

EXTENDING THE COMMON-MODE RANGE OF DIFFERENCE AMPLIFIERS

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Extending the common-mode range of difference amplifiers allows their use in a wider variety of reduced power-supply applications.

The INA117 has a specified common-mode input range of $\pm 200V$ when operating on standard $\pm 15V$ power supplies. At power-supply voltages above $\pm 13V$, the INA117 input range is limited to $\pm 200V$ by the power capabilities of its internal input resistors. On reduced power supplies, the input range is limited by the common mode input range of the internal op amp.

The linear common-mode input range of the internal op amp extends to within 3V of its power supply voltage. For example, with a $\pm 15V$ power supply, the common-mode input range of the internal op amp is $\pm 12V$. Because the INA117 internal resistor network divides the input by 20, the actual input range of the INA117 would be $20 \cdot (\pm 12V)$, or 240V, for $\pm 15V$ power supplies. Similarly, reducing the power supply voltage to $\pm 6V$ will limit the input common-mode voltage to $\pm 60V$.

There are two approaches to boosting the common-mode input range for reduced power supply applications: Offsetting the common-mode range by a fixed amount, and dynamically adjusting the common-mode range to follow the input common-mode signal.

OFFSETTING THE INPUT COMMON-MODE RANGE WITH A CONSTANT VOLTAGE

In many applications, the common-mode signal range is known and the common-mode input range of the difference amplifier can be adjusted to coincide with the required range. For example, the $\pm 60V$ common-mode range of the INA117 operating on $\pm 6V$ supplies could be shifted to range from +0V to +120V, or +50V to +170V.

To offset the common-mode range, the reference connection of the difference amplifier is connected to an offsetting voltage, V_x , instead of ground. With the reference connected to an offsetting potential, a second difference amplifier must be used to refer the output back to ground.

One way to offset the input voltage is to connect the reference pins 1 and 5 to the negative supply voltage as shown in Figure 1. Another possibility is to derive the offset voltage from a zener diode connected to the negative power supply as shown in Figure 2. In either case, the total common-mode range of the INA117 is unchanged and shifted by $-19 \cdot (V_x)$.

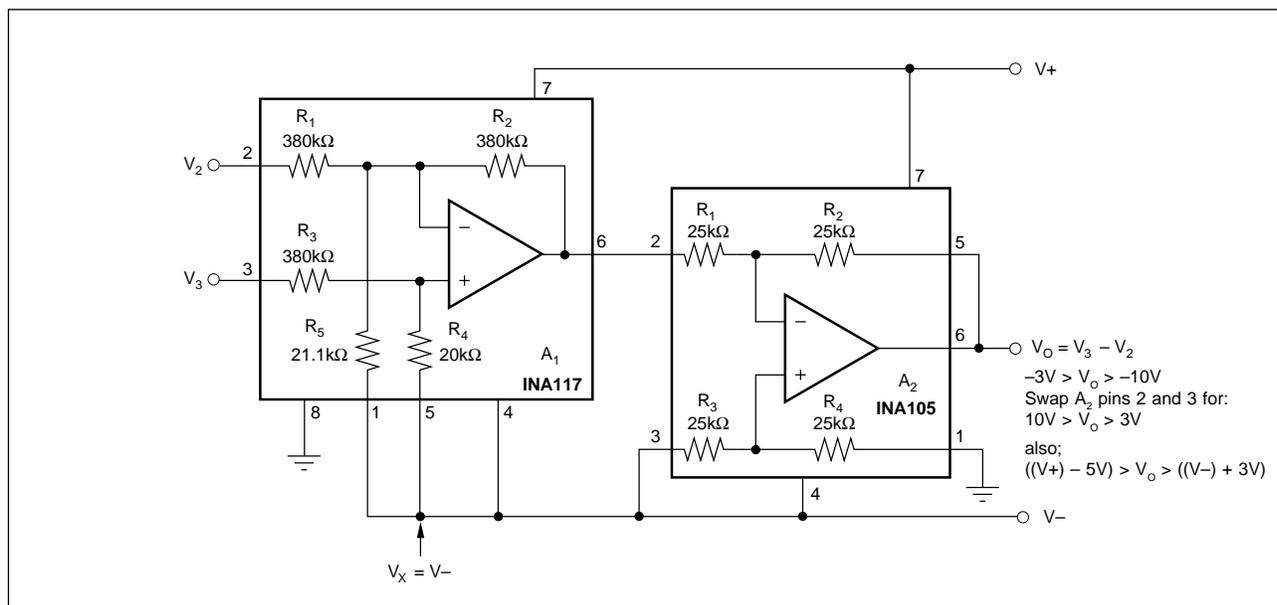


FIGURE 1. Offsetting the INA117 Common-Mode Input Range Using the Negative Power Supply as a Reference.

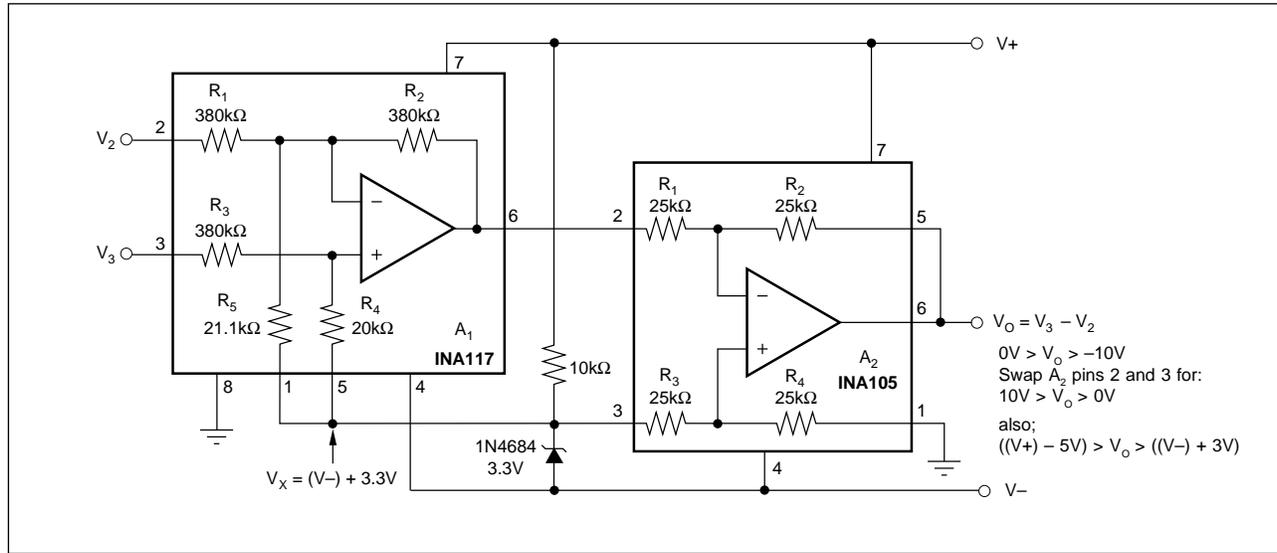


FIGURE 2. Offsetting the INA117 Common-Mode Input Range with a Zener Reference.

Since the input voltage can swing to within 3V of the power supply, the following relationships apply for the INA117:

$$V_R = 20 \cdot [(V+) + |V-| - 6V]$$

$$V_L = 20 \cdot [(V-) + 3V] - 19 \cdot V_X$$

$$V_H = V_R - V_L$$

Where

V_R = total common-mode range [V]

V_L = minimum common-mode signal [V]

V_H = maximum common-mode signal [V]

$V+$, $V-$ = positive, negative power supply [V]

$|V-|$ = absolute value of the negative power supply [V]

V_X = offset voltage (from ground) [V]

POWER SUPPLY	COMMON-MODE INPUT RANGE (V)		
	$V_X = 0^{(1)}$	$V_X = V_{-}^{(2)}$	$V_X = (V-) + 3.3^{(3)}$
$\pm 15V$	-240 to +240 ⁽⁴⁾	45 to 525 ⁽⁴⁾	-18 to 462 ⁽⁴⁾
$\pm 12V$	-180 to +180	48 to 408 ⁽⁴⁾	-15 to 345 ⁽⁴⁾
$\pm 9V$	-120 to +120	51 to 291 ⁽⁴⁾	-12 to 228 ⁽⁴⁾
$\pm 6V$	-60 to +60	54 to 174	-9 to 111

NOTES: (1) Reference connected to GND (normal operation). (2) Reference connected to $V-$ (see Figure 1). (3) Reference connected to $V-$ through 3.3V zener (see Figure 2). (4) Voltages greater than $\pm 200V$ are shown for reference only. INA117 maximum rated operating voltage is $\pm 200V$.

TABLE I. INA117 Common-Mode Input Range for Selected Power Supplies and Reference Offsets.

The same principles can be applied to the INA105 difference amplifier as shown in Figures 3 and 4. With an allowable voltage swing to within 3V of the power supply, the following relationships apply for the INA105:

$$V_R = 2 \cdot [(V+) + |V-| - 6V]$$

$$V_L = 2 \cdot [(V-) + 3V] - V_X$$

ADJUSTING THE COMMON MODE RANGE DYNAMICALLY

Another way to boost the common-mode range of a difference amplifier is to drive the reference connection dynamically in response to changes in the input. A circuit to boost the input range of the INA117 is shown in Figure 5. A third amplifier, A_3 , along with resistors R_7 , R_8 , and R_6 is used to derive, invert, and scale the input level presented to the reference connection.

The value for R_6 depends on the power supply voltages and op amp used for A_3 . To maximize the common-mode range, R_6 should be selected so the output of A_3 is at its maximum swing limit when the inputs to the difference amplifier op amp are at 3V from the opposite power supply. The OPA1013 is a good choice for A_3 since its outputs are guaranteed to swing within 2V of the power supply rails.

Using the OPA1013 op amp for A_3 , and considering the allowed swing to within 3V of the power supply voltage, the following relationships apply for the INA117.

$$V_{CM} = \pm \{20 \cdot ((V+) - 3V) - 19 \cdot V_X\}$$

$$V_X = (V-) + 2V$$

$$R_6 = -0.5M\Omega \cdot V_X / V_{CM}$$

Where:

V_{CM} = common-mode input range [V]

R_6 = value of R_6 [Ω]

POWER SUPPLY (V)	V_{CM} (V)	R_6 (k Ω)
± 15	$\pm 487^{(1)}$	13.3
± 12	$\pm 370^{(1)}$	13.7
± 9	$\pm 253^{(1)}$	13.7
± 6	± 136	14.7

NOTES: (1) Voltages above $\pm 200V$ are shown for reference only. INA117 maximum rated operating voltage is $\pm 200V$.

TABLE II. INA117 Common-Mode Input Range for Selected Power Supplies Using Figure 5 Circuit.

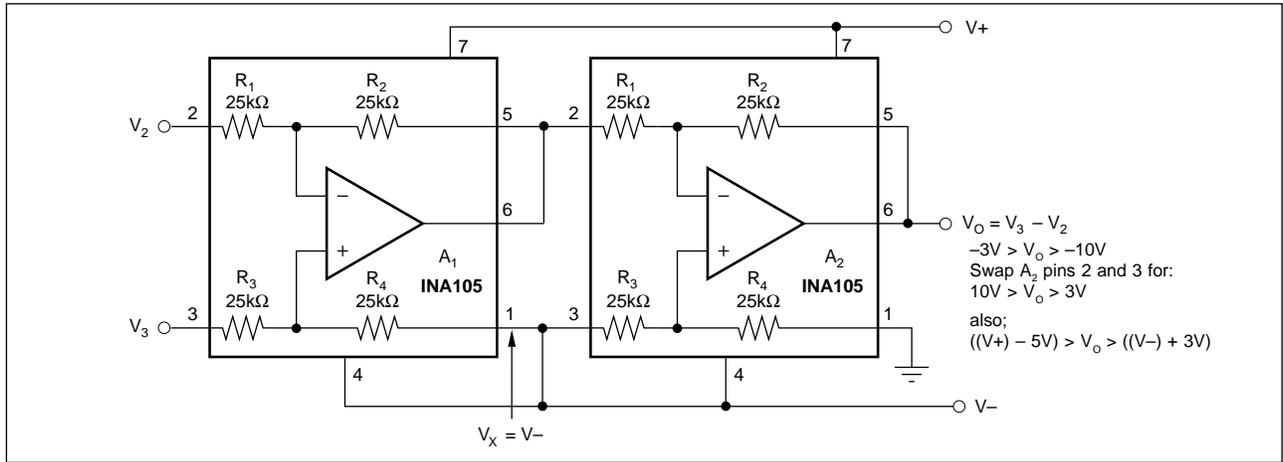


FIGURE 3. Offsetting the INA105 Common-Mode Input Range Using the Negative Power Supply as a Reference.

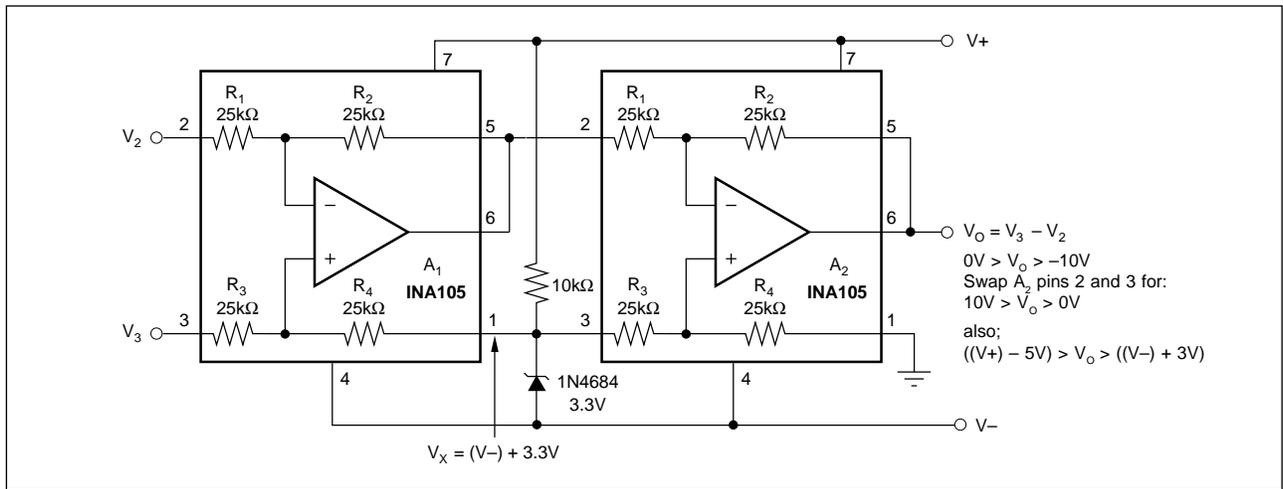


FIGURE 4. Offsetting the INA105 Common-Mode Input Range with a Zener Reference.

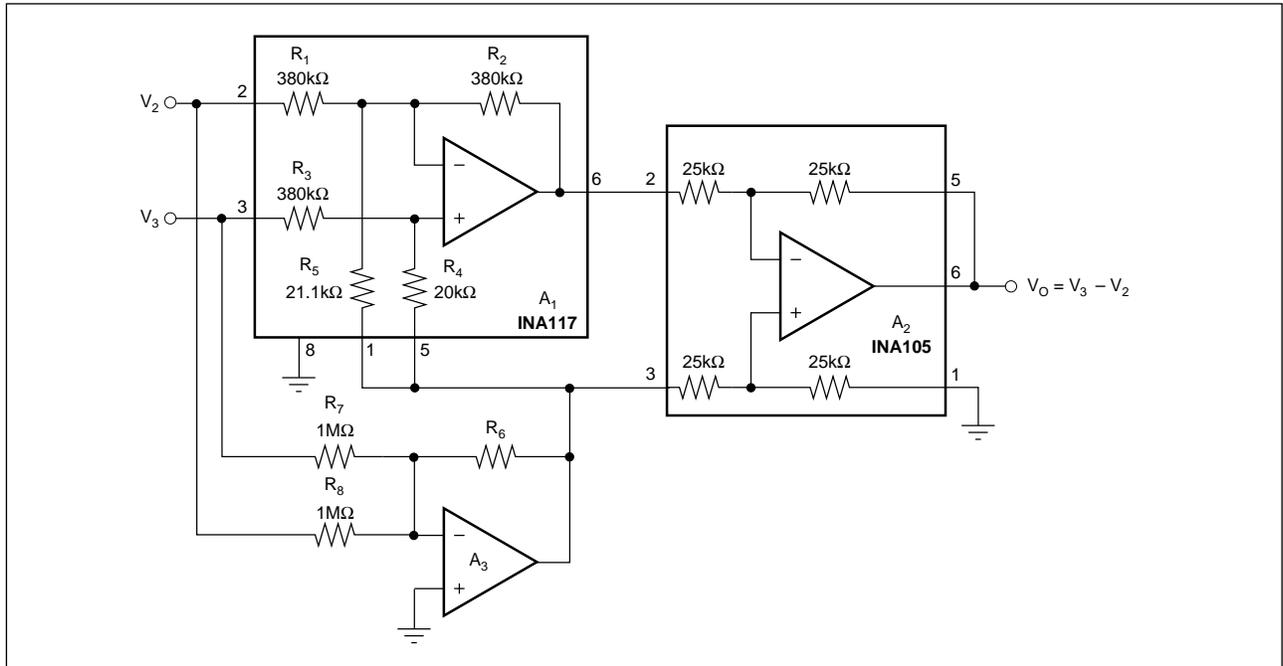


FIGURE 5. Boosting the INA117 Common-Mode Input Range Dynamically.

In the circuit of Figure 5, the true common-mode signal drives the INA117 reference, V_X . Often it is adequate to drive the reference in response to the common-mode signal at just one input pin (either pin 2 or 3). In this case one common-mode sense resistor (either R_7 or R_8) can be omitted. The value of the feedback resistor, R_6 , must then be doubled.

The same principles can be applied to the INA105 difference amplifier as shown in Figure 6. Using the same 3V, 2V rules, the following relationships apply for the INA105.

$$V_{CM} = \pm\{2 \cdot ((V+) - 3V) - V_X\}$$

$$V_X = (V-) + 2V$$

$$R_6 = -0.5M\Omega \cdot V_X/V_{CM}$$

OUTPUT RANGE LIMITATIONS

Keep in mind that with any of these techniques, the common-mode range refers to the input of the difference amp only. To make use of the extended common-mode range, the output swing limitations of the difference amp must also be observed.

The output of the INA117 or INA105 is guaranteed to swing at least $\pm 10V$ on $\pm 15V$ power supplies. However, a negative output can actually swing to within 3V of the negative power supply (to $-12V$ on $\pm 15V$ supplies).

With zero differential input voltage to the difference amplifier, the output will be at zero volts with respect to the reference connection, V_X . The circuits in Figure 1 or 3 will not work with zero differential input. Since the difference amp reference pin is connected to $V-$, the output of the difference amp would saturate to its negative swing limit in an attempt to swing to $V-$. For the circuit to work, the differential input must be at least 3V so that the output of the difference amplifier is at 3V from $V-$. The input to the difference amplifier can be either +3V or -3V and the input connections (pins 2 and 3) can be interchanged to provide the proper output swing.

The circuits in Figures 2 and 4 will function with zero differential input since the reference is connected 3.3V from $V-$. Output swing in response to input signal must, however, always be in the positive direction. As before, the inputs of both difference amplifiers can be connected to accommodate any polarity of input/output swing.

If bipolar output swing is required, offset from the rail must be large enough to accommodate the common-mode offset as well as the output swing. When using the Figure 5 or 6 circuit, the V_X terms in the equations must be replaced by:

$$[(V-) + 3V + V_{SW}] \text{ for negative swings}$$

and by

$$[(V+) - 5V - V_{SW}] \text{ for positive swings}$$

Where:

$$V_{SW} = \text{difference amp output swing relative to reference, } V_X$$

$$(V_{SW} = \text{difference amp differential input since the gain} = 1)$$

The boosted common-mode range for positive inputs is different than for negative inputs due to the differences in the difference amplifier output swing limitations:

For positive common-mode inputs:

$$V_{CMH} = 20 \cdot ((V+) - 3V) - 19 \cdot V_{XH}$$

$$R_{6H} = -0.5M\Omega \cdot V_{XH}/V_{CMH}$$

$$V_{XH} = [(V-) + 3V + V_{SW}]$$

For negative common-mode inputs:

$$V_{CML} = 20 \cdot ((V-) + 3V) - 19 \cdot V_{XL}$$

$$R_{6L} = -0.5M\Omega \cdot V_{XL}/V_{CML}$$

$$V_{XL} = [(V+) - 5V - V_{SW}]$$

Where:

$$V_{CMH} = \text{highest common-mode input voltage [V]}$$

$$V_{CML} = \text{lowest common-mode input voltage [V]}$$

Since only one value for R_6 can be used, the smaller value must be selected if the common-mode input is bipolar. The total common-mode swing is limited by this value.

Reducing the difference amplifier output swing increases the possible common-mode input range. If a higher output swing is needed, add gain after the difference amplifier as shown in Figure 7. In this circuit an optional $f_{-3dB} = 1kHz$ filter is added ahead of the gain stage. The filter reduces output noise at the expense of signal bandwidth reduction. If filtering is not desired, connect the difference amp output directly to the noninverting input of the output amplifier.

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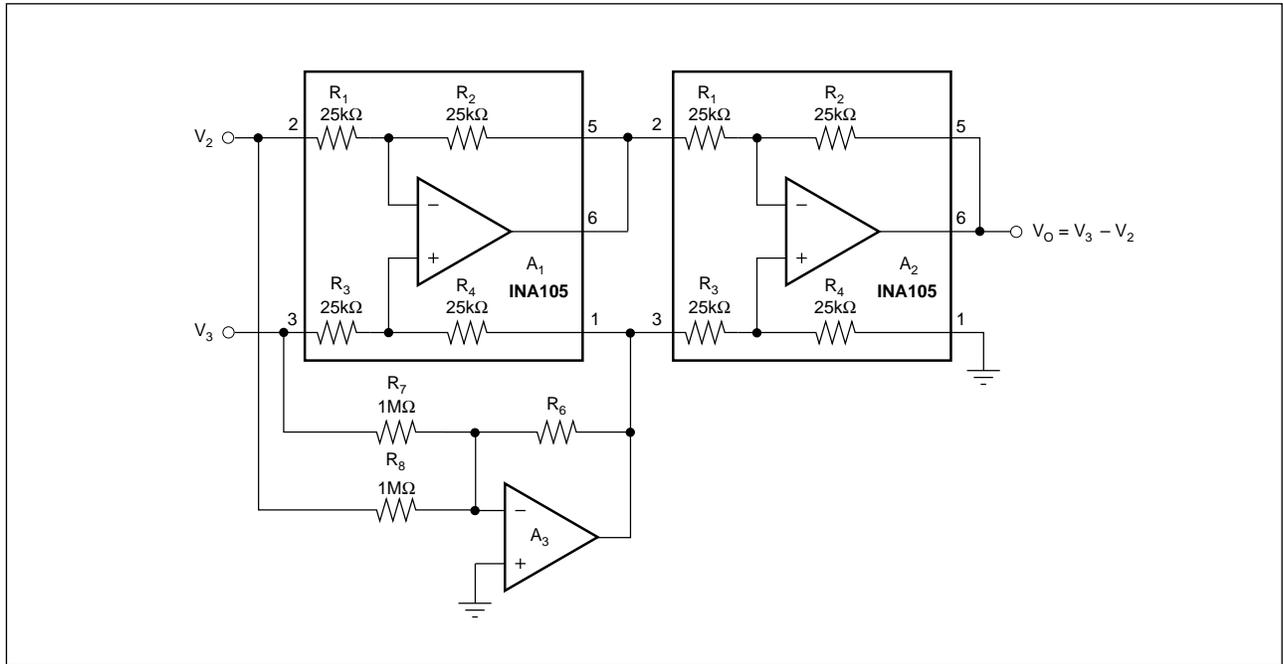


FIGURE 6. Boosting the INA105 Common-Mode Input Range Dynamically.

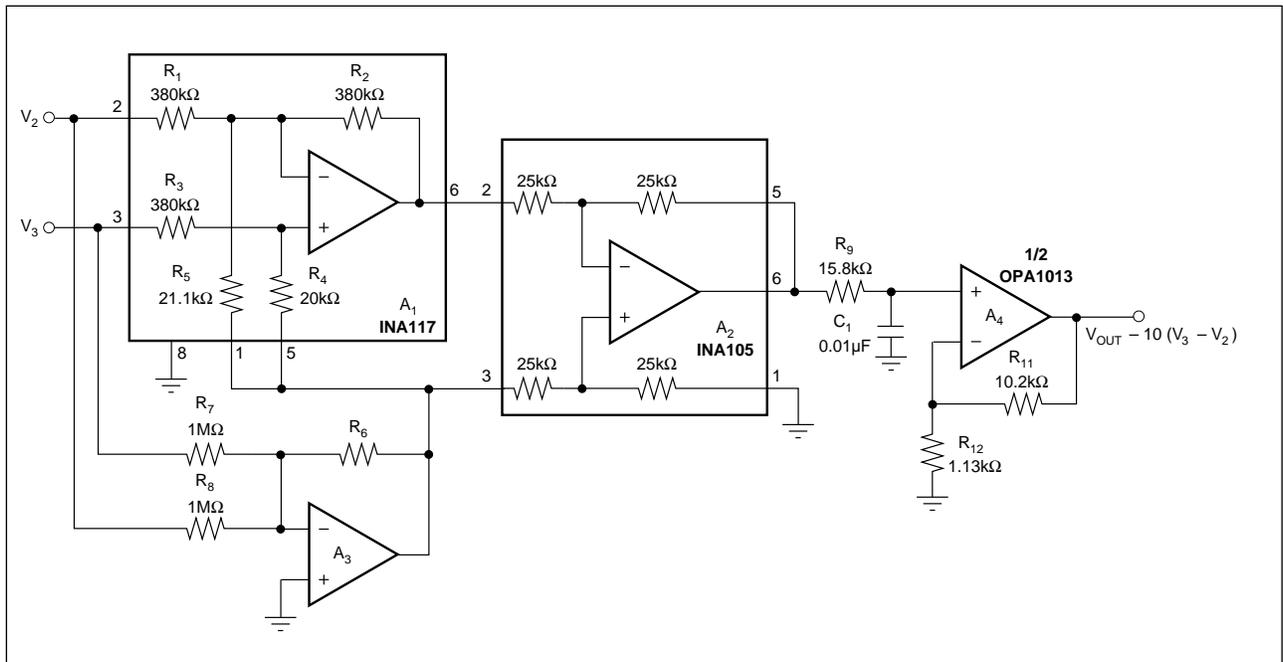


FIGURE 7. Boosted Common-Mode Input Range INA117 with Noise Filtering and Added Gain after the 2nd Difference Amplifier to Further Extend INA117 Common-Mode Input Range.

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