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

**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].

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

* R Optional to Protect LM358 & LM324

Devices from Transient Current Spikes

**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.

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

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

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

**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.

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

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

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

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

**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.

\[ V_{out} = -R_5 \frac{V_1 + V_2 + V_3}{R_1 + R_2 + R_3} \]

*\( R_5 \) 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.

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

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

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

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

* \( R_3 \) 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.

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

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

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

**Figure 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.

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

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

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

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

\* 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.

\[ V_{\text{out}} = -\frac{1}{R_1 C_1} \int_{t_1}^{t_2} V_{\text{in}} \, dt \]
\[ f_c = \frac{1}{2\pi R_1 C_1} \]
\[ R_1 = R_2 \]

* R2 Optional for Input Bias Current Cancellation

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.

\[ V_{\text{out}} = I_{\text{in}} R_1 \]
Figure 1-13. Reference Voltage Generator

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

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

Simulate this design by downloading TINA-TI and the schematic.
$V_{out} = 1.8V \Rightarrow Diode\ Off$

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

$R_1$ 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.

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

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

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

**Figure 1-16. Double-Ended Limit Detector**

Simulate this design by downloading TINA-TI and the schematic.
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.
**Figure 1-20. Offset Voltage Adjustment for Voltage Followers**

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

\[
\text{Offset Range} = V_{\text{supply}} \frac{R_2}{R_1}
\]

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

\[
R_1 \gg R_2
\]

**Figure 1-21. Offset Voltage Adjustment for Difference Amplifiers**

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

\[
R_2 = R_4 + R_5
\]

\[
R_1 = R_3
\]

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

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

\[
R_5 \ll \text{Offset Equivalent Resistance}
\]
$R_3 \parallel R_4 \leq 10k\Omega$

$\text{Offset Range} = \frac{R_3 \parallel R_4}{R_1}$

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

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

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.

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.
Figure 2-3. Free-Running Multivibrator

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

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.

**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.

\[ I_{out} = \frac{V_{out}}{R_1} \]

\[ V_{in} < 0 \]
$I_{out} = V_{in} \frac{R_2}{R_s(R_1 + R_2)}$

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

**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.
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 Circuit](image)

Figure 3-1. Instrumentation Amplifier

The output voltage is given by:

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

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

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.

\[
V_{out} = \frac{10^{-4}R_2R_3}{R_1}(V_{in+} - V_{in-})
\]

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

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

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

\[
R_2 = R_3 = R_4 = R_5
\]

\[
R_1 = R_6 = 10R_3
\]

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

* R_2 and R_5 Optional for Input Bias Current Cancellation
Figure 3-4. Instrumentation Amplifier With ±10-V Common Mode Range

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

Figure 3-5. High Input Impedance Instrumentation Amplifier

Simulate this design by downloading TINA-TI and the schematic.
Figure 3-6. Bridge Amplifier With Temperature Sensitivity

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 3-7. Precision Diode

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

\[ V_{out} = V_{in} \text{ if } V_{in} > 0 \]

Figure 3-8. Precision Clamp

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

\[ V_{out} = V_{in} \text{ if } V_{in} < V_{ref} \]
**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.

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

* \( R_4 \) 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.

\[ V_{out} = V_{in, avg} \]

\[ 0 < V_{in} < V_{cc} - V_{D1} \]

Ensure Op Amps Remain in Linear Range

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

**Figure 3-11. Peak Detector**

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

\[ V_{out} = |V_{in}| \quad R_2 = R_1 \quad \frac{GBW_{U2}}{4} = \frac{1}{2\pi R_1 C_1} \]

**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.

\[ f_o = \frac{1}{2\pi R_4 \sqrt{C_1 C_2}} \]
\[ R_4 = R_5 \]
\[ R_1 = R_3 \]
\[ R_t = \frac{R_1}{2} \]

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.

\[ f_o = \frac{1}{2\pi \sqrt{R_1 R_2 C_1 C_2}} \]
**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.

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.

\[ V_{out} = \frac{R_1R_3}{R_2}I_L \]

**Figure 3-23. Current Monitor**

Simulate this design by downloading TINA-TI and the schematic.
\[ V_{out} = \frac{0.1V}{\mu A} \text{ from } D1, D2 \]

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.
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.
Figure 3-28. Temperature Probe

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

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

* Value Can Be Changed for 0V at 0°C

\[ ^{\wedge} \text{Value Can Be Changed for 100mV/°C} \]

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.

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

**Figure 3-31. High Input Impedance AC Follower**

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

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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