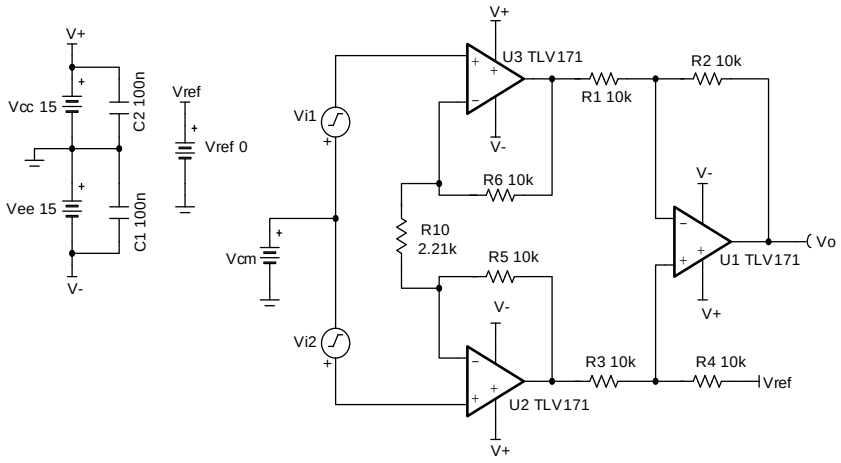
# Three op amp instrumentation amplifier circuit

## Design Goals

| Input $V_{idiff}$ ($V_{i2}$ - $V_{i1}$) | | Common-mode Voltage | Output | | Supply | | |
|---|---|---|---|---|---|---|---|
| $V_{i\ diff\ Min}$ | $V_{i\ diff\ Max}$ | $V_{cm}$ | $V_{oMin}$ | $V_{oMax}$ | $V_{cc}$ | $V_{ee}$ | $V_{ref}$ |
| -0.5V | +0.5V | ±7V | –5V | +5V | +15V | –15V | 0V |

## Design Description

This design uses 3 op amps to build a discrete instrumentation amplifier. The circuit converts a differential signal to a single-ended output signal. Linear operation of an instrumentation amplifier depends upon linear operation of its building block: op amps. An op amp operates linearly when the input and output signals are within the device's input common-mode and output swing ranges, respectively. The supply voltages used to power the op amps define these ranges.




## Design Notes

1. Use precision resistors to achieve high DC CMRR performance
2. $R_{10}$ sets the gain of the circuit.
3. Add an isolation resistor to the output stage to drive large capacitive loads.
4. High-value resistors can degrade the phase margin of the circuit and introduce additional noise in the circuit.
5. Linear operation is contingent upon the input common-mode and the output swing ranges of the discrete op amps used. The linear output swing ranges are specified under the $A_{ol}$ test conditions in the op amps datasheets.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**Design Steps**

1. Transfer function of this circuit:

$$V_o = (V_{i2} - V_{i1}) \times G + V_{ref}$$

When $V_{ref} = 0$, the transfer function simplifies to the following equation:

$$V_o = (V_{i2} - V_{i1}) \times G$$

where $G = \frac{R_4}{R_3} \times \left(1 + \frac{2 \times R_5}{R_{10}}\right)$

2. Select the feedback loop resistors $R_5$ and $R_6$:

Choose $R_5 = R_6 = 10\ k\Omega$ (Standard Value)

3. Select $R_1$, $R_2$, $R_3$, $R_4$. To set the Vref gain at 1V/V and avoid degrading the instrumentation amplifier's CMRR, ratios of $R_4/R_3$ and $R_2/R_1$ must be equal.

Choose $R_1 = R_2 = R_3 = R_4 = 10\ k\Omega$ (Standard Value)

4. Calculate $R_{10}$ to meet the desired gain:

$$G = \frac{R_4}{R_3} \times \left(1 + \frac{2 \times R_5}{R_{10}}\right) = 10\ \frac{V}{V} \quad (\qquad)$$

$$R_4 = R_3 = 10\ k\Omega$$

$$\rightarrow G = \left(1 + \frac{2 \times 10\ k\Omega}{R_{10}}\right) = 10\frac{V}{V} \rightarrow \left(1 + \frac{20k\Omega}{R_{10}}\right) = 10\frac{V}{V}$$

$$\frac{20\ k\Omega}{R_{10}} = 9\frac{V}{V} \rightarrow R_{10} = \frac{20k\Omega}{9} = 2222.2\ \Omega \rightarrow R_{10} = 2.21\ k\Omega \quad \text{(Standard Value)} \tag{1}$$

5. To check the common-mode voltage range, download and install the program from reference [5]. Edit the INA_Data.txt file in the installation directory by adding the code for a 3 op amp INA whose internal amplifiers have the common-mode range, output swing, and supply voltage range as defined by the amplifier of choice (TLV172 in this case). There is no $V_{be}$ shift in this design and the gain of the output stage difference amplifeir is 1 V/V. The default supply voltage and reference voltages are ±15 V and 0 V, respectively. Run the program and set the gain and reference voltage accordingly. The resulting $V_{CM}$ vs. $V_{OUT}$ plot approximates the linear operating region of the discrete INA.



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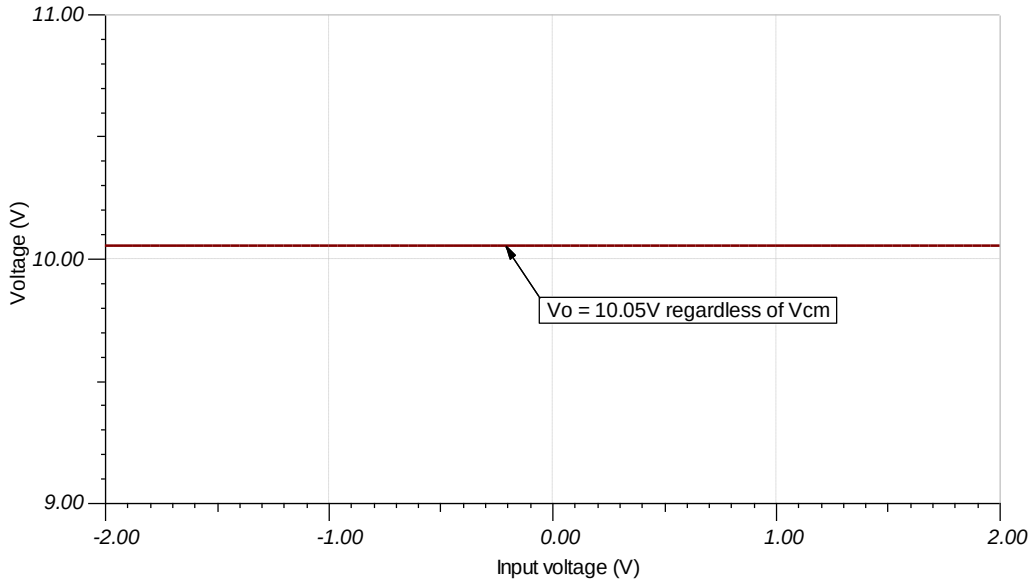
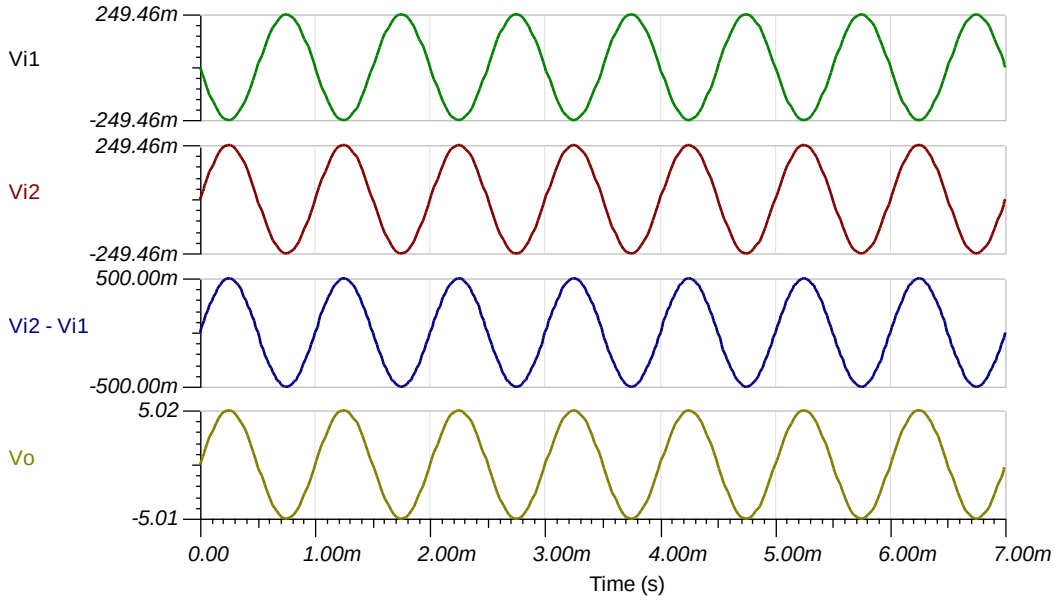
## Design Simulations

### DC Simulation Results




### Transient Simulation Results





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**References:**


1. Analog Engineer's Circuit Cookbooks
2. SPICE Simulation File SBOMAU8
3. TI Precision Labs
4. *Instrumentation Amplifier $V_{CM}$ vs. $V_{OUT}$ Plots*
5. Common-mode Range Calculator for Instrumentation Amplifiers


**Design Featured Op Amp**

| TLV171 | |
|---|---|
| **$V_{ss}$** | 4.5V to 36V |
| **$V_{inCM}$** | (V–) – 0.1V < Vin < (V+) – 2V |
| **$V_{out}$** | Rail–to–rail |
| **$V_{os}$** | 0.25mV |
| **$I_q$** | 475µA |
| **$I_b$** | 8pA |
| **UGBW** | 3MHz |
| **SR** | 1.5V/µs |
| **#Channels** | 1,2,4 |
| www.ti.com/product/tlv171 | |

**Design Alternate Op Amp**

| | OPA172 | OPA192 |
|---|---|---|
| **$V_{ss}$** | 4.5V to 36V | 4.5V to 36V |
| **$V_{inCM}$** | (V–) – 0.1V < Vin < (V+) – 2V | $V_{ee}$–0.1V to $V_{cc}$+0.1V |
| **$V_{out}$** | Rail–to–rail | Rail–to–rail |
| **$V_{os}$** | 0.2mV | ±5µV |
| **$I_q$** | 1.6mA | 1mA/Ch |
| **$I_b$** | 8pA | 5pA |
| **UGBW** | 10MHz | 10MHz |
| **SR** | 10V/µs | 20V/µs |
| **#Channels** | 1,2,4 | 1, 2, 4 |
| | www.ti.com/product/opa172 | www.ti.com/product/opa192 |



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Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
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