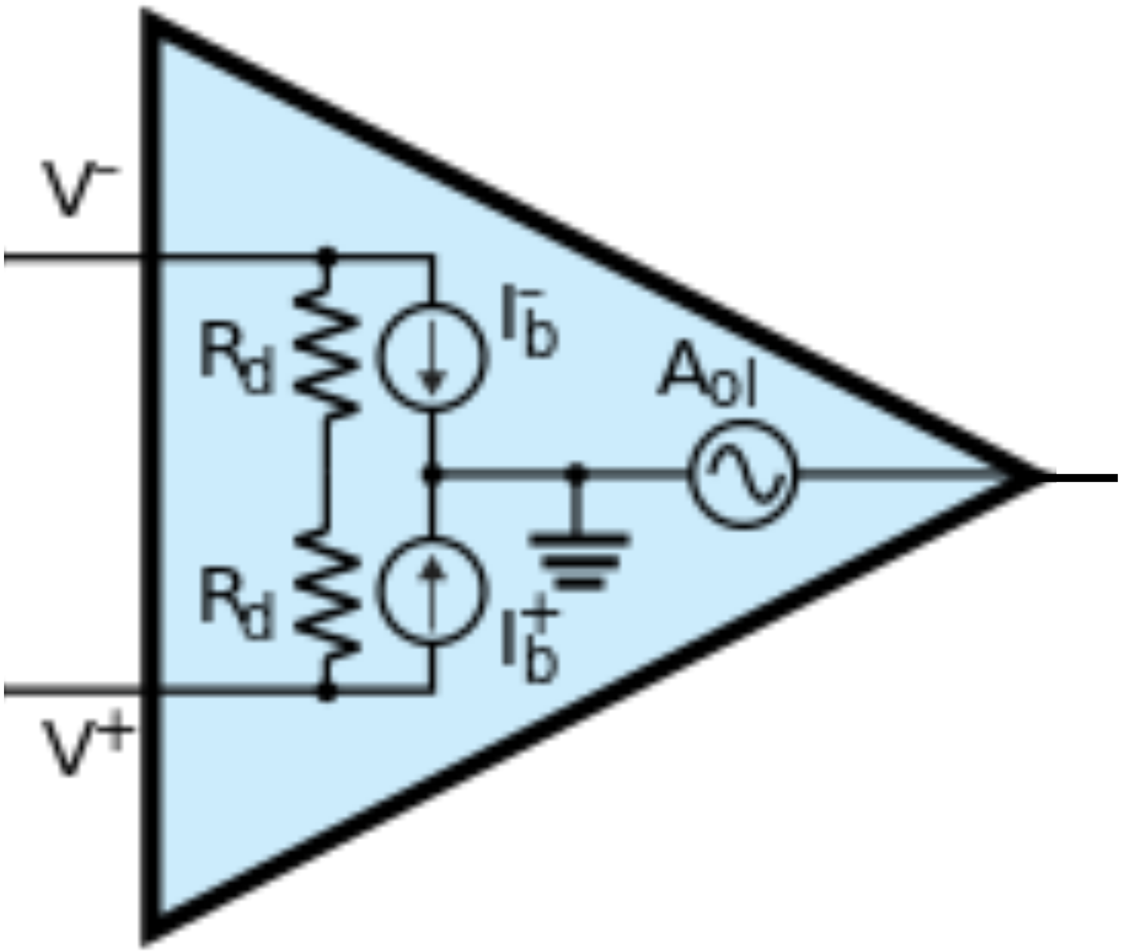
PHYS127AL Lecture 15

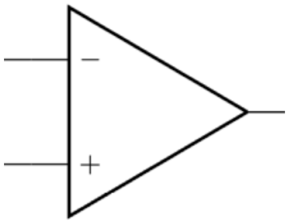
David Stuart, UC Santa Barbara

Non-ideal op-amp properties



Review: Op-amp golden rules

The op-amp golden rules were:
1). No input current, $I_+ = 0$ and $I_- = 0$, i.e., $X_{in} = \infty$
2). $V_- = V_+$ with negative feedback
    Or, output is enormous gain differential amp

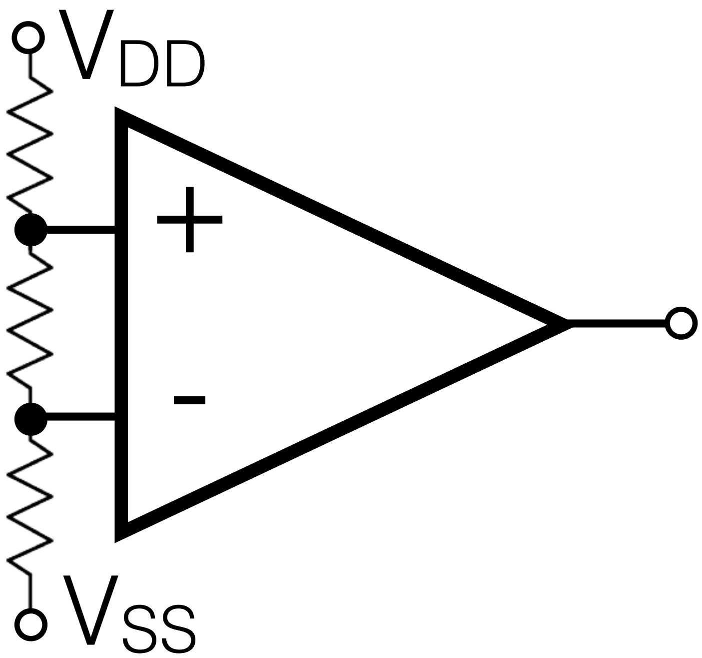


This simple view allowed analyzing many op-amp circuits, but it is only a first approximation.

Now we'll see some of the corrections, or limitations of this model and how to mitigate them.

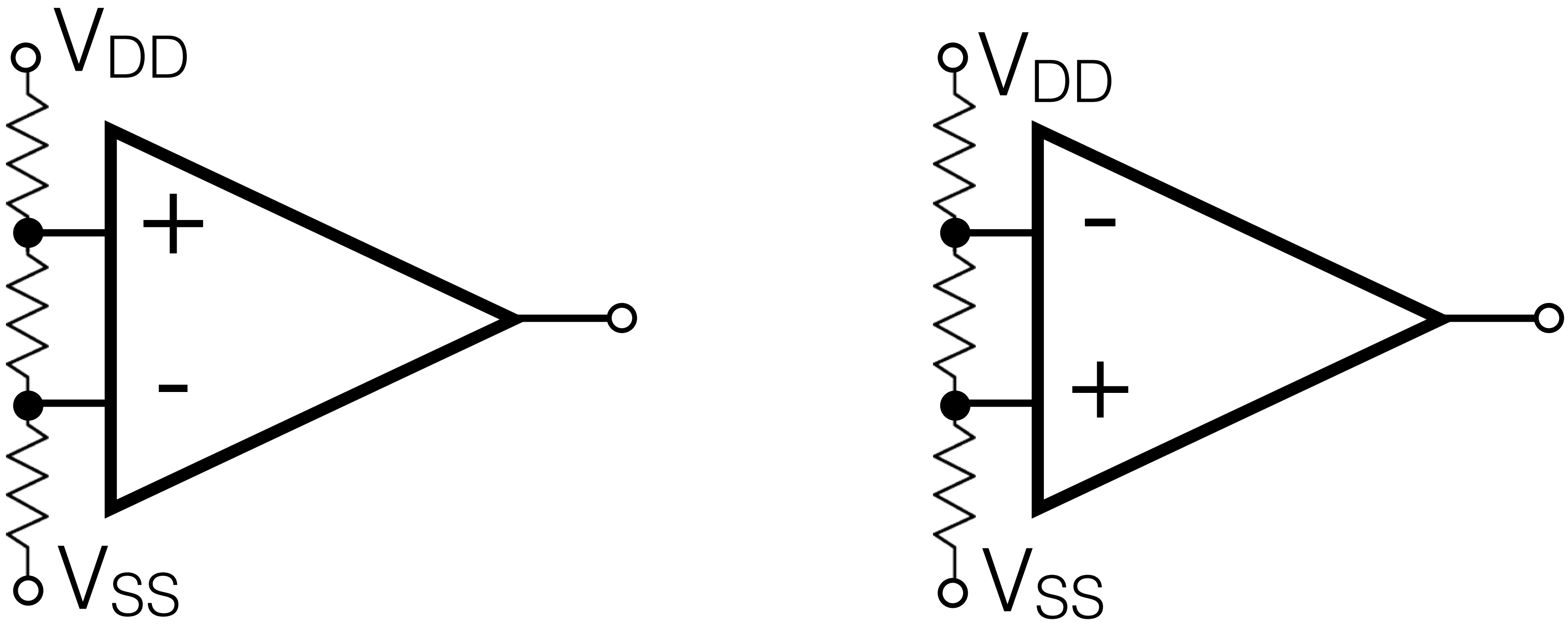
Rail-to-rail

What is the output of this circuit?



Rail-to-rail

What is the output of this circuit? And this one?



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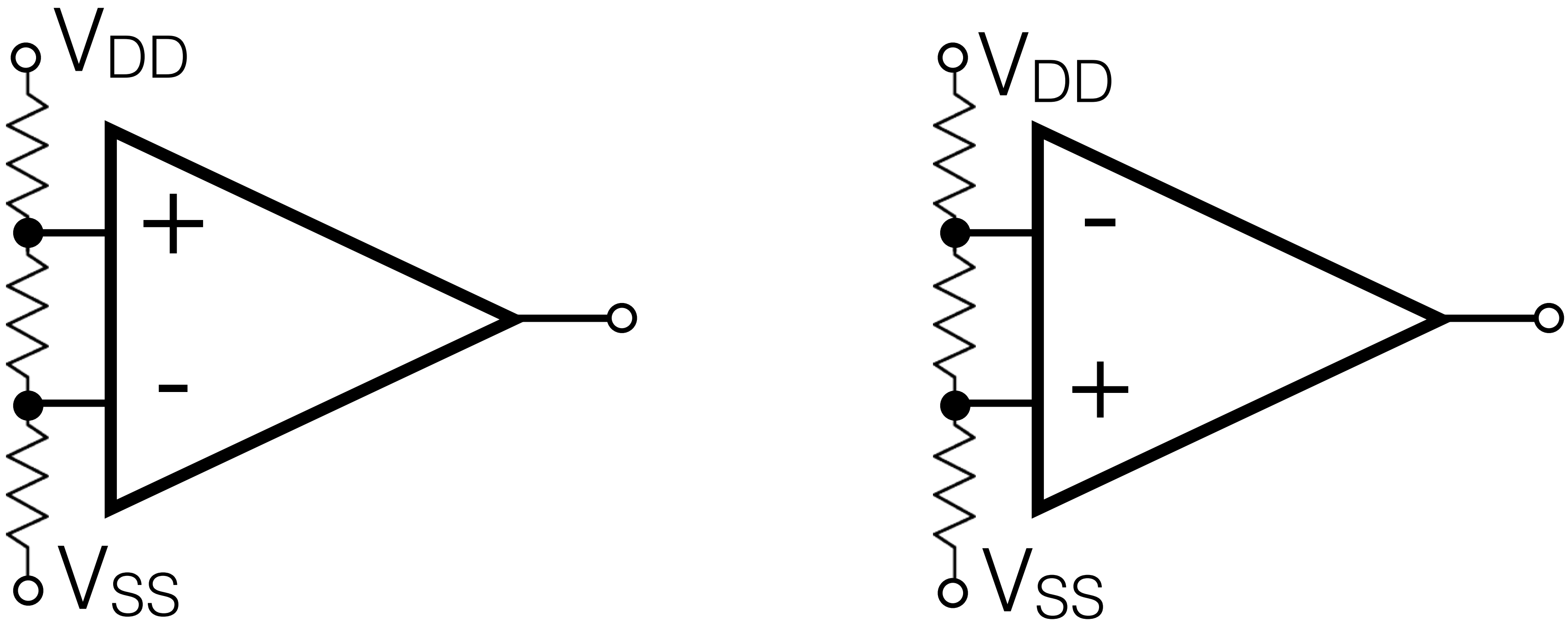
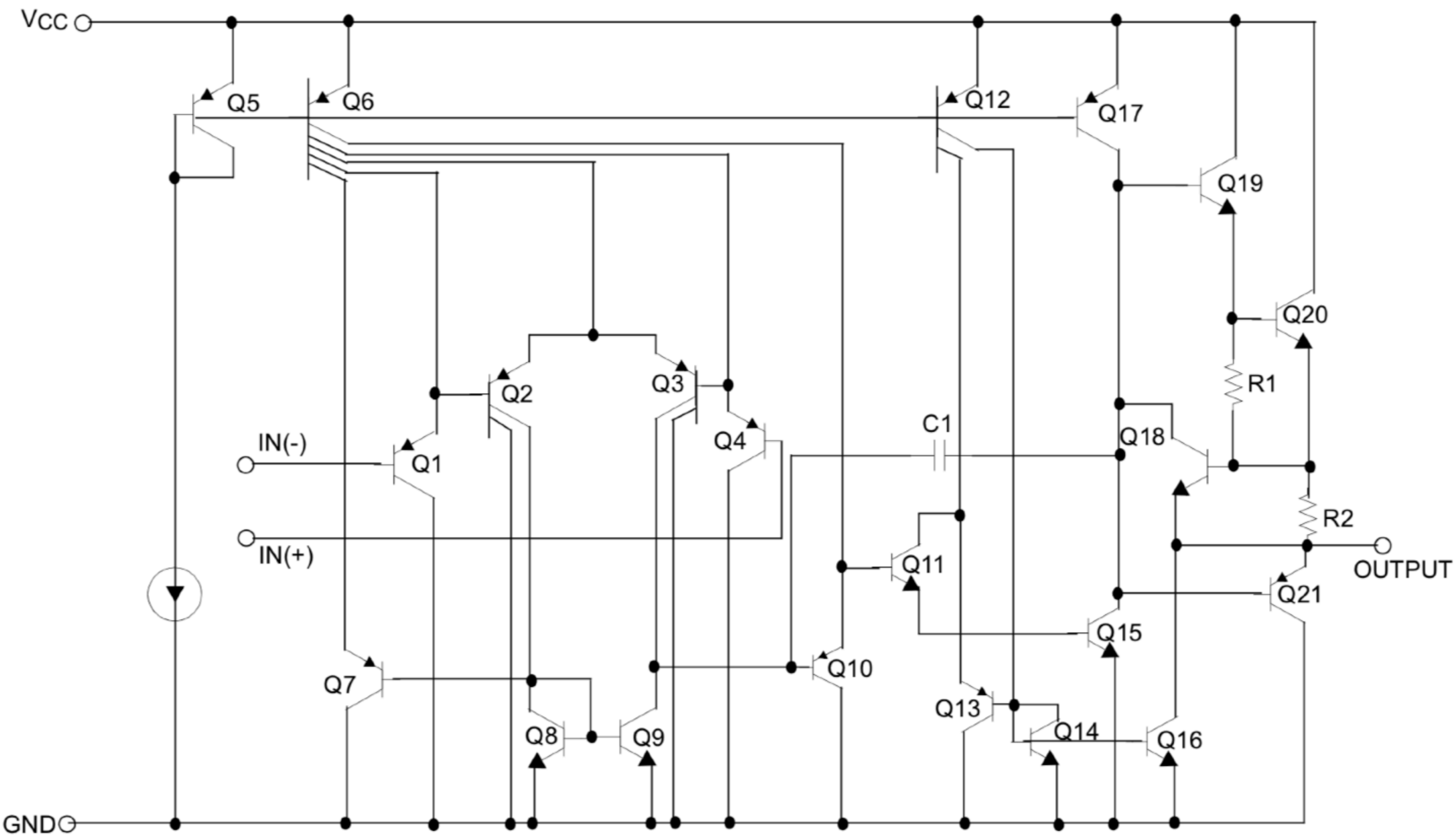


The golden answers are V_{DD} and V_{SS}.
The "non-ideal" answers are *a bit below* V_{DD} and *a bit above* V_{SS}.
Real op-amps can't go all the way to the power supply rails.

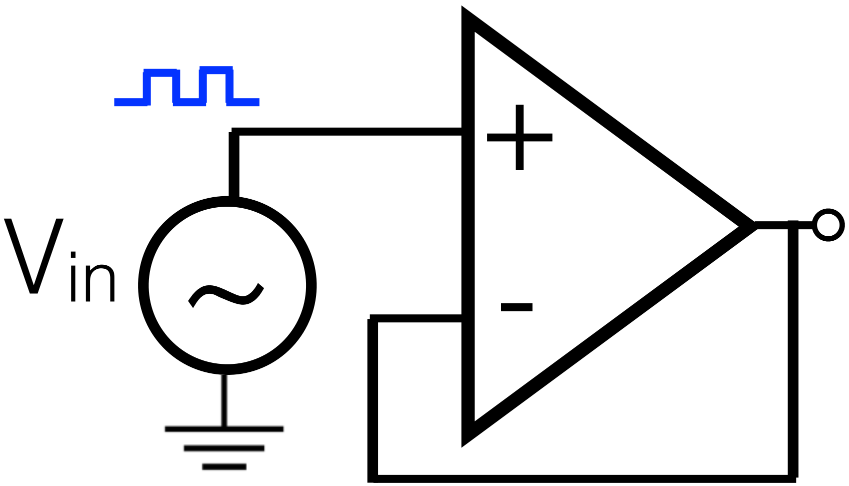
Rail-to-rail

Real op-amps can't go all the way to the power supply rails.
E.g., here is a simplified schematic of the KA358; note the output stage.



Slew rate

What is the output of this circuit?



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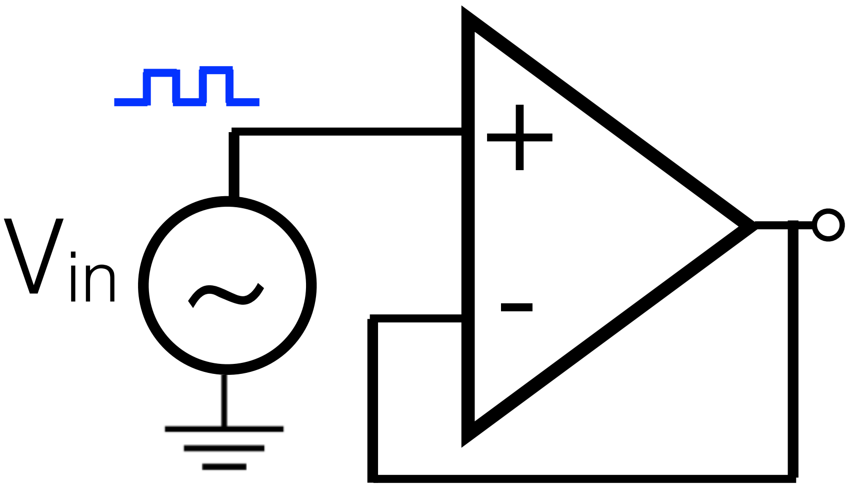
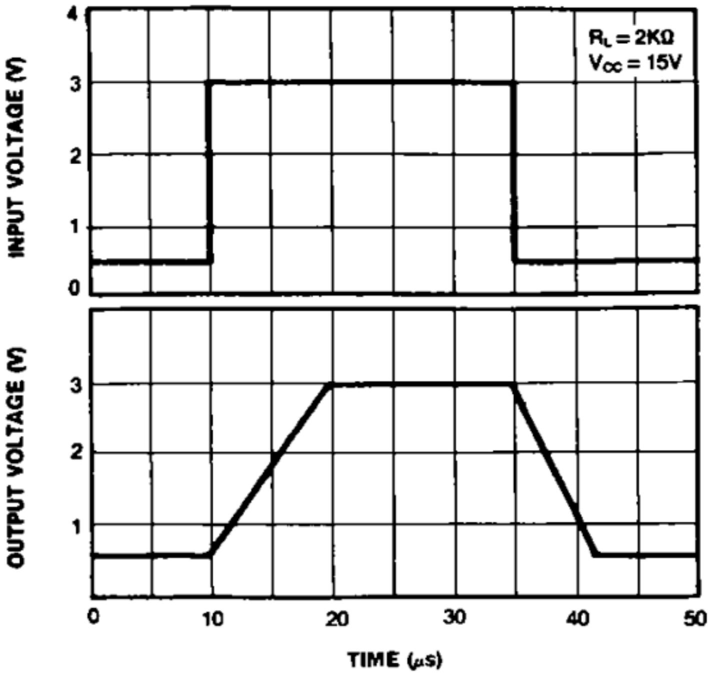
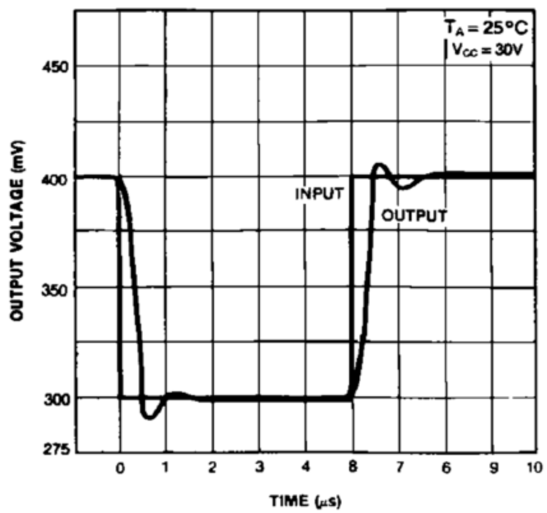




The output has a maximum "slew rate" that is ~ linear.



KA358 slew rate is ~0.15 V/μs.
Fast amps can reach > 1000 V/μs.

This limits speed, particularly for large V_{DD}.

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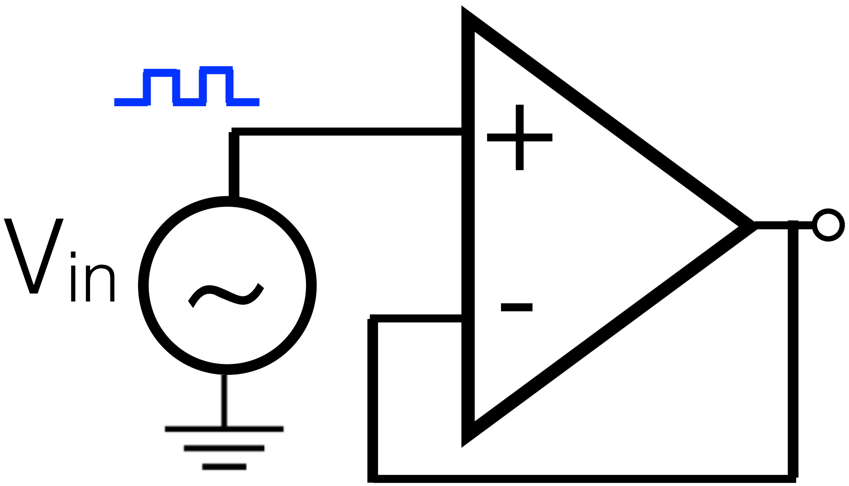

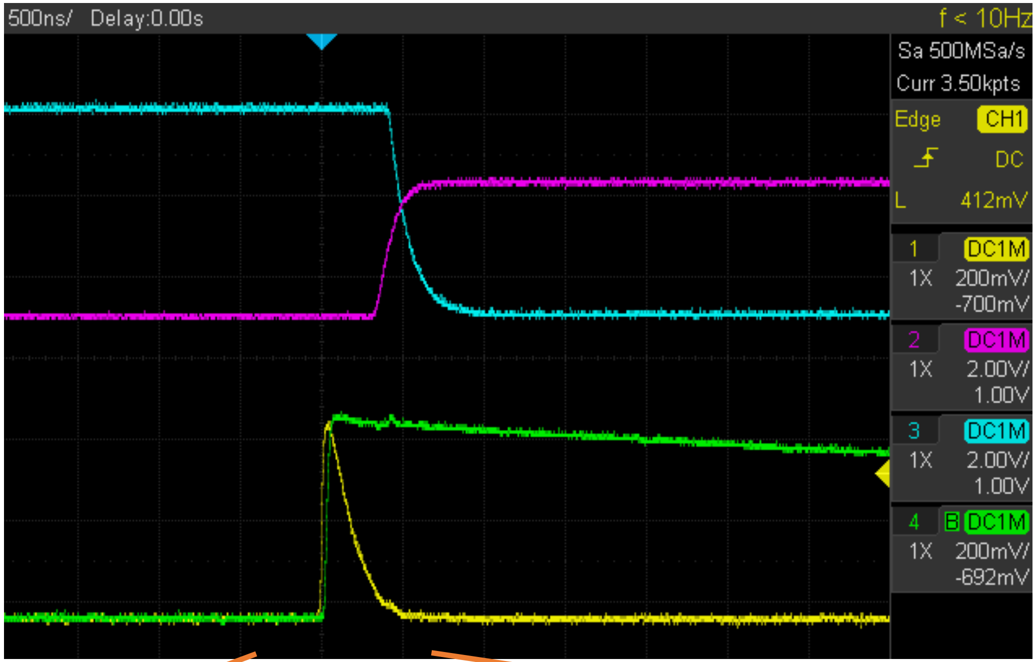

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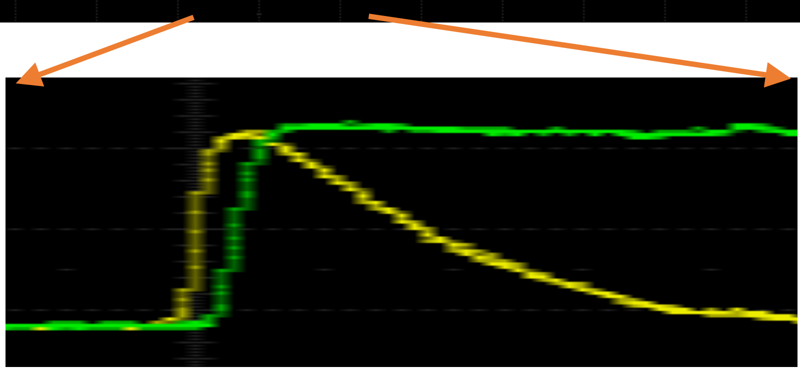


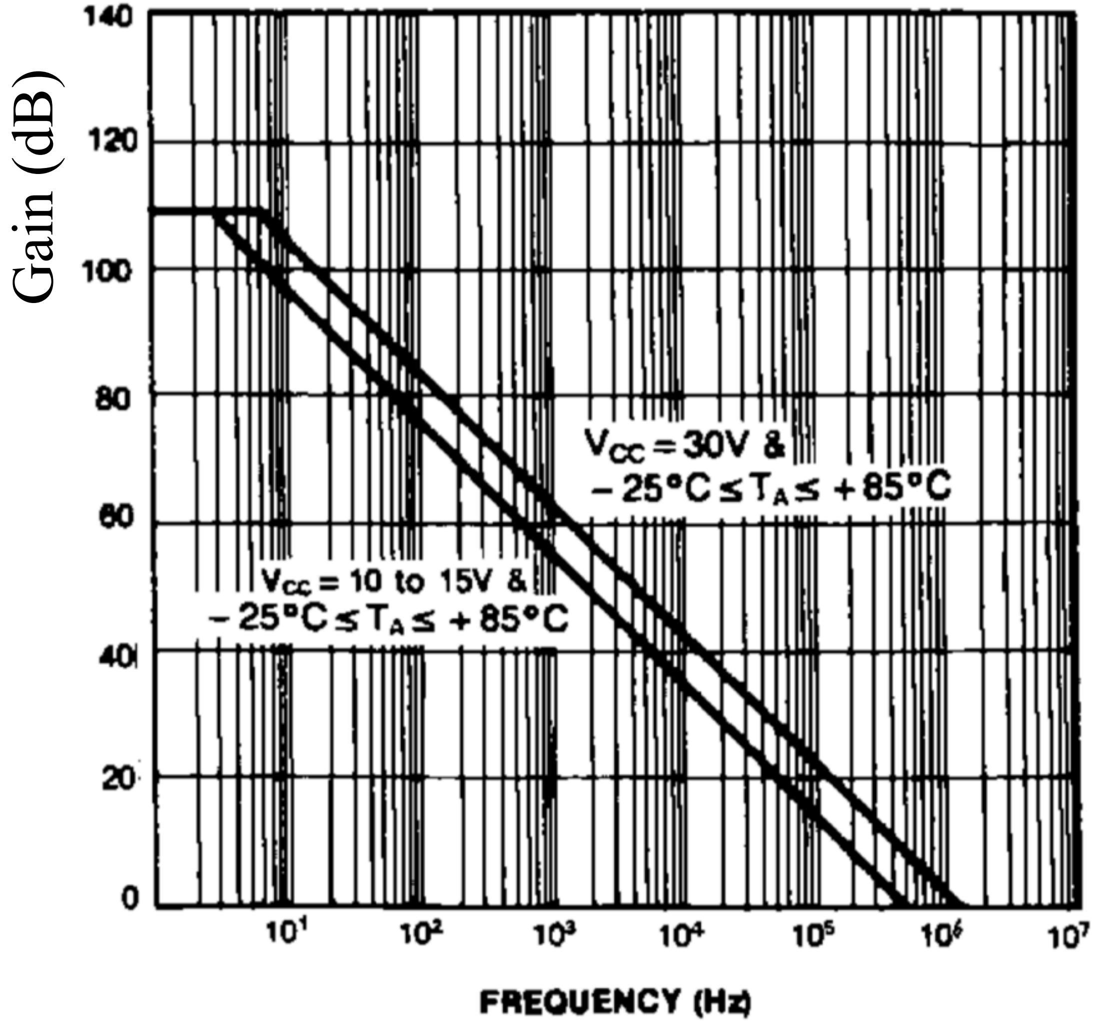
Also can have a propagation delay.

Roll off of open-loop gain

The gain degrades at high frequency

Datasheet often specifies the "gain bandwidth product" which is frequency (aka bandwidth) at which open-loop gain falls to one.

KA358



Roll off of open-loop gain

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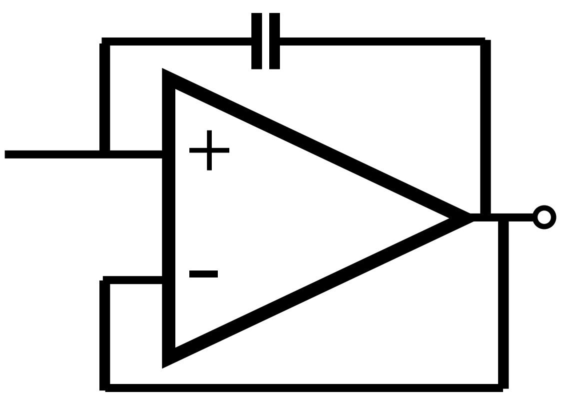
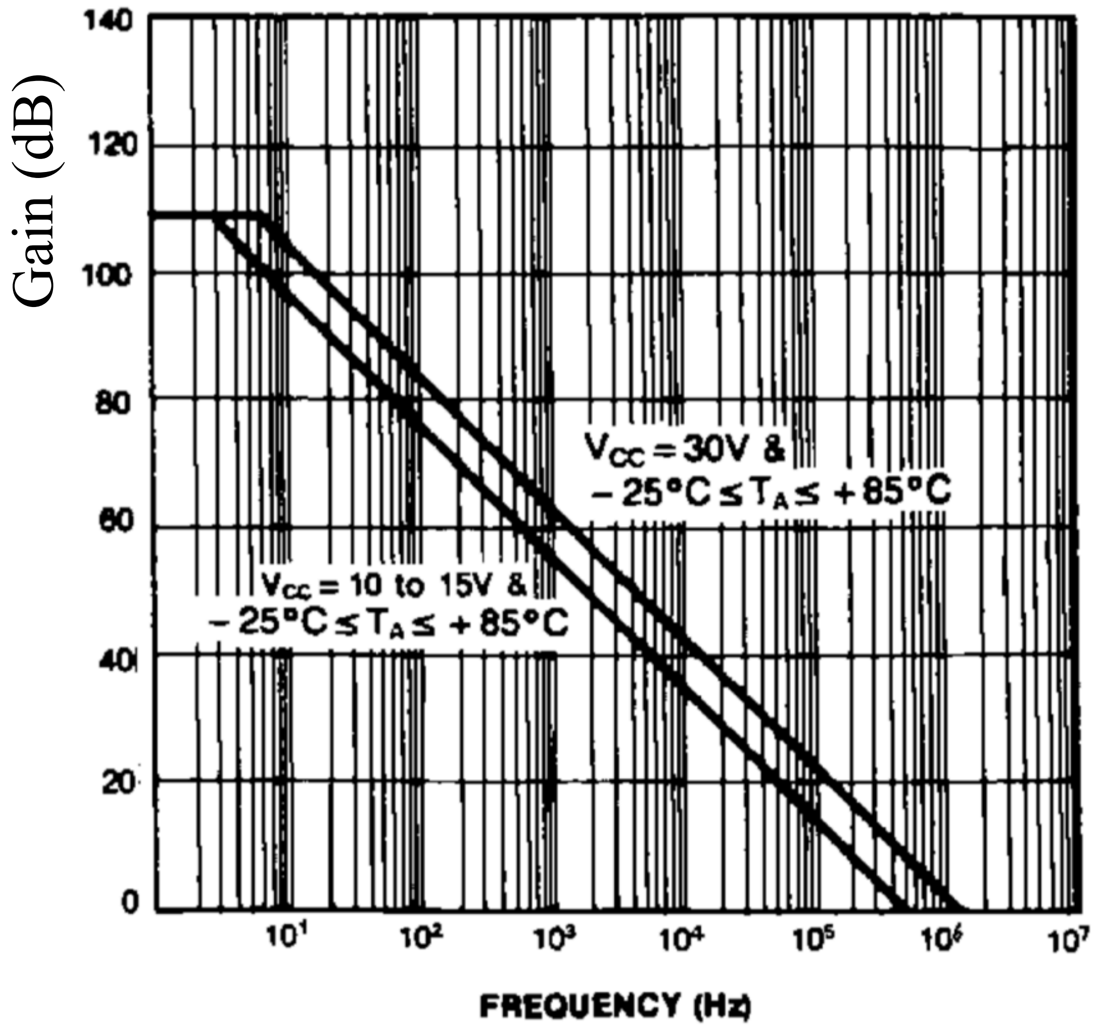
Datasheet often specifies the "gain bandwidth product" which is frequency (aka bandwidth) at which open-loop gain falls to one.

Roll off is often intentional to avoid oscillation at high frequency due to parasitic positive feedback.

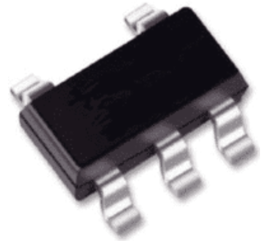


KA358

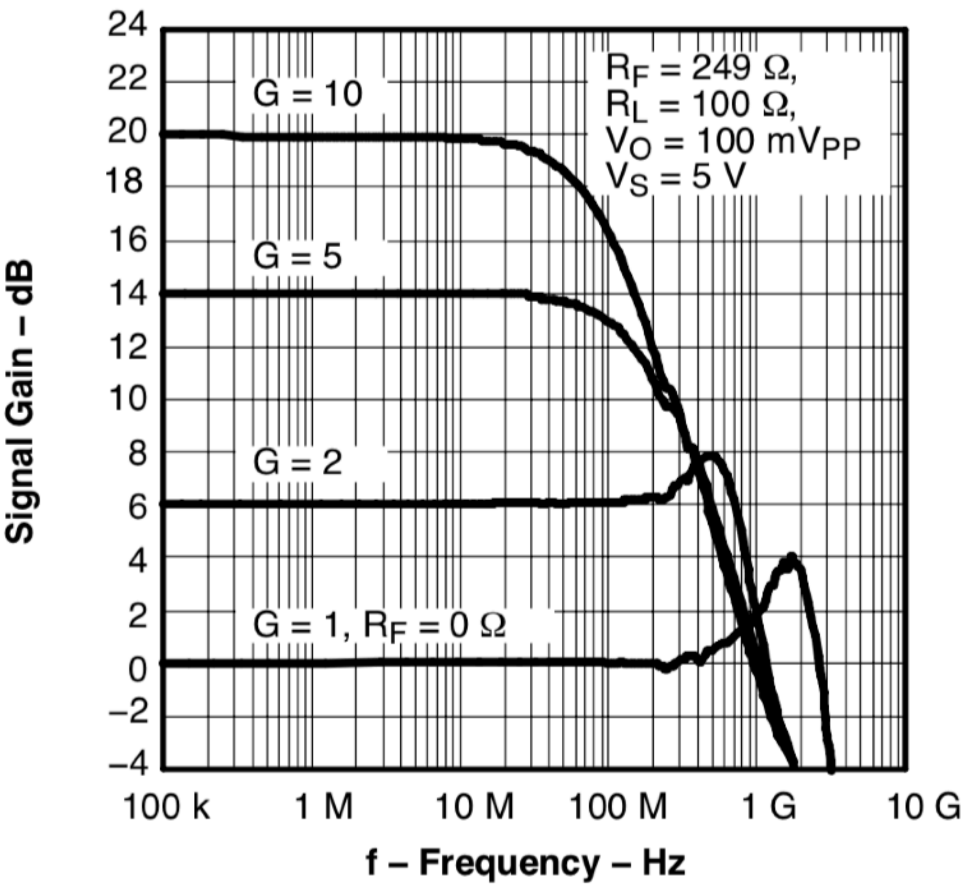


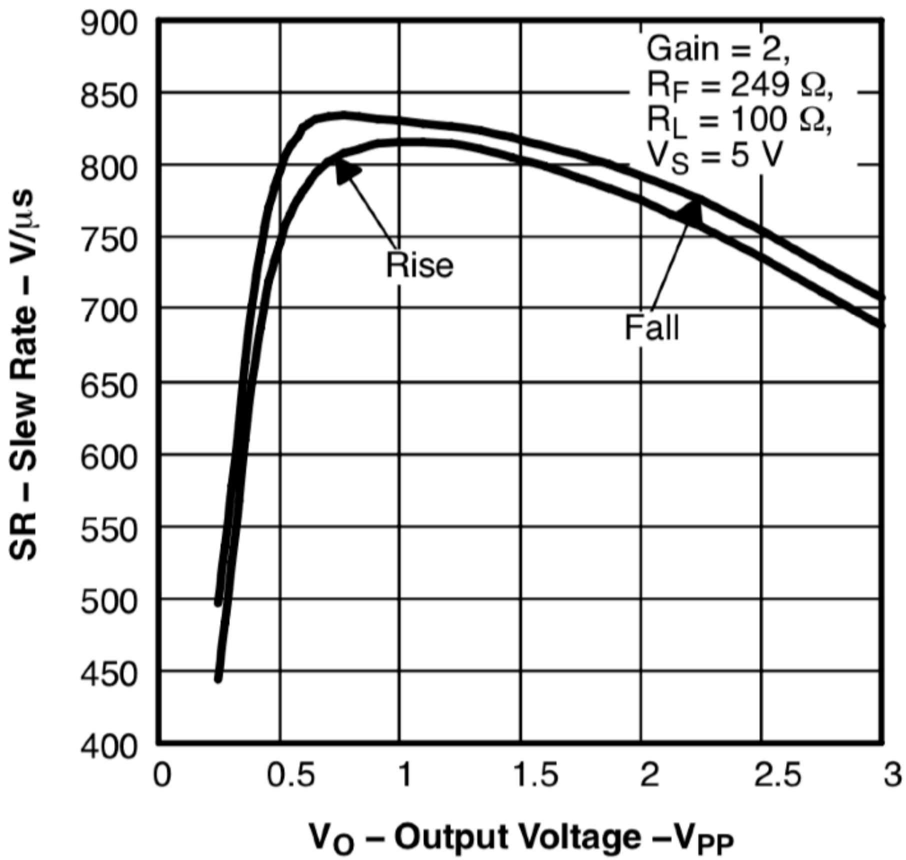
Roll off of open-loop gain

The gain degrades at high frequency
(This op-amp has lower supply limits, 5V not 15V)



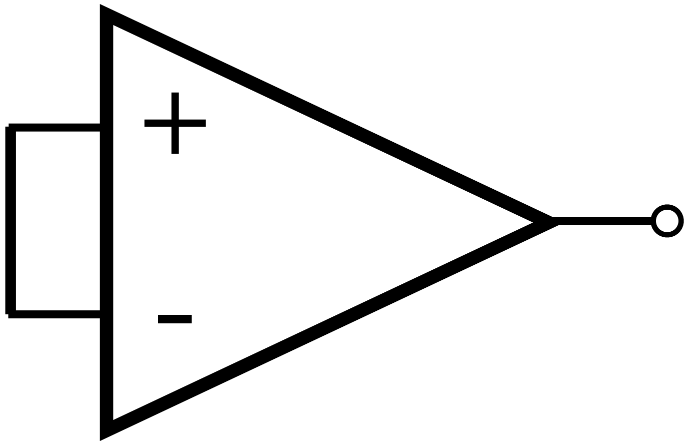
THS4304
$6 op-amp





Input offset

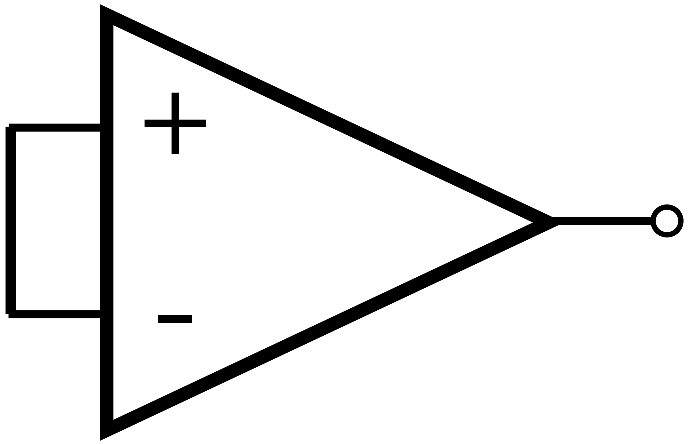
What is the output of this circuit?

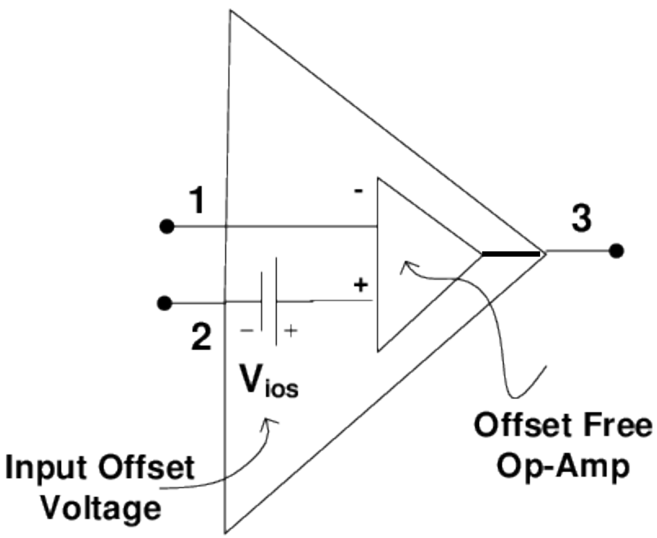


Input offset

What is the output of this circuit?

Nearly V_{DD} or V_{SS}. Which one it will be is set by "input offset voltage".





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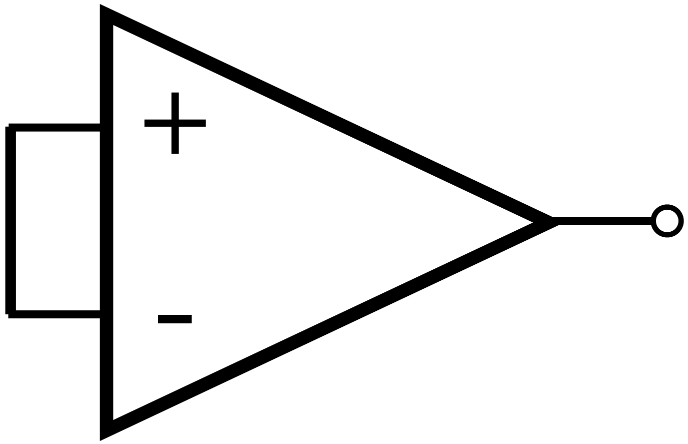
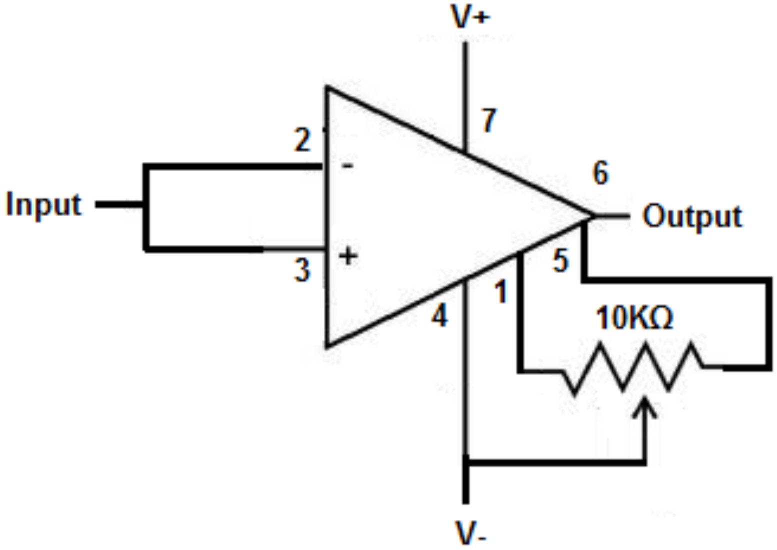
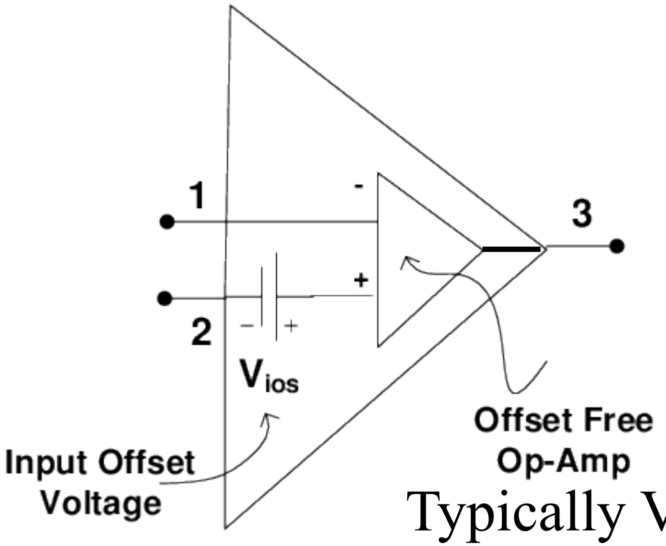
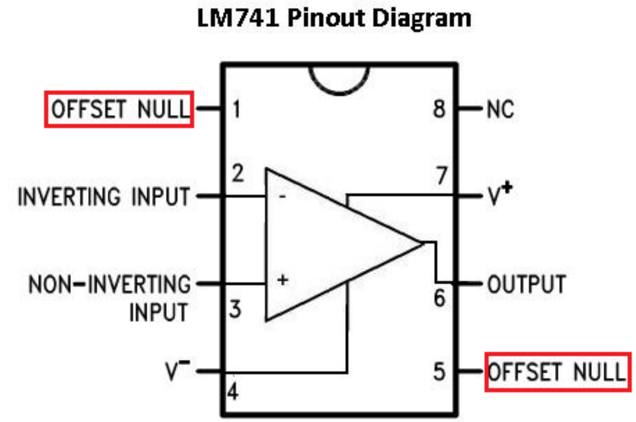






Typically $V_{ios} \cong 1$ mV



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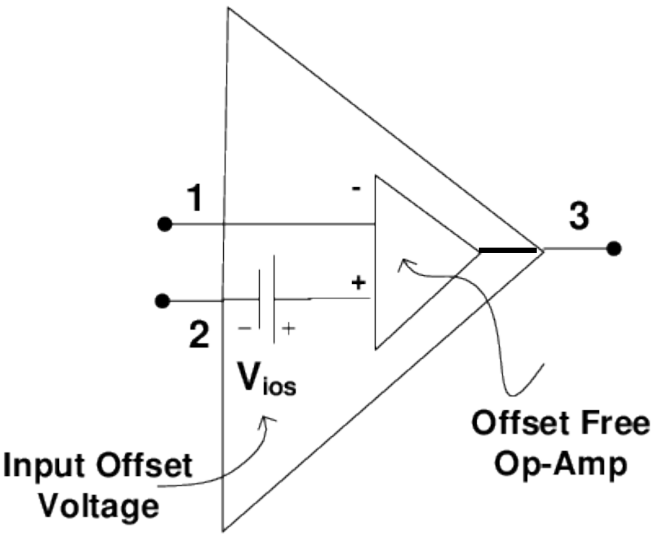
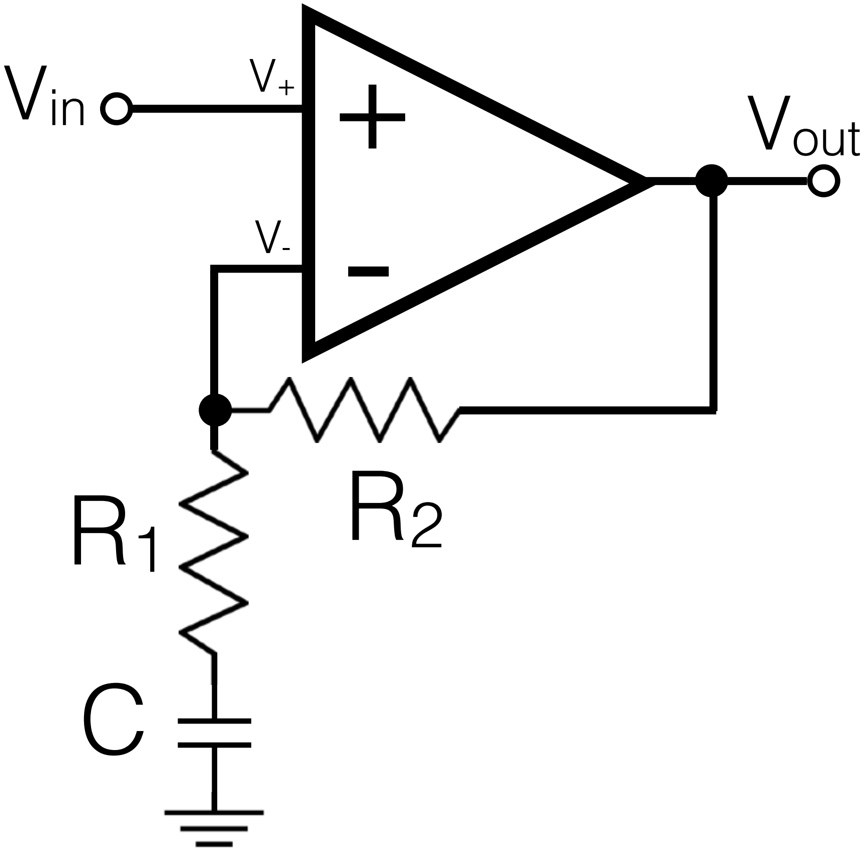
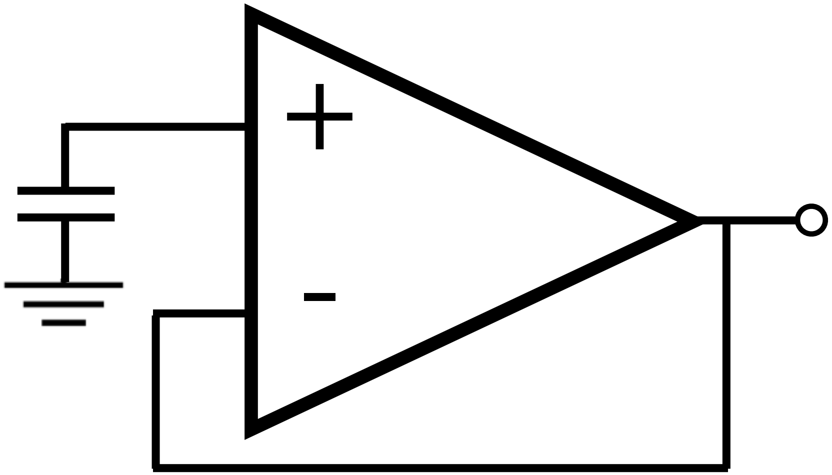




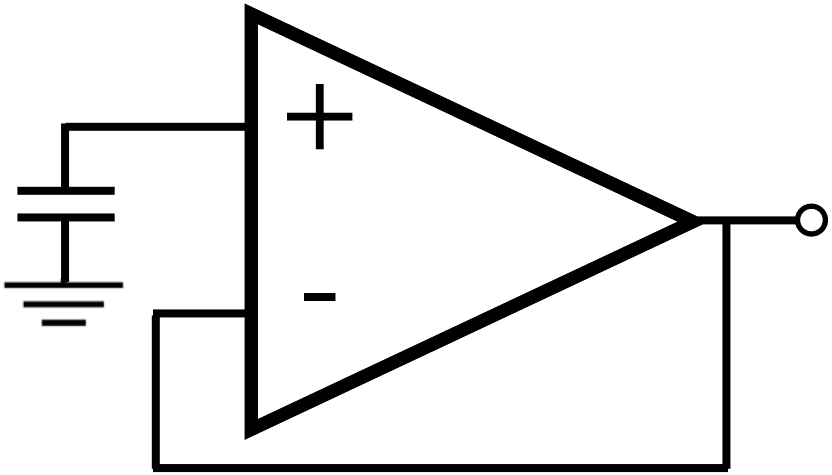
Input offset current

What is the output of this circuit?



Input offset current

What is the output of this circuit?
The output "follows" the voltage across the capacitor.
Golden rules say $I_+ = 0$ so capacitor maintains same charge.



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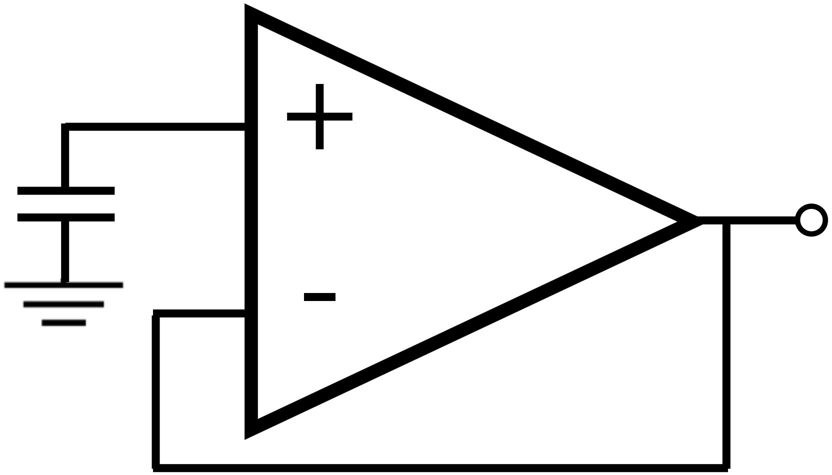

There is a small leakage current, typically 10's of pA to 10's of nA.

This limits stability time for integrators or S&H.

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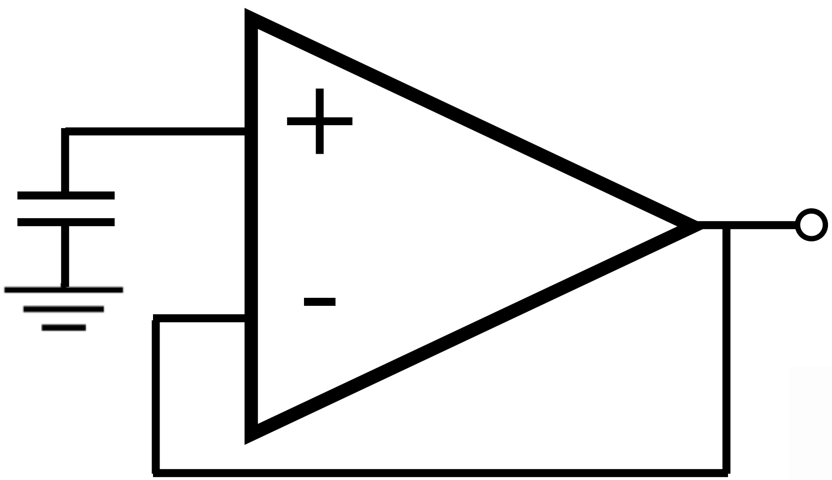
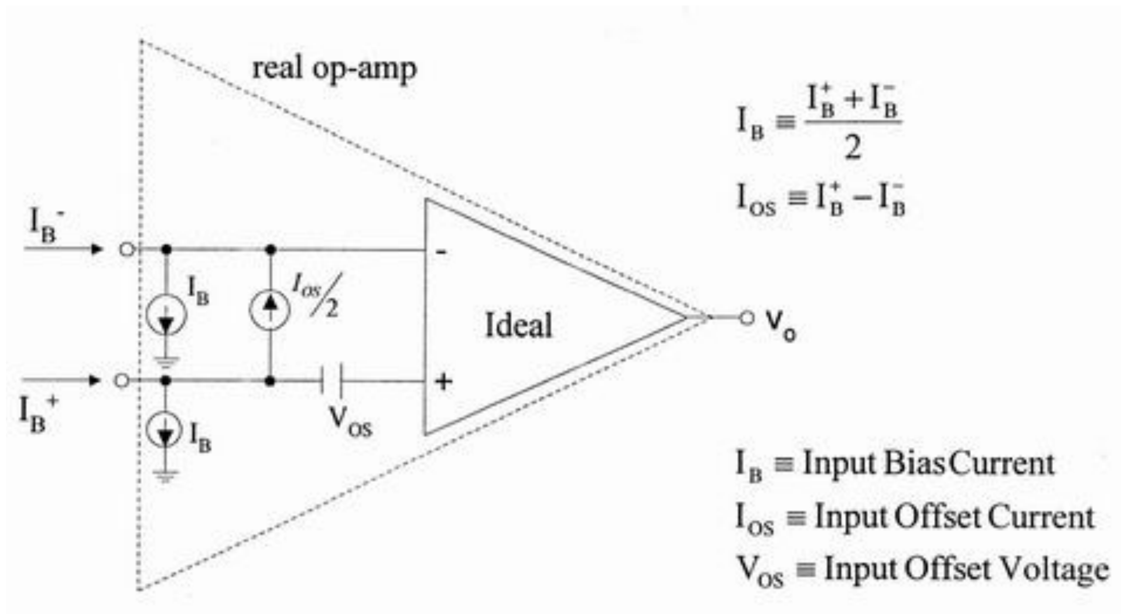


There is a small leakage current, typically 10's of pA to 10's of nA. Most often I_{OS} is much <u>smaller</u> than I_B.



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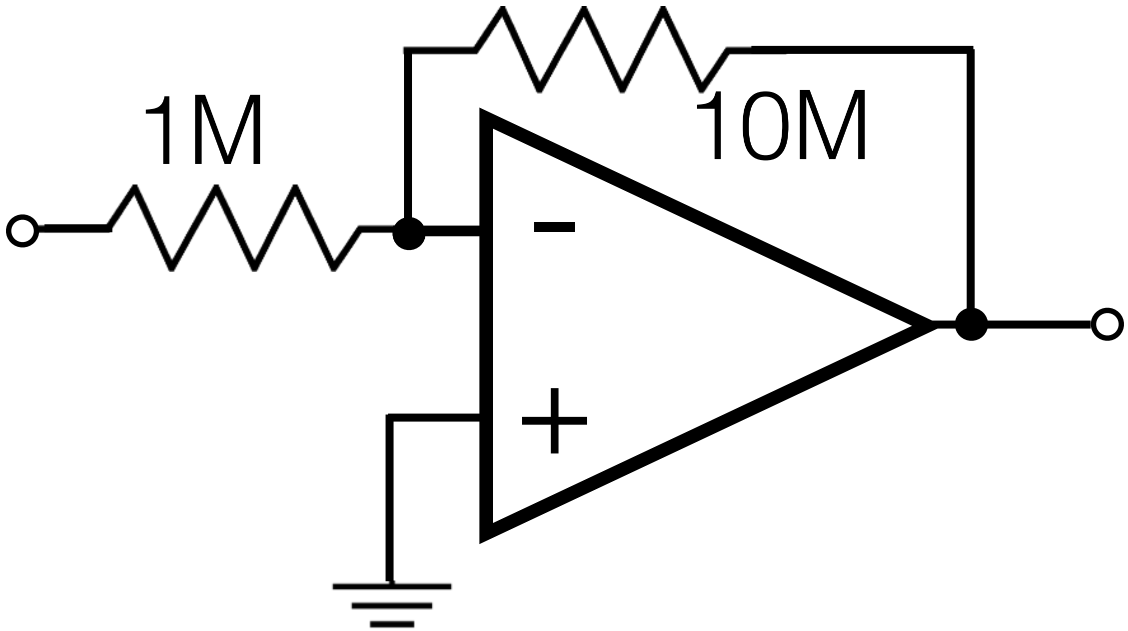
Input offset current

This biases an inverting amplifier with large resistors.
Want R_1 large for input impedance, but I_B*R is a voltage offset.



10 nA*1M = 10mV. Then gain of 10 gives an output bias of 100 mV.

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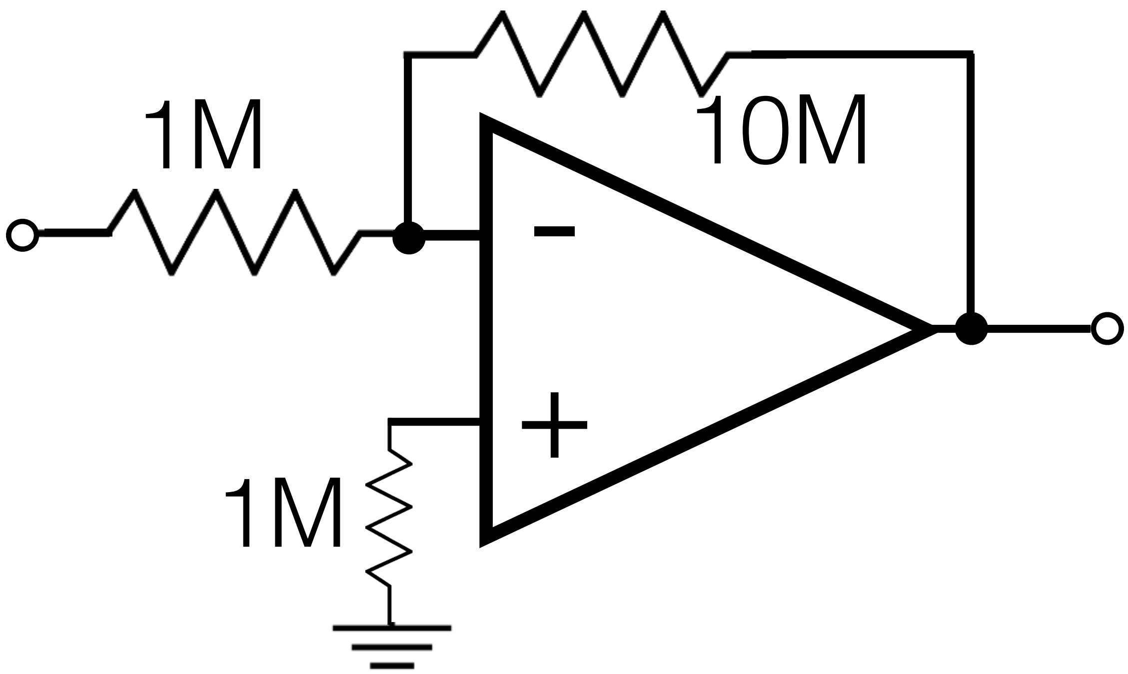
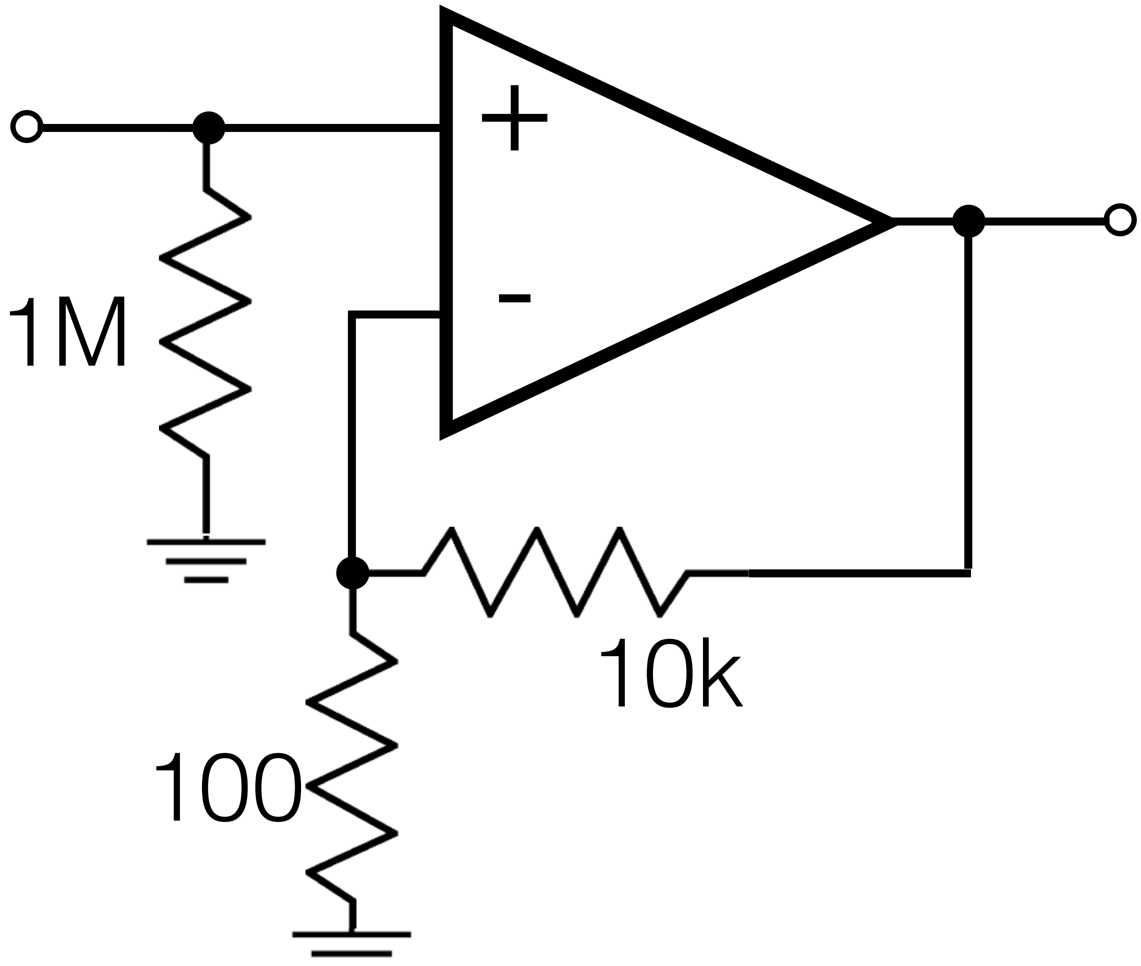


10 nA*1M = 10mV. Then gain of 10 gives an output bias of 100 mV.
Solution is to give the other input the same voltage offset; works if I_{OS} small compared to I_B.

Input offset current

Similar solution works for non-inverting amplifiers.



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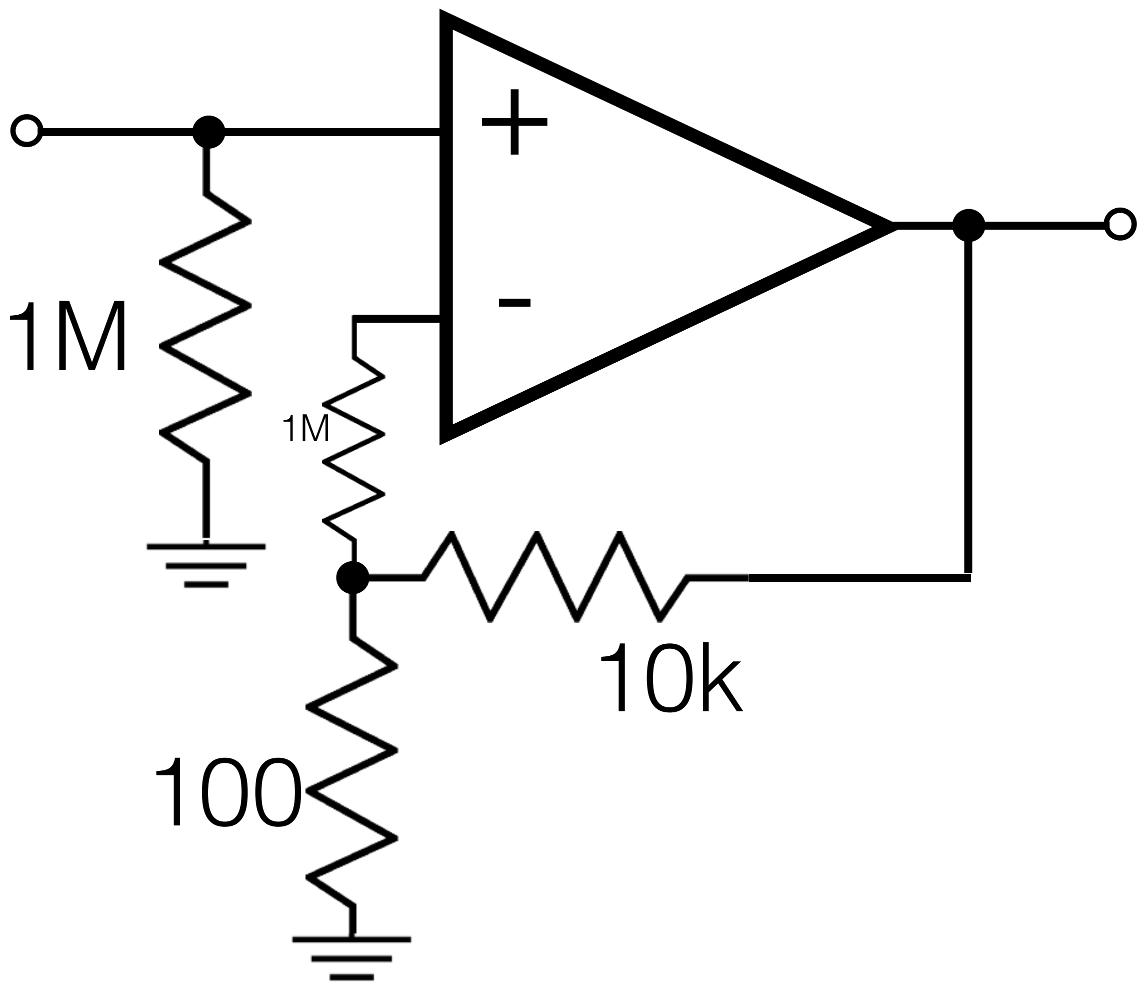

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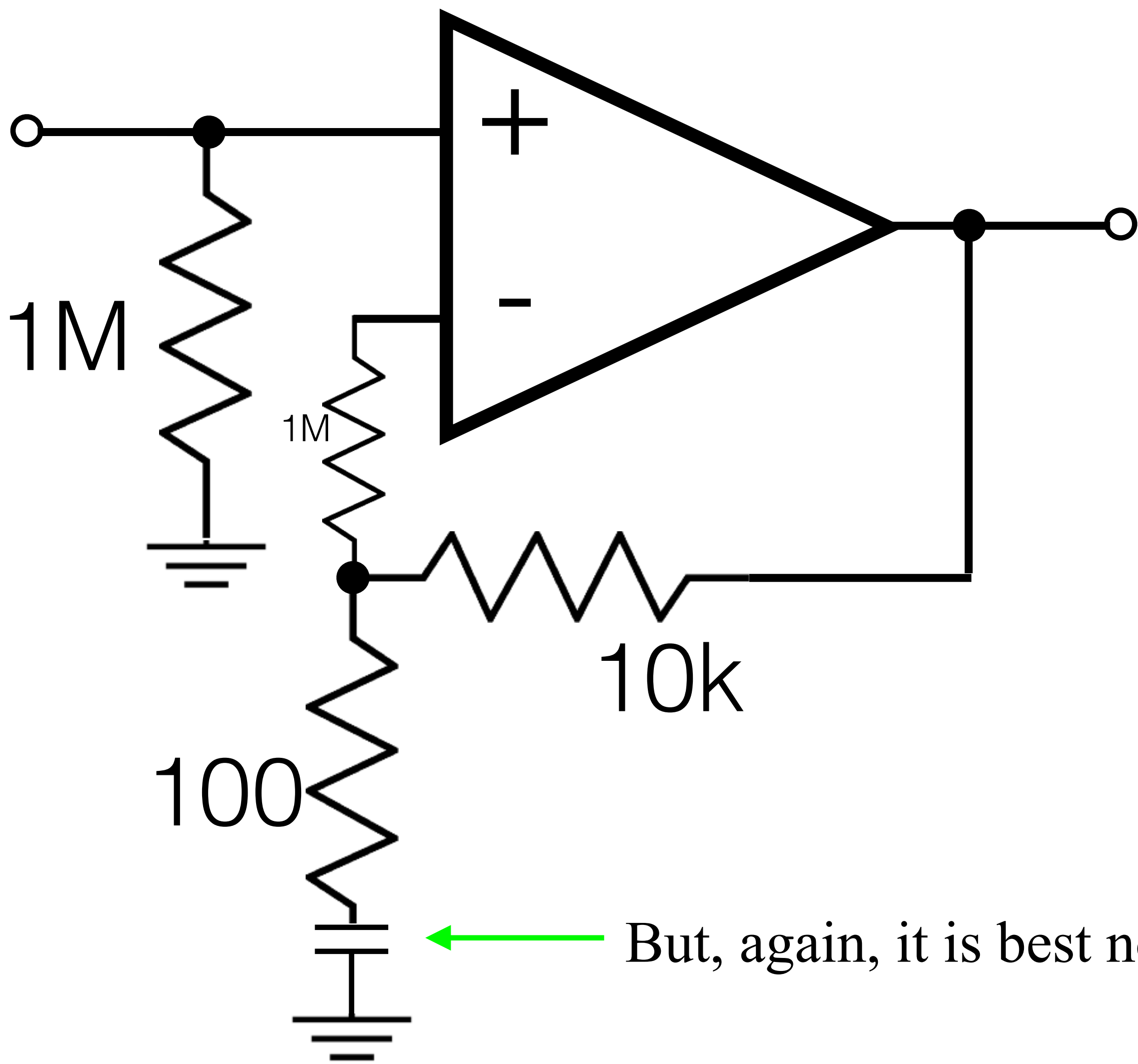

But, again, it is best not to amplify the DC offsets.

Noise

There is intrinsic noise in the inputs.

Typically $10\ \mathrm{nV}/\sqrt{\mathrm{Hz}}$ and $1\ \mathrm{pA}/\sqrt{\mathrm{Hz}}$

Really only critical for precision measurements, and we will talk about ways to suppress it next week.

Pick your optimum

There are thousands of op-amp designs. They optimize on various parameters:

Rail-to-rail
Power supply range
Power consumption
Speed
- GBP, Slew-rate

Input bias current
Input offset current
Input offset voltage
Flexibility
- Multi-circuits
- Offset-null
- Package

Operating temperature range
Price
- Often dominated by batch size.

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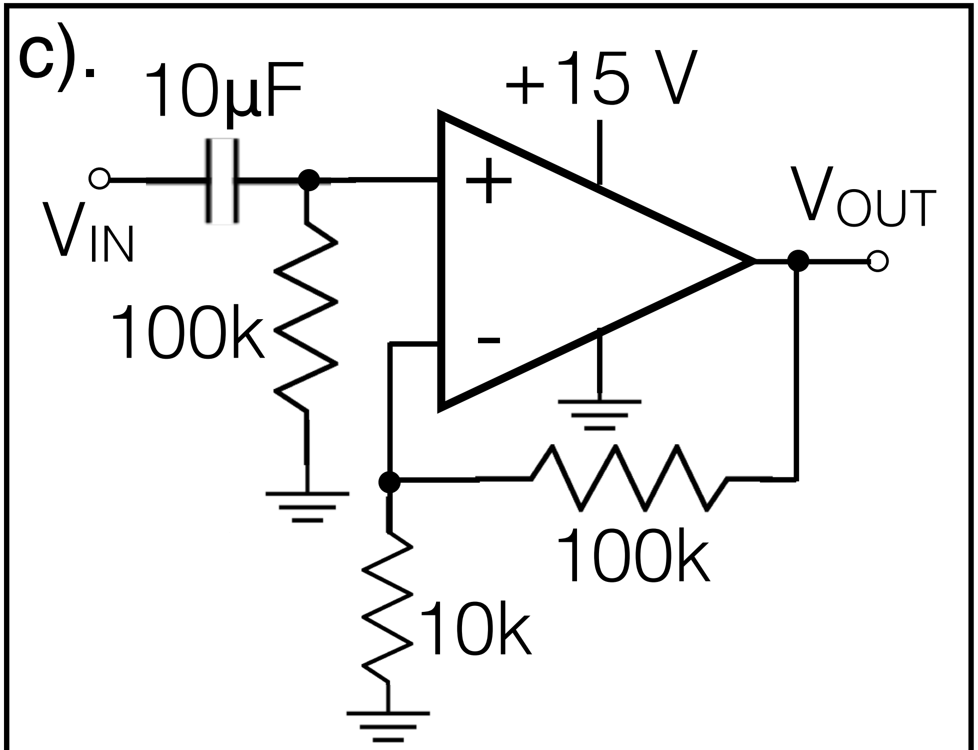
Electronics component vendors:
[Newark]
[Digikey]
[Arrow]

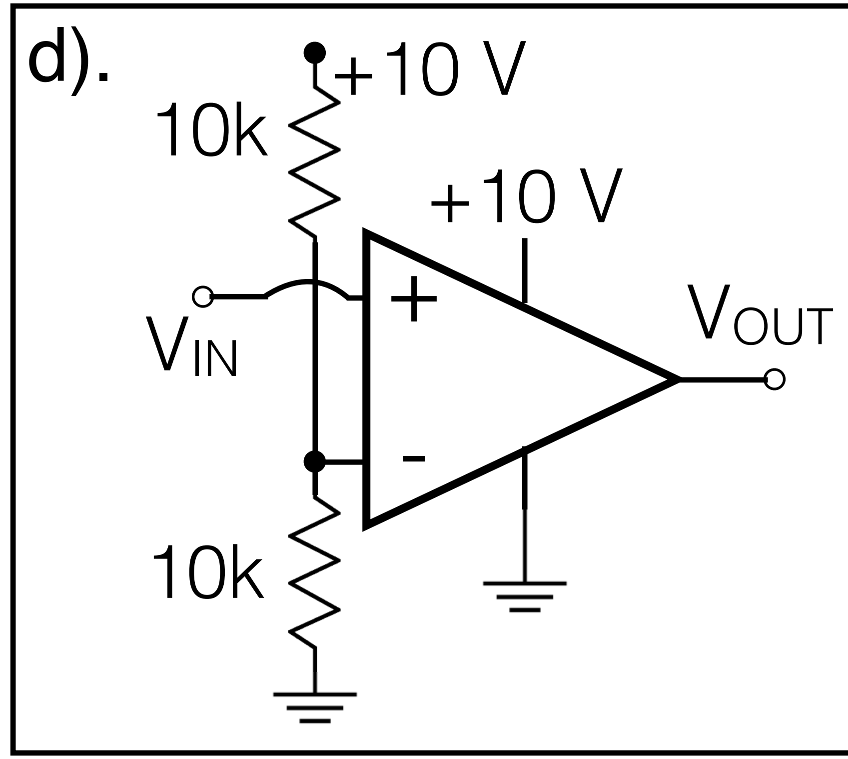
Lab 9 and extra credit projects

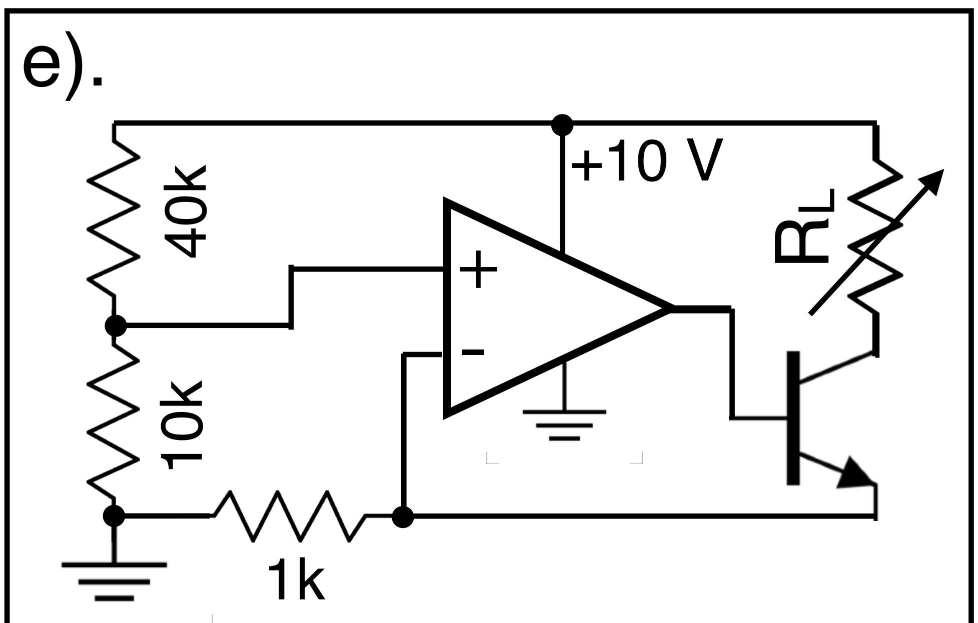
Lab 9 will be a grab-bag of options

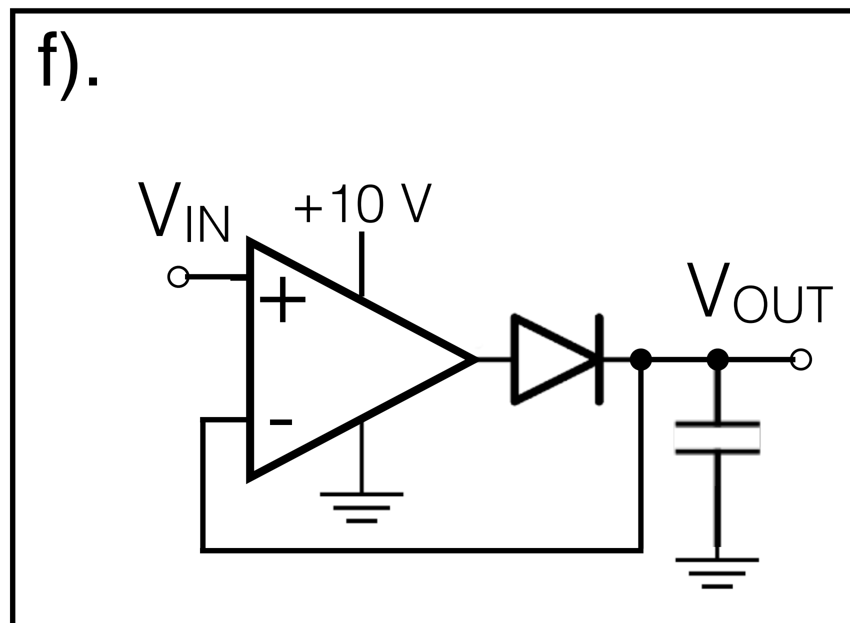
No lab 10 during dead week.
That time available for extra credit project work.

Extra credit projects due (ELOG complete) Sunday, June 13th at noon.
Email me when you have completed it.

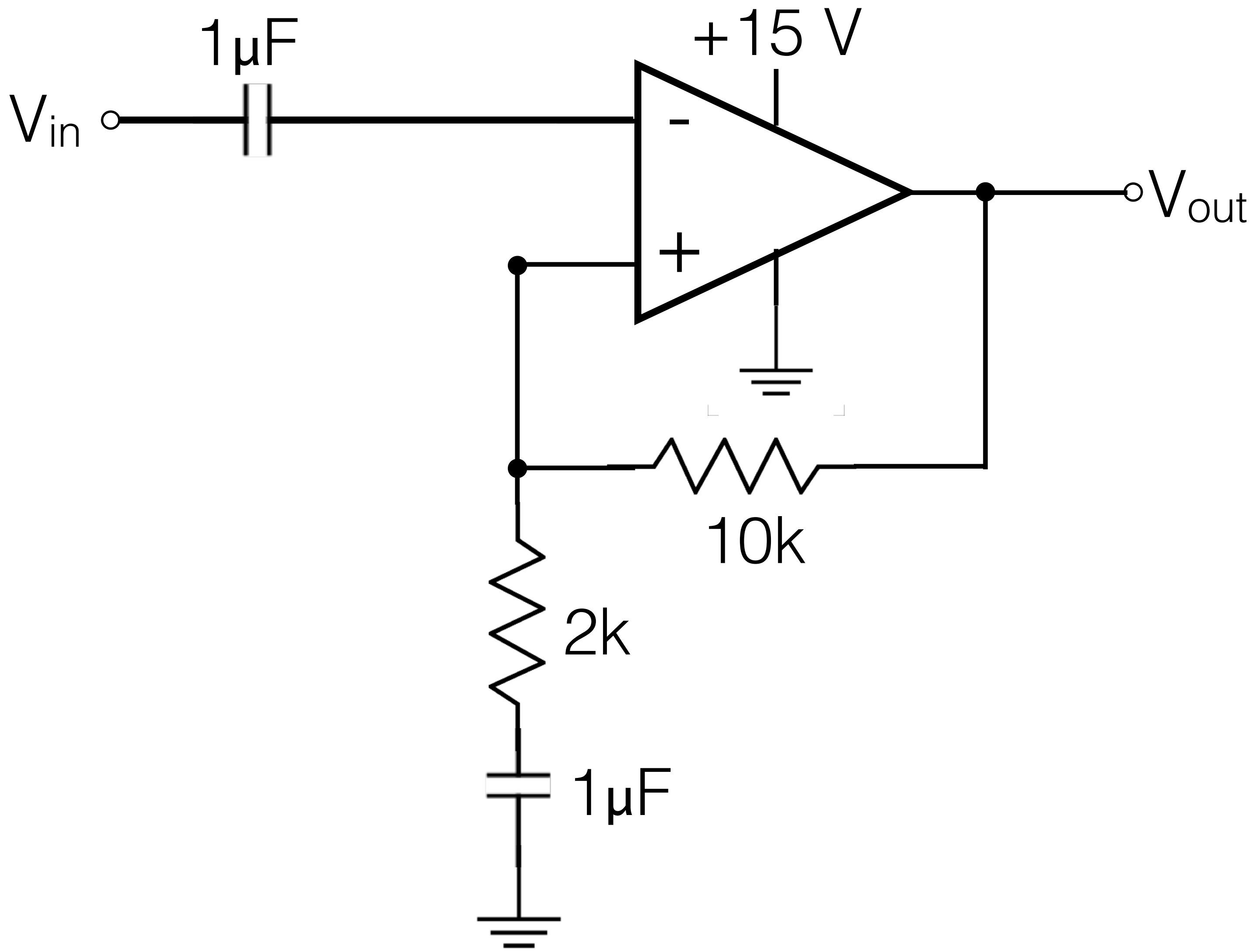

c).
10μF
+15 V
V_{IN}
V_{OUT}
100k
100k
10k


d).
+10 V
10k
+10 V
V_{IN}
V_{OUT}
10k


e).
+10 V
40k
R_L
10k
1k


f).
V_{IN}
+10 V
V_{OUT}

What is wrong with this circuit?



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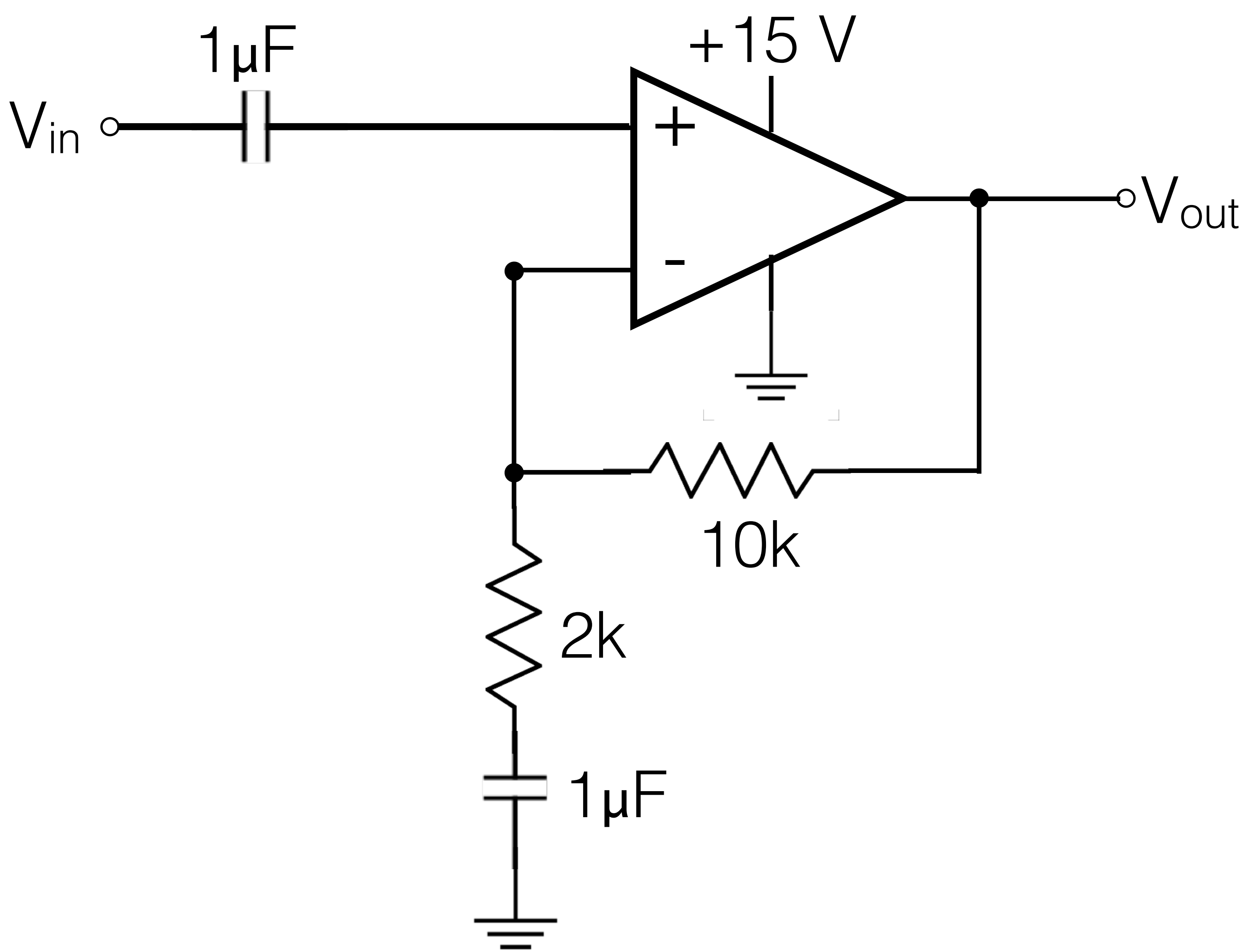
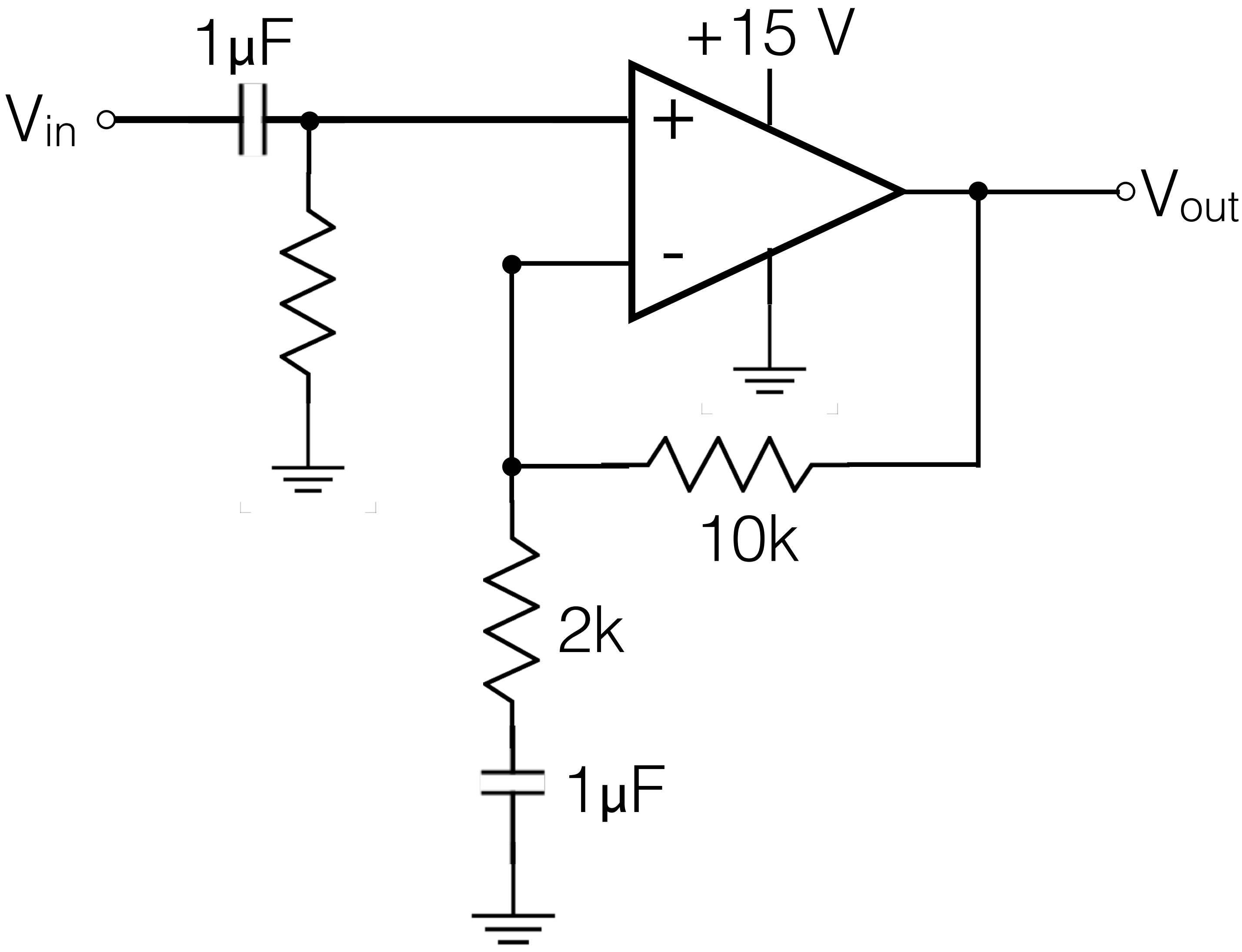
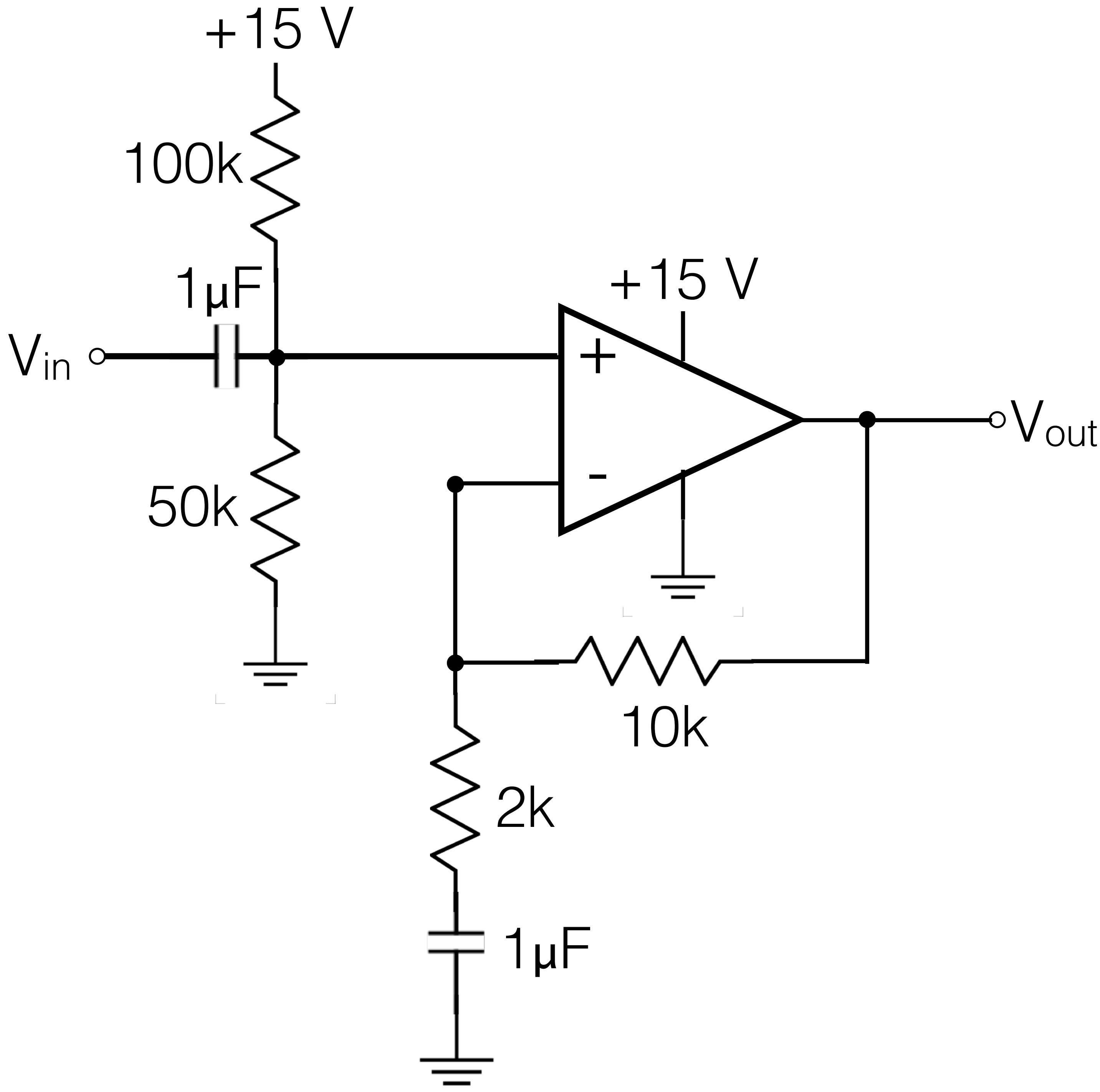




1µF
+15 V
Vin
Vout
+
-
10k
2k
1µF


+15 V
100k
1μF
V_{in}
50k
+15 V
+
-
V_{out}
10k
2k
1μF