6.301 Solid-State Circuits

Recitation 15: Op-Amp Non-Idealities
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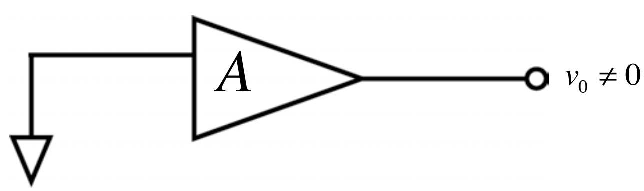
It will come as no surprise to you that op-amps are not perfect, and that these imperfections will impact circuit performance to a certain degree. The challenge for a designer who is using an op-amp is to figure out which performance metrics are most critical for his/her application.

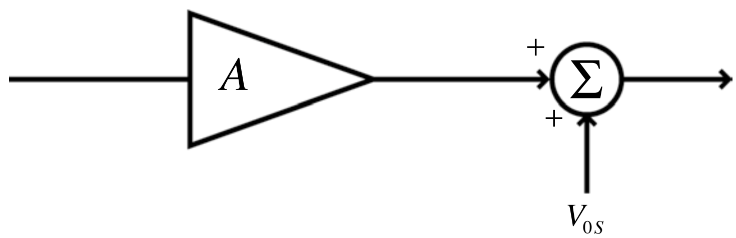
An almost complete list of non-idealities for op-amps is given below:

Input Offset Voltage	V_{0S}
Input Bias Current	I_{IB}
Input Offset Current	I_{0S}
Finite Gain	A_0
Common Mode Rejection Ratio	$CMRR$
Power Supply Rejection Ratio	$PSRR$
Finite Gain-Bandwidth Product	$\omega_\mu/2\pi$
Output Slew Rate	SR
Input Resistance	R_{IN}
Output Resistance	R_0

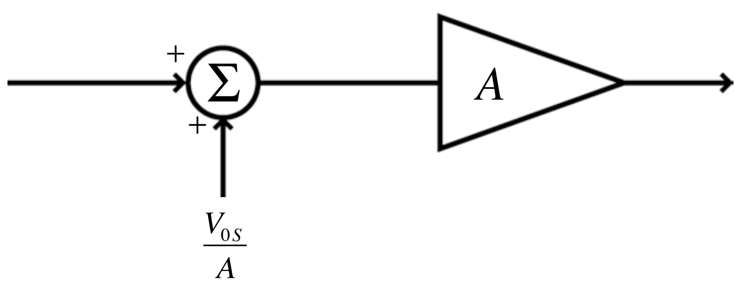
Let's start with offset voltage. An offset refers to the fact that when you ground the input of a DC amplifier you do not get a zero voltage at the output.



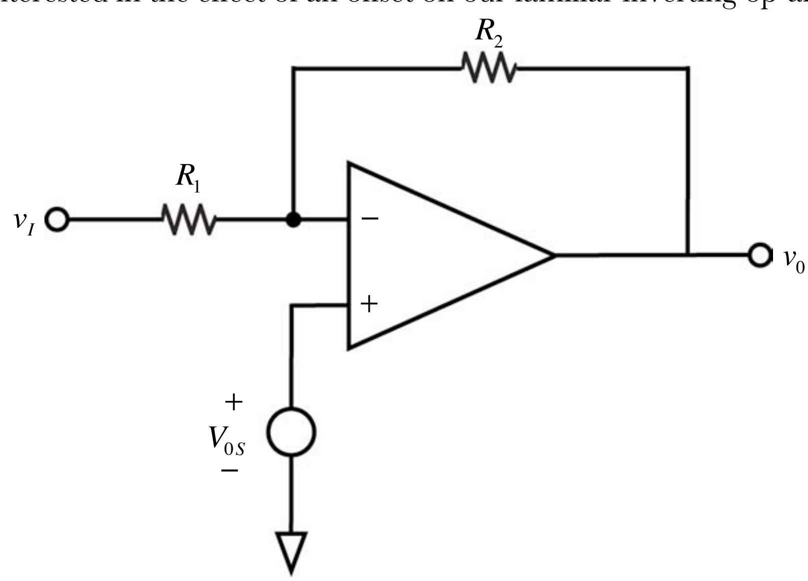
We model this in ways that you might expect. If, when we ground the input of this DC amp, we measure AV output voltage of V_{0S} , we can adjust our diagram according to:



In this case, we speak of V_{0S} as the "offset referred to the output." That is to differentiate it from the "offset referred to the input," as follows:



Many times, it will be more convenient analytically to choose one form over the other. For instance, suppose we were interested in the effect of an offset on our familiar inverting op-amp amplifier.



Using the approximation that $v_t \simeq v$, we have

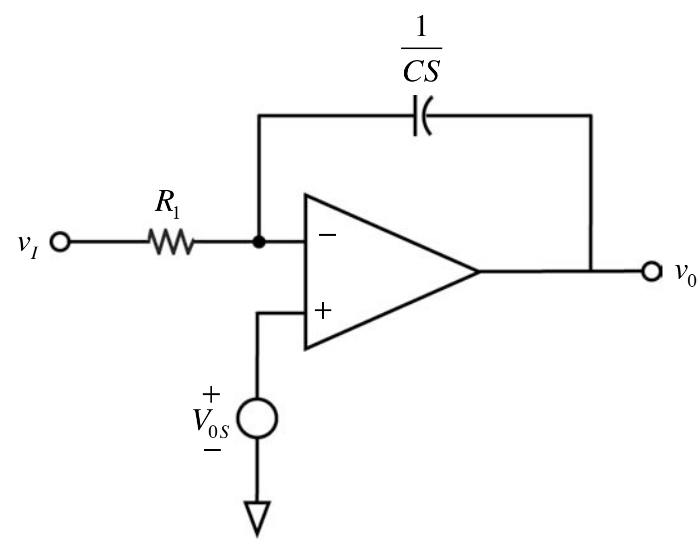
$$\frac{v_I - V_{0S}}{R_1} = \frac{V_{0S} - v_0}{R_2}$$

$$\frac{R_2}{R_1}\left(v_I - V_{0S}\right) - V_{0S} = -v_0$$

$$\boxed{v_0 = V_{0S}\left(1 + \frac{R_2}{R_1}\right) - v_I \frac{R_2}{R_1}}$$

So the more gain we ask for, the more offset we can expect at the output.

Note that this is a more serious impairment for op-amp integrators.

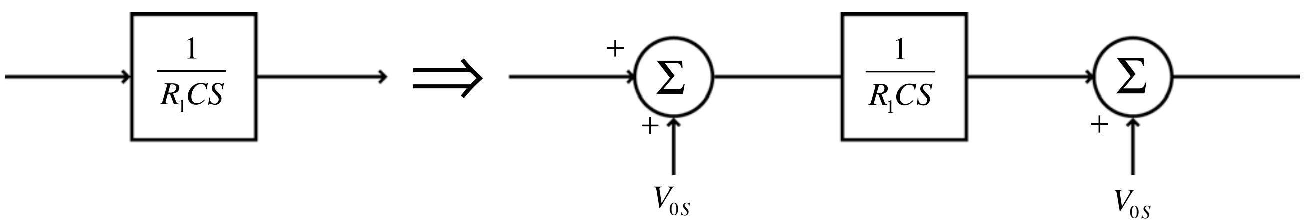


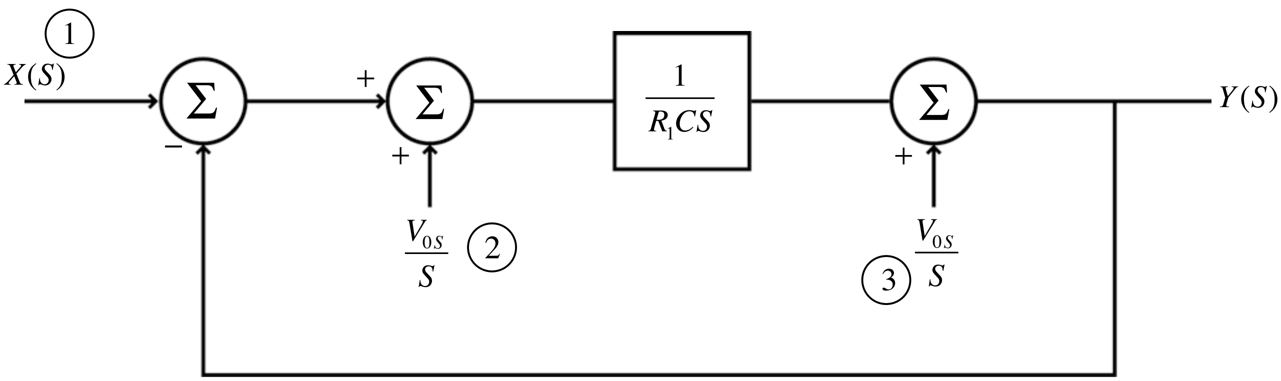
Substituting in the expression we just derived:

$$v_0 = V_{0S}\left(1 + \frac{1}{R_1 CS}\right) - v_I \frac{1}{R_1 CS}$$

$$v_0(t) = V_{0S} + \underline{\underline{\frac{1}{R_1 C}\int V_{0S}dt}} - \frac{1}{R_1 C}\int v_I(t)dt$$

This is one reason why you never see op-amp integrators used in a stand-alone, open-loop way: They just integrate their own offset until they hit a supply rail. In the context of a control loop, we'd be okay:





Apply superposition:

(1) $$Y(S) = \frac{1}{R_1CS+1} X(S)$$

(2) $$Y(S) = \frac{1}{R_1CS+1} \frac{V_{0S}}{S}$$ Treating the offset like a step.

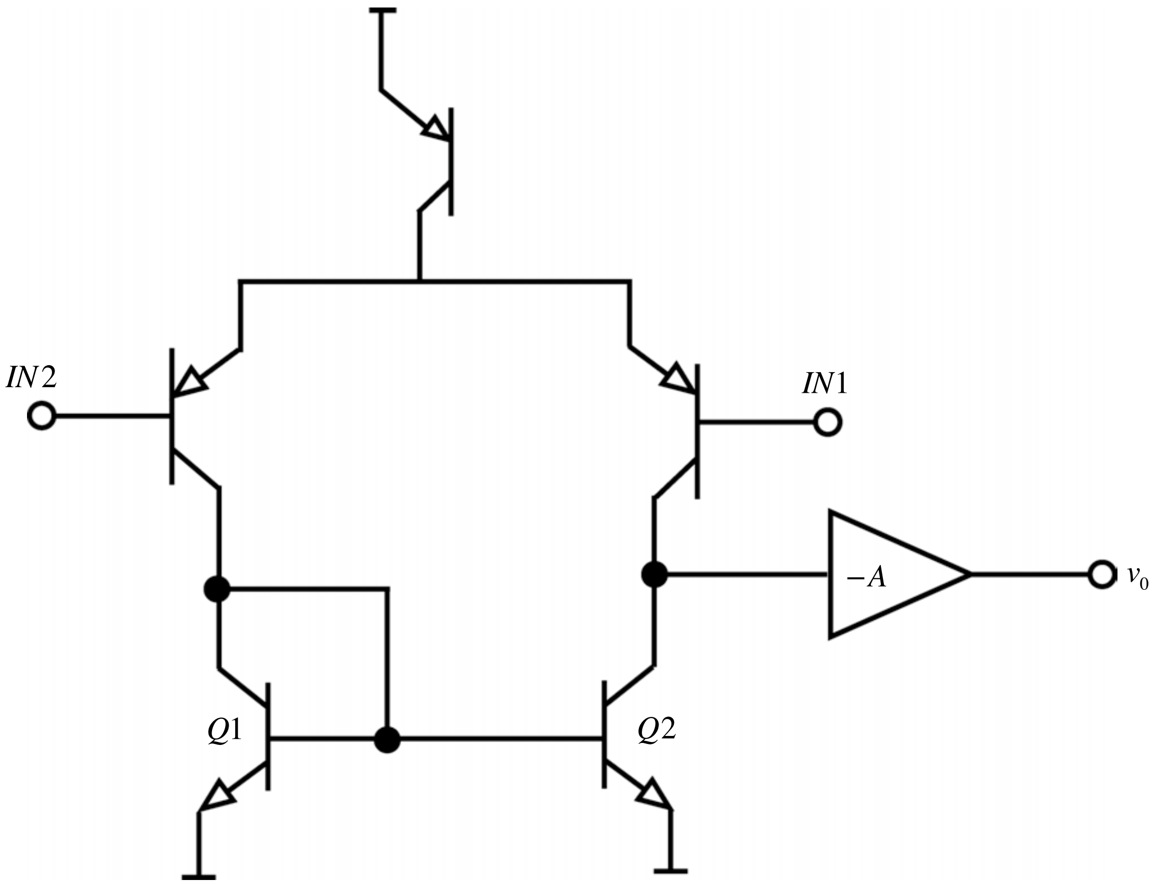
Final value theorem $y(t)\big|_{t=x} = V_{0S}$

(3) $$Y(S) = \frac{R_1CS}{R_1CS+1} \frac{V_{0S}}{S}$$

Final value theorem $y(t)\big|_{t=\infty} = 0$

CLASS EXERCISE: Where does this offset come from?

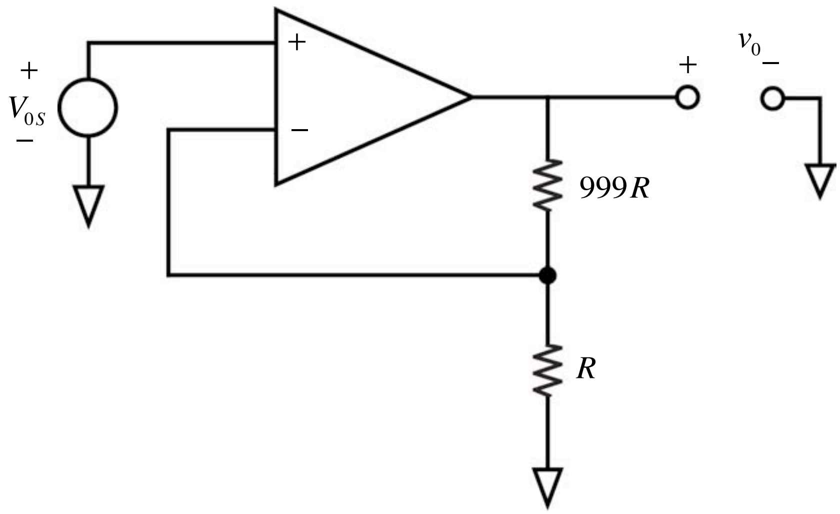
Consider the simple op-amp from the last recitation:



(1) Remind yourselves of which input is the inverting terminal, and which input is the non-inverting terminal.

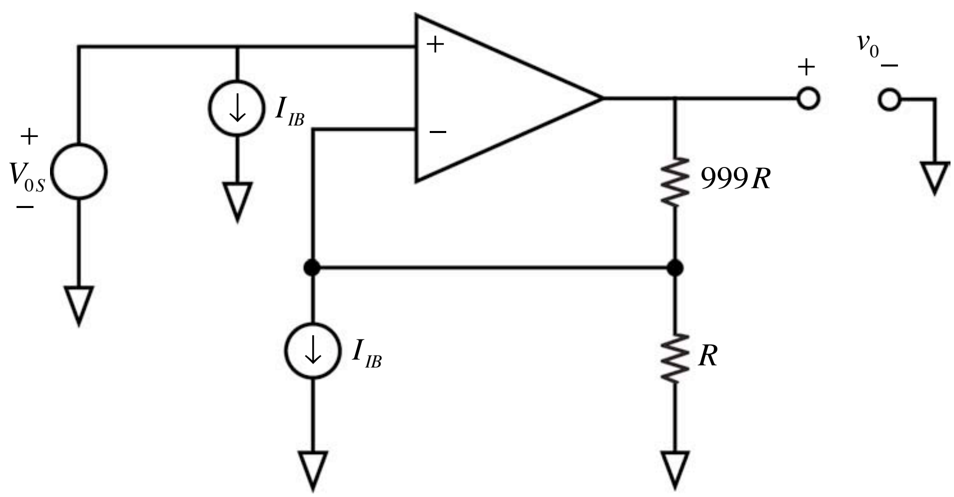
(2) Notice that there will be an imbalance created by the base currents of Q_1 and Q_2. How should we apply a differential voltage on $IN1$ and $IN2$ to correct this?

So how would you measure the input referred offset of a real op-amp? Pretty easy



$$v_0 = \left(1 + \frac{999R}{R}\right)V_{0S} = 1000\,V_{0S}$$

Only caveat: Remember that bipolar op-amps have input bias currents too. They can be modeled:



If you're measuring offset, make sure that $I_{IB}R \ll V_{0S}$.

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