Application Report

AN-31 amplifier circuit collection

ABSTRACT

This application report provides basic circuits of the Texas Instruments amplifier collection.

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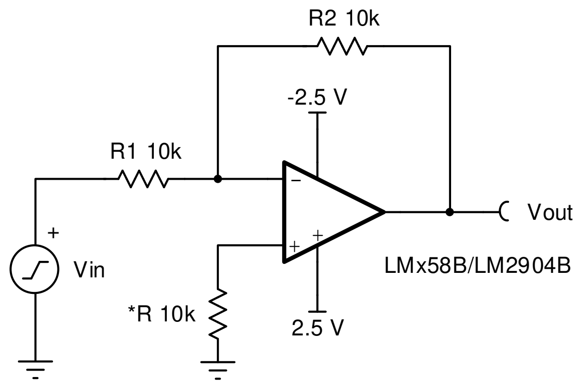
1 Basic Circuits



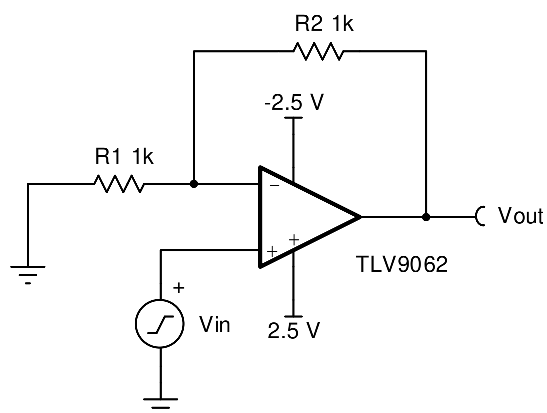
$$V_{out} = -\frac{R_2}{R_1} V_{in}$$

$$*\, R\ Optional\ to\ Protect\ LM358\ \&\ LM324$$

$$Devices\ from\ Transient\ Current\ Spikes$$

Figure 1-1. Inverting Amplifier

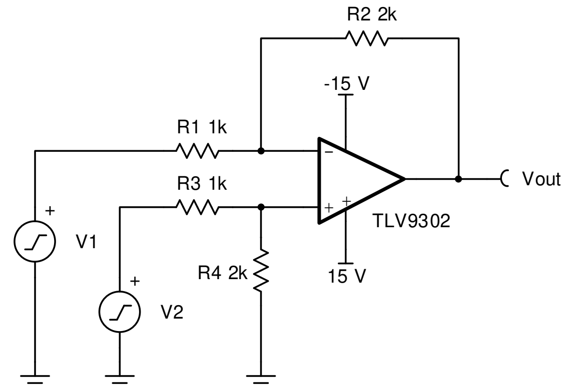
See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic. To learn more about *R and how to protect LM358/LM2904 devices from transient current spikes at the input, see [23].



$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

Figure 1-2. Non-Inverting Amplifier

See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



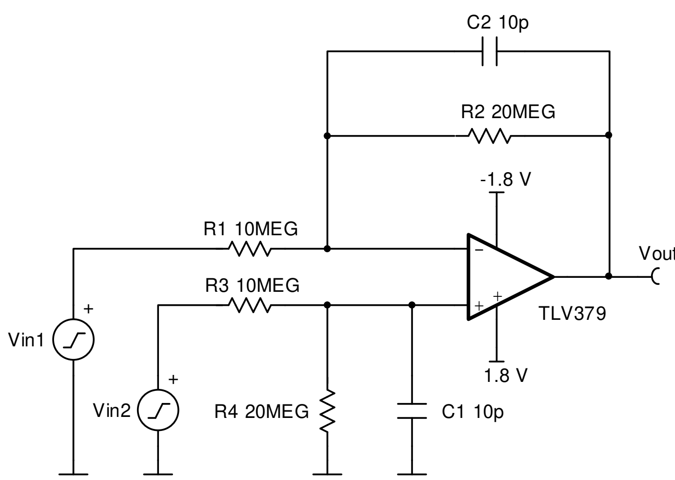
$$V_{out} = \left(\frac{R_4}{R_3 + R_4}\right)\left(1 + \frac{R_2}{R_1}\right)V_2 - \frac{R_2}{R_1}V_1$$

$$For\ R_1 = R_3\ and\ R_2 = R_4$$

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

Figure 1-3. Difference Amplifier

See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = \left(\frac{R_4}{R_3 + R_4}\right)\left(1 + \frac{R_2}{R_1}\right)V_2 - \frac{R_2}{R_1}V_1$$

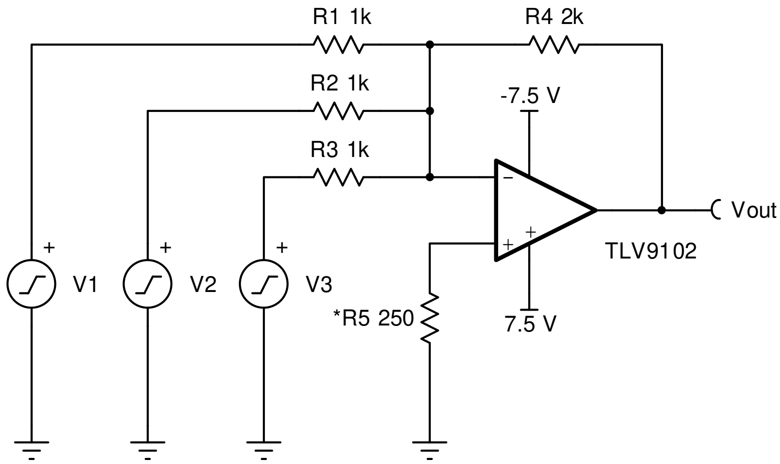
$$For\ R_1 = R_3\ and\ R_2 = R_4$$

$$V_{out} = \frac{R_2}{R_1}(V_2 - V_1)$$

$$f_{cutoff} = \frac{1}{2\pi C_2 R_2}$$

Figure 1-4. Low-Power Difference Amplifier

See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.

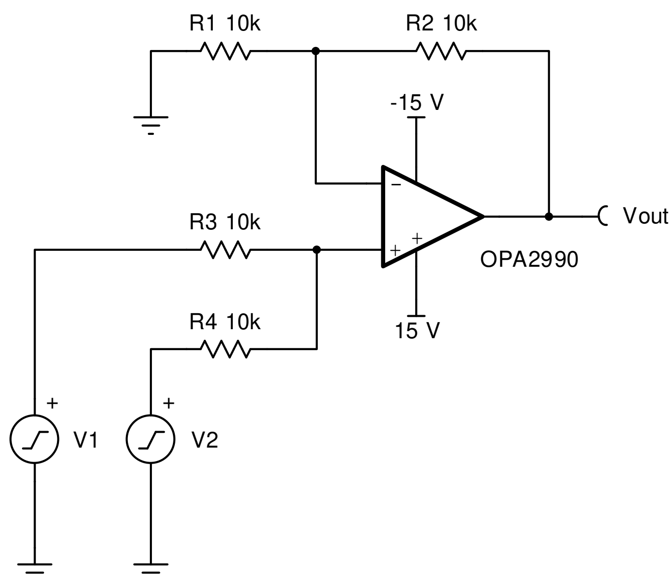


$$V_{out} = -R_4\left(\frac{V_1}{R_1}+\frac{V_2}{R_2}+\frac{V_3}{R_3}\right)$$

$$* R_5\ Optional\ for\ Input\ Bias\ Current\ Cancellation$$

Figure 1-5. Inverting Summing Amplifier

See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.

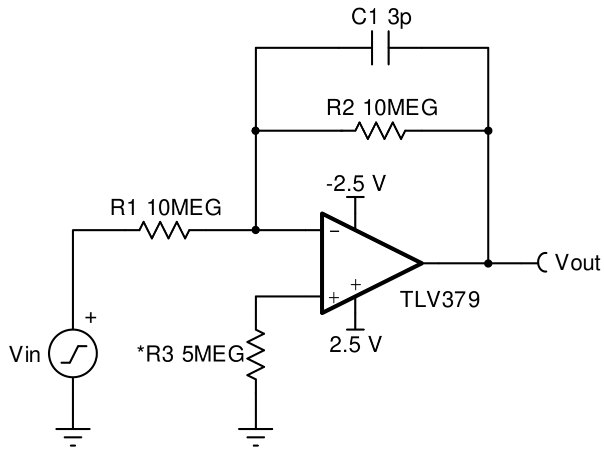


$$V_{out} = \left(1+\frac{R_2}{R_1}\right)\left(V_1\frac{R_4}{R_3+R_4}+V_2\frac{R_3}{R_3+R_4}\right)$$

$$V_{out} = \left(1+\frac{R_2}{R_1}\right)\left(\frac{R_4}{R_3+R_4}\right)(V_1+V_2)\ if\ R_3 = R_4$$

Figure 1-6. Non-Inverting Summing Amplifier

See Analog engineer's circuit cookbook: amplifiers for more information. Simulate this design by downloading TINA-TI and the schematic.

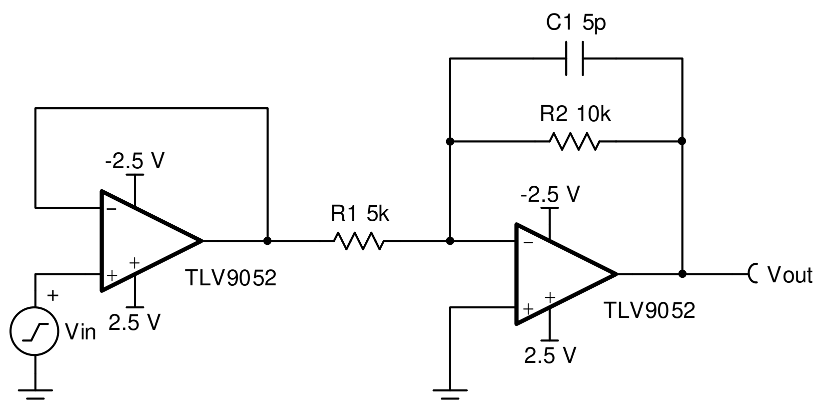


$$V_{out} = -\frac{R_2}{R_1}V_{in}$$

$$*\,R_3\ Optional\ for\ Input\ Bias\ Current\ Cancellation$$

Figure 1-7. Inverting Amplifier With High Input Impedance

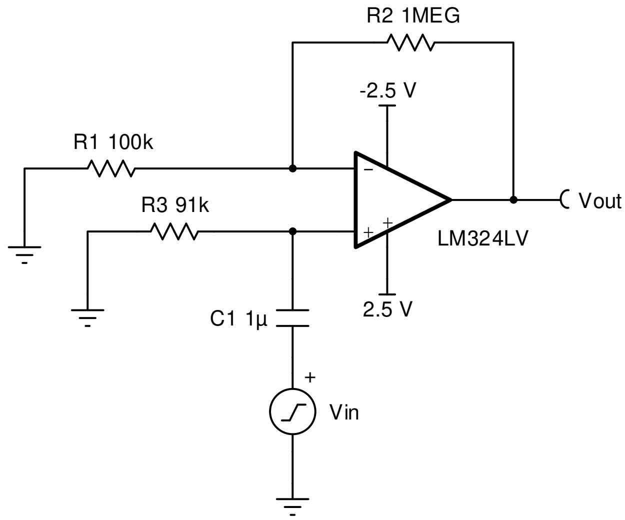
Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = -\frac{R_2}{R_1}V_{in}$$

Figure 1-8. Two-Stage Inverting Amplifier With High Input Impedance

Simulate this design by downloading TINA-TI and the schematic.



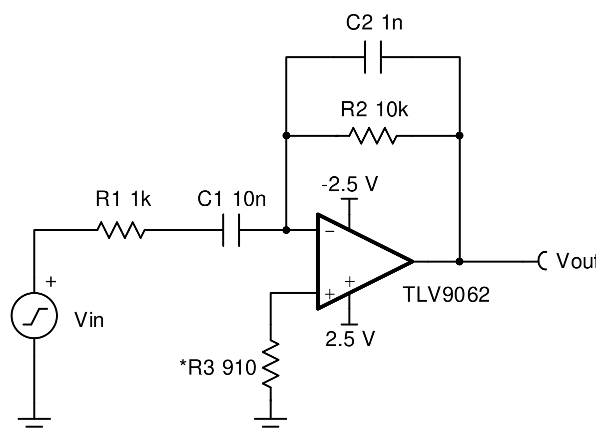
$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

$$R_3 = R_1 || R_2 \; for\; CMRR$$

$$f_{cutoff\;\;low} = \frac{1}{2\pi \times C_1 \times R_3}$$

Figure 1-9. AC Coupled Non-Inverting Amplifier

See Analog engineer's circuit cookbook: amplifiers for more information. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = -\frac{dV_{in}}{dt}$$

$$f_c = \frac{1}{2\pi R_2 C_1} V_{in}$$

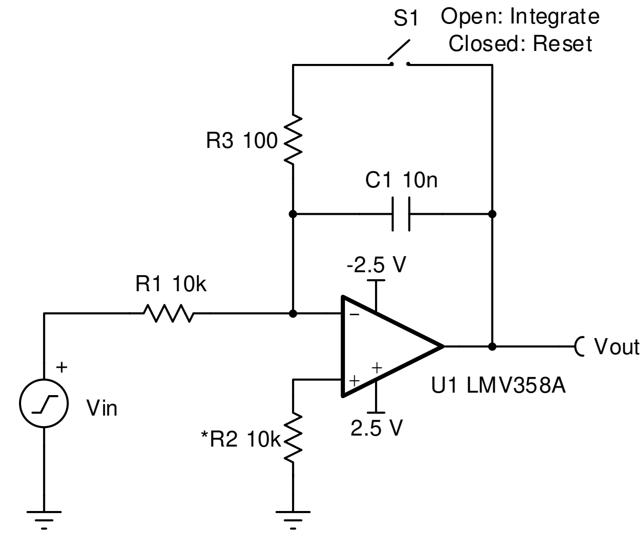
$$f_h = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_2 C_2}$$

$$f_c \ll f_h \ll f_{unity\;\;gain}$$

$$* R_3\; Optional\; for\; Input\; Bias\; Current\; Cancellation$$

Figure 1-10. Practical Differentiator

See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = -\frac{1}{R_1 C_1}\int_{t_1}^{t_2} V_{in}\, dt$$

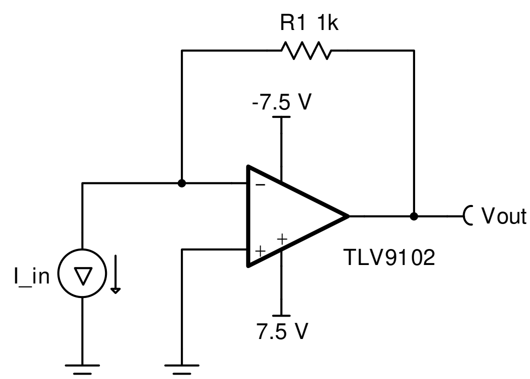
$$f_c = \frac{1}{2\pi R_1 C_1}$$

$$R_1 = R_2$$

$$* R_2 \ Optional\ for\ Input\ Bias\ Current\ Cancellation$$

Figure 1-11. Integrator

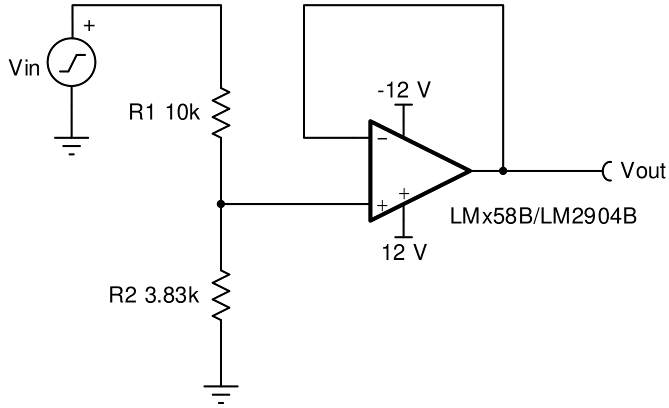
See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = I_{in} R_1$$

Figure 1-12. Current to Voltage Converter (Transimpedance Amplifier)

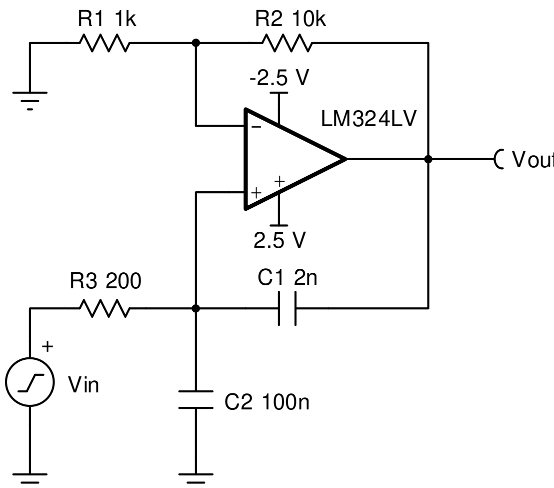
See Analog engineer's circuit cookbook: amplifiers or [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = \frac{R_2}{R_1 + R_2} V_{in}$$

Figure 1-13. Reference Voltage Generator

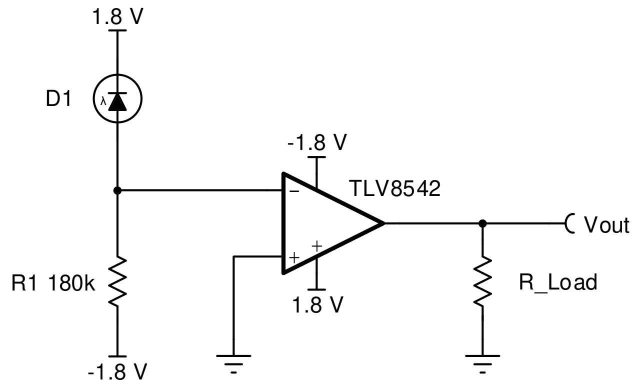
Simulate this design by downloading TINA-TI and the schematic.



$$C_1 \leq \frac{R_1}{R_2} C_2$$

Figure 1-14. Neutralizing Input Capacitance to Optimize Response Time

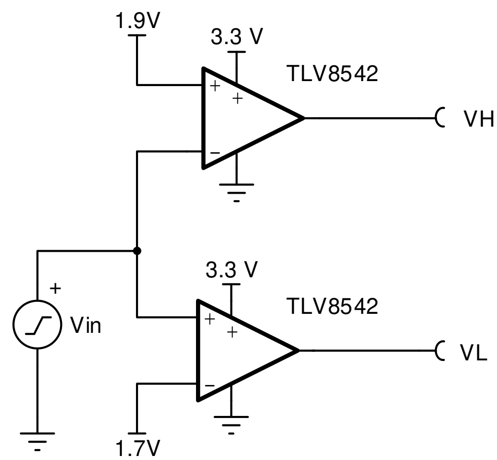
Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = 1.8V => Diode\ Off$$
$$V_{out} = -1.8V => Diode\ On$$
$$R_1\ Controls\ Sensitivity\ to\ Light$$

Figure 1-15. Threshold Detector for Photodiodes

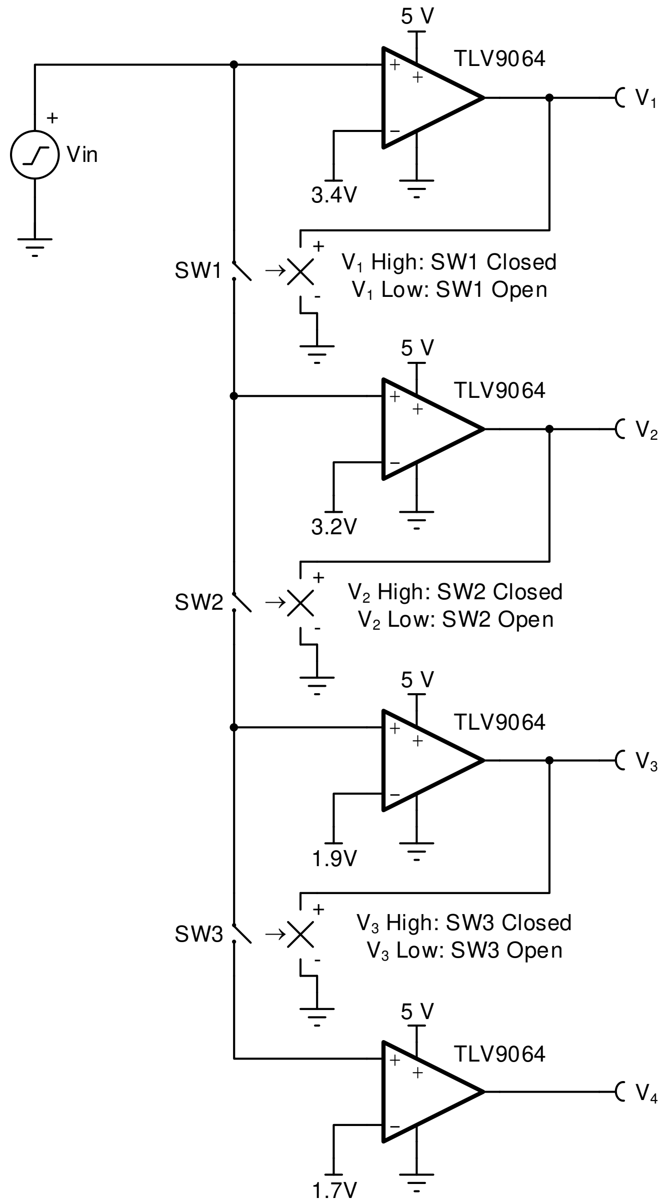
For more information on modeling photodiodes, see [8]. Simulate this design by downloading TINA-TI and the schematic.



$$If\ V_{in} > 1.9V, then\ V_H = 0\ and\ V_L = 3.3V$$
$$If\ 1.9V > V_{in} > 1.7V, then\ V_H = 3.3V\ and\ V_L = 3.3V$$
$$If\ V_{in} < 1.7V, then\ V_H = 3.3V\ and\ V_L = 0$$

Figure 1-16. Double-Ended Limit Detector

Simulate this design by downloading TINA-TI and the schematic.



$$V_{in} > 3.4V \rightarrow V_1 = 1, V_2 = 1, V_3 = 1, V_4 = 1$$

$$3.4V > V_{in} > 3.2V \rightarrow V_1 = 0, V_2 = 1, V_3 = 1, V_4 = 1$$

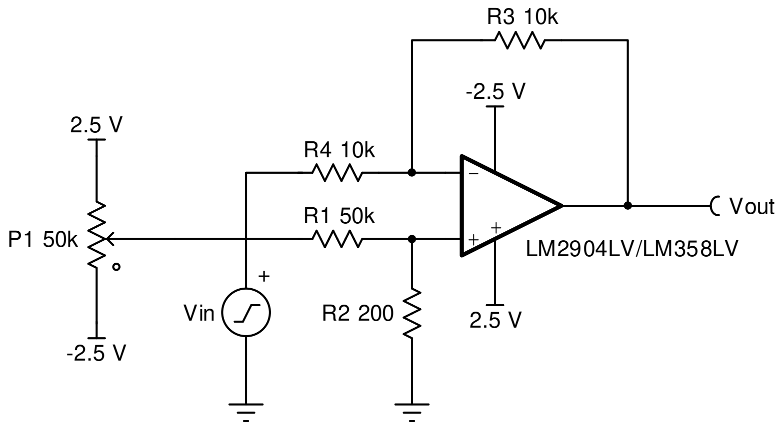
$$3.2V > V_{in} > 1.9V \rightarrow V_1 = 0, V_2 = 0, V_3 = 1, V_4 = 1$$

$$1.9V > V_{in} > 1.7V \rightarrow V_1 = 0, V_2 = 0, V_3 = 0, V_4 = 1$$

$$1.7V > V_{in} \rightarrow V_1 = 0, V_2 = 0, V_3 = 0, V_4 = 0$$

Figure 1-17. Multiple Aperture Window Discriminator

Simulate this design by downloading TINA-TI and the schematic.



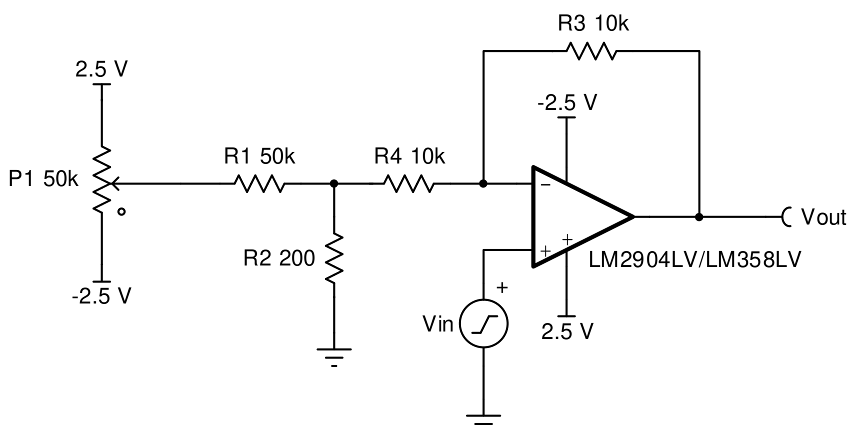
$$Offset\ Range = V_{supply}\left(\frac{R_2}{R_1}\right)$$

$$V_{out} = \left(-\frac{R_3}{R_4}\right)V_{in}$$

$$R_1 \gg R_2$$

Figure 1-18. Offset Voltage Adjustment for Inverting Amplifiers

Simulate this design by downloading TINA-TI and the schematic.



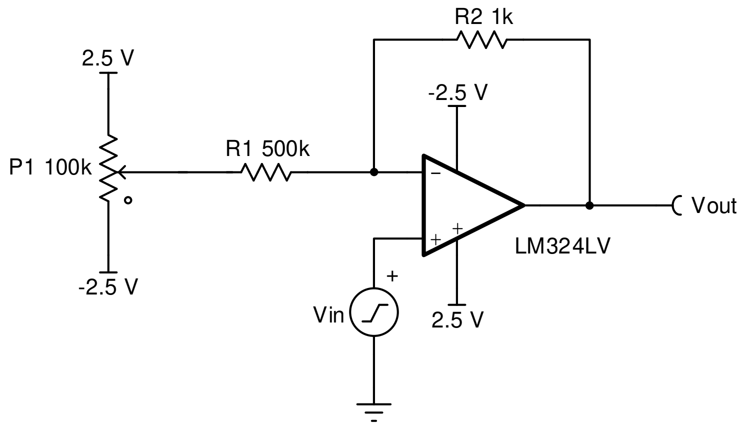
$$Offset\ Range = V_{supply}\left(\frac{R_2}{R_1}\right)$$

$$V_{out} = \left(1 + \frac{R_3}{R_2 + R_4}\right)V_{in}$$

$$R_1 \gg R_2\ and\ R_4 \gg R_2$$

Figure 1-19. Offset Voltage Adjustment for Non-Inverting Amplifiers

Simulate this design by downloading TINA-TI and the schematic.



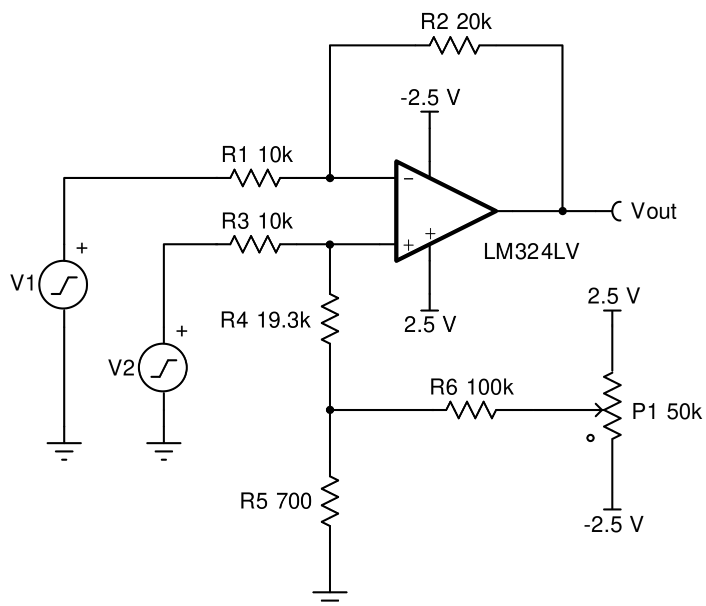
$$Offset\ Range = V_{supply}\left(\frac{R_2}{R_1}\right)$$

$$V_{out} \approx V_{in}$$

$$R_1 \gg R_2$$

Figure 1-20. Offset Voltage Adjustment for Voltage Followers

Simulate this design by downloading TINA-TI and the schematic.



$$R_2 = R_4 + R_5$$

$$R_1 = R_3$$

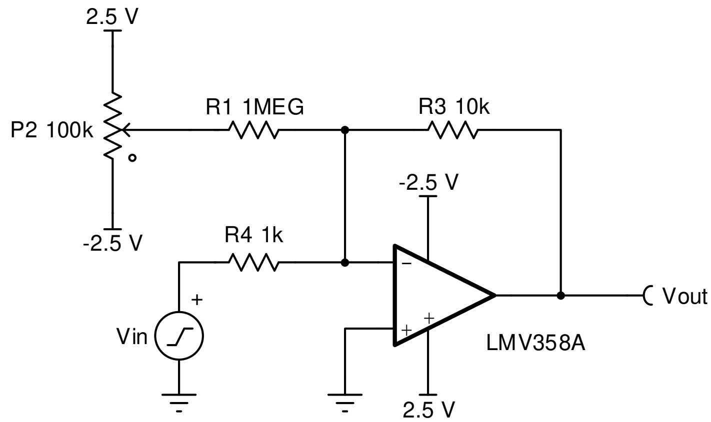
$$Offset\ Range = V_{supply}\left(\frac{R_5}{R_5 + R_6}\right)\left(\frac{R_3}{R_3 + R_4}\right)$$

$$V_{out} = \left(\frac{R_2}{R_1}\right)(V_2 - V_1)$$

$$R_5 \ll Offset\ Equivalent\ Resistance$$

Figure 1-21. Offset Voltage Adjustment for Difference Amplifiers

Simulate this design by downloading TINA-TI and the schematic.



$$R_3||R_4 \leq 10k\Omega$$

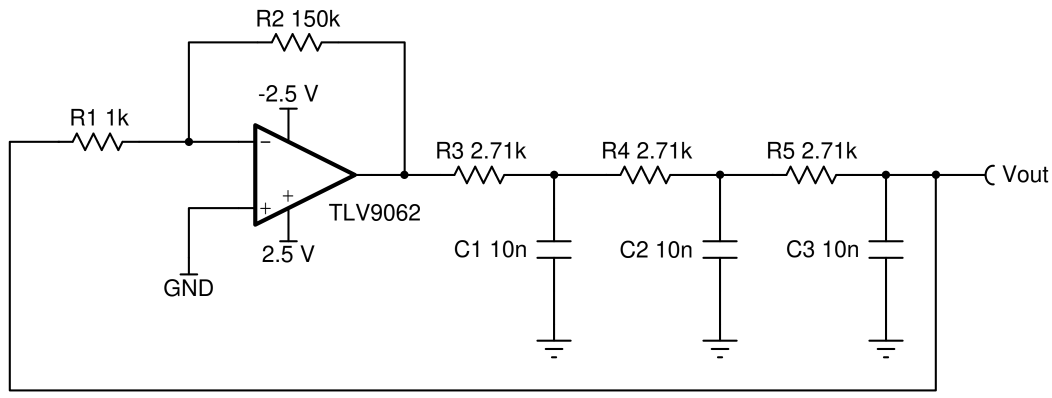
$$Offset\ Range = V_{supply}\left(\frac{R_3||R_4}{R_1}\right)$$

$$V_{out} = \left(-\frac{R_3}{R_4}\right)V_{in}$$

Figure 1-22. Offset Voltage Adjustment for Inverting Amplifiers With Source Resistance

Simulate this design by downloading TINA-TI and the schematic.

2 Signal Generation



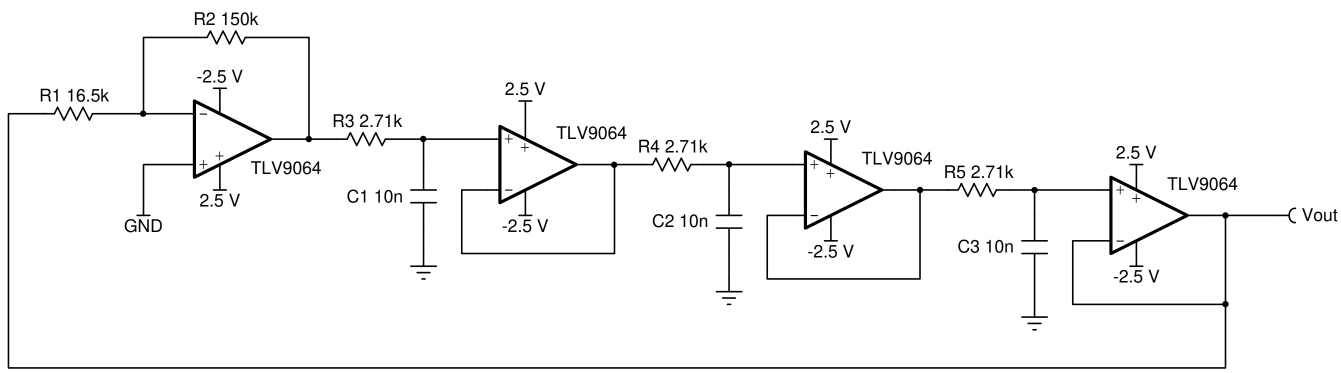
$$\frac{R_2}{R_1} \gg 8$$

$$Let\ R = R_3, R_4, R_5\ and\ C = C_1, C_2, C_3$$

$$f_{oscillation} \approx \frac{\tan(60°)}{2\pi RC}$$

Figure 2-1. Sine Wave Generator With Low Component Count

For more information on this configuration, also known as a phase-shift oscillator, see [9] and [10]. Simulate this design by downloading TINA-TI and the schematic.



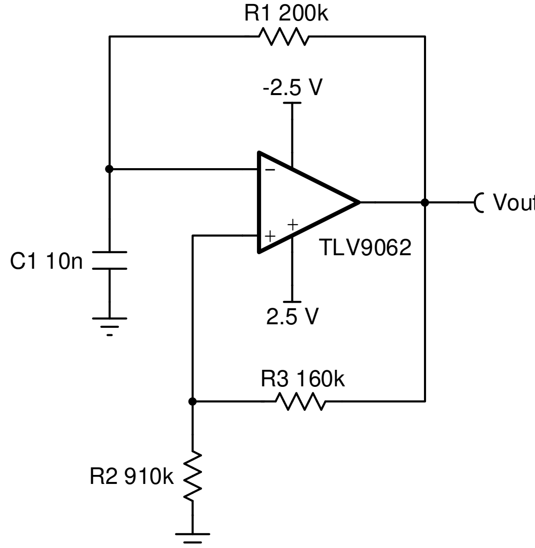
$$8 \leq \frac{R_2}{R_1} \leq 10$$

$$Let\ R = R_3, R_4, R_5\ and\ C = C_1, C_2, C_3$$

$$f_{oscillation} = \frac{\tan(60°)}{2\pi RC}$$

Figure 2-2. Sine Wave Generator

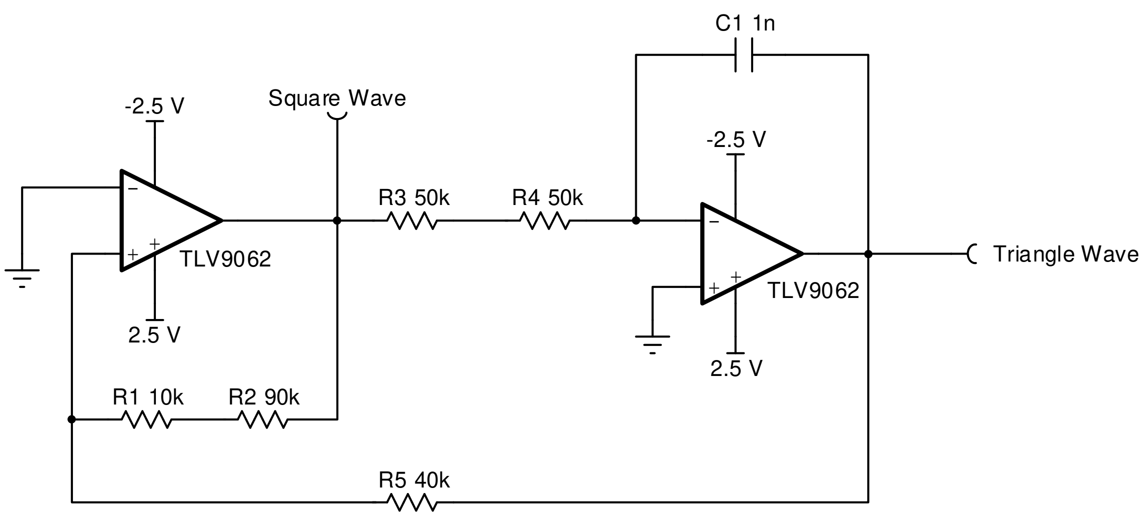
For more information on this configuration, also known as a buffered phase-shift oscillator, see [9] and [10]. Simulate this design by downloading TINA-TI and the schematic.



$$f_{oscillation} = \frac{1}{2R_1C_1 ln\left(1+2\frac{R_2}{R_3}\right)}$$

Figure 2-3. Free-Running Multivibrator

Simulate this design by downloading TINA-TI and the schematic.

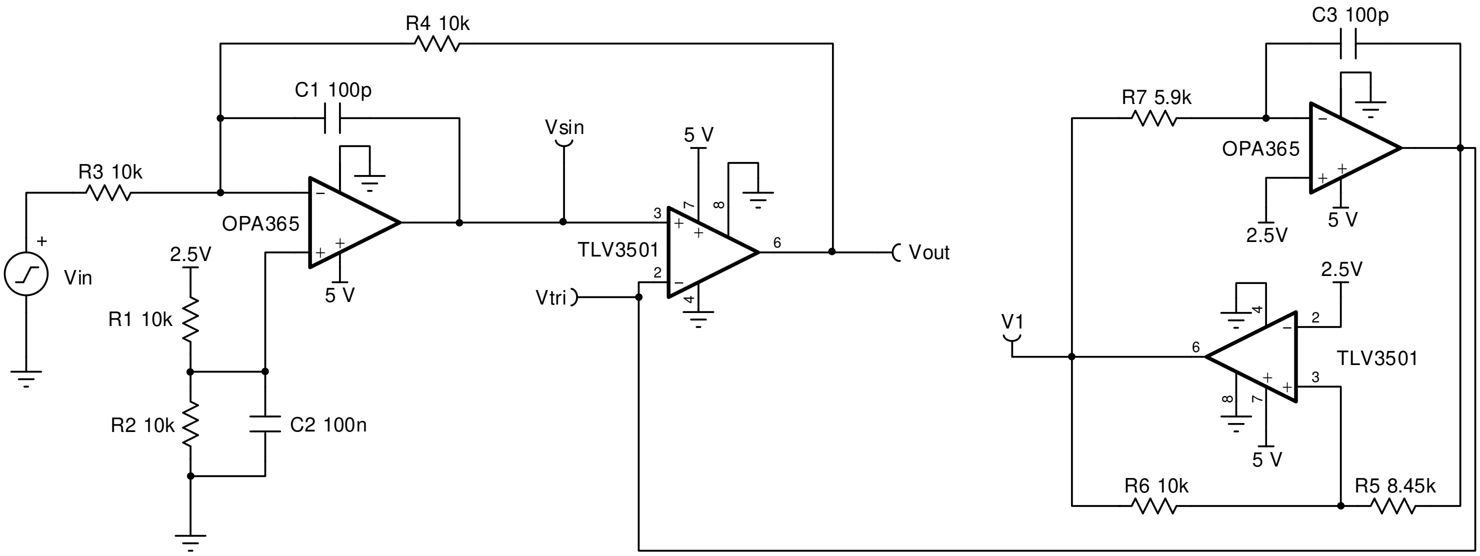


$$Amplitude_{triangle} = V_{cc}\frac{R_5}{R_1+R_2}$$

$$f_{oscillation} = \frac{2}{\pi C_1(R_3+R_4)}\ for\ R_3+R_4 > 100k\Omega$$

Figure 2-4. Function Generator

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



$$R_1 = R_2 = R_3 = R_4$$

$$V_{tri} > |V_i|$$

$$\frac{R_5}{R_6} = \frac{|V_{tri}|}{|V_1|} \; for \; V_1 = V_{ref}$$

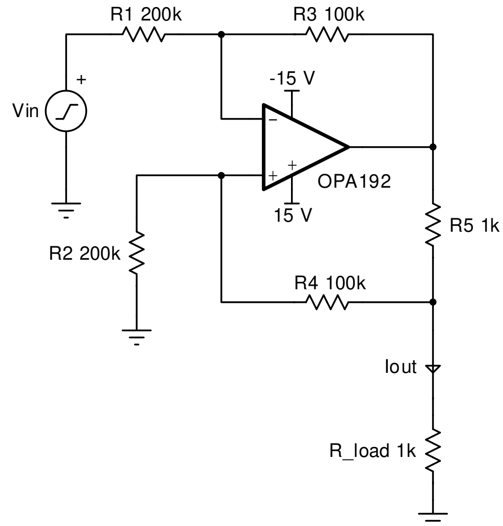
$$f_{oscillation} = \frac{R_6}{4 \times R_7 \times R_5 \times C_3}$$

$$C_1 > \frac{1}{2\pi \times R_4 \times f_{oscillation}}$$

$$C_2 = \frac{1}{2\pi \times f_{noise\ filter} \times (R_1||R_2)}$$

Figure 2-5. Pulse Width Modulator

See Analog engineer's circuit cookbook: amplifiers for more information. Simulate this design by downloading TINA-TI and the schematic.



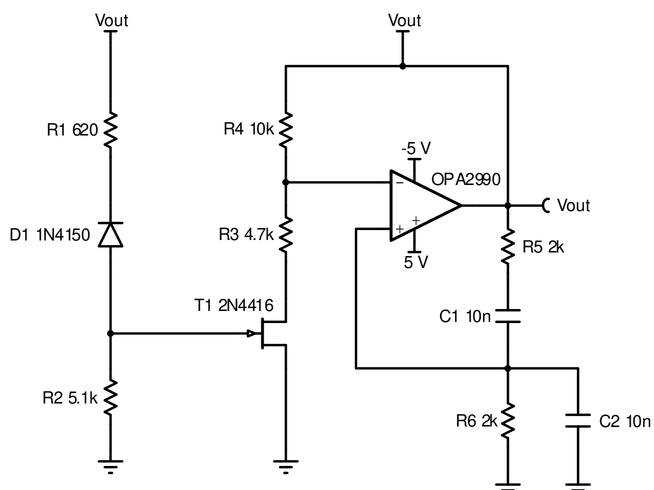
$$I_{out} = -\frac{R_3 V_{in}}{R_1 R_5}$$

$$R_3 = R_4 + R_5$$

$$R_1 = R_2$$

Figure 2-6. Improved Howland Current Pump

For an in-depth dive into this configuration, see our [11]. Simulate this design by downloading TINA-TI and the schematic.



$$f_{oscillation} = \frac{1}{2\pi C_1 R_5}$$

$$Set\ Gain = 3.1$$

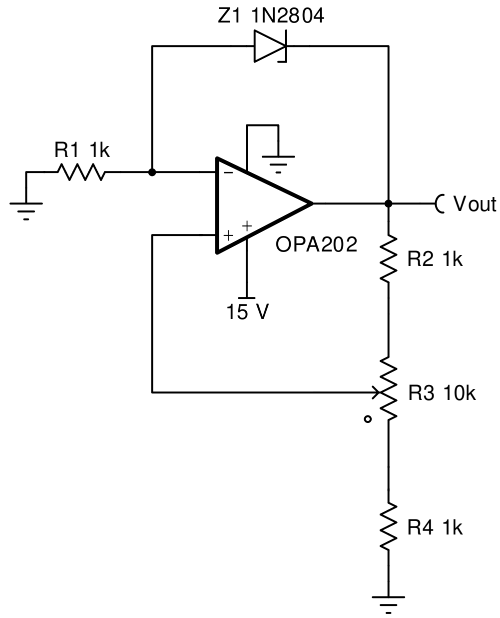
$$Gain = \frac{R_3 + R_4}{R_4}$$

$$R_5 = R_6$$

$$C_1 = C_2$$

Figure 2-7. Wien Bridge Oscillator With Automatic Gain Control

Simulate this design by downloading TINA-TI and the schematic.



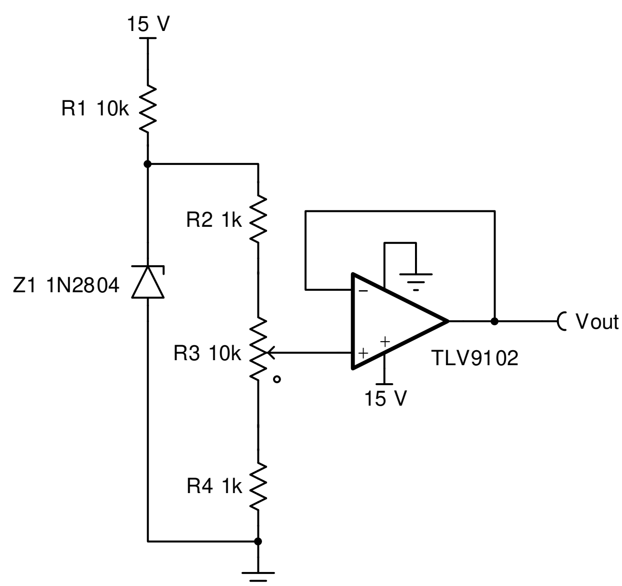
$$7.58V \leq V_{out} \leq 13.93V$$

$$R_1 \; controls \; V_{out,max}$$

$$R_2, R_4, \& \; V_{zener} \; control \; V_{out,min}$$

Figure 2-8. Positive Output Voltage Reference

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



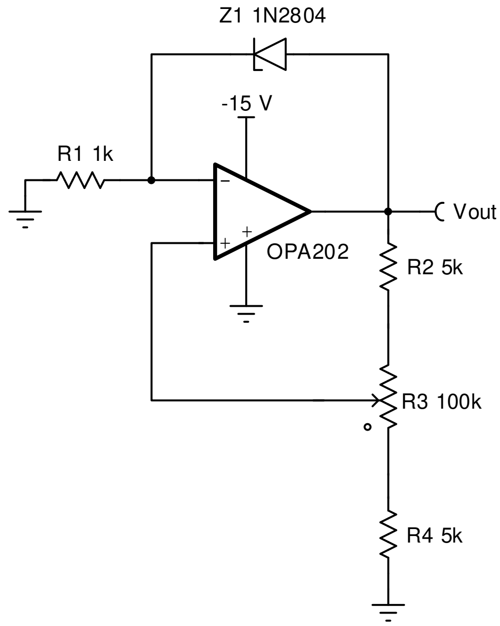
$$500mV \leq V_{out} \leq 5.5V$$

$$Decreasing \; R_2 \; \& \; R_4 \; increases \; V_{out} \; range$$

$$V_{zener} \; adjusts \; V_{out} \; range$$

Figure 2-9. Buffered Positive Voltage Reference

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



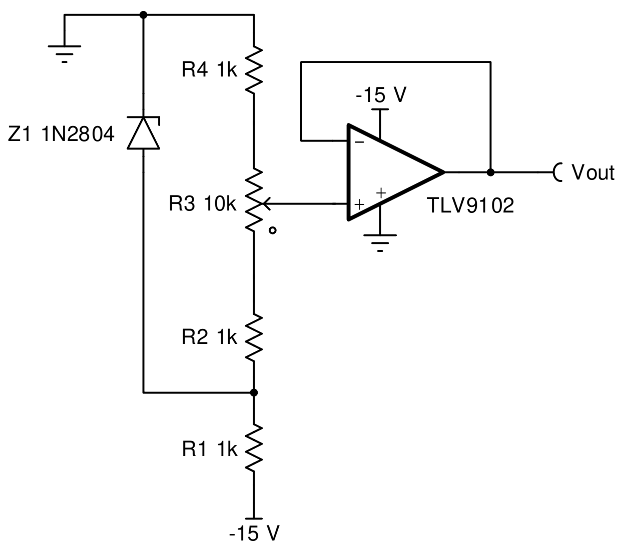
$$-13.9V \leq V_{out} \leq -7.6V$$

$$Decreasing\ R_2\ and\ R_4\ increases\ V_{out}\ range$$

$$V_{zener}\ adjusts\ V_{out}\ range$$

Figure 2-10. Negative Output Voltage Reference

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



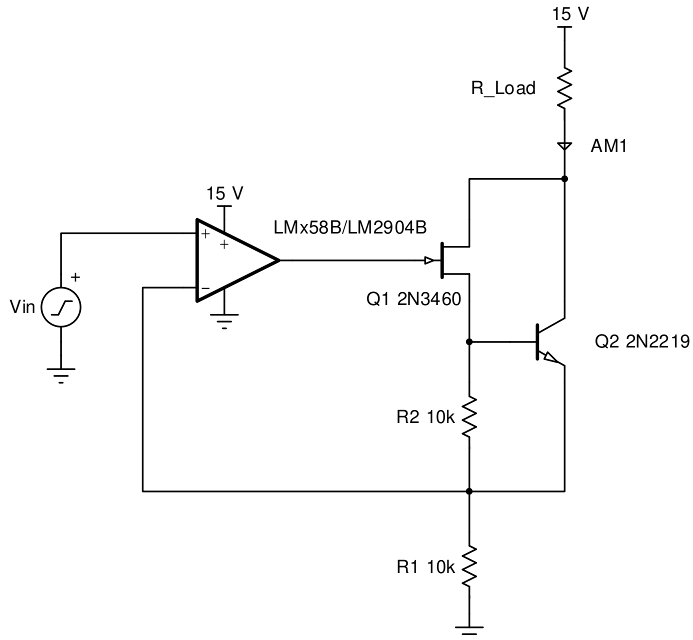
$$-5.5V \leq V_{out} \leq -500mV$$

$$Decreasing\ R_2\ \&\ R_4\ increases\ V_{out}\ range$$

$$V_{zener}\ adjusts\ V_{out}\ range$$

Figure 2-11. Buffered Negative Voltage Reference

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.



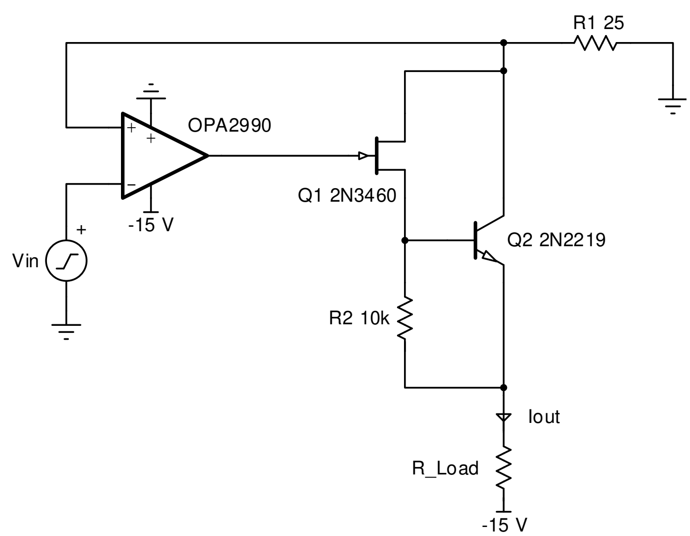
$$I_o = \frac{V_{in}}{R_1}$$

$$V_{in} \geq 0V$$

$$Ensure\ R_1 \gg R_{Load}$$

Figure 2-12. Current Sink

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.

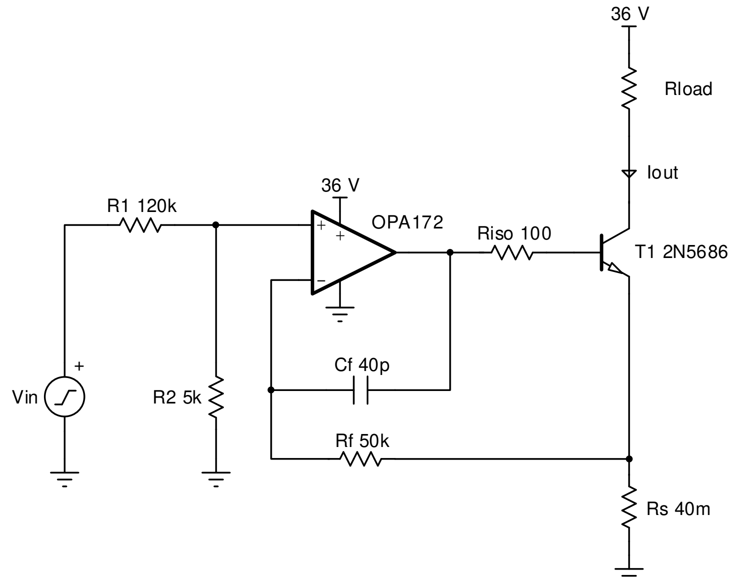


$$I_{out} = \frac{V_{out}}{R_1}$$

$$V_{in} < 0$$

Figure 2-13. Current Source

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.

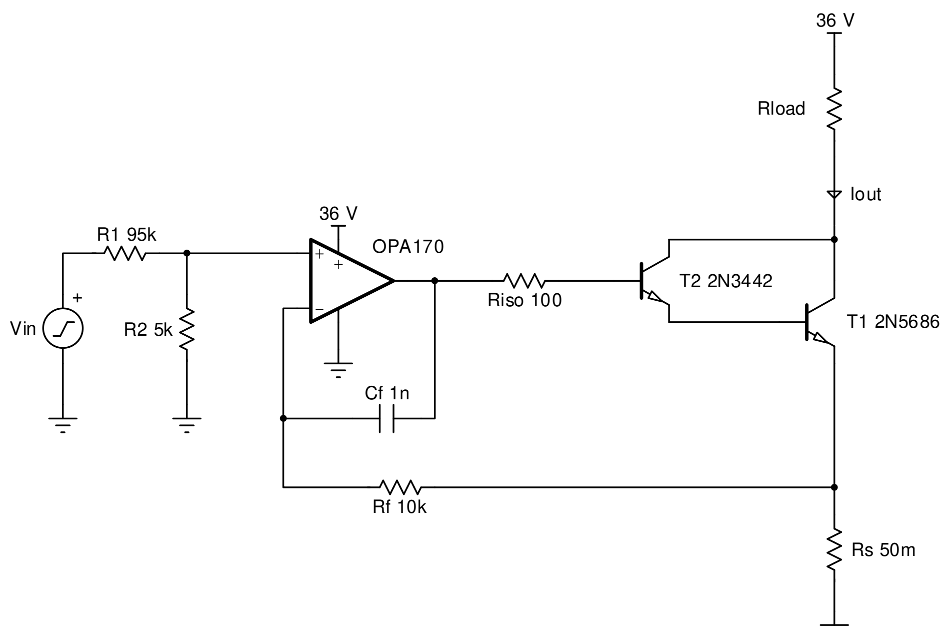


$$I_{out} = V_{in} \frac{R_2}{R_s(R_1 + R_2)}$$

$$R_s = \frac{V_{in,max}}{I_{out,max}}$$

Figure 2-14. Voltage-to-Current Converter With BJT Output

Simulate this design by downloading TINA-TI and the schematic.

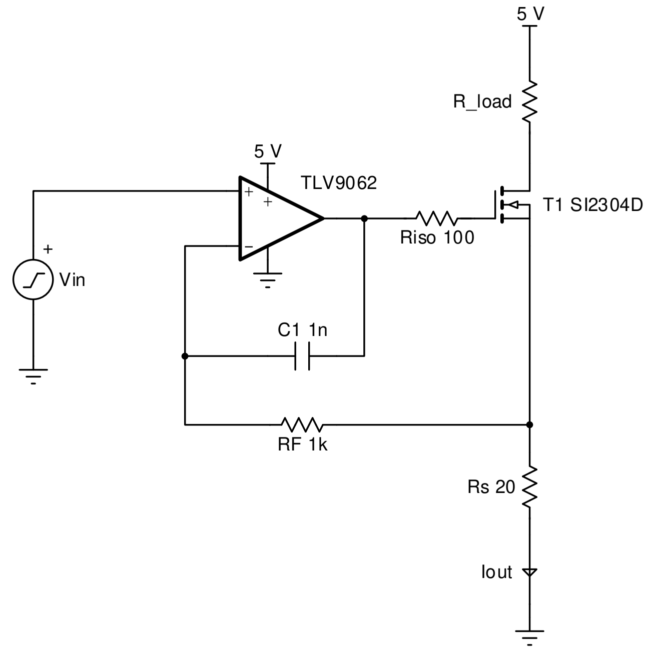


$$I_{out} = V_{in} \frac{R_2}{R_s(R_1 + R_2)}$$

$$R_s = \frac{V_{in,max}}{I_{out,max}}$$

Figure 2-15. Voltage-to-Current Converter With Darlington Pair Output

Simulate this design by downloading TINA-TI and the schematic.



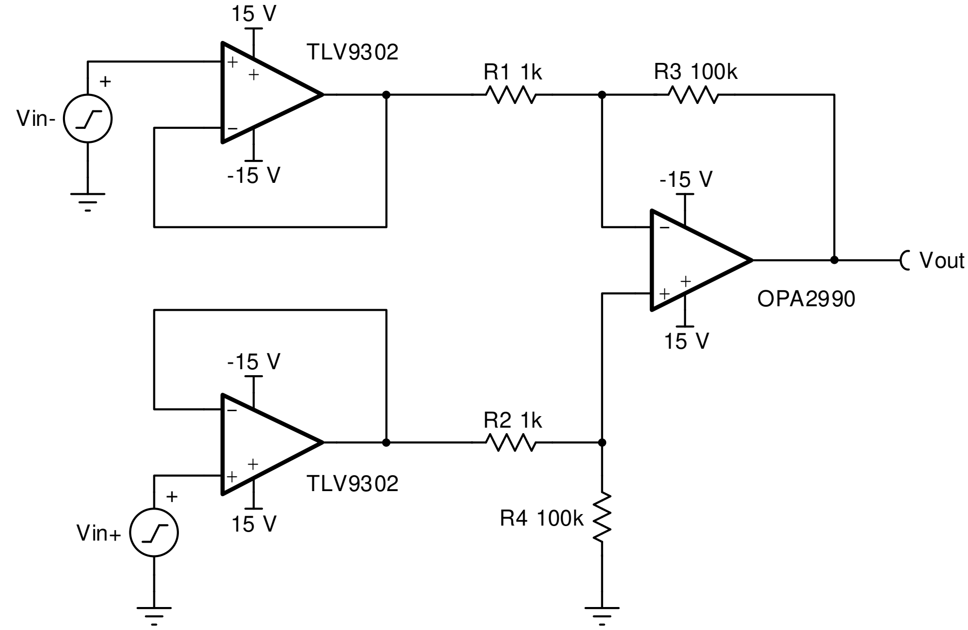
$$I_{out} = \frac{V_{in}}{R_s}$$

$$R_s = \frac{V_{in,max}}{I_{out,max}}$$

Figure 2-16. Voltage-to-Current Converter With MOSFET Output

Simulate this design by downloading TINA-TI and the schematic.

3 Signal Processing

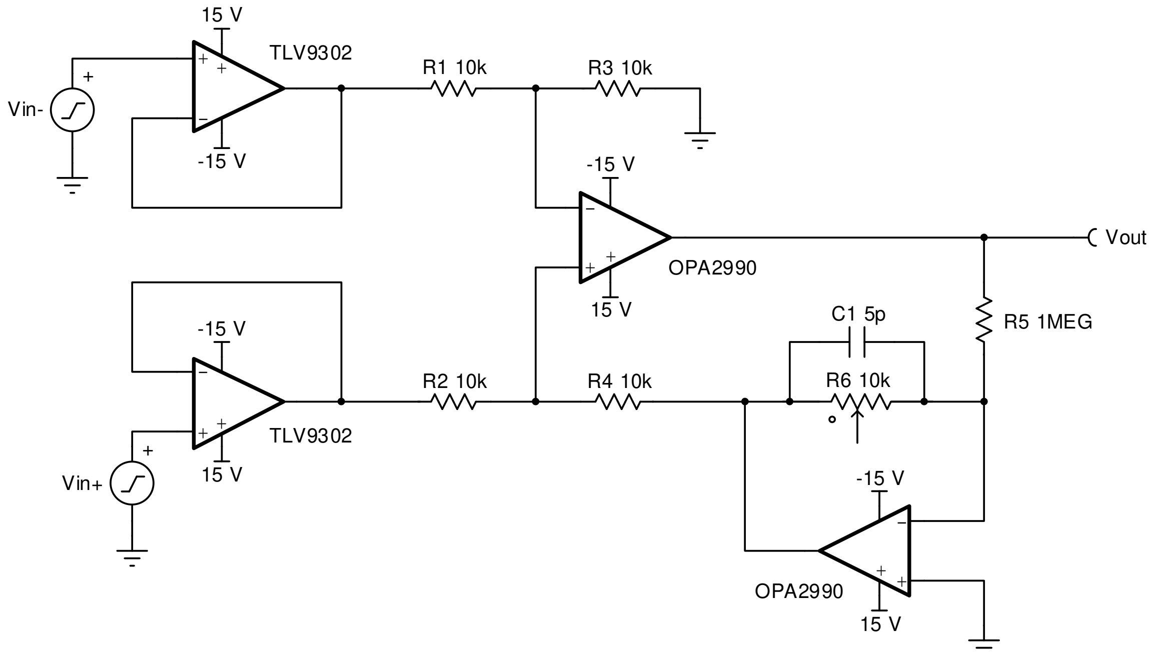


$$V_{out} = \frac{R_3}{R_1}(V_{in+} - V_{in-})$$

$$\frac{R_3}{R_1} = \frac{R_4}{R_2}$$

Figure 3-1. Instrumentation Amplifier

Simulate this design by downloading TINA-TI and the schematic.

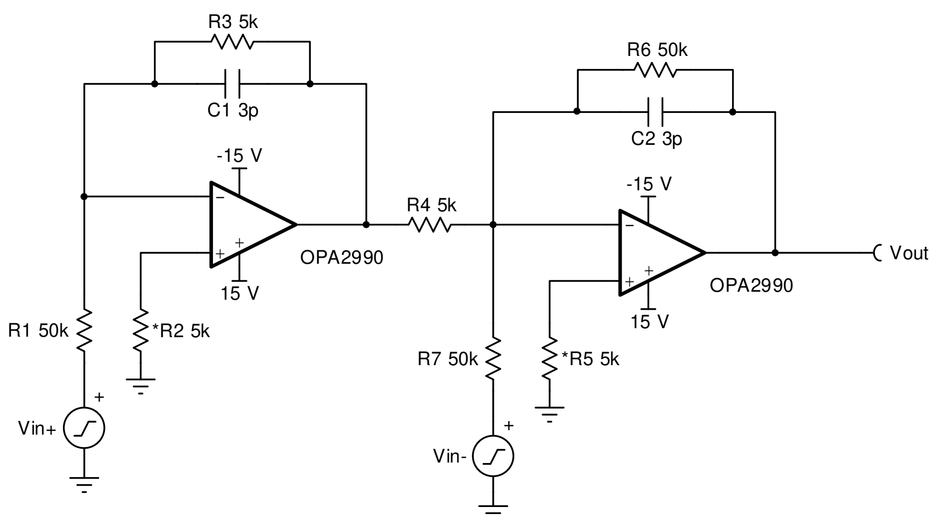


$$V_{out} = \frac{10^{-4} R_6 R_3}{R_1}(V_{in+} - V_{in-})$$

$$\frac{R_3}{R_1} = \frac{R_4}{R_2}$$

Figure 3-2. Variable Gain Instrumentation Amplifier

Simulate this design by downloading TINA-TI and the schematic.



$$R_2 = R_3 = R_4 = R_5$$

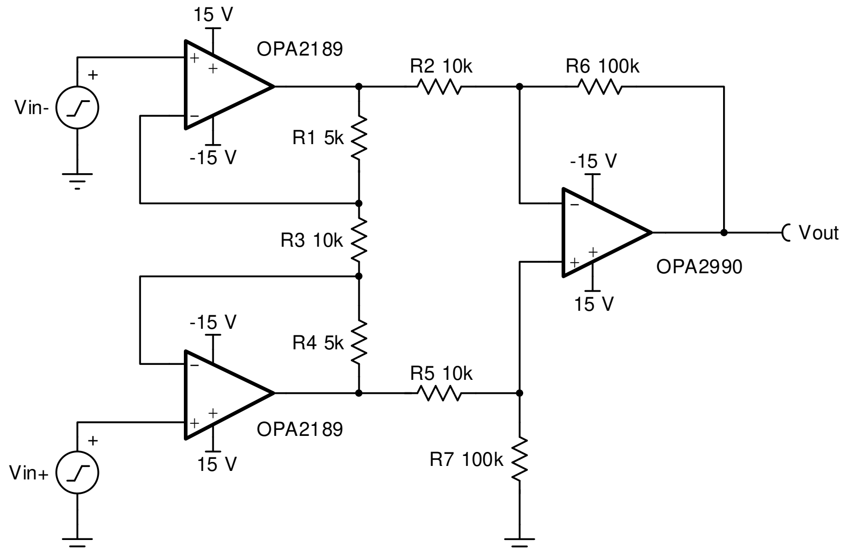
$$R_1 = R_6 = 10R_3$$

$$V_{out} = \left(\frac{R_7}{R_6}\right) V_{in}$$

$* R_2 \ and \ R_5 \ Optional \ for \ Input \ Bias \ Current \ Cancellation$

Figure 3-3. Instrumentation Amplifier With ±100-V Common Mode Range

Simulate this design by downloading TINA-TI and the schematic.



$$R_1 = R_4$$

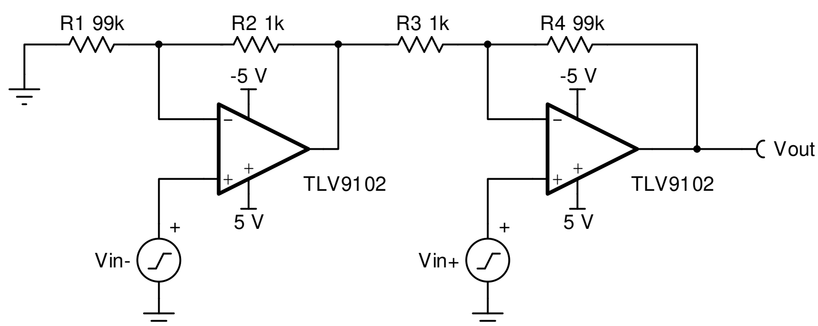
$$R_2 = R_5$$

$$R_6 = R_7$$

$$V_{out} = \frac{R_6}{R_2}\left(1 + \frac{2R_1}{R_3}\right)V_{in}$$

Figure 3-4. Instrumentation Amplifier With ±10-V Common Mode Range

Simulate this design by downloading TINA-TI and the schematic.

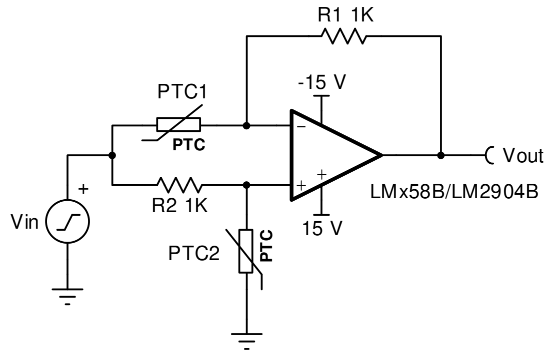


$$R_1 = R_4 \,\&\, R_2 = R_3$$

$$V_{out} = \left(1 + \frac{R_1}{R_2}\right)V_{in}$$

Figure 3-5. High Input Impedance Instrumentation Amplifier

Simulate this design by downloading TINA-TI and the schematic.

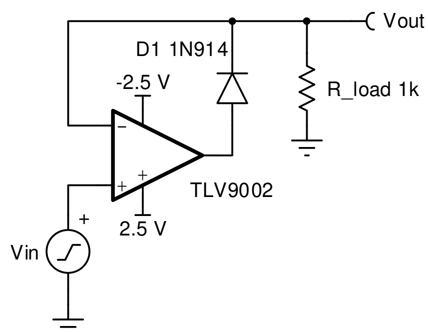


$$\frac{R_1}{R_{PTC1}} = \frac{R_2}{R_{PTC2}}$$

$$V_{out} = V_{in}\left(1 - \frac{R_1}{R_{PTC1}}\right)$$

Figure 3-6. Bridge Amplifier With Temperature Sensitivity

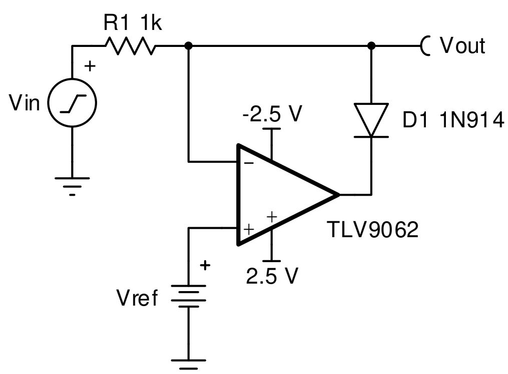
Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = V_{in} \ if \ V_{in} > 0$$

Figure 3-7. Precision Diode

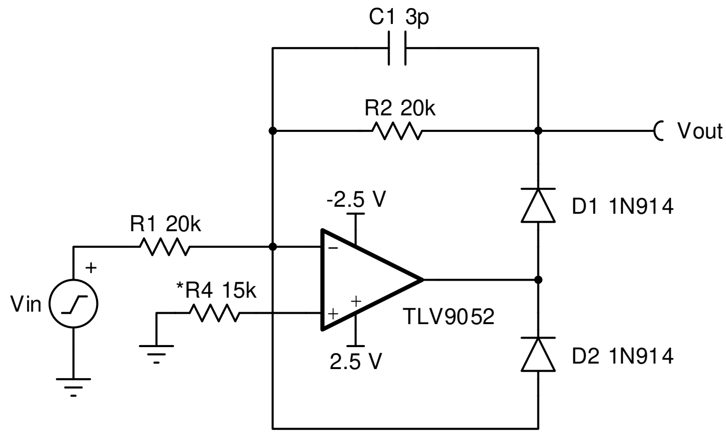
For more information on this configuration, see [12]. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = V_{in} \ if \ V_{in} < V_{ref}$$

Figure 3-8. Precision Clamp

For more information on this configuration, see [12]. Simulate this design by downloading TINA-TI and the schematic.

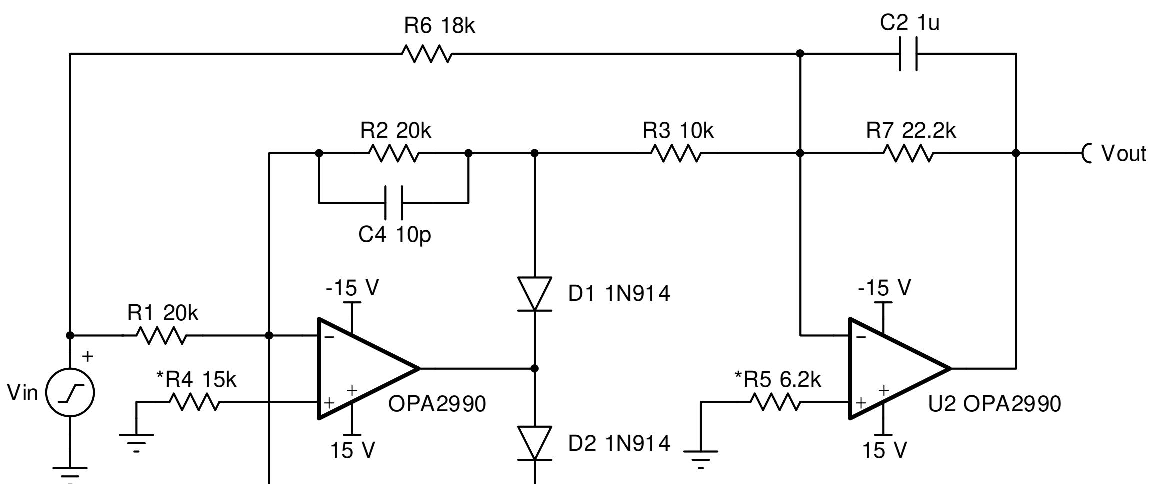


$$V_{out} = |V_{in}|$$

$$* R_4 \ Optional \ for \ Input \ Bias \ Current \ Cancellation$$

Figure 3-9. Fast Half Wave Rectifier

For more information on this configuration, see [12]. See Analog engineer's circuit cookbook: amplifiers for more information. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = V_{in,avg}$$

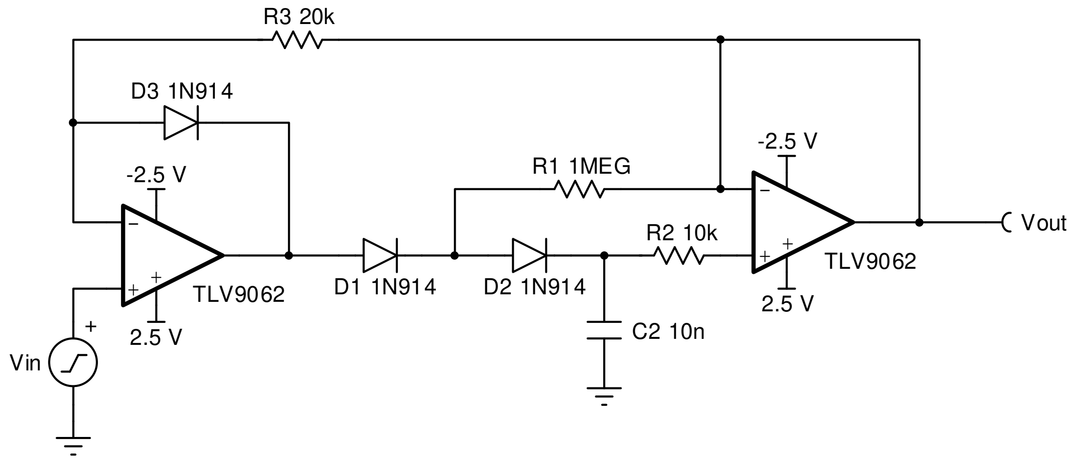
$$0 < V_{in} < V_{cc} - V_{D1}$$

$$Ensure \ Op \ Amps \ Remain \ in \ Linear \ Range$$

$$* R_4 \ and \ R_5 \ Optional \ for \ Input \ Bias \ Current \ Cancellation$$

Figure 3-10. AC to DC Converter

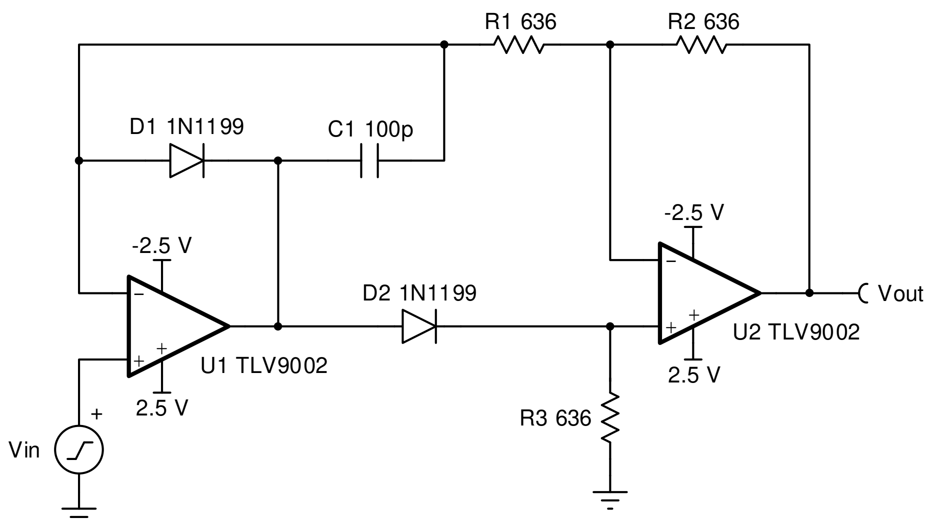
For more information on this configuration, see [12]. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = V_{peak}$$

Figure 3-11. Peak Detector

Simulate this design by downloading TINA-TI and the schematic.



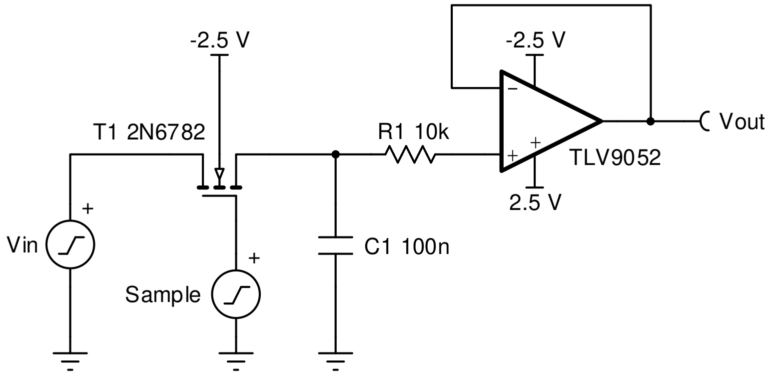
$$V_{out} = |V_{in}|$$

$$R_2 = R_1$$

$$\frac{GBW_{U2}}{4} = \frac{1}{2\pi R_1 C_1}$$

Figure 3-12. Absolute Value Amplifier

For more information on this circuit, see [13]. Simulate this design by downloading TINA-TI and the schematic.

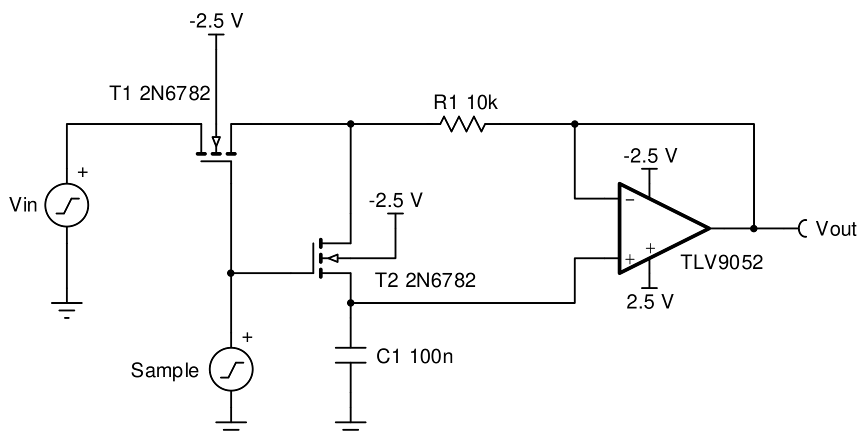


$$t_{sample} \propto C_1$$

$$Droop\ Rate \propto \frac{1}{C_1}$$

Figure 3-13. Sample and Hold I

For more information on this circuit, see [14]. Simulate this design by downloading TINA-TI and the schematic.

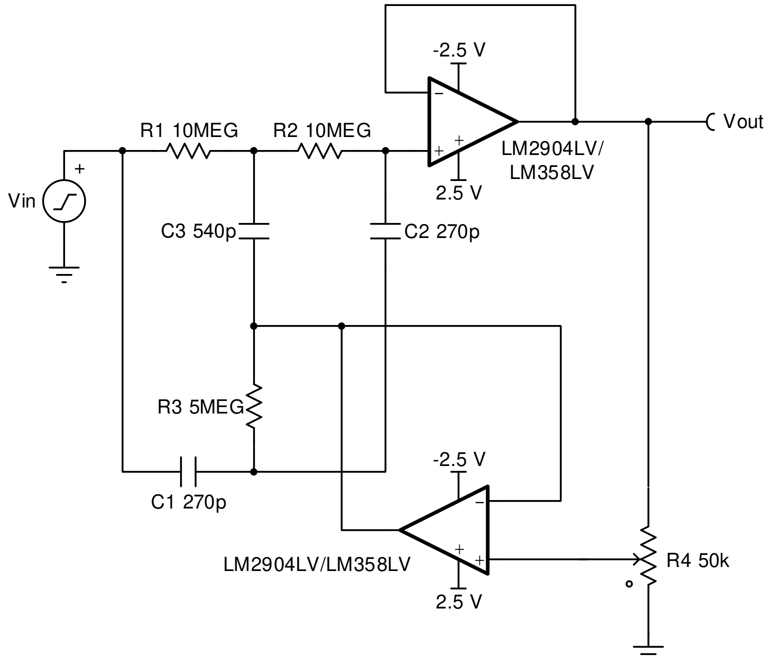


$$t_{sample} \propto C_1$$

$$Droop\ Rate \propto \frac{1}{C_1}$$

Figure 3-14. Sample and Hold II

For more information on this circuit, see [14]. Simulate this design by downloading TINA-TI and the schematic.



$$f_o = \frac{1}{2\pi R_1 C_1}$$

$$R_1 = R_2 = 2R_3$$

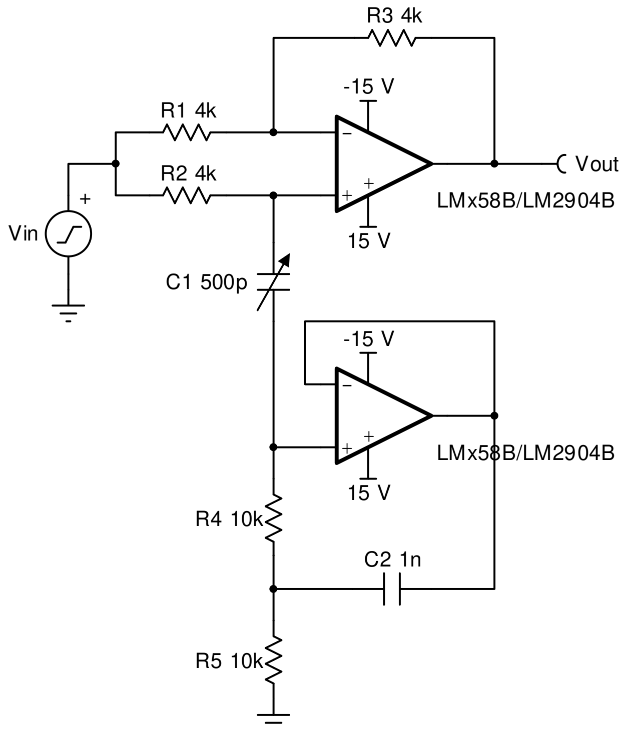
$$2C_1 = 2C_2 = C_3$$

$$0.25 < Q_{network} < 10$$

$$Increasing\ Potentiometer\ Setting\ Increases\ Q_{network}$$

Figure 3-15. Adjustable Q Notch Filter

For more information on this configuration, see [15] and [16]. Simulate this design by downloading TINA-TI and the schematic.



$$f_o = \frac{1}{2\pi R_4 \sqrt{C_1 C_2}}$$

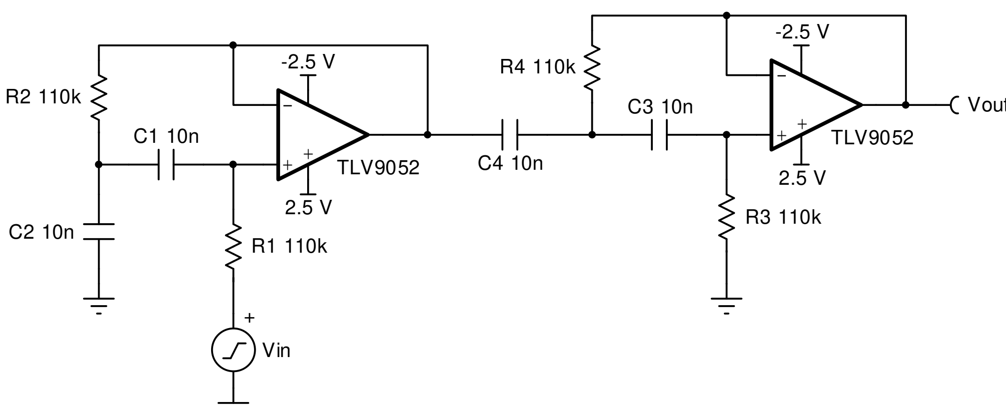
$$R_4 = R_5$$

$$R_1 = R_3$$

$$R_4 = \frac{R_1}{2}$$

Figure 3-16. Easily Tuned Notch Filter

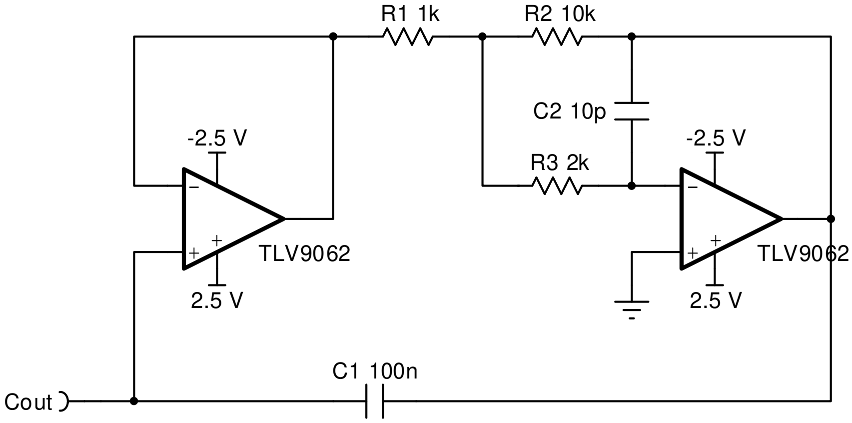
For more information on this configuration, see [15] and [16]. Simulate this design by downloading TINA-TI and the schematic.



$$f_o = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}$$

Figure 3-17. Sallen-Key Two-Stage Bandpass Filter

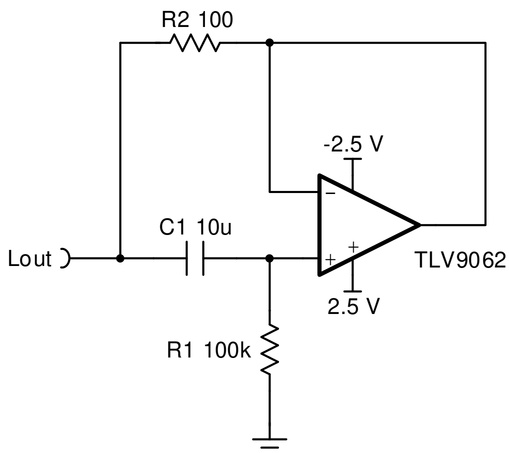
For more information on this configuration, see [17]. Simulate this design by downloading TINA-TI and the schematic.



$$C_{out} = \left(1 + \frac{R_2}{R_1}\right) C_1$$

Figure 3-18. Two-Stage Capacitance Multiplier

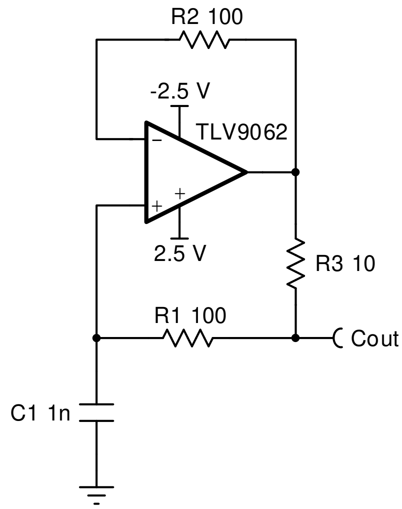
Simulate this design by downloading TINA-TI and the schematic.



$$L_{out} = R_1 R_2 C_1$$
$$Z_{out} = R_2 + j\omega R_1 R_2 C_1$$

Figure 3-19. Simulated Inductor

For more information on this configuration, see [19]. Simulate this design by downloading TINA-TI and the schematic.



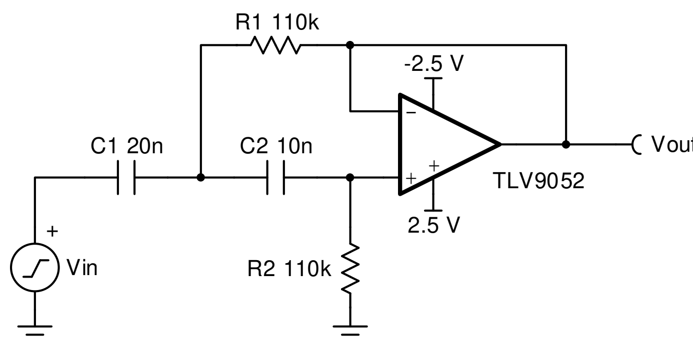
$$C_{out} \approx \frac{R_1}{R_3} C_1$$

$$C_1 \geq 100 \times C_{in\ amplifier}$$

$$R_{source} \gg R_3$$

Figure 3-20. Capacitance Multiplier

Simulate this design by downloading TINA-TI and the schematic.



$$R_2 = mR_1$$

$$C_2 = nC_1$$

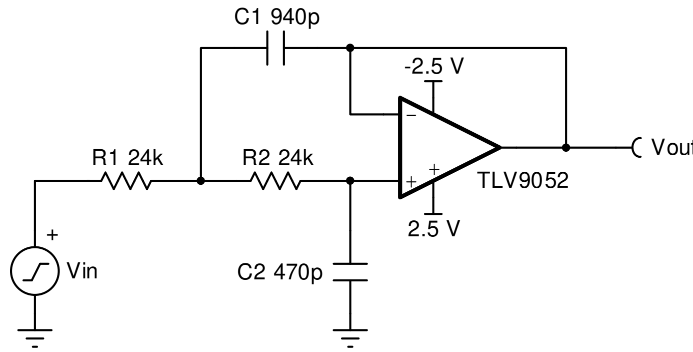
$$f_c = \frac{1}{2\pi RC\sqrt{mn}}$$

$$Q = \frac{\sqrt{mn}}{m+1}$$

$$Choose\ m\ and\ n\ for\ desired\ f_c\ and\ Q$$

Figure 3-21. High Pass Sallen-Key Active Filter

For more information on this configuration, see [17]. Simulate this design by downloading TINA-TI and the schematic.



$$R_1 = mR_2$$

$$C_1 = nC_2$$

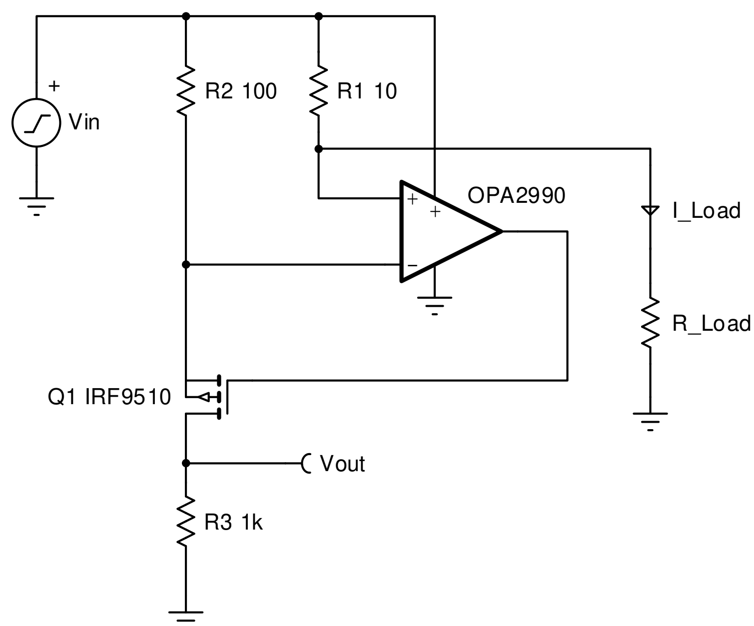
$$f_c = \frac{1}{2\pi RC\sqrt{mn}}$$

$$Q = \frac{\sqrt{mn}}{m+1}$$

$$Choose\ m\ and\ n\ for\ desired\ f_c\ and\ Q$$

Figure 3-22. Low Pass Sallen-Key Active Filter

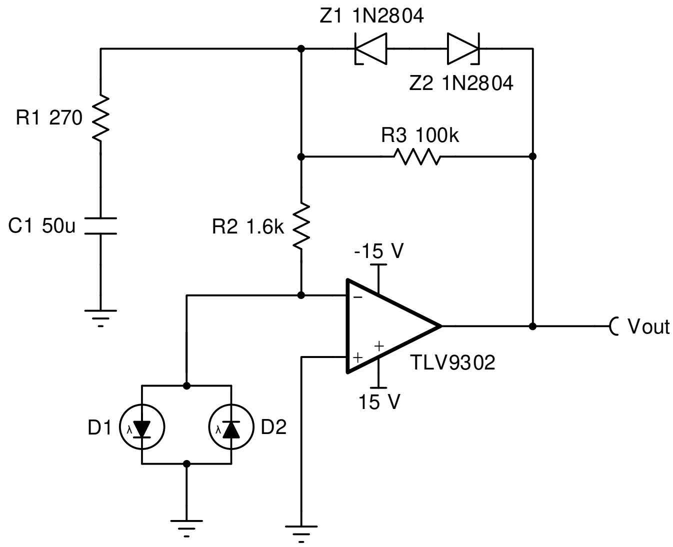
For more information on this configuration, see [17] and [18]. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = \frac{R_1 R_3}{R_2} I_L$$

Figure 3-23. Current Monitor

Simulate this design by downloading TINA-TI and the schematic.

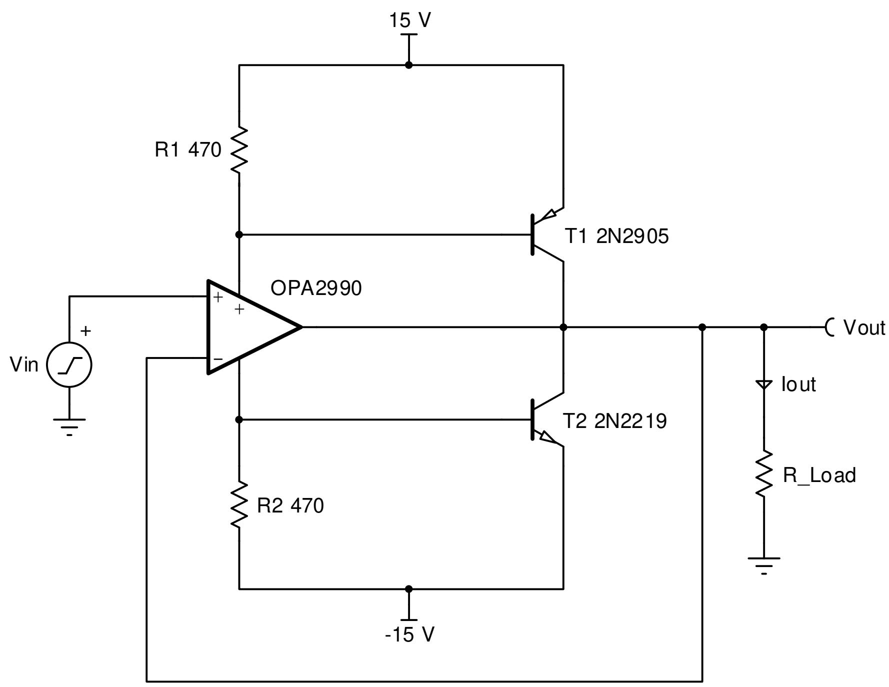


$$V_{out} = \frac{0.1V}{\mu A} \; from \; D1, D2$$

$$Linear \; Range \; through \; 60\mu A$$

Figure 3-24. Saturating Servo Preamplifier With Rate Feedback

For more information on modeling photodiodes, see [8]. More information on this configuration can be found in [20]. Simulate this design by downloading TINA-TI and the schematic.

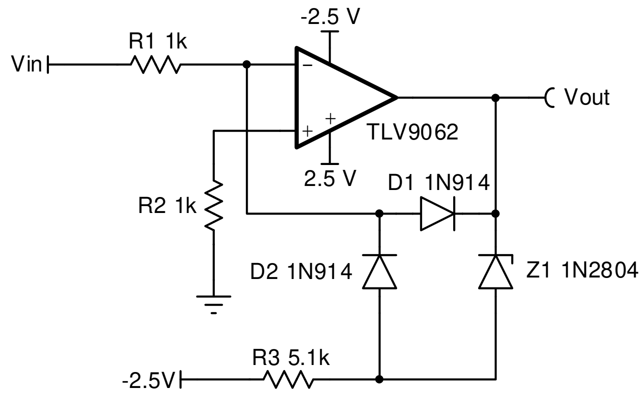


$$V_{out} = V_{in}$$

$$Q_1 \; and \; Q_2 \; Increase \; I_{out}$$

Figure 3-25. Power Booster

Simulate this design by downloading TINA-TI and the schematic.

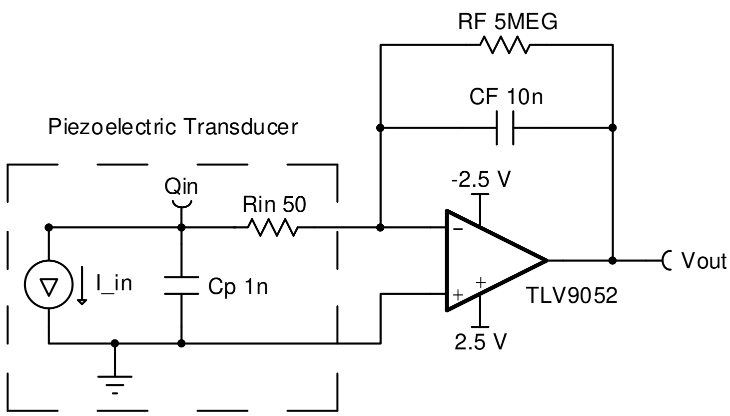


Time to Detect Falling, Zero Crossing Reduced by ~65%

Versus Using Amplifier as Comparator

Figure 3-26. Fast Zero Crossing Detector

Simulate this design by downloading TINA-TI and the schematic.



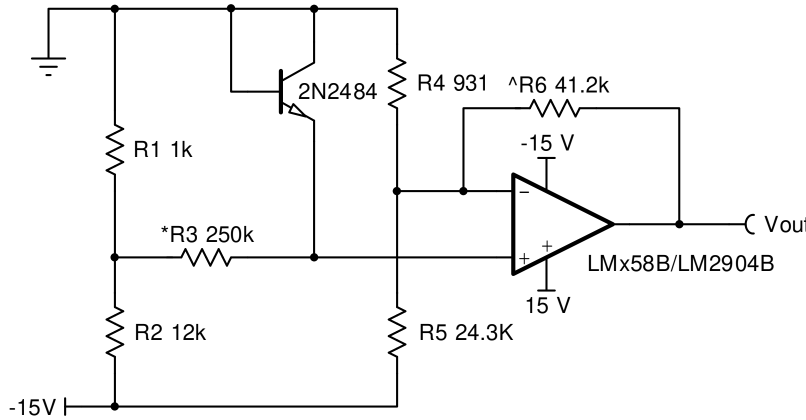
$$Gain = \frac{V_{out}}{Q_{in}} = \frac{1}{C_F}$$

$$f_{LPF} = \frac{1}{2\pi R_F C_F}$$

$$f_{HPF} = \frac{1}{2\pi R_{in} C_{in}}$$

Figure 3-27. Amplifier for Piezoelectric Transducer

For more information on this configuration, see [21] and [22]. Simulate this design by downloading TINA-TI and the schematic.



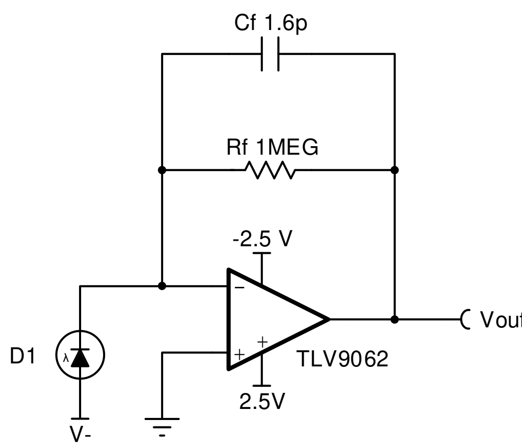
$$V_{out} = 103.9mV/°C - 383mV$$

$$* Value\ Can\ Be\ Changed\ for\ 0V\ at\ 0°C$$

$$\hat{}Value\ Can\ Be\ Changed\ for\ 100mV/°C$$

Figure 3-28. Temperature Probe

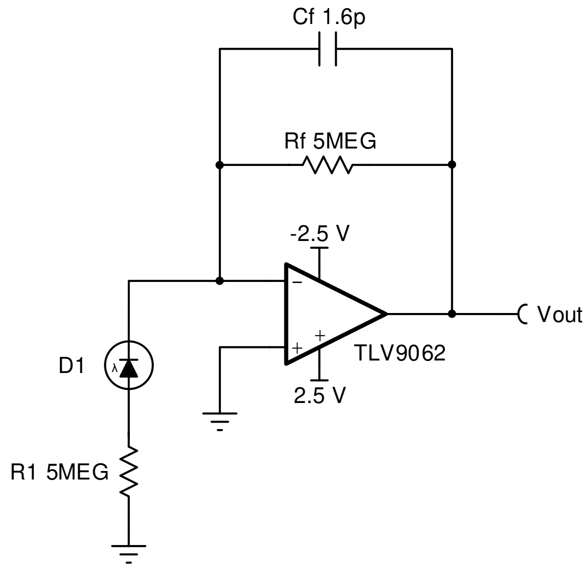
Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = R_f I_D$$

Figure 3-29. Photodiode Amplifier I

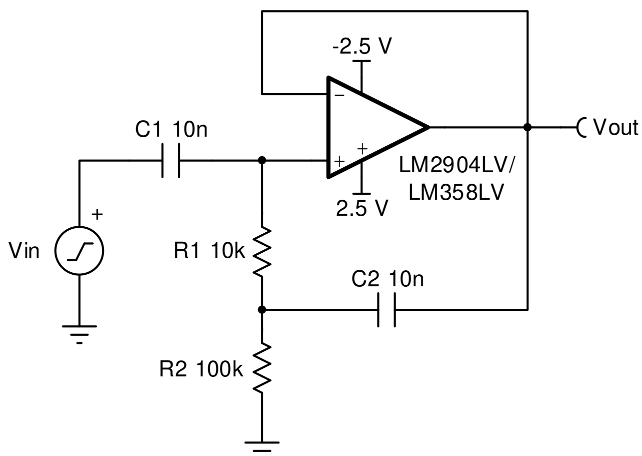
For more information on modeling photodiodes, see [8]. See Analog engineer's circuit cookbook: amplifiers or [2] for more information on this circuit. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = 5V/\mu A \times \frac{R_f}{R_1}$$

Figure 3-30. Photodiode Amplifier II

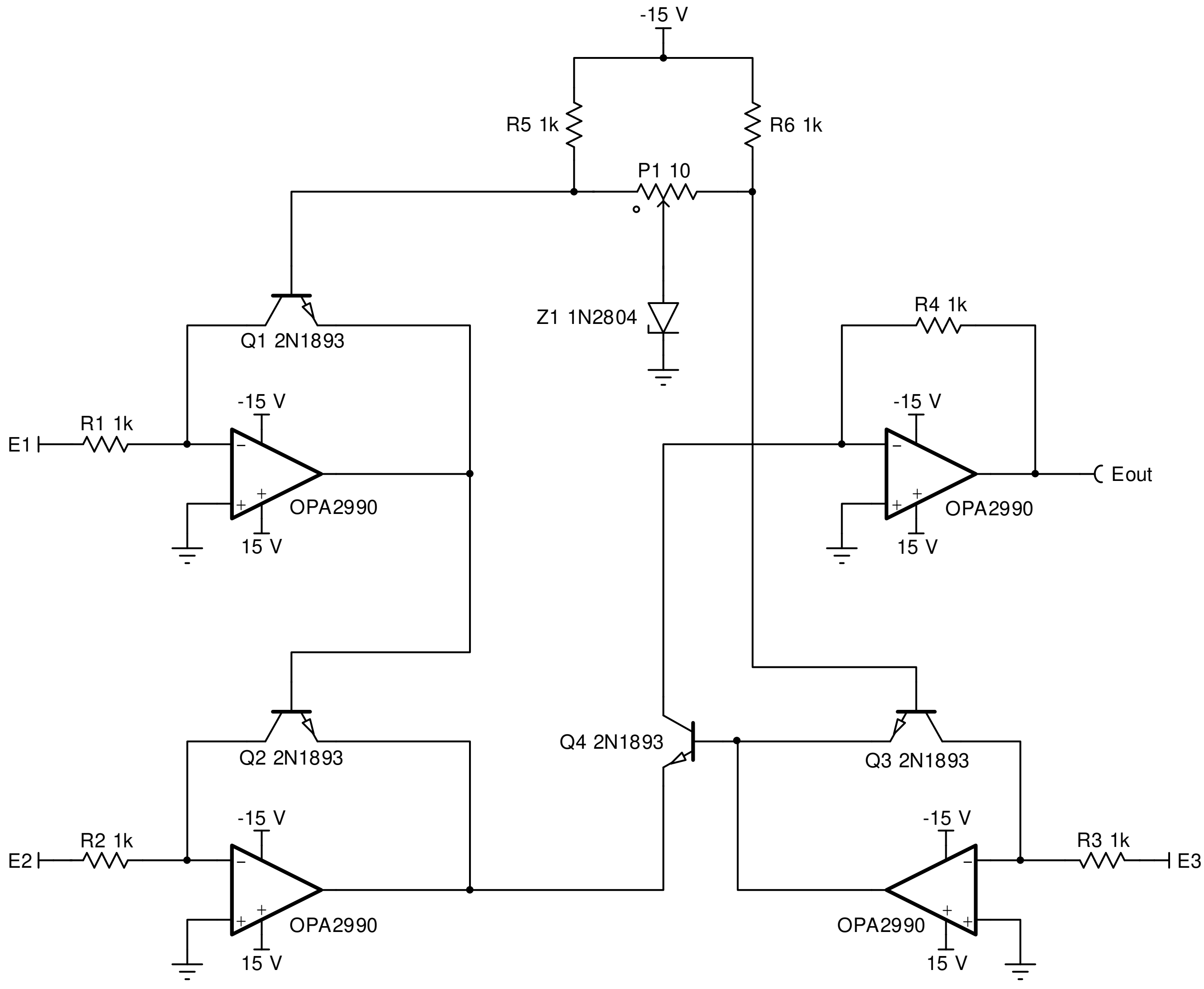
For more information on modeling photodiodes, see [8]. See Analog engineer's circuit cookbook: amplifiers for more information on this circuit. Simulate this design by downloading TINA-TI and the schematic.



$$V_{out} = \frac{(R_1 + R_2)C_1 s + C_1 C_2 R_1 R_2 s^2}{1 + (R_1 + R_2)C_1 s + C_1 C_2 R_1 R_2 s^2} V_{in}$$

Figure 3-31. High Input Impedance AC Follower

Simulate this design by downloading TINA-TI and the schematic.



$$E_{out} = \frac{E_1 E_2}{E_3}$$

$$R_1 = R_2 = R_3 = R_4$$

Figure 3-32. Multiplier/Divider

Simulate this design by downloading TINA-TI and the schematic.

4 References

1. To learn more about the design of many of these and other amplifier configurations, consult our *Analog engineer's circuit cookbook on amplifiers*.
2. Alternatively, more information on several of these circuits can be found in our app note entitled, *AN-20 an applications guide for op amps*.
3. To learn more about the characteristics of amplifiers, common techniques used in amplifier circuit design, and a variety of other amplifier topics, consult our Texas Instruments Precision Labs video series on amplifiers.
4. For specific questions regarding your design, reach out to our engineers via e2e, our online forum.
5. For a handy reference guide for your analog designs, check out the *Analog Engineer's Pocket Reference Guide* available for free in pdf form.
6. Use our Analog Engineer's Calculator to help crunch design equations.
7. Check out our Amplifier's Product Page to quickly sort through our products and find the amplifier(s) that best fit your needs.
8. For more information on modeling photodiodes including the model used in this design, see the *1 MHz, single-supply, photodiode amplifier reference design*.
9. For more information on sine-wave oscillators, check out TI's app note on the *Sine-wave oscillator*.
10. Alternatively, see our note on the *Design of op amp sine wave generators*.
11. For more on the Howland Current Pump, see *AN-1515 a comprehensive study of the Howland current pump*.
12. For more information on the Precision Diode, Precision Clamp, Half Wave Rectifier, and AC to DC Converter circuits, see our *LB-8 precision AC/DC converters* application note.
13. More information on the Absolute Value Amplifier can be found in our app note on *Precision absolute value circuits*.
14. To learn more about Sample-and-Hold configurations, see our application note on the *Specifications and architectures of sample-and-hold amplifiers*.
15. For more information on Q Notch Filters, see our *LB-5 high Q Notch filter* on the subject.
16. Further analysis of notch filters can be found in our app note on *High-speed notch filters*.
17. For more information on Sallen-Key filter design, see our *Analysis of the Sallen-Key architecture* application note on the subject.
18. For more information on Low Pass Sallen-Key filter design, see our *Active low-pass filter design* application note.
19. More information on simulated inductors can be found in our application note entitled, *An audio circuit collection, part 3*.
20. More information on a variety of circuits can be found in our *AN-4 monolithic op amp—the universal linear component* application note.
21. To learn more about the theory behind, design of, and simulation of piezoeletric transducers and their amplifiers, see this *Signal conditioning piezoelectric sensors* application note.
22. Additional information on piezoelectric transducers can be found in our analog applications journal entry, *Signal conditioning for piezoelectric sensors*, on the subject.
23. For more information on the LM324/LM358 device family and how to properly connect unused inputs, see *Application design guidelines for LM324/LM358 devices*.

Revision History

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision C (March 2019) to Revision D (October 2020)	Page
• Changed TINA-TI hyperlinks throughout document	3
• Changed Figure 2-3 Free-Running Multivibrator equation	15

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