

AN-31 amplifier circuit collection

ABSTRACT

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

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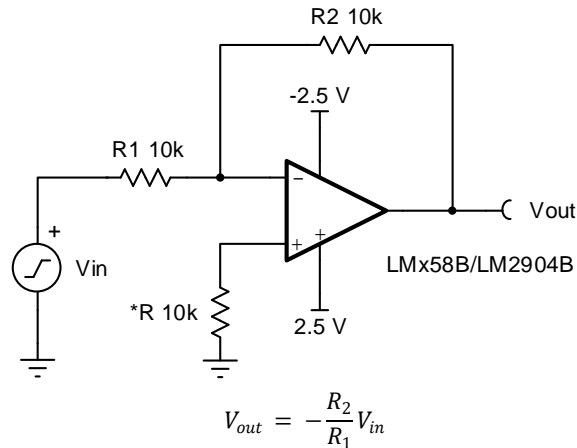
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1 Basic Circuits



** R Optional to Protect LM358 & LM324*

Devices from Transient Current Spikes

Figure 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].

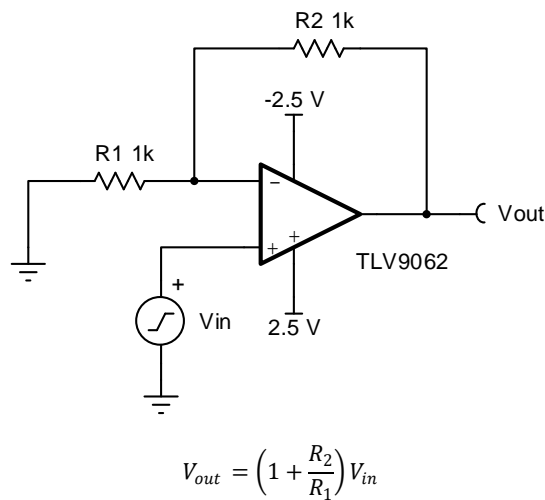
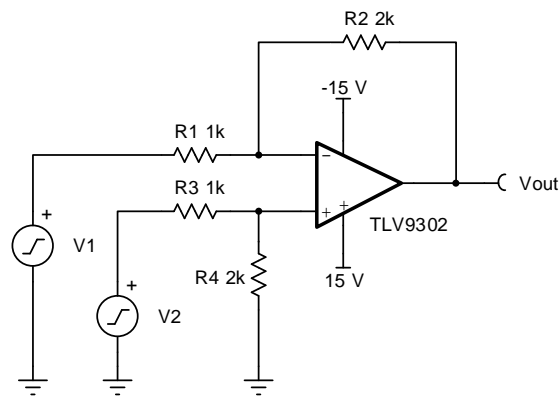


Figure 2. Non-Inverting Amplifier

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



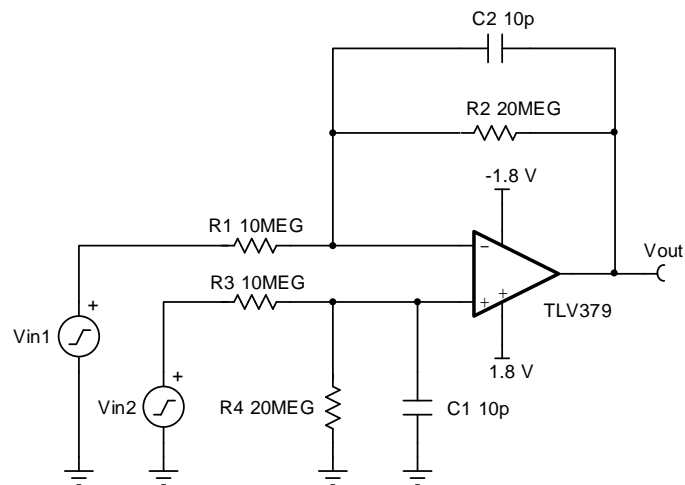
$$V_{out} = \left(\frac{R_4}{R_3 + R_4} \right) \left(1 + \frac{R_2}{R_1} \right) V_2 - \frac{R_2}{R_1} V_1$$

$$\text{For } R_1 = R_3 \text{ and } R_2 = R_4$$

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

Figure 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](#).



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

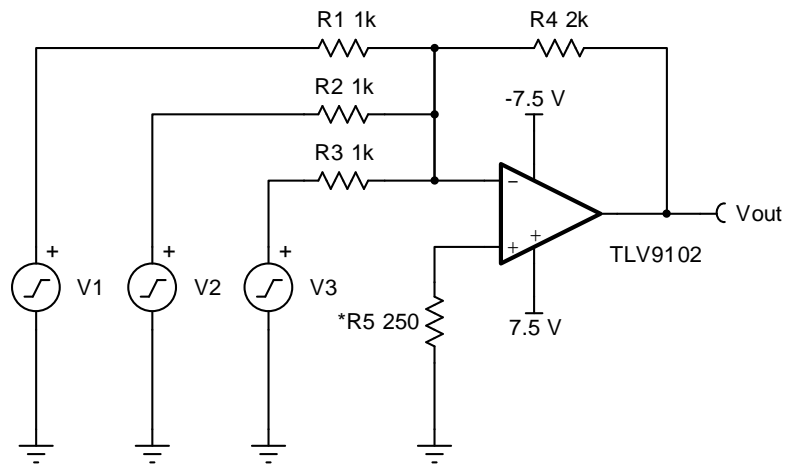
$$\text{For } R_1 = R_3 \text{ and } R_2 = R_4$$

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

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

Figure 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](#).

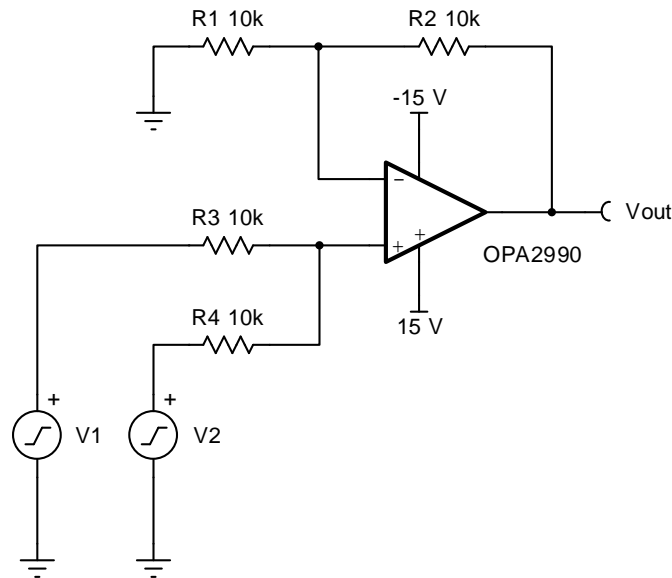


$$V_{out} = -R_4 \left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3} \right)$$

* R₅ Optional for Input Bias Current Cancellation

Figure 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](#).

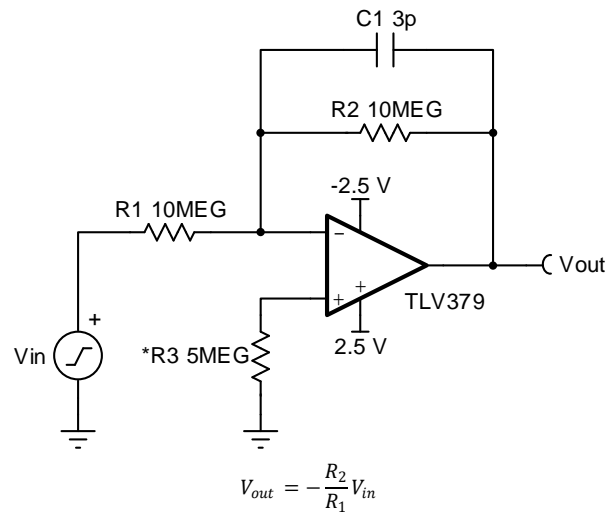


$$V_{out} = \left(1 + \frac{R_2}{R_1} \right) \left(V_1 \frac{R_4}{R_3 + R_4} + V_2 \frac{R_3}{R_3 + R_4} \right)$$

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

Figure 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](#).



* R₃ Optional for Input Bias Current Cancellation

Figure 7. Inverting Amplifier With High Input Impedance

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

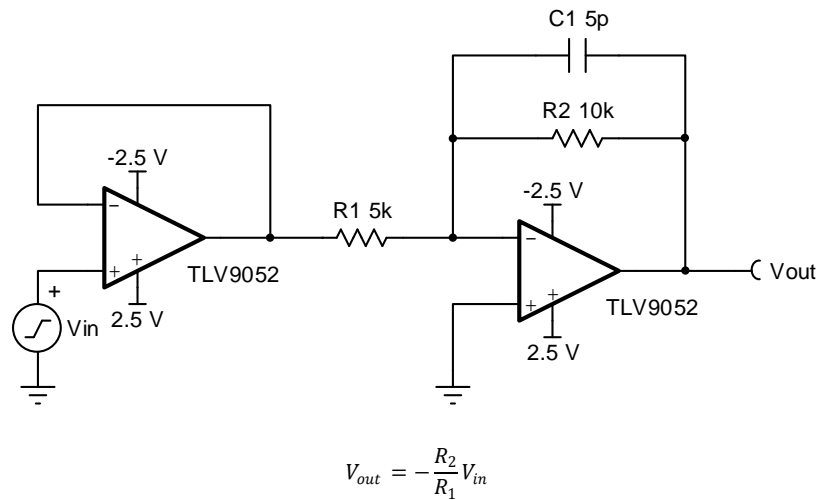
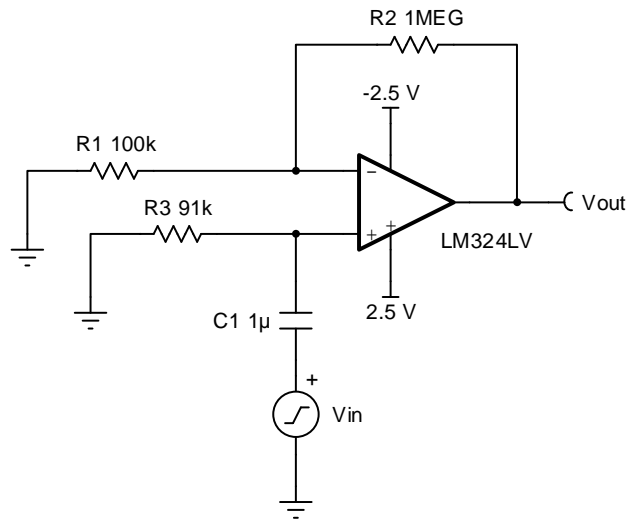


Figure 8. Two-Stage Inverting Amplifier With High Input Impedance

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



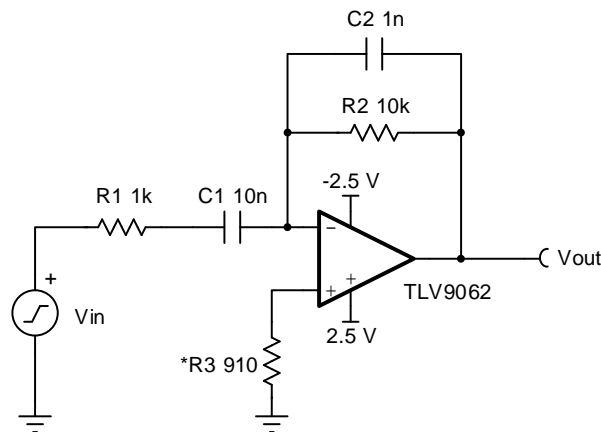
$$V_{out} = \left(1 + \frac{R_2}{R_1}\right) V_{in}$$

$$R_3 = R_1 || R_2 \text{ for CMRR}$$

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

Figure 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](#).



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

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

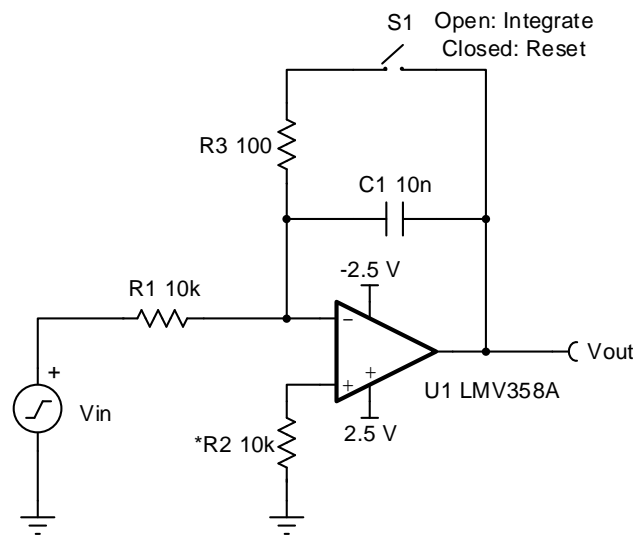
$$f_h = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_2 C_2}$$

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

* R₃ Optional for Input Bias Current Cancellation

Figure 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](#).



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

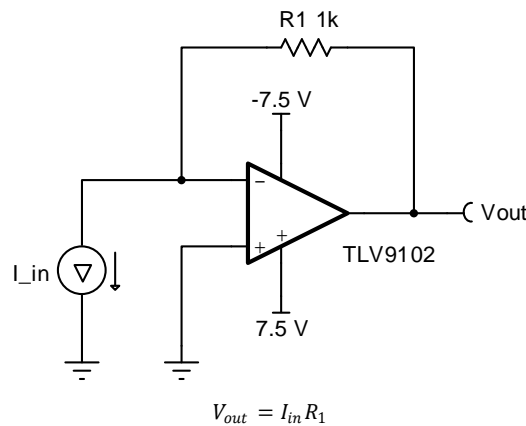
$$f_c = \frac{1}{2\pi R_1 C_1}$$

$$R_1 = R_2$$

* R₂ Optional for Input Bias Current Cancellation

Figure 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 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](#).

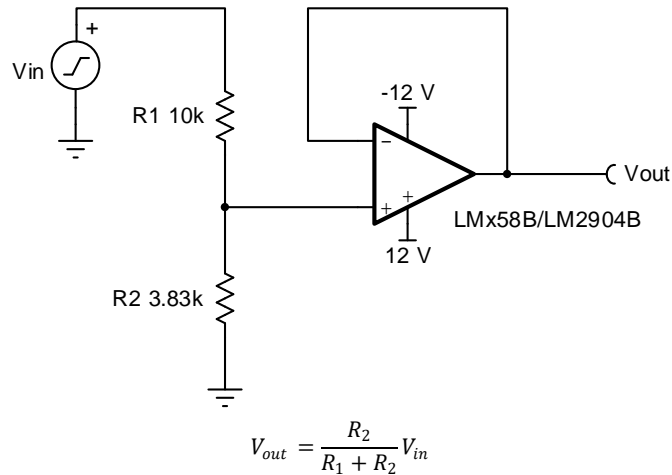


Figure 13. Reference Voltage Generator

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

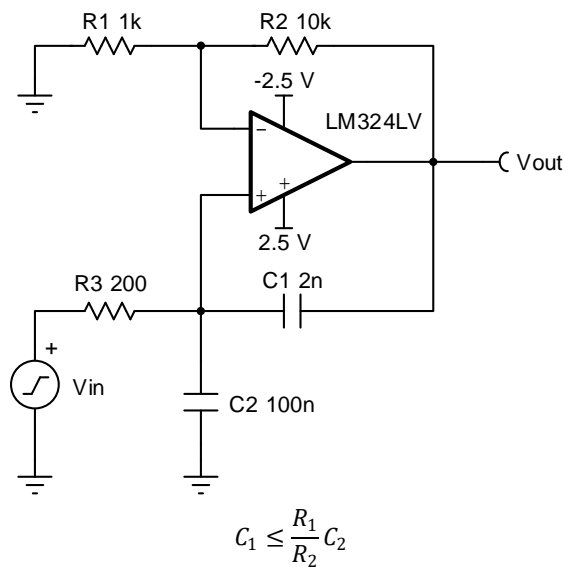
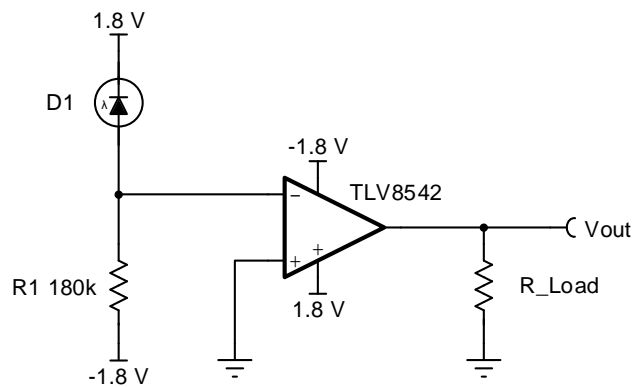


Figure 14. Neutralizing Input Capacitance to Optimize Response Time

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

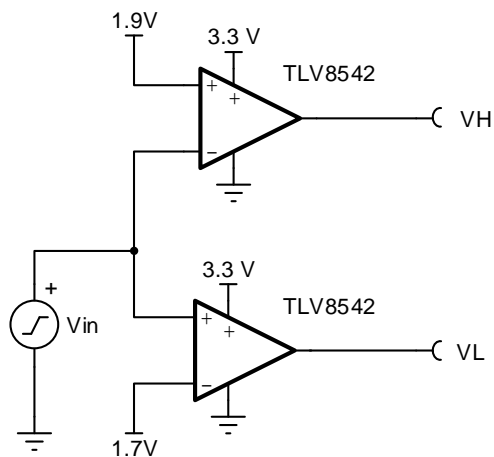


$$V_{out} = 1.8V \Rightarrow \text{Diode Off}$$

$$V_{out} = -1.8V \Rightarrow \text{Diode On}$$

$$R_1 \text{ Controls Sensitivity to Light}$$
Figure 15. Threshold Detector for Photodiodes

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

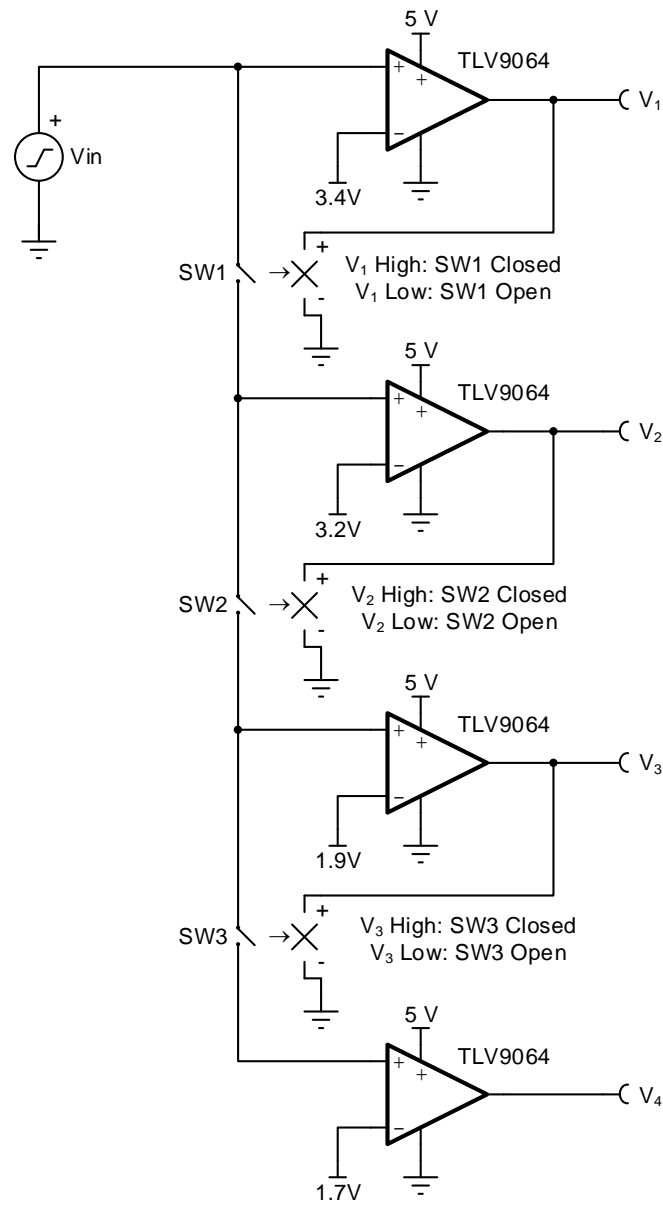


$$\text{If } V_{in} > 1.9V, \text{ then } V_H = 0 \text{ and } V_L = 3.3V$$

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

$$\text{If } V_{in} < 1.7V, \text{ then } V_H = 3.3V \text{ and } V_L = 0$$
Figure 16. Double-Ended Limit Detector

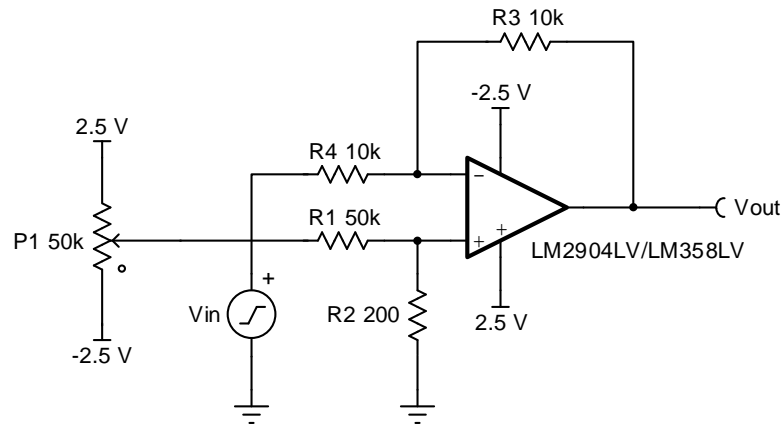
Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



$$\begin{aligned}
 V_{in} > 3.4V &\rightarrow V_1 = 1, V_2 = 1, V_3 = 1, V_4 = 1 \\
 3.4V > V_{in} > 3.2V &\rightarrow V_1 = 0, V_2 = 1, V_3 = 1, V_4 = 1 \\
 3.2V > V_{in} > 1.9V &\rightarrow V_1 = 0, V_2 = 0, V_3 = 1, V_4 = 1 \\
 1.9V > V_{in} > 1.7V &\rightarrow V_1 = 0, V_2 = 0, V_3 = 0, V_4 = 1 \\
 1.7V > V_{in} &\rightarrow V_1 = 0, V_2 = 0, V_3 = 0, V_4 = 0
 \end{aligned}$$

Figure 17. Multiple Aperture Window Discriminator

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



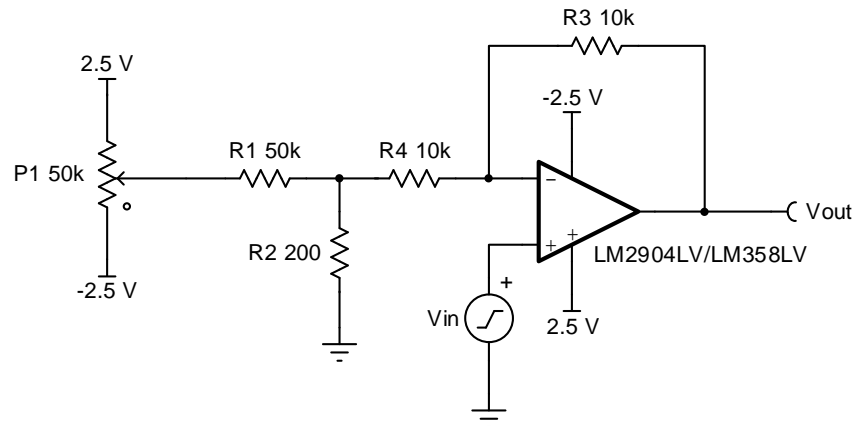
$$\text{Offset Range} = V_{\text{supply}} \left(\frac{R_2}{R_1} \right)$$

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

$$R_1 \gg R_2$$

Figure 18. Offset Voltage Adjustment for Inverting Amplifiers

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



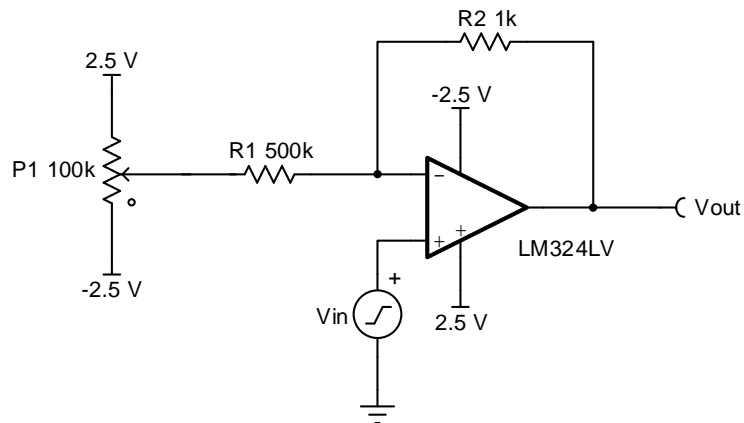
$$\text{Offset Range} = V_{\text{supply}} \left(\frac{R_2}{R_1} \right)$$

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

$$R_1 \gg R_2 \text{ and } R_4 \gg R_2$$

Figure 19. Offset Voltage Adjustment for Non-Inverting Amplifiers

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



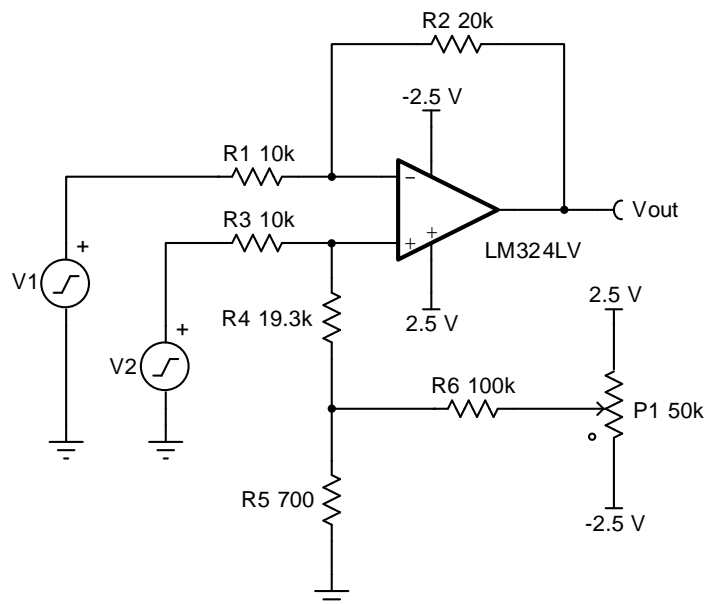
$$\text{Offset Range} = V_{\text{supply}} \left(\frac{R_2}{R_1} \right)$$

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

$$R_1 \gg R_2$$

Figure 20. Offset Voltage Adjustment for Voltage Followers

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



$$R_2 = R_4 + R_5$$

$$R_1 = R_3$$

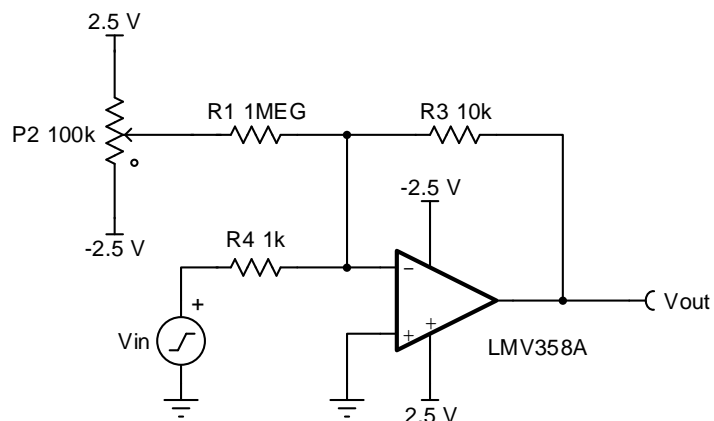
$$\text{Offset Range} = V_{\text{supply}} \left(\frac{R_5}{R_5 + R_6} \right) \left(\frac{R_3}{R_3 + R_4} \right)$$

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

$$R_5 \ll \text{Offset Equivalent Resistance}$$

Figure 21. Offset Voltage Adjustment for Difference Amplifiers

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



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

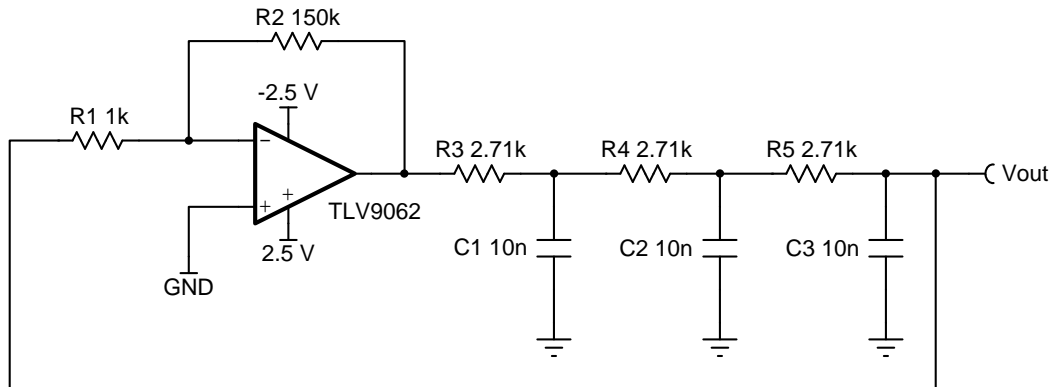
$$\text{Offset Range} = V_{\text{supply}} \left(\frac{R_3 || R_4}{R_1} \right)$$

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

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

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

2 Signal Generation



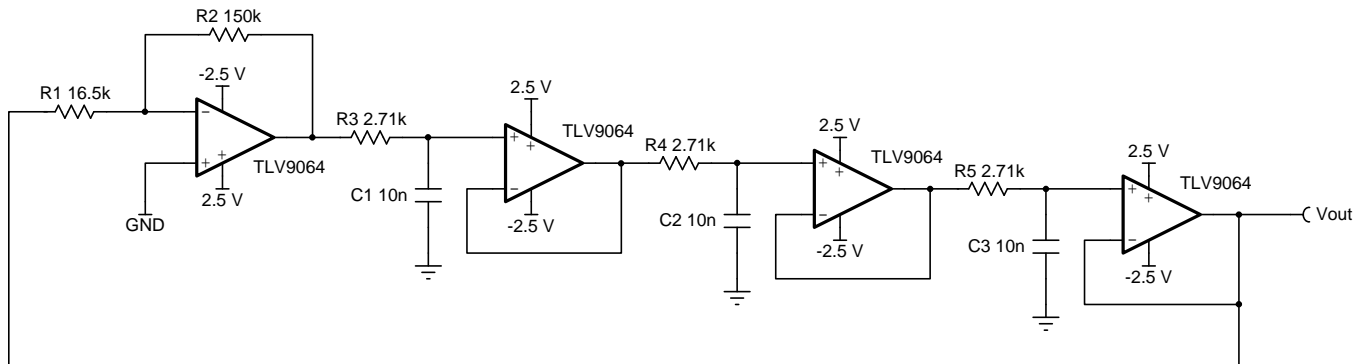
$$\frac{R_2}{R_1} \gg 8$$

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

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

Figure 23. 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 $C = C_1, C_2, C_3$

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

Figure 24. 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](#).

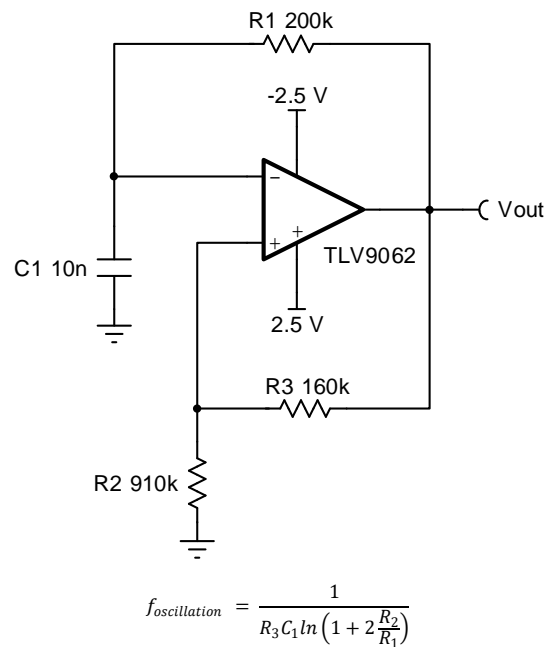


Figure 25. Free-Running Multivibrator

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

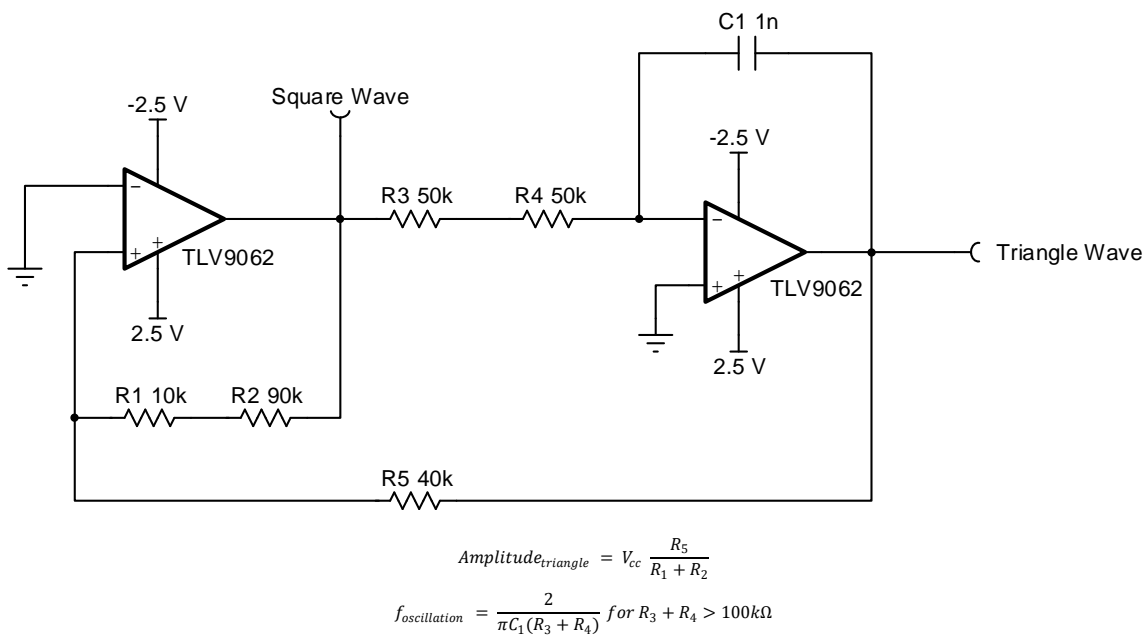
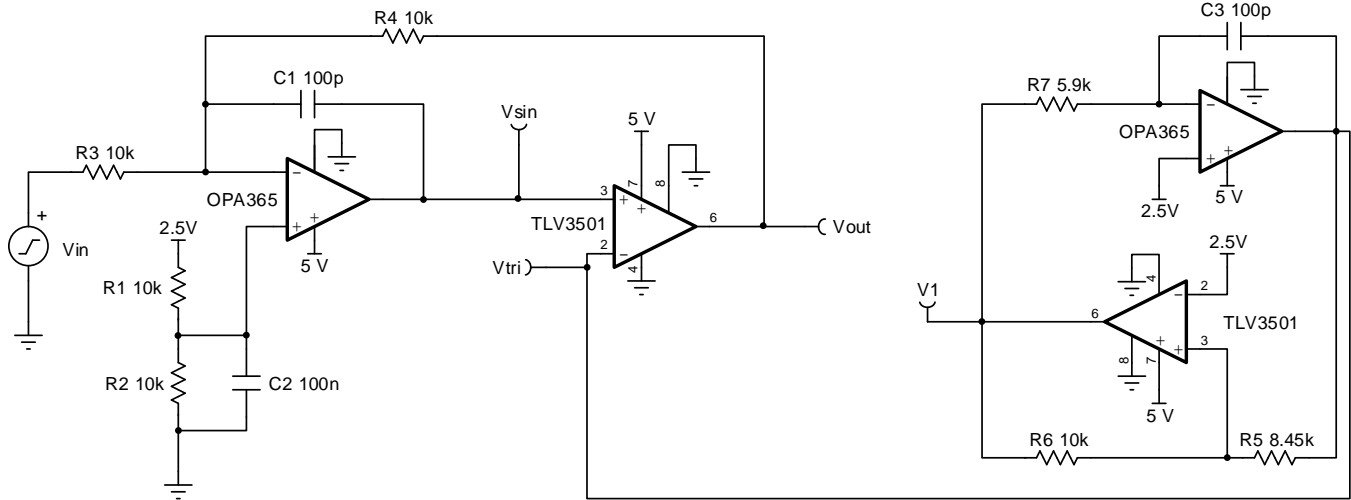


Figure 26. Function Generator

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



$$R_1 = R_2 = R_3 = R_4$$

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

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

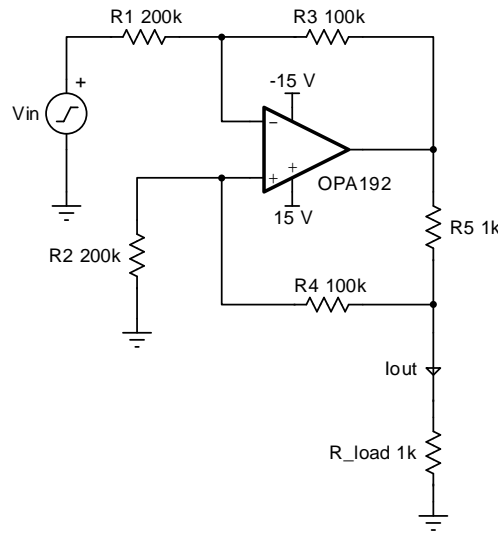
$$f_{oscillation} = \frac{R_6}{4 \times R_7 \times R_5 \times C_3}$$

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

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

Figure 27. Pulse Width Modulator

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



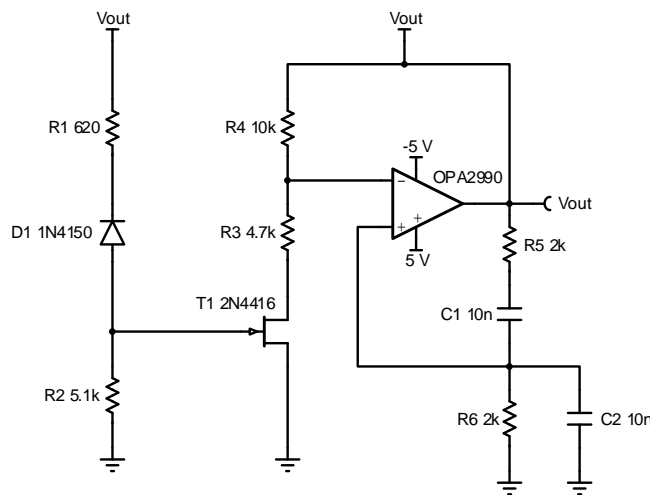
$$I_{out} = -\frac{R_3 V_{in}}{R_1 R_5}$$

$$R_3 = R_4 + R_5$$

$$R_1 = R_2$$

Figure 28. 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

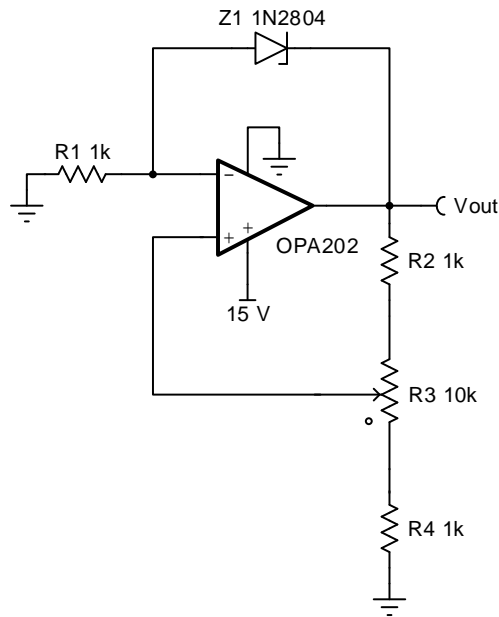
$$Gain = \frac{R_3 + R_4}{R_4}$$

$$R_5 = R_6$$

$$C_1 = C_2$$

Figure 29. Wien Bridge Oscillator With Automatic Gain Control

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

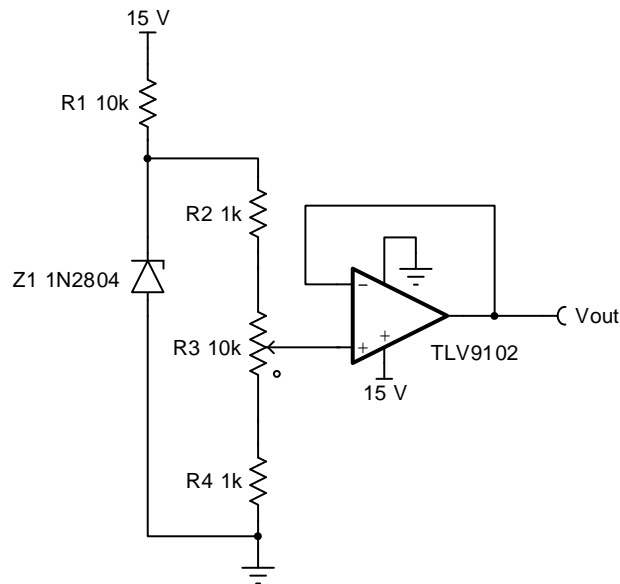


$$7.58V \leq V_{out} \leq 13.93V$$

R_1 controls $V_{out,max}$
 $R_2, R_4,$ & V_{zener} control $V_{out,min}$

Figure 30. Positive Output Voltage Reference

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

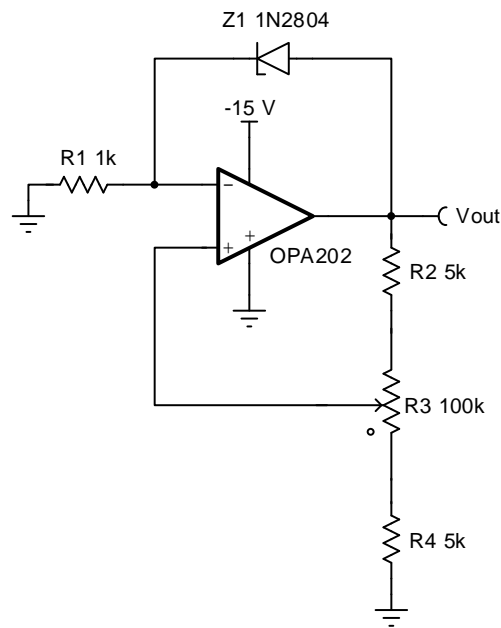


$$500mV \leq V_{out} \leq 5.5V$$

Decreasing R_2 & R_4 increases V_{out} range
 V_{zener} adjusts V_{out} range

Figure 31. Buffered Positive Voltage Reference

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



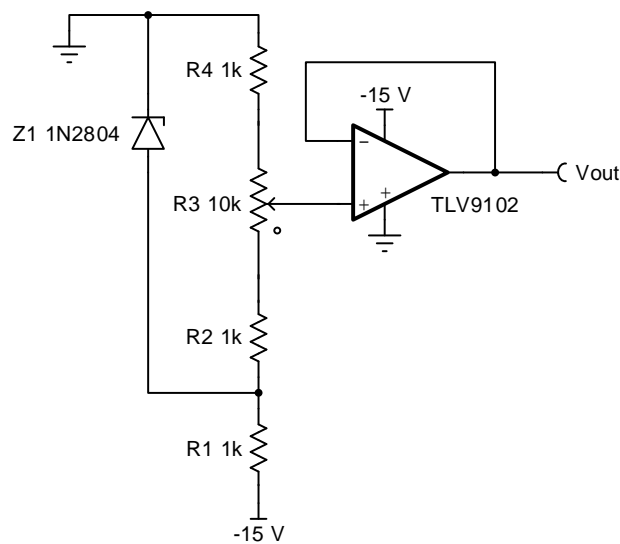
$$-13.9V \leq V_{out} \leq -7.6V$$

Decreasing R_2 and R_4 increases V_{out} range

V_{zener} adjusts V_{out} range

Figure 32. 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 33. Buffered Negative Voltage Reference

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

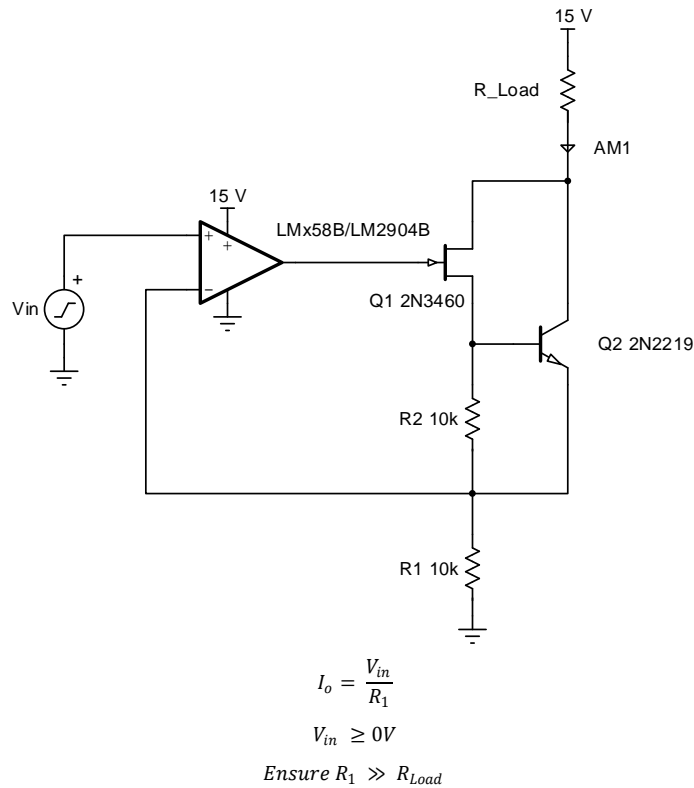


Figure 34. Current Sink

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

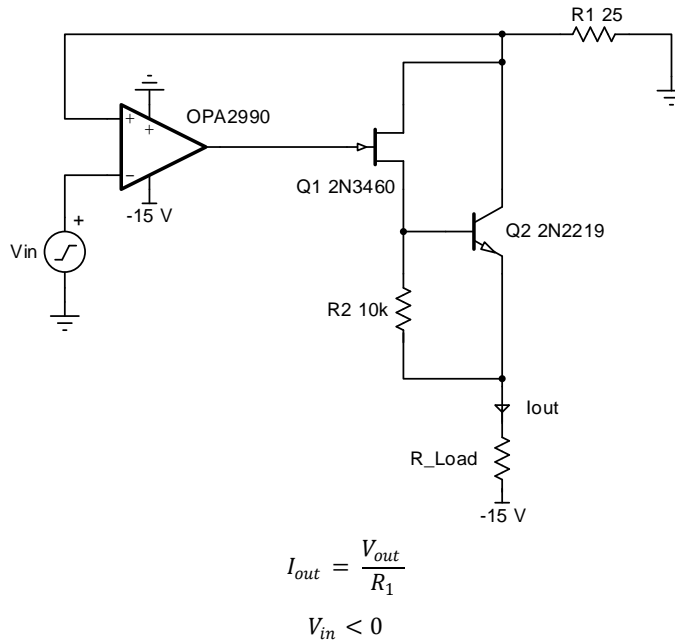
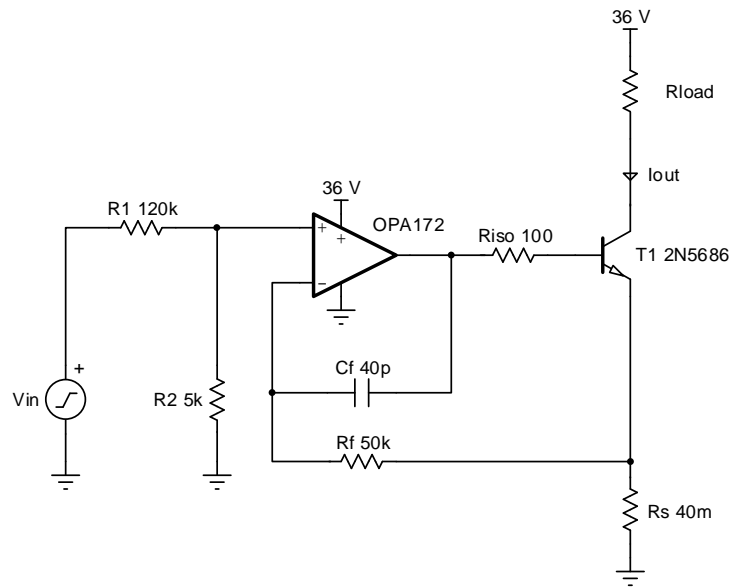


Figure 35. Current Source

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

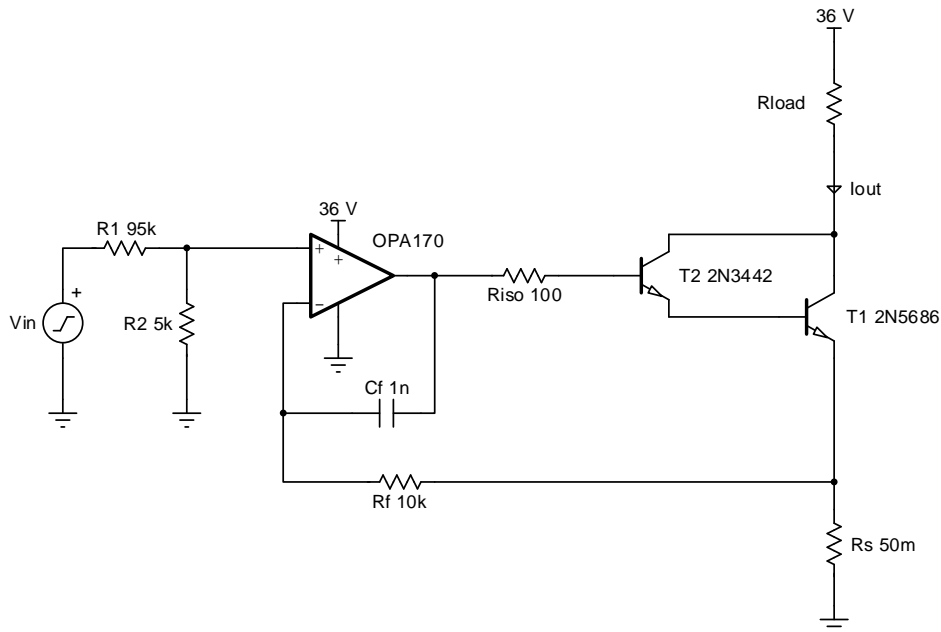


$$I_{out} = V_{in} \frac{R_2}{R_s(R_1 + R_2)}$$

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

Figure 36. Voltage-to-Current Converter With BJT Output

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

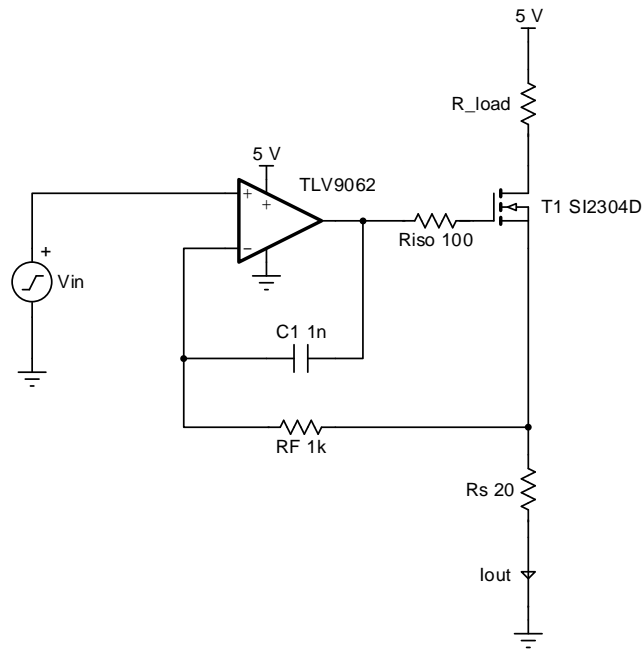


$$I_{out} = V_{in} \frac{R_2}{R_s(R_1 + R_2)}$$

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

Figure 37. Voltage-to-Current Converter With Darlington Pair Output

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



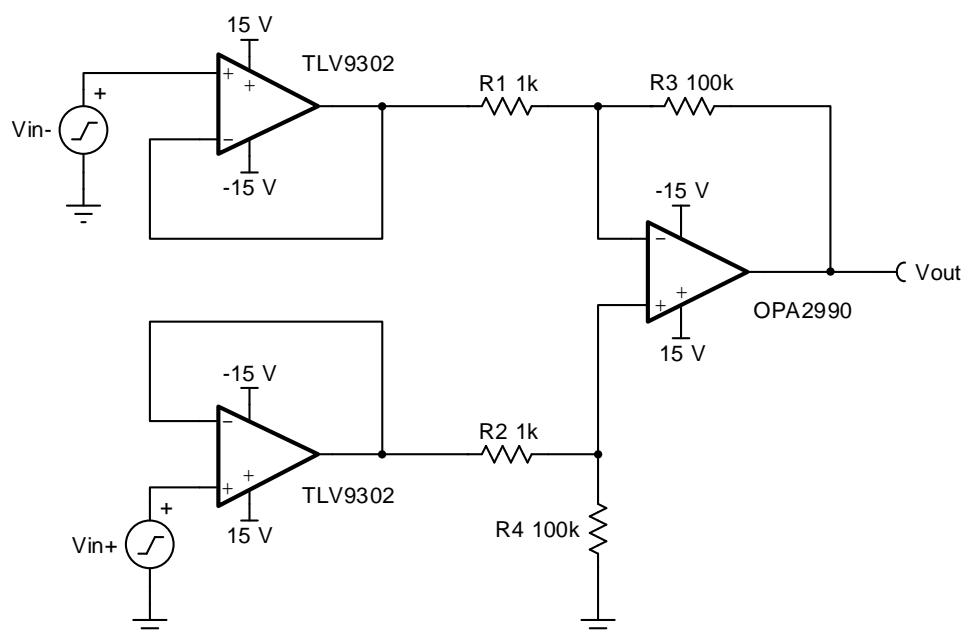
$$I_{out} = \frac{V_{in}}{R_s}$$

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

Figure 38. Voltage-to-Current Converter With MOSFET Output

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

3 Signal Processing

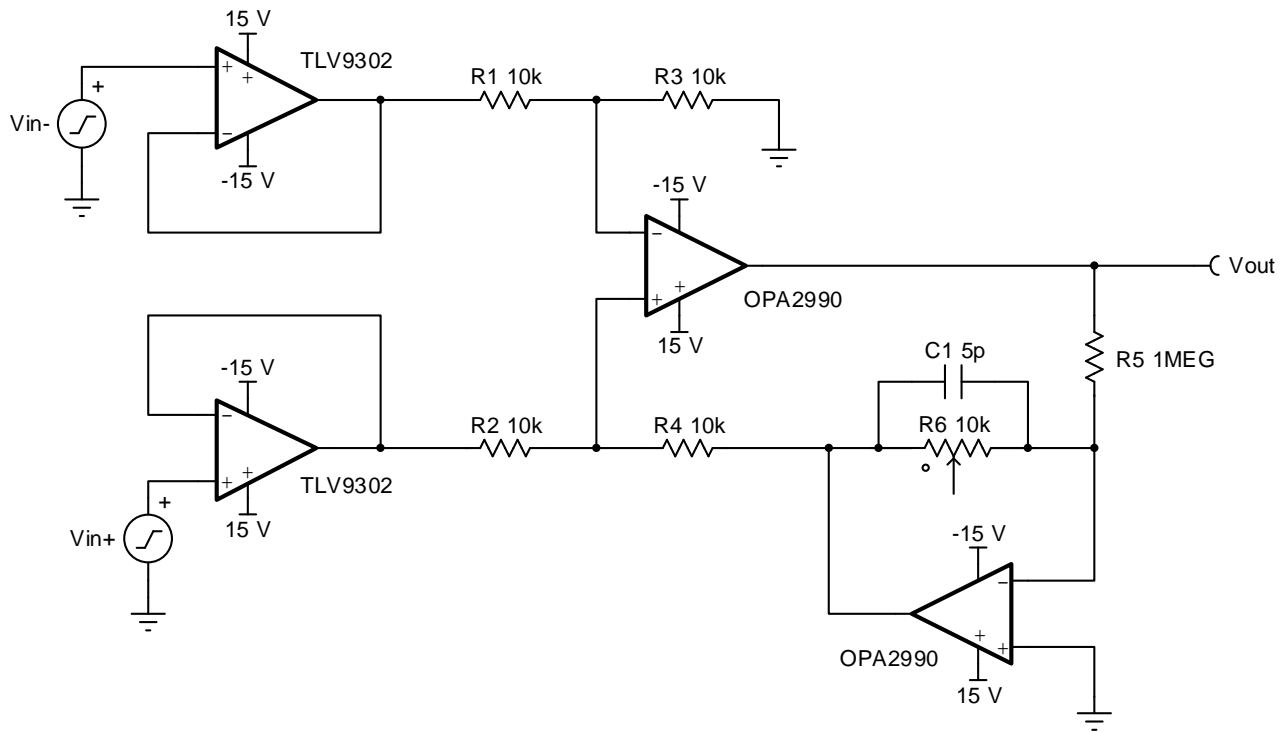


$$V_{out} = \frac{R_3}{R_1} (V_{in+} - V_{in-})$$

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

Figure 39. Instrumentation Amplifier

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

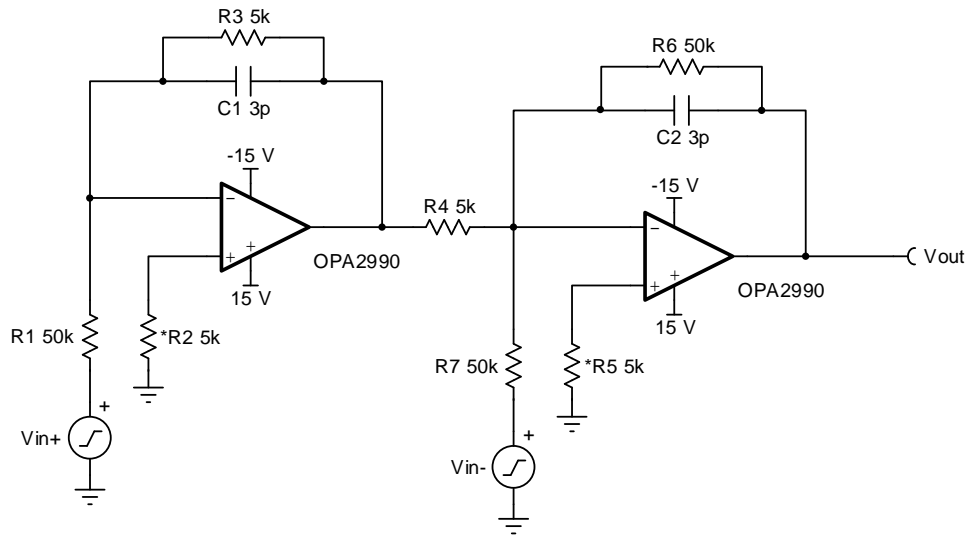


$$V_{out} = \frac{10^{-4} R_6 R_3}{R_1} (V_{in+} - V_{in-})$$

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

Figure 40. Variable Gain Instrumentation Amplifier

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



$$R_2 = R_3 = R_4 = R_5$$

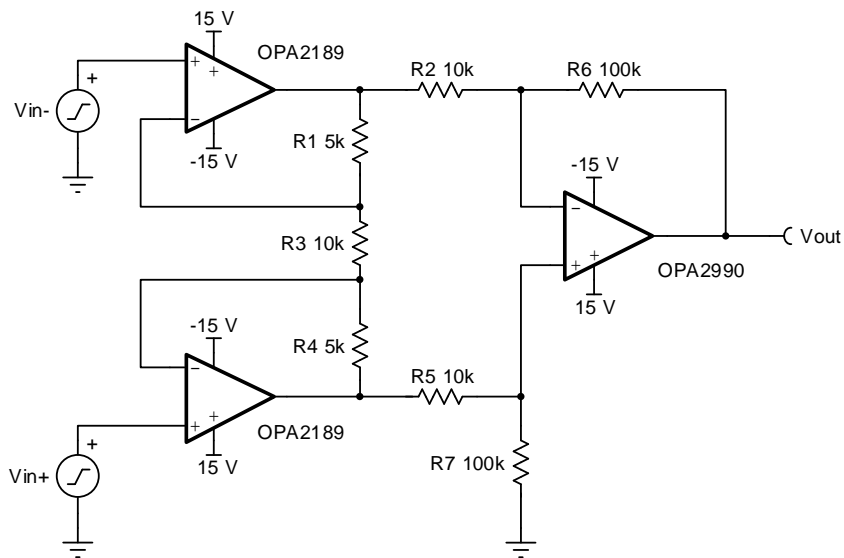
$$R_1 = R_6 = 10R_3$$

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

* R_2 and R_5 Optional for Input Bias Current Cancellation

Figure 41. 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 42. Instrumentation Amplifier With ±10-V Common Mode Range

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

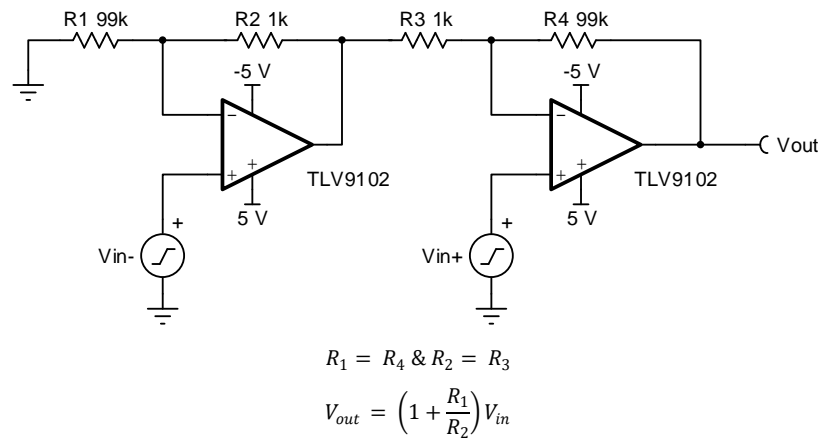


Figure 43. High Input Impedance Instrumentation Amplifier

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

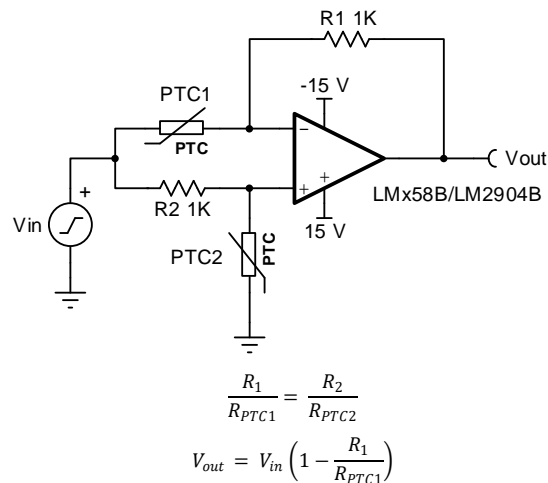


Figure 44. Bridge Amplifier With Temperature Sensitivity

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

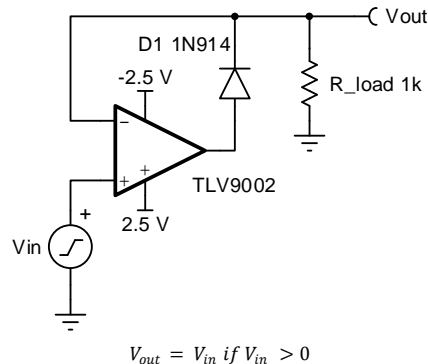


Figure 45. Precision Diode

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

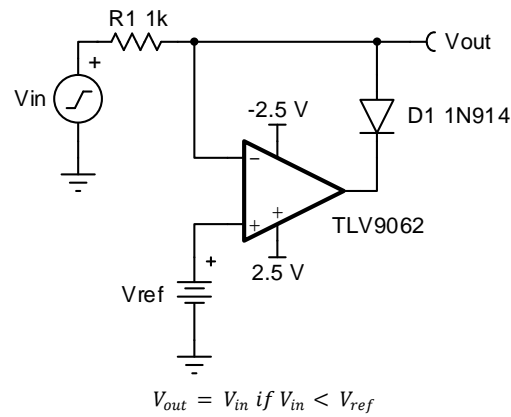
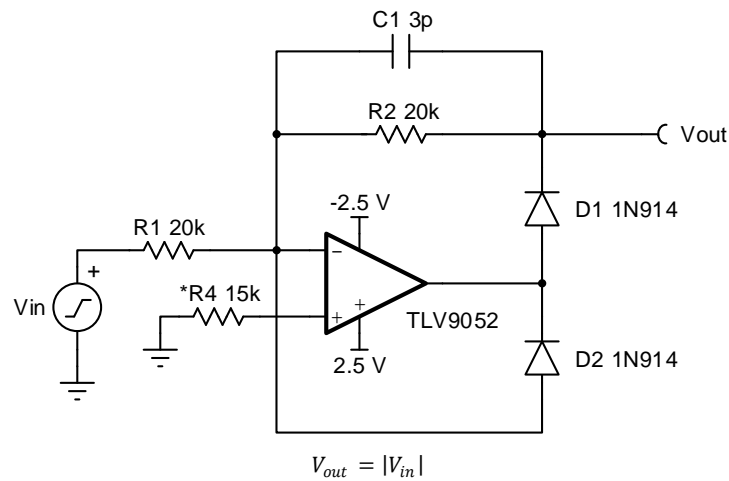


Figure 46. Precision Clamp

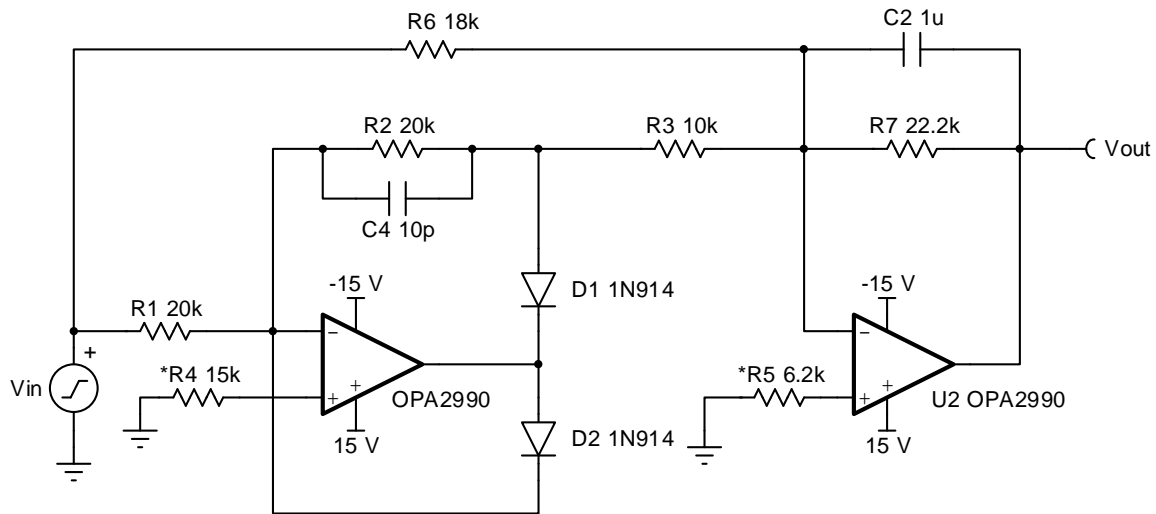
For more information on this configuration, see [12]. Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



* R₄ Optional for Input Bias Current Cancellation

Figure 47. 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](#).



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

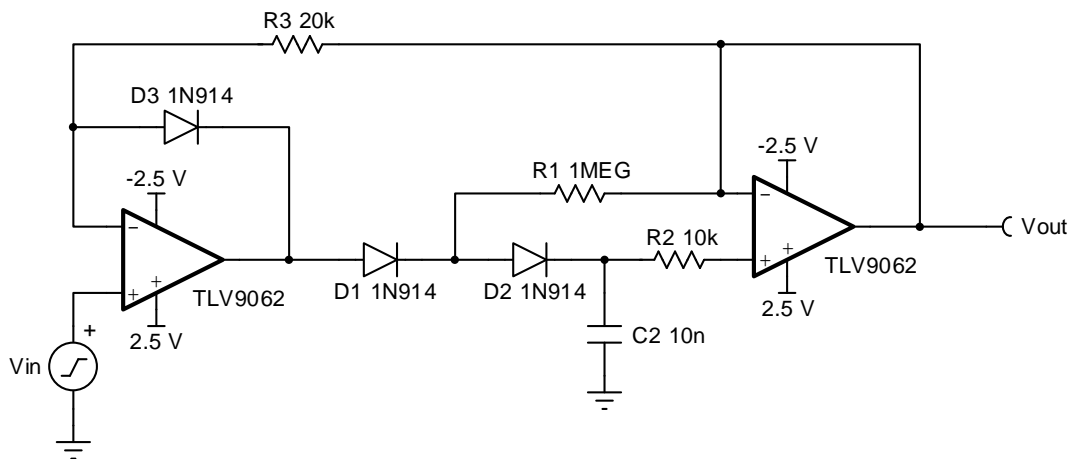
$$0 < V_{in} < V_{cc} - V_{D1}$$

Ensure Op Amps Remain in Linear Range

* R₄ and R₅ Optional for Input Bias Current Cancellation

Figure 48. AC to DC Converter

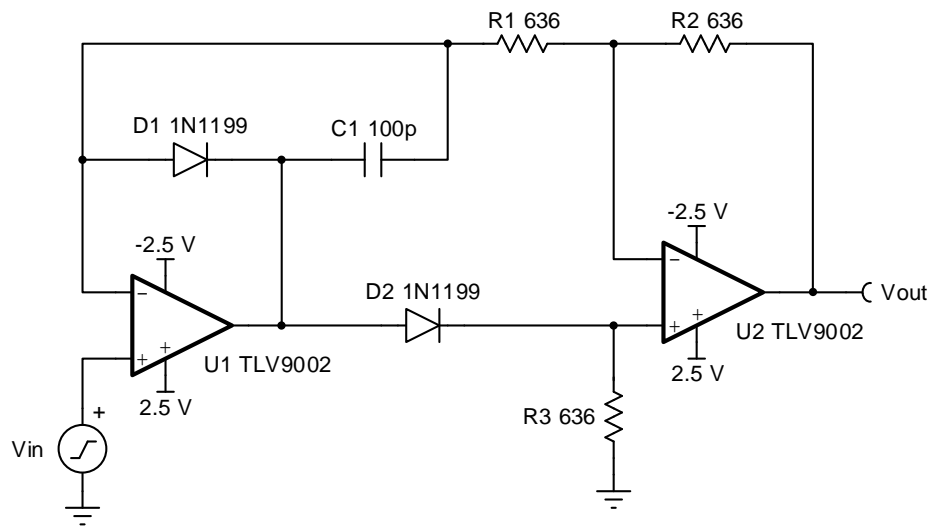
For more information on this configuration, see [12]. Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



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

Figure 49. Peak Detector

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



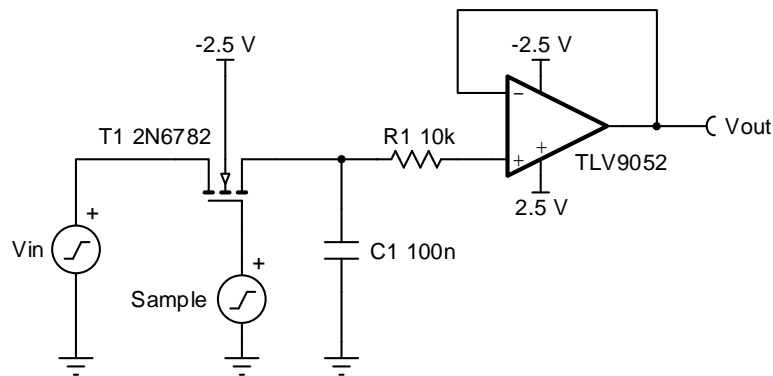
$$V_{out} = |V_{in}|$$

$$R_2 = R_1$$

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

Figure 50. 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 51. Sample and Hold I

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

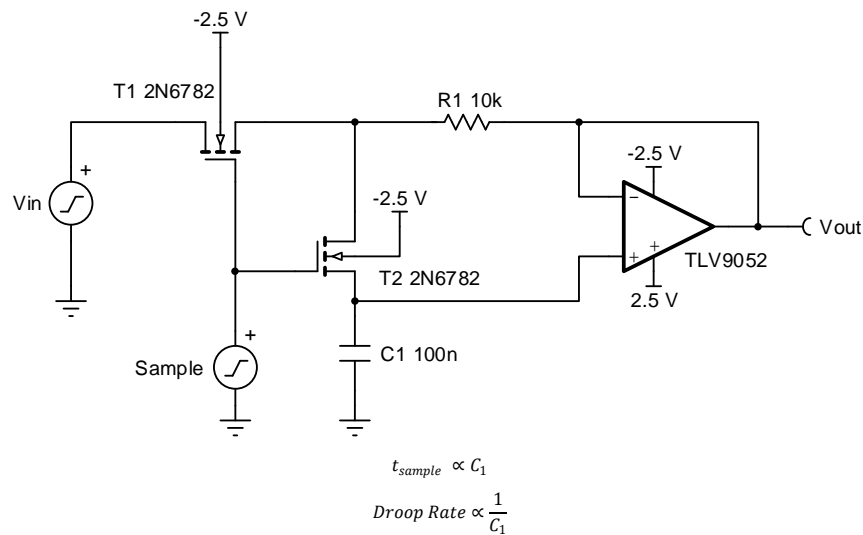
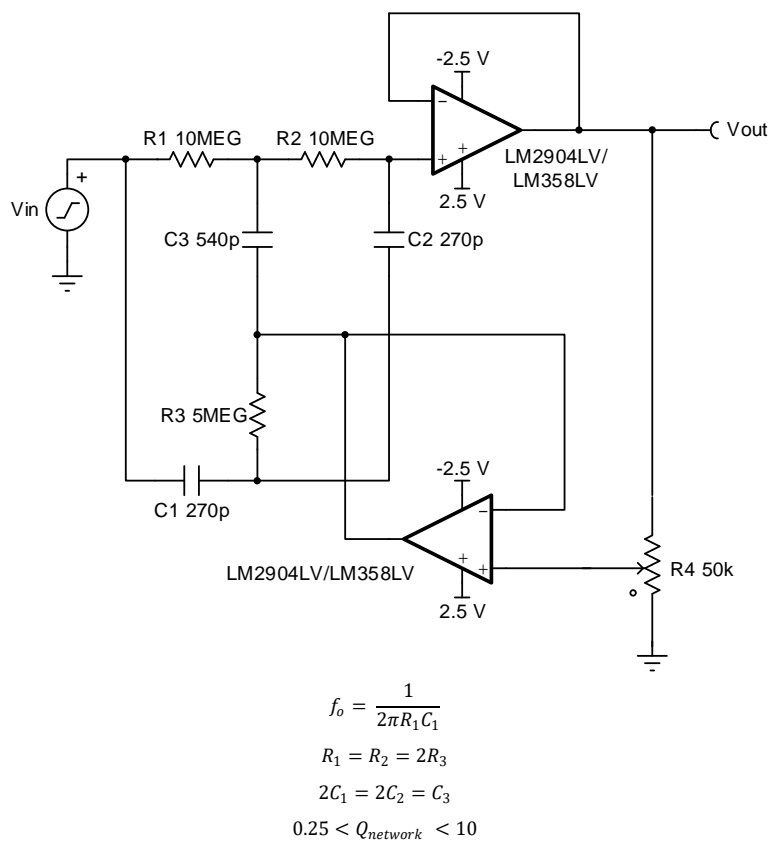


Figure 52. Sample and Hold II

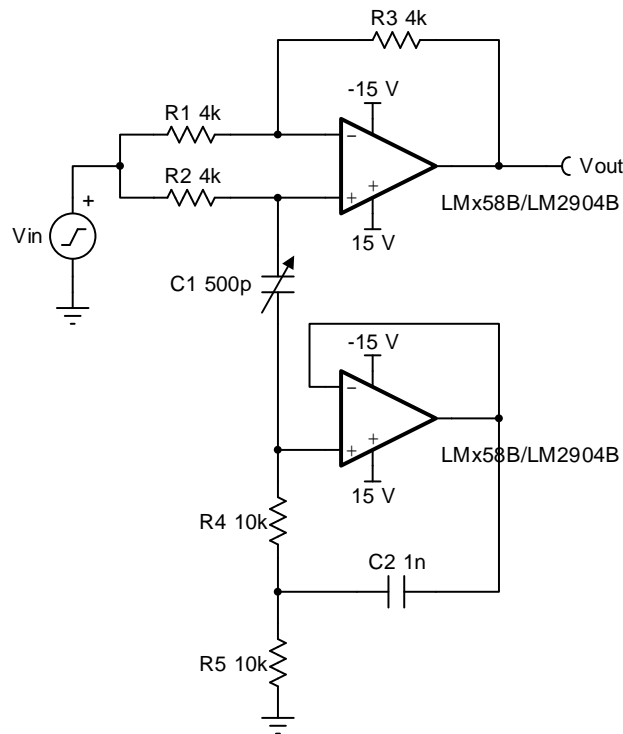
For more information on this circuit, see [14]. Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



Increasing Potentiometer Setting Increases $Q_{network}$

Figure 53. Adjustable Q Notch Filter

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



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

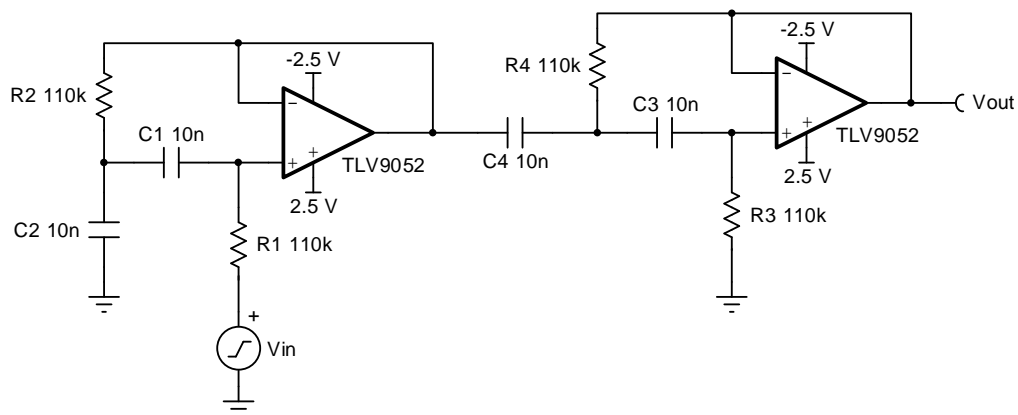
$$R_4 = R_5$$

$$R_1 = R_3$$

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

Figure 54. 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 55. Sallen-Key Two-Stage Bandpass Filter

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

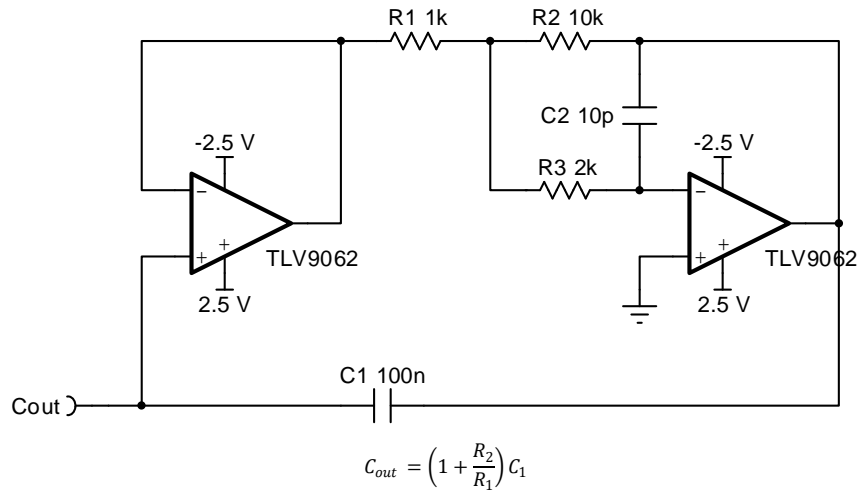


Figure 56. Two-Stage Capacitance Multiplier

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

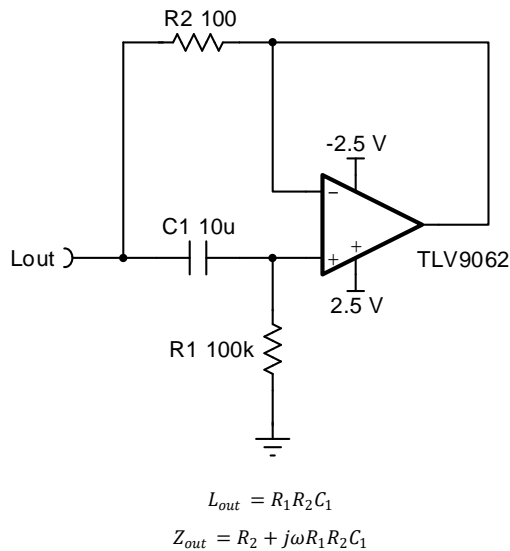
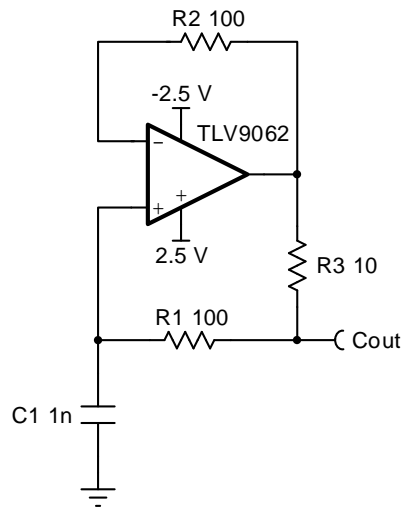


Figure 57. Simulated Inductor

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



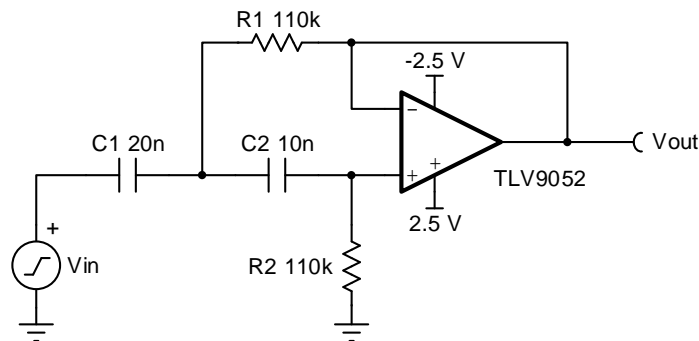
$$C_{out} \approx \frac{R_1}{R_3} C_1$$

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

$$R_{source} \gg R_3$$

Figure 58. Capacitance Multiplier

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



$$R_2 = mR_1$$

$$C_2 = nC_1$$

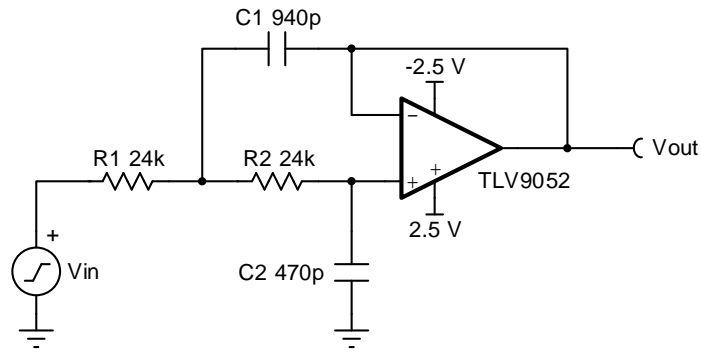
$$f_c = \frac{1}{2\pi RC\sqrt{mn}}$$

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

Choose m and n for desired f_c and Q

Figure 59. High Pass Sallen-Key Active Filter

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



$$R_1 = mR_2$$

$$C_1 = nC_2$$

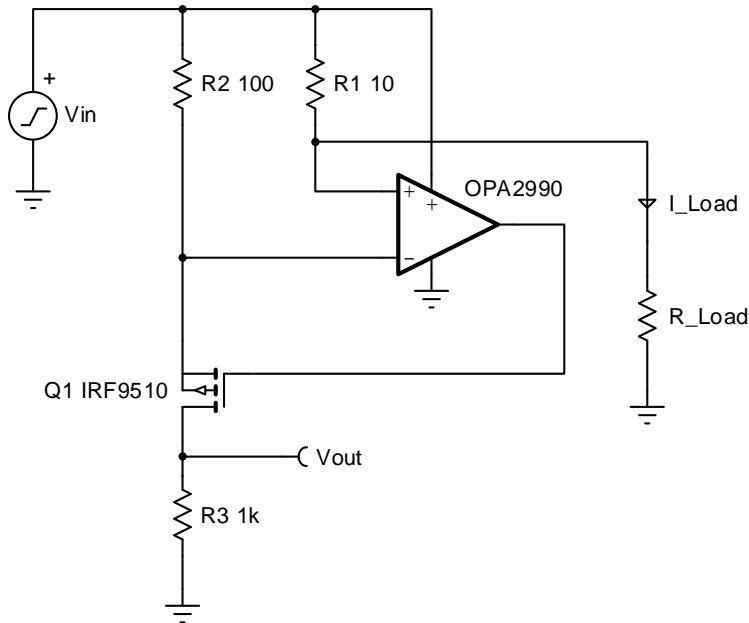
$$f_c = \frac{1}{2\pi RC\sqrt{mn}}$$

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

Choose m and n for desired f_c and Q

Figure 60. Low Pass Sallen-Key Active Filter

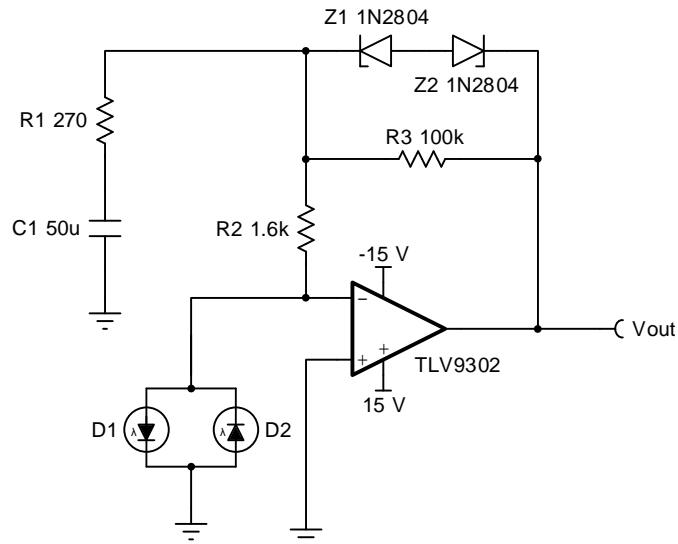
For more information on this configuration, see [17] and [18]. Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



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

Figure 61. Current Monitor

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).

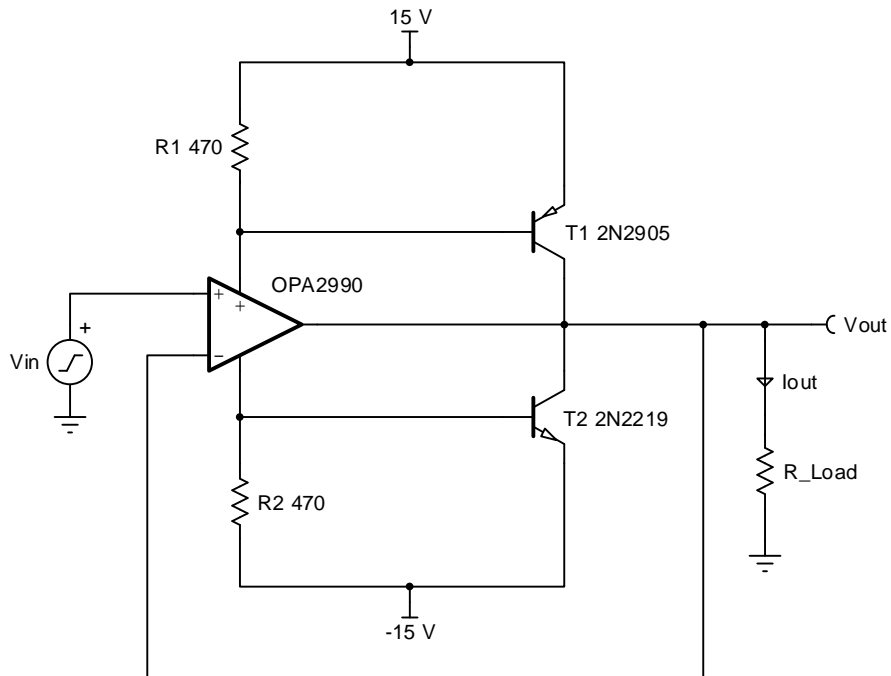


$$V_{out} = \frac{0.1V}{\mu A} \text{ from } D1, D2$$

Linear Range through 60μA

Figure 62. 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](#).

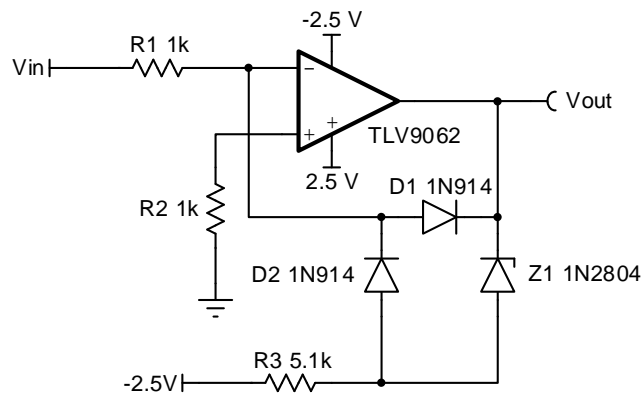


$$V_{out} = V_{in}$$

Q_1 and Q_2 Increase I_{out}

Figure 63. Power Booster

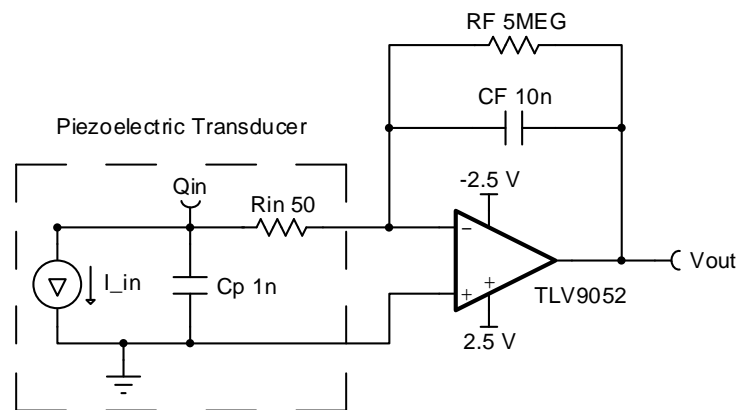
Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



*Time to Detect Falling, Zero Crossing Reduced by ~65%
Versus Using Amplifier as Comparator*

Figure 64. Fast Zero Crossing Detector

Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



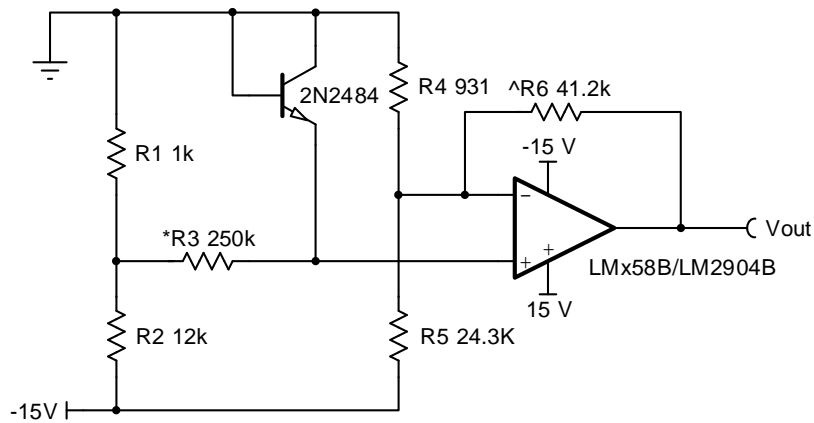
$$Gain = \frac{V_{out}}{Q_{in}} = \frac{1}{C_F}$$

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

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

Figure 65. Amplifier for Piezoelectric Transducer

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



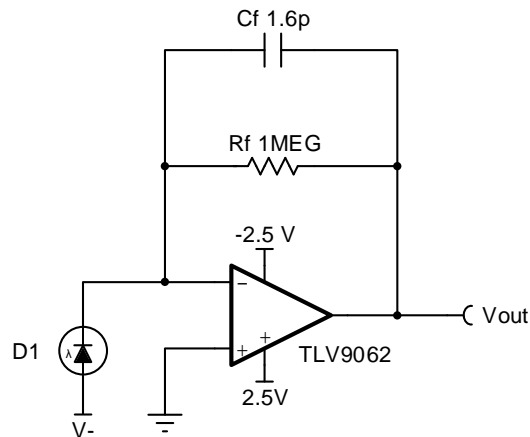
$$V_{out} = 103.9mV/^{\circ}C - 383mV$$

* Value Can Be Changed for 0V at 0°C

^Value Can Be Changed for 100mV/°C

Figure 66. Temperature Probe

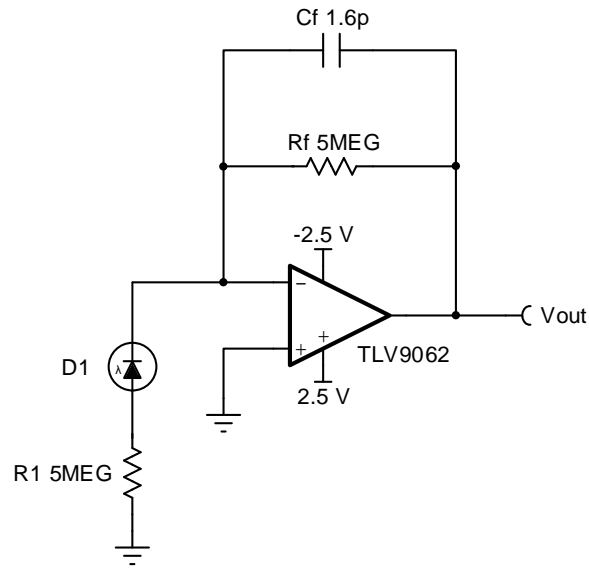
Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



$$V_{out} = R_f I_D$$

Figure 67. Photodiode Amplifier I

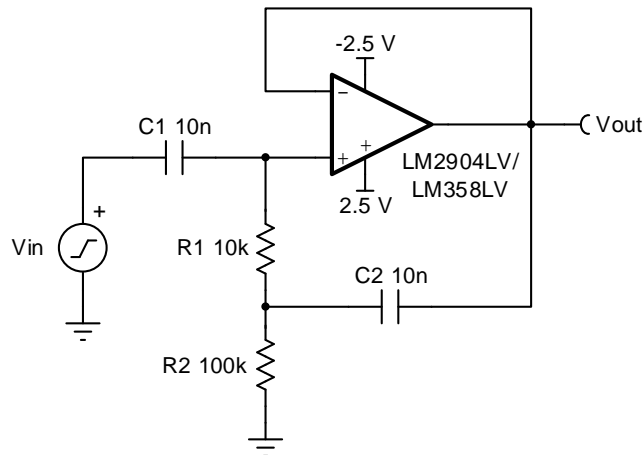
For more information on modeling photodiodes, see [8]. See [Analog engineer's circuit cookbook: amplifiers](#) or [2] for more information on this circuit. Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



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

Figure 68. Photodiode Amplifier II

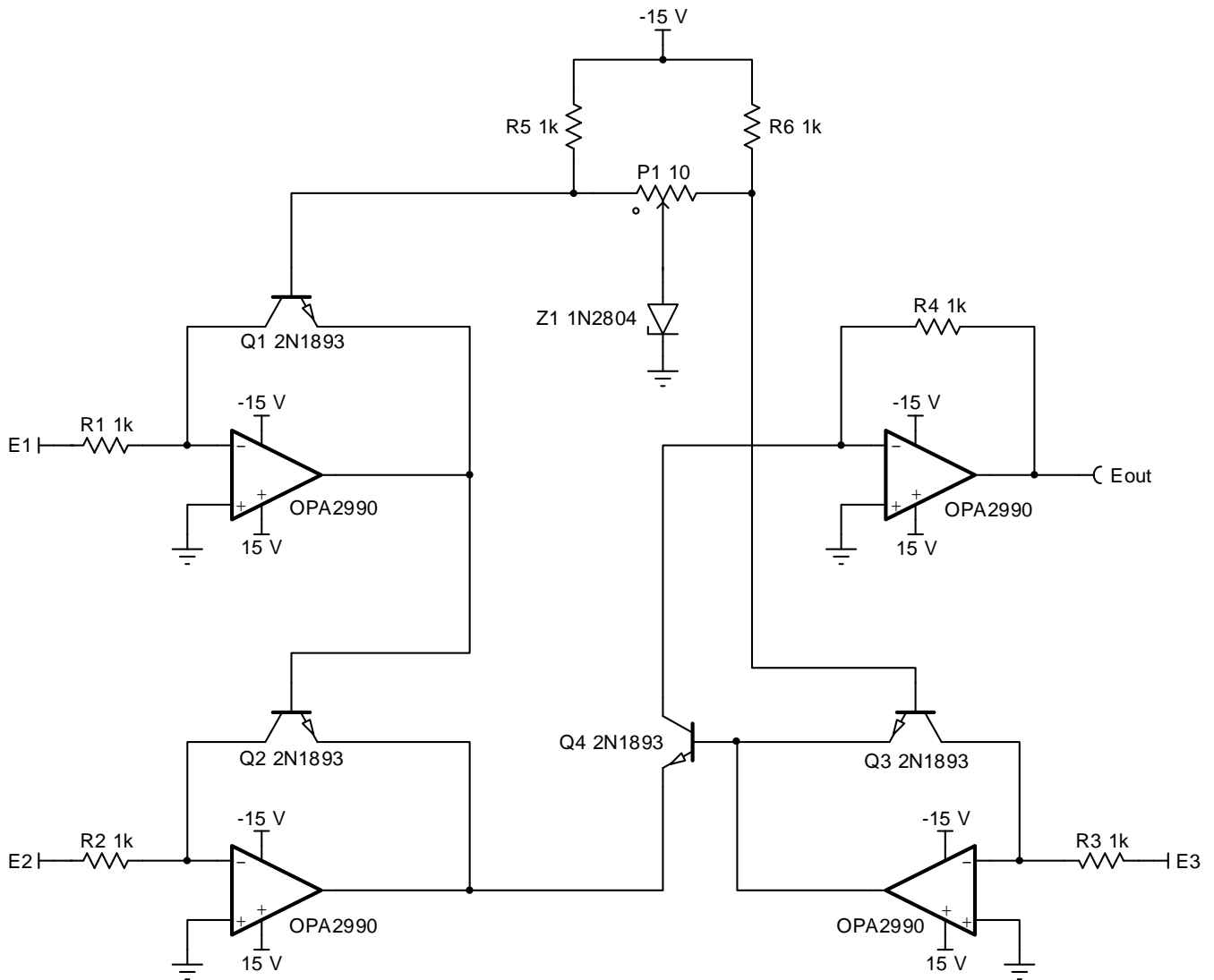
For more information on modeling photodiodes, see [8]. See [Analog engineer's circuit cookbook: amplifiers](#) for more information on this circuit. Simulate this design by downloading [TINA-TI](#) and the [schematic](#).



$$V_{out} = \frac{(R_1 + R_2)C_1s + C_1C_2R_1R_2s^2}{1 + (R_1 + R_2)C_1s + C_1C_2R_1R_2s^2} V_{in}$$

Figure 69. 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 70. 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 piezoelectric 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](#).

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