Analog Electronic Circuits
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Lecture – 84
Usage of Current Mirror (Part B)

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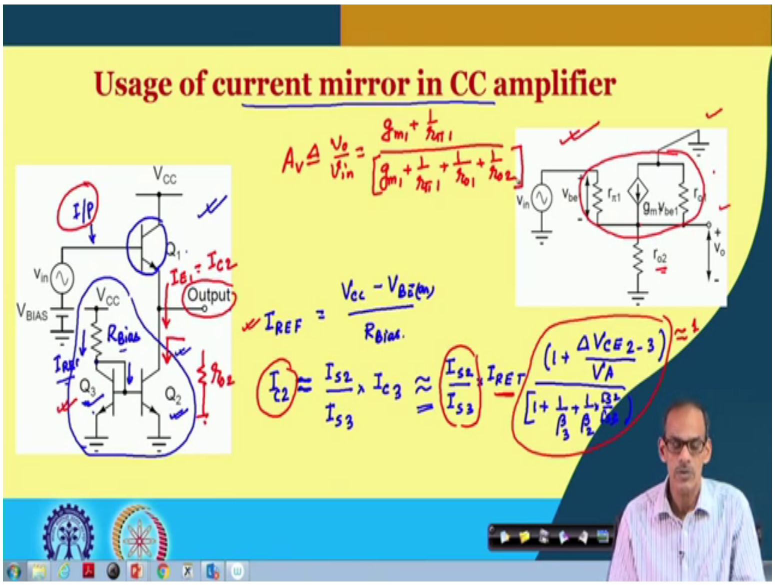

So, dear students welcome back after the break. So, before the break we are talking about usage of current mirror for CE amplifier, and also CS amplifier. Now we also can see that usage of current mirror for Common Collector amplifier as well. So, here we do have the transistor level circuit transistor 1 it is the main amplifying transistor input port is here.

And then the output port it is here and earlier what we said is that the current of this transistor it can be set by one reference current. So, instead of having reference current this is what we do have the implementation of the current source. In fact, if you see that it consists of a bias resistor R B maybe you can see B i a s bias. So, V CC to collector of transistor 3 we do have this R Bias and based on the value of this R Bias we can get a current here and we call this is I REF the reference current and expression of I reference equals to V CC minus V BE on of transistor 3 divided by R Bias.

So, that is the reference current and we do have the current mirror getting constructed by transistor 3 and transistor 2. And if we ignore on the current the early voltage effect and the beta R loss. So, we can say that the collector current of transistor 2 I C2 it is well approximated by I S of transistor 2 divided by I S of transistor 3 multiplied by I C 3.

So, this is the exact equation assuming transistor 2 and transistor 3 they are identical and then this may be well approximated by I S 2 by I S 3 into this I reference. And strictly speaking this approximation it is associated with the drop of the 2 non-ideal factors; namely 1 plus difference of the V CE voltage of transistor 2 minus transistor 3 divided by early voltage.

And in the denominator we do have non ideality factor which is which is 1 plus. So, it is. In fact, it is function of beta and all. So, we do have 1 by beta of transistor 3 then 1 by beta of transistor 2; multiply it by whatever I S 2 divided by I S 1 sorry I S 3 and so, and so. Here we assume that this non ideality factor it is approximately equal to 1 and hence, we do we can approximate this collector current equals to this reference current multiplied by the reverse saturation current ratio of the transistor 2 and transistor 3.

And the I reference current is given. So, that sets the emitter current of transistor 1. So, I E 1 it is equal to I C 2. Now, once we get the DC operating point then to find the gain from input to primary input to primary output we can draw the small signal equivalent circuit and since the current mirror here it is not carrying any signal. So, the equivalent circuit small signal equivalent circuit coming out of the current mirror it is only r o of transistor 2.

So, that is what we do have here this is the; this the model of transistor 1 and collector is connected to V CC which is ac ground and at the emitter we do have r o 2 and rest of the things in terms of signal it is not carrying any signal so that can be a dropped and again you can analyze this circuit to find what will be the corresponding gain. So, A V equals 2 to which is defined as V o divided by V in and that we have discussed that it is gain it is gm 1 plus 1 by r pi and then divided by gm 1 plus 1 by r pi of transistor 1 plus 1 by r o 1 plus 1 by r o 2 ok.

So, similar to common collector amplifier the current mirror can also be used for common drain amplifier which is the MOSFET counterpart of this circuit.

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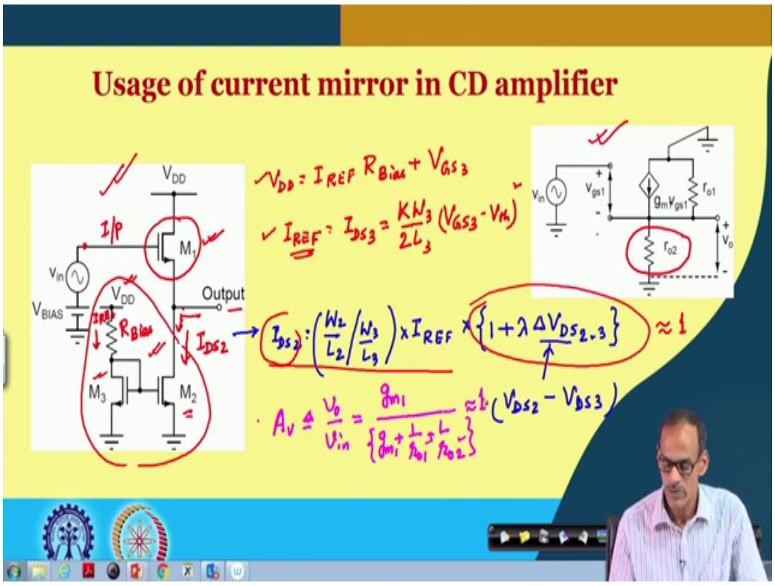

So, in the next slide we will see the circuit here we do have the main circuit. Transistor 1 it is M 1 it is primarily the main circuit the amplifier circuit, which is connected in common drain configuration this is the input port and this is the output port and here we do have the bias circuit we do have say resistor R Bias and this R Bias it is connected between the supply voltage and the diode connected transistor M 3.

So, we can say that V DD equals to I into whatever I bias we do have or you can say I reference multiplied by R Bias plus V GS of transistor 3. And on the other hand and this reference current I REF is also equal to V DS 3 which is of course, K multiplied by W by L of transistor 3 by 2 into V GS 3 minus VT squared. So, we may drop the 1 plus lambda V DS part. And so, equating see or utilizing say these 2 equations we can get the I reference current and that reference current; I reference that defines the I DS current of transistor 2.

So, I DS 2 so, I DS 2 it is equals 2. In fact, it is function of W by L of transistor 2 divided by W by L of transistor 3 multiplied by this I reference current. In fact, this strictly speaking it should be multiplied by 1 plus lambda into V DS difference V DS difference of transistor 2 minus transistor 3. So, this part of course, this is V DS of transistor 2 minus V DS of transistor 3.

So, by dropping this part by dropping this part or approximately making this part equal to 1. So, we can get the expression of the current here which defines the current of transistor 1. Again by once you get the DC operating point then to get the input to output relationship, you can draw the small signal equivalent circuit. Similar to the previous circuit here since the current mirror is not carrying any signal current.

So, it is a small signal equivalent circuit out of the current mirror it is only the R DS of transistor 2 we are denoting this by R O2 and then by analyzing this circuit we can get the voltage gain equals 2 which is defined as V o divided by V in. So, that is equal to gm divided by gm 1 divided by gm 1 plus 1 by r o 1 plus 1 by r o 2 this we already have derived before.

So, that is how we can find the gain and that is how we can get the corresponding operating point for the common drain amplifier. Now of course, since this both the resistors are very high you can well approximate this by 1. Now, next thing is that the current mirror can also be used our rather frequently used for differential amplifier. So, our next topic or next subtopic it is how current mirror can be used for differential amplifier.

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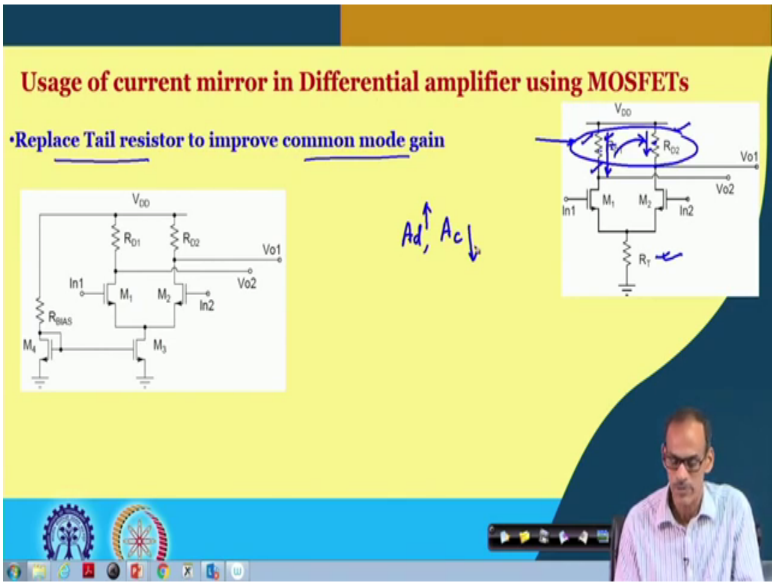

So in fact, there are different possible applications and the applications of the current mirror on differential amplifier it is having 3 folds. One is for replacing this tail resistor; and if you replace this tail resistor that will improve the common mode gain. And then you can replace the these 2 loads by active load and the active load can be biased using current mirror and then in addition to that instead of having the active load bias from external current reference or DC current reference we may replace this by something called current mirror load.

So, this current current flowing through this left half can be mirrored into the right half and that mirroring it is different from normal DC mirror. Because, this left arm it also carries some signal and once you make the current mirror here; obviously, the signal also propagates from left to right through that current mirroring and it is consequence it is that it improves both the differential mode gain as well as the common mode gain; which means that the active current mirror load it improves the differential mode gain and decreases the common mode gain.

So, let us see one by one how the replacement or utilization of current mirror can be deployed to improve the performance of differential amplifier. So, in this circuit what we are what we mentioned here it is essentially this R T we are replacing by a current mirror here.

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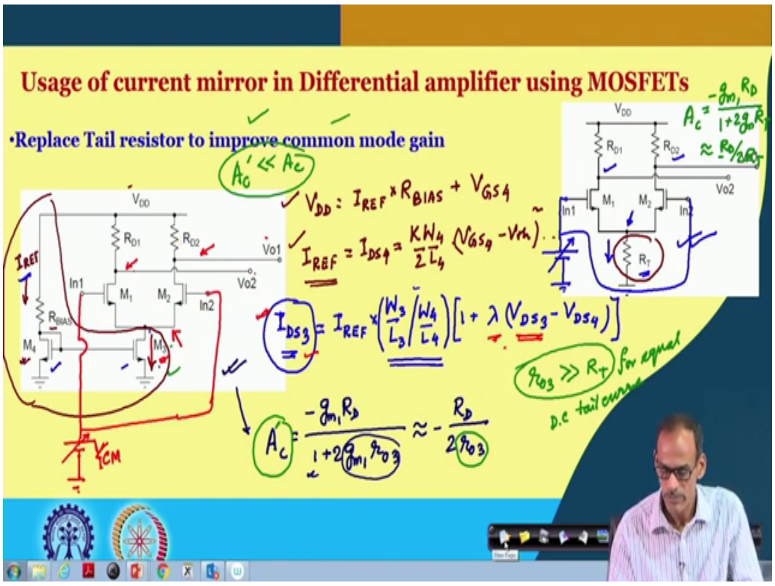

And this current mirror it is of course, it is current it is said by the DC supply voltage and then R Bias and whatever it is dimension we do have. In fact, similar to the previous case here again if I say that this is the reference current I REF reference; then you can say V DD equals to I reference multiplied by R BIAS plus V GS of transistor 4. On the other hand I reference. So, I reference it is also equal to I DS of transistor 4 and we know this I DS and V GS it is having known relationship.

So, K W by L [music] by 2 into V GS 4 minus V th squared. We can drop the one plus lambda V DS part and again utilizing these 2 equations we can find the reference current as we have discussed earlier. So, once you get this reference current from that you can find what will be the corresponding current flowing through transistor 3.

So, in fact, that gives us I DS 3 or tail transistor current; it is primarily defined by this I reference current, multiplied by W by L of transistor 3 divided by W by L of transistor 4 because of the current mirror property. And then we can also consider one plus lambda V DS or probably you can drop this part lambda V DS 3 minus V DS 4.

So, assuming V th of these 2 transistors they are equal and their corresponding k parameter equal and assuming lambda of the 2 transistors are also equal we do obtain this current equation.

And note that incident this ratio it is also there in case if this ratio aspect ratio of transistor 3 and transistor 4 are same; then again this part it will be 1 and then this current it will be I REF. Otherwise if the this ratio it is having some other value then we can get this value different from IREF, but nevertheless this I reference current it is defining the tail transistor current.

Now, in contrast to this circuit which you have discussed before, if you change the DC voltage or common mode DC voltage in the circuit coming here and here if you vary this DC current this node voltage the source node voltage also changes. And if we have simple tail resistor if this voltage it is changing then the corresponding tail current also changes; and the corresponding DC voltage as a result at the output DC voltage that is that also changes.

Now in comparison with this if you consider this circuit having the tail current mirror suppose we do have a DC voltage common DC voltage at both the inputs again if we vary this common DC voltage then the voltage here it will vary. But then this current since it is having very weak dependency on V DS through lambda. Then hardly this current changes depending on the depending on the value of lambda or you can say equivalent resistance the variation here it will be very small.

So, we may say that as long as this voltage it is such that transistor 3 it is in saturation region. Then the quotient current here it hardly depends on this common mode voltage whatever we have said that this is V common and if this input common rather input common mode voltage. So, if this current is not changing then of course, DC voltage here and here they are also not changing.

In fact, in case if we have common mode signal then also we can say that the corresponding common mode signal coming at the 2 outputs it is it hardly depends on the common mode input.

In other words, if you see the common mode gain; common mode gain of say this circuit which is as you have discussed minus gm into R D divided by 1 plus 2 times gm into R T. On the other hand, if you consider say this circuit the common mode gain it is minus gm 1 into R D divided by 1 plus 2 times gm 1 into r d is 3 or r o 3.

Now, if you compare this part and this part in fact, we can well approximate this by dropping this 1 and then the expression becomes R D divided by 2 times r o 3. Whereas, for this case the previous circuit this is becoming R D divided by 2 times R T of course, with a minus sign.

So, if we compare this 2 expression since r o 3 it is the output resistance of transistor 3 in saturation region we know that r o 3 it is much higher than the passive resistor R T for same for equal tail current tail current; I should say DC tail current all right. And since this is much higher then we can say that this common the common mode gain of this circuit having this active device at the tail it is having much lower common mode gain.

So, if I call say this is A c dash and this is A c. So, we can say that this A c dash it is much smaller than A c. So, that is why we say that it improves the common mode gain of the differential amplifier. So, now, if you replace the load part by active current mirror then what will be getting is the improvement of common mode and differential mode gain.

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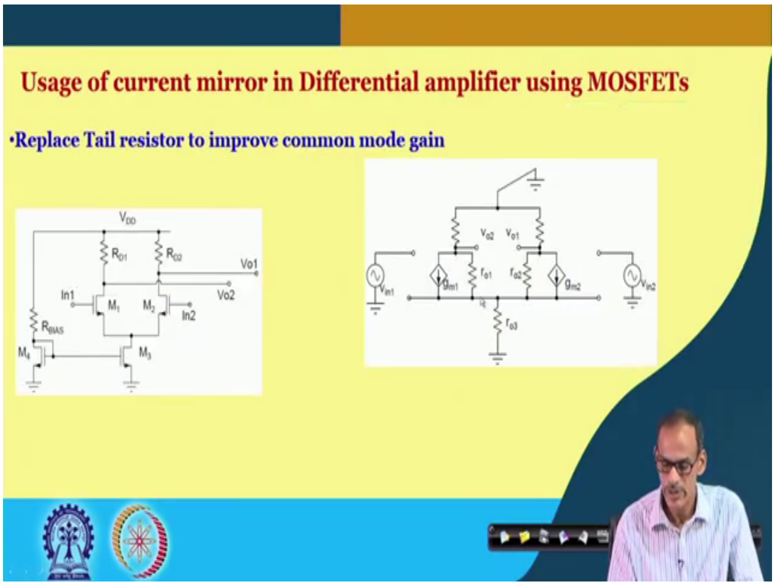

So, in fact, here we do have the small signal equivalent circuit and using this small signal equivalent circuit again you can derive the expression. And so, what we said is you already have compared so probably we can skip this part; and we can directly go to the differential mode gain improvement by replacing the load part.

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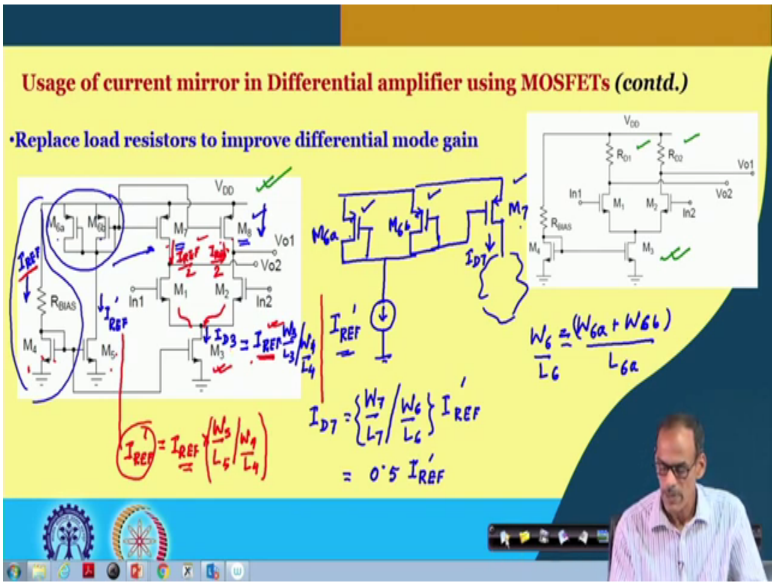

Now, here we already have replace the tail transistor, but then we do have the passive load. Now, these 2 passive loads it can be replaced by active device as shown here.

So, R D 1 it is getting replaced by transistor 7 and R D 2 it is getting replaced by transistors 8 and they are getting biased from this is current and this is of course, a current mirror. So, we do have 2 transistor M 6 a and then M 6 b both are diode connected and they are connected together and suppose we do have some reference current.

So, this is M 6 a, this is M 6 b and then we are mirroring this current to say transistor 7. So, this is transistor 7 and then we do have some circuit connected here ok. Now if I say that let me call this is I reference dash and since by the virtue of current mirror; if I consider this transistor and this transistor they are identical then the current flow here if I call this is I D 7, then I D 7 can be given as W by L of transistor 7 divided by W by L of transistor 6.

Now since these 2 transistors they are identical we may say that W 6 is essentially summation of the 2 W's; W a plus W b. So, W 6 divided by L 6 is essentially summation of these 2 W s divided by the corresponding L and L they are same either we may say that L a or b. And so, this is getting multiplied by I reference dashed. Now if I say all the transistors are identical; obviously, this part it becomes 0.5 I REF. Which means that only half of this reference current is flowing through transistor 7.

So, likewise transistor 8 and M 6 it is forming current mirror. So, the current flow here it is again half of this I reference or I REF dashed. So, now we do have the reference circuit which and it is having its reference current say I REF and this reference current it is getting mirror to transistor 3. So, if I call this is ID of transistor 3 which is equal to I reference multiplied by W by L of transistor 3 divided by W by L of transistor 4.

So, that is. So, we do obtain the current here in terms of I reference. Likewise, here also we can get the current relationship namely I reference dashed it becomes I reference multiplied by W by L of transistor 5 divided by W by L of transistor 4 by dropping 1 plus lambda V DS part. So, what you can say that this reference current if say transistor 4 and 5 and 3 are identical; then we can say this is equal to I REF this is also equal to I REF and the current flowing through this transistor and this transistor they are I reference by 2.

So, this is also I reference by 2 and y. So, this 2 I reference half of the 2 that I reference together it is giving the total I reference here. So, that makes the current source coming from transistor 7 and 8. It is well balanced with the capability of transistor 3 which is working as current sink.

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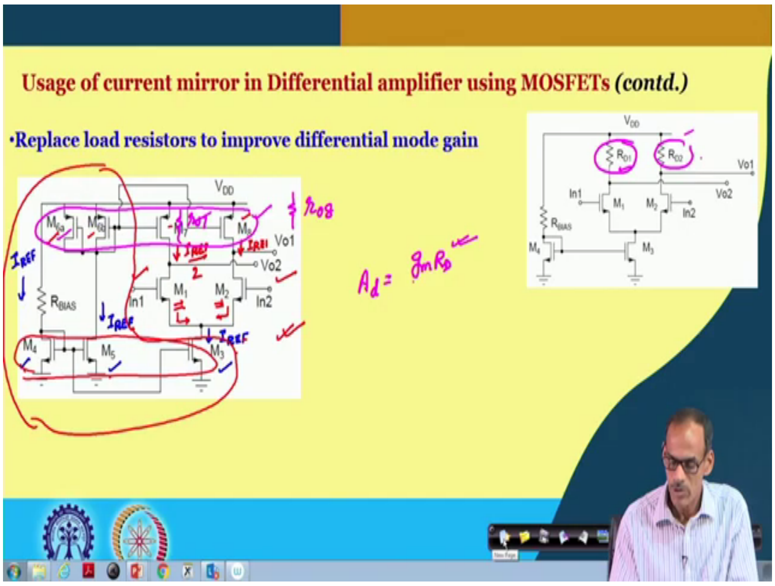

So, let me summarize here what I would like to say on this slide. If I assume that the this transistor this transistor and transistor 3 they are identical then if I say this is I reference, that makes this current is I reference and also this current is I reference. On the other hand if I assume that all the 4 transistors they are identical that makes this current equal to I reference by 2 likewise, this also I reference by 2.

So, that is how we can say that DC current wise. So, if and of course, this I reference current it is in case if we have same DC voltage applied here and if I consider M 1 and M 2 they are identical. So, that makes this I reference current it is getting splitted into 2 parts or equal parts are coming from 1 and 2 and that makes everything is getting well balanced.

And in fact, this is very common particularly for integrated circuit we want to keep transistor 1, 2 anyway they should be matched and likewise, transistor 7 and 8 they should be matched and in addition to that whatever the bias circuit we do have or bias arrangement we do have.

So, here also we want this 3 transistors and transistors they should be identical likewise not only this 2 PMOS transistor, but also the 2 bias transistors namely M 6 a and M 6 b they should also be identical. And for integrated circuit that is not very difficult to achieve and that is frequently getting used. In fact, this arrangement as expected since we are replacing the resistors here by active devices the corresponding resistances offered by this active resistance or active devices namely r o 8 and r o 7 they are much higher than the R D we are we do have here.

And we know we know that the differential mode gain it is equals to gm into R D and since we are replacing this R D by this active devices. So, we are expecting the gain should be higher. In fact, just for convenience probably or to convince yourself.

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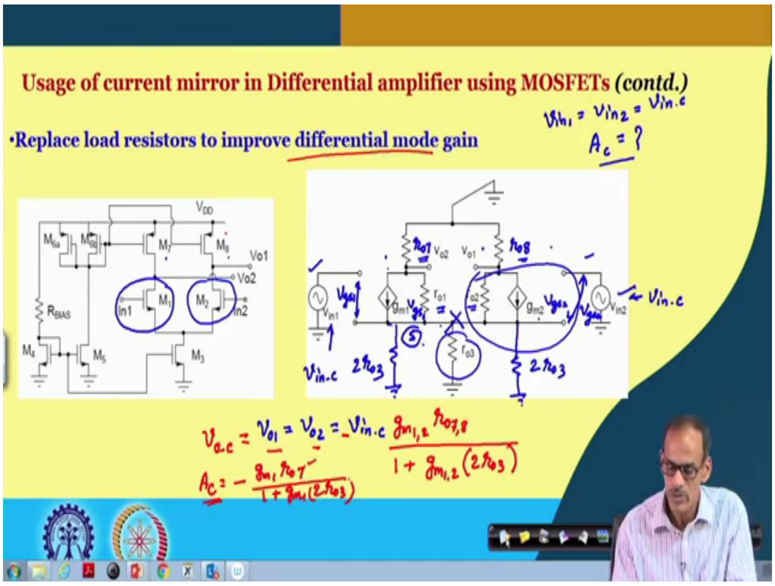

We can draw this small signal equivalent circuit here and as you can see the transistor 1; model of this transistor 1 it is given here. So, we do have r o 1 and then gm one into v gs 1 v gs 1 it is given here, coming from primary input and whatever the source node voltage you do have likewise.

We do have transistor 2 a model of transistor 2 here; which consists of r o 2 and gm 2 into v gs 2 and v gs 2 it is the gate 2 source voltage of transistor 2. So, this is the v gs 2 that is coming from in to and whatever the source voltage you do have. And then transistor 7 and transistor 8 they are giving r o 7 and r o 8 and then if you analyze this circuit what we can find that the common mode gain to get the common mode gain we have to make v in 1 equals to v in 2 equals to v in common.

And in that case both the voltage here and here they are same and left half and right half assuming these 2 resistors are identical the left and right half are identical. So, probably we can split this resistor into 2 equal parts, as we have discussed before namely; 2 times r o 3 here and 2 times r o 3 here and then we can remove this part and then this voltage of course, this is v in c this is also V in c and then from that you can find the both v o 1 equals to v o 2 equals to v in c multiplied by gm 1 or 2 then multiplied by r o 7 or 8 divided by 1 plus this d generator.

So, that is gm 1 2 multiplied by 2 times r o 3 and so, this is the both the outputs are same. So, we can say that this is the common output voltage for common mode operation. And we can so likewise, so you can get the corresponding common mode gain it is of course, it is having a minus sign.

So, that gives us common mode gain equals to gm 1 r o 7 divided by 1 plus gm 1 2 times r o 3 right. So, for differential mode of operation. So, by replacing these 2 transistors what we are getting is the common mode gain of course, it got increased compared to the original circuit. But the differential mode gain it is also getting increase. So, this increase of the common mode gain it may not be having any drastic effect as the differential mode gain is also getting increased.

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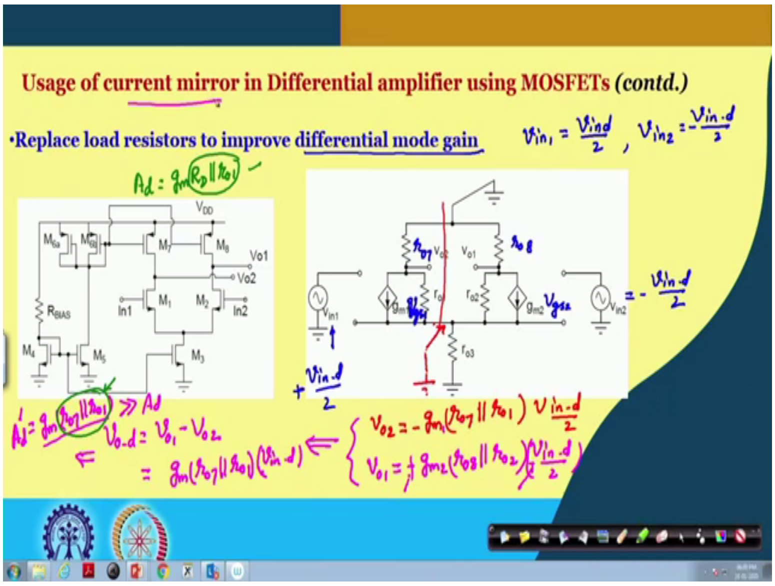

Now, for differential mode gain what you can do in this circuit for a differential mode gain we can make v in 1 equals to v in d by 2 and v in 2 equals to v in d by 2 with a minus sign and we do have all these elements r o 7, r o 8 then this is gm into v gs 1 gm into v gs 2. And so, this is v in d by 2 with a plus sign and this is equal to minus v in d by 2 and as we have said earlier that makes this node virtual ground.

So, we can simply then split this part and then we can find the expression of v o 2 equals 2. So, since this is AC ground. So, this is equal to gm into r o 7 in parallel with r o 1 multiplied by the differential half of the differential input and with a minus sign. So, likewise if you consider v o 1. So, that is equal to minus gm of course, this is 1 and this is 2. So, we may drop that subscript 1 or 2 assuming there I equal.

So, this is multiplied by r o 8 in parallel with r o 2 multiplied by v in d by 2 with a minus sign here. So, this minus and this minus they are getting cancelled. So, we can remove that. So, from that we can see the differential output v o d equals to v o 1 minus v o 2. So, that is equal to gm into r o 7 in parallel with r o 1 assuming the respective terms are equal. So, this multiplied by v in d and from that we can get from this you can get the differential mode gain equals to gm into r o 7 in parallel with r o 1.

So, now the differential mode gain got increased from the previous value in the original circuit it was Ad it was gm into rd though these 2 resistors they are coming in parallel, but you may recall this rd it was in parallel with r o 1 and definitely this is much higher than this 1 as a result this new Ad if I call this is Ad dashed it is much higher than previous Ad. So, we can say that, that is how the circuit gain it is getting changed by deploying the current mirror in differential amplifier.

So, we have discussed about the MOSFET differential amplifier the situation it is very similar if you consider BJT version. Let me take a break and then again we will be coming back.