Analog Engineer's Circuit

Three Op Amp Instrumentation Amplifier Circuit

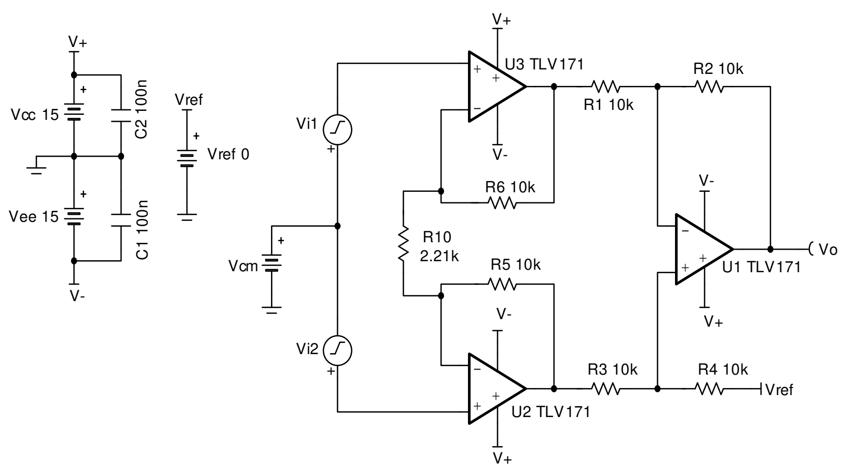
Amplifiers

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}
-0.5 V	+0.5 V	±7 V	–5 V	+5 V	+15 V	–15 V	0 V

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 data sheets.

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:

   $$\text{Choose } R_5 = R_6 = 10\,k\Omega \text{ (Standard Value)}$$

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

   $$\text{Choose } R_1 = R_2 = R_3 = R_4 = 10\,k\Omega \text{ (Standard Value)}$$

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

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

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

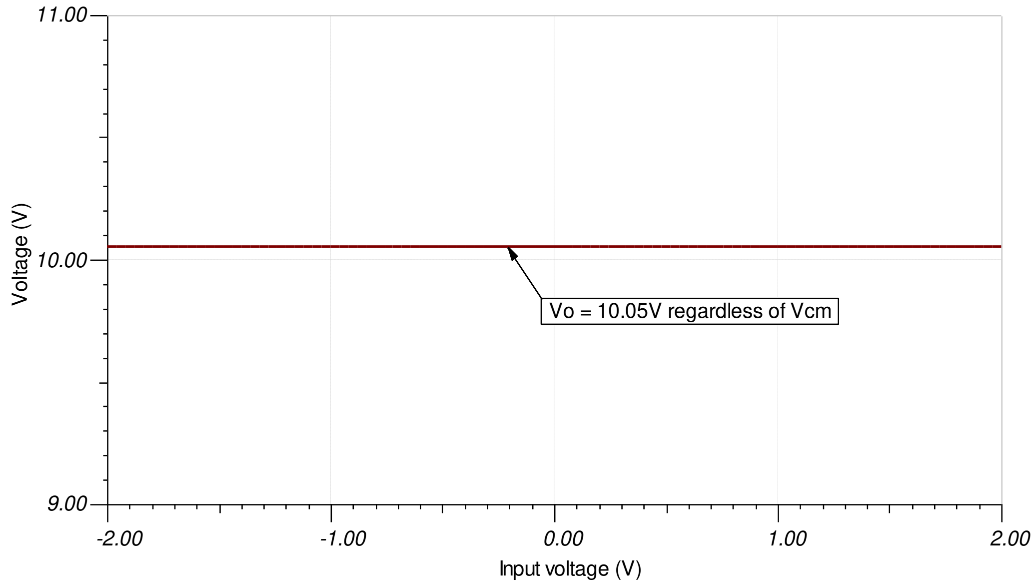
   $$\rightarrow G = \left(1 + \frac{2 \times 10\,k\Omega}{R_{10}}\right) = 10\ \frac{V}{V} \rightarrow \left(1 + \frac{20\,k\Omega}{R_{10}}\right) = 10\ \frac{V}{V}$$

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

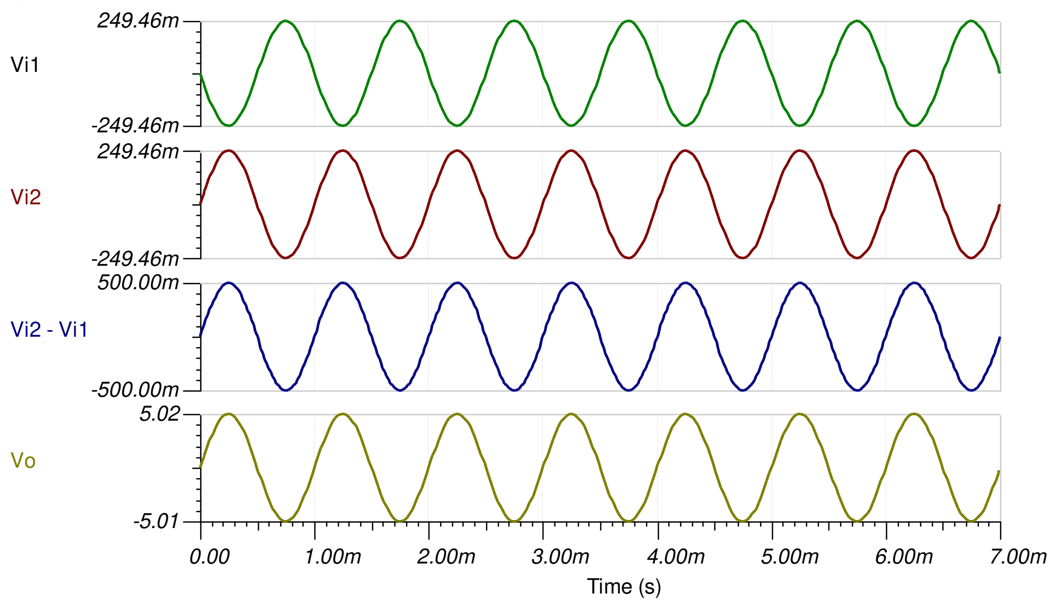
5. To check the common-mode voltage range, download and install the program from reference [5]. Edit the INA_Data.txt file in the installation directory by adding the code for a 3 op amp INA whose internal amplifiers have the common-mode range, output swing, and supply voltage range as defined by the 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}	4.5 V to 36 V
V_{inCM}	(V–) – 0.1 V < Vin < (V+) – 2 V
V_{out}	Rail–to–rail
V_{os}	0.25 mV
I_q	475 µA
I_b	8 pA
UGBW	3 MHz
SR	1.5 V/µs
#Channels	1,2, and4
TLV171	

Design Alternate Op Amp

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