Two op amp instrumentation amplifier circuit

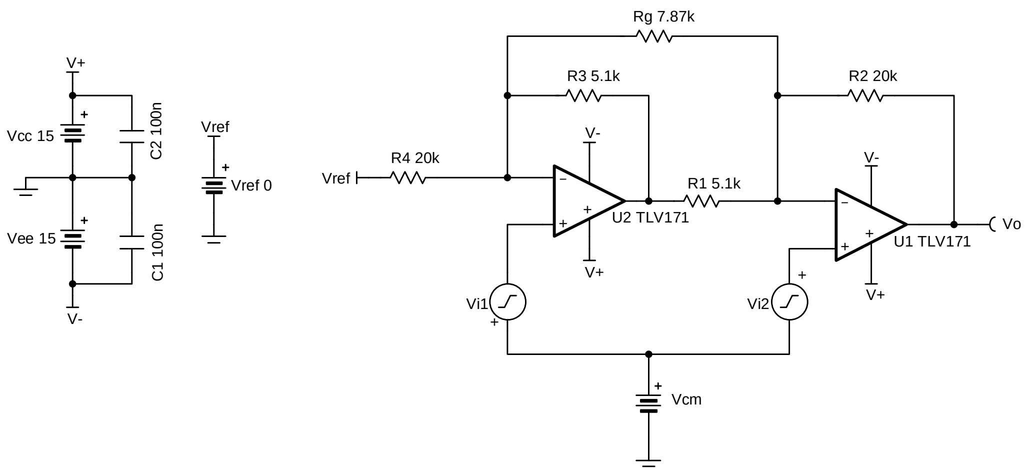
Design Goals

Input $V_{iDiff}(V_{i2} - V_{i1})$		Output		Supply		
V_{iDiff_Min}	V_{iDiff_Max}	V_{oMin}	V_{oMax}	V_{cc}	V_{ee}	V_{ref}
+/–1V	+/–2V	–10V	+10V	15V	–15V	0V

V_{cm}	Gain Range
+/-10V	5V/V to 10V/V

Design Description

This design amplifiers the difference between V_{i1} and V_{i2} and outputs a single ended signal while rejecting the common–mode voltage. Linear operation of an instrumentation amplifier depends upon the linear operation of its primary 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. R_g sets the gain of the circuit.
2. High–value resistors can degrade the phase margin of the circuit and introduce additional noise in the circuit.
3. The ratio of R_4 and R_3 set the minimum gain when R_g is removed.
4. Ratios of R_2/R_1 and R_4/R_3 must be matched to avoid degrading the instrumentation amplifier's DC CMRR and ensuring the V_{ref} gain is 1V/V.
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.

Design Steps

1. Transfer function of this circuit.

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

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

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

   where G is the gain of the instrumentation amplifier and $G = 1 + \frac{R_4}{R_3} + \frac{2R_2}{R_g}$

2. Select R_4 and R_3 to set the minimum gain.

   $G_{min} = 1 + \frac{R_4}{R_3} = 5\frac{V}{V}$

   Choose $R_4 = 20k\Omega$

   $G_{min} = 1 + \frac{20k\Omega}{R_3} = 5\frac{V}{V}$

   $R_3 = \frac{R_4}{5-1} = \frac{20k\Omega}{4} = 5k\Omega \rightarrow R_3 = 5.1k\Omega$ (Standard Value)

3. Select R_1 and R_2. Ensure that R_1/R_2 and R_3/R_4 ratios are matched to set the gain applied to the reference voltage at 1V/V.

   $\frac{V_{o\_ref}}{Vref} = (-\frac{R_3}{R_4}) \times (-\frac{R_2}{R_1}) = \frac{R_3 \times R_2}{R_4 \times R_1} = 1\frac{V}{V}$

   $\frac{R_2}{R_1} = \frac{R_4}{R_3} \rightarrow R_1 = R_3 = 5.1k\Omega$ and $R_2 = R_4 = 20k\Omega$ (Standad Value)

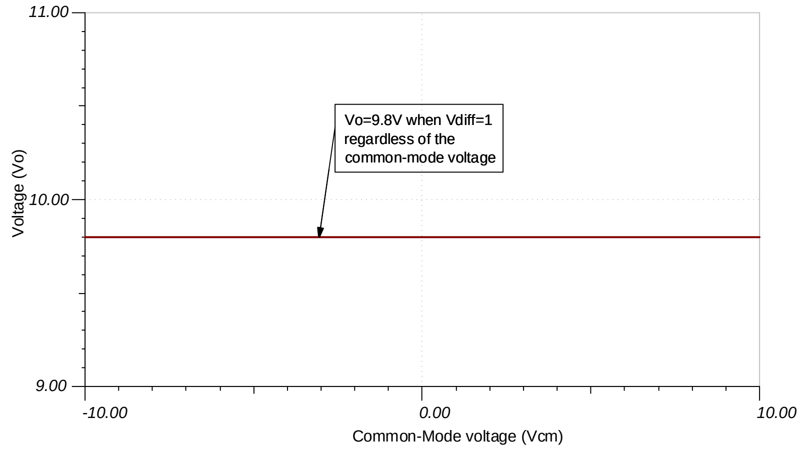
4. Select R_g to meet the desired maximum gain G = 10V/V.

   $G = 1 + \frac{R_4}{R_3} + \frac{2R_2}{R_g} = 1 + \frac{20\ k\Omega}{5.1\ k\Omega} + \frac{2 \times 20\ k\Omega}{R_g} = 10\ V / V$

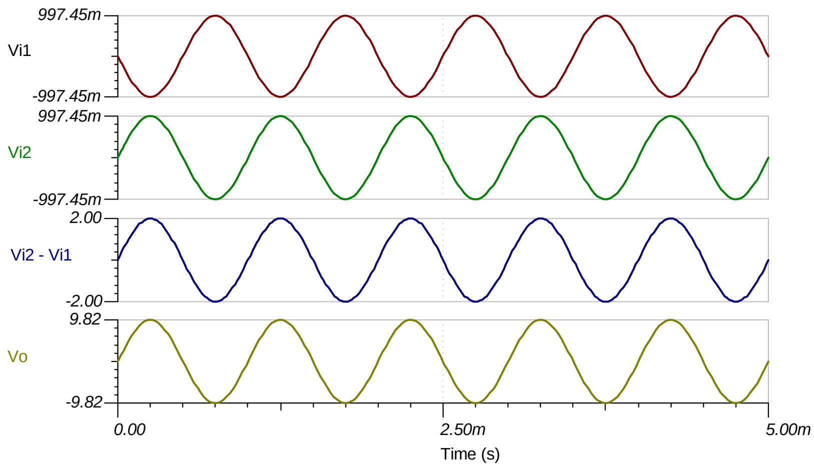
   $R_g = 8\ k\Omega \rightarrow R_g = 7.87\ k\Omega$ (Standard Value)

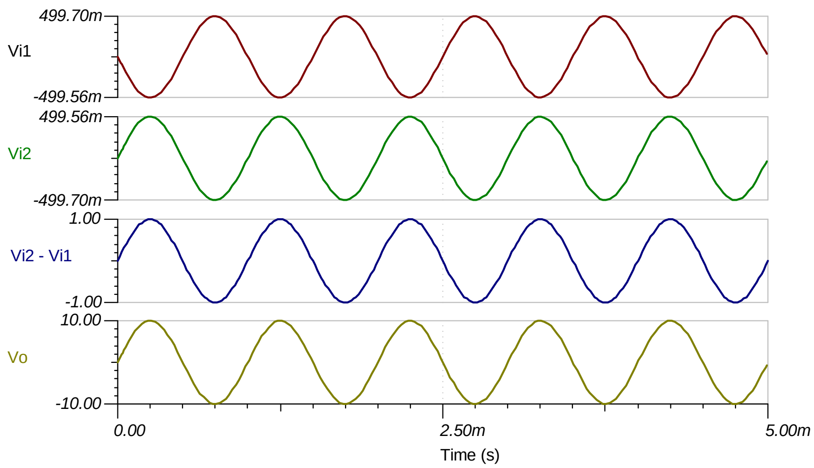
Design Simulations

DC Simulation Results



Transient Simulation Results





References:

1. Analog Engineer's Circuit Cookbooks
2. SPICE Simulation File SBOMAU7
3. TI Precision Labs
4. V_{CM} vs. V_{OUT} plots for instrumentation amplifiers with two op amps
5. Common-mode Range Calculator for Instrumentation Amplifiers

Design Featured Op Amp

TLV171	
V_{ss}	4.5V to 36V
V_{inCM}	(V_{ee}–0.1V) to (V_{cc}–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	
V_{ss}	4.5V to 36V
V_{inCM}	(V_{ee}–0.1V) to (V_{cc}–2V)
V_{out}	Rail–to–rail
V_{os}	0.2mV
I_q	1.6mA
I_b	8pA
UGBW	10MHz
SR	10V/µs
#Channels	1,2,4
www.ti.com/product/opa172	

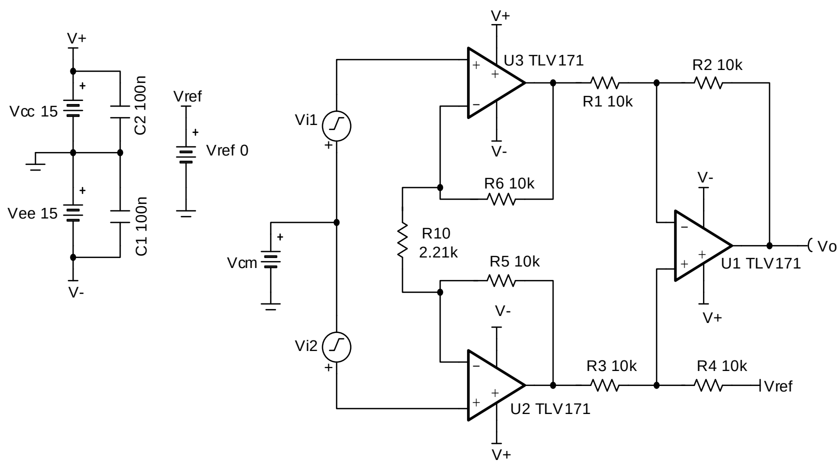
Three op amp instrumentation amplifier circuit

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.

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:

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

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

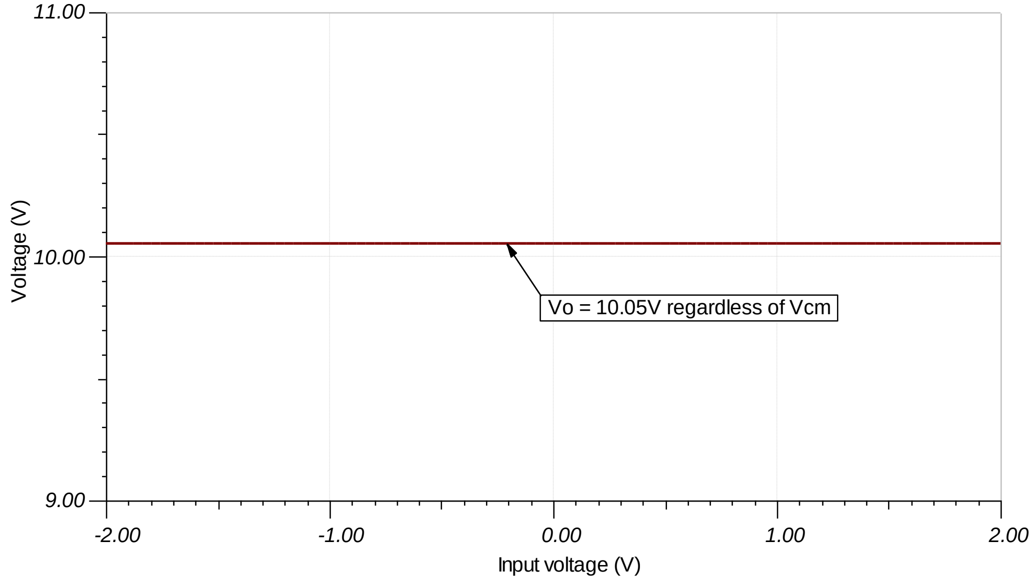
$$\rightarrow G = \left(1 + \frac{2 \times 10\ k\Omega}{R_{10}}\right) = 10\frac{V}{V} \rightarrow \left(1 + \frac{20 k\Omega}{R_{10}}\right) = 10\frac{V}{V}$$

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

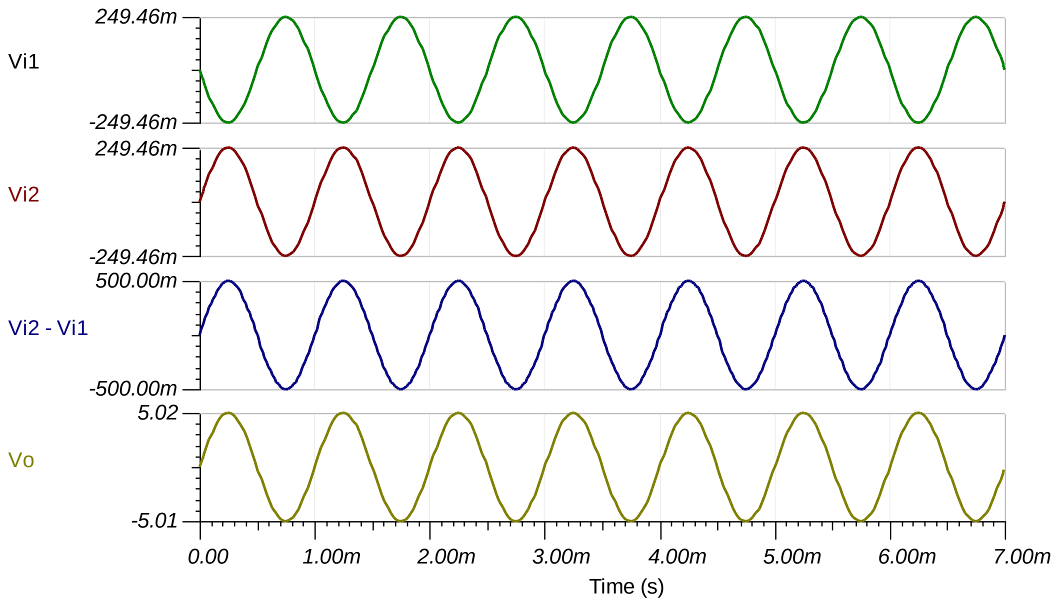
5. To check the common-mode voltage range, download and install the program from reference [5]. Edit the INA_Data.txt file in the installation directory by adding the code for a 3 op amp INA whose internal amplifiers have the common-mode range, output swing, and supply voltage range as defined by the 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.

Design Simulations

DC Simulation Results



Transient Simulation Results



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