Analog Electronic Circuits
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Lecture – 83
Usage of Current Mirror (Part-A)

Dear students welcome back to our online certification course on Analog Electronic Circuits, myself, Pradip Mandal from E and EC department of IIT Kharagpur. Today's topic of discussion is Usage of Current Mirror. So, we have started the current mirror circuit and today we will be talking about its application.

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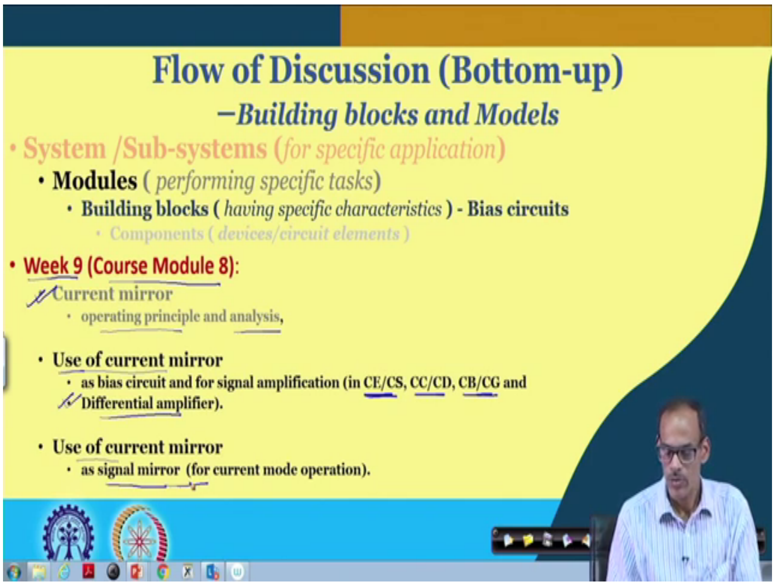

So, according to our overall plan we are in week 9. In fact, this is course module 8. Wehave talked about current mirror, its operating principle and analysis in the previous lecture. Today we are going to discuss more detail of the current mirror specifically its application and we do have different applications for this current mirror. One is in common emitter and common source amplifier based on whether it is BJT or MOSFET based implementation. Likewise, in common collector and common drain and common base and common gate and also in differential amplifier.

So, in this lecture in fact, we can also see the usage of current mirror in signal mirroring particularly within the differential amplifier, we will be talking about its application as current mirroring circuit.

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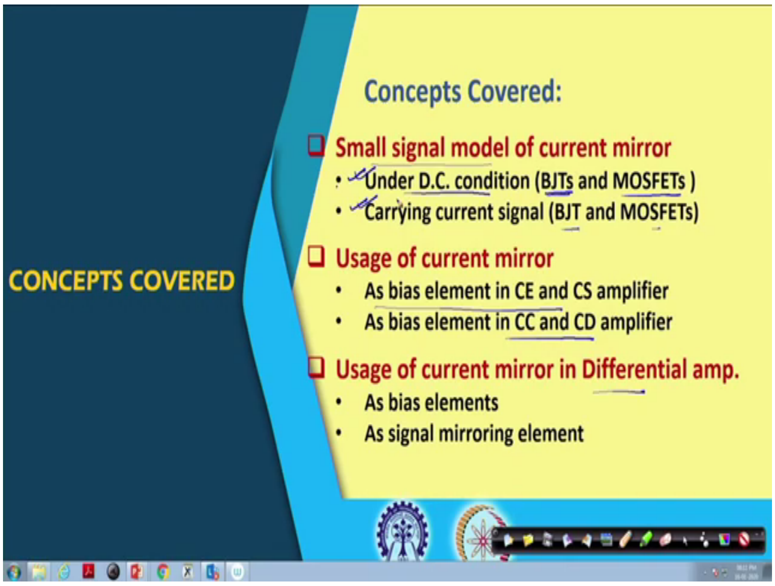

So, what are the concepts we are planning to cover or what are the sub topic we are going to cover today is the following. To understand or to appreciate the effect of common current mirror in amplifier standard amplifier where, we normally talk about the linearize circuit whether it is common emitter or common source or common collector or common drain or for that matter even for differential amplifier.

We need to understand the small signal model of current mirror and to go into the small signal model we do have two possible situation. One is the current mirror may not be carrying any signal namely under DC condition what is the small signal equivalent circuit and then we do have the second possible situation where the current mirror may carry signal in the form of current. And we will be talking about both BJT and MOSFET version of the use the small signal model. So, let me talk about the small signal model of current mirror implemented by MOSFET.

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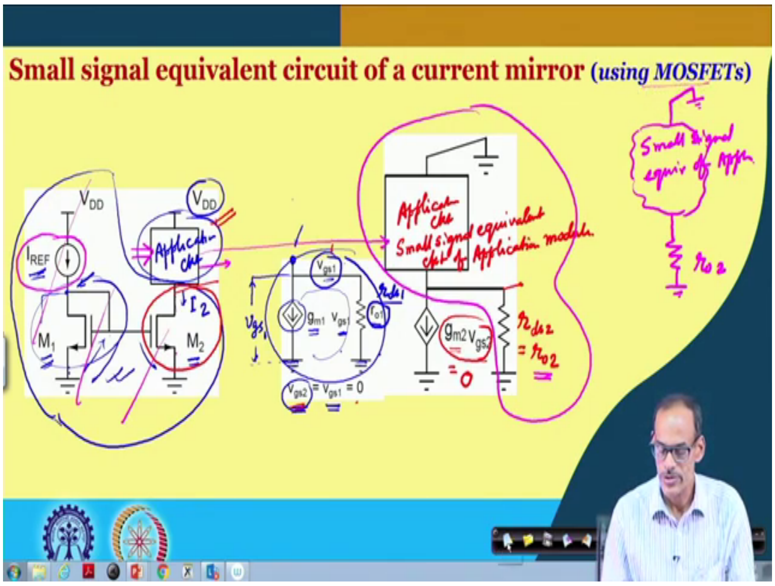

So, here we do have the current mirror circuit, we do have transistor 1 it is diode connected and the we do have reference current dc current that is getting mirrored into this branch through this transistor 2 and here we do have the application circuit.

So, we do have the application circuit which is connected to the power supply and the current flow here as we have discussed that this current flow here it is defined by whatever the current we do have here. Now, if you want to have say small signal model of this entire circuit along with the application circuit, we need to know what will be the small signal model of the current mirror.

So, here we do have the small signal model for transistor 1, it is having g m 1 multiplied by v gs 1 that is the current flow voltage dependent current flow and v gs it is here. So; that means, whatever the voltage you do have here it is the v gs v gs 1 and then we do have from drain to ground we do have the resistance. Earlier we is to call this is r ds; r ds 1, for fair comparison with BJT version here we are instead of writing r ds 1 here we are writing r o 1.

So, I should say this is synonymous situation. So, let me stick to this notation. So, we do have voltage here which is v ds as well as v gs, so we can say that this is the voltage. Now, for small signal model this is dc current so; obviously, we have to make the current here it is since it is 0. So, we can say it is this circuit is open.

So, we do have open circuit here and then if this portion it is open. Then if we if we have this small signal equivalent circuit what we can see here the solution of this voltage v gs voltage it should be 0. That is because if I consider say this loop and this is having a solution only when the v gs 1 equals to 0 and mainly because this side as well as this side they are connected to ground.

So, that makes the v gs 1 equals to 0 and incidentally v gs 1 and v gs 2 they are equal. So, that makes v gs 2 also equal to 0. On the other hand the small signal model for transistor 2 m 2, we do have g m2 multiplied by v gs 2 and v gs 2 as I said that it is same as v gs 1.

And also it is having drain to source resistance either we call this is r ds 2 or in this discussion we are calling this is say r o2 and then we do have the application circuit. So, now, this is the actual application circuit and here this is the small signal equivalent circuit of the application circuit. So, this is small signal equivalent circuit of the application module and then whatever the voltage we do have we do have this voltage. Now, since v gs 2 it is equal to 0, so we can say this part it is equal to 0.

So, as a result what we have it is small signal model, we do have only this part left behind. Which means that if we do have this reference current is having only Dc component and then suppose in the application circuit we do have some analog signal coming and then probably we like to know what will be its corresponding transfer function. Then to get the linearized circuit of the entire portion we need to draw the small signal circuit here and out of this entire current mirror what we will be having it is only r o2 left behind.

So, I should say the small signal equivalent circuit whenever we do have a current mirror, then it will be very simple we do have the small signal equivalent circuit of the; small signal equivalent circuit equivalent of application and then we do have simply this resistance r o2 and then of course, in this node it is connected to AC ground ok. So, likewise whenever we do have a current mirror having getting implemented by a BJT instead of MOS, then also we will be getting similar kind of circuit.

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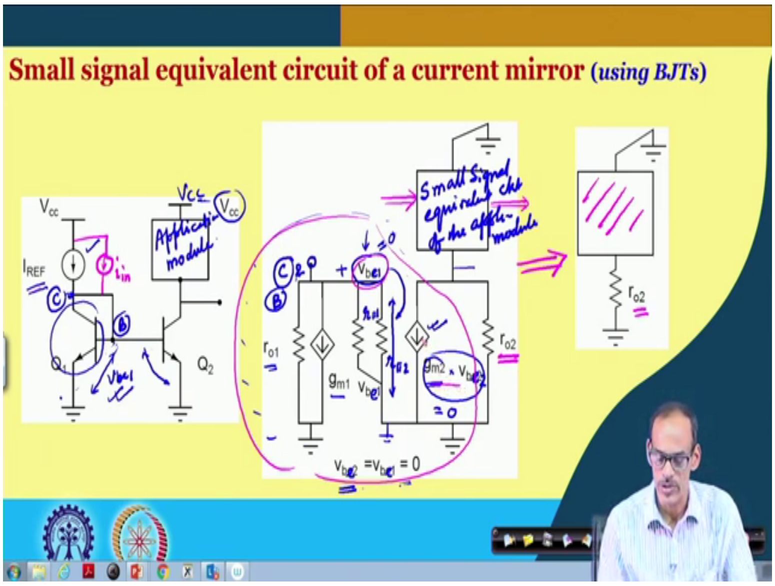

So, let us see that. So, here we do have; here we do have the current mirror and again we do have a reference current is only dc, here we do have the application circuit or application module and we like to draw the small signal equivalent circuit here. So, this is the V cc and to draw the small signal equivalent circuit what we have for transistor 1 we do have r o1 from its collector to emitter. So, this is the I should say collector node as well as the base node and base node as base node and collector nodes they are connected together.

And then we do have g m into v be 1. And what is the v be 1? This is the voltage we do have the v be 1 this should be v be 1. And we do have a course r pi unlike BJT MOSFET, here we do have r pi 1 and then we do have r pi 2. So, these two registers they are coming in parallel and then whatever the voltage you do have here it is v be 1. In fact, the voltage across this v be 1 it is the voltage here and that v be 1 incidentally it is same as v be 2 or rather v be 2 it is equal to v be 1.

And again since it is a dc current for small signal equivalent circuit this is open and in this network, particularly in this network if you see here we do have ground connection here also we do have the ground connection and the only solution for this v be is equal to 0. So, that makes v be 2 also equal to 0. So, this current flow here voltage dependent current flow it is gm into v b e 2 and since this is 0 this part it is also becoming 0. And here we do have the small signal equivalent circuit of the application module, equivalent circuit of the application module.

And so now, whenever we are feeding signal to this application circuit and we like to know what is its corresponding transfer function, then this portion entire portion we can completely omit we can just consider this r o2. As a result the corresponding small signal equivalent circuit it becomes like this. So, this is the small signal equivalent circuit of the application module and then only r o2 it is there.

So, that is how we consider the small signal equivalent circuit for a situation where the current mirror it is not carrying any signal current or rather whenever the reference current is dc. Situation when may arise when this reference current may have a signal part namely say i in.

And in that case; obviously, this will; this will not be 0 and this may carry some signal to this voltage dependent current source. So, let us see that situation.

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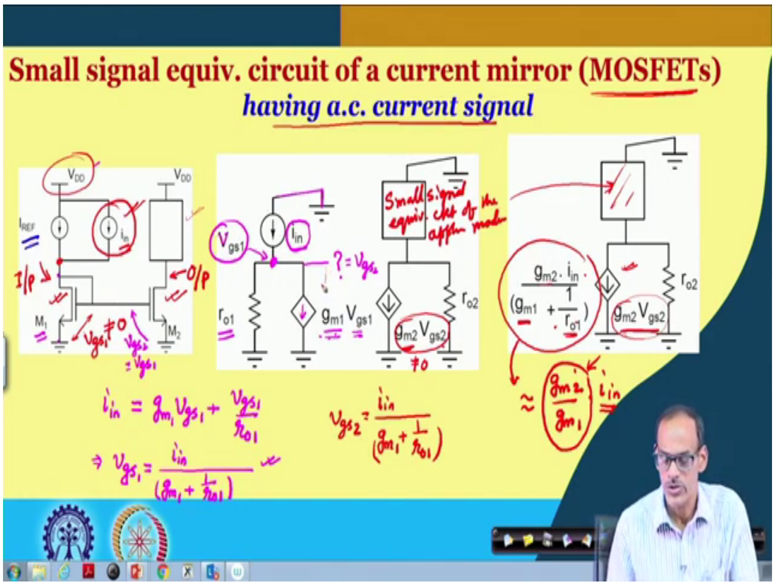

So, in the next slide we do have this situation, yes. Here we do have the basic current mirror and now the difference here it is along with the dc reference current it is also having signal current i in. So, this signal current it is again it is coming from either dc you are whatever it is, but finally, at the collect the drain node of the MOSFET it is arriving and it may be producing a voltage here.

So, this v gs 1 is now it is function of i in and it is nonzero. So, here we do have the small signal equivalent circuit drawn here for transistor 1 we do have voltage dependent current source which is g m 1 into v gs 1. So, this is v gs 1 and the v gs is v gs and v ds they are equal. So, v gs 1 it is here. So, from drain to source we do have r ds 1 or r o1 along with this voltage dependent current source g m 1 into v gs that is the circuit. Now, here we do have the input signal current. So, whenever we are drawing the small signal equivalent circuit we have to make this is ac ground and this part will be eliminating dc part, but then we have to consider the small signal part.

Now, if you analyze this circuit to find what will be the corresponding voltage which is also equal to v gs 2, we can consider i in that at this node we can apply k cl. So, i in equals to g m 1 into v gs 1 plus v gs 1 divided by r o1. So, that gives us; that gives us the expression of v gs 1 in terms of i in. So, that is equal to i in divided by g m 1 plus 1 by r o1 and v gs 2 and v gs 1 they are same. So, this is v gs 2 which is also equals to v gs 1 and its expiration is given here.

So, v gs; v gs 2 equals to i in divided by g m 1 plus 1 by r o1. So, that makes this current g m 2 into v gs 2 it is nonzero and as a result whenever we will be drawing the small signal equivalent circuit of this entire part. So, we do have the small signal circuit here; small signal equivalent circuit of the application module and along with that we have to consider this. So, after multiplying with g m 2 this current source which is g m 2 into v gs 2 it is having this expression namely, i in multiplied by g m 1 divided by sorry g m 2 divided by g m 1 plus 1 by r o1.

In fact, this can be well approximated by gm two divided by gm one by ignoring 1 by r o1. So, this is g m 2 divided by gm one multiplied by i in and of course, here we do have the application circuit. So, in this case we can say that whatever the current we do have if it is signal current. So, its effect in this application circuit can be considered by considering this voltage dependent current source which is the input signal here multiplied by g m 2 divided by g m 1. Now, this part depending on the ratio aspect ratio of these two transistors it may provide again or it may be equal to 1 or it may be sometimes depending on the situation it may be even less than 1.

So, that is how we consider the small signal equivalent circuit when the current mirror it is carrying a signal current. So, that is what we said that if the current mirror it is having ac current signal entering into it. So, it is conveying the current to the other side. So, here you can see that this is the input to the current mirror and this is the corresponding output and its gain we can say that g m 2 divided by g m 1.

So, similar to this MOSFET version if you consider BJT there also will be getting similar kind of expression only thing is that here will be having r pi also. So, let me quickly go into that yeah.

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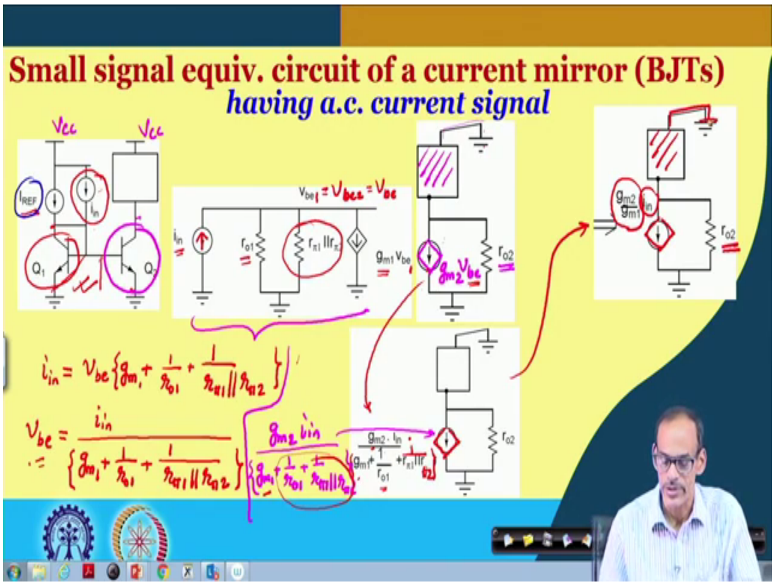

So, here we do have the circuit yeah. So, this is the current mirror where we do have current is having dc part along with that we do have the signal current. So, this dc part in the small signal equivalent circuit that can be removed, but we have to keep this small signal part. So, this i in we have to keep it sorry this polarity it should be in this direction i in based on this convention. and then we do have the small signal model of Q 1 which is which is having the collector to emitter resistance which is r o1 and then we do have the g m 1 into v be 1 and then we do have r pi of transistor 1 along with r pi or transistor 2 in parallel.

So, we can directly see that we do have one more resistance and it produces whatever the voltage here we may call this is v be 1 equals to v b e 2 incidentally and that you may also call this is v be combined v be 1. So, the other side the small signal equivalent circuit for Q 2, we do have voltage dependent current source. So, this is dependent current source we can say this is g m 2 multiplied by v be and then its collector to emitter register r o2 and then we do have the small signal equivalent circuit of the application circuit and then this V cc, now it is connected to ground.

In the small signal equivalent circuit now if you analyze this circuit again similar to the previous case namely MOSFET based current mirror you can get the expression of v be in terms of i in. So, if you if you consider this i in and if you equate it to all the current components which are essentially function of v be. So, v be multiplied by g m 1 plus 1 by r o1 plus 1 by r pi 1 in parallel with r pi 2. So, from that we can say that v be expression of v be, v be 1 or v be 2. So, that is equal to i in divided by gm 1 plus 1 by r o r o1 divided and plus 1 by r pi 1 in parallel with r pi 2.

And this v be it is same as the v be of transistor 2. So, as a result the this voltage dependent current source it can be written in this form. So, we can say that it becomes after multiplying with g m 2, we do have this current it is shown here. So, g m 2 multiplied by i in divided by g m 1 plus 1 by r o1 plus 1 by r pi 1 in parallel with r pi 2.

So, let me rewrite whatever it is given here it is having multiple mistakes. So, it is g m 2 i in divided by gm 1 plus r 1 by r o 1 plus 1 by r pi 1 in parallel with r pi 2. So, that is the expression for this current. In fact, similar to the previous case this part you may ignore. So, in the denominator you do have effectively g m 1.

So, this equivalent circuit may be written in this form. So, the current source here dependent current source here which is i in multiplied by g m 2 divided by g m 1 in parallel with r o2 and then of course, we do have the application circuits small signal equivalent circuit of the application module which is connected to ac ground.

So, now, we have covered this small signal equivalent circuit of current mirror for different cases namely if it if the current mirror is not having any signal current, then it is the equivalent circuit is very straightforward. Whereas, if the current mirror it is having input current then of course, that current it is coming to the application circuit. Now, let us try to see the application or usage of current mirror in different circuits.

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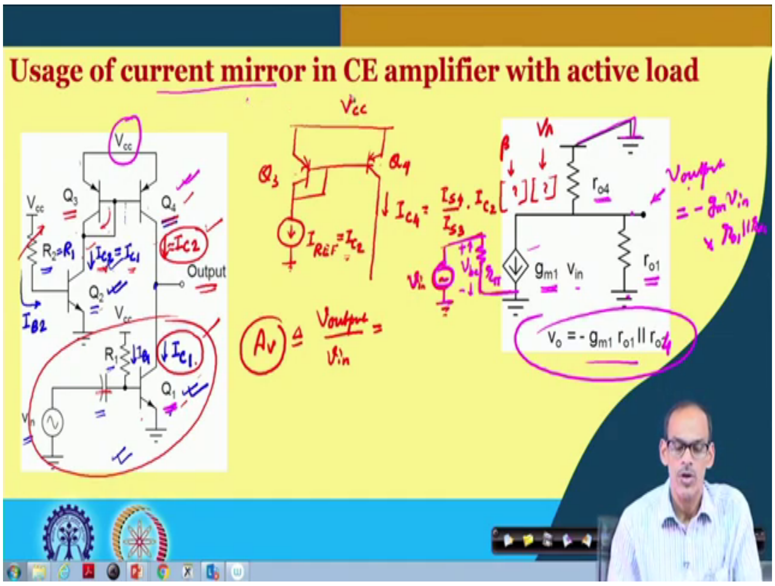

So, to start with let me consider common emitter or common source amplifier let me see which one I do have yeah and to start with I do have common emitter amplifier with active load. So, this is this is the main circuit where transistor 1 it is working as amplifying device, input signal we are feeding through the coupling capacitor and then R 1 it is providing bias current I B. So, this is more like a fixed bias common emitter amplifier. At the collector instead of connecting the passive load here we do have Q 4 which is working as active load.

In fact, we have discussed about the active load circuit considering an independent bias here, but instead of having a bias this may be baited one particularly if we have say transistors NPN 2 NPN transistors they are identical. Then what we can do? We can place say R 2 here which is equal to R 1 this r 1. So, that provides the base current here which is say I B 2 which is equal to I B 1 assuming these two transistors they are identical that provides this current and this current identical. So, I can say this is I C 1 and this I C 2; I C 2 becomes equal to I C 1 assuming that transistor 2 and transistor 1 they are identical.

Now, by the virtue of this current mirror and if I assume that this Q 3 and Q 4 they are identical then this current I C 2 it is getting mirrored here. So, the current flowing through transistor 4 which is also equals to I C 2. I should say approximately equal to because as you may recall that because of the base current loss there will be a small difference between this current and this current. And if I assume that this is very close to this I C 2 and then I C 2 and I C 1 they are equal that makes this current and this current are getting matched which we are looking for um.

And not only they are matched the both the transistors transistor 4 and transistor 1 are in active region of operation right. Here you might have observed one important changes in the current mirror, if you see this Q 3 and Q 4 they are forming a current mirror, but type of transistors here we have used it is p and p. So, we do have PNP transistor, we do have a current flow here in this case I reference is equal to I C of transistor 2. So, this Q 3 and Q 4 which are together connected to supply voltage and then we do have a current mirror getting form.

So, this current mirror it is very similar to NPN transistor based current mirror. So, whatever the discussion we had before namely the expression of this current in terms of I S ratio of the two transistors multiplied by this current multiplied by non ideality factors. One it is due to the base current loss another one it is due to early voltage finite early voltage that can be considered. So, so the expression of I C 4 equals to I S 4 divided by I S 3 multiplied by I C 2 and then we do have two non ideality factors coming there. One is due to beta loss or I B current and other one it is due to the finite value of early voltage ok.

Now, here the as I say that the requirement here it is these two transistors they are identical that makes probably many a times it is not so difficult to achieve that, but in integrated circuit. But for discrete component based circuit still there may be an issue of getting two transistors having identical situation.

So, I should say theoretically it is fine, but practically you may have to in case if you want to make this circuit working you may have to tune this register to ensure that this two currents under active region of operation they are equal ok. So, once we have the these two currents are equal, then to get the gain you can. So, the voltage gain which is defined by v out or v output here divided by v in. So, that can be obtained by considering its small signal equivalent circuit.

So, if you consider this part small signal equivalent circuit where this capacitor it is working as a short. So, we do have directly v in coming here. So, we do have the v in coming to the base let me use a different color otherwise you may get confused in yeah. So, we do have v in here and then we do have r pi and then we do have. So, this voltage is v be incidentally that is equal to v in as we have discussed earlier.

So, we do have gm into v in is the voltage dependent current source and then for transistor 1 its collector to emitter we do have a register r o 1. On the other hand for transistor 4, we do have r o4 and we do have supply voltage which is ac ground. Now, the voltage coming here it is the output voltage and this output voltage if we analyze this circuit this output voltage is equal to minus g m 1 into v in multiplied by the two resistors in parallel.

So, we do have r o1 in parallel with ro 4. In fact, so this is the expression this should be r o4 instead of r o 2, it is r o4. So, that is how we can say that we can use the current mirror in common emitter amplifier. So, likewise we can use common emitter current mirror in common source amplifier also.

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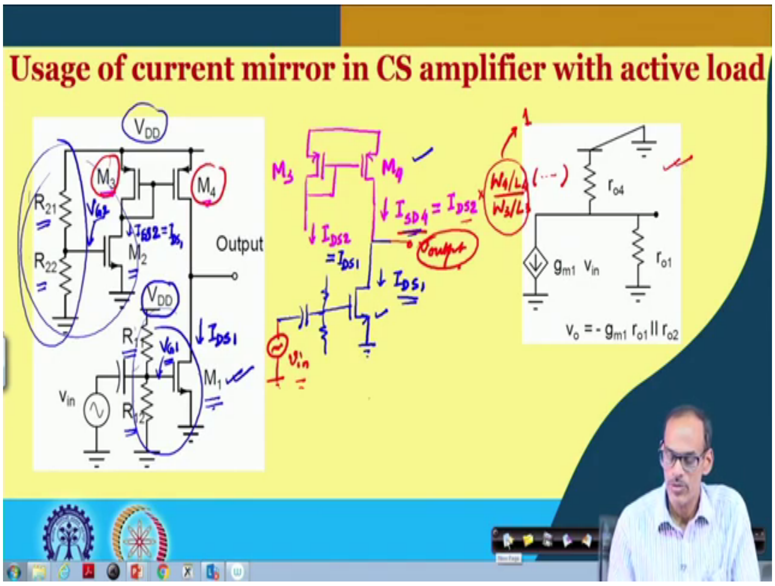

So, in the next slide we do have the corresponding circuit. So, as you can see here transistor 1 it is working as amplifying circuit it is having its bias to get a meaningful voltage here we do have V dd supply along with that R 11 and R 12 are informing the potential divider to get V G 1. So, likewise here we do have a potential divider consists of R 21 and R 22 along with the supply voltage to generate a gate voltage V G 2. Now, if we consider these two transistors M 1 and M 2 they are identical, then if this potential divider here and potential divider here they are identical providing equal gate voltage, then we can say I DS or transistor 1 equals to I DS of transistor 2.

So, we can say this I DS 2 equals to I DS 1 assuming that dc wise this part and this part are identical and then we do have current mirror form by M 3 and M 3 this is a current mirror constructed using PMOS transistor. So, here we are assuming that M 3 and M 4 are identical. So, if they are identical then whatever the current it is flowing namely I DS 2 it is nicely getting mirrored here. So, we can say that I SD 4 equals to I DS 2 or to be more precise it is it is having a ratio aspect ratio relationship.

So, we considered W 4 by l 4 divided by W 3 by L 3 then multiplied by whatever non ideality factor and if I assume that this is equal to 1 which means that transistor 3 and transistor 4 their identical that makes I SD 4 equals to I DS 2 and then at the lower side we do have transistor 1 which is having I DS 1. So, that makes and the current here it is equal to this 1 assuming this I DS 2 equals to I DS 1.

So, with this assumption it may not be very difficult to match the current of the amplifying device and the active load device and many a times in integrated circuit particularly integrated circuit matching getting the matched characteristic of 2 transistor it is not so difficult and this circuit it is hence quite frequently used in integrated circuit.

After getting the dc operating point correct we can probably try to get the gain of the circuit and the gain it is defined by the voltage coming here v output divided by v in. So, to get the relationship between this output signal and input signal we can draw the small signal equivalent circuit.

So, here we do have the small signal equivalent circuit let me clear the board and yeah. So, yeah some part of the small signal equivalent circuit is missing.

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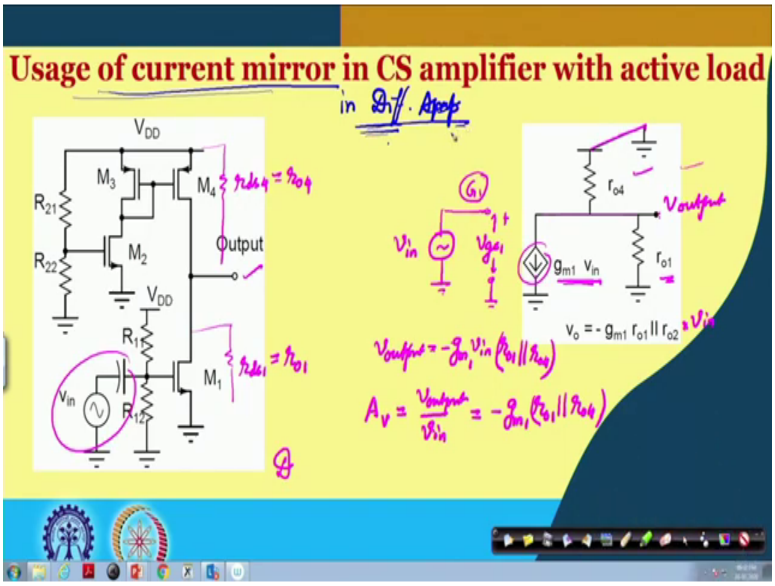

So, let me draw that part particularly this part we do have the input directly coming here to the gate node of transistor 1 and that produces v gs 1 and incidentally this v gs 1 equals to v in. So, we can see that voltage dependent current source it is g m 1 into v in and at the output side we do have this r ds 1 which we are denoting now by r o 1. So, we do have r o1 likewise we do have r ds 4 which we are denoting by r o 4. So, we do have r o 4.

And this is of course, it is ac ground and the output signal it is coming at this node. Now, analyzing this circuit we what we can get it is v output equals to the current flow with a minus sign of course, with this convention of this current; current direction. So, this is gm 1 into v in multiplied by r o1 in parallel with r o4 and yeah. So, I should say yeah I should have multiplied by v in. So, that gives us the voltage gain A v equals to v output divided by v in equals to minus gm 1 r o1 in parallel with r o4 right.

So, likewise this current mirror it is also having application in differential amplifier. So, this usage of current mirror is also there in differential amplifier an in differential amplifier the current mirror not only it can be used as biasing element, but also it is used as current carrying element. So, the discussion there it will be quite involved. So, we will be discussing that, but let me take a break and then we will be talking about usage of current mirror in differential amplifier. So, we will be coming back after the break.

Thank you.