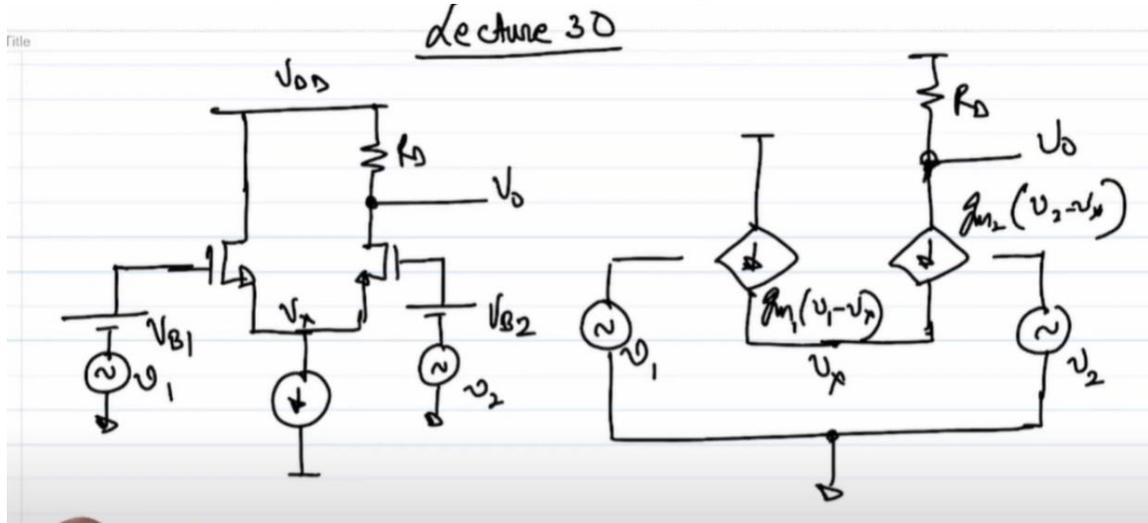


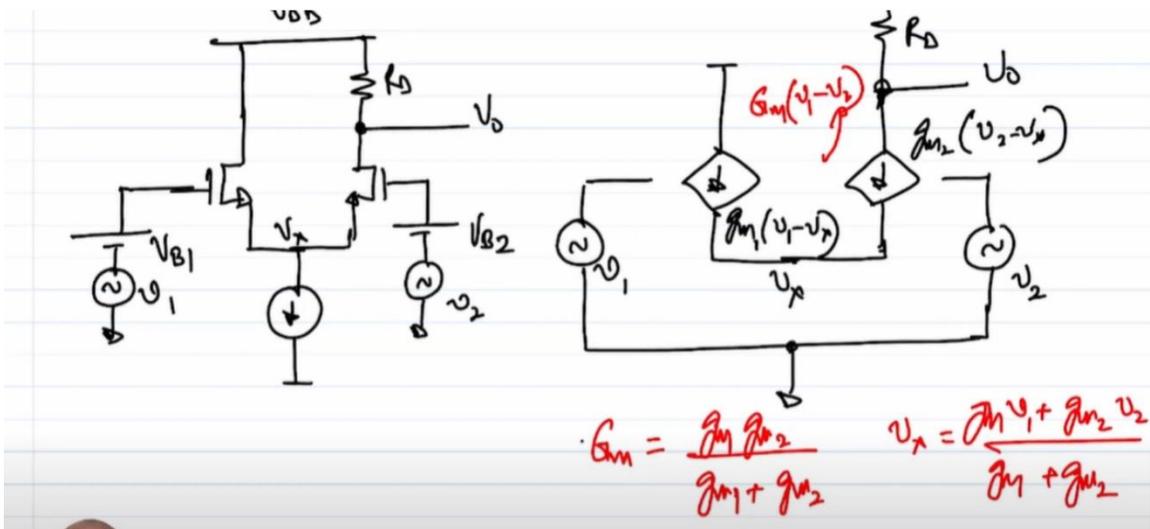
**Course name- Analog VLSI Design (108104193)**  
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**Department – Electrical Engineering**  
**Institute – Indian Institute of Technology Kanpur**  
**Week- 10**  
**Lecture- 30**

Welcome back, this is lecture 30. In the previous lecture we were discussing a differential amplifier right. So, let us continue our discussion on the same topic. So, this was the structure that we were interested in. And we also saw that and we also saw that the current that comes out of this structure right. So, if we apply, so the incremental equivalent of this structure is essentially this, where the  $V_x$  terminal is open in its incremental sense.



So, this current becomes  $g_m V_1$  minus  $V_x$  and the other current becomes  $g_m$ , so  $g_{m1}$ , this is  $g_{m2} V_2$  minus  $V_x$  and this goes into the load resistance  $R_d$  right. So, this was essentially the incremental equivalent of our structure and we are getting the output from this right. And what did we see, we saw that this is nothing but this the current the incremental current that is flowing into the resistance  $R_d$  was how much? The incremental current that was flowing in after we did KCL, KVL and all those applications and everything was proportional to some proportionally constant  $g_m$  times  $V_1$  minus  $V_2$ , where  $g_m$  was  $g_{m1}$ ,  $g_{m2}$  by  $g_{m1}$  plus  $g_{m2}$  right ok. And what was  $V_x$ ?  $V_x$  was also essentially weighted average of all the voltages, incremental voltages at  $v_1$  and  $V_2$  right.

So, this is essentially  $g_{m1} V_1$  plus  $g_{m2} V_2$  by  $g_{m1}$  plus  $g_{m2}$ , this is what we this is what we observed right. So, as it turns out, as it turns out this differential amplifier structure is a very ubiquitous structure and it is used everywhere and instead of using this entire symbol each time what we generally tend to do is reduce the footprint of the symbol and express it in a much compact form. So, what I mean by that is what is the common source amplifier?



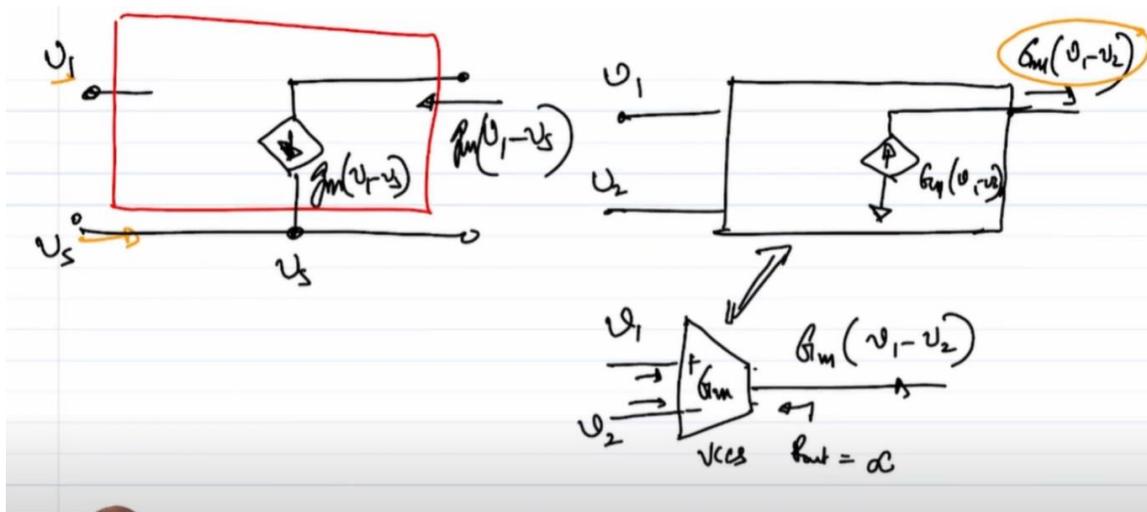
A common source amplifier is a case where I have an input let us say I call it  $V_1$  right. So, this current is  $g_m$  times  $V_1$  and this is flowing out, I am including channel in modulation. So, your common source amplifier essentially becomes this, the stuff inside the box is a common source amplifier.

Why? Because the current that is coming in is  $g_m$  times  $V_1$ , where  $V_1$  is a voltage between some reference and which is connected to the source and the gate voltage right. So, in case of a, if we have to black box our differential amplifier, so what should that black box look like? So, in case of a, if I black box the differential amplifier and instead of sketching this entire differential amplifier topology, what should it look like? It would look like as if there is a current of some  $g_m$  times  $V_1$  minus  $V_2$  that is flowing out when there is an input  $V_1$  and  $V_2$  correct and where is this current flowing out? This current is essentially flowing out of some internal reference right. What is the difference between this structure and the common source amplifier? The structure that is, the difference is that reference point in case of a common source amplifier was a source terminal and the voltage at the input side was being also referred to that source terminal. However, in our case in a differential amplifier the output current is still the difference between two terminals right. In case of a common source amplifier the output current was a difference between the gate terminal and the source terminal.

In our differential amplifier case the output current is again difference of two terminals that is  $V_1$  and  $V_2$  but note that neither  $V_1$  or  $V_2$  are source terminals right. So, that is a critical difference other than that as far as the current output is concerned this is exactly similar to a common source amplifier ok. So, in other words ok, so if I have to make it more explicit I should say I should maybe say it in this way if this is  $V_s$  and this is  $V_1$ . So,

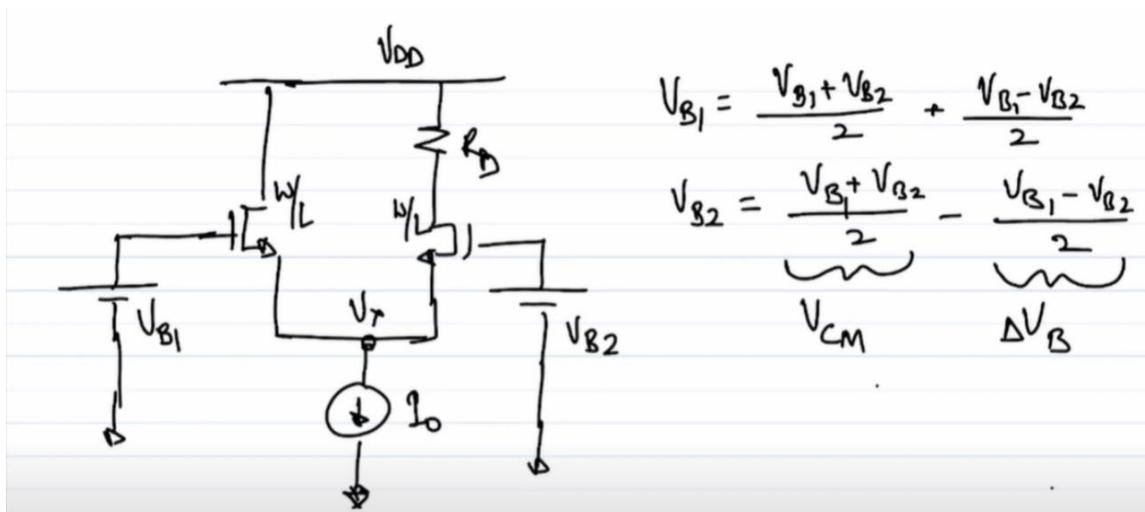
this current is  $g_m V_1$  minus  $V_s$  this is  $g_m V_1$  minus  $V_s$  right. Note that this  $V$  current  $g_m V_1$  minus  $V_s$  is flowing into the source.

In our case in a differential amplifier the output current is again still proportional to  $V_1$  and  $V_2$  right just like in case of in case of our common source amplifier the current is proportional between  $V_1$  and  $V_s$ . However, this current is not flowing into the source the flowing current is flowing into some internal reference ok and that is why this structure is again shortened and expressed in this format. And, we simply call this  $g_m$  where it is assumed this structure that you see here right this almost like a triangle whose nose has been chopped off right it is almost like a triangle whose nose has been chopped off. So, this is a voltage controlled current source whose proportionally constant is  $g_m$ . So, whenever we have this structure this means that I am referring to this structure right which means the current that is coming out is  $g_m$  times  $V_1$  minus  $V_2$  ok.



So, going forward in another lecture or so you will see that we will not whenever we are trying to deal with differential amplifiers in a broader sense right when you have to deal with multiple amplifiers put together then we will see that we will not write we will not represent that differential amplifier with multiple voltage control current sources. We will essentially combine all of them right we will combine this multiple voltage control current sources that a differential amplifier is that is used to make a differential amplifier and put it in and represent them as a symbol and the symbol is something that I just showed here. So, all you have to be mindful about is this input impedance from either of these terminals are infinity right. So, here it is open circuit no current flows in also the other thing that you need to note is what is output impedance? Output impedance is also infinity because it is a voltage control current source ok fine. So, let us get back to what we were discussing.

So, let us assume to start off that since the structure as from the perspective of the transistors and the way we are feeding the input same symmetric let us assume that both of these are have same W by L. They did not have the same W by L, but let us assume that they have to start off ok. And also let us assume that we are only bothered with Poisson condition right now and let us again assume further assume that this voltage is  $V_{B1}$ , this voltage is  $V_{B2}$  right right ok. So, if you recall when we stopped for when we stopped that when we ended the previous lecture we were in the midst of representing inputs as sum of common mode and differential inputs right. So, why is this relevant? This is relevant because I can say that  $V_{B1}$  is equal to sum  $V_{B1} + V_{B2}$  over 2 plus  $V_{B1} - V_{B2}$  over 2 right and  $V_{B2}$  to be equal to right.



So, let us say  $V_{B1} + V_{B2}$  over 2 to be to be a common mode right let us call this  $V_{cm}$  and let us call this  $\Delta V_B$  right. So, if that is the case what we will what do I see? I can represent these inputs as  $V_{cm}$  connected at both nodes both inputs and another signal which is  $\Delta V_B$   $\Delta V_B$  here and  $\Delta V_B$  minus  $\Delta V_B$  at the other terminal correct. So, why am I doing all these things? I am doing all these things because if  $\Delta V_B$  is small right if it falls within that range of small signal whatever we call it as small signal if that is true then I can express that. So, if  $\Delta V_B$  is within code small then it can be expressed as a differential input on top of common mode  $V_{cm}$  correct ok. So, if we so why are we saying this? We are doing all these things because ultimately we love symmetry right.

If we have symmetry then circuit analysis becomes easier right. So, that is why we would like to break it up in such a way that we like to arrange the inputs for our analysis in such a way that a symmetry is established ok. So, if this were the case under quiescent condition right under quiescent condition what we mean by quiescent condition? Under this the quiescent condition seems to be that when  $\Delta V_B$  were not there and we only had  $V_{cm}$

right. If we only had  $V_{cm}$  what can you comment on the current let us say I call this  $I_1$  and I call this  $I_2$  what will be current  $I_1$  and  $I_2$ ? So,  $I_1$  will be half  $\mu_n C_{ox} W$  over  $L$   $V_{cm}$  minus  $V_x$  minus threshold voltage whole square what will be  $I_2$ ? This will also be half  $\mu_n C_{ox} W$  over  $L$   $V_{cm}$  minus  $V_x$  minus threshold voltage whole square. So, essentially what is the scenario  $I_1$  is equal to  $I_2$  and since  $I_1$  plus  $I_2$  is  $I_0$ .

$$V_{B1} = \frac{V_{B1} + V_{B2}}{2} + \frac{V_{B1} - V_{B2}}{2}$$

$$V_{B2} = \frac{V_{B1} + V_{B2}}{2} - \frac{V_{B1} - V_{B2}}{2}$$

If  $\Delta V_B$  is "small" then it can be expressed as a differential i/p on top of common mode  $V_{CM}$ .

$$I_1 = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{CM} - V_x - V_{TH})^2$$

$$I_2 = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{CM} - V_x - V_{TH})^2$$

So, this becomes  $I_0$  over 2 right. So, at under quiescent condition both the quiescent currents through both the transistors  $M_1$  and  $M_2$  are identical right. So, this current is  $I_0$  over 2 and this current is also  $I_0$  over 2 correct. So, why am I bothered with this? I am bothered with this because now if we introduce this plus minus  $\Delta V_B$  minus  $\Delta V_B$  what can we say? We can say that application of plus  $\Delta V_B$  and minus  $\Delta V_B$  will create an incremental current right and how much that incremental current will be? This will be equal to  $g_m$  times  $V_1$  minus  $V_2$  what is  $V_1$  in this case  $V_1$  is plus  $\Delta V_B$  and what is  $V_2$ ? It is minus  $\Delta V_B$  right. So, in essence on top of the quiescent currents  $g_m$  times 2  $\Delta V_B$  right.

So, what will be the current? What will be the total current through  $M_1$ ? So, total current through  $M_1$  will be  $I_0$  by 2 plus  $g_m \Delta V_B$  and total current through  $M_2$  will be  $I_0$  by 2 minus  $g_m \Delta V_B$ . Why minus? Because note that the incremental current is flowing in the opposite direction that to that of  $I_0$  by 2 right. So, essentially the current is decreasing right. Another way of thinking about it is when you are applying plus  $\Delta V_B$  at the gate of  $M_1$  and minus  $\Delta V_B$  at the gate of  $M_2$  what is happening to the overdrive of  $M_1$ ? You are increasing the overdrive of  $M_1$  and you are decreasing the overdrive of  $M_2$ . Now note that the current of  $I_0$  earlier was splitting equally between both  $M_1$  and  $M_2$  because

they had identical overdrives.

Now that you have more overdrive on M1 and less overdrive in M2 then more current will tend to gravitate towards M1 and less to M2 and how much will be that more and small b if we can apply small signal approximation then that will be gm times delta Vb ok. And what is gm? gm was gm1 gm2 by gm1 plus gm2, but what is gm1 and gm2 now? gm1 and gm2 are quiescent transconductance of M1 and M2 evaluated under what condition? Evaluated on the condition under the condition that both of them have currents of I0 by 2. So gm1 what is gm1? gm1 is under root 2 mu n Cox W over L I0 by 2 which is exactly equal to gm2 and let us call this gm. So effectively this gm becomes gm of 2 gm by 2 right gm1 by 2 ok right ok. So it seems like it seems like the incremental current right.

$$\text{Total current through } M1 = I_{0/2} + G_m \Delta V_B$$

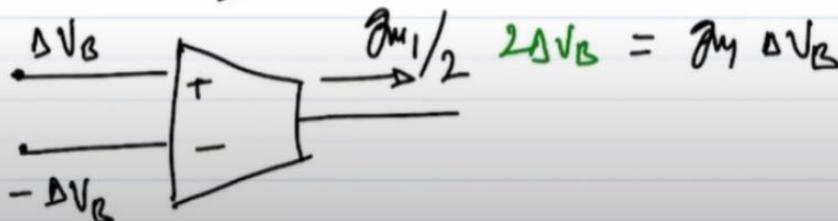
$$\text{" " " } M2 = I_{0/2} - G_m \Delta V_B$$

$$G_m = \frac{g_{m1} g_{m2}}{g_{m1} + g_{m2}}$$

$$= \frac{g_{m1}}{2}$$

$$g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_{0/2}}$$

$$= g_{m2} = g_{m1}$$

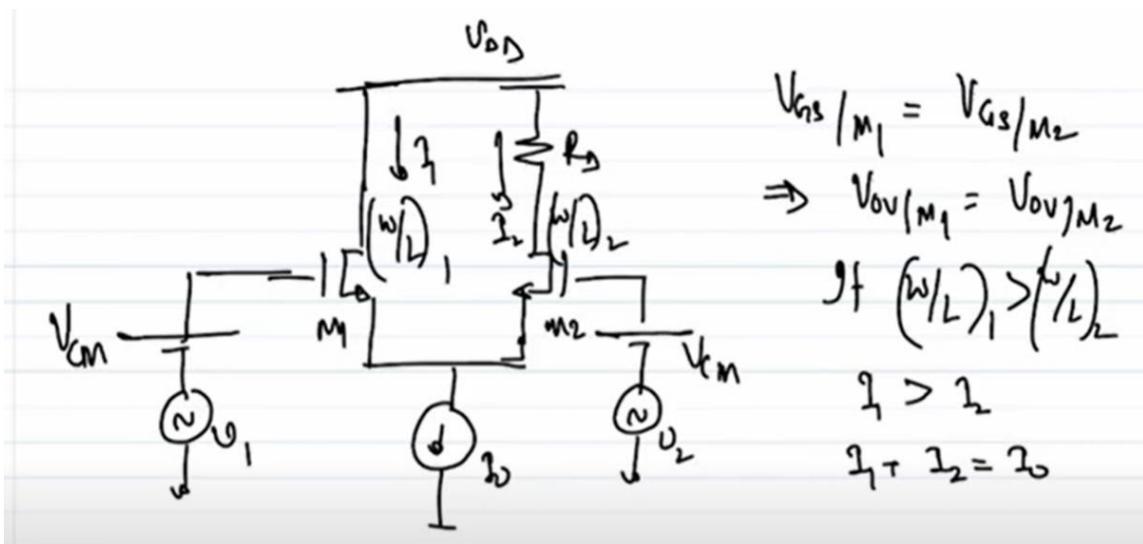


So if I have to represent this again as a in the symbolic form that we just derived what are we seeing? We are seeing incrementally if we have an input delta Vb here minus delta Vb here the current that is flowing out is gm1 by 2 times 2 delta Vb which is equal to gm1 times delta Vb ok. So fine so what is the moral of the story? The moral of the story is there are several models the primary one that we are discussing in this case was if we do not have identical bias conditions at the inputs at the gates of M1 and M2 and assuming that the biases are slightly off right by slightly off I mean the delta Vb is difference between the bias can be attributed I mean can be thought of a small signal difference then we can as

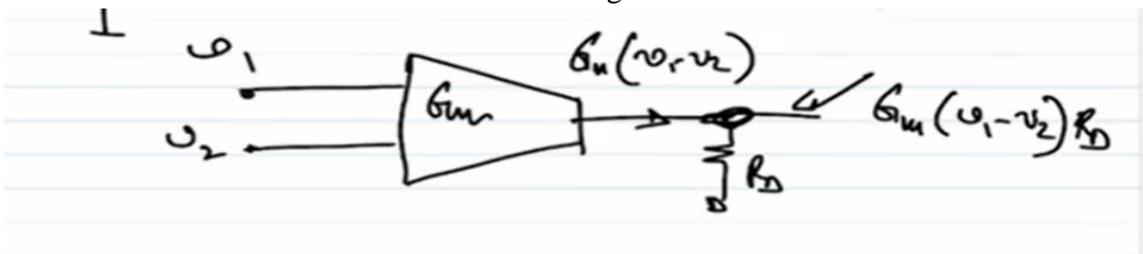
well say that both the transistors are biased identically with a common mode voltage which is average of the biases and we understand that because the biases are different there will be a difference current the current will not be identical between the two branches, but the difference current can be approximated as a small signal difference which is equivalent to the trans conductance the equivalent trans conductance of the differential amplifier which is  $g_{m1} g_{m2}$  by  $g_{m1} + g_{m2}$  which is equal to  $g_{m1}$  by 2 in this case and times the voltage difference of the two inputs right. So, since we have this way of since we have a mechanism of dealing with difference voltages even if the difference is in the bias right. So, what we will do going forward is assume that things both the transistor are biased with identical bias voltages right and whatever input we might be applying at their gates or the difference in input can be because of difference in bias voltages or for some difference at some input difference achieved we will relegate all of them to say to as if they are part of some input fine. So, in essence what we are essentially doing is this the structure that we will be dealing with from now on is same bias let us call this  $V_{cm}$  and we will have some input  $V_1$  and let us call this  $V_{cm}$  also and we will have some input  $V_2$  ok fine.

Now what about the sizes of  $m_1$  and  $m_2$  right we did not assume the sizes of  $m_1$  and  $m_2$  mean kind of sneakily assume that both the sizes are identical but they also need not be identical right. I mean you can free country you can have a you can decide to choose  $W$  by  $L$  of  $m_1$  and  $m_2$  to be different yes indeed you can. So, if that is the case what is going to happen intuitively what do you think is going to happen if  $W$  by  $L_1$  is more than  $W$  by  $L_2$  if  $W$  by  $L_1$  is more than  $W$  by  $L_2$  then the  $m$  then  $m_1$  is stronger than  $m_2$  correct note that the  $V_{gs}$  of both  $m_1$  and  $m_2$  are identical right. So  $V_{gs}$  of  $m_1$  is equal to  $V_{gs}$  of  $m_2$  why because both their gates are twice and twice both their gates are at same voltages the sources are tied together and the threshold voltage are also same which means they have same overdrive also which means  $V$  overdrive of  $m_1$  is equal to  $V$  overdrive of  $m_2$  correct. So, if the  $W$  by  $L$  of  $m_1$  is more than  $W$  by  $L$  of  $L_2$  correct.

So, then if  $W$  by  $L_1$  is greater than  $W$  by  $L$  of  $m_2$  then what is going to happen the  $I_1$  right the current  $I_1$  will be greater than 2 and what is sacrosanct the sacrosanct condition is  $I_1 + I_2$  is always equal to  $I_0$  correct. So, you can write out the equations you can write out the saturation condition equations of  $m_1$  and  $m_2$  and you will be able to find out what will be the exact  $I_1$  and what will be the exact  $I_2$  once you know what the exact  $I_1$  and  $I_2$  are then you will know what the transconductance are what is  $G_{m1}$  and  $G_{m2}$  moment you know what the transconductance are then you can effectively use the structure and say that in order to establish.



what is a small signal equivalent I can essentially represent these guys as this guy as  $V_1$   $V_2$   $G_m$  where  $G_m$  is  $G_{m1}$   $G_{m2}$  by  $G_{m1}$  plus  $G_{m2}$  the current that is flowing out right current that is flowing out is  $G_m$  times  $V_1$  minus  $V_2$  where now note that  $G_m$  is not identical I mean  $G_{m1}$  is not equal to  $G_{m2}$  right. So, in this case I have to say that then  $G_{m1}$   $G_{m2}$  becomes  $G_{m1}$   $G_{m2}$  by  $G_{m1}$  plus  $G_{m2}$  correct and where is this incremental current flowing this incremental I mean all we have done is show you the incremental structure of this guy right without the  $R_D$  correct we have been only dealing with the incremental structure of the voltage control current source without the  $R_D$  where is this guy flowing this current is flowing this is flowing into  $R_D$  and what voltage it will generate here the voltage that it will generate is  $G_m$  times  $V_1$  minus  $V_2$  times  $R_D$  correct. So, which essentially means that what is the gain what is the differential gain differential gain is  $G_m$  times  $V_1$  sorry I mean. So, what is  $V_0$   $V_0$  is  $G_m$  times  $V_1$  minus  $V_2$  times  $R_D$  or differential gain is  $V_0$  over  $V_1$  minus  $V_2$  which is  $G_m$  times  $R_D$  right fine.

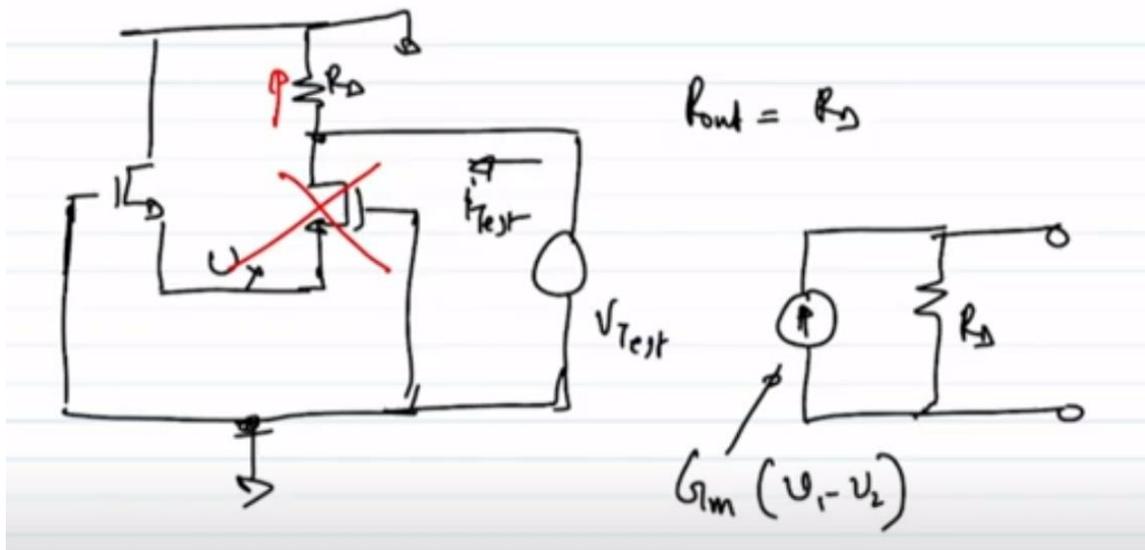


$$v_0 = G_m (v_1 - v_2) R_D$$

$$\Rightarrow A_{diff} = \frac{v_0}{v_1 - v_2} = G_m R_D$$

So, another way of representing representing the same structure is to is to not a nice is to not is to sketch a Norton equivalent of the same and if we have to sketch a Norton

equivalent of a structure what will we see let us do let us do one from scratch I am not showing the biasing now I let us assume we have only we have the biasing there, but I am not showing it explicitly if this is  $V_0$  right. So, if we have to do the incremental not an equivalent what should we do we should short it right now note that this short is an incremental short right not an absolute short if this is an incremental short how much current will flow into that incremental short the current that incremental current that is flowing in flowing out is  $G_m$  times  $V_1$  minus  $V_2$  and where will this current go this current will go into this into this node and it will only go into the short right because it cannot it need not go into  $R_d$  because it is seeing a zero impedance in the short. So, this short circuit current  $I_{sc}$  will be  $G_m$  times  $V_1$  minus  $V_2$  great. So, so this becomes  $I_{sc}$  what is the what is the output impedance what is the output impedance is how do I know what is output impedance. So, so this is shorted this is  $R_d$  this is shorted also because while doing output impedances we do not consider we have desensitized the input desensitizing a voltage source is equivalent to shorting the voltage source and we can remove this current source also because in an incremental sense current source is irrelevant  $V_x$  and we apply a test voltage here and we have to find out what this test current right this test current here.

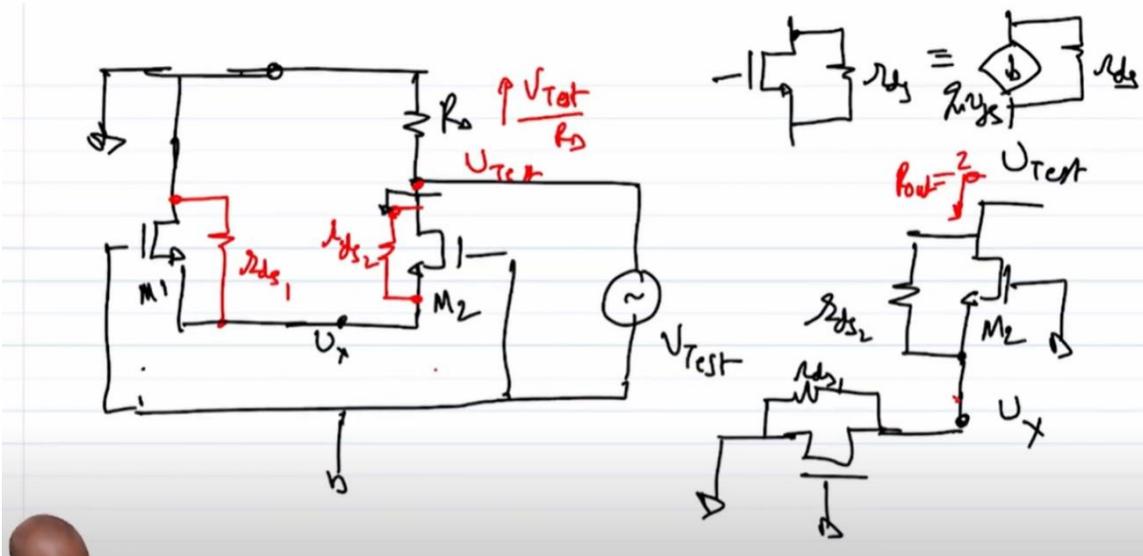


Ok, ok. So let's do it in two ways in one way let's neglect the channel and modulation right if we neglect the channel and modulation what do you think will be the current that is that is flowing in. So, if we neglect channel and modulation what is the  $R_d$ s what is the  $R_d$ s of this device this  $R_d$ s is infinite which means this is out of picture what do you think is happening with gate the gates are shorted right the gates are shorted to ground right which means that there cannot be there cannot be any current right because there is no way the source voltage can be excited because nothing is nothing can flow from top to bottom right.

So, this is equivalent to saying that no current flows here. So, this guy does not exist right then what is the where will the test current go the test current can only go upstairs into  $R_D$ . So, what is what is  $R_{out}$  then  $R_{out}$  is equal to right.

So, what is the Norton equivalent of a structure become the Norton equivalent of a structure becomes a current source the short circuit current is a current source and the output resistance is  $R_D$  this current source value is  $g_m$  times  $V_1$  minus  $V_2$  correct. Note the direction of the current right the direction of the current is flowing out right flowing into the load because the direction of the current is as shown here ok. So, this is different from a common source amplifier where the direction of the current is flowing out of the load ok. So, next let us consider what is going to be the output resistance in presence of channel length modulation right.

So, let us do that. So, again we would like to and we will assume that the biases are set right. So, we will not be showing the biases explicitly. So, this goes ground this also goes to ground this is  $V_x$  we apply a test voltage and we have to figure out what is the effective resistance right. So, let us do it in two parts.



So, this is also grounded right ok. So, let us do it in two parts. So, first part let us say that we like to find out what is the current going down and what is the current going up. What is the current going up is easy what is the current going up the current going into  $R_D$  is  $V_{test}$  over  $R_D$ . So, no problem with that we need to establish what is the current flowing downwards. So, how should we establish that? So, we will have to then put back the resistances correct.

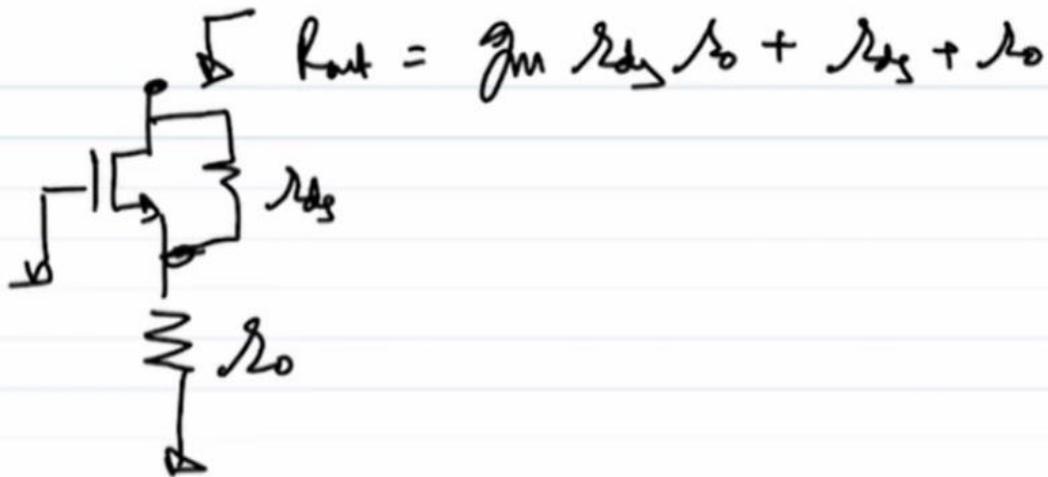
So, let us call this  $r_{ds1}$  let me take some extra space because otherwise I will not have time place to accommodate all the components. So, let us call this  $r_{ds1}$  we will have here  $r_{ds2}$  this is shorted right. So, we do not need this and this is also shorted fine. So, this if we have to find out what is the impedance looking down this seems to be a complicated structure. So, moment something becomes slightly complicated what we would like to do is break it down into smaller structures that is the principle of engineering anyways.

So, you break it down break things down into smaller structures and try to make sense of it. So, what when I say that what do I essentially mean? What I essentially mean is this. So, if I only look at this structure right if I only look at this structure what should I see? You would see this you would see by the way note that ok. I think I have sketched the  $r_{ds1}$   $r_{ds2}$  the other direction this should be  $r_{ds1}$  this should be  $r_{ds2}$  right. So, this is  $r_{ds1}$  ok sorry this is  $r_{ds2}$  because we are applying this voltage here right.

Note that what we are assuming is when we when I sketch when I sketch a transistor and place  $r_{ds}$  here what I am essentially assuming is structure is equivalent to this right. So, I do not want to replace the transistor with this incremental equivalent all the time. So, I am superimposing I am superimposing the resist incremental output resistances on top of the transistor and we assume that the transistor represents a ideal voltage control current source right. So, that is the inherent assumption fine that is something that we need to understand before we proceed fine.

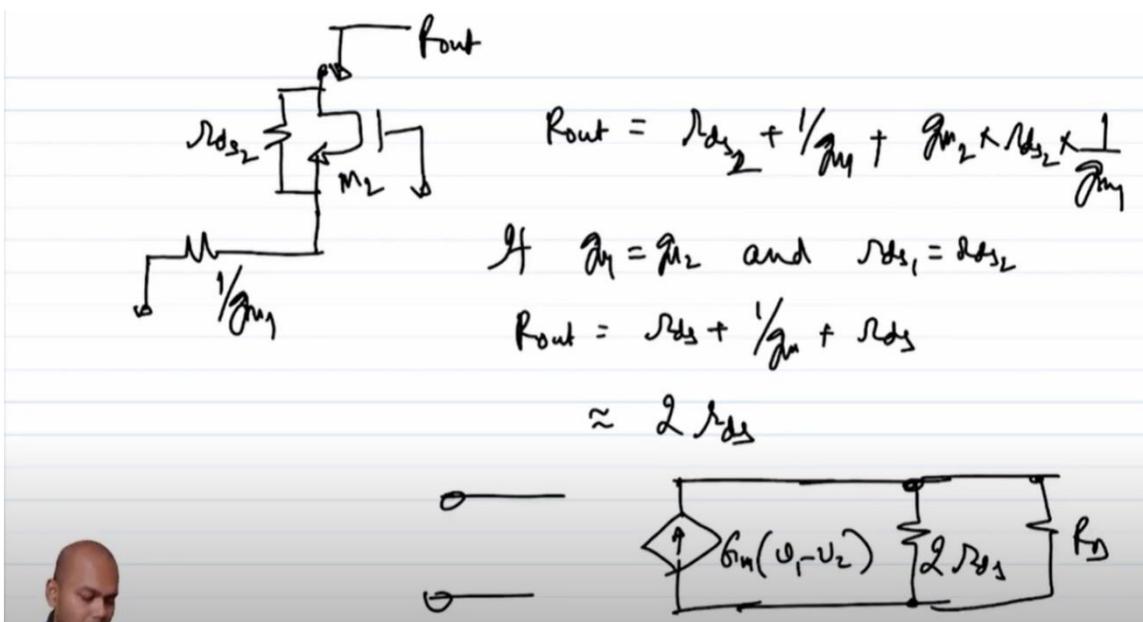
So, this if this is  $m_2$  right. So, what is this node? This node becomes  $V_x$  and what is connected to  $V_x$ ? What is connected to  $V_x$ ? We have  $m_1$  whose gate is grounded right whose  $m_1$  whose gate is grounded and the drain is shorted correct and  $m_1$  also has its output resistance  $r_{ds1}$  ok fine. So, we what are we looking for? We are looking for the output resistance looking down right we are looking for the output resistance here right. So, again this seems to be a complicated structure. So, let us simplify it further. So, how should we simplify it? So, in order to simplify it we first need to take a break pause for a moment and try to answer this question that is there a particular structure that we are comfortable with from the from whatever we have done in this course right.

So, can you recall a structure which has which has in which something is connected to the source of the transistor and we need to find out the output resistance of that structure looking into the drain of the transistor have we done that? So, what I am essentially saying is this have we done have we found out the output resistance of this contraption before looking into the drain let us say this is some  $R_o$  we have right we have when we were doing cascode current mirrors right when we were doing right cascode configurations we found out what is output resistance and what was output resistance? This  $R_{out}$  was  $g_m$  times  $r_{ds}$  times  $R_o$  plus  $r_{ds}$  plus  $R_o$  correct.



So, do you see a resemblance of this structure with this structure? There seems to be one resemblance because at least we have the structure here which is equivalent to this structure, but we have something connected at the source of the transistor instead of  $R_o$ . So, if we can find out what is this equivalent  $R_o$  right in terms of the parameters of M1 then we are all set. So, essentially what we are what we are what is the next question that we are asking? The next question that we are asking is what is the impedance looking into the this terminal of M1? So, right what is the looking in impedance into that terminal of M1 have we done that before? Yes, we have because have we done this structure before this is grounded this is grounded what is the looking in impedance here we have done this before what is that? That is equal to  $1/g_m$  plus  $V_{ds}$  correct. This is almost equal to  $1/g_m$  as long as the  $g_{ds}$  is  $g_m$  is much more than  $g_{ds}$  right.

So, which essentially means that what does this structure what does this structure reduce to the structure reduces to the following structure. So, we have something connected here what is connected here  $1/g_m$  and this is  $r_{ds2}$  and we are trying to find out what is the impedance looking here right what is  $R_{out}$ . Then what is  $R_{out}$  if we use if we if you simply plug this in this in this formulae what should I get? I should get clearly the summation of  $2 R$ 's  $r_{ds2}$  plus  $1/g_m$  plus what is the important thing what is the extra stuff? Extra stuff is  $g_m$  of this guy  $g_m$  of  $m_2$  right times  $r_{ds}$  of  $m_2$  right gain of the gain of intrinsic gain of the transistor times the load right what is the load  $1/g_m$  correct. So, if  $g_{m1}$  is equal to  $g_{m2}$  if the bias if  $W$  by  $L$ 's are same right if  $g_{m1}$  is equal to  $g_{m2}$  then  $R_{out}$  becomes  $r_{ds}$  plus  $1/g_m$  plus  $r_{ds}$  again  $r_{ds}$  will be same because if  $g_{m1}$  equal to  $g_{m2}$  then  $r_{ds1}$  also is likely to be equal to  $r_{ds2}$  because same current same size. So, the same  $r_{ds}$  which is approximately equal to  $2 r_{ds}$  right.



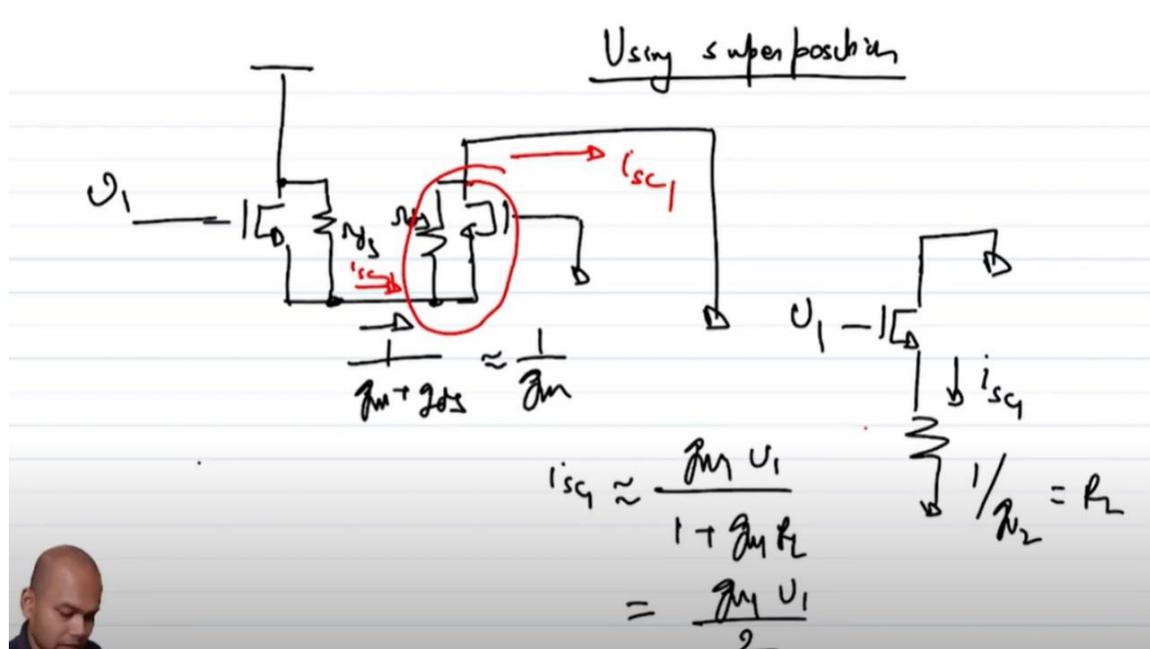
So, this is approximately equal to  $2 r_{ds}$  right ok. So, what does the Norton equivalent of our structure reduce to? Now the Norton equivalent of our structure is becomes  $g_m$  times  $V_1$  minus  $V_2$   $2 r_{ds}$  and  $r_D$  in parallel because why this  $r_D$  is in parallel because note that now the resistance looking down resistance looking down becomes  $r$  down let us say becomes  $2 r_{ds}$  what is  $R_{up}$ ?  $R_{up}$  becomes  $r_D$ . So, these two are in parallel. So, essentially we get we get this structure this becomes a Norton equivalent of our differential amplifier ok. Now you might turn around and say that I have cheated because I while trying to find out the agreemental resistances I use channel and modulation all good, but while trying to find out the transconductance equivalent transconductance I have till now neglected channel and modulation right.

So, what happens if I do not neglect channel and modulation while trying to figure out what is what is the transconductance? So, this is going to we can do that also. So, I would like to assure you that I have not cheated, but I have made some approximations right. So, what is the approximation let us see. So, since we are shorting the output I did not bother with the  $r_D$  because this are anyways getting shorted ok.

So, let us call this  $r_{ds}$  let us call this  $r_{ds}$  ok. So, how should we go about figuring this out? We can go about figuring this out in one of two ways let us do the generic ways first right what is the generic way? The generic way is use superposition right. So, let us use superposition if we use superposition what is going to happen we will use we will use  $V_1$  once and  $V_2$  ground while grounding  $V_2$  then we will apply  $V_2$  and then ground  $V_1$  right. So, we will use superposition what should we get? What do you think will happen? We will let us use the same funda. So, what is the impedance looking in here? This is 1 over

gm plus gds which is again approximately 1 over gm correct. Then what is the current that is flowing in? What is the current that is flowing in here? What is this current that will be flowing out right this is Isc this current that will be flowing out will be this current right will be equal to Isc because if I consider this to be a box whatever goes inside the box has to come outside the box from the other terminal because nowhere else it can go right.

Whatever comes into this circle has to go out from the other circle it is like a pipe right whatever comes in has to go out from the other side because it cannot leak anywhere else there is no path to leak right. So, if the short circuit current is Isc let me call this Isc 1 right Isc 1 then the current at the input of the at the source terminal of the transistor will also be Isc 1 essentially what the question that we are asking is what is this? This is 1 by gm what is this current? This current is Isc 1 right this is V1 it is bounded. What is this current? Note that this structure is also something that we have done before right remember a voltage control current source which was loaded with a with a resistance remember that remember the topology of common drain amplifier what was the incremental current when the when the moment amplifier was trying to drive a load the incremental current was I mean if let us say this is equal to some RL. So, what would have been the incremental current? In this case Isc 1 was gm1 by gm1 V1 by this is again approximation gm1 V1 by gm1 by 1 plus gm1 RL correct.

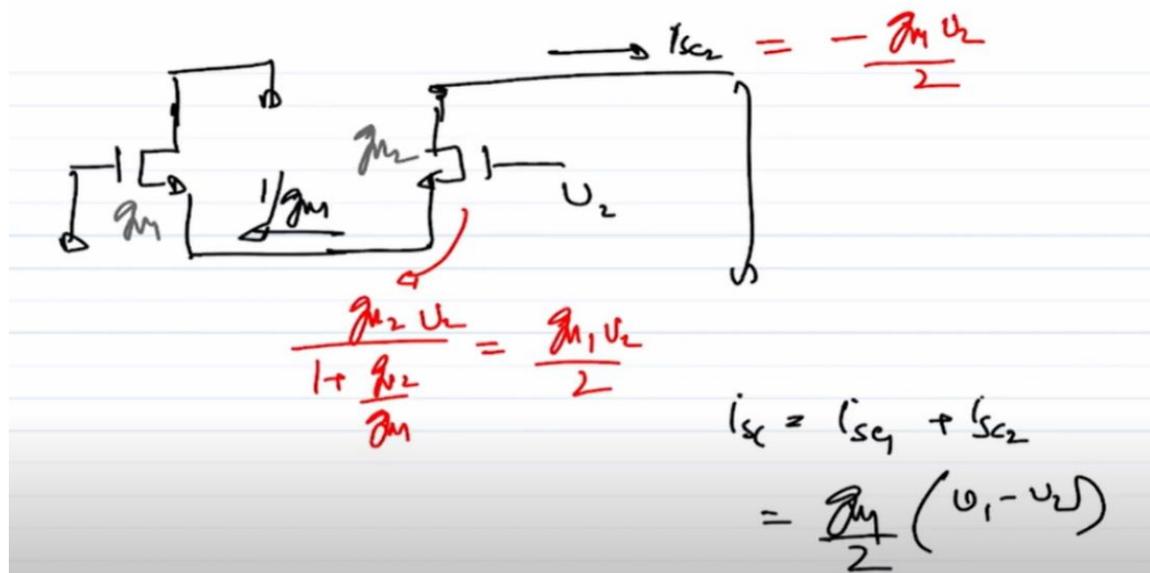


So, this was gm2 right this is gm2. So, this is equal to in this case equal to gm1 V1 by 2 because gm1 is equal to gm2 and RL is 1 by gm2. So, this becomes Isc 1 becomes gm1 by 2 times V1 correct. Now let us put back V2 let us put back V2 and short V1. So, then what

should we get? Short  $V_1$  put back  $V_2$  and let us try to find out what will be the  $I_{sc1}$   $I_{sc2}$  correct. So, same old same old what is it? So, the what is the impedance now looking this side? This is  $1$  by  $g_{m1}$  right if that is the impedance looking that  $1$  by  $g_{m1}$  what is the current? What is this current? This current will be this is  $g_{m1}$  this is  $g_{m2}$ .

So, this current will be  $g_{m2}$  by  $g_{m2}$   $V_2$  by  $1$  plus  $g_{m2}$  by  $g_{m1}$  times  $1$  plus by  $g_{m2}$  by  $g_{m1}$  right  $R_L$  is  $g_{m1}$ . So, this is equal to  $g_{m1}$   $V_2$  by  $2$  because  $g_{m1}$  equal to  $g_{m2}$  correct. So, what is  $I_{sc1}$ ?  $I_{sc2}$  then  $I_{sc2}$  becomes minus  $g_{m1}$   $V_2$  by  $2$  correct. So, what is the total  $I_{sc}$ ? Is the superposition of two  $I_{sc}$ s? So,  $I_{sc}$  becomes  $I_{sc1}$  plus  $I_{sc2}$  which becomes  $g_{m1}$  minus  $V_1$  minus  $V_2$  by  $2$  right. You see I mean essentially channel length modulation does not really affect the affect the transconductance to a significant amount right.

So, if we take intelligent approximations we can get away with without taking the full blown models right essentially that is what the takeaway is. Also note that you must have also already seen that we have used while trying to analyze this circuit we have used a lot of our past knowledge right. We have used the formulae that we have used before right how and what did we do? We broke the circuit up into multiple small fractions, multiple small parts so that we can break it down into elements such that into not any old elements into elements that are known to us right. So, we have covered those elements, we have covered those structures at the beginning of the course or the first half of the course right. So, we are dragging our we are using those existing knowledge to analyze these circuits right.



So, my sincere request will be if you find this type of analysis slightly tricky then go back a few lectures and re-familiarize yourself with the structures of common gate amplifier, common drain amplifier right and what will be the input, what will be the short circuit current, what will be the output impedance, re-familiarize yourself with these structures so that using these topologies such that analysis of these topologies using those structures will be will become easier right. Because going forward you will see that we will be using abstractions of these structures repeatedly right. If we have like 10 transistors in a network it is physically not possible to put small signal equivalents of all of them together and do an analysis. I mean it is possible definitely but it will take you hours. A simulator can do that job much faster than we humans beings can.

However, even if you can do that it will not give us any insight. So, in order to get an insight what we would like to do is to black box items into smaller and smaller sections so that we understand what those sections are and use those elements as is. This is equivalent to the example that you can think of this is equivalent to learning tables right. When we were in school we used to be told that you learn the tables of 4, 5, 6, 7, 8, 9 and all those things right. So, one might turn around and say we know that a table is repeated addition right. So, if I tell you what is if I ask you what is 7 times 8 I can say that 7 times 8 is 7 plus 7 plus 7 plus 7 and go on 8 times and I will get an answer and it will be correct.

But it will be super inefficient right because if I know this know the multiplication table of 7 then I know 7 times 8 is 56 right. So, if you compare yourself with somebody who knows the table and with somebody who knows the principle behind it and spends the entire time figuring out what 7 times 8 is then you can readily guess who will be able to go further right using that information right. So, now that we have graduated from the single transistor circuits of common source amplifier, common drain amplifier, common gate amplifier right. So, I have request you to I have request you to re-familiarize yourself with the structures of with the at least the rudimentary behaviors and the rudimentary output impedance, short circuit currents or the nautilus equivalence of those of those structures. So, that we can pull them and use them for our advantages going forward right ok. .