

Course name- Analog VLSI Design (108104193)
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Welcome back. Okay, so up until now, we have been discussing common source amplifier and various aspects of it. So, you must have noticed that we have been using some something, we have been using a series combination of two sources in order to add the incremental output incremental input to the bias right, but why what do I mean by that? So, we wanted to bias the transistor to bias the transistor we needed a battery of value V_{gs} cube and also we wanted to we wanted to apply the incremental small signal equivalent and for that we needed to add another signal so that it adds to the voltage of the battery and how can you add? You add two voltage sources in series the voltage adds up and that is what we did we did we essentially said that this is what our structure is if this is V_i the V_{gs} cube is voltage will be V_{gs} cube plus V_i okay. Now, while this works perfectly there are some practical issues with it and what are those practical issues? One of the very most important practical issues is that you cannot not often you can have access to two terminals of a battery right. What I mean by that is let us say you have when you when you want to use typically when you want when you are making an IC when you are making a chip right you have one master power supply and you have to derive all voltages all subsequent voltages that are needed from that power supply and typically that power supply is the highest power supply that is available anywhere right. So, now let us say you have this VDD or response to that power supply right whatever I mean 30 volt or 20 volt or whatever power supply that you have or maybe 5 volt this VDD is a maximum power supply, but that is the only battery that you are allowed to have right.

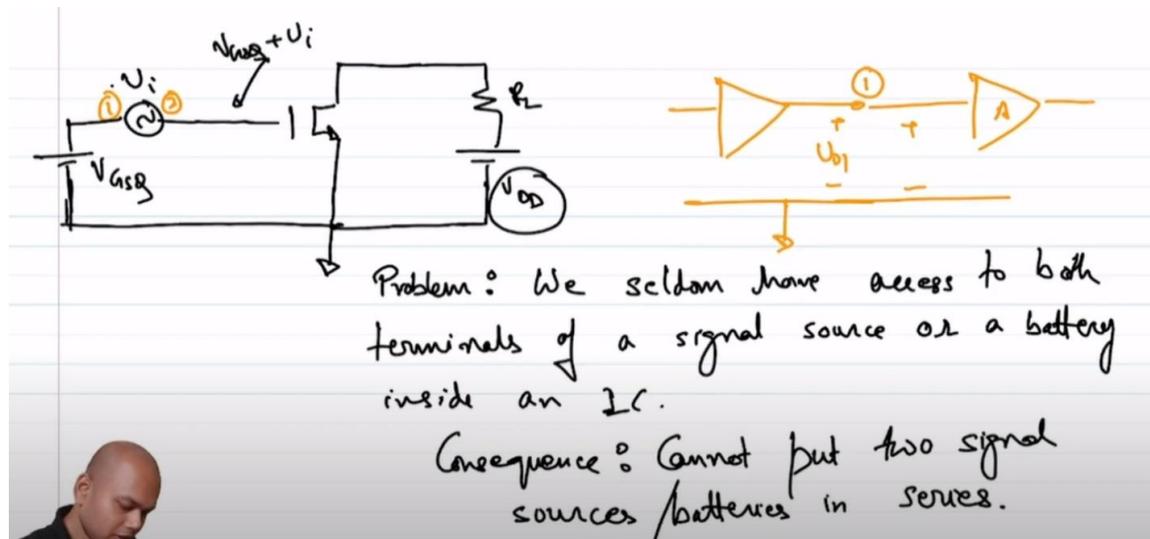
So, where from will you get where from will you get this battery V_{gs} cube whose where you need access to where you need access to both the terminals. One might say that I do not want to I do not want to use this I can as well say that instead of doing this I will do this I will use a smaller battery and a voltage source in series and this value of V_{gs} cube I have derived from VDD right. Fair enough argument to make right. I have a VDD or I have a battery VDD right I put a register divider or something and I reduce the value to the required V_{gs} cube value and that acts as the battery and then I apply my input as I have shown here the output of that the terminal at the gate of the MOSFET will be V_{gs} cube plus V_i right.

If you can do that this will work, but there is another issue. The issue is how would you get this V_i very often this V_i you do not have access to both terminals of the signal source.

One very common example is when let us say one stage is driving another stage right. So let us say there is one stage one amplifier stage whose output is this and this output is reference to say V_{O1} is reference to some ground ok and this is supposed to drive another amplifier stage which is also reference to this common ground right. What I what I am trying to point out here is that in the picture on the left you are assuming that you have access to both the terminals 1 and 2 of the signal source, but in reality you probably have only access to terminal 1 because the other terminal is implicit ground right.

So the problem essentially is that we seldom have access to both nodes of the battery or even the signal source right. So the problem is we seldom have access to both terminals of a signal source or a battery inside an IC right which essentially means that even though you can put two batteries in series in principle you can buy one battery from the market you can get another battery from the market and put them in series, but you cannot do that in practice when you are building an IC right. So implication is consequences cannot put two signal sources or batteries in series. Note that this is a constraint in an integrated circuit environment right. If you if you are getting batteries separately right this did not always be a constraint.

However, if you are in the lab and you are using a signal source you can see if you have been in any analog circuit lab you will see that signal sources are these big boxes right out of which two wires come out one reference where is almost always rounded right. So in even without even in an environment where you do not have to deal with the idiosyncrasies of an integrated circuit it can become difficult to put a signal source and a battery in series right.

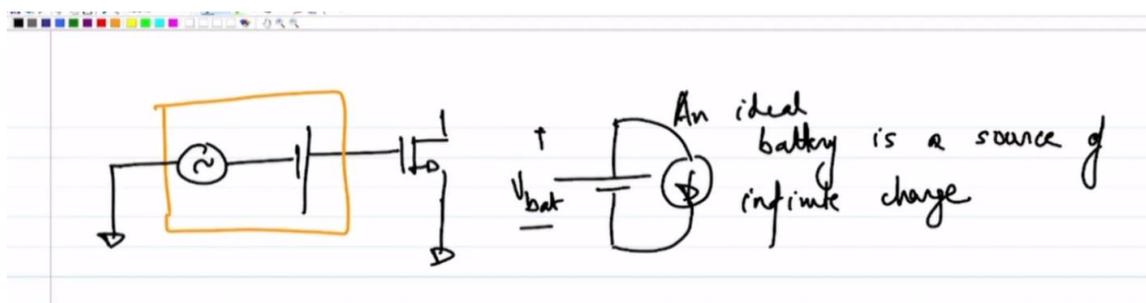


So, the crux of the problem is that we cannot do this. If we cannot do this what else can we do so that will be the that will be the point of discussion in the rest of this lecture okay. So

what is the issue? The issue is I mean to rephrase the issue we want a scenario where we want to have a signal source and a battery combination like this where this has to be the MOSFET right.

And this I can assume to be ground because I mean the signal sources is is being driven by somebody where there is an implicit ground right. So we want this combination right we want to get this combination, but the problem is that we cannot stack two signal source one signal source and a battery like like this right. Now in order to in order to resolve this problem we will have to go back to the fundamental definition of a battery. So what is a battery? In principle what is a battery? A battery right so a battery is a source or let me say an ideal battery. Ideal battery is a source of infinite charge right.

Why do I so say so? Because I say that because if I draw if I put a current source in parallel with it and I keep on drawing what is the current source doing? The current source is drawing charges out of the battery right. So even if I keep on drawing charges out of the battery for infinite amount of time the battery will still hold a value of whatever it was supposed to hold which essentially means that the voltage across the element hasn't really changed even though you have been able you were drawing you have drawing charges out of it for indefinite amount of time right. So in other words I can say that it's a ocean of charges right it's a battery is a ocean of charges even if you take few buckets of water out of the ocean the level of the ocean doesn't really change. Similarly even if you take few coulombs of charge out of the battery the voltage of the battery doesn't really change right. So now I mean what is the equivalent analogy? What do you think among the elements that we know right among the RLC elements that we know which element corresponds closely to the behavior of a battery? You guessed it right it's a capacitor right.



A capacitor and an infinitely large capacitor is indistinguishable from an ideal battery right. Why do I say so? Let's say this is an infinite large capacitor let's say I call it C infinity and I have a voltage let's say V_{bat} across it. So what is the charge? The charge will be Q will be C infinity times V_{bat} right and if I draw some charge out of it right if I draw some charge out of it right so let's say I draw ΔQ charge out of it correct. So what is the net

charge? What is the net charge after I drew ΔQ charge out of it? The net charge will be Q minus ΔQ right. So after I drew ΔQ charge out of this battery what will be the voltage across the battery? The voltage across this is V_{new} will be the charge divided by C infinity correct.

So I get Q by C infinity minus ΔQ by C infinity. What is Q by C infinity? Q by C infinity was V_{bat} minus ΔQ by C infinity. What is ΔQ over C infinity under the assumption that C infinity is infinitely large? Yes. So limiting value of ΔQ by C infinity by C infinity tends to infinity is 0 this goes to 0 which means V_{new} is equal to V_{bat} right. So in other words an infinitely large capacitor is indistinguishable from a battery.

Now you might turn around and say from where will I get an infinitely large capacitor? I agree that's the problem we will address that some somewhere down the line but for the time being let us assume that it is a large enough capacitor right. It is a large enough capacitor which is able to which for value will be able to act like a battery right. What is large enough? We will define later but let us assume that we have taken one step forward in replacing in replacing a battery right.

$$Q = C_{\infty} V_{bat} \quad \begin{array}{l} \text{An infinitely large capacitor} \\ \text{is indistinguishable from} \\ \text{an ideal battery} \end{array}$$

$$V_{new} = \frac{Q - \Delta Q}{C_{\infty}} = \frac{Q}{C_{\infty}} - \frac{\Delta Q}{C_{\infty}} \quad \lim_{C_{\infty} \rightarrow \infty} \frac{\Delta Q}{C_{\infty}} = 0$$

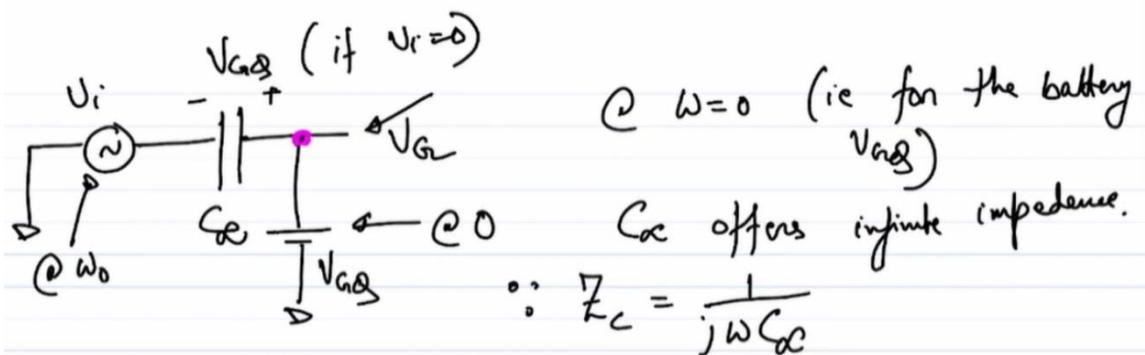
$$= V_{bat} - 0$$

$$\Rightarrow V_{new} = V_{bat}$$

So if we if we if we if we agree with this right if we agree with this what is the solution? The solution is I have a voltage source E I and I wanted to have a battery right I wanted to have a battery having V_{gq} but I cannot have a battery what is alternative? Alternative is replace the battery with the C infinity capacitor right but what is the charge across this capacitor? If we do not do anything the charge across the capacitor will be 0 right which means we'll have to somehow we'll have to somehow charge the capacitor to the value of V_{gq} right. So how do I charge a capacitor? One way to charge the capacitor is to say A so let me do this let me apply a battery here of value V_{gq} if I do this right what will be the charge what will be the charge across C infinity? Assume for this assume for the time being that V_i is equal to 0 right if V_i is equal to 0 what do you think will be the voltage across C infinity? The voltage across C infinity will be V_{gq} right right if V_i is equal to 0.

Now so this is V_{gq} if V_i is equal to 0 but does this solve the problem? Now let's assume V_i is not 0 now let's assume V_i is not 0 if V_i swings what happens to this gate voltage? The gate voltage as you can see doesn't change why because it is connected directly to the battery V_{gq} correct so this gate voltage is connected to a battery V_{gq} whatever happens to the rest of the world the voltage at the gate of your MOSFET will not change correct so that's a problem isn't it? So what's the solution? So to understand this let's try to figure out what is the root cause of the problem so let me redraw let me get rid of the MOSFET for the time being and let's concentrate what is happening ok. So the problem here is when the input is swinging right when the V_i is swinging when V_i is swinging this voltage is stuck at V_{gq} right and where is this where is where is this incremental current that will appear due to this V_i where will it go? The incremental current however large it might be will go into will go into this battery right and because the battery gives you no impedance right battery is essentially an ideal short right if you super position what will you do? Will essentially say that V_{gq} is an ideal short because it is an ideal short the current that is flowing out of V_i is not able to change this voltage V_g right. Since this voltage we are not able to affect this voltage V_g simply because V_{gq} is an ideal short this is causing this is causing the problem correct. So what is the solution? We cannot have we cannot have an ideal short but we also want but we also want the voltage V_g across across the capacitor right. So if we now divide this problem into two different sub problems right and we say that while we are while V_i is a sinusoid right this battery here is a DC right V_i is is with getting applied at frequency omega naught however the battery V_{gq} is at a frequency zero right okay.

So what is the what is the impedance offered by the capacitor? What is the impedance offered by the capacitor at frequency zero? So at omega equal to zero I_e for V_{gq} for the battery V_{gq} C infinity offers infinite impedance. Why? Because because the impedance offered by a capacitor is of the capacitor is 1 by 1 by omega times infinity if omega tends to 0 or omega is exactly equal to 0 then the I forgot to put the J then the mod of Z_c is essentially essentially infinity right. So what is the moral of the story then? The moral of the story is that the capacitor is giving you infinite impedance to V_{gq} right.



Now what impedance that C infinity offer to Vi? So since Zc is 1 over j omega C infinity so if omega is equal to 0 Zc is equal to infinity right. If omega is equal to omega naught what is Zc? Zc is equal to 1 by j omega C infinity and under the condition that C infinity tends to infinity what do I get? This offers zero impedance right.

$$\therefore Z_c = \frac{1}{j\omega C_\infty}$$

If $\omega = 0$ $Z_c = \infty$

If $\omega = \omega_0$ $\lim_{C_\infty \rightarrow \infty} Z_c = \lim_{C_\infty \rightarrow \infty} \frac{1}{j\omega C_\infty} = 0$

C_∞ acts as a short ckt for ω_0 .

So in other words C infinity offers acts as a short circuit for omega naught correct. Let me highlight this these are vital conclusions and it should not surprise us that C infinity is acting like a short circuit for omega naught because what was C infinity replacing? C infinity was replacing a battery right and a battery what is the incremental equivalent of a battery? The incremental equivalent of a battery is an ideal battery the short circuit right. It should not it should not be surprising that C infinity of acts as a short circuit at omega naught. However, a battery also gives zero impedance at DC however a capacitor does not so that is the key difference between a battery and the capacitor right. So which a capacitor is a frequency selective circuit frequency selective element which essentially means that at zero frequency it gives you infinite impedance.

So now can we leverage this can we leverage this and see if something can be done. Thank you.