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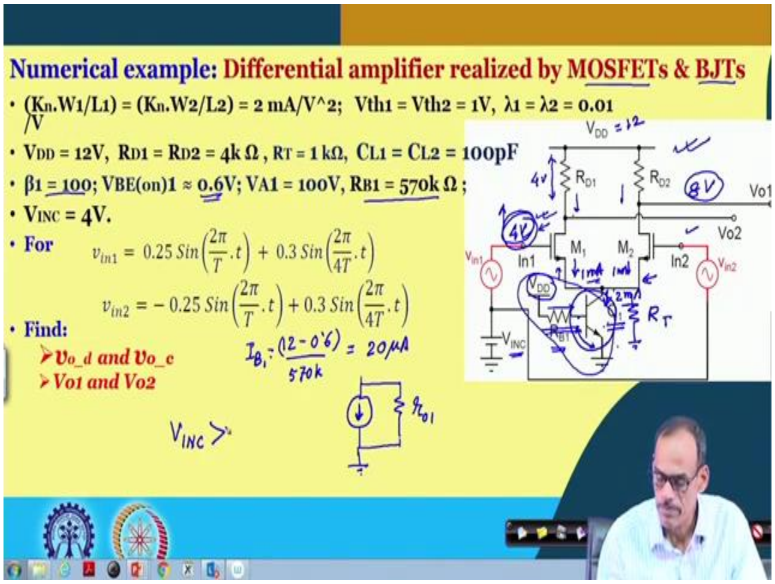

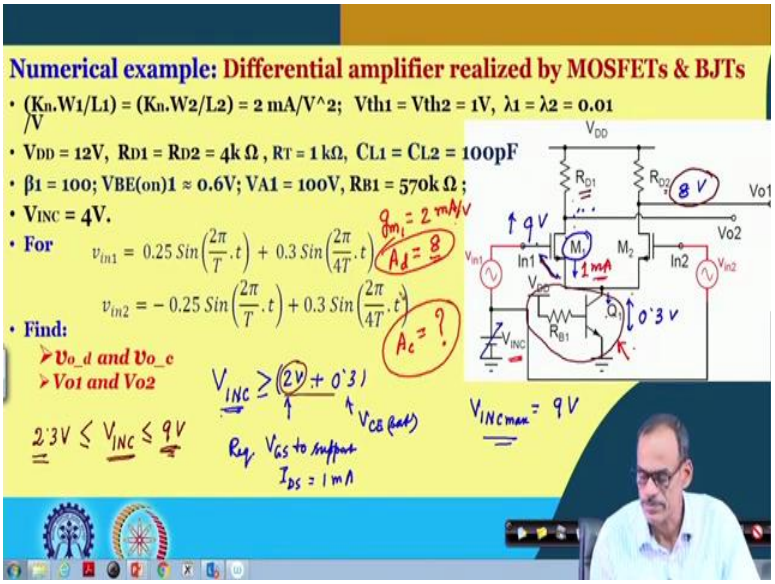

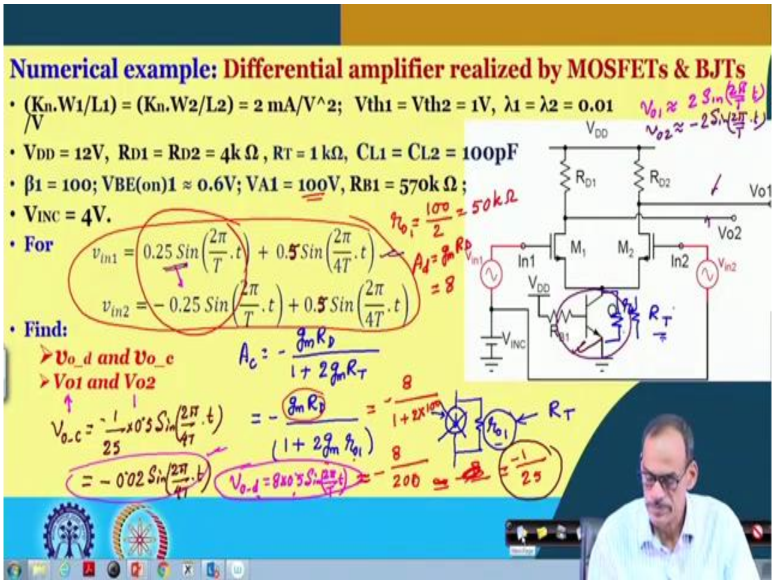

So we do have a differential amplifier and also I must say that in this circuit this is the first time we are trying to combine both MOSFET and BJTs together within one amplifier, and this is of course intentional just to give you a confidence that you can mix BJT as well as MOS in a, in your circuit. As long as you are following the fundamental basic guidelines, then you can mix it properly.

So, here as I said that this R_T, earlier we used to use R_T, that has been replaced by this device. In fact, if you see the device characteristic you may see that it is almost working as one ideal current source but it may be having some finite conductance. And this conductance sorry inverse of this conductance is basically r_{o1}. Now, what is this current? This DC current can be obtained by considering its base bias.

At the base we do have R_{B1} and that is connected to 12 V supply. And R_{B1} its value it is given it is 570 kΩ. And if I consider V_{BE} = 0.6 V then from that we can get, so $I_{B1} = \frac{V_{CC}-V_{BE(on)}}{R_B} = \frac{12\ V - 0.6\ V}{570\ k\Omega}$ = 20 μA and then we do have β = 100. So, the corresponding current here it is 2 mA.

Now since, the left branch and right branch they are identical and we do have equal DC voltage coming there V_{INC}, so we can say that in both the transistors I_{DS} = 1 mA. And again, this biasing condition it is such that we are retaining the output DC voltage, so we do have 4 V drop across R_{D1} and R_{D2} and then we do have DC voltage of 8 V. So, we do have 4 V here. And now this current, this current is in fact it is more dependent on the lower transistor rather than this voltage.

In fact it can be shown that even if say this voltage it is rising and hence this voltage it may be rising, but since this transistor it is in active region of operation, its current it is predominantly defined by its base current and the β. So, the tail current it is remaining same as 2 mA. So, I should say the DC operating point here it is not really much dependent on this voltage, unless we are making this voltage it is very small and forcing the source node very low, pushing this transistor Q_1 into saturation.

So, as long as that is, that is ensured, and then you can say that both this current and this current they are remaining 1 mA. And to get that we can say that V_{INC} if it is higher than, let me clear to the board, so, we can say that the if V_{INC} it is higher than the required 2 V here and V_{CE} is at 0.3 V, then we can say that the current here it will be 2 mA and current here it will be 1 mA.

So, as long as V_{INC} is higher than required 2 V to support 1 mA of current plus 0.3 V the $V_{CE(sat)}$. So this is $V_{CE(sat)}$ and this is the required V_{GS} to support I_{DS} = 1 mA. Now, if this V_{INC} as I said it is higher and higher it will not create any problem. In fact, if this voltage it is rising the voltage here it is still remaining at 8 V.

Of course, this is the lower limit of V_{INC}, so likewise if this is 8 V the upper limit of V_{INC} on the other hand it can be obtained by considering the limiting case when transistor-1 it is just entering into the triode region. So, when will it be in triode region? $V_{INC(max)}$ once it is reaching to a value where this transistor it is entering into triode region from saturation and that time this is 8 V and the corresponding voltage here it will be 1 V higher than 8 V, that means this is 9 V.

So, $V_{INC(max)}$ it is 9 V. So, in summary what we can say that V_{INC}, V_{INC} it is having a nice range, the upper limit it is 9 V and lower limit it is 2.3 V. Of course, this upper and lower limit they depends on how we are setting this current and what is the value of this resistance is and of course, to support this current what is the required V_{GS} basically this part. So now, in this circuit at least we do have better definition of input common mode range or better limit, strict limit of the input common mode voltage.

Now if we are keeping this V_{INC} within this range as I said that the current is not changing and so is the DC voltage it is not changing and also since the current flow here it is remaining 1 mA the corresponding g_m, g_m it is also remaining very close to 2 mA/V, and the corresponding gain it is remaining close to this 8. And in case if you are placing a resistor here of course, the corresponding current depends on the V_{INC} and hence, the corresponding g_m will also be changed and then of course, the corresponding differential mode gain.

So, that is the advantage of having this active tail resistor, the biggest advantage of having this tail resistor it is we yet to discuss is that the corresponding common mode gain. In fact, let us try to see what the corresponding common mode gain is. So, to calculate the common mode gain we know that the in the expression of common mode gain we do have $g_m \times R_D$ and in the denominator we do have $(1+2g_mR_T)$.

Now, while we do have this active device instead of passive element, what about the r_o we do have, that is playing the role of R_T. Because if I consider its small signal equivalent circuit out of this still current source, where this part is the DC and for DC of course, we have to remove this part and then we will be having this r_{o1} it is left behind in the small signal equivalent circuit.

So, r_{o1} it is essentially playing the role of R_T. So, it is now, it is now intuitive that common mode gained it becomes – g_mR_D, g_{m1} or g_{m2} both are same R_{D1} and R_{D2} they are also same. And in the denominator we do have $(1+2g_mr_{o1})$. And if you see its magnitude r_{o1}, so r_{o1} if I consider its early voltage of say 100 V and its current flow it is 2 mA, so that gives us its $r_{o1} = \frac{100\text{ V}}{2\text{ mA}} = 50\text{ k}\Omega$.

So, the value of this common mode gain it is equal to numerator part it is we already have calculated 8 and the denominator part we do have (1 + 2 × (2 m) × 50 k). So, that is equal to $-\frac{8}{201}$. So, we may approximate this by 200 so that is equal to, so that $\approx -\frac{8}{200} = -\frac{1}{25}$, which means that if we apply same signal, this differential and whatever the common mode signal you do have as we have discussed earlier.

Let me consider this is 0.5 and 0.5 and there what we have seen is that the common mode signal it was quite prominent, it may not be higher or equal to the differential part but at least it was quite prominent. But by replacing this passive element by this active device since, now we are getting common mode gain it is $\frac{1}{25}$, so that gives us the $v_{oc} = -\frac{1}{25} \times 0.5 \sin\left(\frac{2\pi}{4T} \cdot t\right)$ V$= -0.02 \sin\left(\frac{2\pi}{4T} \cdot t\right)$ V.

On the other hand the differential part since, the differential mode gain it is remaining 8. So $A_d = g_m R_D$ so, that remains 8. So this differential part on the other hand it remains same as what we have seen it is 4 V.

So, the differential part, v_{o_d} on the other hand it is $8 \times 0.5 \sin\left(\frac{2\pi}{T} \cdot t\right)$ V. So, then if I combine and say this differential signal and common mode signal, since the common mode signal it is very small compared to differential part then individual signal they will be very close to fully complementary to each other.

So, we can say that $v_{o1} \approx 2 \sin\left(\frac{2\pi}{4T} \cdot t\right)$ V. And $v_{o2} \approx -2 \sin\left(\frac{2\pi}{4T} \cdot t\right)$ V. So, to summarize, replacing this tail it is also helping to suppress this common mode part and still maintaining the differential signal quite prominent, particularly if you observe the output the, the signals there it is almost like complementary to each other.

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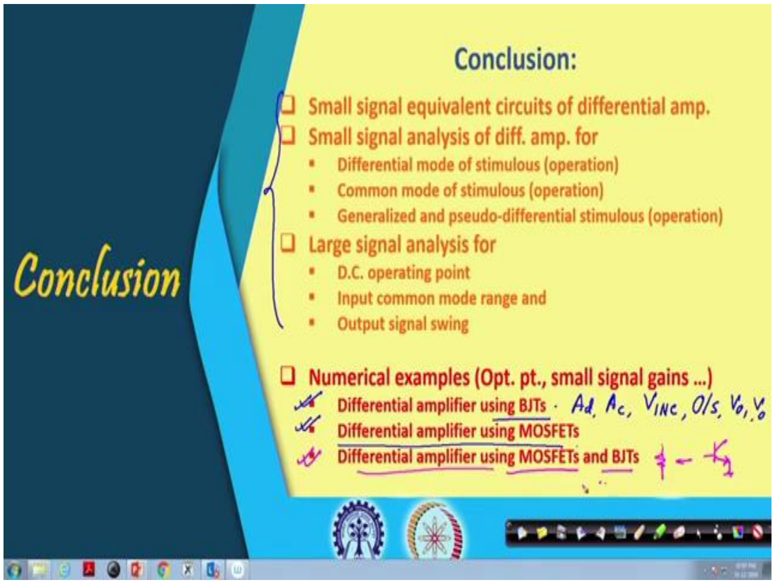

I think we do have covered whatever we have planned today. So as I say that the small signal equivalent circuit and analysis those things it has been done in our previous lectures and in today's lecture primarily we have focused on numerical examples, mainly with extensive calculation on differential amplifier using BJT, for calculation of the operating point then differential mode gain, common mode gain, then range of the V_{INC}, output showing and also we have seen that what are the different outputs are there and same thing we have done quite an extent for the differential amplifier having MOSFET.

And then we also have discussed about the differential amplifier having both MOS and BJT. Particularly what we have seen is that even though this differential amplifier its gain it is not so high, differential gain it was only 8 in our example, but by replacing the tail resistor R_T by active device 1 NPN transistor, that helps us to really suppress the unwanted common mode signal quite an extent, and ensuring that at the output we are getting almost complementary signal. I think that is all to share. Thank you for listening.