Analog Circuits
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Module - 07
Lecture – 06

We saw how to realise the pMOS common source amplifier, and we analyzed all its characteristics of small and large signal. Now every circuit that we know that is all the different biasing techniques, and the control sources, we can derive from scratch for pMOS just like we did for nMOS. But of course, it would be less efficient what would be more efficient is to systematically convert every nMOS circuit that we know into pMOS circuits. And similarly if we drive circuit with pMOS, we should be able to immediately write down the nMOS circuit without doing a lot of extra work and it is turns out that it can be done very easily.

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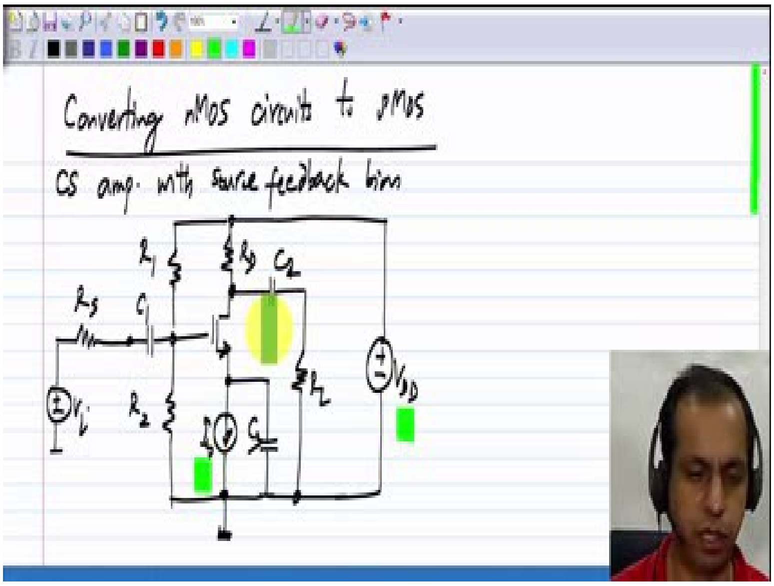

I will take the example of common source amplifier with source feedback biasing , but exactly the same principle applies to any other circuit. And by taking this example, we also will have illustration of another circuit using pMOS transistors. We have v_i , R_s and a coupling capacitor, a voltage divider to establish the gate voltage of the nMOS transistor, the current source at source terminal to provide bias, and a capacitor across it to short it for signal frequencies. This is the ground the lower rail is ground.

And at the drain, let me assume that we have a drain bias resistor R_D and a load resistance R_L , which is connected to ground; C_2, C_1, C_3, I_o, R_1, R_2 this is the circuit with nMOS transistors. Now as you well know the small signal picture of nMOS and pMOS are exactly the same the operating points have exactly the opposite polarity. So, how do I convert this to pMOS it is very, very easy. First of all identify the sources that establish the operating point and in this case that is I_o and V_{DD}. So, first let us see how to setup the pMOS transistor with the correct operating point.

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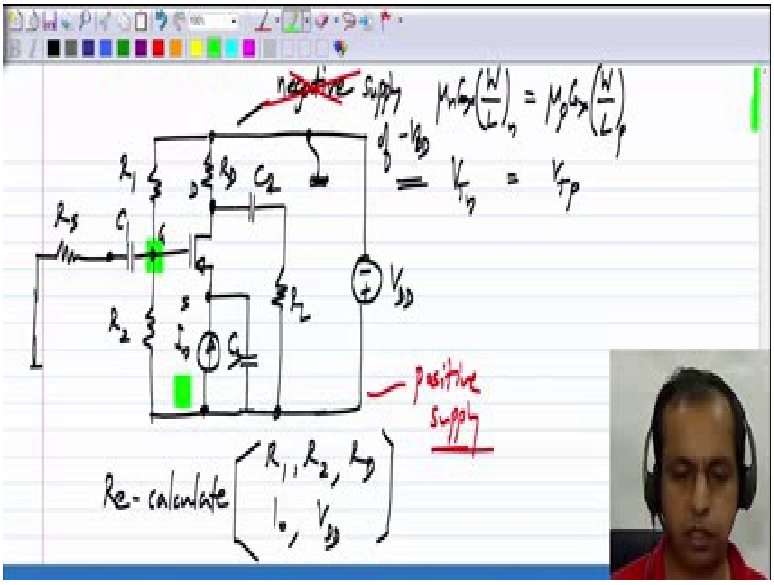

All I have to do is again because I am discussing the operating point I will set $v_i = 0$ or in other words this will be a short circuit. Now let me replace this with a pMOS transistor keeping the terminal correspondences, the nMOS transistor has it drain connected here, gate there and the source there. And I will do exactly the same for the pMOS. Now for pMOS the arrow is pointing inwards and this is what it looks like. Note that this is not how I conventionally do it; in my earlier examples, I do the source of the pMOS on top and drain at bottom, this is the opposite of. Because the polarities are opposite in the operating point picture, I replace this with $-V_{DD}$ or I can say that this is V_{DD}. And similarly, this current source becomes - I_o or it just points upwards. So, this is the operating point picture now that is all that is there to it.

It turns out that now in this case, the current from source to drain of the pMOS transistor will be I_o and because we reverse the sign of V_{DD}, the voltage between R_1 and R_2 . And in fact between any two nodes voltage in this circuit will be exactly the negative of what we had before, and that is exactly what we want for the pMOS transistor, because V_{GS} in a nMOS transistor is positive, V_{SG} in a pMOS transistor is positive , or V_{GS} is negative and so on. Similarly, the current flows from drain to source in an nMOS transistor, and from source to drain in a pMOS transistor. So, this takes care of the operating point. Now the operating point is the same that is if let say that $\mu_n c_{ox}$*(W/L) of the nMOS transistor is the same as $\mu_p c_{ox}$*(W/L) of the pMOS transistor and the threshold voltage of n and threshold voltage of a pMOS transistors are exactly the same. Then doing this will ensure that the operating point conditions are exactly the same for the pMOS and nMOS except for a reversal of polarity. Of course these conditions are not always true.

So, what happens is that this new circuit will be identical* if parameters for the same, because parameters are not the same, the conditions would have changed and that you can fix by changing the values of the components. Remember the circuit topology is perfectly all right; it is values of the components that you have to recompute. So, recalculate all the values, it could be all the registers R_1, R_2, R_D and so on which establish the operating point or it is also I_o and maybe even V_{DD}. These have to be recomputed, if the parameters are different, but the topology, the circuit diagram itself is perfectly same.

Now like I said earlier we prefer to operate with positive voltages that is if we have a reference node as ground then the supply voltage is positive that is we are like to operate with positive supply voltages. This particular circuit operates with the negative supply voltage, because this is still the reference node as I have drawn it, this is reference node. And this is a negative supply, as far as small signal picture nothing has changed because both this and this are small signal grounds, but this is now a circuit with a negative supply now this can lead to complications first of all general preference and also so far away looking at circuits which have a single transistor we could have circuit nMOS and pMOS transistors together.

Now we cannot be using positive supply for nMOS and negative supply for pMOS that is redundant. So, we would like to use positive supply for all transistors in the circuit and that is why we have to convert this to positive supply and that is very easily done instead of calling this the reference node I call this the reference node. So, if this becomes the reference node this is no longer the supplier this is the positive supply. So, that now take care of that aspect as well we have now a proper circuit with the pMOS transistor with a positive supply and finally, the way we draw circuits is normally with ground at the bottom and positive supply on top. So, all I have to do is to flip this picture upside down if I do that

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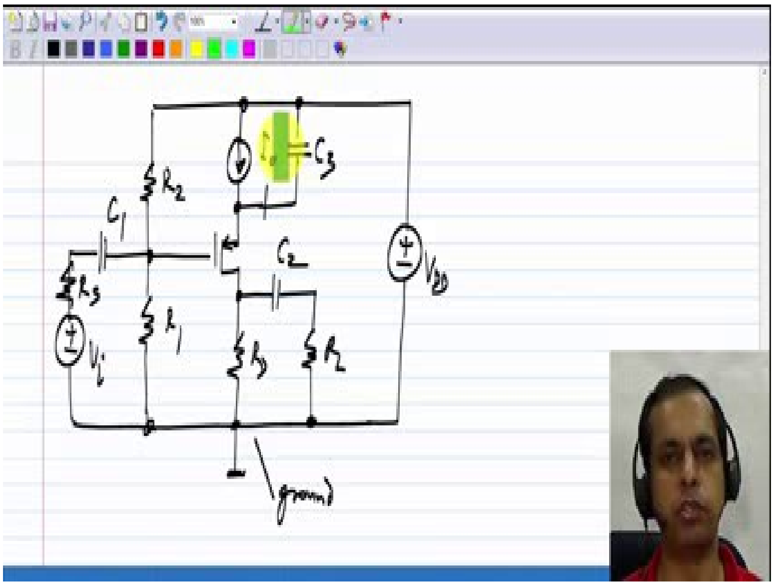

What will I get R_2 there, and R_1 there, remember this is the slip picture compared to what I had earlier that is I_o. We have R_D going to the bottom rail, upper rail is this and we have a capacitor C_3 which shorts out this I_o for signal frequency, and here we ac couple the load with C_2 and now this is our common reference point. So, this is the ground of the circuit, so I connect R_L to whatever the ground is.

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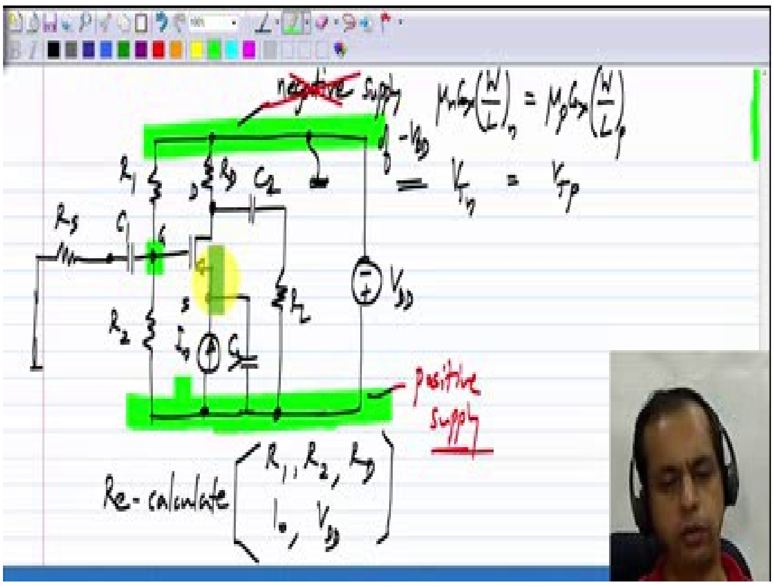

If you recall here, I have connected R_L to this node. Now I will connect it to that node because that is called the ground, and it does not matter for the signal picture because this point and that point are exactly the same in the signal picture both are small signal grounds. Like I have mentioned earlier this R_L is not a physical resistor, but representation of whatever comes afterwards and it is always refer to the common reference node or ground of the circuit, so it is there.

Then what about the input exactly the same, so we have C_1 here, and input is again referred to a common reference node of the circuit. And it will also have resistance R S. Again this v_i , R_s combination is not a physical , voltage source in series with resistance, but it is a representation of what comes before the circuit and it is referred to the common reference nodes or ground of the circuit. And it is very easy to see that as far as the signal picture is concerned absolutely nothing changes because this and that are both small signal grounds. So, whether this was connected there or here nothing changes. So, that is all that is there to it.

Now this circuit will look quite unfamiliar, because we have not discussed it earlier, but we should realise that this is a trivial modification of the nMOS circuit into pMOS. So with a clean algorithm like this, you can convert all the nMOS circuits that you know into pMOS or if you come up the new circuit with pMOS into nMOS. The bottom line is you should not have any additional confusion when you see pMOS circuits, you should be able to immediately see what is happening, because we use a positive supply these are always drawn upside down, the source are on top and so on, but that should not cause any confusion. As an exercise you can take every circuit that you encountered before with nMOS and convert them to pMOS.

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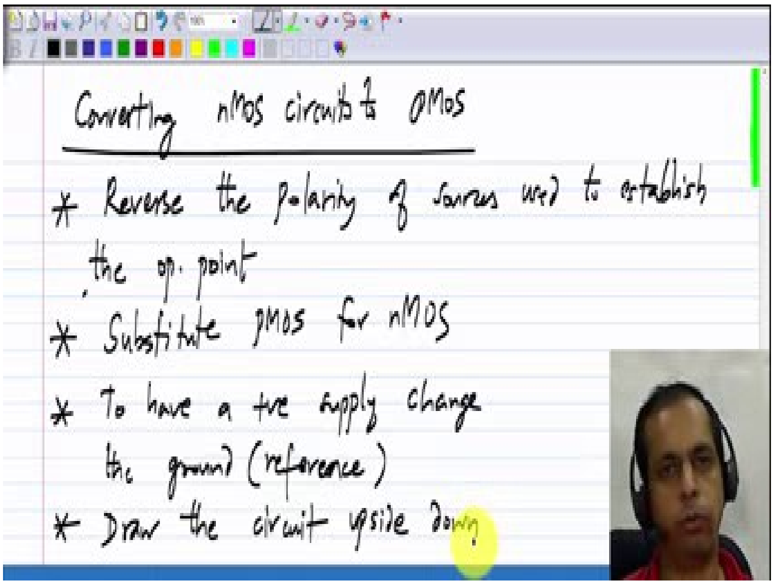

To convert nMOS circuits to pMOS obviously, the functionality will be exactly the same. reverse the polarity of sources used to establish the operating point and of course, substitute pMOS for nMOS and if you have more than one , you need to substitute all of them and also you could have a circuit that contains both nMOS and pMOS transistors you can come up with the opposite counterpart where pMOS is changed to nMOS and nMOS change to pMOS forms. So, now, again you can see something that I have emphasized earlier that the variety of circuits is enormous because you want to synthesis some functionality there is a variety of choices at every decision point like for instance you can change the type of biasing and so on. And we have additional degree of freedom you could use nMOS or pMOS. So, it is extremely important to understand the logic behind the circuit and not try to memorize individual circuits.

So, if you do that any circuit whatever kind of bias or whatever kind of transistors it is using , you should be able to see what the circuit does easily and this next part is to have a positive supply to change the ground that is the reference. And just to follow the convention you draw the circuit upside down on this is not likely necessary, you could live with other kind of drawing, but most of the time drawing are done like this with the ground at the bottom and positive supply rail at the top. So, it is best to do this.

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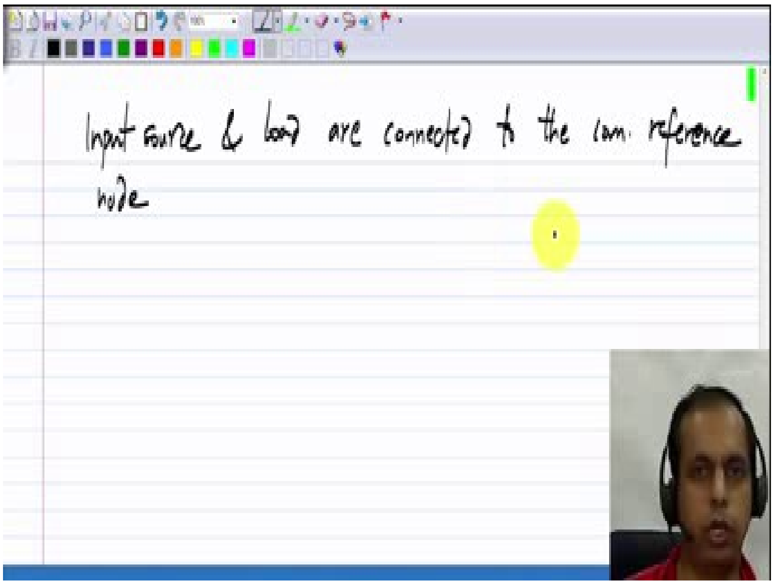

Then finally, usually the input source and the load are connected to the common reference node and this has to be changed.

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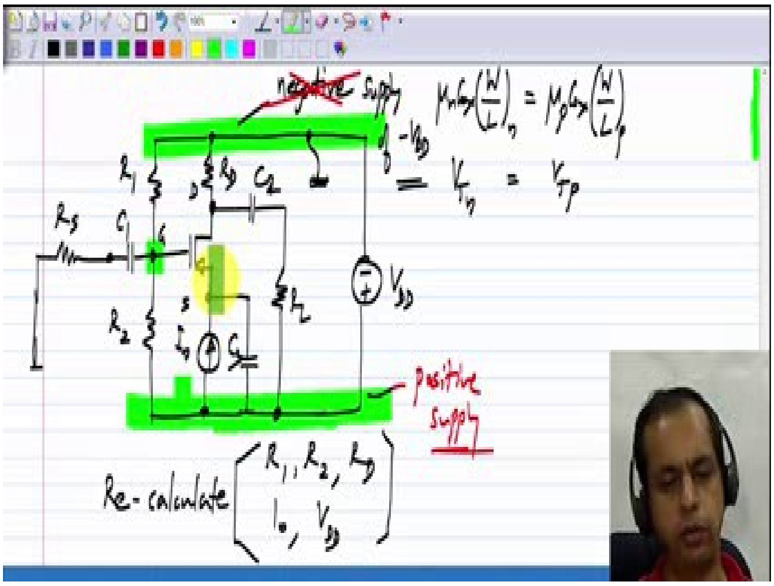

Because first when you come up with the circuit you see that is R_L is returning to the side which is to the side which has the source of the MOS transistor, but then when you change it to the common reference ground, later it is going towards the drain of the MOS transistor. But it makes absolutely no difference, because these are at same potential small signal wise, but because this is the common reference ground it is common to return to the both load and source to this ground.

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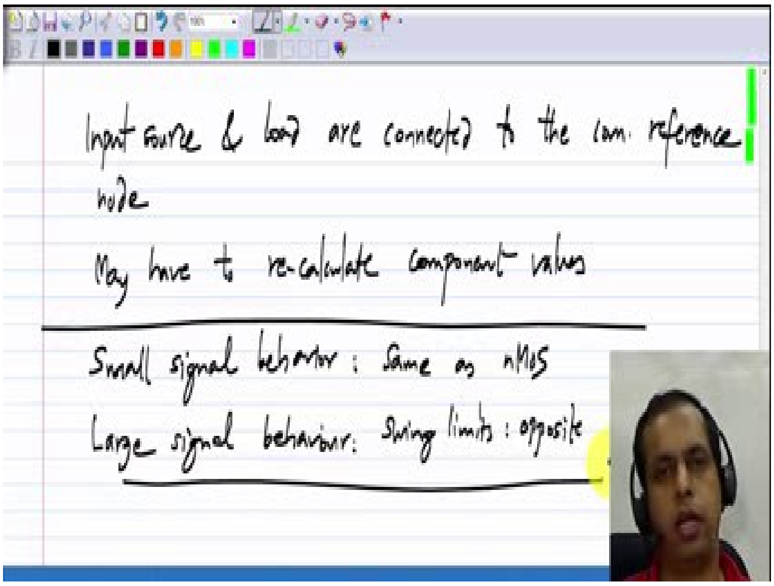

And finally, what is the result, you will have a legitimate circuit and operational circuit with pMOS transistors, but you may have to recalculate component values, because the nMOS and pMOS transistors will not have the same current factor and the threshold voltage. So, you have to recalculate the component values so that you get the same functionality that you had before. And the resulting circuit, will have the same small signal behaviour as the nMOS circuit. What will be different is that large signal behaviour will be different and how is it different the swing limits will be opposite that is if the upper swing limit was caused by saturation nMOS in the circuit it will be by cut off in the pMOS circuit and so on.

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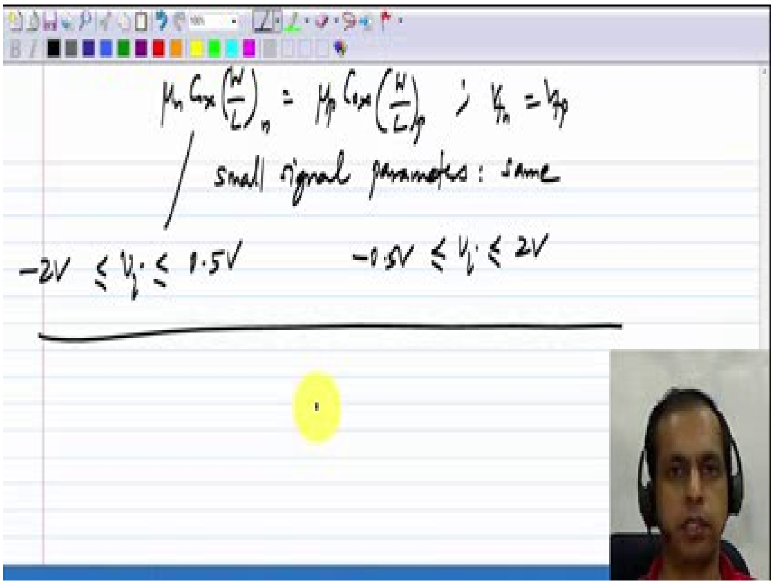

And just to further illustrate that let us say that you do have a case where the current factors are exactly the same for the pMOS and nMOS. And the threshold voltage are also exactly the same. So, when you take the nMOS circuit and convert it to pMOS, it will be working with exactly the same small signal gain. So, small signal gain, input resistance, output resistance will be exactly the same, because you do not have to change any component values at all. but the swing limits will be reversed if nMOS circuit had, let us say v_i which was limited to half a volt on the positive side and minus two volts on the negative side, the pMOS circuit would be limited to plus two volts on the positive side and minus half a volt on the negative side, because the swing limits will be reversed so that is the difference between nMOS and pMOS. And this also provides you additional flexibility sometimes it is more convenient to use pMOS, sometimes nMOS which we will see when you come to more sophisticated circuits.