Analog Electronic Circuits
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Lecture – 88
Numerical Examples on Current Mirror and its Application (Part-C)

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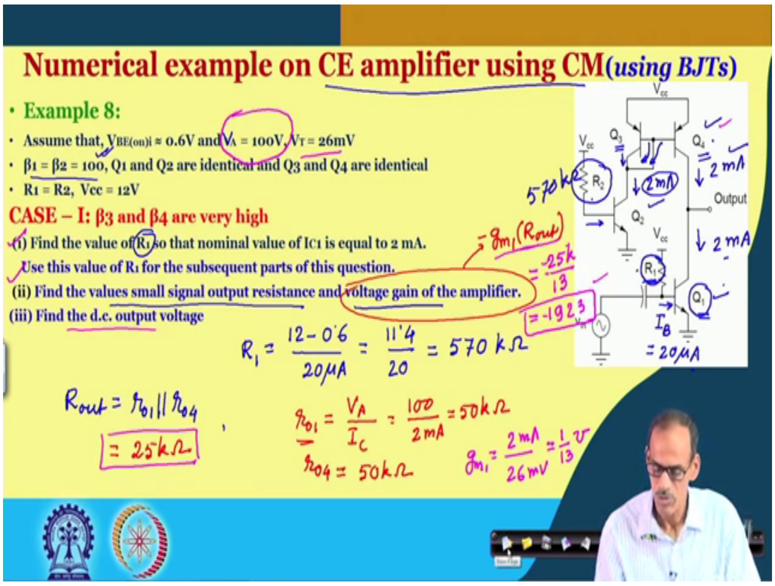

Dear students, welcome back after the break. So, we are going through different numerical examples and now we are going to talk about one common emitter amplifier which is using current mirror and particularly to bias the active load say Q 4. We are using current mirror and transistor 1; it is the amplifying device then we are assuming that Q 1 and Q 2 they are identical and also we are assuming that whatever the this Q 3 and Q 4 are also identical.

So, to get the I C current of transistor 1 and collector current or transistor 4 equal. We want the current flow through transistor 2 should be equal to current flow through transistor 1. And since, Q 1 and Q 2 are identical having the same beta value of 100. So, then the value of this resistance bias resistance, based biased resistance R 1 should be identical to this transistor the register R 2.

So, that the base current here and base current here, DC base current they should be equal. So, also we do have othered information namely all the devices are having early voltage 100 volt and with this information let we try to find what will be the value of this resistance to get the collector current I C 1 equals to 2 milli ampere.

So, since the beta is 100 so, the I B it is should be equal to 20 microampere. So, to get the value of this R 1 to get 20 microampere, the R 1 should be equals to V cc, that is 12 volt minus V BE point 6 volt divided by 20 micro ampere. So, this is 11.4 divided by 20 yeah. So, that is equal to you know 570 kilo ohm. So, the value of this resistance as well as this resistance they are equal to 570 kilo ohm.

So, with that we do have this current is also 2 milli ampere and if we assume that the base current loss it is ignorable, then you can say that collector current of transistor 3 it is also 2 milli ampere which is getting mirrored to transistor 4, so, that is making this current also 2 milli ampere. So, that is how these 2 currents; currents of transistor 1 and transistor 4 they are getting matched.

Now, with this information let us try to find the small signal output resistance and voltage gain of the amplifier. So, we are assuming both the devices are in active region. So, the output resistance R out equals to parallel connection of r o 1 and r o 4. Whereas, this r o 1, r o 1 equals to V A divided by this I C. So, that is equal to 100 divided by 2 milli ampere. So, that is giving us 50 kilo ohm.

So, same thing we can get for transistor 4, r o 4 equals to 50 kilo ohm and that gives us 25 kilo ohm. So, the output resistance it is 25 kilo. Now we like to get what will be the gain of this amplifier. So, the gain of the amplifier of course, the voltage gain of this amplifier it is g m 1 multiplied by this R out with a minus sign. So, what is the value of the g m 1? Now gm 1 equals to I C.

So, that is 2 milli ampere divided by 26 milli volt, that is the V T given there. So, this is equal to 1 by 13 mho. So, the voltage gain so, the voltage gain it is 50, 25 kilo divided by 13. So, that is coming how much this is 25, almost 200 or to be more precise rather 25 k divided by, no not 200, it is close to 2000 rather yeah.

So, the gain it is coming 1923. So, that is the voltage gain we are getting. So, as it is expected that since we do have active load. So, the gain it is expected to be very high and the output resistance is also high. Now, next part of this question it is to find DC output voltage we need to consider this V A, the early voltage very carefully ok. Now let me clear the board and then again we will talk about the DC voltage.

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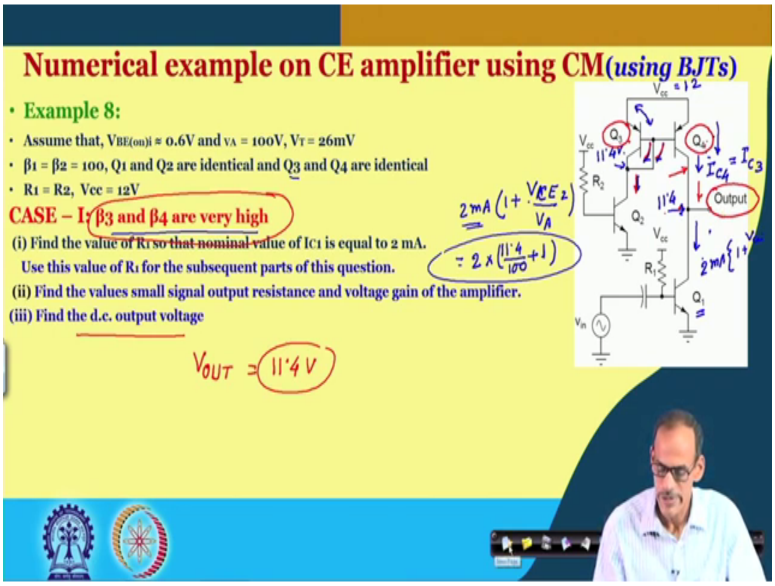

As I said that the current flow current flow here and here should be equal and if you see it carefully the DC voltage here it is defined by this V cc minus V BE drop. So, I should say the voltage here it is. So, this is 12 volt. So, the voltage here it is 12 minus 0.6 so, that is 11.4 volt.

Now, with this 11.4 volt here we can say that whatever the current we do have. So, that may be 2 milli which is of course, 1 approximation that we are assuming 1 plus lambda V ds part equals to 1 please stop here.

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So, the current flow here it is to be more precise it is 2 milli ampere multiplied by 1 plus V A divided by sorry, this is V CE of transistor 2 divided by V A. So, the current here it is 2 multiplied by V CE it is 11.4 divided by 100 plus 1. So, whatever the current. Now if you see this current is getting mirrored here ignoring the base current loss here, because for transistor 3 and transistor 4, we have considered their betas are very high.

So, they are identical, this information it is also given. So, we can assume that the collector current of transistor 4 it is same as collector current of transistor 3. So, I C 4 equals to I C 3. So, this I C 3 as I said that this current is also equal to this and on the other hand this current the collector current of transistor 1 it is also 2 milli ampere multiplied by this kind of factor 1 plus it is V CE divided by V A.

So, if this voltage here it is say 11.4, then you can say that this current and this current they are becoming equal. In in intuitively also you can say that if this voltage it is 11.4. So, that makes the current here and current here, they are equal and also the current flow in transistor 3 and transistor 4 they are equal. So, that makes everything is consistent.

So, that gives us the DC output voltage V OUT should be equal to 11.4 volt right. But of course, if the value of early voltage or in case we cannot ignore say this base current and then of course, the corresponding the current here and here there will be a mismatch and the DC voltage here it will deviate from here. So, in the next numerical example it is continuation of this, the same example, but considering finite value of this beta of transistor 3 and 4 will be giving us a situation where we need to consider mismatch of the 2 current and then we can try to find what will be the change of this output voltage right.

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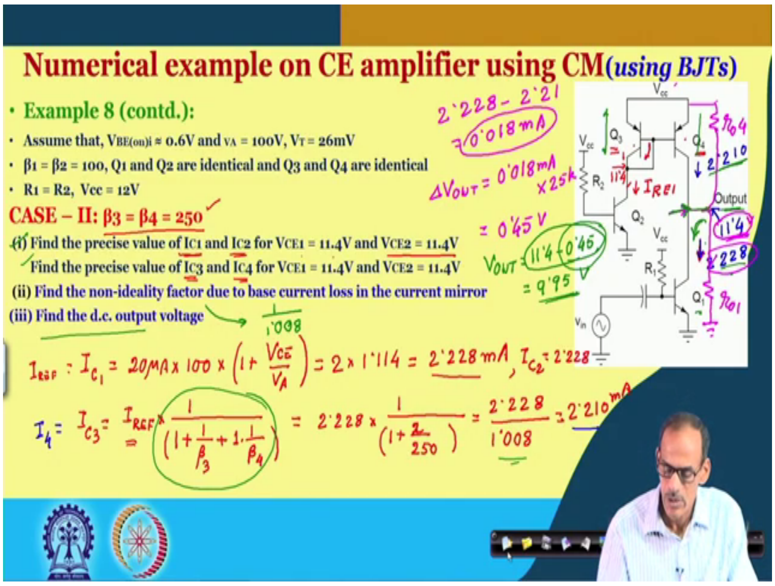

So, in the next slide we are going to talk about that yeah. So, as I said that the problem here it is very similar, except that transistor 3 and transistor 4 they do have beta equals to 250. Now, here we can try to find what will be the current I C 1 and I C 2 at V CE equals to 11.4. Why 11.4? As I say that is the voltage here it is 11.4 and suppose if we make this voltage also 11.4, then we know this current and this current they will be equal. And just now we have calculated that I C 1 equals to 2 milli ampere. In fact, that is the base current 20 micro ampere multiplied by beta that is 100 multiplied by 1 plus V CE, which is 11.4 divided by V A.

In fact, if you do the calculation here what you will get it is the 2 into 1.114. In other words, this is 2.228 milli ampere. In fact, this is same for I C 2 also. So, I C 2 also equals to 2.228. Assuming that V CE 2 it is 11.4. We can also try to find what will be the corresponding current here in transistor 3 and a transistor 4. If we ignore the if we ignore the base current loss, then we are expecting that this current and this current it will be same. But we do have some loss here so, to get the I C 3 what you can say that I C 2 now it is working as the reference current for this current mirror I REF.

So, I REF equals to I C 1 and it is value it is given here. So, I C 3 equals to this I REF and also we have to consider the non ideality factor due to the base current loss and that is 1 by 1 by beta 3 plus I is ratio, so, that is 1 multiplied by 1 by beta 4. So, we do have 2.228 is the I reference current multiplied by 1 divided by 1 plus 1 by 250. In fact, both of them are 250s. So, we can simply say this is 2 divided by 250 and so, this is equal to 2.228 divided by 1.008 right. So, 2 divided by 250 right. So, this is 2 divided by 250 yeah. So, this is becoming 2.228 divided by 1.008. So, that is equal to now 2.228 divided by 1.008. So, that is equal to 2.210 milli ampere.

Now, the same current, same current it is also flowing through transistor 4 as they are identical. So, now, you can see that if we try to hold this voltage at 11.4, then the current flow here it is 2.228. On the other hand, the current coming from transistor 4 it is 2 on the other it is 2.210. So, we do have some excess current requirement and so, that current it is point so, we do have additional requirement here. So, that current is 2.228 minus 2.21. So, additional 0.018 milli ampere of current we are looking from this node.

Now where this current it will be coming from. So, of course, we do have in the small signal equivalent circuit we do have r o 4 which is connected to the supply. And then also we do have r o 1. In fact, these 2 together you may say that it is providing R OUT and the other end of the R OUT, it is connected to 11.4 volt. So, as we are looking for this excess current, there will be a change of this voltage with respect to 11.4 volt by an amount of so, if I say del V OUT. So, this del V OUT it will be 0.018 milli ampere multiplied by whatever the output resistance.

And we have calculated the output resistance it was 25 k. So, that gives us a voltage difference or voltage variation which is equal to 25 multiplied by 1 point so 0.018. So, that is equal to 0.45 volt. So, the voltage here at the output the DC voltage it will be equal to V OUT equals to 11.4 minus 0.45. So, that is equal to 9.95 volt. Why it is minus? That is because we are demanding more current here so, naturally the voltage it will be coming down.

In case if this current it is higher than the current flow through transistor 1 for 11.4 volt DC, then the corresponding voltage here it would be higher positive. So, in this case since the current flow here it is more. So, we do have reduction of the voltage and it is finally, going to this one. So, yeah so, we have calculated these 2 currents and then also we have calculated this non ideality factor. In fact, this is the non ideality factor which is 1 divided by. So, this non ideality factor is 1 divided by 1.008. And then the corresponding DC voltage it is given here yeah. So, that is how you can approach. So, here what we have seen that precision level or these 2 currents are important, otherwise this voltage it may be having a big change. See suppose this the early voltage here and early voltage of the other transistor if they are having mismatch then also it is expected to have mismatch of these 2 current leading to significant amount of variation of this output voltage.

This may be a case when the output node it is high impedance node. So, even a small mismatch of the current may lead to significant amount of voltage variation. In this case though this variation it is not much, but there may be a situation in practical situations this difference it may be so large, probably 1 of the transistor may be pushed towards the saturated condition or saturation region of operation. So, we need to be little careful. Now let us go into different types of examples or application circuit of current mirror namely. differential amplifier. So, in the next example, example 9; we will be talking about differential amplifier where we are using current mirror yeah.

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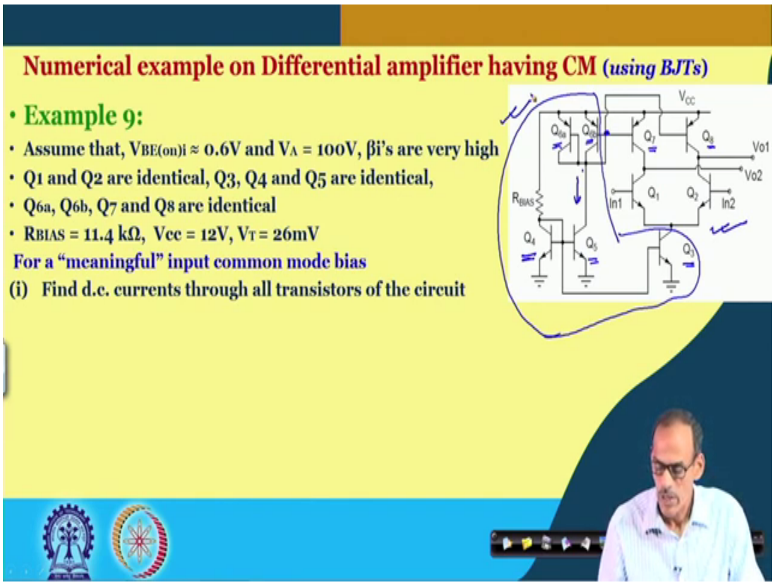

So, here is the circuit first of all we do have the main differential amplifier and then we do have the bias circuit here. In fact, if you see here the bias circuit it is having number of current mirror. So, Q 4 and Q 5 they are forming a current mirror, Q 4 and Q 3 they are also forming a current mirror and whatever the current is flowing here that is again getting mirror to transistor 7 as well as transistor 8 and the corresponding diode connector transistors Q 6 a and Q 6 b together it is mirroring the current. In fact, this circuit we have discussed in a while we have analyzed the circuit. Now let we go into it is numerical calculation. What we have the information given here it is transistor yeah.

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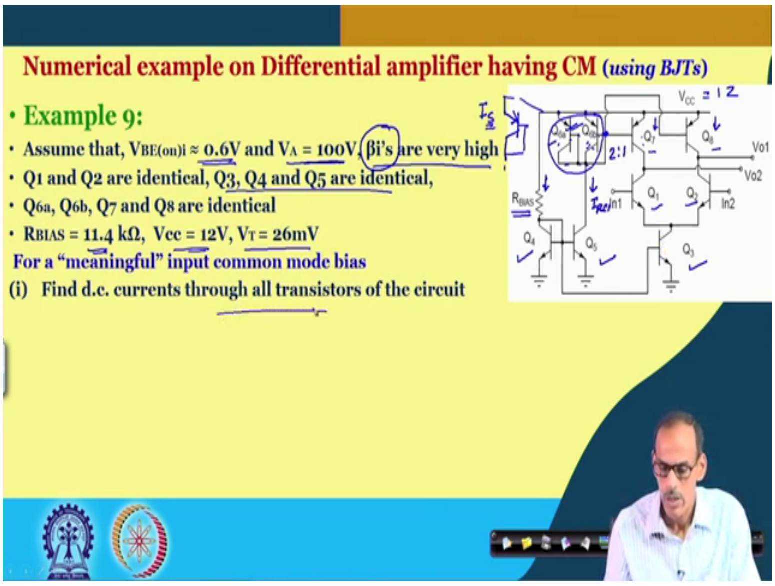

So, transistor 1 and 2, they are well matched. So, since it is differential amplifier so, we are looking for that. And then Q 3, Q 4 and Q 5 they are also identical. So, they are also matched NPN transistor. On the other hand Q 7, Q 8, they need to be identical for differential amplifier of performance point of view. In addition to that Q 6 a and Q 6 b individually they are also identical to Q 7 and Q 8. So, I should say all the 4 transistors they are identical.

Now, the moment we make transistor 6 and 6 a and 6 b parallelly connected, namely they are collectors they are connected together emitters are connected together and base also they are connected together. So, you may equivalently say that we do have 1 transistor which is say Q 6 which is similar to or it is identical to a parallel connection of this transistor, assuming that the I s of this transistor it is 2 times of I s of individual Q 6 a and Q 6 b.

So, we may say that this current mirror it is mirroring the current with a ratio of 2 is to 1 rather whatever the current we do have here I reference current. So, half of that current it will be flowing here and another half it will be flowing there. So, that is that is what we have to keep in mind.

Now, here in this circuit the bias registered it is given to us that is 11.4 k and then supply voltage of course, this is 12 volt and thermal equivalent voltage it is 26 milli volt and V BE 1 as usual we are taking point 6, early voltage it is 100 volt and let me assume that beta of all transistors they are quite high. So, we can ignore the base current loss.

In fact, many of the bias circuits we may not be looking for precision level of the current we like to get nominal value of the current and to get that we can many a times we do ignore the effect of beta. Anyway, so, this is given to us and let we calculate the reference current here and then let we calculate the current through all the other transistors. So, how do we proceed? First of all, the current flow through this R BIAS.

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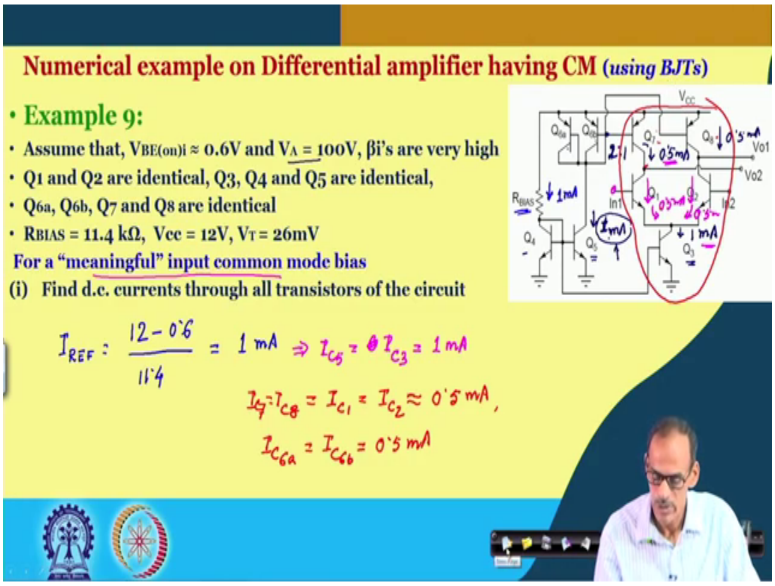

So, R BIAS it is we may call I reference, I reference equals to 12 volt supply minus V BE on of transistor 4 divided by R BIAS so, that is 11.4; so, that is equal to 1 milli ampere. For simplicity that why I have picked up the value here. So, that the reference current here it is 1 milli ampere. Now we do have transistor 5 and transistor 3 they are well matched with transistor 4. So, we can see that this current is 1 milli ampere same thing here also.

Now, you may consider this early voltage and then you can precisely get the value of this current, but many a times we may rather ignore that precision level. So, we can consider this nominal current of 1 milli ampere it is flowing through both these transistors. And as I said that this diode connected transistor it is mirroring the current in the ratio of 2 is to 1. So, half of this 1 milli ampere. So, that is 0.5 milli ampere. It is flowing through transistor 7 and likewise 0.5 milli ampere current is flowing through transistor 8.

Now if I say that we do have meaningful DC voltage here and here. So, that is what we said meaningful input common mode bias you do have then current flow here and current flow here they are identical. So, I should say half of this current is coming through transistor 1 and the other half it is coming through transistor 2.

So, current flow here it is 0.5 and here also it is 0.5 milli ampere. In fact, this 0.5 milliampere it is consistent with the current flow through 7 and 8 respectively. So, that makes the current flow through transistor 5 and transistor 3 equal to 1 milli ampere. On the other hand current flow through transistor 7 then I C 8 equals to I C 1 equals to I C 2, all of them are approximately 0.5 milli ampere.

In fact, current flow through transistor 6 a and 6 b, they are also equal to 0.5 milli ampere. With this information now we can try to say that we can calculate what will be the gain and since the nominal currents they are consistent we can assume that all the transistors namely Q 1, Q 2, Q 7, Q 8 and Q 3 are in active region of operation. So, in the main circuit, we are keeping all the devices in proper region of operation then we can calculate the small signal gain.

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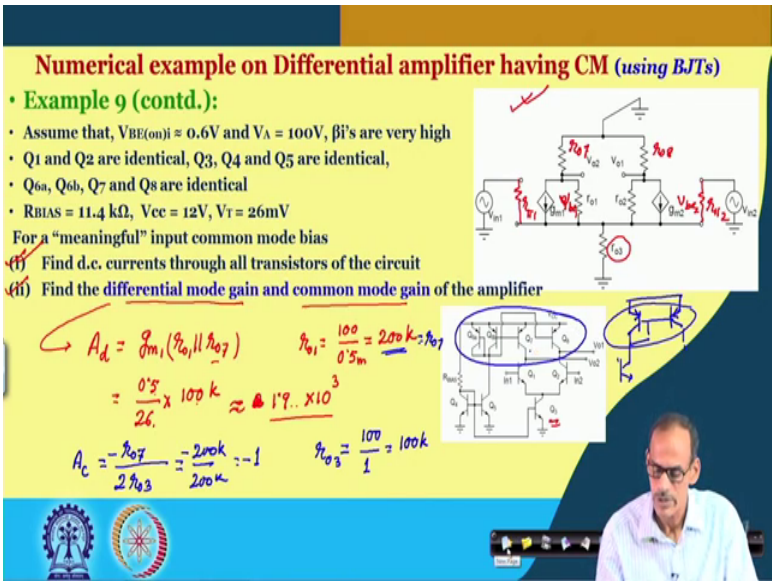

So, in the in the next slide as you have done before, once you know the operating point then we can calculate the small signal gain. So, the second so, this part we already have done. So, in the second part; we need to find the differential mode gain and common mode gain. Here we do have the small signal equivalent circuit where we do have yeah of course, we are not showing this r pi, r pi 1 and r pi 2 and transistor 7 and 8, they are giving r o 7 and r o 8.

We do have r o 1 and r o 2 and a current flow here it is g m 1 into V BE 1 and V BE 2 here. And then transistor 3, it is having resistance of r o 3 and as we have discussed before for this circuit the volt differential mode gain ad equals to g m 1 into r o 1 in parallel with r o 7. And gm 1 it is I c so, that is 0.5 milli ampere divided by 26 milli volt multiplied by these 2 resistances. So, what is the value of this resistance r o 1? r o 1 equals to early voltage of 100 divided by current of 0.5 milli ampere. So, that is equal to 2 100 k. So, likewise r o 7. So, this 2 together it is giving 100 k. So, the gain here it is. So, this 2 both of them are in milli.

So, roughly we do have 2000. So, if it is 50 by 26 we are making close to 2 or 1.9 something, 1.9 something something 1000, 10to the power 3. So, that is the gain, differential mode gain. On the other hand the common mode gain it is the expression it is r o 7 divided by 2 times of r o 3 and r o 7, it is 200 k on the other hand r o 3.

So, r o 7, it is also like this. r o 3 it is 100 that is early voltage divided by 1 milli ampere of current. So, that is equal to 100 k and so, that gives us 200 by 200 k equals to 1 of course, with a minus sign. So, that is how we can get the common mode gain and differential mode gain of this circuit. We can also work out on differential amplifier having current mirrored using MOSFET, probably I do have that in the next slide.

But before that instead of using the load connected through a current mirror, we may have current mirror load within the circuit itself. Namely, m seven can be made diode connected and it is corresponding current it may be coming to the output. So, in the next example, what we have it is the circuit where transistor 7, it is diode connected and that current it is getting mirrored to transistor 8.

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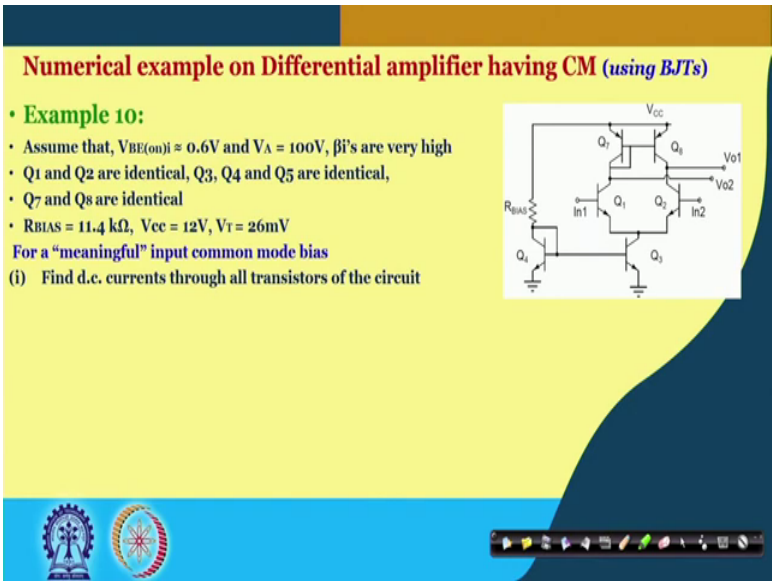

So, yeah so, here it is the circuit. Let me take a short break and then again will be resuming here.