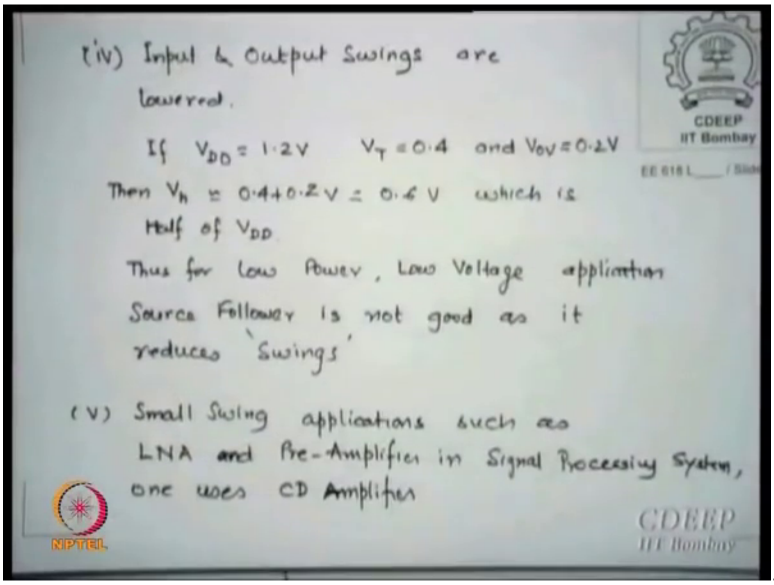

The second problem which I see in buffers is you know at the end of please remember input signal may be small, but normally what is the purpose of an amplifier the output should be larger that is why gain we call it is not it. The problem with this source followers are that their output and input swing both get lowered and example I gave some values let us say I have an amplifier which I am using with V DD 1.2 volt thresholds of 0.4 volt and over voltage or these are not very accurate value, but roughly. So, we see the headroom now available to me is 0.4 plus 0.2, which is 0.6, which is almost half of the power supply; that means, just to turn on device on I have now. So, much voltage lost by me is that clear.

So, I have very small swings are now available for output or input is that point clear VGS minus vt to keep device on below this you cannot turn on above this; that means, if this value is 0.6 or even more in some cases then the available swing to you is very small is that correct. So, only when as very very small signal amplifications you are doing this may be fine, otherwise this may create a problem. So, source follower should be always thought of very low signal amplifiers; however, low power low voltage applications and you need many times in biomedical affliction larger swings for E C G for a measurement for example, such amplifier may not be used, because these swings are very small there.

So, accuracy of measurement becomes very small. So, these are amplifiers which should not be used when you are looking for higher swings. So, where do you use them [FL] use

[FL] we use them we use them as small swing applications are in the case of rf for example, front end which is low noise amplifiers or in a normal other not necessarily rf, but other amplifier systems the first stage amplifier, which is called pre amplifier you can also saw the reason behind the input may not come from very high impedances particularly if like in case of rf system and antenna as 50 Ohm or 75 ff balloons now you are inputting that signal, which as at very low impedance.

So, the first amplifier which is going to amplify signal and the signal is very low you are pushing it higher at that time this may be beautiful is that point clear to you. So, do not think that these are not useful, but do not arbitrarily put any time source follower thinking [FL] gain [FL] 1 no create problems it does create problems in actual designs. The last 2 applications will not explain maybe I can, but. So, you ask then only thing.

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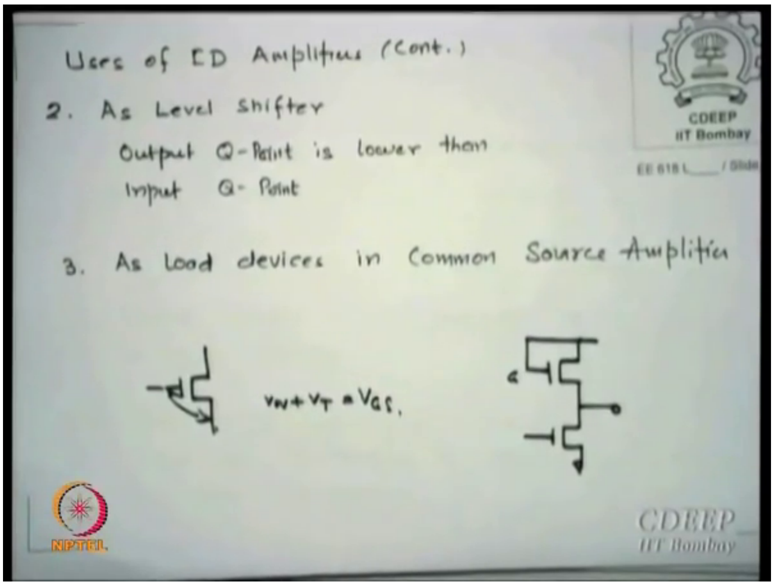

The other application of a source follower is the level shifter.

Student: (Refer Time: 66:46).

What is level shifter [FL] level raj in amplifier may what is level DC point.

Student: (Refer Time: 66:55).

So the output Q point.

Student: (Refer Time: 67:07).

That is DC value is lower than input DC point, why VGS minus vt [FL]. So, [FL] vov plus vt [FL] I repeat what I am saying if I want this amplifier to work this value the vov plus vt is VGS. So, [FL] voltage [FL] voltage [FL] at least vov plus vt [FL] DC [FL] is that clear.

Student: (Refer Time: 67:36).

[FL] voltage [FL] as a level shifter we can use this because the input level to output level can be how much shift I can do vov plus vt not very large, but at least it can go down, you want further open another stage for that it will reduce further. Then the last part it can be used as a load it can be loose used as a load if I have an amplifier say n channel device this is my gate this is my this this is like a source follower and this can do a good job for you to gain or R o high we are looking for R o high na.

So, this can give you good R o these are some techniques. So, this is why I have brought this to a notice when to use what is most important in designs. So, source followers are only used for level shifting for aligning pre amp and for finally, as low device do not use that as an amplifier of any other use it has no good features. They are not top of frequency response it may have further impacts on them when I go frequency response I will explain more which one is even worse among them is that.

Thank you for the day.