Analog Electronic Circuits
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Lecture – 89
Numerical Examples on Current Mirror and its applications (Part-D)

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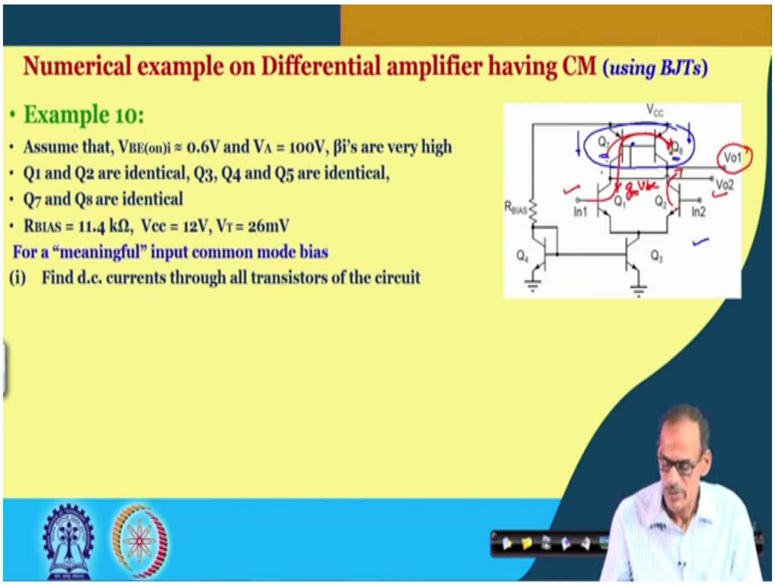

Yeah. Welcome back to our next example. So here we do have the differential amplifier and the load of course, it is active load, but internally we do have current mirror. So, what we are expecting here it is transistor 7 DC wise it will be mirroring its own DC current into transistor 8 and that is good. In fact, we want this current should also be same as this 1 from balance point of view. So, we do not have to put any external circuit to bias here and in addition to that this transistors 7 it may also mirror signal current, in case if we have say gm into V b current it is coming here at the collector.

So, that current is also getting mirrored here. So it is expected it is expected that the signal it is whatever the differential signal or common mode signal, it will be arriving to this output through this transistor 2 as well as through transistor 1 and then through the current mirror. So, we will see the consequence in this numerical example I hope you recall the analysis we have done for this circuit.

So, in the numerical examples we will be reestablishing the same thing, to start with we do have to find the DC currents through all the transistors.

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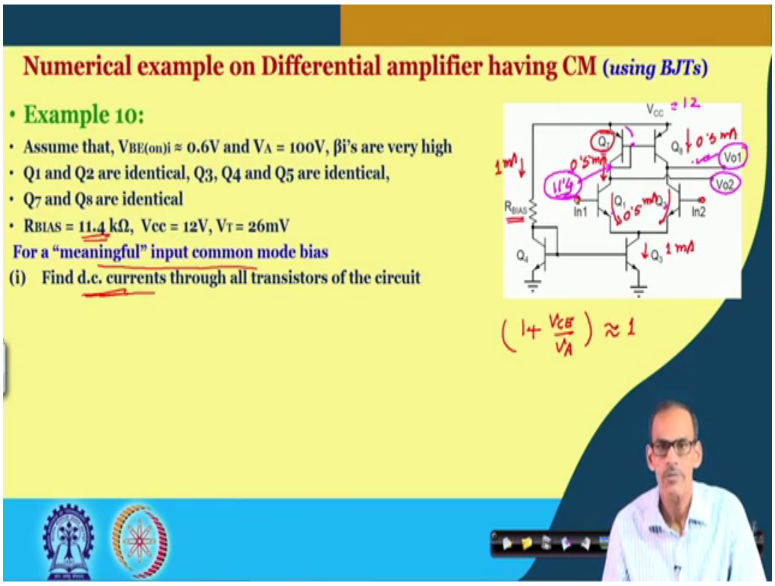

Again the value of this register it is 11.4 k, so that makes this current equals to 1 milliampere. So, the current flow here it is also 1 milliampere and if we are applying meaningful input common mode DC then half of the current is flowing here and remaining half it is here. So, each one of them it is 0.5 milliampere so this 0.5 milliampere it is getting mirrored here. So, the current flow here it is 0.5 through transistor 7 as well as transistor 8.

Now yeah so it is now it is pretty straightforward so if you if you ignore this early voltage to calculate the nominal quiescent current, namely 1 plus VCE by VA if you consider it is approximately equal to 1 for DC condition DC current. Then the circuit analysis it becomes really simple and also we like to say that since this is transistor 7 it is diode connected.

So, the voltage here it is decided by the 12 volt minus 0.6 so the voltage here it is 11.4. In fact, it can be shown that the DC voltage at this point assuming Q 1 Q 2 identical Q 7 Q 8 identical it is also 11.4 volt. So, I should say DC voltage at output 1 and output 2 both are 11.4 volt, now with this information let we calculate the small signal gain namely differential mode gain and common mode gain in the next slide.

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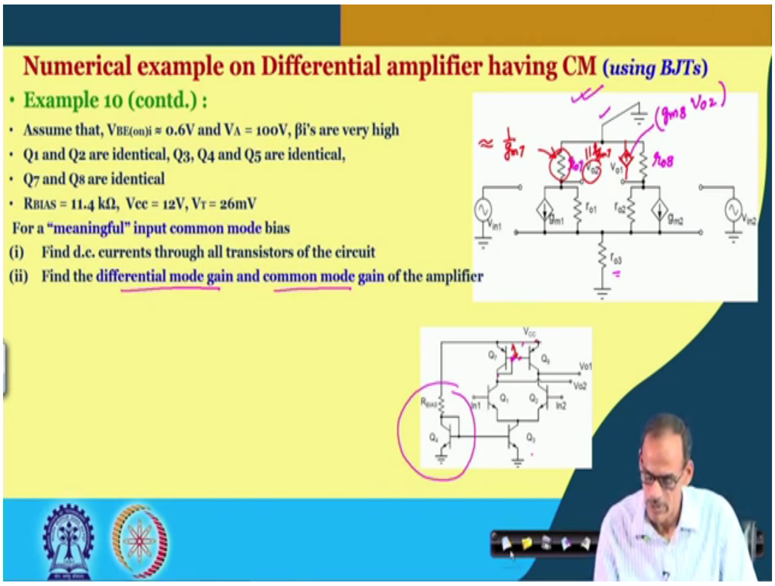

So, yeah so now our next calculation it is we need to find differential mode gain and common mode gain. And here we do have most of the small signal model this part of course, we are in the small signal model we are removing we are keeping only ro 3 and on the other hand for transistor 8 we do have ro 8 and then ro 7. In fact, since it is diode connected we should also give this ro 7 in parallel with 1 by gm 7.

So, the voltage coming here Vo 2 it is predominantly it will be defined by 1 by gm 7 and whatever the signal current is flowing through this. So, approximately we can say that this resistor it is 1 by gm 7, so then whatever the voltage it is producing here that voltage it is also deciding the Vb voltage of transistor 8.

So, through the transistor 8 there will be a current flow, signal current flow and this signal current flow. Of course, it will be it will be corresponding gm 8 multiplied by the Vb here which is it is basically this is Vo 2 because this node it is ground.

So, the voltage Vbe voltage it is gm 8 multiplied by Vo 2, so in in summary now to analyze this circuit we can just simplify and saying that this resistance it is 1 by gm 7 this is ro 8.

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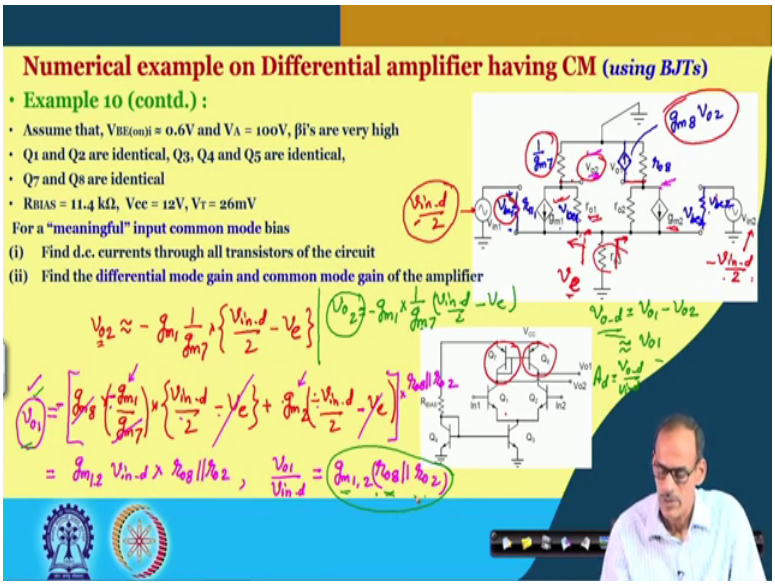

But in addition to that we do have a current flow here which is gm 8 multiplied by Vo 2 and then we do have ro 1 ro 2 then we do have g m 1 into Vbe 1, so this is Vbe 1 across this r pi so Vbe 1 here.

So, likewise here we do have Vbe 2 so Vbe 2 multiplied gm 2 it is giving the current here. And to get the differential mode gain what we can say we can make this voltage equals to V in d by 2 and this voltage on the other hand it is minus V in d by 2. And in fact, this is common node this is common node the impedance looking into this device and this device. If I ignore this part strictly speaking they are not same, the impedance looking into the source of transistor 1.

It is smaller primarily because at its collector we do have a smaller resistance compared to whatever the resistance we do have. In fact, there may be a detailed calculation by which you can find that this voltage it is tilted towards Vdd V in d by 2 compared to minus V in d by 2. If the 2 resistances they are equal then only you can say this is ac ground, but whatever it is we may say that it is having Vs voltage that makes this Vbe voltage which is this V in d by 2 minus Vs.

On the other hand the voltage here it is minus V in d by 2 and then minus this Vs and then that produces this current. And this current it is producing a voltage compared to this impedance we may ignore this ro 1 even though it is connected to this node which is having the signal, but as the signal here it is very small. We may see that output voltage Vo 2 it is well approximated by gm 1 multiplied by 1 by gm 7.

So, that is the impedance at this node and then V in d by 2 minus I should not say s let it be Ve because this is common emitter voltage. So, that is the voltage you do have here so the current flow at this node on the other hand it will be gm 8 multiplied by this voltage which is gm 1 by gm 7 with a minus sign multiplied by V in d by 2 minus Ve. So, this is the current at this point in addition to that we do have this current also, so we do have gm 2 and then we do have minus V in d by 2 minus Ve.

So, this is the total current and if I multiply this current by the impedance at this node which is practically it is ro 8 in parallel with ro 2, so that gives us the output voltage Vo 1. In fact, if you see here gm 7 and gm 8 we may cancel it out and if I consider gm 1 and gm 2 they are equal then this we do have a minus sign here and minus sign here that makes it is plus and here you have minus sign so we can say even this part is also getting removed. So, with this approximation what you are getting here it is gm 1 so we do have gm 1 here and then of course, with a minus sign here because the current is departing this node.

So, we will be having a minus sign so this minus sign and this minus sign and this minus sign they are getting converted into plus. So, eventually gm 1 or gm 2 multiplied by this V in d, multiplied by this net output resistance which is practically ro 8 and ro 2 in parallel. So, if I say that final output voltage if I call this is the net output voltage Vo 1 by differential input here which is equal to gm 1 or 2 multiplied by ro 8 in parallel with ro 2 on the other hand the voltage at this node Vo 2.

So, Vo 2 on the other hand so this is equal to it is very small so whatever the voltage you do have that is getting multiplied by gm 1, but then that is again multiplied by 1 by gm 7. So, this is V in d by 2 minus Ve, but whatever it is these two gms in the same order of magnitude as a result you may say that this voltage it is very small compared to Vo 1. And if I say that output voltage differential output voltage Vod defined as Vo 1 minus Vo 2.

So, all practical purposes it is equal to Vo 1 and then the expression of V 1 it is given here to find the gain differential mode gain Ad. So, that is equal to that is defined as Vod divided by V in d and that is given by gm 1 into ro 8 into in parallel with ro 2. So, numerical value to calculate numerical value let we consider let we calculate gm 1 and gm ro 8 and ro 2.

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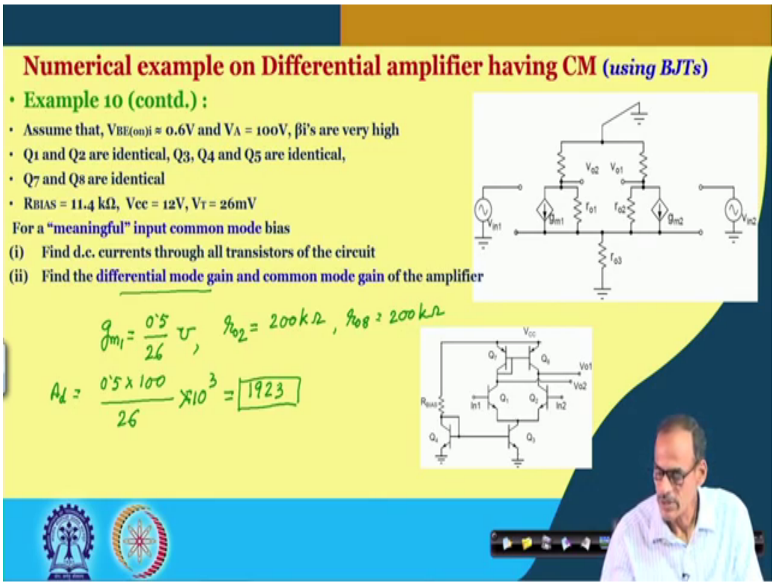

In fact, we already have d done this calculation gm 1 equals to 0.5 divided by 26. And so this is this much of more and ro 2 equals to 200 k also ro 8 equals to 200 k and that gives us the differential mode gain equals to 0.5 into 100 divided by 26. So, that is equal to so this into 1000 so this is equal to 50, I should say 50 divided by 26 multiplied by 1000 so that is 1 9 2 3 to be more precise.

So, that is the differential mode gain, on the other hand the common mode gain. So, the common mode gain it is essentially it is a bit tricky.

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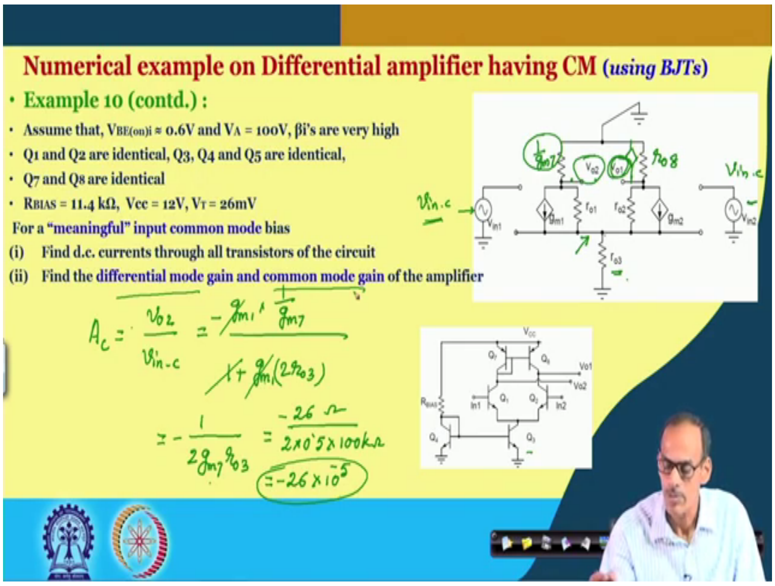

Here we do have this resistor it is practically 1 by gm 7, and if we apply same voltage here and same voltage here namely V in c. So, that makes this voltage and this voltage to be equal so, even though we do have ro 8 connected here. But we do have voltage dependent current source which depends on this voltage, making this node very insensitive or a smarter way to calculate their common mode voltage we can say that common mode gain.

Essentially, it is Vo 2 divided by V in c and in this circuit since we are applying same voltage here and here V in c with same polarity. In that case this node of course, it is remaining high impedance or rather I should say degenerated node. So, we do have this registered remaining there and it is degenerating the circuit and this gain as you have discussed before it will be the gain of this circuit which is getting degenerated by ro 3 or if I split the circuit it will be rather 2 times of ro 3.

So, the corresponding gain here it is gm 1 multiplied by 1 by gm 7 so that is the impedance here divided by 1 plus gm 1 into 2 times ro 3. In fact, this gm 1 sorry after removing this 1 you can remove this gm 1 also, so that gives us a common mode gain equals to 1 by 2 gm 7 into ro 3. In fact, gm 7 it is given to us and also yeah so it is becoming this is 26 divided by 2 0.5 milliampere 2 into 0.5 and then ro 3 it is 100 k.

So, that gives us how much 2 6 into 10 to the power 5 minus 5 sorry. So, the common mode gain it is really very small, so that makes this circuit it is having differential mode gain it is good and then common mode gain it is quite low, the similar kind of circuit can also be constructed using MOSFET.

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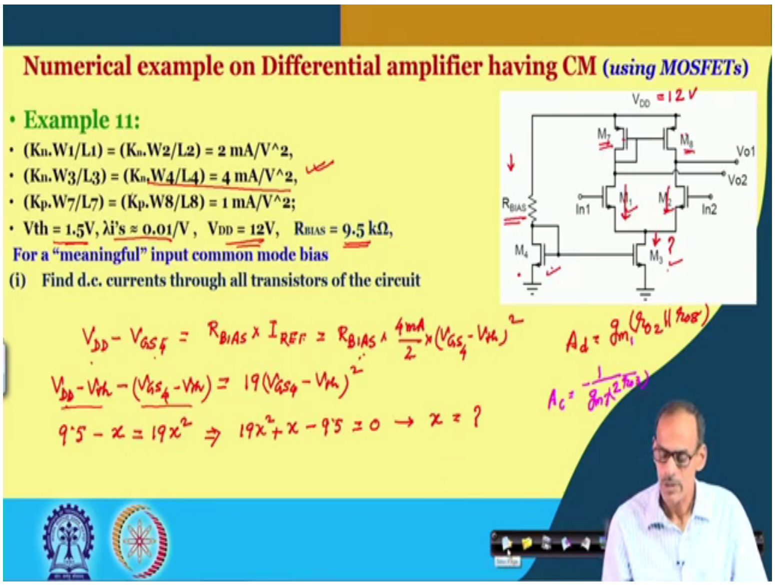

So, in the next slide we will be talking about that so here again we are assuming that these two transistors, these two transistors they are identical, these two transistors they are identical here and the load part also it is active current mirror load and they are also identical. And the supply voltage it is 12 volt bias register it is 9.5 k and let we consider all the lambdas are 0.01 per volt. Threshold voltage of all the transistors it is equal to 1.5 the analysis part it will be very similar to the other circuit.

We just now we have discussed having BJT implementation, but probably the DC operating point may be little different. So, let we calculate the DC operating point we do have 12 volt supply here and we do have the size of transistor 4, it is given here rather trans conductance factor it is 4 milliampere per volt square. If we calculate it carefully what you can get here it is the current flow it is actually it is equal to 1 milliampere.

So, 4 is it 1 milliampere this is 3 and 4 they are equal that is fine let me calculate this one. So, we do have the VDD minus Vs or VGS of transistor 4 and so that is equal to this R bias, R bias multiplied and this I and so this I reference.

So, this I reference on the other hand it can be defined by this transistor so we do have R bias multiplied by 4 milliampere by 2 into VGS minus Vth square. And so here what we can do we can yeah so we can add 1 Vth and then subtract 1 Vth. So, we can say VDD minus Vth minus VGS 4 minus Vth equals to we do have 9 here 9.5 here and then 2 here. So, that gives us 19 into 19 into VGS 4 minus Vth square and this part it is it is 9.5 So, we can say this 9.5 minus let you consider this is x is equal to 19 x square right.

So, from that we can find what will be the corresponding x so we do have 19 x square plus x and then minus 9.5 equals to 0. So, from that we can find what is the x and then you can consider this two are having current mirror so; obviously, then you can find what will be the current flow here. And then half of the current it is flowing here, so then here also the corresponding current it will be half of that.

So, that is how we can proceed probably you can work it out and once you get the operating point then you can find the differential mode gain. Which is again gm into ro 2 in parallel with ro 8 and the common mode gain on the other hand it is ac equals to minus 1 by gm 7 into 2 into ro 3. Probably you can work it out so since it is similar kind of example so I will skip that part.

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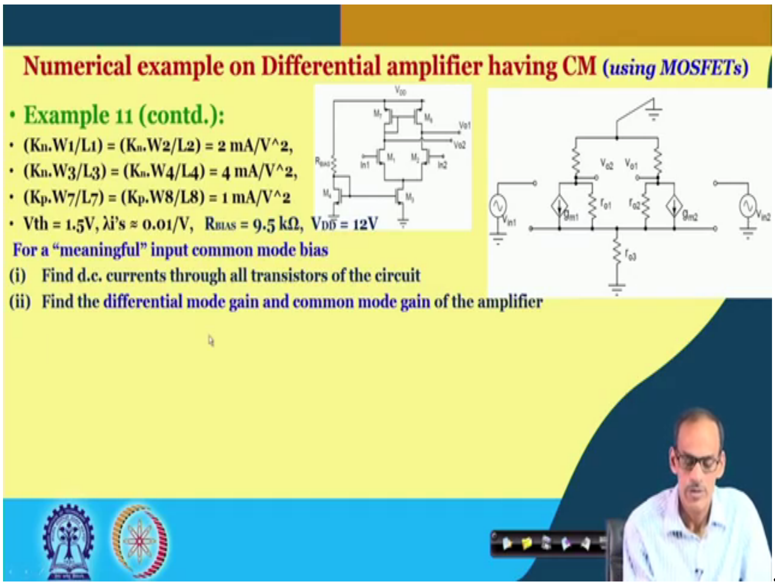

So, yeah so this is and then you can probably you can find what will be the numerical value.

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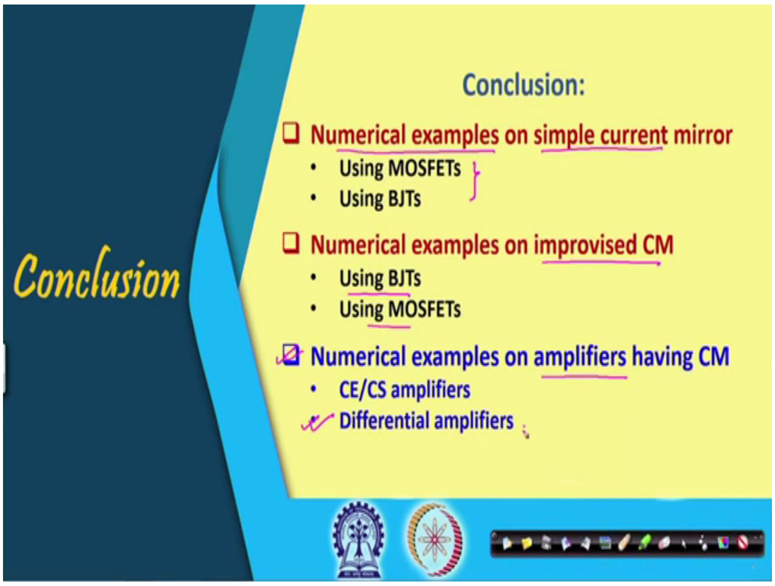

Now, coming to the conclusion of this entire session it is what we have talked about basically we started with numerical examples of simple current mirror. And we have calculated the different transistor current there and then we have talked about numerical examples of improvised current mirror namely the beta helper and then cascade current mirror.

And then we have talked about different numerical examples on amplifier starting with common emitter and common source amplifier, having current mirror as its load. And then we have talked about differential amplifier implemented by BJT as well as the MOSFET. And then there we have considered how to calculate the quiescent current of all the transistors and then we have calculated the differential mode gain and common mode gain, I think that is all to share with you thank you for listening.