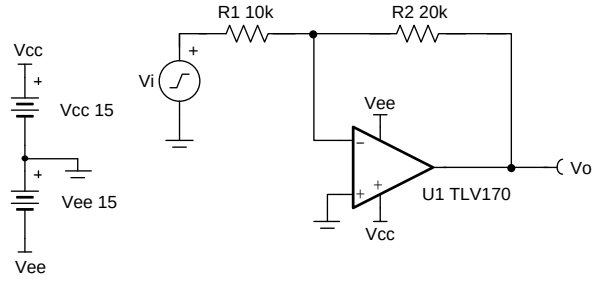
# Inverting amplifier circuit

## Design Goals

| Input | | Output | | Freq. | Supply | |
|---|---|---|---|---|---|---|
| $V_{iMin}$ | $V_{iMax}$ | $V_{oMin}$ | $V_{oMax}$ | f | $V_{cc}$ | $V_{ee}$ |
| –7V | 7V | –14V | 14V | 3kHz | 15V | –15V |

## Design Description

This design inverts the input signal, $V_i$, and applies a signal gain of –2V/V. The input signal typically comes from a low-impedance source because the input impedance of this circuit is determined by the input resistor, $R_1$. The common-mode voltage of an inverting amplifier is equal to the voltage connected to the non-inverting node, which is ground in this design.






## Design Notes

1. Use the op amp in a linear operating region. Linear output swing is usually specified under the $A_{OL}$ test conditions. The common-mode voltage in this circuit does not vary with input voltage.
2. The input impedance is determined by the input resistor. Make sure this value is large when compared to the source's output impedance.
3. Using high value resistors can degrade the phase margin of the circuit and introduce additional noise in the circuit.
4. Avoid placing capacitive loads directly on the output of the amplifier to minimize stability issues.
5. Small-signal bandwidth is determined by the noise gain (or non-inverting gain) and op amp gain-bandwidth product (GBP). Additional filtering can be accomplished by adding a capacitor in parallel to $R_2$. Adding a capacitor in parallel with $R_2$ will also improve stability of the circuit if high value resistors are used.
6. Large signal performance may be limited by slew rate. Therefore, check the maximum output swing versus frequency plot in the data sheet to minimize slew-induced distortion.
7. For more information on op amp linear operating region, stability, slew-induced distortion, capacitive load drive, driving ADCs, and bandwidth please see the Design References section.

### Design Steps

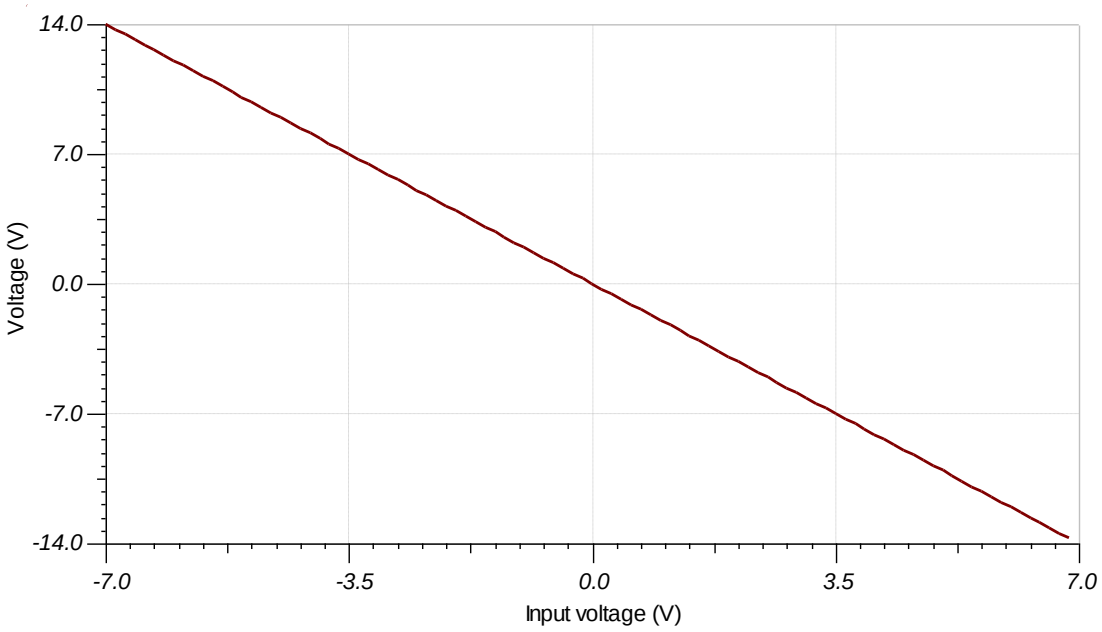
The transfer function of this circuit is given below.

$$V_o = V_i \times \left(-\frac{R_2}{R_1}\right)$$

1. Determine the starting value of $R_1$. The relative size of $R_1$ to the signal source's impedance affects the gain error. Assuming the signal source's impedance is low (for example, 100Ω), set $R_1$=10kΩ for 1% gain error.
   $$R_1 = 10k\Omega$$
2. Calculate the gain required for the circuit. Since this is an inverting amplifier use $V_{iMin}$ and $V_{oMax}$ for the calculation.
   $$G = \frac{V_{oMax}}{V_{iMin}} = \frac{14V}{-7V} = -2\frac{V}{V}$$
3. Calculate $R_2$ for a desired signal gain of –2V/V.
   $$G = -\frac{R_2}{R_1} \rightarrow R_2 = -G \times R_1 = -\left(-2\frac{V}{V}\right) \times 10k\Omega = 20k\Omega$$
4. Calculate the small signal circuit bandwidth to ensure it meets the 3kHz requirement. Be sure to use the noise gain, or non-inverting gain, of the circuit.
   $$GBP_{TLV170} = 1.2MHz \quad ($$
   $$NG = 1 + \frac{R_2}{R_1} = 3\frac{V}{V}$$
   $$BW = \frac{GBP}{NG} = \frac{1.2MHz}{3V/V} = 400kHz$$
5. Calculate the minimum slew rate required to minimize slew-induced distortion.
   $$V_p = \frac{SR}{2 \times \pi \times f} \rightarrow SR > 2 \times \pi \times f \times V_p$$
   $$SR > 2 \times \pi \times 3kHz \times 14V = 263.89\frac{kV}{s} = 0.26\frac{V}{\mu s}$$
   - $SR_{TLV170}$=0.4V/µs, therefore it meets this requirement.
6. To avoid stability issues ensure that the zero created by the gain setting resistors and input capacitance of the device is greater than the bandwidth of the circuit.
   $$\frac{1}{2 \times \pi \times (C_{cm} + C_{diff}) \times (R_2 \parallel R_1)} > \frac{GBP}{NG}$$
   $$\frac{1}{2 \times \pi \times \ 3pF + 3pF \ \times \frac{20k\Omega \times 10k\Omega}{20k\Omega + 10k\Omega}} > \frac{1.2MHz}{3V/V}$$
   $$43.77MHz > 400kHz$$
   - $C_{cm}$ and $C_{diff}$ are the common-mode and differential input capacitances of the TLV170, respectively.
   - Since the zero frequency is greater than the bandwidth of the circuit, this requirement is met.

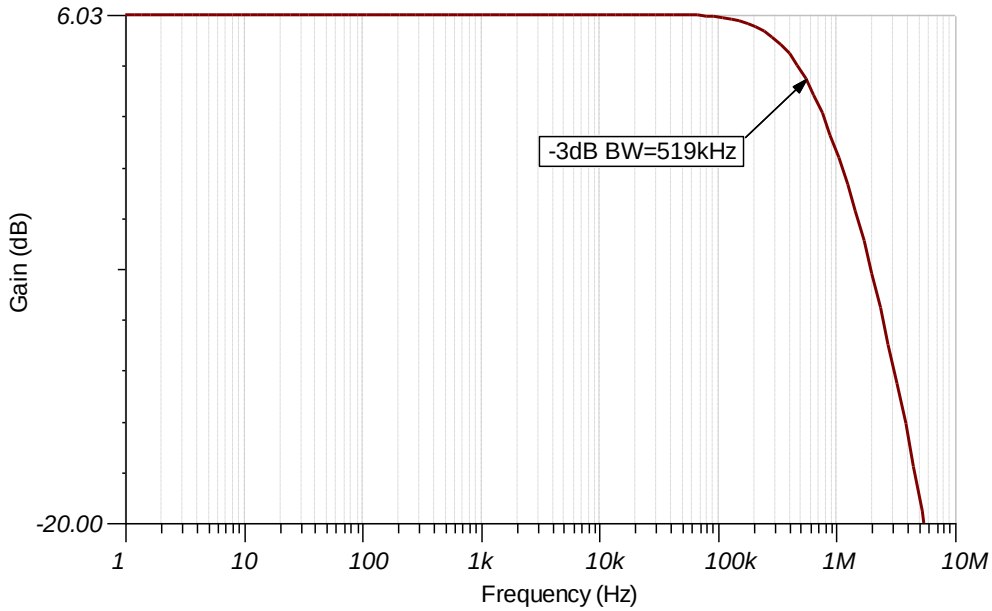
## Design Simulations

### DC Simulation Results



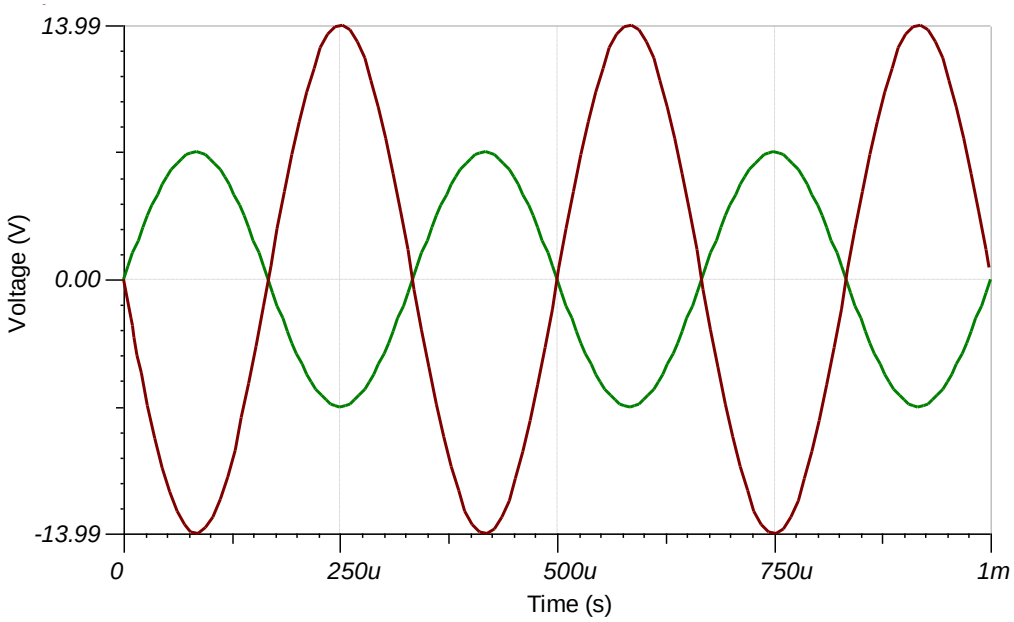

### AC Simulation Results

The bandwidth of the circuit depends on the noise gain, which is 3V/V. The bandwidth is determined by looking at the –3dB point, which is located at 3dB given a signal gain of 6dB. The simulation sufficiently correlates with the calculated value of 400kHz.



### Transient Simulation Results

The output is double the magnitude of the input, and inverted.



### Design References

See Analog Engineer's Circuit Cookbooks for TI's comprehensive circuit library.

See circuit SPICE simulation file SBOC492.

For more information on many op amp topics including common-mode range, output swing, bandwidth, and how to drive an ADC please visit TI Precision Labs.

### Design Featured Op Amp

| TLV170 | |
|---|---|
| $V_{ss}$ | ±18V (36V) |
| $V_{inCM}$ | (Vee-0.1V) to (Vcc-2V) |
| $V_{out}$ | Rail-to-rail |
| $V_{os}$ | 0.5mV |
| $I_q$ | 125µA |
| $I_b$ | 10pA |
| **UGBW** | 1.2MHz |
| **SR** | 0.4V/µs |
| **#Channels** | 1, 2, 4 |
| www.ti.com/product/tlv170 | |

### Design Alternate Op Amp

| LMV358 | |
|---|---|
| $V_{ss}$ | 2.7 to 5.5V |
| $V_{inCM}$ | ($V_{ee}$–0.2V) to ($V_{cc}$–0.8V) |
| $V_{out}$ | Rail-to-rail |
| $V_{os}$ | 1.7mV |
| $I_q$ | 210µA |
| $I_b$ | 15nA |
| **UGBW** | 1MHz |
| **SR** | 1V/µs |
| **#Channels** | 1 (LMV321), 2 (LMV358), 4 (LMV324) |
| www.ti.com/product/lmv358 | |

## Revision History

| Revision | Date | Change |
|---|---|---|
| A | January 2019 | Downscale title.<br>Added link to circuit cookbook landing page. |