Operational Amplifiers - Part 1

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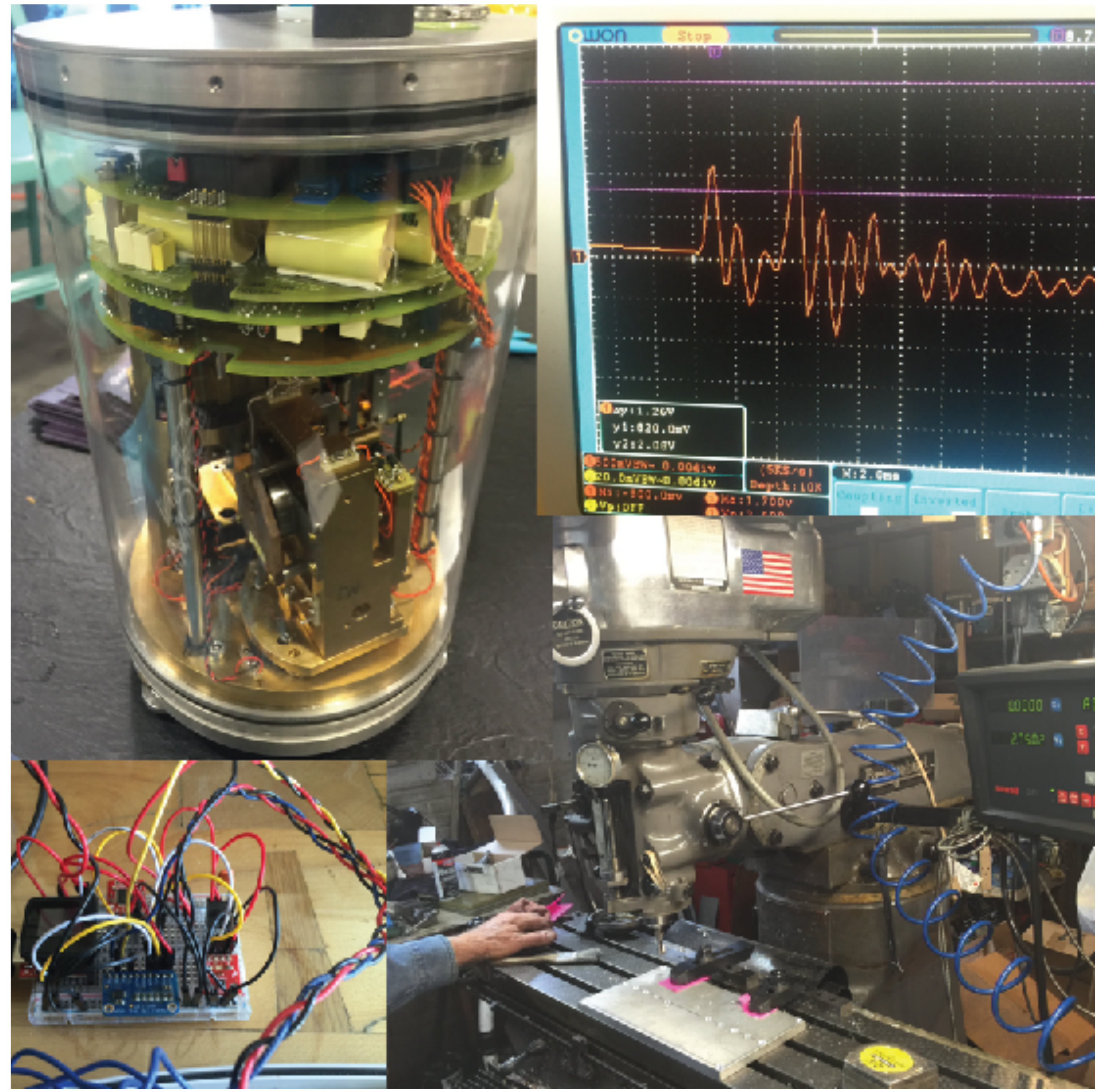
Techniques of Geoscientific Experimentation

October 27, 2016



In the lab, operational amplifiers are often used to make small signals larger so we can more easily measure them

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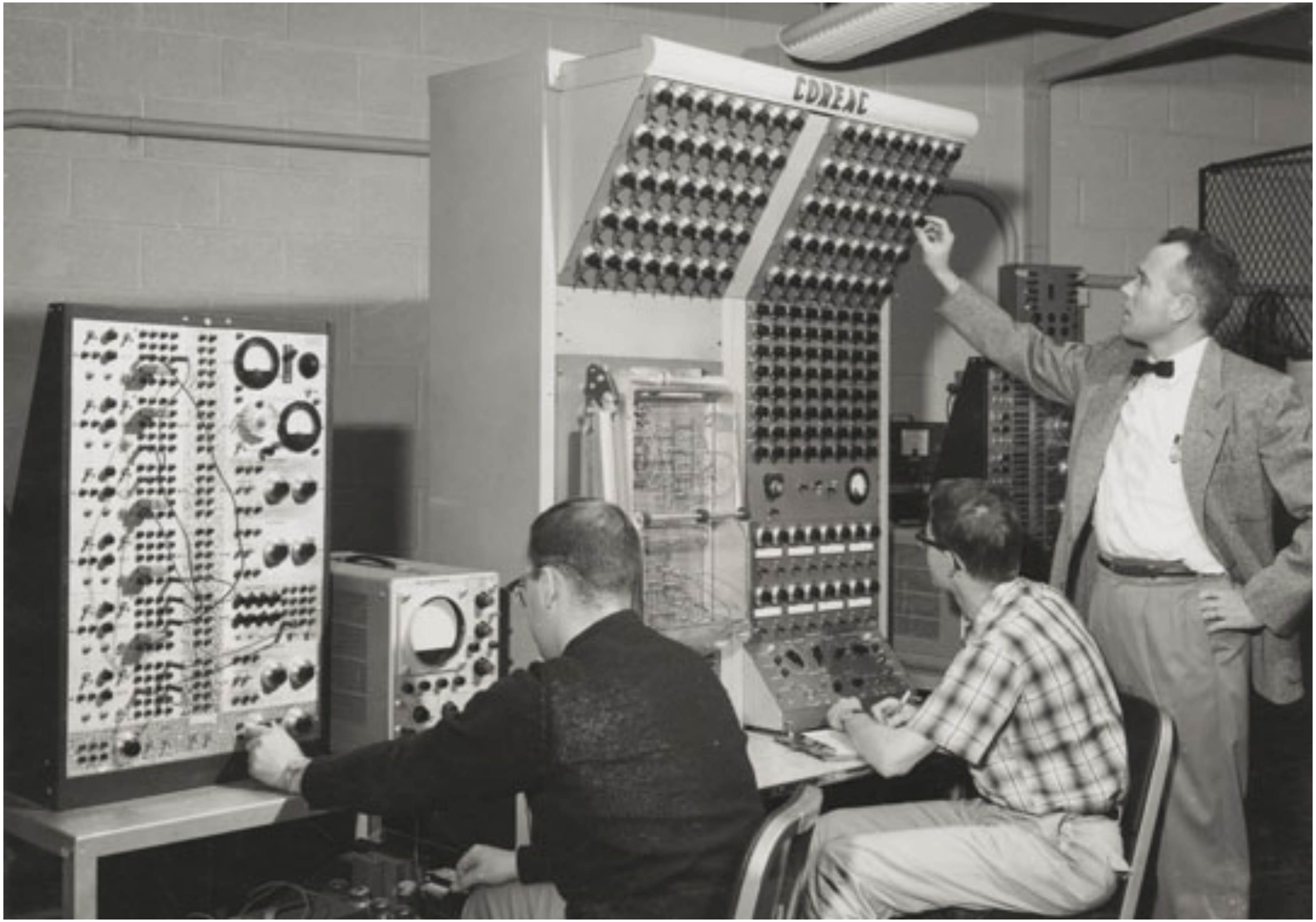
X1000!

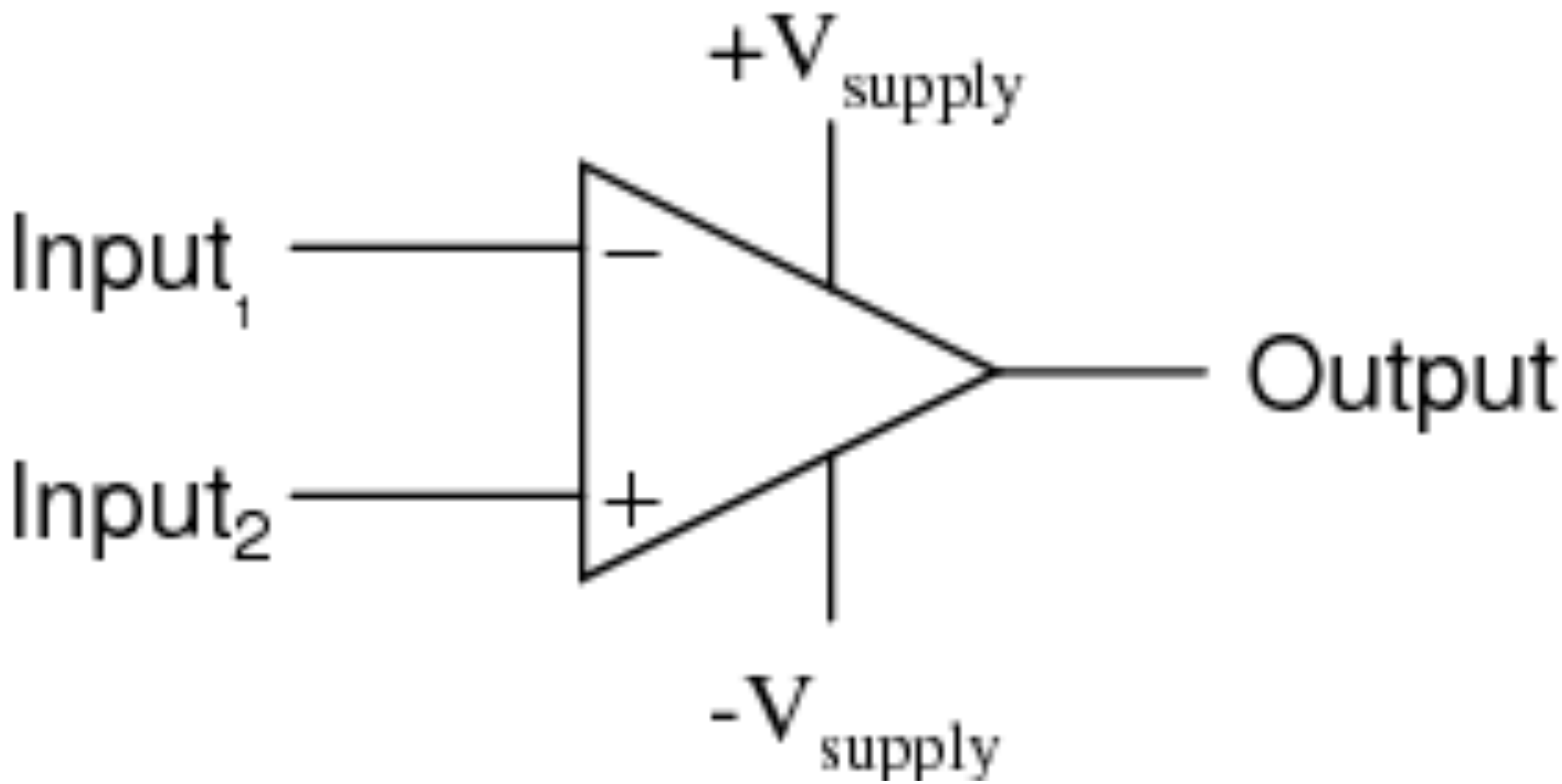
= 590 mV/lb or 0.59 V/lb

The name operational amplifiers implies more than a simple amplifier though



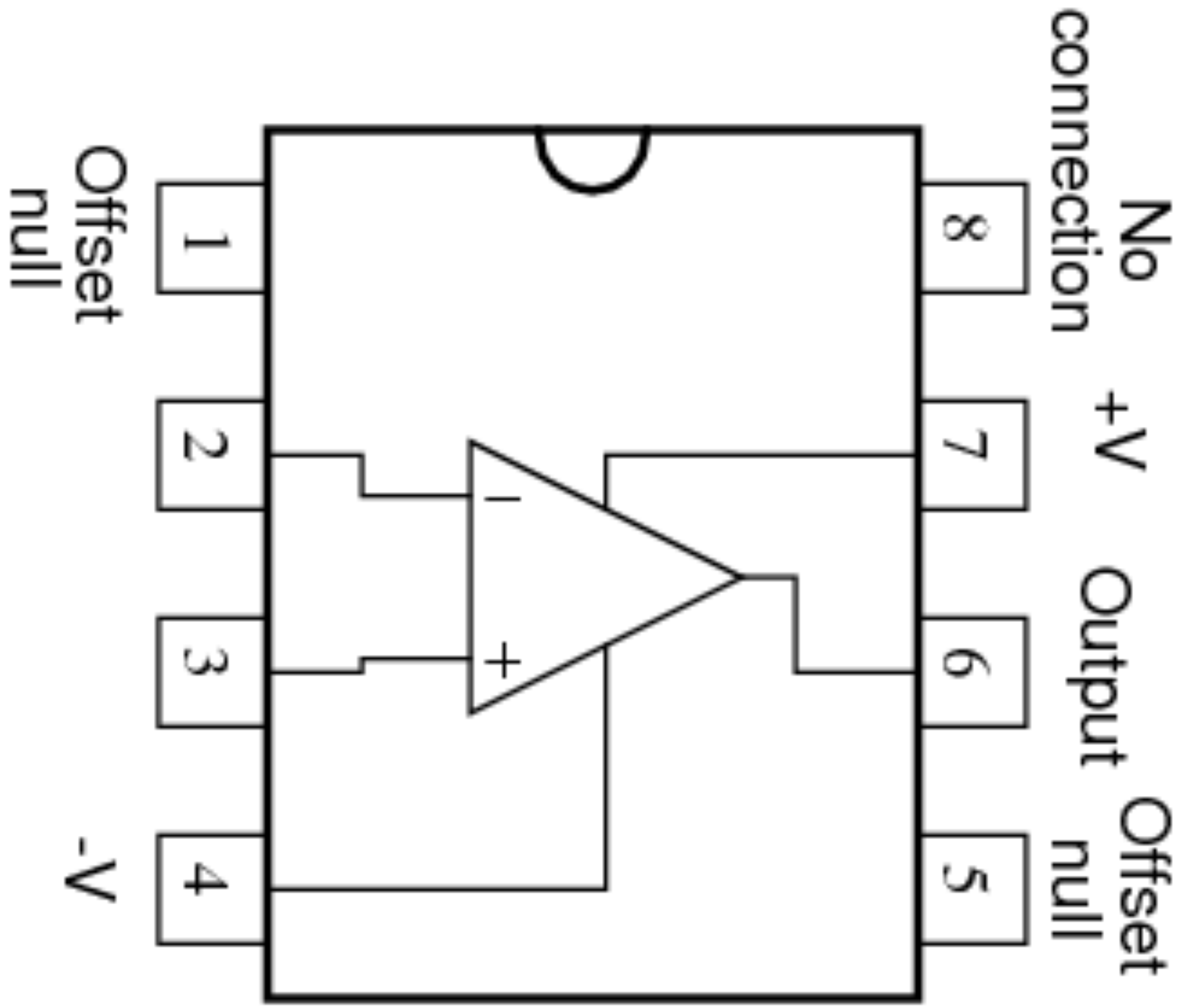
Images: Cornell

Let's look at some terminals of the operational amplifier



Images: allaboutcircuits.com

Real amplifiers have a few more connections that we'll get to

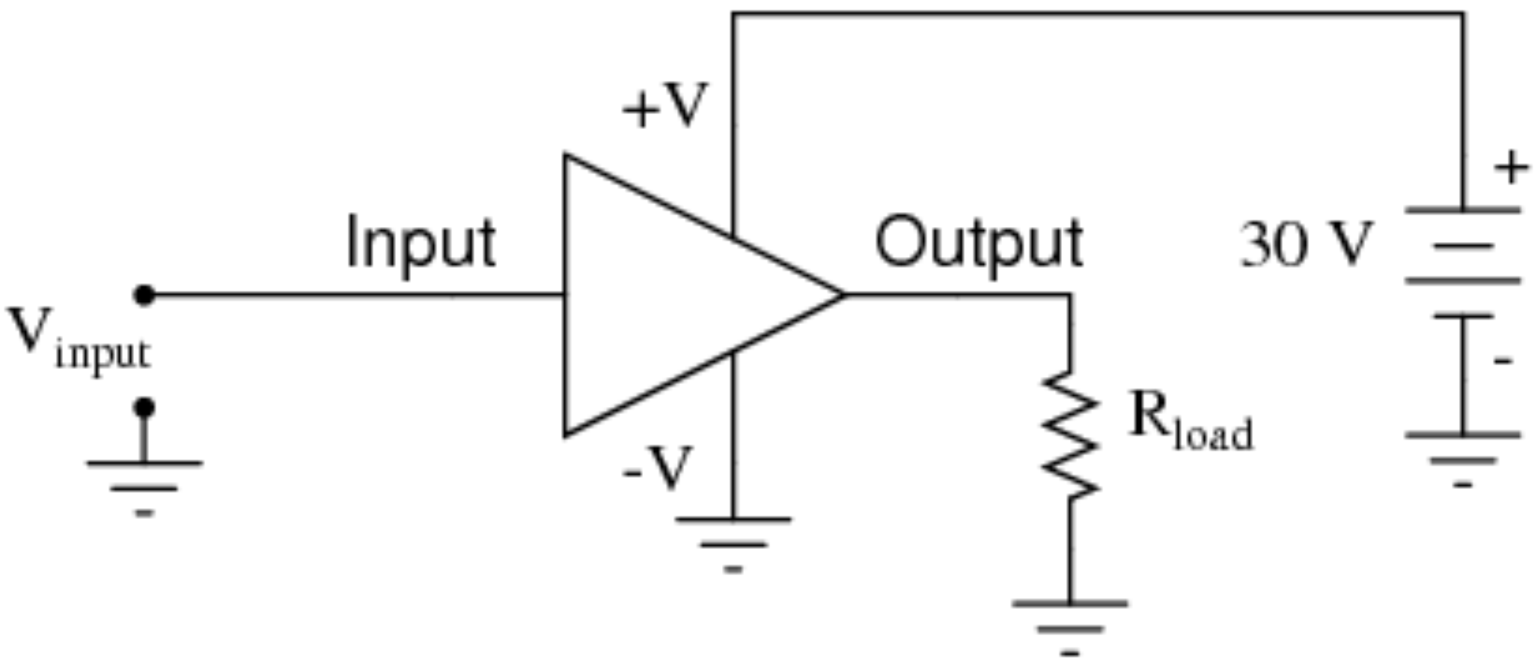


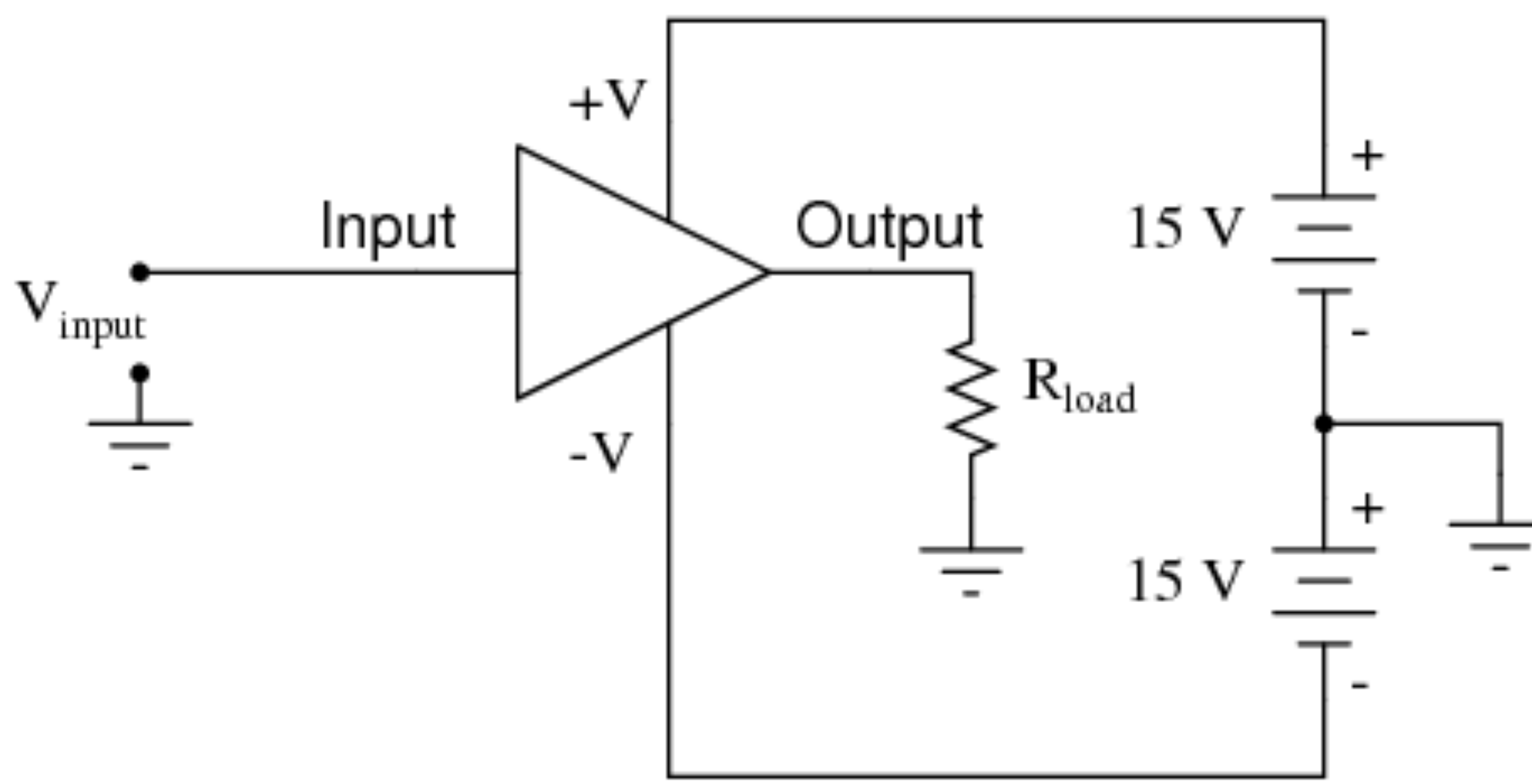
Images: allaboutcircuits.com

Understanding the ideal op-amp is enough to examine many circuits, but can be problematic in actual design

1. Infinite open-loop voltage gain
2. Infinite input impedance
3. Zero output impedance
4. Zero noise contribution
5. Zero DC output offset
6. Infinite bandwidth

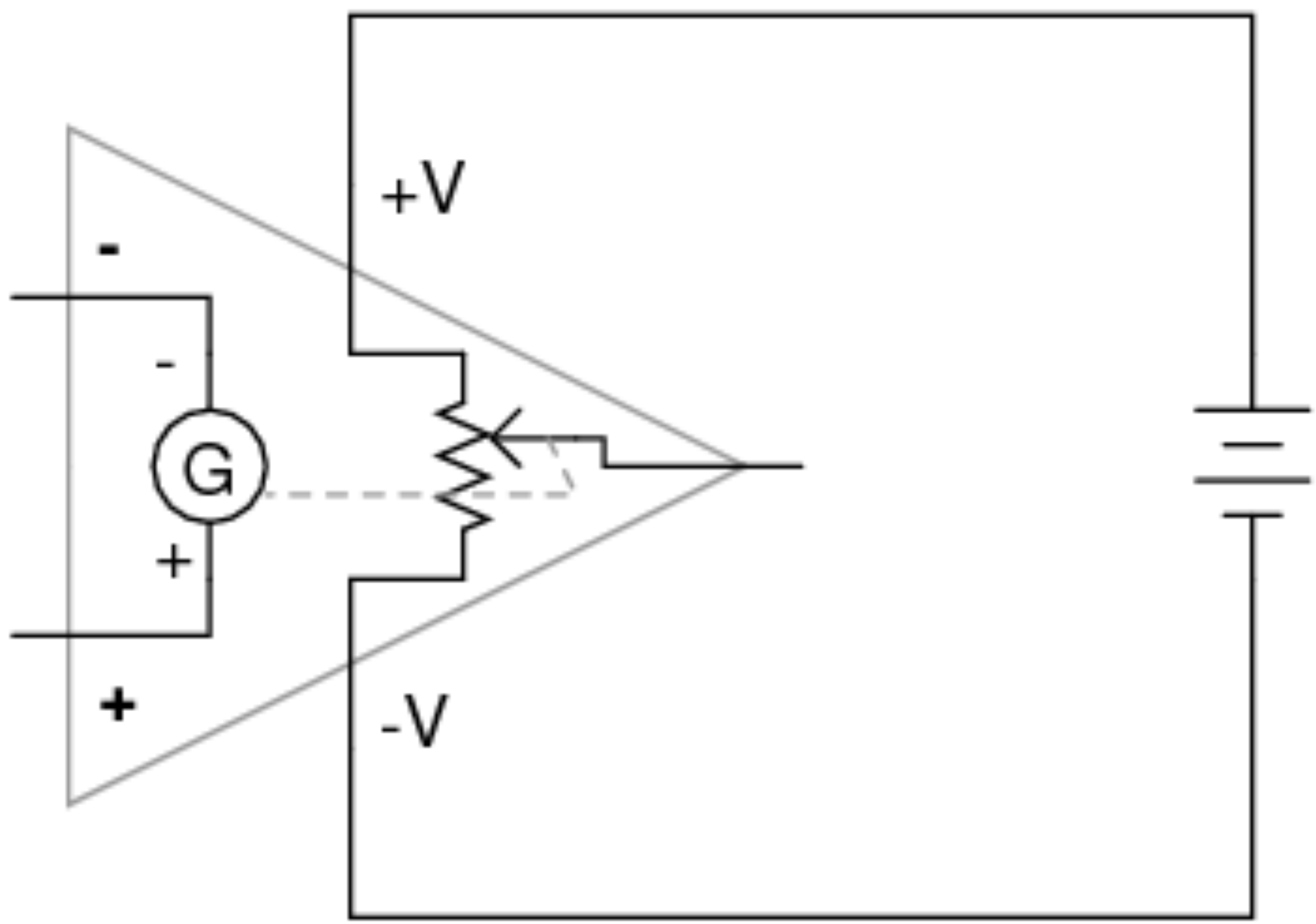
Op-amps can be powered by unipolar or bipolar power supplies





Images: allaboutcircuits.com

You can think of an operational amplifier in this simplified model - the output should always be the sum of the inputs with the open loop gain applied!



Images: allaboutcircuits.com

Open loop gain is the gain with NO feedback from output to input.

It is generally 20,000 - 200,000 in real op-amps

TEXAS INSTRUMENTS

LM741

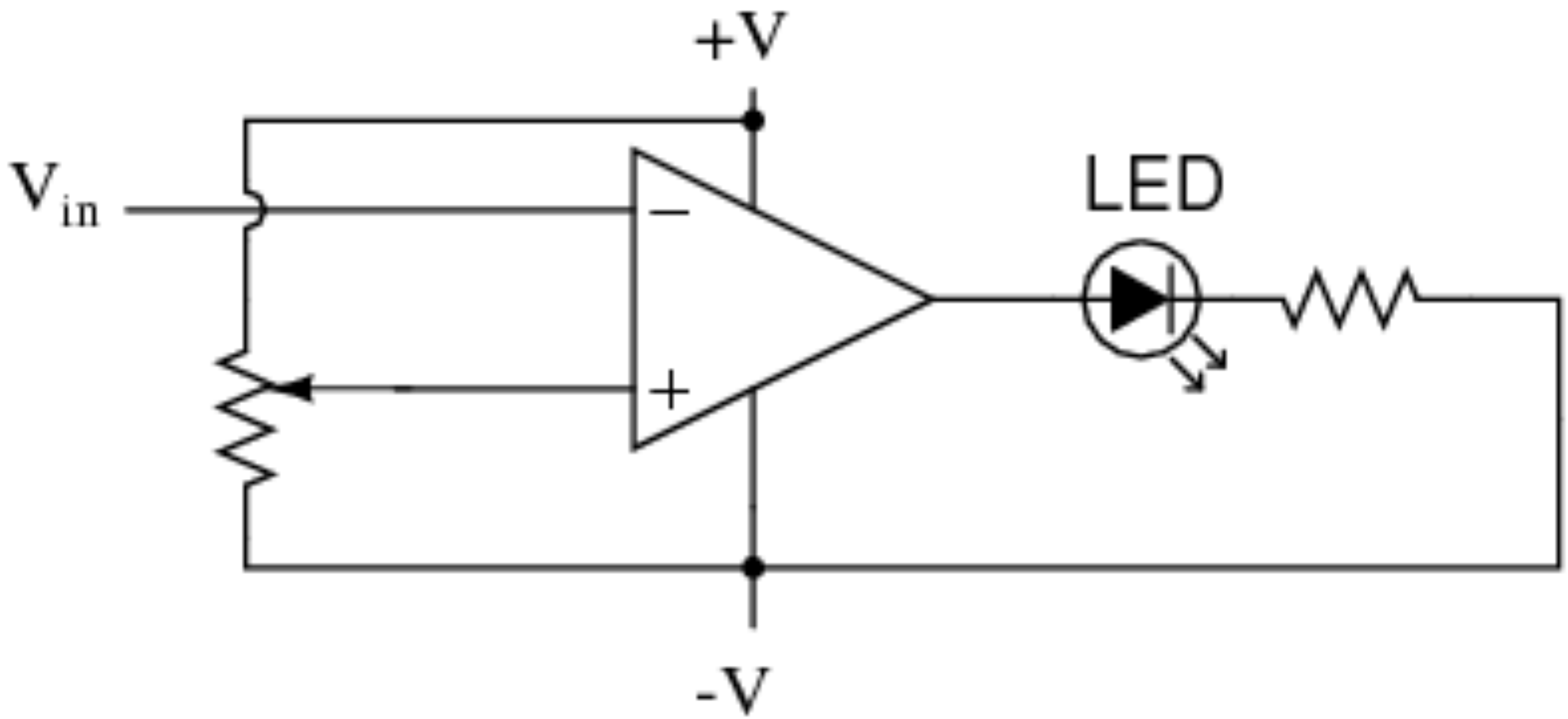
SNOSC25D – MAY 1998 – REVISED OCTOBER 2015

LM741 Operational Amplifier

6.5 Electrical Characteristics, LM741 [(1)]

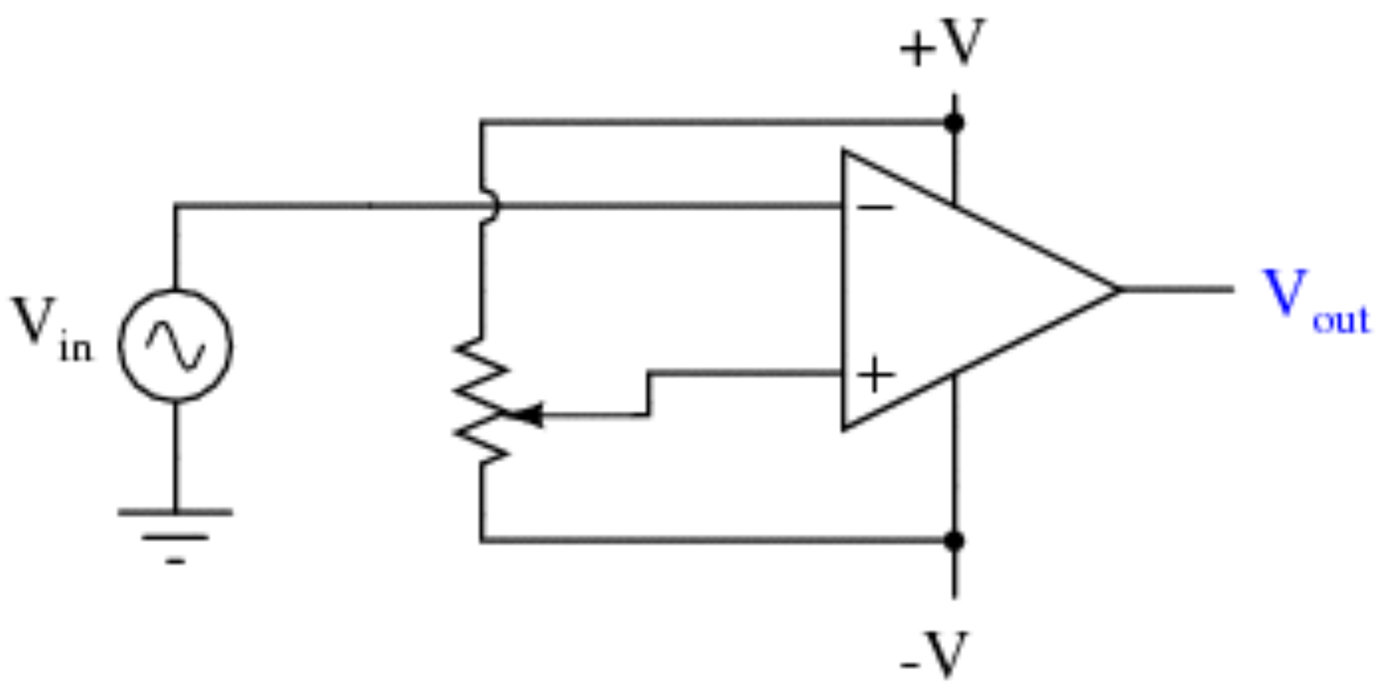
PARAMETER		TEST CONDITIONS		MIN	TYP	MAX	UNIT
Input offset voltage		R_S ≤ 10 kΩ	T_A = 25°C		1	5	mV
			T_{AMIN} ≤ T_A ≤ T_{AMAX}			6	mV
Input offset voltage adjustment range		T_A = 25°C, V_S = ±20 V			±15		mV
Input offset current		T_A = 25°C			20	200	nA
		T_{AMIN} ≤ T_A ≤ T_{AMAX}			85	500	
Input bias current		T_A = 25°C			80	500	nA
		T_{AMIN} ≤ T_A ≤ T_{AMAX}				1.5	μA
Input resistance		T_A = 25°C, V_S = ±20 V		0.3	2		MΩ
Input voltage range		T_{AMIN} ≤ T_A ≤ T_{AMAX}		±12	±13		V
Large signal voltage gain		V_S = ±15 V, V_O = ±10 V, R_L ≥ 2 kΩ	T_A = 25°C	50	200		V/mV
			T_{AMIN} ≤ T_A ≤ T_{AMAX}	25			
Output voltage swing		V_S = ±15 V	R_L ≥ 10 kΩ	±12	±14		V
			R_L ≥ 2 kΩ	±10	±13		
Output short circuit current		T_A = 25°C			25		mA
Common-mode rejection ratio		R_S ≤ 10 Ω, V_{CM} = ±12 V, T_{AMIN} ≤ T_A ≤ T_{AMAX}		80	95		dB
Supply voltage rejection ratio		V_S = ±20 V to V_S = ±5 V, R_S ≤ 10 Ω, T_{AMIN} ≤ T_A ≤ T_{AMAX}		86	96		dB
Transient response	Rise time	T_A = 25°C, unity gain			0.3		μs
	Overshoot				5%		
Slew rate		T_A = 25°C, unity gain			0.5		V/μs
Supply current		T_A = 25°C			1.7	2.8	mA
Power consumption		V_S = ±15 V	T_A = 25°C		50	85	mW
			T_A = T_{AMIN}		60	100	
			T_A = T_{AMAX}		45	75	

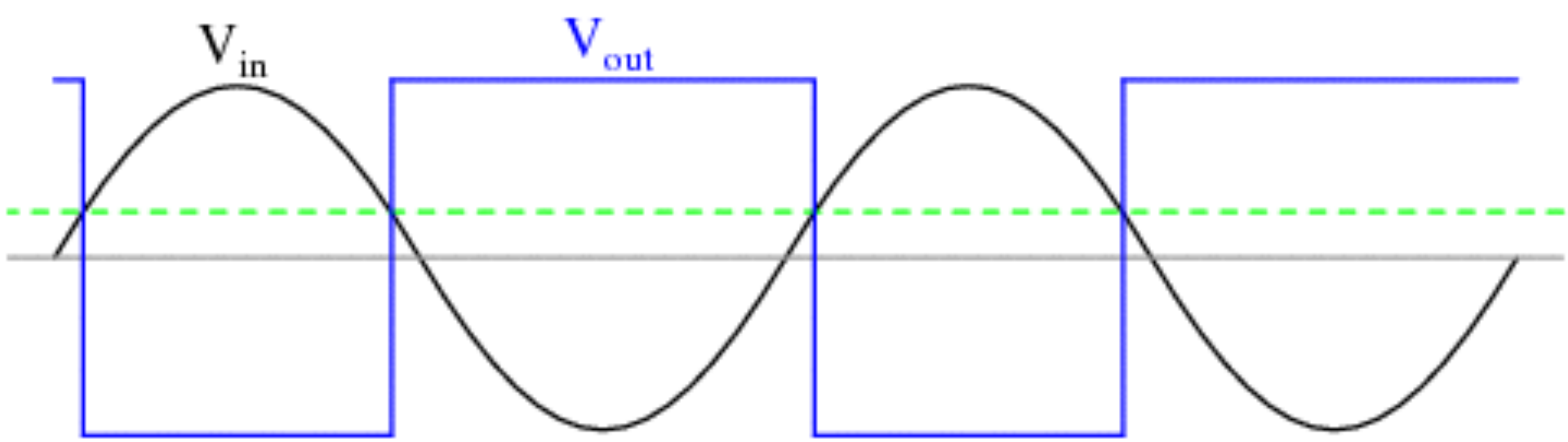
In an open loop configuration we can build a voltage comparator



Images: allaboutcircuits.com

Squaring up a waveform is another common application





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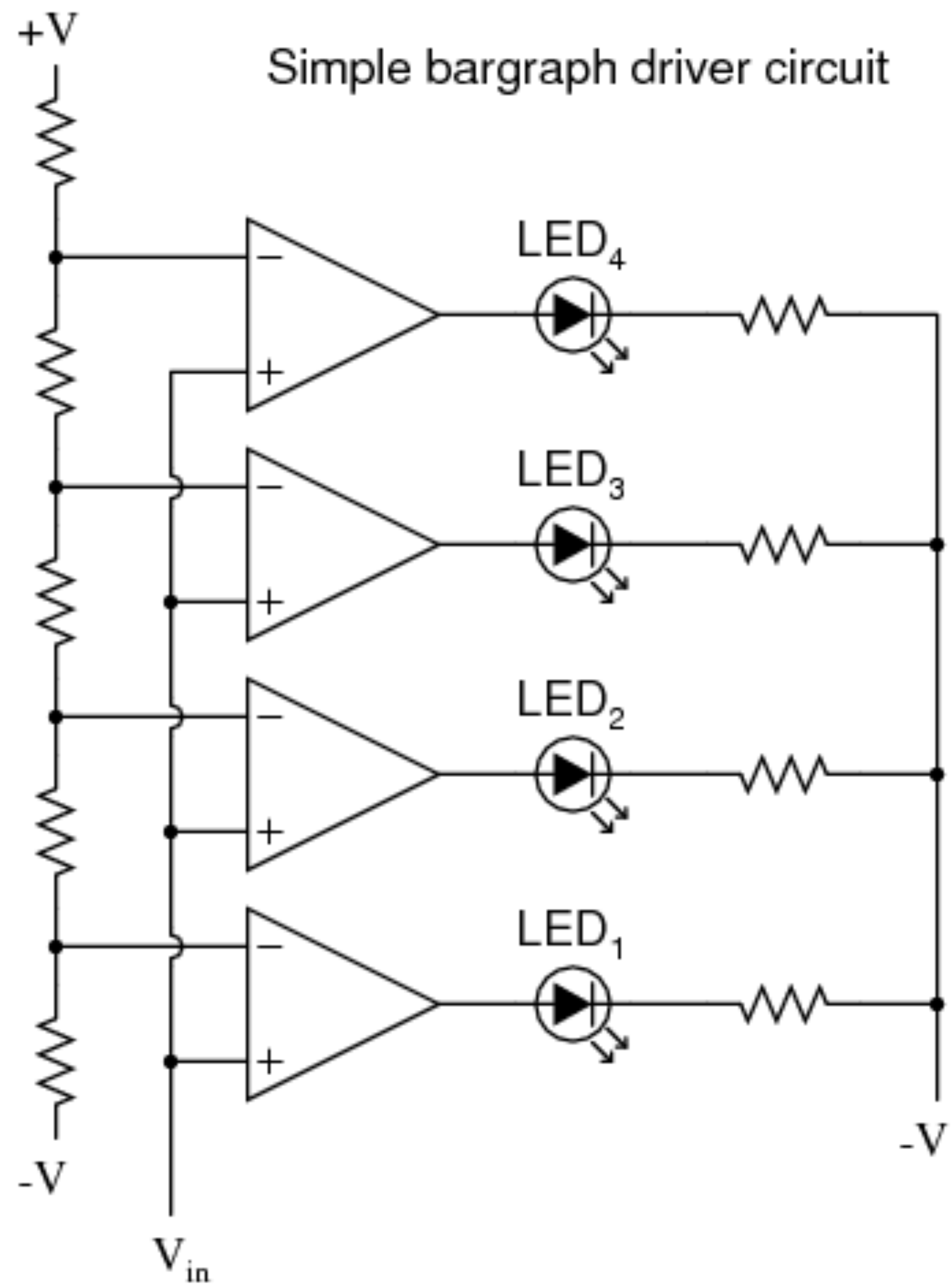
A voltage divider and series of comparators can make an LED bargraph driver



Images: allaboutcircuits.com

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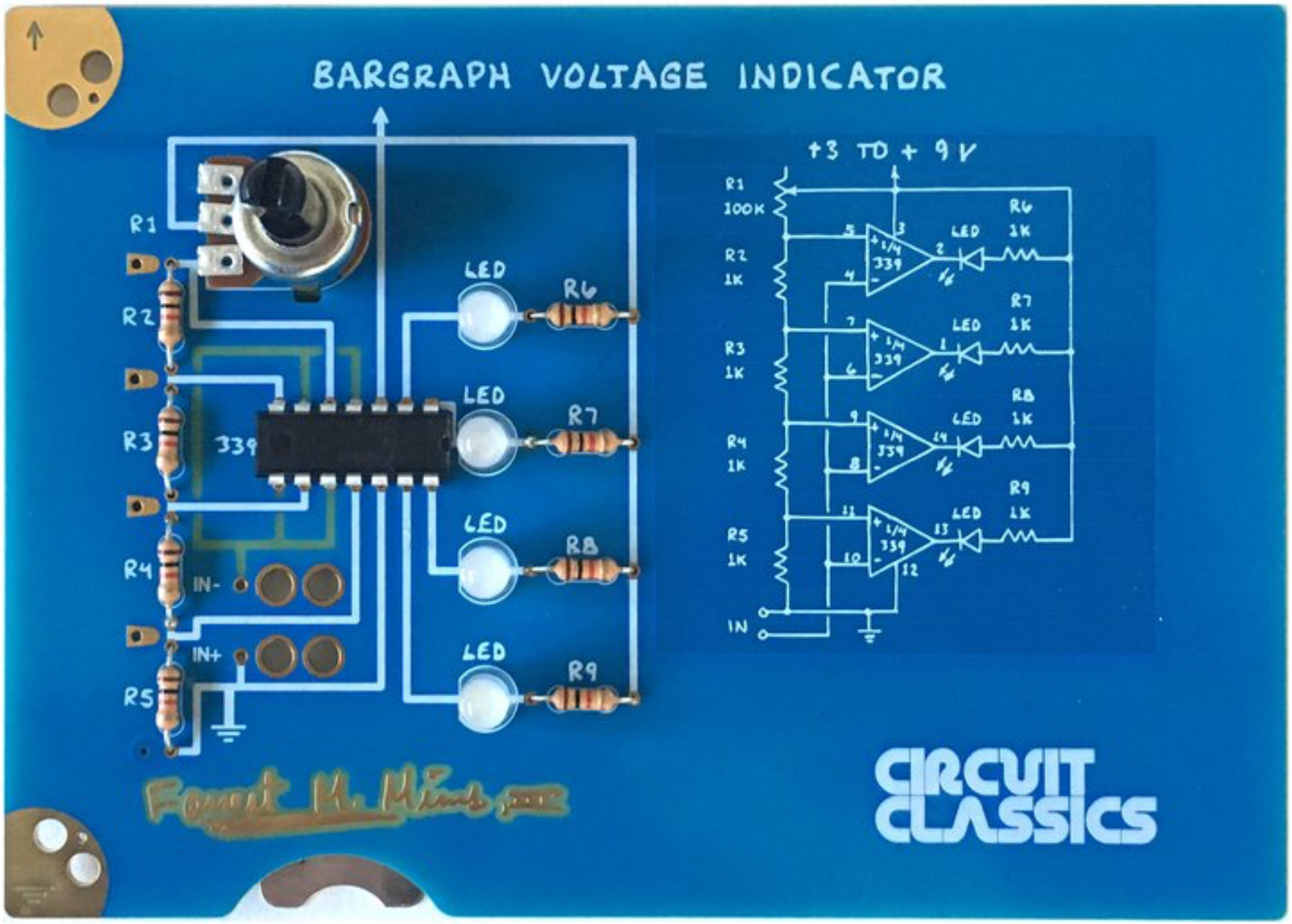
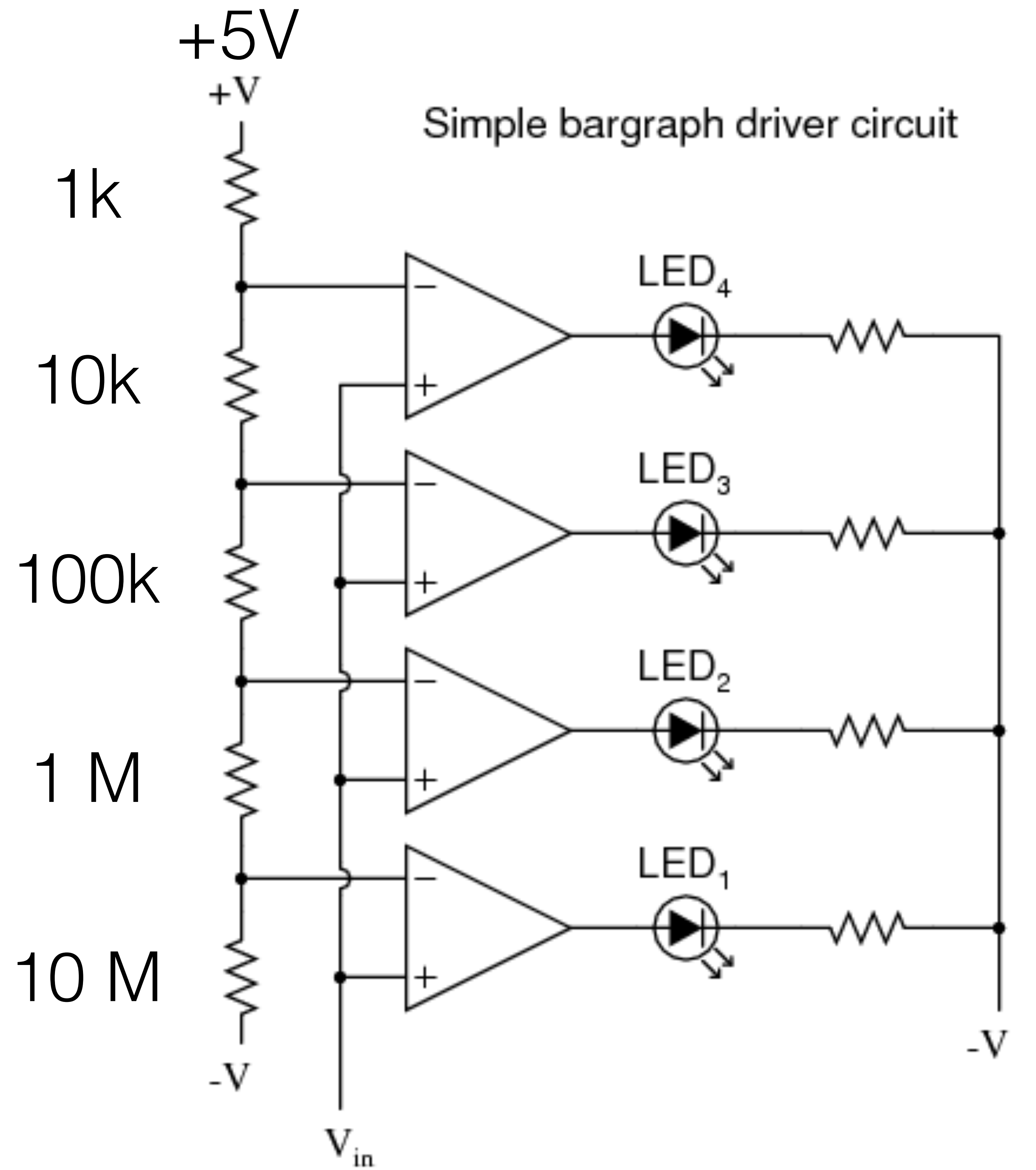


Images: Crowd Supply

Activity: Calculate the voltage at which each LED will switch on



Images: allaboutcircuits.com

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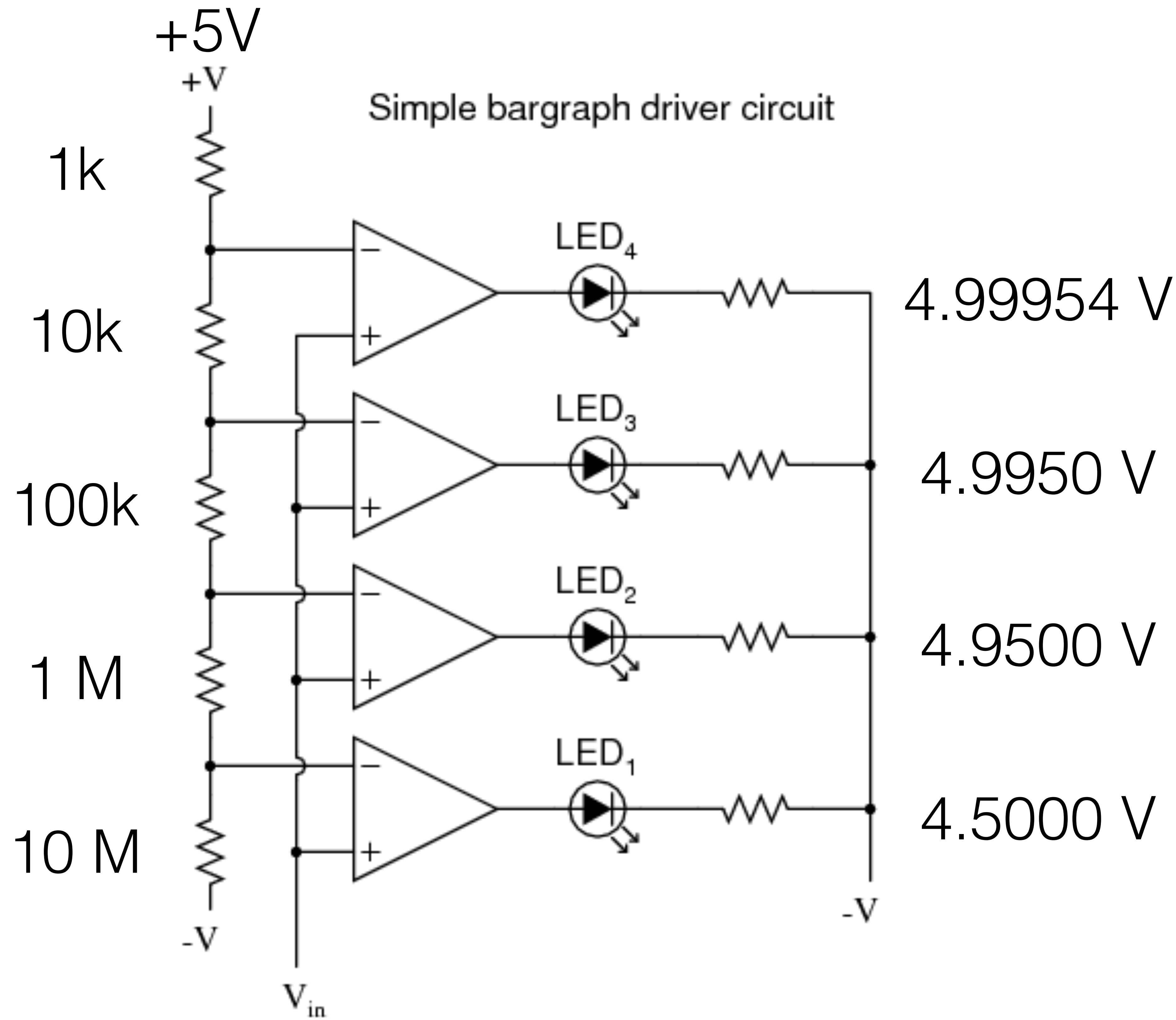
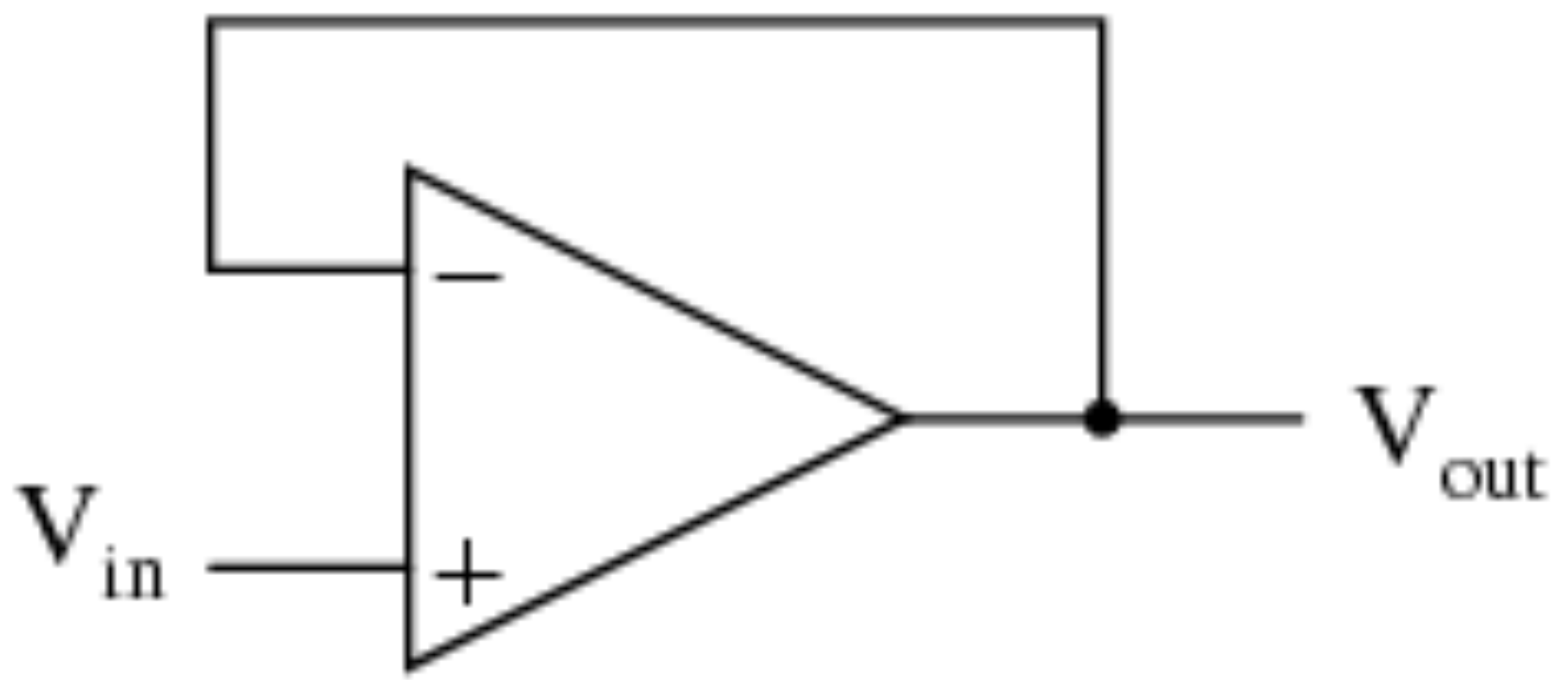


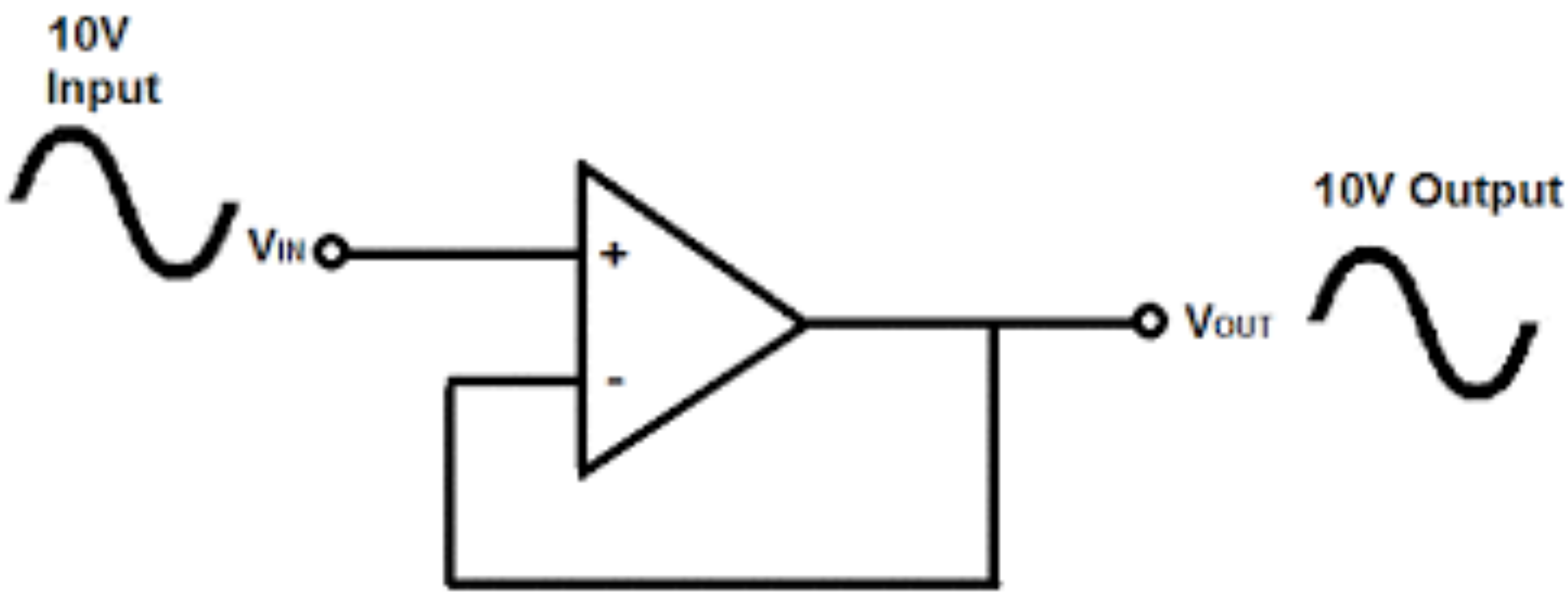
Images: allaboutcircuits.com

What happens if we hook up the amplifier with negative feedback?



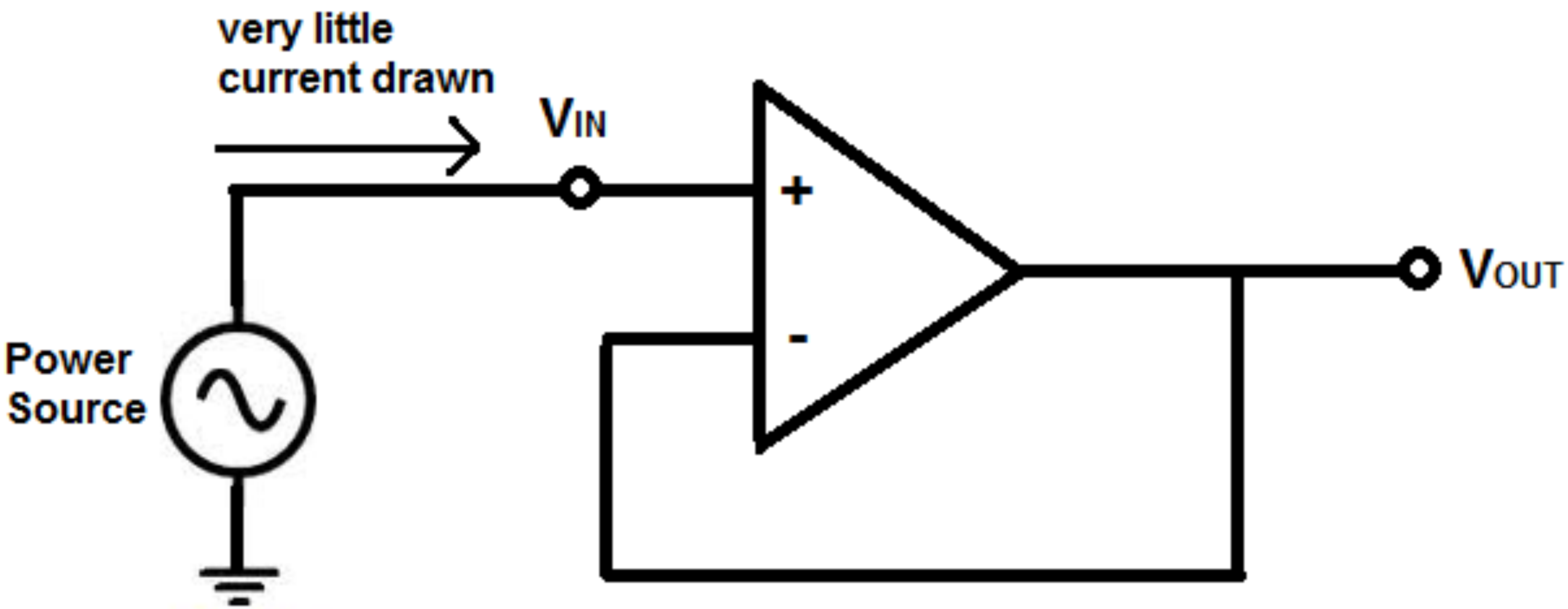
Images: allaboutcircuits.com

This circuit is called a voltage follower



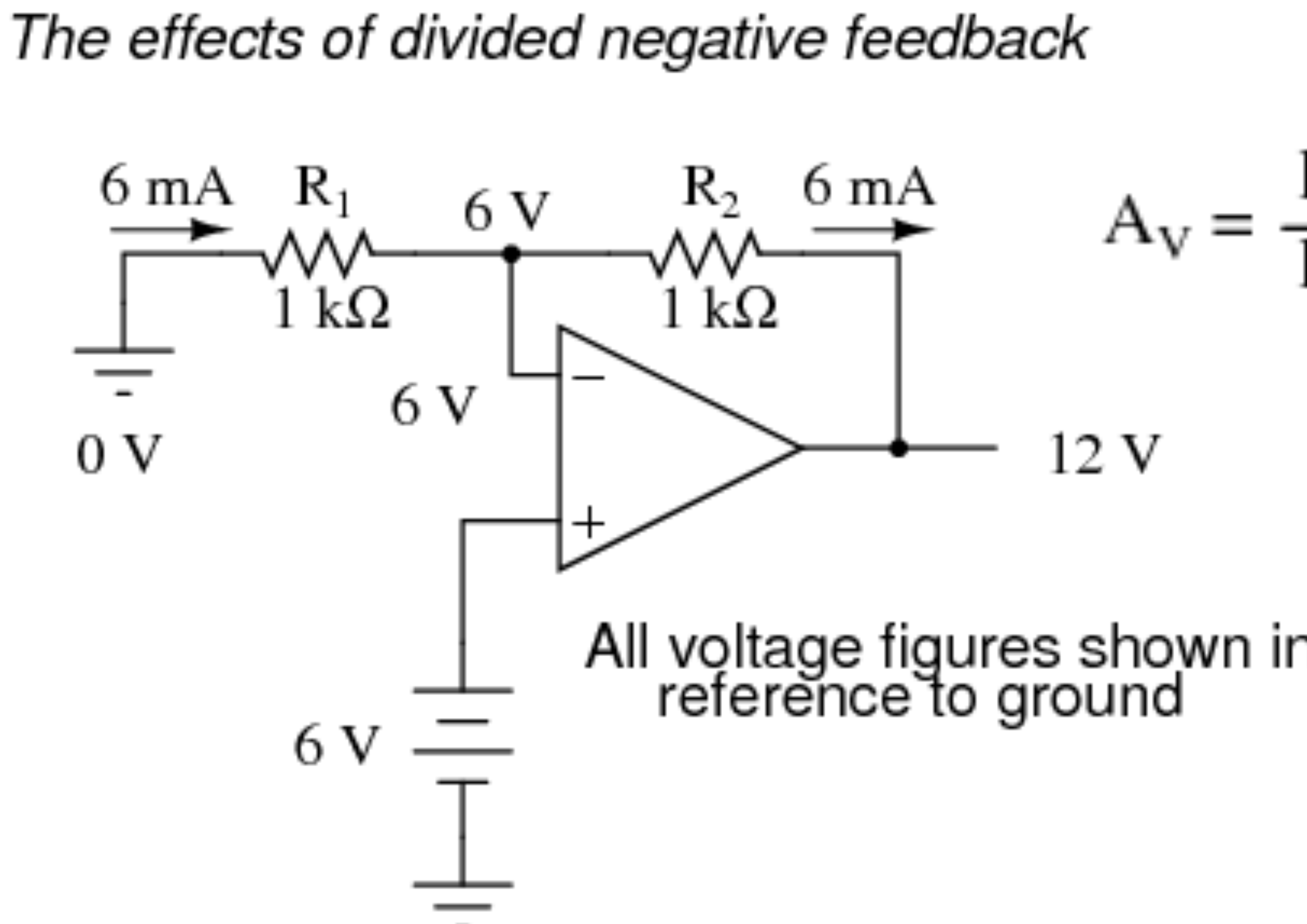
Images: learningaboutelectronics.com

We use voltage followers to buffer between our signal and the load (think back to the ideal op-amp "rules")



Images: learningaboutelectronics.com

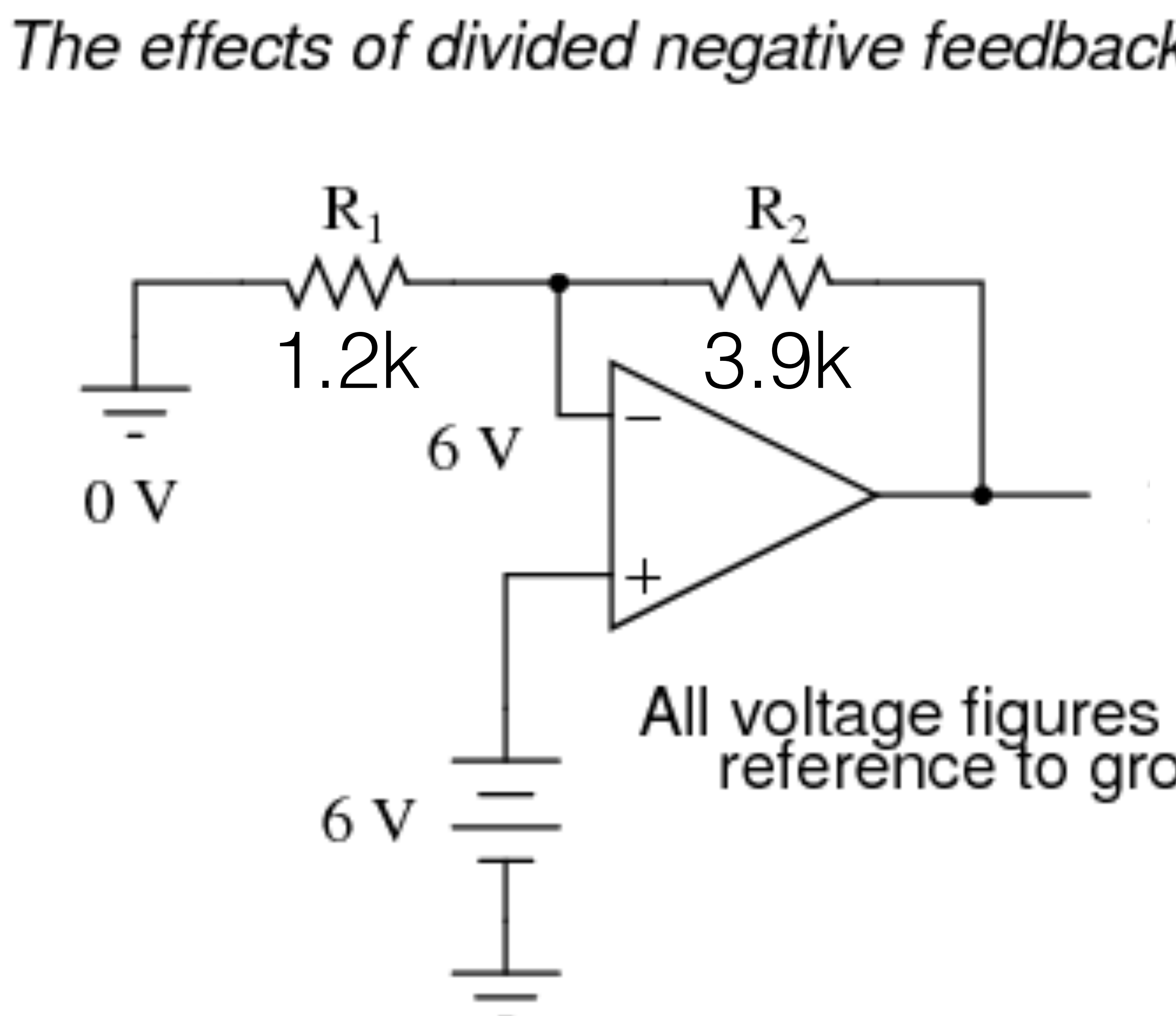
We can place a voltage divider in the negative feedback loop to control the gain of the circuit (non-inventing amplifier)



$$A_V = \frac{R_2}{R_1} + 1$$

Images: allaboutcircuits.com

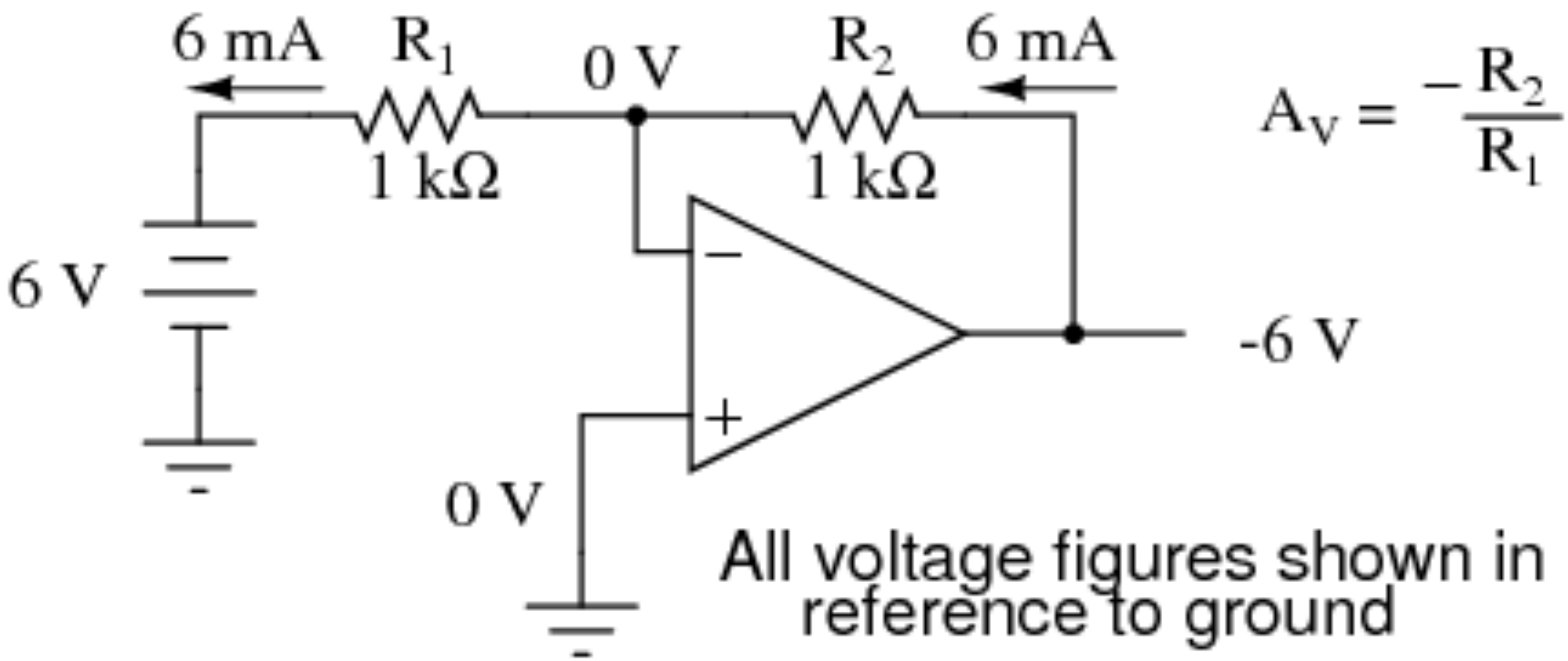
Activity: What is the gain of this circuit? What is the output?



$$A_V = \frac{R_2}{R_1} + 1$$

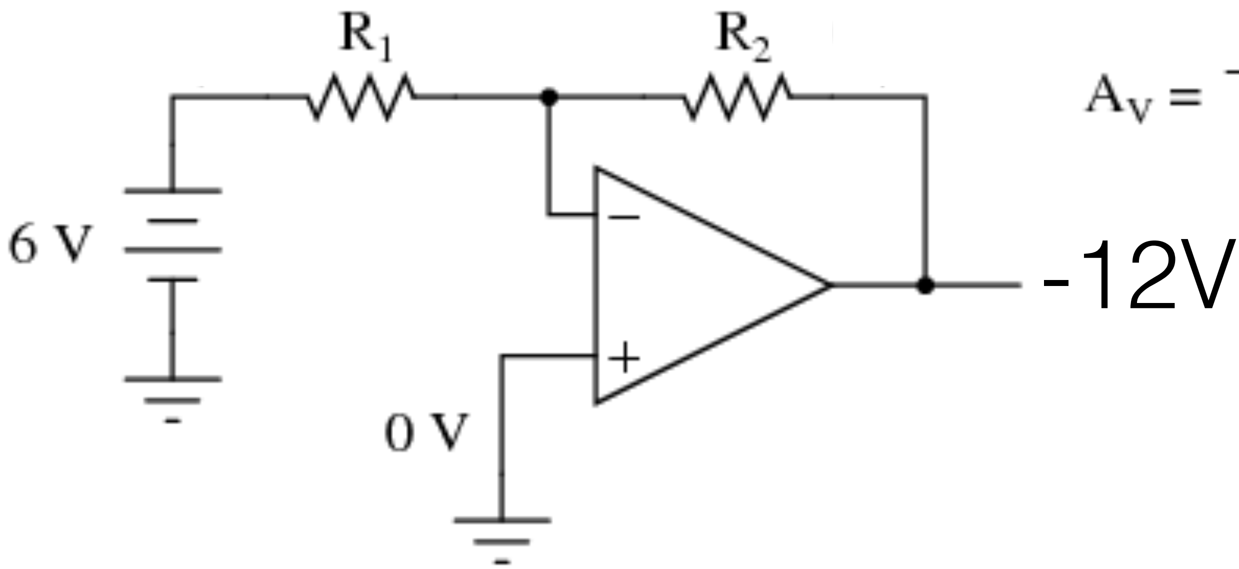
Images: allaboutcircuits.com

By changing where the input is, we can create an inverting amplifier



Images: allaboutcircuits.com

Activity: What are valid combinations of standard value resistors for R1,R2?

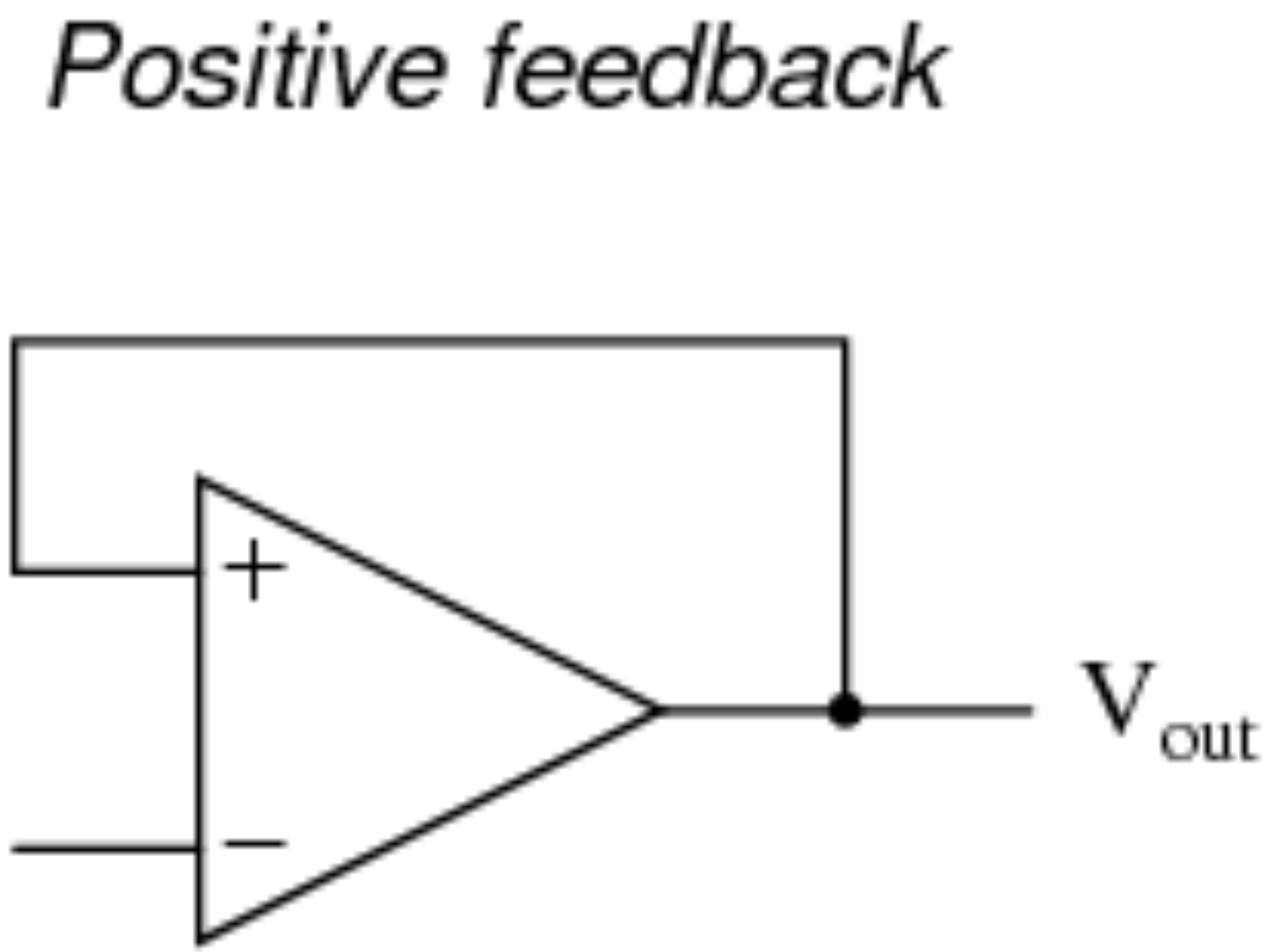


$$A_V = \frac{-R_2}{R_1}$$

Standard Resistor Values (±5%)						
1.0	10	100	1.0K	10K	100K	1.0M
1.1	11	110	1.1K	11K	110K	1.1M
1.2	12	120	1.2K	12K	120K	1.2M
1.3	13	130	1.3K	13K	130K	1.3M
1.5	15	150	1.5K	15K	150K	1.5M
1.6	16	160	1.6K	16K	160K	1.6M
1.8	18	180	1.8K	18K	180K	1.8M
2.0	20	200	2.0K	20K	200K	2.0M
2.2	22	220	2.2K	22K	220K	2.2M
2.4	24	240	2.4K	24K	240K	2.4M
2.7	27	270	2.7K	27K	270K	2.7M
3.0	30	300	3.0K	30K	300K	3.0M
3.3	33	330	3.3K	33K	330K	3.3M
3.6	36	360	3.6K	36K	360K	3.6M
3.9	39	390	3.9K	39K	390K	3.9M
4.3	43	430	4.3K	43K	430K	4.3M
4.7	47	470	4.7K	47K	470K	4.7M
5.1	51	510	5.1K	51K	510K	5.1M
5.6	56	560	5.6K	56K	560K	5.6M
6.2	62	620	6.2K	62K	620K	6.2M
6.8	68	680	6.8K	68K	680K	6.8M
7.5	75	750	7.5K	75K	750K	7.5M
8.2	82	820	8.2K	82K	820K	8.2M
9.1	91	910	9.1K	91K	910K	9.1M

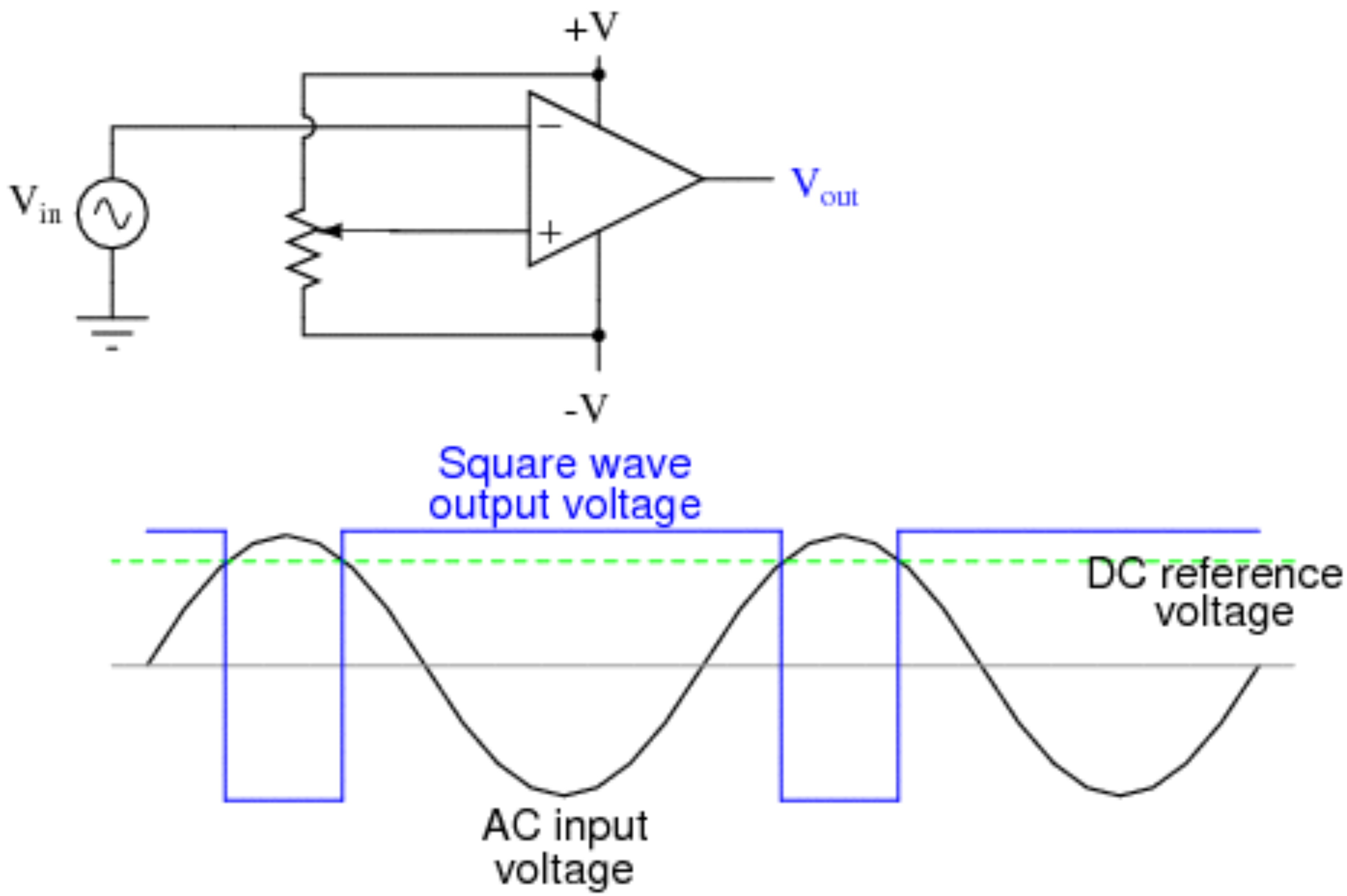
Images: allaboutcircuits.com

We can also use positive feedback, what happens if we ground the inverting input?



Images: allaboutcircuits.com

Remember using a comparator to square a waveform?



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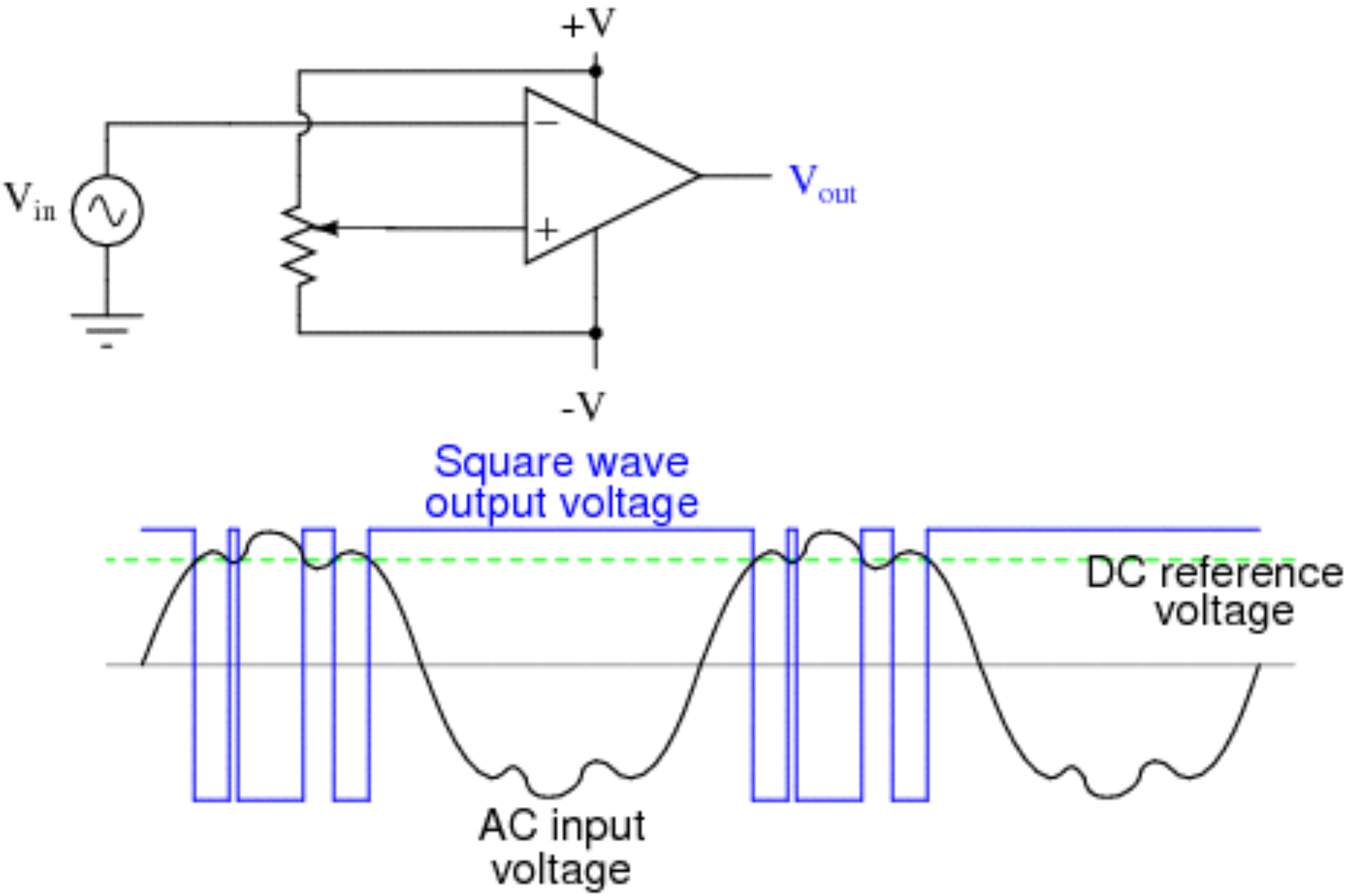
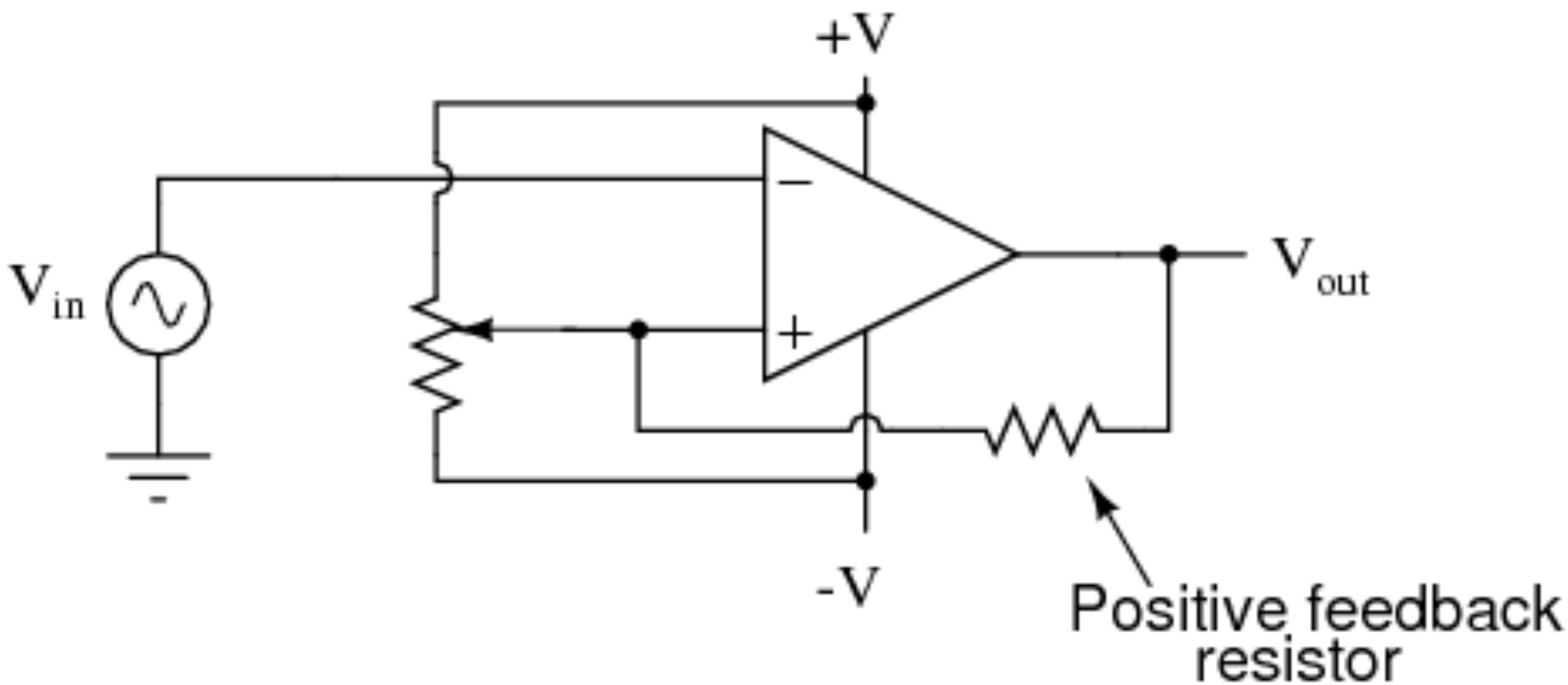
What if there is some noise on the input waveform?



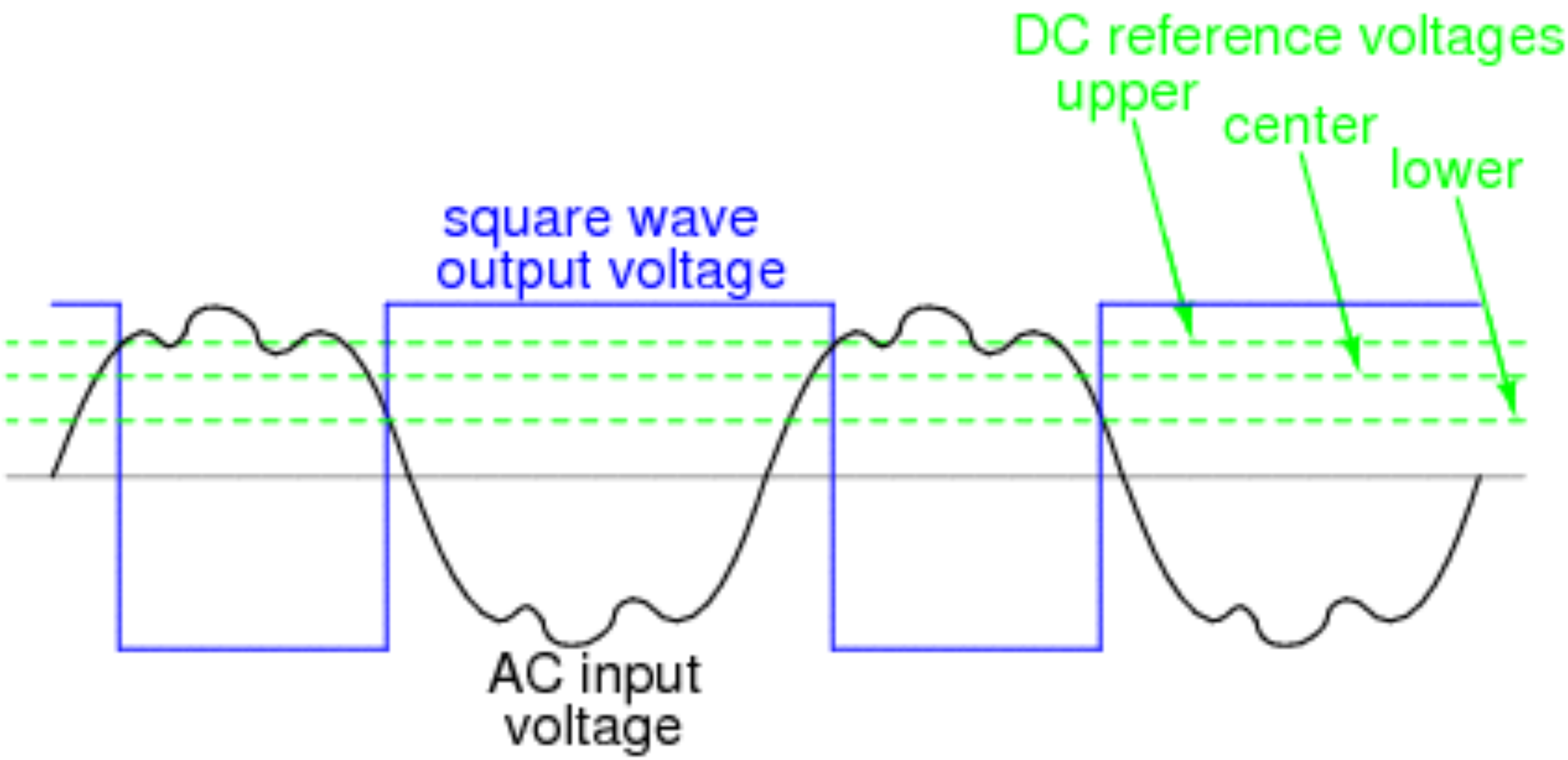
Images: allaboutcircuits.com

Adding some positive feedback imposes hysteresis on the circuit



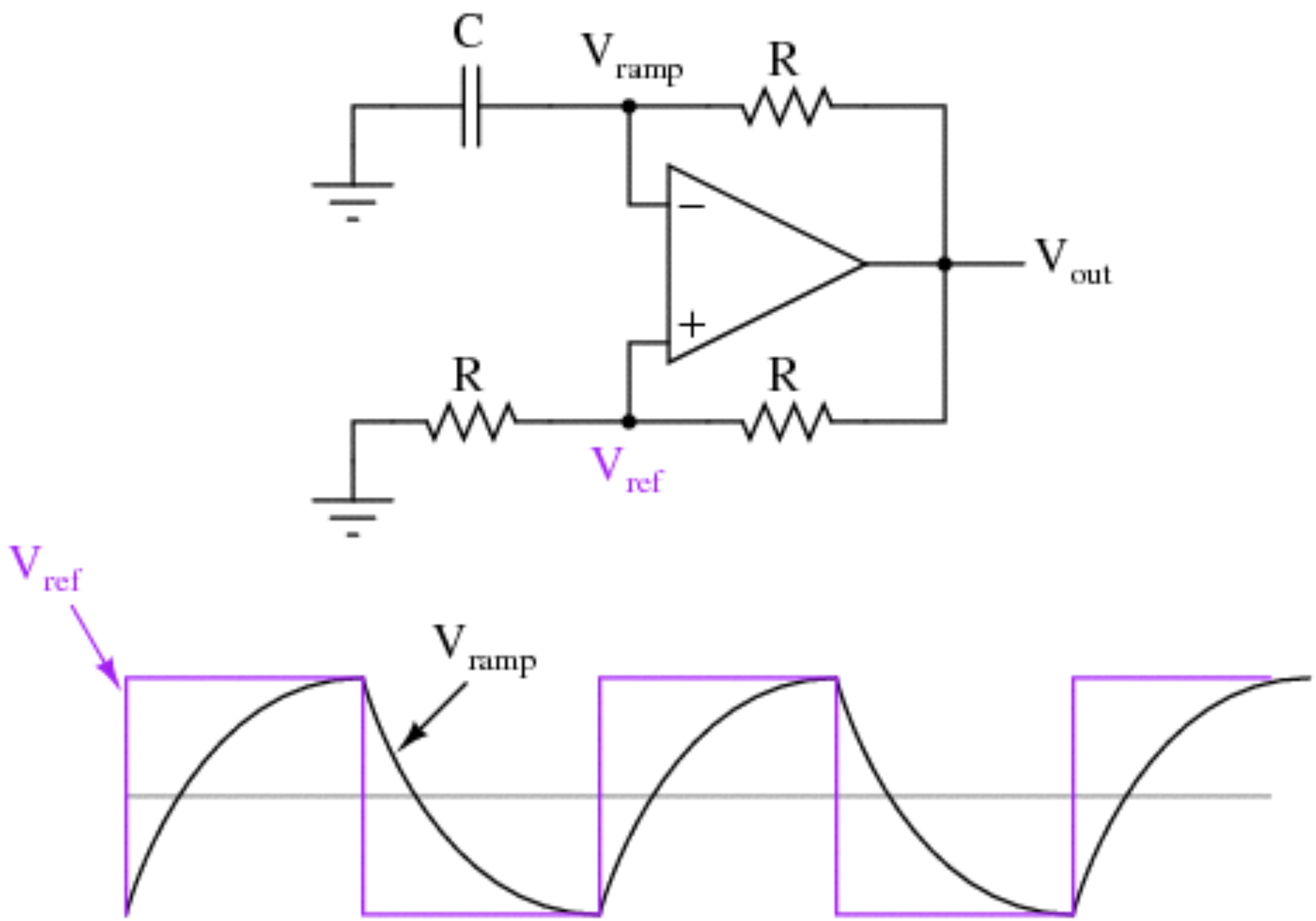
Images: allaboutcircuits.com

This cleans the waveform up dramatically



Images: allaboutcircuits.com

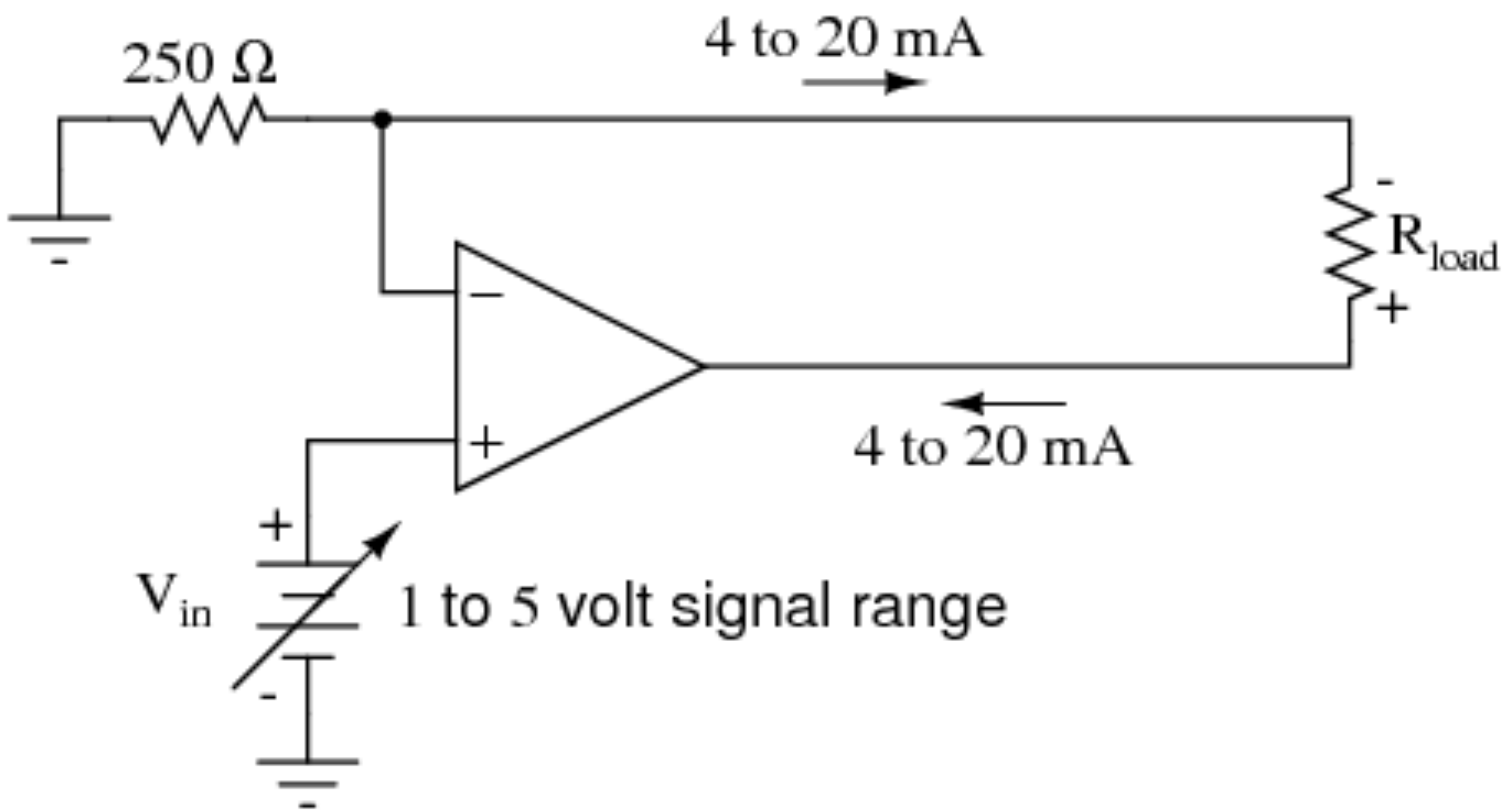
We can even create an oscillator with positive feedback



V_{out} is a square wave just like V_{ref}, only taller

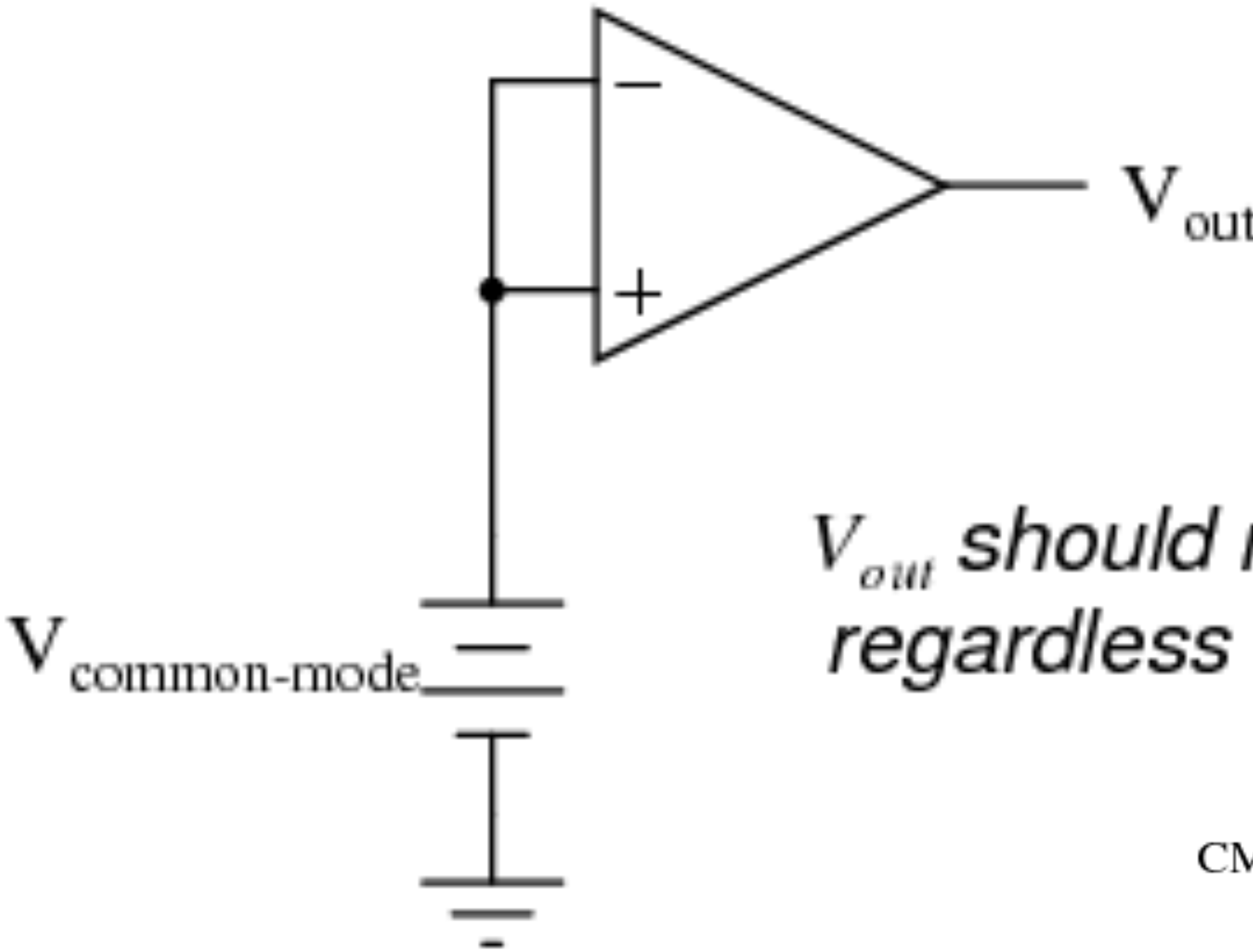
Images: allaboutcircuits.com

We can make voltage to current converters with op-amps for long distance signaling



Images: allaboutcircuits.com

Common mode rejection is a big spec to watch out for!



V_{out} should remain the same regardless of $V_{common\text{-}mode}$

$$\text{CMRR} = \frac{\text{Differential } A_V}{\text{Common-mode } A_V}$$

$$A_V = \frac{\text{Change in } V_{out}}{\text{Change in } V_{in}}$$

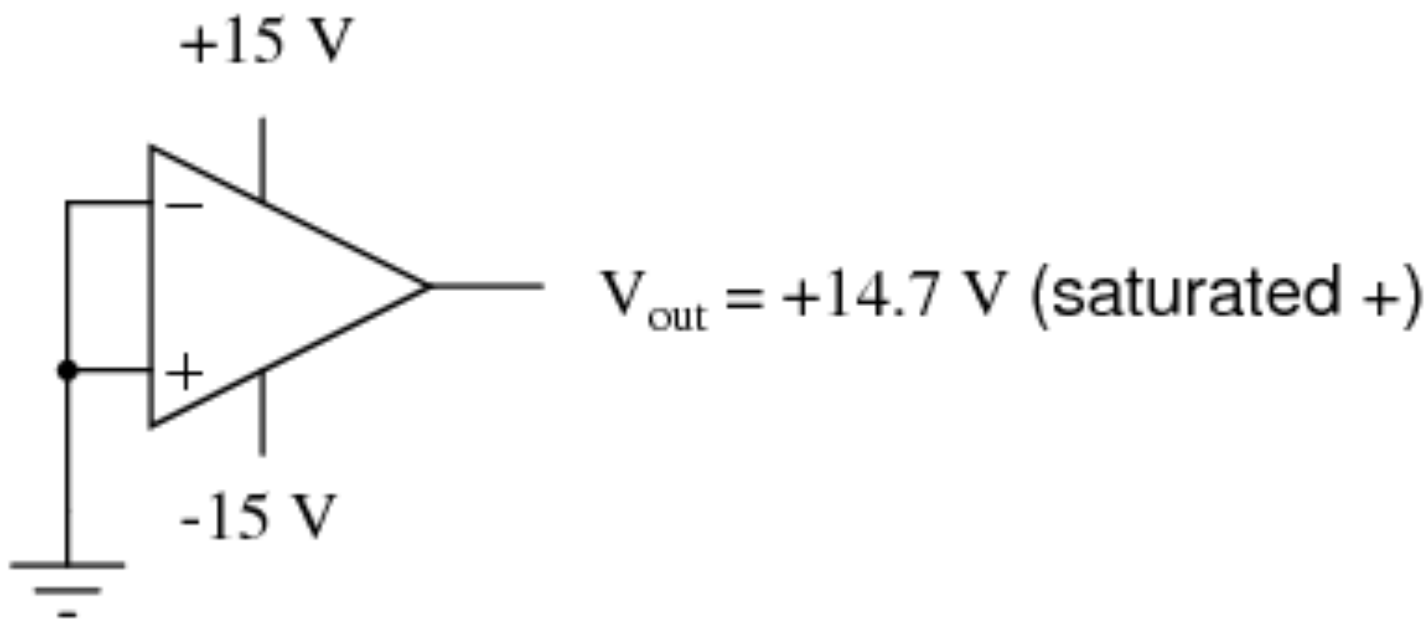
. . . if change in $V_{out} = 0$ . . .

$$\frac{0}{\text{Change in } V_{in}} = 0$$

$$A_V = 0$$

Images: allaboutcircuits.com

Input offset voltage is another non-ideal characteristic of real op-amps



Images: allaboutcircuits.com

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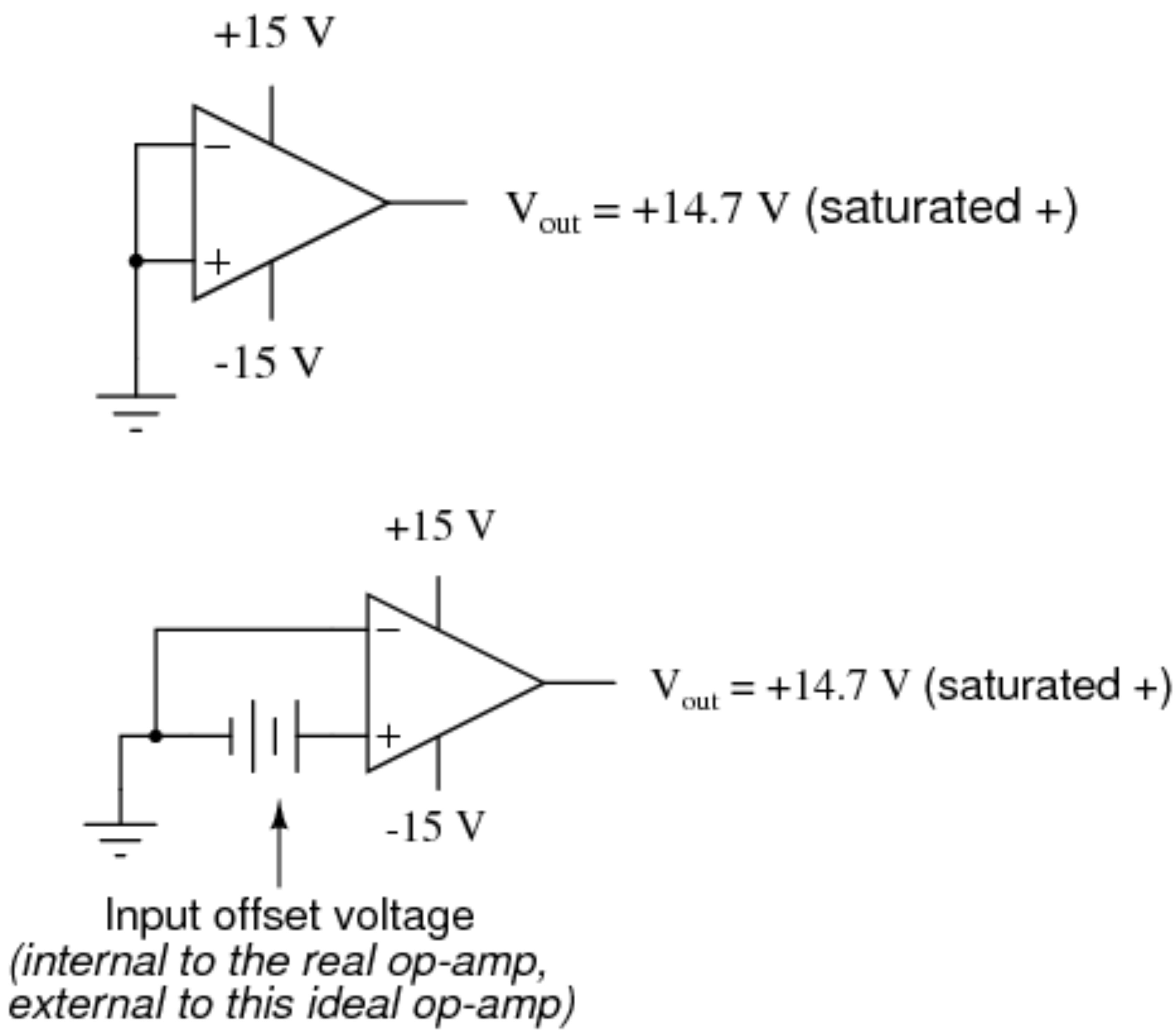
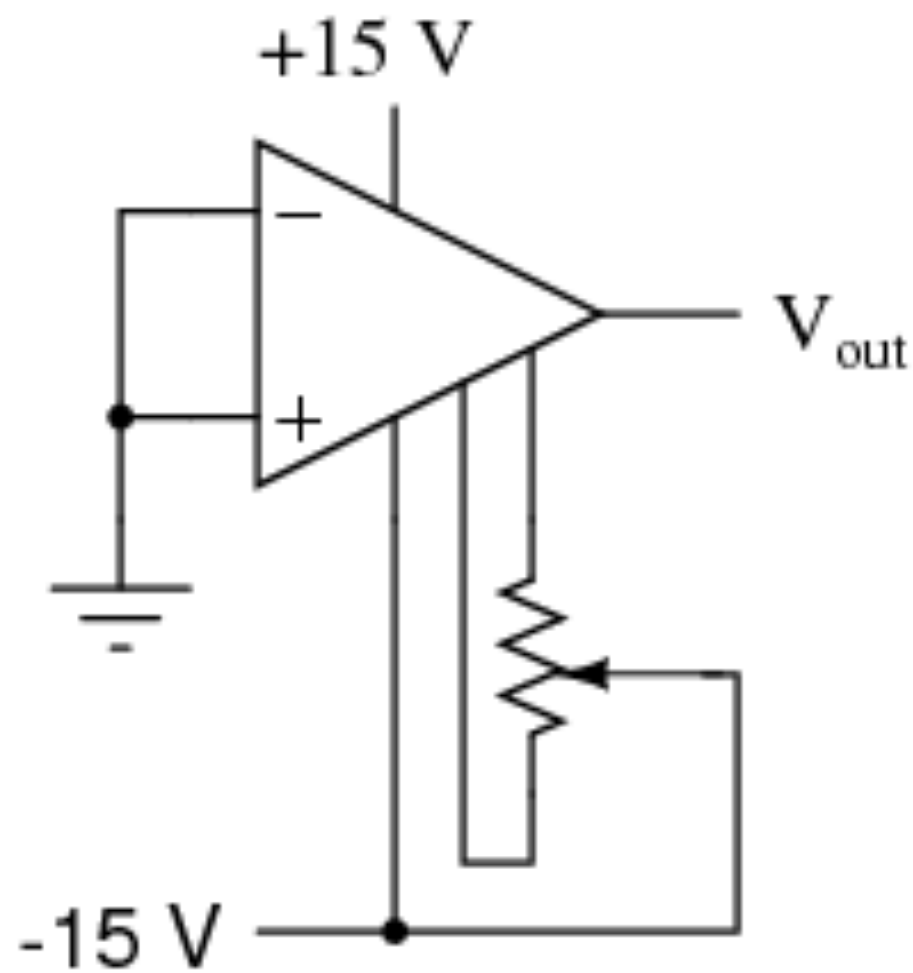


Images: allaboutcircuits.com

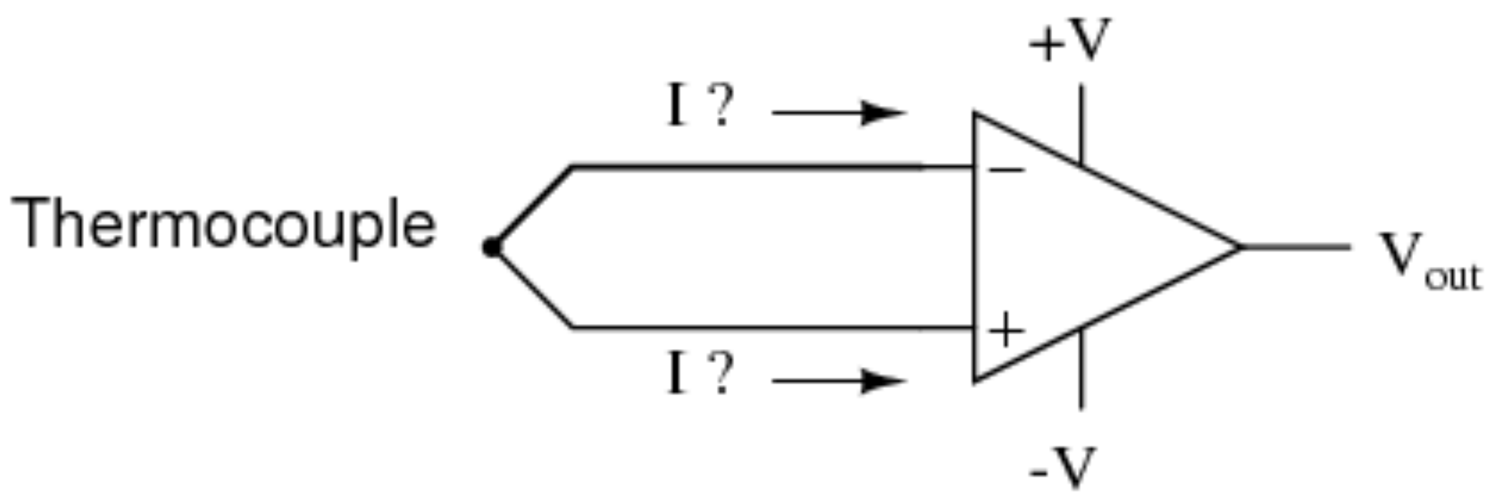
You can use a potentiometer to null the offset if necessary



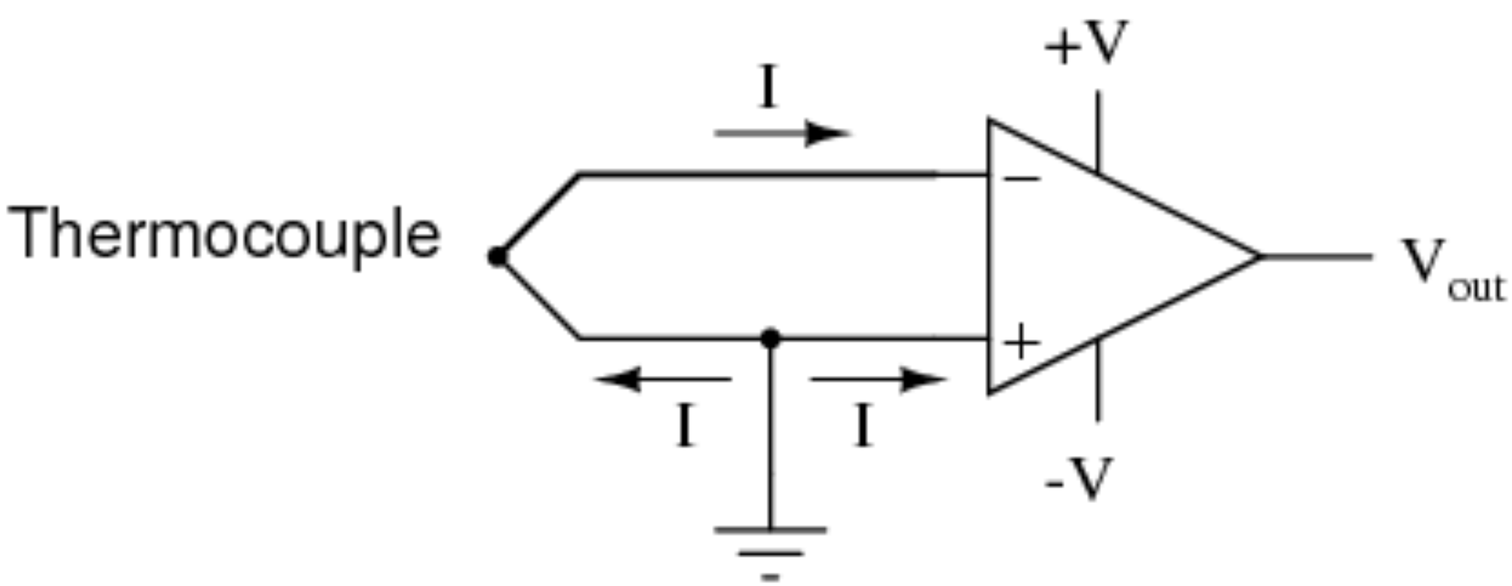
Potentiometer adjusted so that
$V_{out} = 0$ volts with inputs shorted together

Images: allaboutcircuits.com

Input bias currents need a ground path and can be a frustrating problem to realize



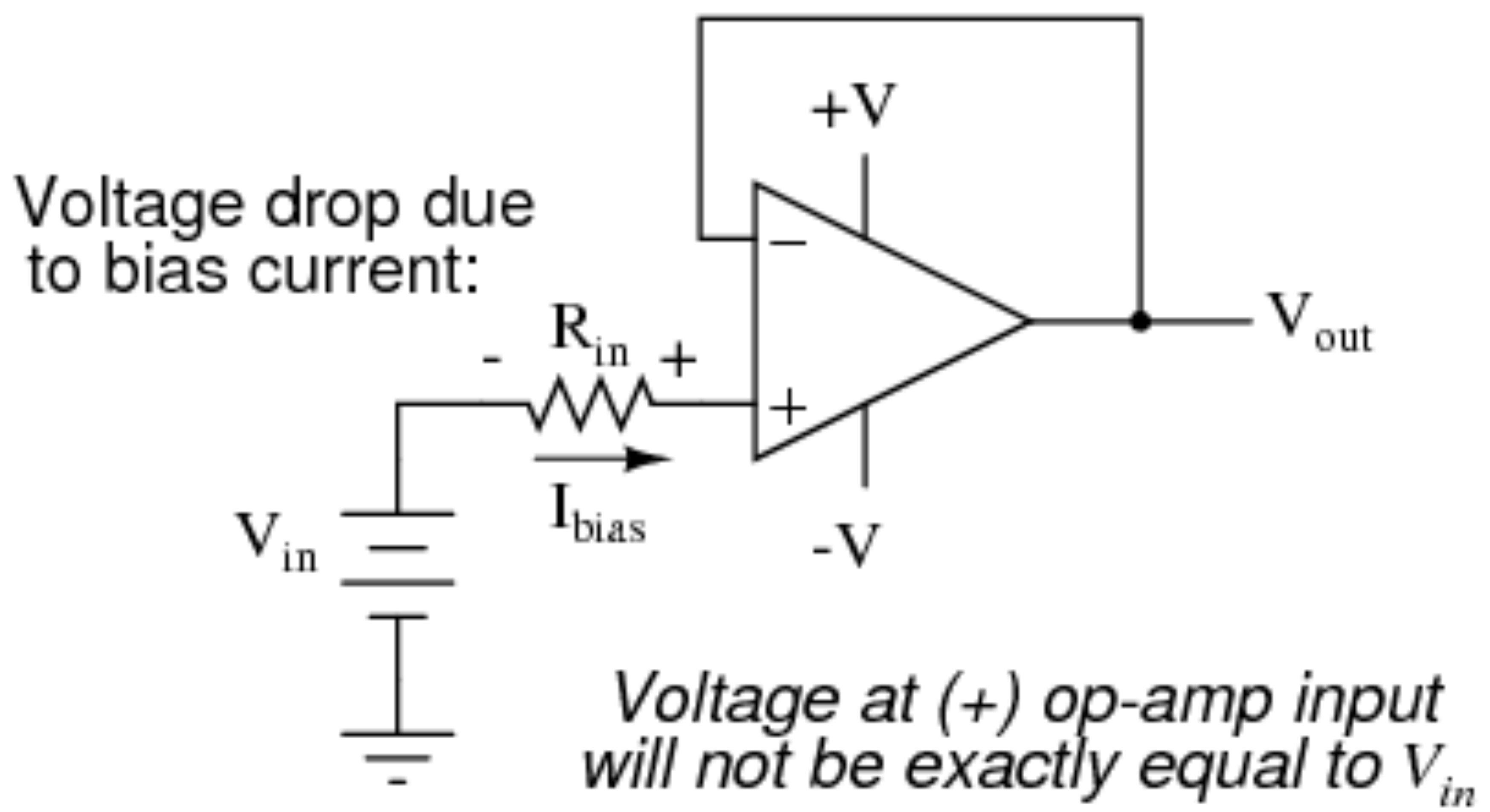
This comparator circuit ***won't*** *work*



This comparator circuit ***will*** *work*

Images: allaboutcircuits.com

They can also cause voltage drops that you don't expect



Images: allaboutcircuits.com

Like any semiconductor, there is a temperature drift

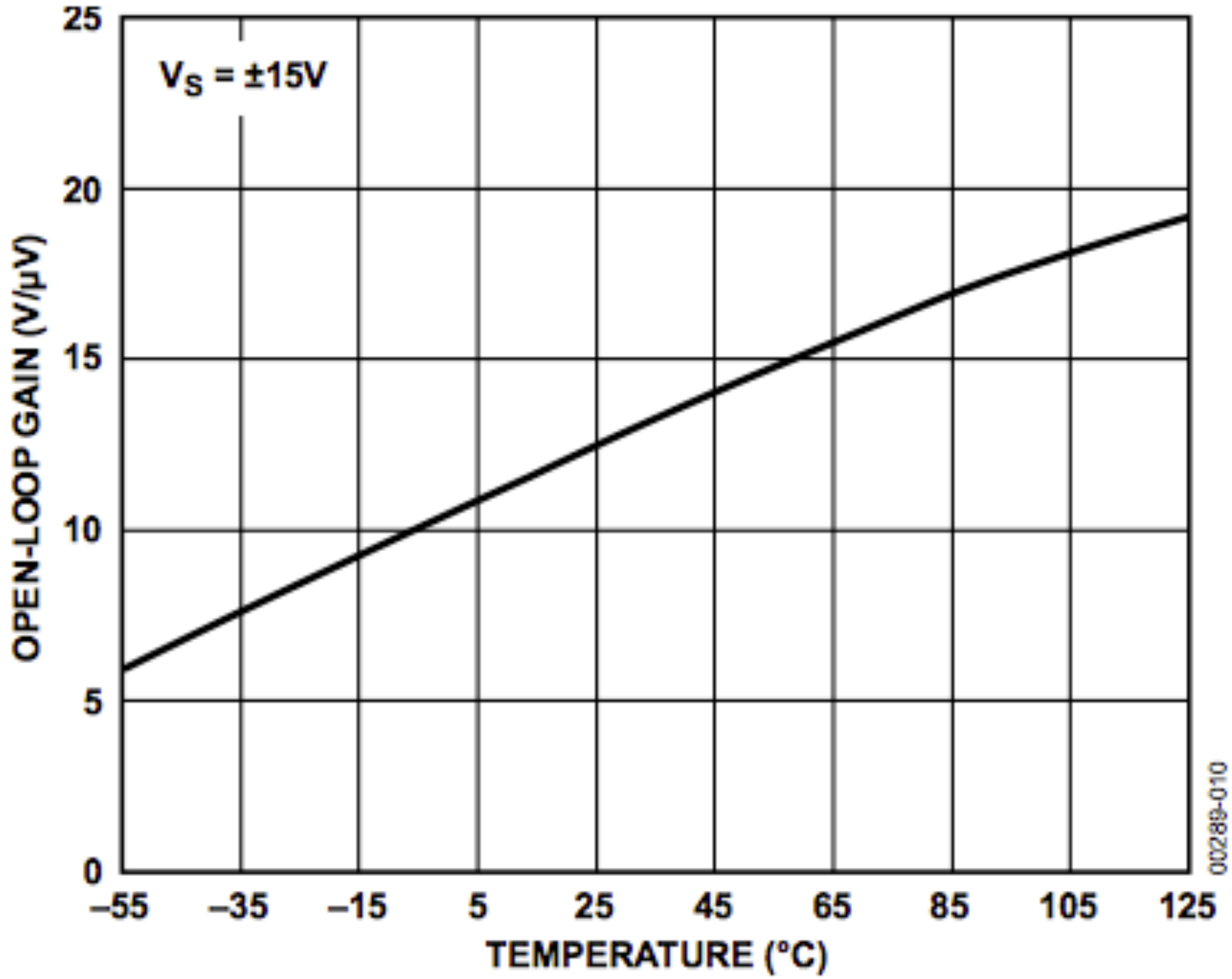
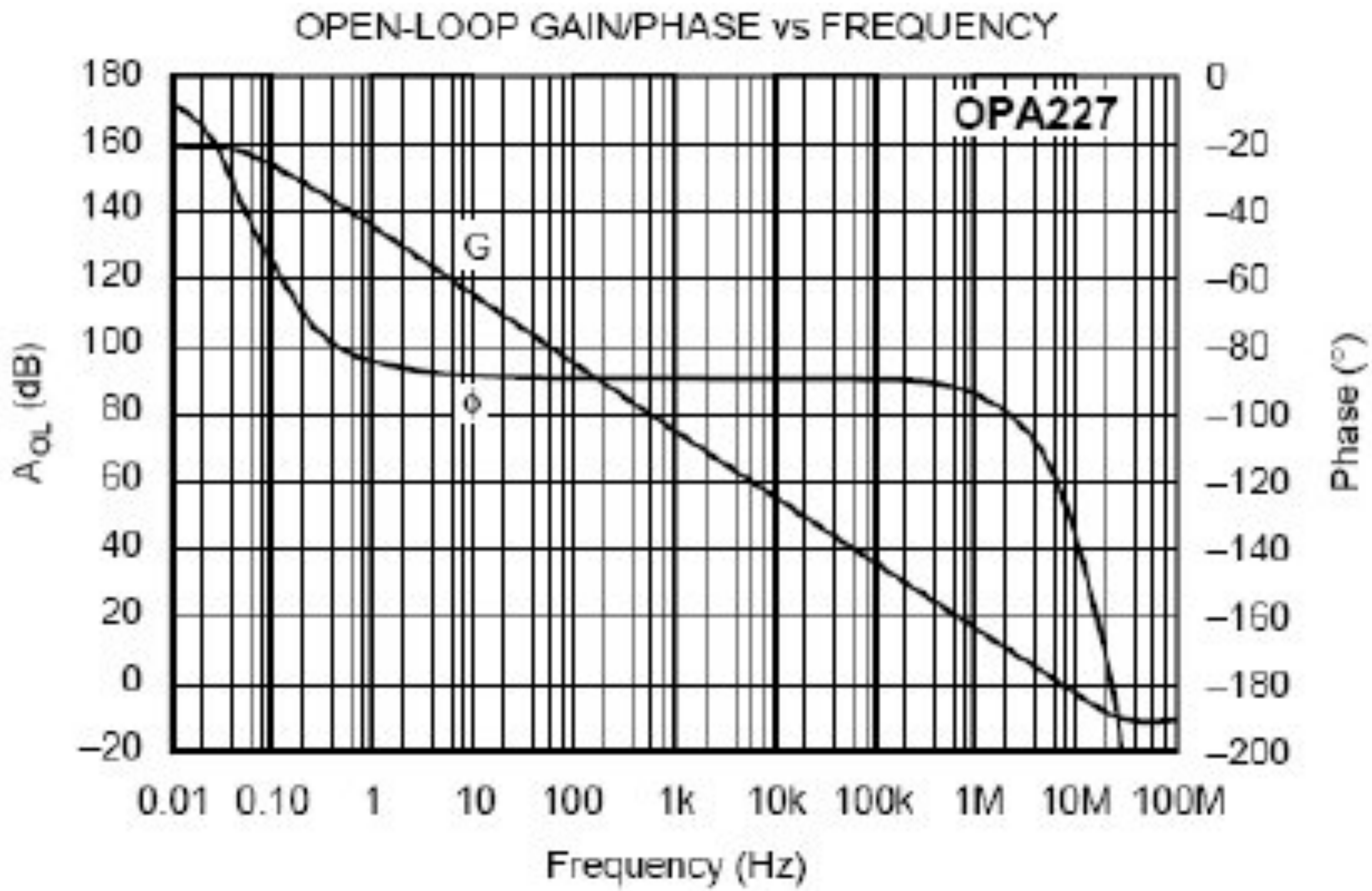


Figure 10. Open-Loop Gain vs. Temperature

Images: Analog Devices

Beware of the frequency response as well



Images: allaboutcircuits.com

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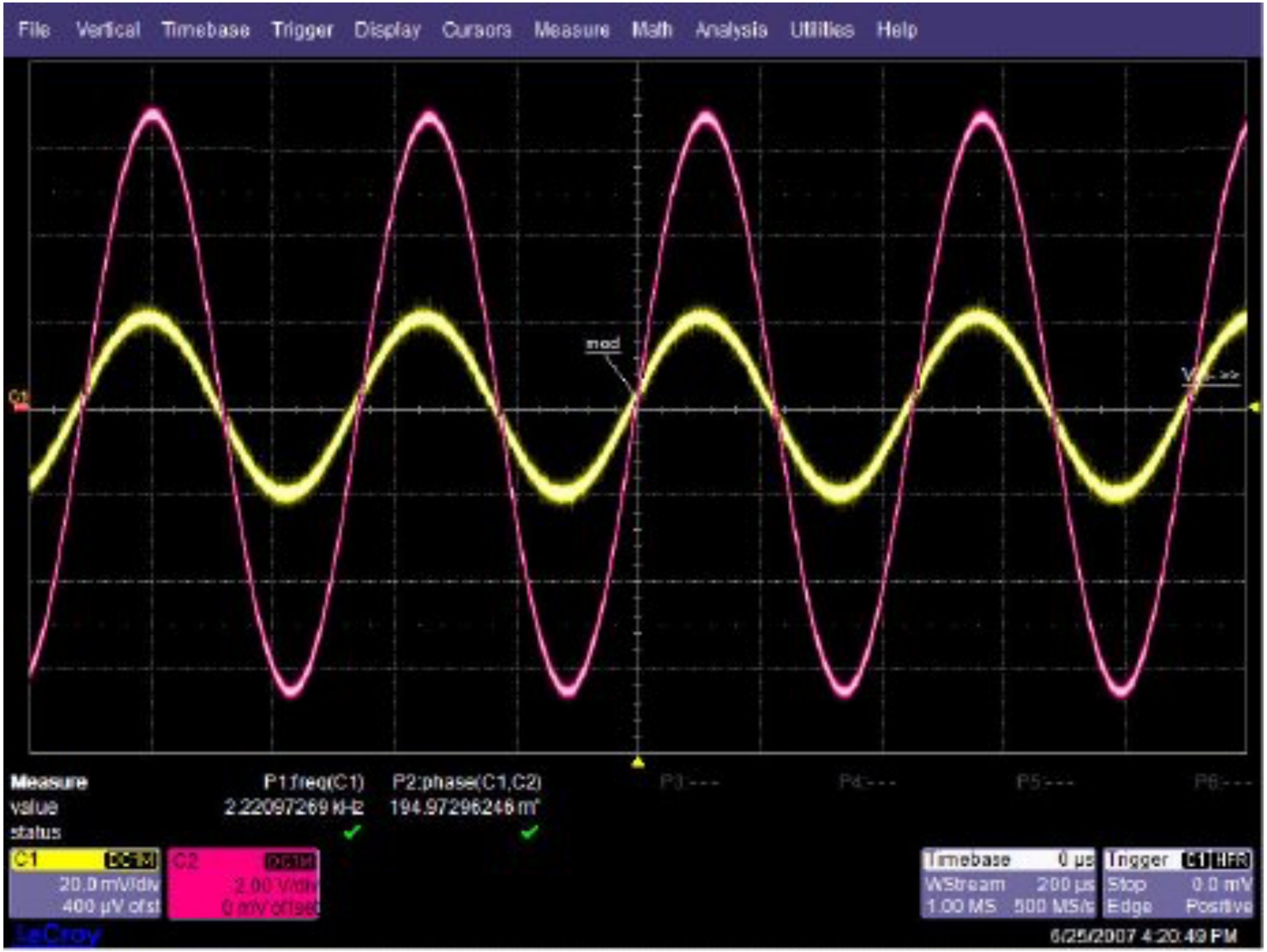

Images: allaboutcircuits.com

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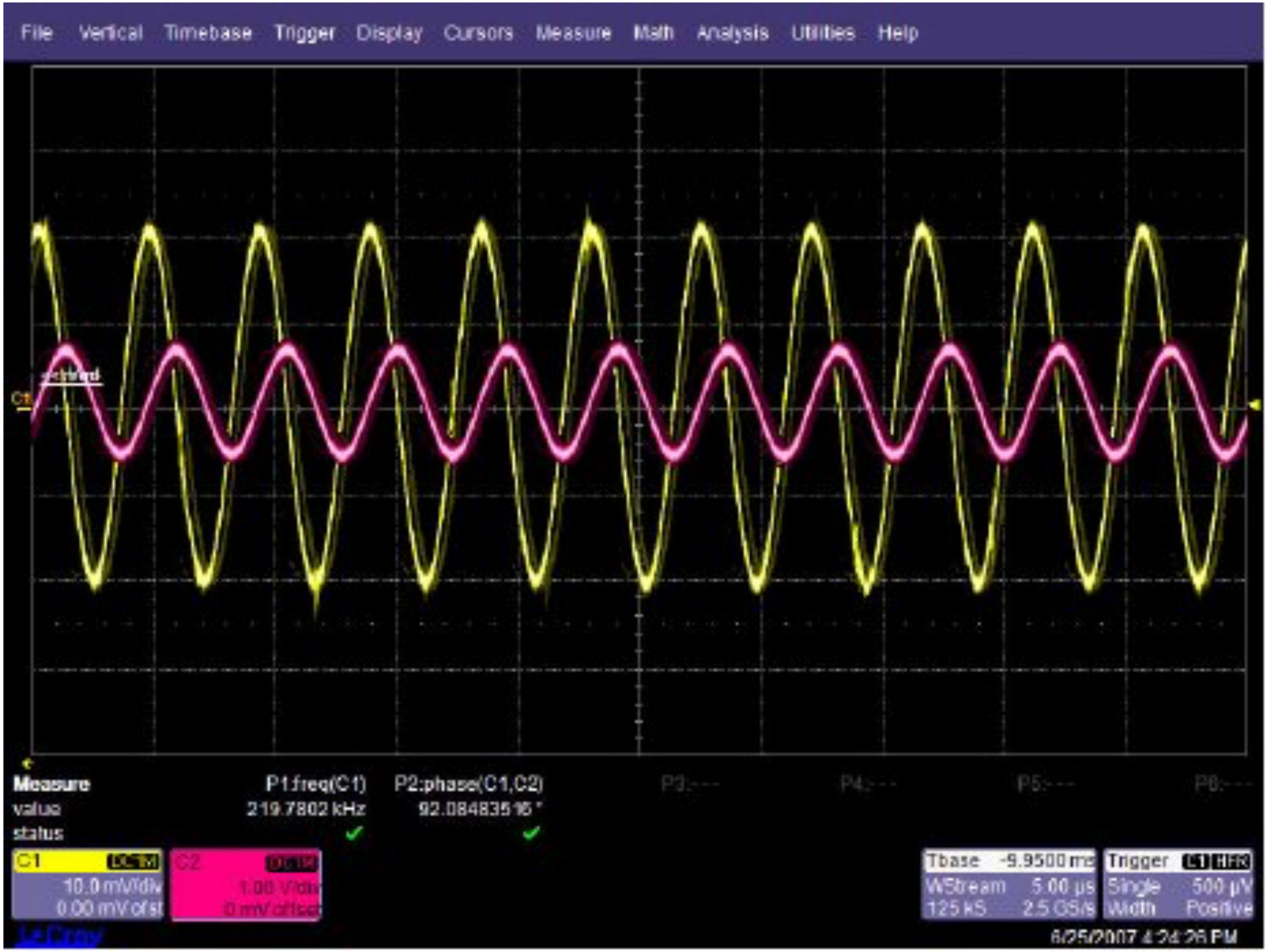

Images: <u>allaboutcircuits.com</u>

Assignment: Projects - it's time to start really cranking on them

Due : 10/25