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

![Inverting Amplifier Circuit](image1)

\[ V_{out} = \frac{R_2}{R_1} V_{in} \]

* 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].

![Non-Inverting Amplifier Circuit](image2)

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

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

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.

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

For \( R_1 = R_3 \) and \( R_2 = R_4 \)

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

\[ f_{outff} = \frac{1}{2 \pi C_2 R_2} \]

**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.
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.

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

* R5 Optional for Input Bias Current Cancellation

Figure 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.

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

\[ V_{out} = \left( 1 + \frac{R_2}{R_1} \right) \left( \frac{R_4}{R_3 + R_4} \right) \left( V_1 + V_2 \right) \text{ if } R_3 = R_4 \]
Figure 1-7. Inverting Amplifier With High Input Impedance

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

\[ V_{out} = -\frac{R_2}{R_1}V_{in} \]

* R3 Optional for Input Bias Current Cancellation

Figure 1-8. Two-Stage 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 1-9. 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.

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

\[R_3 = R_1 || R_2 \text{ for CMRR}\]

\[
f_{\text{cutoff low}} = \frac{1}{2\pi C_1 R_3}
\]

**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.

\[
V_{\text{out}} = -\frac{dV_{\text{in}}}{dt}
\]

\[
f_c = \frac{1}{2\pi R_1 C_1} V_{\text{in}}
\]

\[
f_s = \frac{1}{2\pi R_1 C_1} = \frac{1}{2\pi R_2 C_2}
\]

\[
f_c \ll f_s \ll f_{\text{unity gain}}
\]

* R3 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.

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.
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.

Figure 1-16. Double-Ended Limit Detector

Simulate this design by downloading TINA-TI and the schematic.
Figure 1-17. Multiple Aperture Window Discriminator

Simulate this design by downloading TINA-TI and the schematic.
Figure 1-18. Offset Voltage Adjustment for Inverting Amplifiers

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

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

Simulate this design by downloading TINA-TI and the schematic.
Offset Range = $V_{\text{supply}} \frac{R_2}{R_1}$

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

$R_1 \gg R_2$

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

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

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

Figure 1-21. Offset Voltage Adjustment for Difference Amplifiers

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

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.

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.
\[ f_{\text{oscillation}} = \frac{1}{2R_1C_1 \ln \left( 1 + \frac{R_2}{R_3} \right)} \]

**Figure 2-3. Free-Running Multivibrator**

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

\[ \text{Amplitude}_{\text{triangle}} = \frac{V_{\text{in}}}{R_1} \frac{R_3}{R_1 + R_2} \]
\[ f_{\text{oscillation}} = \frac{2}{\pi C_1(R_3 + R_4)} \quad \text{for} \ R_3 + R_4 > 100k\Omega \]

**Figure 2-4. Function Generator**

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

\[ I_{\text{out}} = \frac{R_3 V_{\text{in}}}{R_1 R_5} \]
\[ R_3 = R_4 + R_5 \]
\[ R_1 = R_2 \]

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

Simulate this design by downloading TINA-TI and the schematic.
Figure 2-8. Positive Output Voltage Reference

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

Figure 2-9. Buffered Positive Voltage Reference

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.
Figure 2-10. Negative Output Voltage Reference

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

Figure 2-11. Buffered Negative Voltage Reference

See [2] for more information. Simulate this design by downloading TINA-TI and the schematic.
Figure 2-12. Current Sink

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

\[ I_p = \frac{V_{in}}{R_1} \]
\[ V_{in} \geq 0V \]
Ensure \( R_1 \gg R_{Load} \)

Figure 2-13. Current Source

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

\[ I_{out} = \frac{V_{in} R_2}{R_1(R_1 + R_2)} \]
\[ R_s = \frac{V_{in, max}}{I_{out, max}} \]

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

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

\[ I_{out} = \frac{V_{in} R_2}{R_1(R_1 + R_2)} \]
\[ R_s = \frac{V_{in, max}}{I_{out, max}} \]

Simulate this design by downloading TINA-TI and the schematic.
Figure 2-16. Voltage-to-Current Converter With MOSFET Output

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

![Instrumentation Amplifier Diagram]

\[
V_{\text{out}} = \frac{R_3}{R_1} (V_{\text{in+}} - V_{\text{in-}})
\]

\[
\frac{R_3}{R_1} = \frac{R_4}{R_2}
\]

Figure 3-1. Instrumentation Amplifier

Simulate this design by downloading TINA-TI and the schematic.
Figure 3-2. Variable Gain Instrumentation Amplifier

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

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

Simulate this design by downloading TINA-TI and the schematic.
**Figure 3-4. Instrumentation Amplifier With ±10-V Common Mode Range**

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

\[ V_{out} = \frac{R_6}{R_2} \left( 1 + \frac{2R_3}{R_5} \right) V_{in} \]

**Figure 3-5. High Input Impedance Instrumentation Amplifier**

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

\[ V_{out} = \left( 1 + \frac{R_2}{R_3} \right) V_{in} \]
Figure 3-6. Bridge Amplifier With Temperature Sensitivity

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

Figure 3-7. Precision Diode

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

Figure 3-8. Precision Clamp

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

\[ V_{\text{out}} = |V_{\text{in}}| \]

\*R_4 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.

\[ V_{\text{out}} = V_{\text{in,avg}} \]
\[ 0 < V_{\text{in}} < V_{cc} - V_{D1} \]

Ensure Op Amps Remain in Linear Range

\*R_4 and R_5 Optional for Input Bias Current Cancellation
\[ V_{out} = V_{peak} \]

**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.
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.

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.
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.
**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.

\[
f_0 = \frac{1}{2\pi R_1 C_2}
\]

\[
\begin{align*}
R_4 &= R_5 \\
R_1 &= R_3 \\
R_3 &= \frac{R_1}{2}
\end{align*}
\]

**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.

\[
f_0 = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}}
\]
Figure 3-18. Two-Stage Capacitance Multiplier

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

Figure 3-19. Simulated Inductor

For more information on this configuration, see [19]. Simulate this design by downloading TINA-TI and the schematic.
Figure 3-20. Capacitance Multiplier

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

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.
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.

Figure 3-23. Current Monitor

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

Figure 3-25. Power Booster

Simulate this design by downloading TINA-TI and the schematic.
Figure 3-26. Fast Zero Crossing Detector

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

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.
\[ V_{\text{out}} = 103.9 \text{mV/°C} - 383 \text{mV} \]

*Value Can Be Changed for 0V at 0°C

^Value Can Be Changed for 100mV/°C

**Figure 3-28. Temperature Probe**

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

\[ V_{\text{out}} = R_f I_D \]

**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.
\[ V_{out} = \frac{5V}{\mu A} \times \frac{R_f}{R_1} \]

**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.

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

**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 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*.

Revision History

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

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