

# Inverting Amplifier With T-Network Feedback Circuit



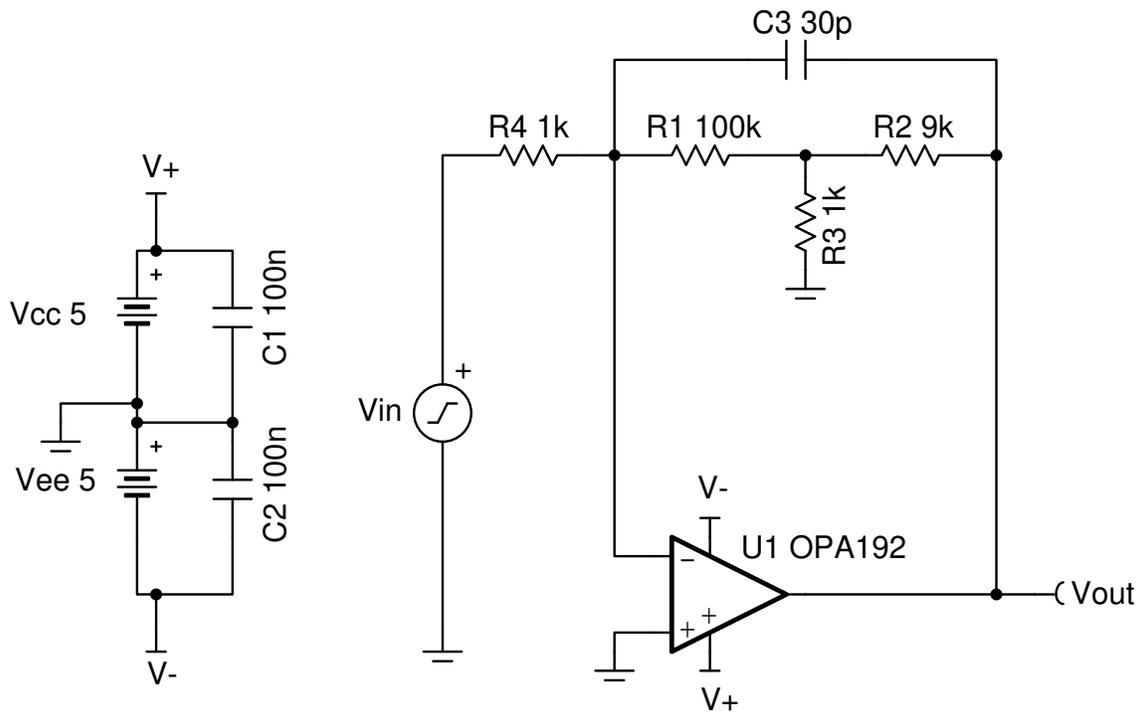
Amplifiers

Design Goals

Input		Output		BW	Supply	
$V_{iMin}$	$V_{iMax}$	$V_{oMin}$	$V_{oMax}$	$f_p$	$V_{cc}$	$V_{ee}$
-2.5mV	2.5mV	-2.5V	2.5V	5kHz	5V	-5V

Design Description

This design inverts the input signal,  $V_{in}$ , and applies a signal gain of 1000V/V or 60dB. The inverting amplifier with T-feedback network can be used to obtain a high gain without a small value for  $R_4$  or very large values for the feedback resistors.



Design Notes

1.  $C_3$  and the equivalent resistance of feedback resistors set the cutoff frequency,  $f_p$ .
2. The common-mode voltage in this circuit does not vary with input voltage.
3. Using high-value resistors can degrade the phase margin and increase noise.
4. Avoid placing capacitive loads directly on the output of the amplifier to minimize stability issues.
5. Due to the high gain of the circuit, be sure to use an op amp with sufficient gain bandwidth product. Remember to use the noise gain when calculating bandwidth. Use precision, or low offset, devices due to the high gain of the circuit.
6. For more information on op amp linear operating region, stability, slew-induced distortion, capacitive load drive, driving ADCs, and bandwidth see the [Design References](#) section.

## Design Steps

1. Calculate required gain.

$$\text{Gain} = \frac{V_{o\text{Max}} - V_{o\text{Min}}}{V_{i\text{Max}} - V_{i\text{Min}}} = \frac{2.5\text{V} - (-2.5\text{V})}{2.5\text{mV} - (-2.5\text{mV})} = 1000 \frac{\text{V}}{\text{V}} = 60\text{dB}$$

2. Calculate resistor values to set the required gain.

$$\text{Gain} = \left( \frac{\frac{R_2 \times R_1}{R_3} + R_1 + R_2}{R_4} \right)$$

Choose the input resistor  $R_4$  to be  $1\text{k}\Omega$ . To obtain a gain of  $1000\text{V/V}$ , normally a  $1\text{-M}\Omega$  resistor would be required. A T-network allows us to use smaller resistor values in the feedback loop. Selecting  $R_1$  to be  $100\text{k}\Omega$  and  $R_2$  to be  $9\text{k}\Omega$  allows calculation of the value for  $R_3$ .  $R_2$  is in the  $10\text{k}\Omega$  range so the op amp can easily drive the feedback network.

$$R_3 = \left( \frac{R_2 \times R_1}{(\text{Gain} \times R_4) - R_1 - R_2} \right) = \left( \frac{9\text{k}\Omega \times 100\text{k}\Omega}{(1000 \times 1\text{k}\Omega) - 100\text{k}\Omega - 9\text{k}\Omega} \right) = 1\text{k}\Omega$$

3. Calculate  $C_3$  using the equivalent resistance of the feedback resistors,  $R_{\text{eq}}$ , to set the location of  $f_p$ .

$$R_{\text{eq}} = \left( \frac{R_2 \times R_1}{R_3} + R_1 + R_2 \right) = \left( \frac{9\text{k}\Omega \times 100\text{k}\Omega}{1\text{k}\Omega} + 100\text{k}\Omega + 9\text{k}\Omega \right) = 1.009\text{M}\Omega$$

$$f_p = \frac{1}{2\pi \times R_{\text{eq}} \times C_3} = 5\text{kHz}$$

$$C_3 = \frac{1}{2\pi \times R_{\text{eq}} \times f_p} = \frac{1}{2\pi \times 1.009\text{M}\Omega \times 5\text{kHz}} = 31.55\text{pF} \approx 30\text{pF} \text{ (Standard Value)}$$

4. Calculate the small signal circuit bandwidth to ensure it meets the 5 kHz requirement. Be sure to use the noise gain, NG, or non-inverting gain of the circuit.

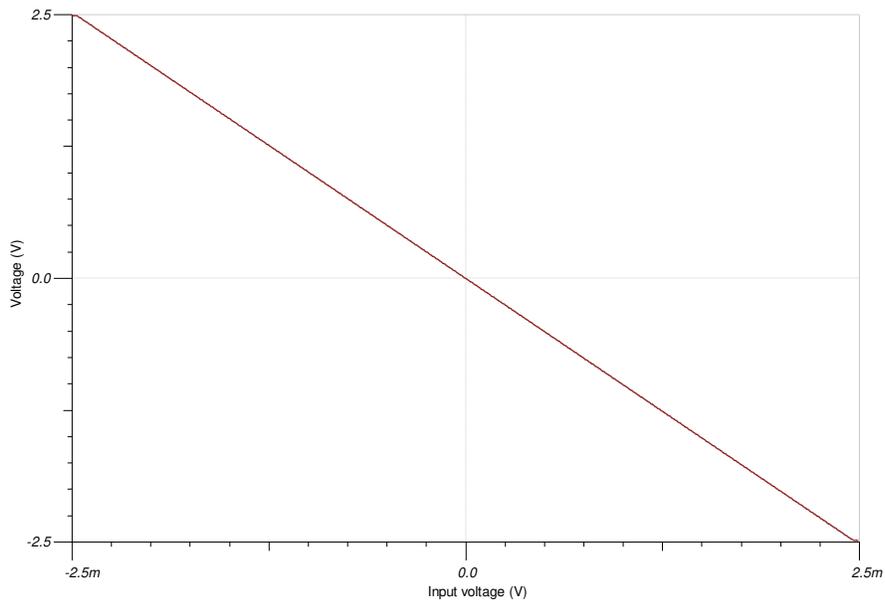
$$\text{NG} = 1 + \frac{R_{\text{eq}}}{R_4} = 1 + 1009 = 1010 \frac{\text{V}}{\text{V}}$$

$$\text{BW} = \frac{\text{GBP}}{\text{NG}} = \frac{10\text{MHz}}{1010 \text{V/V}} = 9.9\text{kHz}$$

- $\text{BW}_{\text{OPA192}} = 10\text{MHz}$ ; therefore this requirement is met.

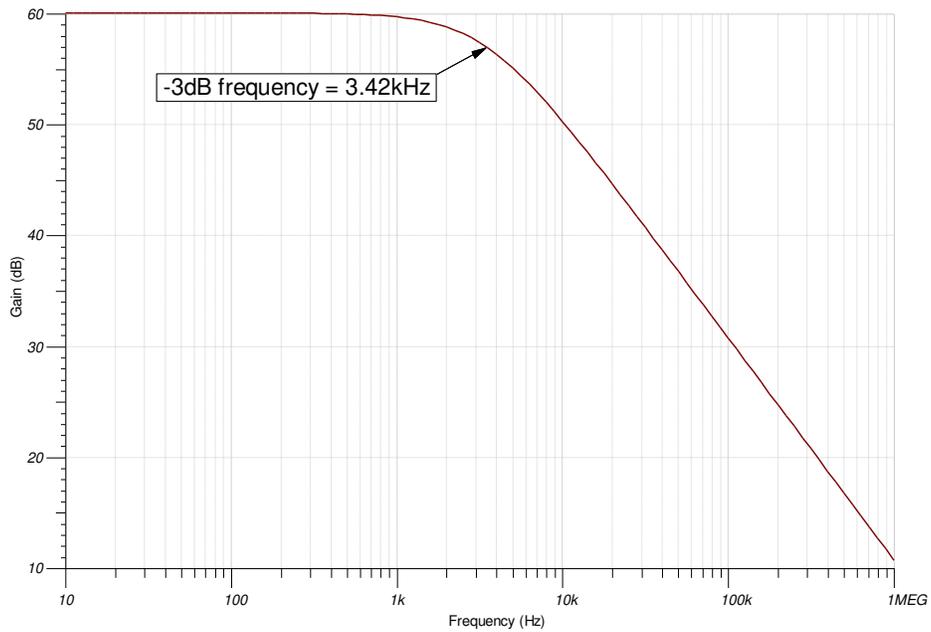
## Design Simulations

### DC Simulation Results

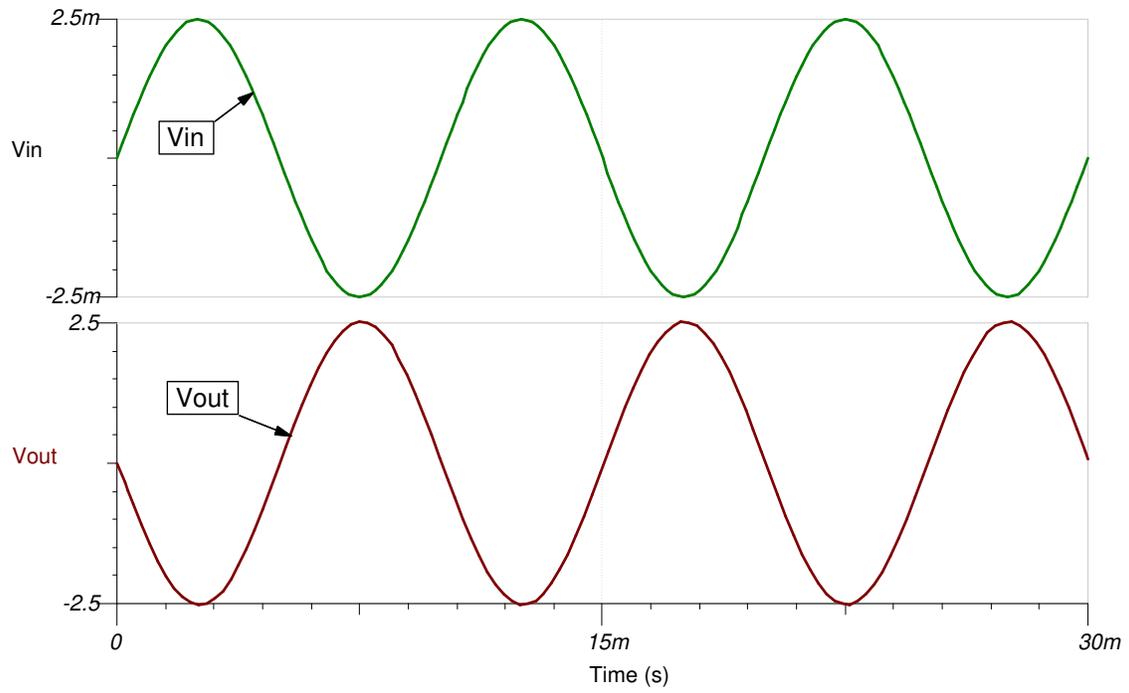


### AC Simulation Results

The simulation is very close to the calculation.



### Transient Simulation Results



## Design References

1. See [Analog Engineer's Circuit Cookbooks](#) for the comprehensive TI circuit library.
2. [TI Precision Labs](#)
3. See the [1 MHz, Single-Supply, Photodiode Amplifier Reference Design](#).

## Design Featured Op Amp

OPA192	
$V_{SS}$	$\pm 2.25V$ to $\pm 18V$
$V_{inCM}$	Rail-to-Rail
$V_{out}$	Rail-to-Rail
$V_{os}$	5 $\mu$ V
$I_q$	1mA
$I_b$	5pA
UGBW	10MHz
SR	20V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/OPA192">www.ti.com/product/OPA192</a>	

## Design Alternate Op Amp

TLV9062	
$V_{SS}$	1.8V to 5.5V
$V_{inCM}$	Rail-to-Rail
$V_{out}$	Rail-to-Rail
$V_{os}$	0.3mV
$I_q$	538 $\mu$ A
$I_b$	0.5pA
UGBW	10MHz
SR	6.5V/ $\mu$ s
#Channels	1,2,4
<a href="http://www.ti.com/product/TLV9062">www.ti.com/product/TLV9062</a>	

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