Analog Circuits
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Module - 06
Lecture – 15

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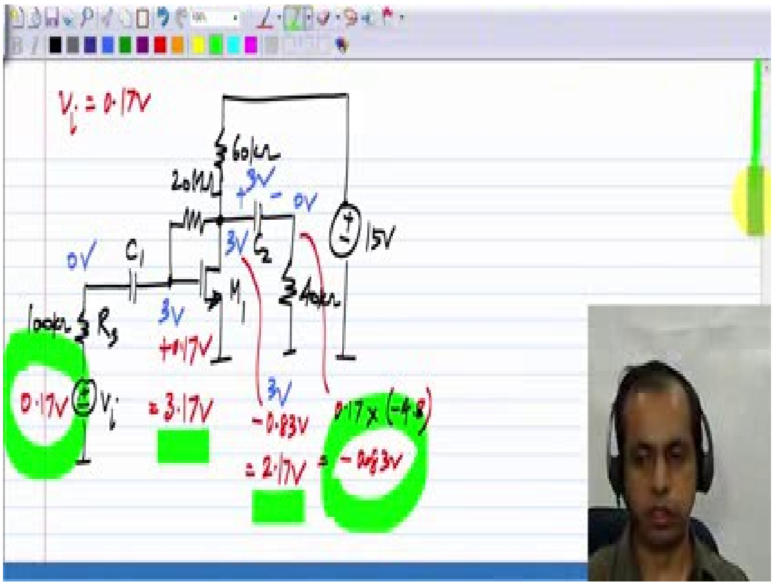

Now, let see what happens at the swing limits. First of all I will write down the quiescent quantities here or the operating point values. So, this is 3 volts and that is 3 volts and the operating point voltage here is zero, when v_i is zero , this is at zero volts and output is also at zero volts. This capacitor will be charged to three volts at the operating point. Now, when a signal v_i is applied obviously, this becomes 3 V + v_i and if you look at the point at which the transistor enters triode region that is when v_i = 0.17 V , this becomes 3 V + 0.17 V = 3.17 V. Now, the output is when v_i is 0.17 volts, the output here is 0.17 * - 4.8 V which is the gain which is - 0.83 volts. And here at the drain, the voltage will be 3 V - 0.83 V; the incremental voltage here and there will be the same, because C_2 acts as a short for signal frequency; in other words C_2 just holds 3 volts.

So, this voltage here would be 3 V- 0.83 V = 2.17 volts. Now you see what has happened, the gate voltage is increased 3.17 volts, the drain voltage as fallen to 2.17 exactly one V_T below the gate. So, clearly now this is at the edge of triode region; any further increase in the input voltage, this will go down further and it will enter the triode region, so this is the limit. At the input, when the input is + 0.17, it will reach the triode region, if you wanted in terms of the output when output is -0.83 volts it would have entered the triode region.

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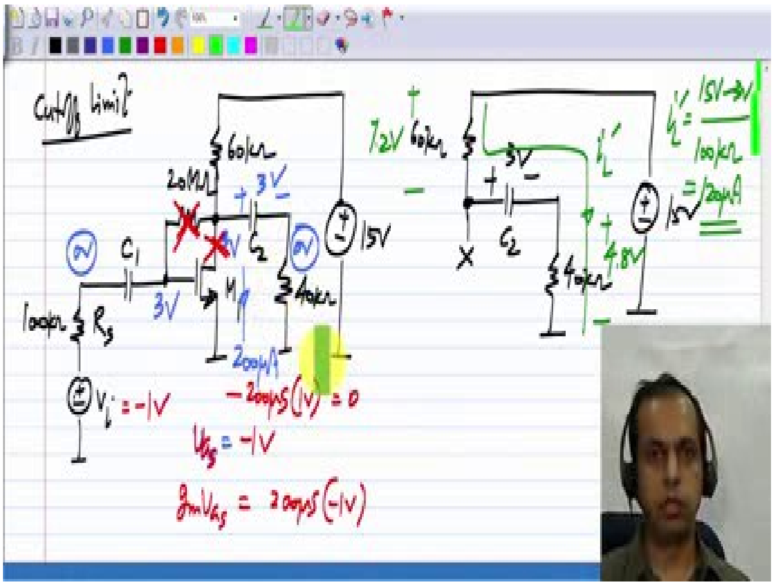

Now, let us look at the cut off limit. Let me again write down the values the quiescent voltage here is 3 volts, there is 3 volts across C_2 it is 3 volts. At the output, it is zero; and at the input also, it is zero, in the operating point or quiescent condition. We evaluated that the cut off limit occurs when v_i is -1 V. The quiescent current here is of course, 200μA. Now when the input is -1 V, the incremental v_{GS} is - 1 V . So, the incremental current would be $g_{m}*$ v_{GS}, which is 200 μS*- 1 V . So, the total drain current is 200 μA - (200 μS * 1 V) which of course, is 0 .

So, at cut off what happen is the transistor is cut off, its drain current is 0 and this is as good as an open circuit. And this resistor of course, we considered it an open circuit because it is so large, it is not exactly an open circuit, but we have chosen it is value to be so high that no current flows through it. So, the condition at cut off is that there is no current here and there is no current there. So, essentially we have just this circuit. So, here it is open circuited and we have C_2 and we have R_L, which is 40 KΩ, 60 KΩ, and 15 volts. And C_2 of course, it holds 3 V , its operating point value because the incremental voltage across C_2 is 0. When we say C_2 is a short circuit for signals , it means that its incremental voltage is zero and presence of the signal which is at some frequency omega. So, across C_2 you have constant 3 V .

So, actually you can evaluate the cut off limit also in this way. In this case, we have 3 volts across this and 15 volts applied across the total. So, the total current that is flowing this way, let me called that I_L'. So, I_L' would be 15 volts - 3 volts divided by the total resistance which is 100 KΩ which is essentially 120 μA.

$I_L' = (15\ V - 3\ V) / (100\ K\Omega) = 120\ \mu A$

Now, I_L' is 120 μA , you can easily calculate that you have 7.2 V across this and 4.8 V across the load.

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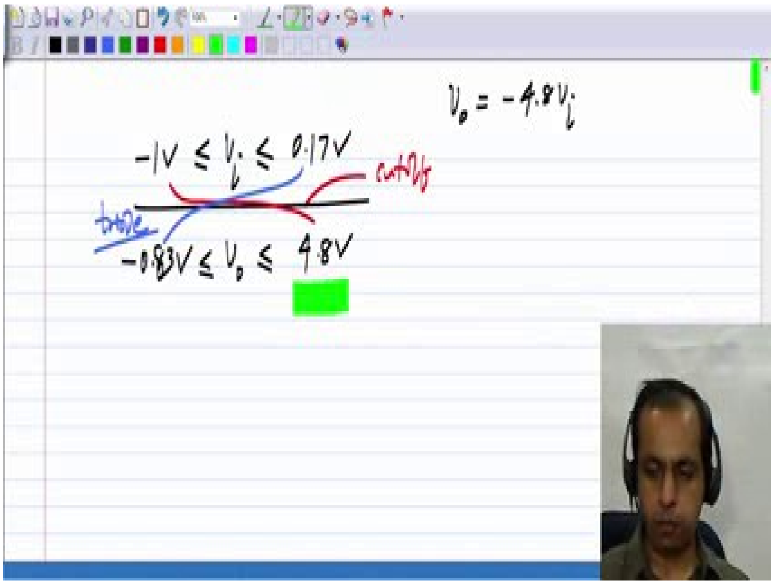

Now, let us go back to our limit in terms of the output what did we say was the limit V naught must be less than 4.8 volts.

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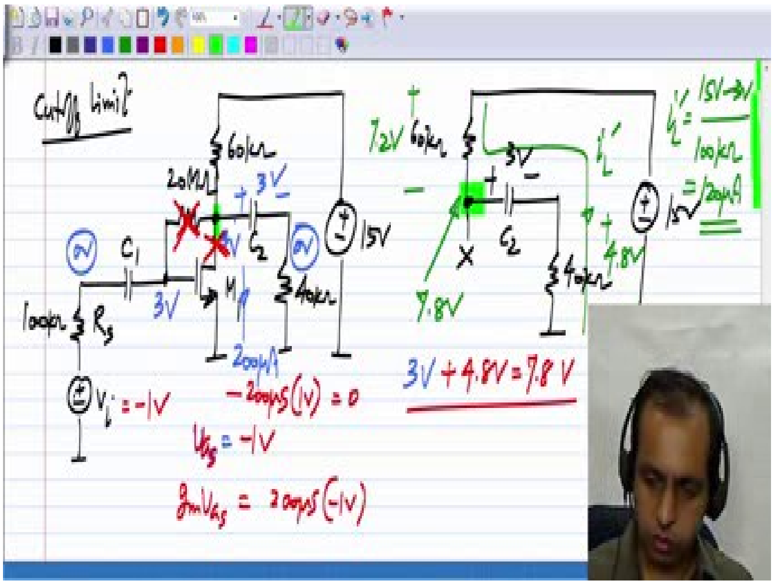

Of course, we should get exactly the same value, because it is the same condition we are evaluating. We just assume that the capacitor holds a constant voltage and this is an open circuit because the transistor cut off so obviously, you get the same limit. So, the output is 4.8 volts, when the transistor just cuts off. And also interesting is what this value is that value is 15 -7.2 which is 7.8 volts.

And another way to calculate the same thing is to add the quiescent drain voltage which is 3 V and the incremental drain voltage which is - g_m*(R_D ‖ R_L) * - 1 V; in another words, 3 volts + 4.8 volts which becomes 7.8. So, when the transistor just cuts off, this point reaches 7.8 volts.

Now, this is actually quite important to remember; occasionally students make the mistake of assuming that because the transistors cut off and there is no current here, there is no current in the 60 KΩ resistor as well. So, that means that this would have reached V V_{DD}, but that is not correct what happen is at this voltage raises and the current in this reduces and the current in this increases. So, when it is 3 volts that is 200 μA here and 200 μA there and no current going that way that is the quiescent condition. As this voltage goes above 3 volts, obviously, the voltage across the resistor reduces and current here reduces, and this voltage also increases, so the current here increases.

So, a part of this current also goes that way and the drain current reduces even further and cut off is the point where all off this current is flowing into that and that current is not zero unless this load resistance is an open circuit, it is infinitely large. So, if this 40 kilo ohm was not there, if it was an open circuit then when the transistor cuts off, this voltage reaches twelve volts, but because we have a load resistance this does not reach V_{DD}. This is an important thing to remember. This also shows you that all our calculations are consistent with each other. We add the increment to the operating point or we can imagine that at cut off there is no current here and current flows that way.

So, this is a summary of swing limit calculation for a different topology that is common source amplifier with drain feedback. The swing limits depend on the exact biasing circuit and quiescent values of V_{DS0} and V_{GS0} and so on. Now with this illustration, you should be able to calculate the swing limits for any circuit, the procedure is always exactly to the same. You find the total $V_{DS(total)}$ or $V_{GS(total)}$ or $V_{D(total)}$ and $V_{G(total)}$ whichever is more convenient for your comparison, and also $I_{D(total)}$. How do you obtain total quantities, you add the operating point quantities to incremental quantities; the incremental quantities are obtained from small signal incremental analysis, which is linear. And then once you have all of things you apply the limits $V_{DS(total)}$ must more than $V_{GS(total)}$ - V_T and $I_{D(total)}$ must be more than zero, and you get the two limits for the signal.

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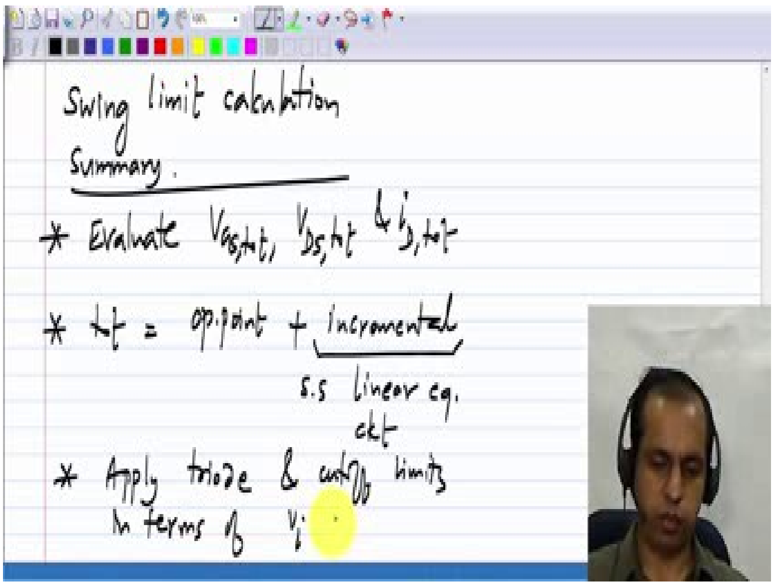

So, this is the summary, evaluate the total quantities, and the total quantities are the sum of the operating point quantities and incremental quantities, and this part come from small signal linear equivalent circuit. And then apply triode and cut off limits. And typically evaluate this in terms of either the input voltage or the output voltage whichever you wish to have. And also by doing circuit analysis, once you evaluate the limit, you should able to say what happen to any other voltage or current in the circuit add those limits, because that again comes from usual incremental analysis.

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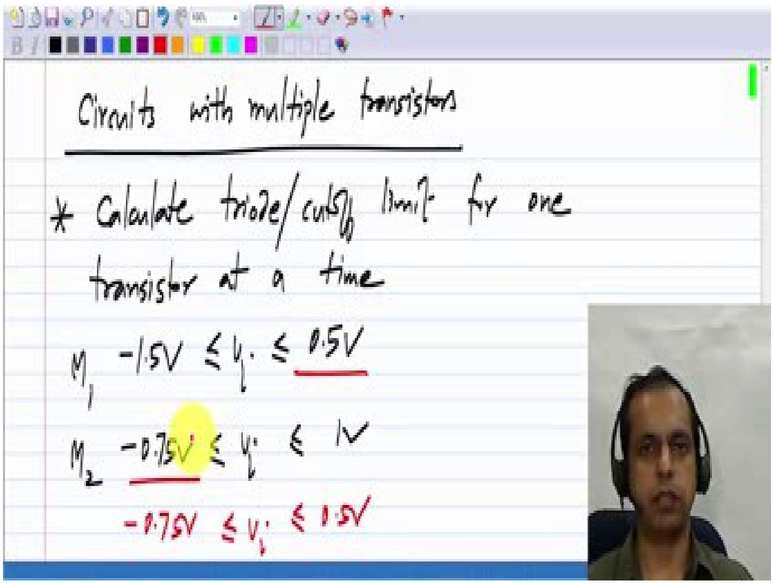

Now, later you will run into circuits with multiple transistors. Now what you do you again do exactly the same thing, but you calculate the triode or cut off limit for one transistor at a time. So now let us because of some transistor M_1 v_i happens to be within these limits. Let us say the upper limit is 1/2 V and lower limit is - 1.5 V, and because of M_2 the upper limit happens to be 1 V and lower limit happens to be - 0.17 V . So, you do it for every transistor, there could be 100 transistor you do it for every one of them, and then what you do you take the worst case that is lowest of upper limits and highest of lower limits and in this particular case; obviously, v_i should be limited to 0.5 V, because otherwise M_1 going to triode region or M_1 will go out of desired region and it has to be greater than - 0.7 volts, otherwise M_2 will go into undesired region. So, you take the worst case limits from all the limits imposed by transistors so that is how you calculate it for multiple transistors. Though we have not discussed many circuits of that type; even if you encounter a circuit with multiple transistors, you should be able to use exactly the same procedure.