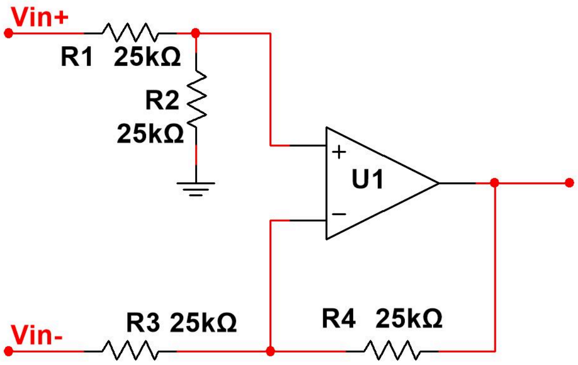
In a previous self-assessment, you used a differential amplifier to investigate differential amplification and common mode rejection. Here it is again, drawn in a slightly different orientation, and with the same resistor value used throughout rather than the two different resistor values in the self-assessment. This configuration is the heart of a special amplifier configuration used frequently as an interface between "real world" parameters like temperature, pressure, force, brightness, etc. and electronic circuits in measurement instruments -- hence the name Instrumentation Amplifier.



Using superposition to disable V_{in+}, determine the gain for V_{in-}. -1

Using superposition to disable V_{in-}, determine the gain for the non-inverting input. 2

Notice that there's a voltage divider between V_{in+} and the non-inverting input. How much of V_{in+} appears at the non-inverting input?

0.5

Multiply the output from the voltage divider by the gain at the non-inverting input to determine the overall gain for V_{in+}.

1

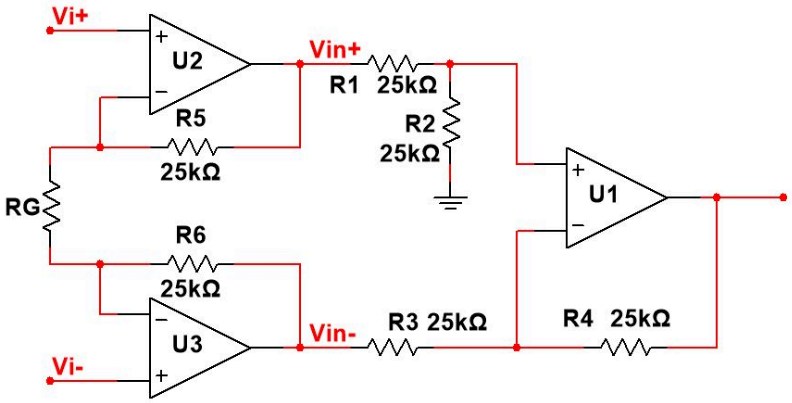
You should have determined that the magnitude of the gains for Vin- and Vin+ are the same, and only the polarity is different. Consequently, a Common Mode signal would be cancelled but a differential signal would be amplified, as shown in the self-assessment.

This amplifier, as shown, has limitations: first, it has no overall gain. But, more significantly, its input impedances are not ideal, and are not the same for the two inputs.

What is the input impedance seen by V_{in-}? 25 kΩ

What is the input impedance seen by V_{in+} (i.e. what resistance exists between Vin+ and ground)? 50 kΩ

The solution to the two issues -- fixed unity gain and poor, unmatched input impedances -- was brilliant. Here it is.



Notice, first of all, that the input impedance problem has been addressed -- both signals are connected directly to high-impedance inputs, so there will be no signal loss at either input.

But what about the gain issue? Let's investigate R_G, the gain setting resistor. Using the concept of the virtual short, the voltage at the top of this resistor is V_{i+} and the voltage at the bottom of the resistor is V_{i-}. Therefore, we can say that the current through R_G is

$$I_{R_G} = \frac{(V_{i+} - V_{i-})}{R_G}$$

Since all of the current through RG must flow between the nodes labelled Vin+ amd Vin-, we can say that

$$V_{in+} - V_{in-} = I_{R_G}\,(2\ R + R_G)$$

Substituting the expression for IRG into this expression, we get

$$V_{in+} - V_{in-} = \frac{(V_{i+} - V_{i-})}{R_G}\,(2\ R + R_G)$$

Now, since the gains for the two differential amplifier inputs are both unity,

$$V_{out} = V_{in+} - V_{in-}$$

So, with a bit of rearranging (check this for yourself), we get

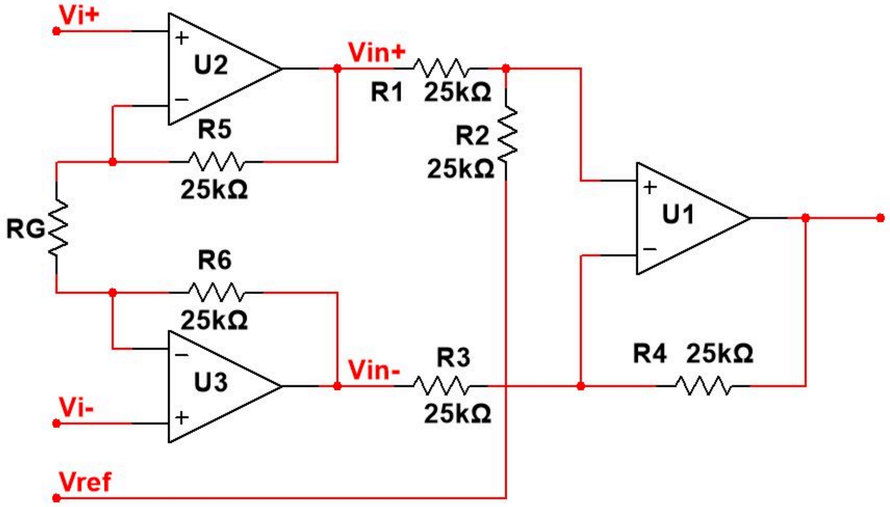
$$V_{out} = \Delta V_{in}\left(\frac{2\ R}{R_G} + 1\right)$$

Since the gain, Av, is V_{out}/V_{in},

$$A_v = \frac{2\ R}{R_G} + 1$$

For a given instrumentation amplifier, R is fixed. In the Burr Brown INA114, the internal impedance is laser-trimmed to 25 kΩ as in the schematics I've provided. Therefore, to set the gain, the designer need only pick an appropriate value for R_G!

The final touch for this extremely versatile circuit is introducing a means of introducing a DC offset. This was done by providing access to the bottom of the voltage divider, allowing the user to reference the circuit to any DC voltage, not just ground, as shown below.



It would have been nice if the designers of the instrumentation amplifier had put a unity gain buffer on the V_{ref} input, but the didn't. Consequently, we suffer from a poor input impedance on this one input, which affects our designs. Typically, to overcome this, we drive the V_{ref} input with an external op amp.

The transfer function for the completed intrumentation amplifier, written basically in the form y = mx + b, looks like this:

$$v_{out} = (v_{in+} - v_{in-})\left(\frac{2\ R}{R_G} + 1\right) + V_{off}$$

where

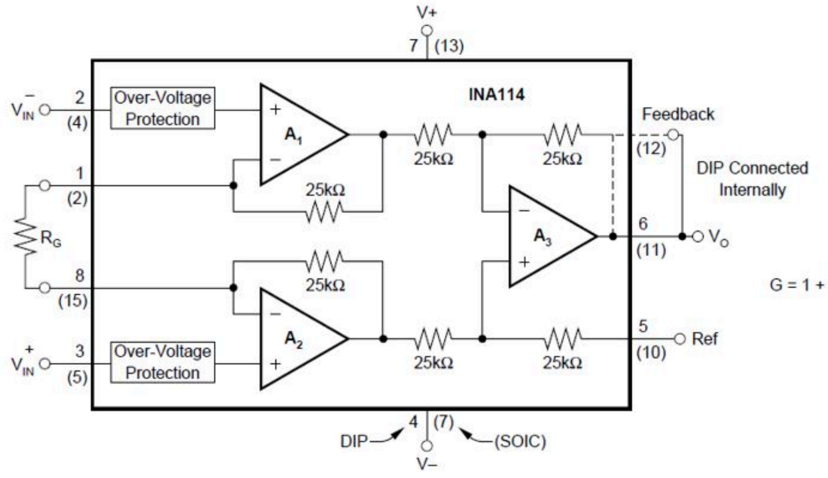
$y=v_{out}$

$m=(2R/R_G + 1)$

$x=(v_{in+}-v_{in-})$

$b=v_{off}$

Here's a snippet of the Burr Brown INA114 data sheet. We use the 8-pin DIP version of this IC, the pins of which are shown without brackets. For some reason, the designers of this chip chose to use the same pins as those on the 8-pin version of the 741, even though the two ICs are definitely not interchangeable. At least it makes memorizing the pin numbers easy!



$$G = 1 + \frac{50k\Omega}{R_G}$$