Analog Electronic Circuits
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Lecture - 16
Robust Biasing with the Current-Mirror and Drain-Gate Resistor

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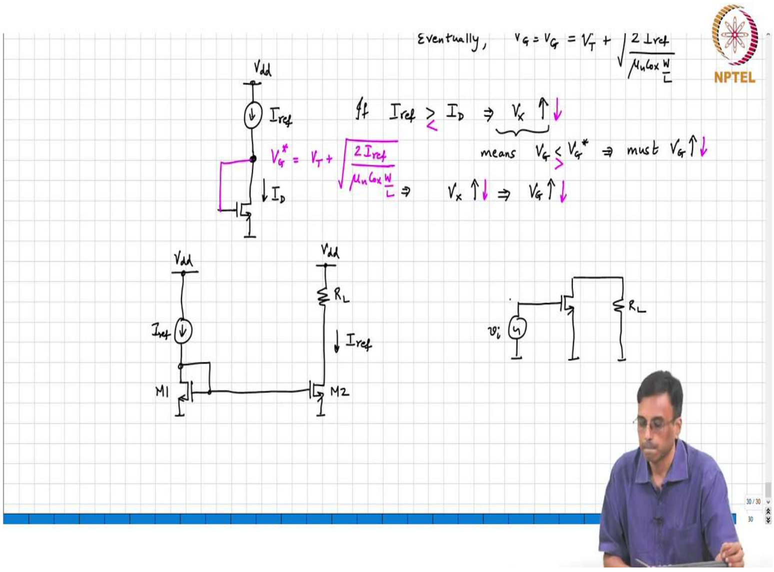

So, you might all be very familiar with this saying this is a diode connected transistor, but you can see that it is diode connected indeed, but the point is that there is negative feedback and action here alright where you are continuously comparing the drain current with?

Student: Reference current.

The reference current and adjusting?

Student: Gate.

The gate voltage appropriately so that the drain current is exactly equal to the reference current. Is that clear? So, this voltage therefore, is V_G^* which is,

$$V_G^* = V_T + \sqrt{\frac{2I_{ref}}{\mu_n C_{ox}\frac{W}{L}}}$$

So, now that we have found the V_G^* if we are on an integrated circuit, then you know so it turns out that if you make you know a 1000 devices on the same IC, it turns out that the threshold voltage of all the devices is?

Student: Same.

It is the same at least to first order, it may not be what you want but?

Student: It's the same.

It is all the same. So, then what can you do? You can use one transistor to find the magic voltage and apply the same?

Student: Magic voltage.

Magic voltage to another transistor. So, this is M1, so this is I_{ref}, this is v_{dd}, this is M2, alright. Since M1 and M2 are exactly identical it follows that the drain current is exactly identical and therefore, the drain potential of M2 is its v_{dd} -I_{ref} R_L and as usual that R_L and v_{dd} must be chosen and such that the transistor M2 operates in?

Student: Saturation.

Saturation. So, we have and this current in the transistor M2 will be maintained at I_{ref} irrespective of whether it is sunny or whether it's rainy and regardless of what the threshold voltage of the transistors. So, this is an example of robustly biasing the transistor M2. So, here it so turns out that M1 and M2 are exact clones, you know they are not even approximately the same like all of us, alright.

And so this is one way of, you know, robustly biasing the transistor we look at other ways, but at this point we have something, but that is not the end of it what we what do we need to do, I mean we have bias the transistor what are we trying to do?

We have to make an amplifier. So, now, we need to convert this into a common source amplifier and you are going to help me do it. Now what do I do? What should I do? So, for incremental signals therefore, let me remind you that for incremental signals we must as far as the amplifier is concerned, it must look like this, alright.

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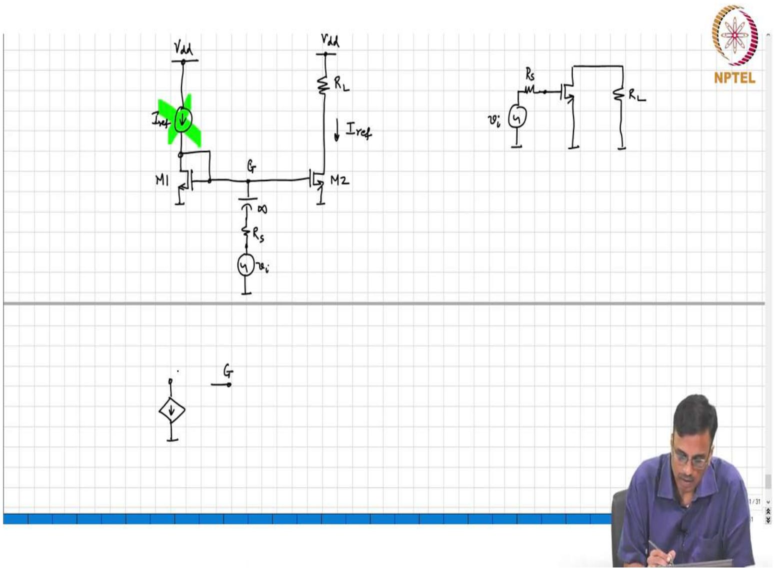

So, I mean perhaps the v_i has some source resistance R_s. So, basically now what we should do is figure out what all needs to be done to the circuit on the left, so that as far as the incremental equivalent is concerned it looks like the?

Student: Circuit.

Circuit on the right. So, this is like you know what you call that Sunday puzzle in the newspaper: find the 6 differences and make sure that you know for incremental signals both of the pictures look exactly the same, ok. So, first difference between the picture on the and the picture on the left. Well we need the source somewhere and the source must connect to the gate of?

Student: M2.

M2. So, let us put down the source here that is v_i that is R_s, alright. So, how do we connect it to M2?

Student: Putting an infinite capacitor.

Putting an infinite capacitor, very good, ok. So, certainly this connection is made alright. Then what else have we done? Let us figure out what we think we are doing. Let us try and see if we are done. How do we figure out if we are done, we actually find the incremental equivalent of the circuit we have on the left and actually make sure that it is the one.

So, what do we do? I mean well there is no magic here you replace you know all components by their incremental equivalent. So, let us go element by element current source open circuit, alright. What comment can we make about M1? By the way what region is M1 operating in?

Student: Saturation.

Saturation because the drain and the gate are with the same potential, ok. So, now, what should I do with M1?

To find the incremental equivalent what do I do? Nothing I just have to replace. So, this is let me call this I do not know let me call this gate voltage G. So, this is G then what should I do in the incremental equivalent?

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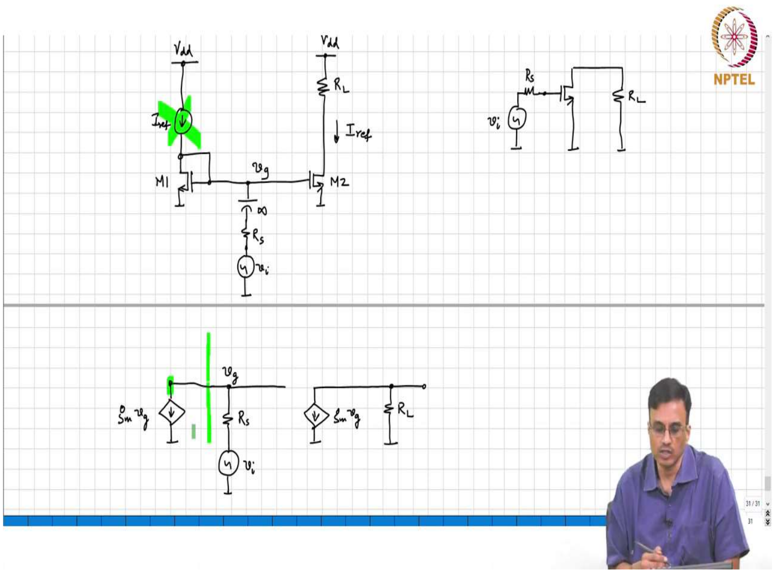

So, this is v_g. So, that is v_g. What should I do? So, this current is what?

Student: g_m times.

g_m times?

Student: v_g.

v_g very good, ok. So, what should I do now? Short circuit the?

Student: Gate and the drain.

The gate and the drain, very good, alright. Then what happens to the infinite capacitor? Short circuit. What happens R_s? Remains there very good. This is v_i, alright. What do we do with M2? Well, that is also g_m times v_g then?

Student: R_L.

R_L. What happens to the other end of R_L?

Student: Grounded.

Grounded, alright. So, now, if you look at the small signal equivalent that we wanted and what we have, what do you see is there any difference, what is the difference? So, by the way before you go there can somebody take a look at this and simplify matters? So, the voltage across this current source is v_g and the current being drawn is?

Student: gm times v_g.

gm times v_g. So, as far as that node is concerned to the left of that green line it looks indistinguishable from a?

Student: Resistance.

Resistance of value $1/g_m$, alright.

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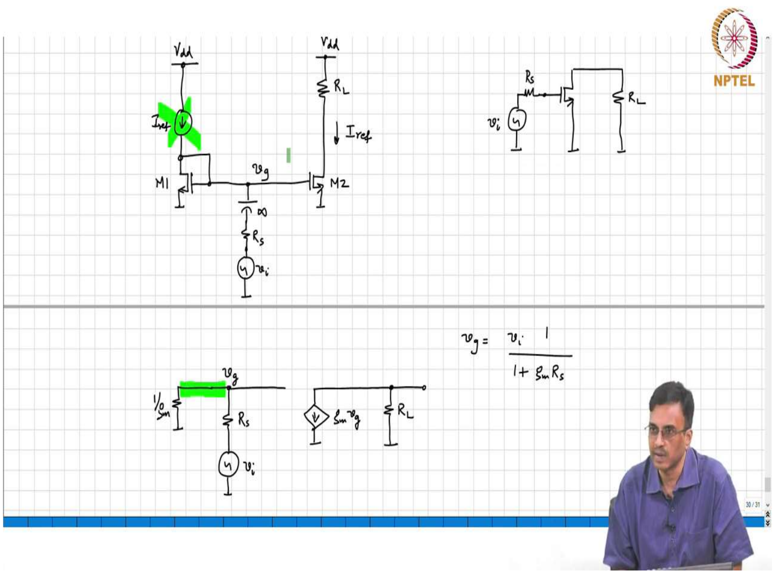

$1/g_m$, ok, alright. So, what is the v_g therefore? It is nothing but?

Students: $1/g_m$.

v_i it is. So, basically v_g is nothing but,

$$v_g = \frac{v_i.1}{1+g_m R_s}$$

So, is this g_m going to be a large number or a small number? We want a lot of gain. So, what comment can we make?

So, what does it mean what happens to v_g? I mean v_g will be a small fraction of v_i, but ideally what do we want there?

We want the whole of v_i not just a small fraction; there is no point in attenuating the signal first and then amplifying it later. So, clearly the problem is? I mean. So, do we have a problem or we do not have a problem?

Student: We have a problem.

We have a problem, ok. So, how do we solve the problem? There are multiple ways of doing it. I mean the bottom line is ok. What is the root cause is this connection. Right. So, what do we do?

So, one way of fixing the problem is basically that incremental current is flowing, you know, in that connection. So, for incremental signals we should break that connection, it makes sense ok. So, how do you break the connection? I mean do you want to break it for DC also?

No, why if you break it for DC what happens?

Student: Bias.

There is no bias. So, basically this voltage must be the same as the gate voltage of M1 must be the same as the gate voltage of M2, correct as far as?

The operating point is concerned; you must only remove that connection between M1s gate and v_g for incremental signals. So, one way of doing it therefore, is?

Student: Gate.

Yeah, what is a short for DC, but you know open for incremental signals an inductor an infinite inductor.

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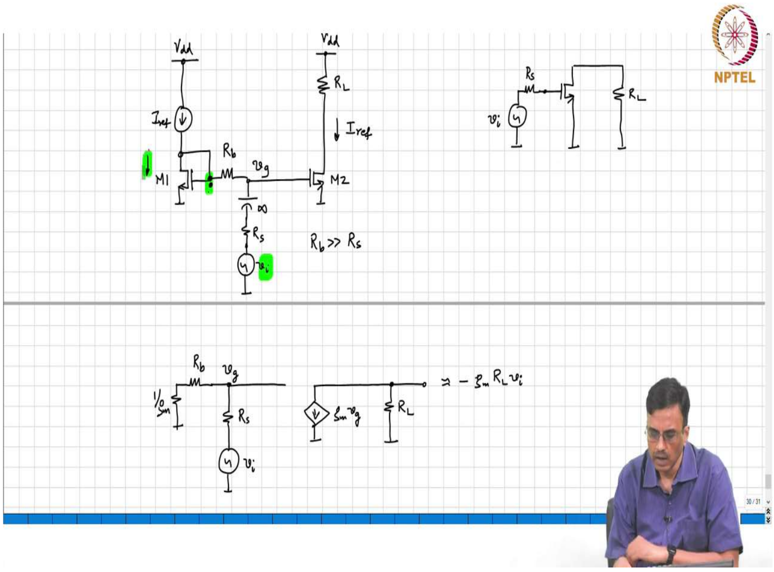

So, one way of doing this is to put an induct like that. Now, what comment can you make? I mean of course, we know that inductors are bulky and correct and so you know, is there something else that we can do?

Yeah. So, basically remember that the inductor is not carrying any current anyway in this particular circuit. So, instead of putting an inductor you can put a resistor R_b. What is the and what comment can you make about R_b compared to what?

Student: R_s.

So, one way of doing it is to basically put R_b much much greater than R_s in which case in incremental equivalent what happens?

Student: Large.

So, this becomes R_b and therefore, since R_b is much larger than R_s, v_g will be approximately equal to?

Student: v_i.

v_i and the output voltage will be approximately or very close to incrementally minus g_m - R_L v_i.

So, this is another example of a common source amplifier and when you compare it with the earlier version that we had you can see that it looks very different, but it is essentially doing the same thing, ok. Now, can somebody comment on signal swing? I mean you know the swing limits? What comment can we make which of the two transistors you think will influence the maximum input we can put in before bad things happen to the output? There are two, so as per our discussion in the last class we have to find the swing limits.

Find the swing limits for each transistor individually and find the minima and then find the minima of the minima. So, it basically is seeming like a very painful affair, but staring at the circuit, what comment can we make about the incremental swing here at that node? What is the incremental voltage at that node? Yeah, if R_b is very very large then the incremental voltage at the gate is?

Student: 0.

Is 0. So, what is the incremental current in M1 is 0 the incremental gate voltage at M1 is also 0. So, what comment can you make about its influence on the swing?

There is no influence at all. So, I mean looking at the circuit itself we should be able to say that I mean as far as swing limits are concerned M1 basically is completely irrelevant it's only M2 that makes the call, correct. I mean in other words whatever amplitude you put in there this voltage is not changing and therefore, this current is not changing. So, it does not matter what large that v_i is, M1 is always going to be in?

Student: Saturation.

Saturation and carrying a current I_{ref}, alright. So, it is only the M2 swing that you have to worry about and that you can do using the usual formulas that the approach that we discussed yesterday.

Just to illustrate that you know when you see a complicated circuit as we discussed yesterday I mean you know you do not have to while it is true that you know in principle you have to find the limits for all transistors and take the least of all of them most of the time you will be able to see directly that many of the transistors do not contribute to these limits at all and you know it makes no sense to sit and analyse the limits for those transistors. Is this clear? Alright.

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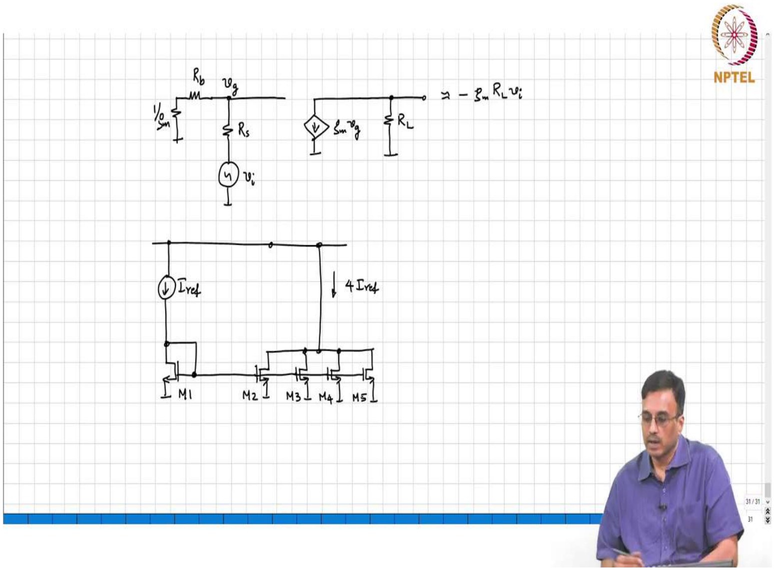

Now, this is basically you know this is this circuit you know as you all very well know is called the current mirror and if you want to make it and it is you know not only used to make copies of the same current. So, if you want for example, 4 I_{ref} what do you think you should do?

Well it is pretty straight forward. I will make 4 copies of the transistor and since all these transistors are identical, the current flowing in this leg is basically 4 I_{ref}, alright, ok. Now, you know sometimes when people are building discrete circuits alright where you do not have this luxury of having multiple identical transistors, let us say you only have one transistor, ok.

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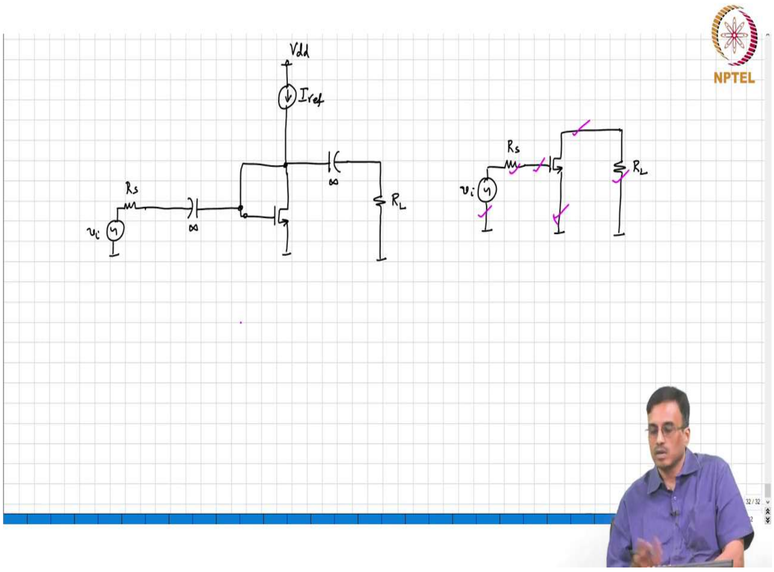

And you want to make a common source amplifier, but you know you want to bias it such that the current is equal to I_{ref} in a robust fashion. So, we basically say this is v_{dd} this is I_{ref} and we have already seen that feeding the drain voltage back to the gate stabilizes the current. So, that the drain current is equal to?

Students: I_{ref}.

I_{ref}, ok. Now, as far as the common source amplifier is concerned, we want an incremental equivalent which looks like this. So, now, the question is what can we do to the circuit on the left? So, that it basically behaves like the circuit on the for incremental signals, correct. Again it is pretty much you know find the six differences and then you know do the needful. So, what all do we have are the differences that you see from the on the what is there in the circuit on the that is not there on the left source, ok. Well that is easy v_i that is the source ok. So, what do I do? How do I hook it to the gate?

Student: Capacitor. Large capacitor.

Large capacitor is very good. We need the load resistors, so what do we do about the load?

Very good. So, I put a big capacitor and remember that we already know how to calculate these large capacitor values. Does it make sense to people? Alright. So, what else? So, clearly this is in place this is in place the transistor source is grounded the drain is connected to R_L

source is connected to the gate, alright. What else have we done? What is the difference? I mean if you draw the incremental equivalent of the circuit that we have will we get the circuit on the?

Student: No.

Now you know what the problem is? In the basic circuit basically I mean in the real circuit the gate and the drain are shorted whereas, they should be?

Students: Open.

Open in the.

Student: Incremental network.

Incremental network. So, you know what you think we could do? We can do multiple things. What do you think we could do?

Well one way of doing it is to basically say I am going to put an infinite inductor, alright.

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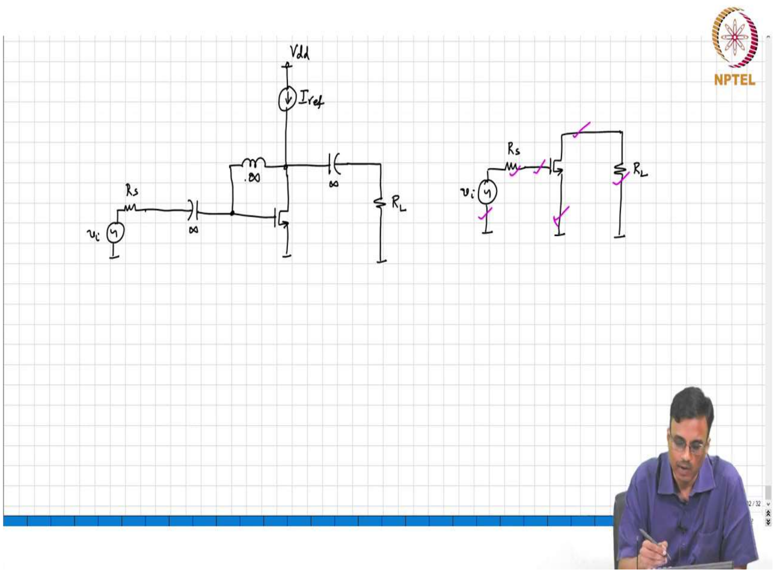

And that you know that basically is a short for quiescent signals and open for?

Student: Incremental.

Incremental signals that basically is something that will work, but it is not terribly practical because the size of the inductor has to be very large which makes it very bulky. So, what comment can we make? Well you put a high value of resistance, alright.

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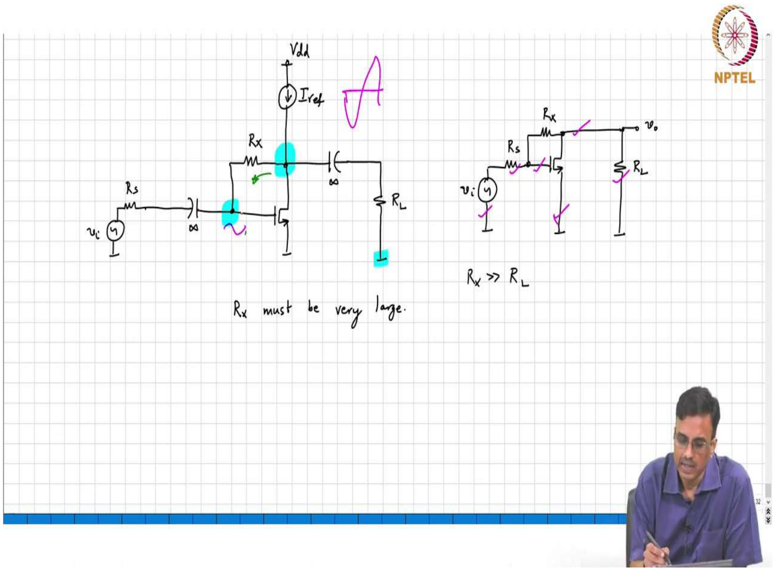

So, now, what is the meaning? So, R_X must be large. So, the question is large compared to? So, one way of doing it is to basically say that you know you have an incremental network. What is the incremental equivalent now? You have an R_X there correct and you find the relationship between v_o and?

Student: v_i.

v_i, correct. It will evidently depend on?

Student: R_X.

R_X. And as R_X tends to infinity the expression will tend to? If R_X becomes infinite what will the incremental gain of the network tend to?

Students: - g_m r.

Minus g_m r. So, of course, if R_X is not infinite then it will mean it will deviate from what you have to figure out?

You know what R_X must be large compared to in order that the gain does not deviate much from $-g_m$. So, one is you know you can do the math intuitively. What do you think of R_X when you say large R_X it must be large with respect to what intuitively?

Student: R_s.

R_s. Let me give you a hint, alright. What comment can you make about the signal swing here versus here at the drain if the amplifier is working properly, what comment can you make about the gate swing versus the drain swing?

Student: Drain must be swinging.

The drain must be swinging?

Student: Lots more.

A lot more, correct. So, if the drain is swinging a lot more in the and the gate is not swinging very much for all practical purposes what comment can you make about the current flowing through R_X? v_g is almost 0. Compared to v_g is only a small fraction of the drain potential, correct. So, what comment can we make about the current flowing through R_X?

Student: v_d/R_X.

Roughly v_d/R_X. What is the current flowing through R_L?

Student: v_d/R_X?

v_d/R_L, correct. So, now, can you tell me what R_X when you say a large R_X?

You want all the drain incremental drain current to flow through?

Student: R_L.

R_L and the voltage across R_X and the voltage across R_L is roughly the same. If you have a large gain then the gate voltage is very small compared to the drain voltage. So, the voltage across R_X which is the difference between this node and this node is almost the same as the difference voltage across R_L which is the difference between the output the drain and the ground, correct. So, the current flowing through R_X. So, if R_X and R_L are comparable then the current flowing through both of them will be comparable. Does that basically mean that the current that the drain the transistor is pumping out is basically only a part of it flowing through?

Student: R_X.

So, R_X must be very large, so what therefore? What does it mean therefore? R_X must be this. Notion of large must be is basically much much larger than R, this way no current is lost in. Does that make sense folks? Alright. So, I mean this is therefore, yet another common source amplifier alright which again as you can see looks very different from the other two amplifiers that we have seen, but as far as the incremental circuit is concerned it is exactly the same.