

INPUT FILTERING THE INA117 ±200V DIFFERENCE AMPLIFIER

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Many customers have asked how to add input filtering to the INA117. Since the INA117 is rated for ±200V input voltage (±500V without damage), it is commonly used in environments with very high input noise or with high-voltage input transients. This bulletin shows how to connect input filters, discusses the errors they can add, and shows how to eliminate the errors.

Figure 1 shows the connection of a differential input filter. A pole is formed by C_1 and the two external input resistors. $f_{-3dB} = 1/(4 \cdot \pi \cdot R_1 \cdot C_1)$. Differential input filtering is preferred because mismatches in filter components do not degrade CMR.

DON'T USE COMMON-MODE INPUT FILTERS ALONE

Don't be tempted to use common-mode input filtering alone (Figure 2) unless you are prepared to carefully match components. Mismatches between the $R_1 \cdot C_2$ time constants reduce AC CMR. The mismatches result in a differential input signal in response to AC common-mode inputs. Even if you successfully match the components for good AC CMR at room temperature, maintaining the match over temperature can be a problem.

A COMBINATION COMMON-MODE AND DIFFERENTIAL INPUT FILTER IS OK

If you want common-mode input filtering, use it in conjunction with differential input filtering as shown in Figure 3. If

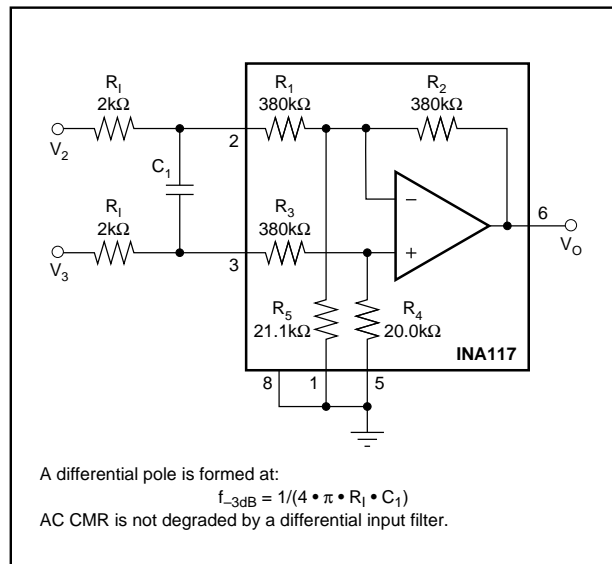


FIGURE 1. INA117 with Differential Input Filter.

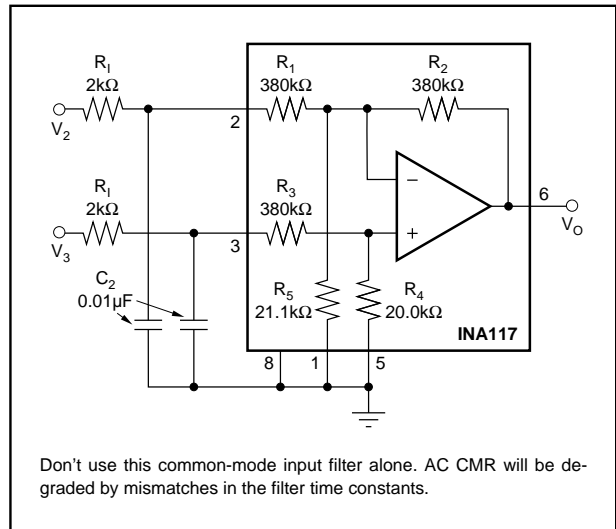


FIGURE 2. INA117 with Common-Mode Input Filter.

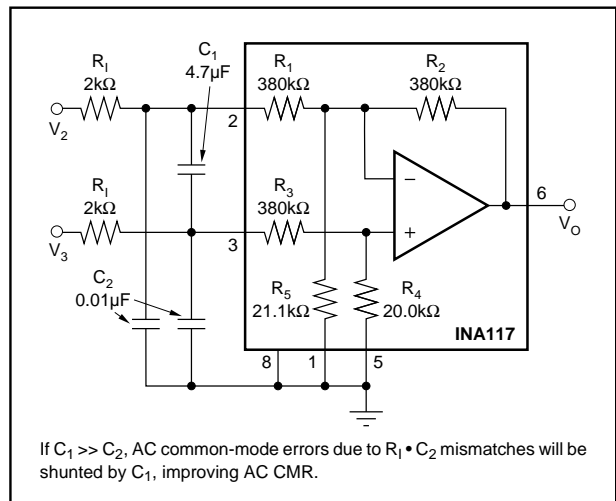


FIGURE 3. INA117 with a Combination Differential and Common-Mode Input Filter.

$C_1 \gg C_2$, AC common-mode errors will be shunted by C_1 so AC CMR can be successfully boosted. A value of $C_1 = 500 \cdot C_2$ is suggested.

Figure 4 shows actual CMR vs Frequency performance plots for the Figure 2 and Figure 3 circuits. Standard INA117 performance is shown for comparison. The standard INA117 has about 60dB CMR at 30kHz. Mismatches of 5% in $R \cdot C$ time constants (5% C_2 mismatch) cause the Figure 2 circuit CMR to drop below 60dB at less than 200Hz. Adding a

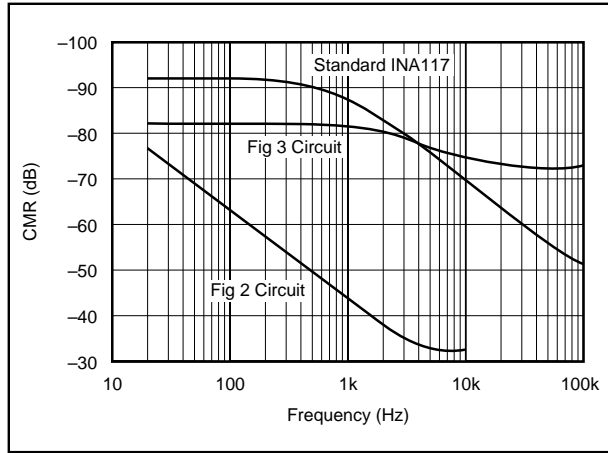


FIGURE 4. CMR vs Frequency Plots for Figure 2 and 3 Circuits with Standard INA117 for Comparison.

4.7 μ F differential input filter capacitor shunts out common-mode filter errors producing greater than 70dB CMR to 100kHz as shown in the plot of Figure 3's performance.

INPUT RESISTORS CAN REDUCE DC CMR

Notice that the DC CMR of the Figure 3 circuit is reduced from ≈ 92 dB to ≈ 82 dB. The CMR reduction is due to mismatches from input filter resistors, R_I .

CMR in the INA117 depends on close resistor ratio matching. For errors in R_1 and R_3 :

$$\text{CMR} = -20 \text{Log}(\%/105)$$

Where:

CMR = CMR for errors in R_1 or R_3 [dB]

% = the error in R_1 or R_3 [%]

The number, 105, in the denominator comes from R_1 , R_3 sensitivity equations.

$$S_{R_1, R_3}^{\text{CMR}} = \pm R_1 / (R_1 + R_4)$$

For example, % = 0.002% is required for the typical 94dB INA117 CMR.

Even though the 2k Ω input resistors are relatively small compared to the 380k Ω input resistors in the INA117, mismatches will reduce CMR. Even if perfectly matched external input resistors are used there can still be problems with CMR.

Although some resistor ratios in the INA117 are carefully matched to achieve good CMR, the R_1/R_3 ratio is not. A typical mismatch of 1% can be expected. The effect is to add an effective 1% mismatch to external resistors. The following worst-case CMR can be expected:

$$\text{CMR} = -20 \text{Log}((\text{ERROR}_1 + \text{ERROR}_2)/105)$$

Where:

ERROR_1 = Error due R_I , R_1 , and R_3 mismatches [%]

$\text{ERROR}_1 = R_I \cdot (T_{OL} + 1) / (R_I + 3.8 \cdot 10^5)$

R_I = DC resistance of external filter resistor, R_I , [Ω]

T_{OL} = Tolerance of R_I [%], i.e. 1.0 for 1%

INA117 GRADE	CMR ₁₁₇ (dB)	ERROR ₂ (%)
INA117BM typ	94	0.002
INA117BM min	86	0.005
INA117KP min	70	0.033

TABLE I. Initial INA117 CMR Values.

R_I (Ω)	ERROR ₁ (%)	ERROR ₂ (%)	CMR (dB)
1k	0.005	0.005	80
2k	0.010	0.005	76
5k	0.026	0.005	71
10k	0.051	0.005	65

TABLE II. Examples of Worst-Case CMR to be Expected (INA117BM and selected 1% R_I s).

ERROR_2 = Initial INA117 error [%]—See Table I

Also,

$$\text{ERROR}_2 = \frac{105}{10(\text{CMR}_{117}/20)}$$

CMR₁₁₇ = Initial INA117 CMR [dB]

See Tables I and II for examples.

CMR TRIM

If you want to use 10k Ω input resistors and must be assured of good DC CMR, you can use the trim circuit shown in Figure 5. Resistor TCR mismatches can limit difference amplifier performance over temperature. Use high quality film resistors and keep $R_I \leq 10$ k Ω for good performance

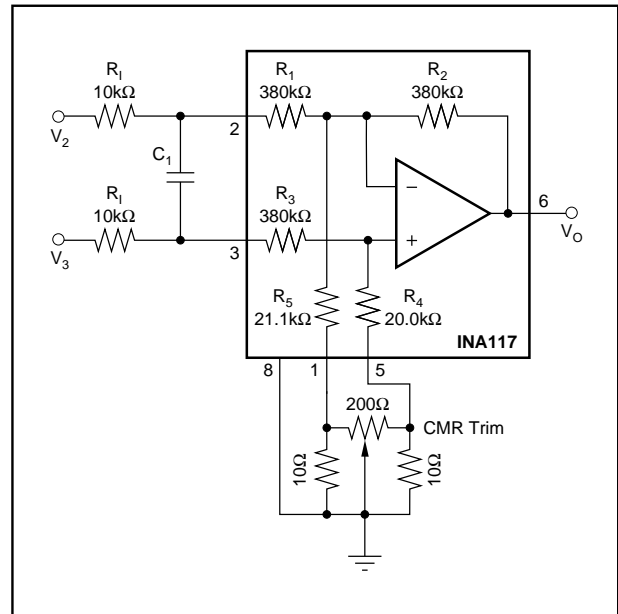


FIGURE 5. INA117 with Differential Input Filter and CMR Trim.

over temperature.

ADDED INPUT RESISTORS CAUSE GAIN ERROR

Adding input resistors to the INA117 causes gain error. When all resistor ratios are properly adjusted for good CMR, INA117 gain is R_2/R_1 . When input filter resistors are added, gain is reduced to $R_2/(R_1 + R_1)$. With $R_1 = 10\text{k}\Omega$, gain is $\approx 0.974 \text{ V/V}$ (approximately -2.6% gain error). Since gain does not depend on R_3 , R_4 , or R_5 , the gain error can not be corrected by adding resistance in series with any pin.

CORRECTING GAIN ERROR

To correct for the gain error introduced by the input filter resistors, you can add a small amount of positive feedback as shown in Figure 6. Resistors R_{4A} , R_{4B} , and R_{5A} must be selected to maintain CMR and to give the proper positive feedback to correct for gain error.

The following procedure is suggested:

$$\text{Set } R_{4A} = 10\Omega$$

This is an arbitrary but adequate value for R_{4A} . It is the smallest standard 1% value. With this small value, even a 5% ratio matching error between R_{4A} and R_{5A} would only degrade INA117 CMR to 82.5dB. In practice, ratio errors will be lower than this when closest standard 1% resistors are used.

Calculate R_{4B} and R_{5A} and use closest standard 1% resistor value.

$$R_{4B} \approx 18 \cdot R_{4A} + \frac{19 \cdot R_2 \cdot R_{4A}}{R_1}$$

With $R_1 < 10\text{k}\Omega$ and $R_{4A} = 10\Omega$ this is an adequate approxi-

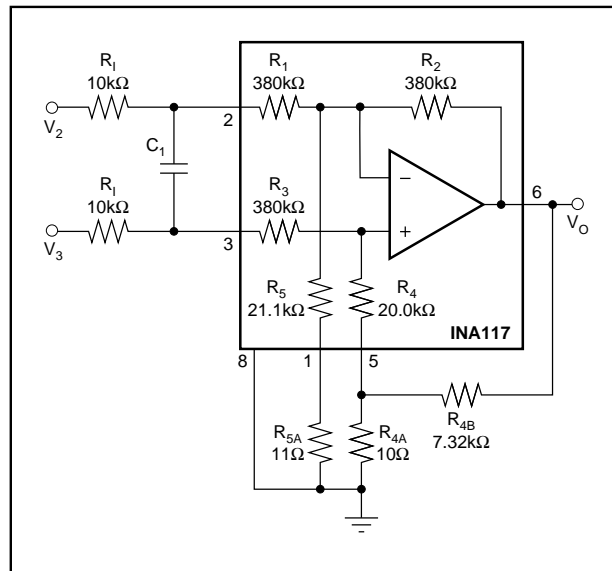


FIGURE 6. INA117 with Differential Input Filter and Positive Feedback Circuit to Compensate for Gain Error Due to R_1 .

mation for all practical purposes.

If $R_2 = 380\text{k}\Omega$, $R_1 = 10\text{k}\Omega$, and $R_{4A} = 10\Omega$:

$$R_{4B} \approx 180 + \frac{72\text{M}\Omega}{R_1} \approx 7.4\text{k}\Omega, \text{ use } 7.32\text{k}\Omega$$

$$R_{5A} \approx \frac{361 \cdot R_2 \cdot R_{4A} \cdot R_{4B}}{324(R_2 \cdot R_{4A}) + 324(R_2 \cdot R_{4B}) - 342(R_{4A} \cdot R_{4B})}$$

With $R_2 = 380\text{k}\Omega$ and $R_{4A} = 10\Omega$:

$$R_{5A} \approx \frac{3.61 \cdot R_{4B}}{3.24 + 0.323991 \cdot R_{4B}}$$

With $R_{4B} = 7.4\text{k}\Omega$, $R_{5A} = 11.13\Omega$, use 11Ω .

FINE-TRIM FOR ZERO GAIN ERROR

You must trim to get zero gain error. The resistors in the INA117 are accurately ratio trimmed to give excellent CMR and gain accuracy, but their absolute values are only accurate to within about $\pm 20\%$. With the values calculated above, gain error will be reduced from approximately -2.6% to about $\pm 0.5\%$.

For lower gain error use the gain-trim circuit shown in Figure 7. The circuit is the same as in Figure 6 except, R_{4B} is replaced with a $5\text{k}\Omega$ fixed resistor and a $5\text{k}\Omega$ pot.

To trim for zero gain error, ground the INA117 inputs (0V input) and measure the offset voltage, V_{OFF} , at the output. Apply a known input voltage, V_{REF} , (e.g. 10.0V) to the INA117 noninverting input. Measure V_{REF} so you know its precise value. Adjust the $5\text{k}\Omega$ pot for the correct INA117

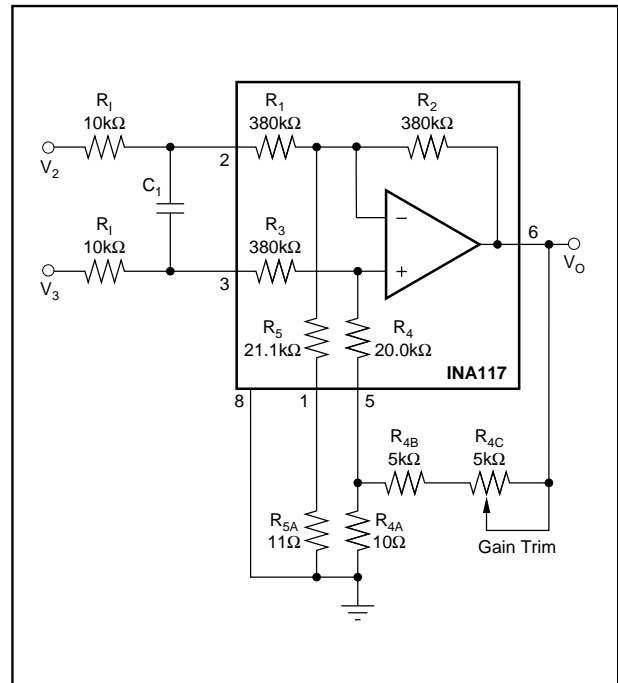


FIGURE 7. INA117 with Differential Input Filter and Gain Trim Circuit.

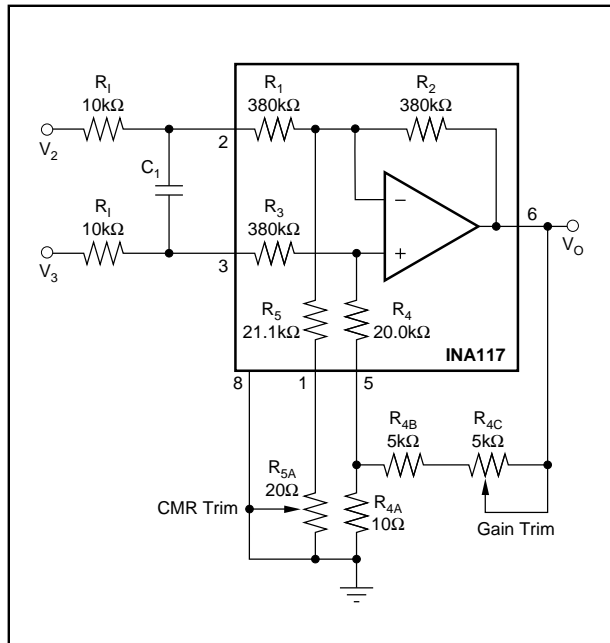


FIGURE 8. INA117 with Differential Input Filter and Both Gain Trim and CMR Trim Circuits.

output voltage: $V_{OUT} = V_{REF} + V_{OFF}$.

You can automate the trim process by using an amplifier with a known gain of 1V/V. The Burr-Brown INA105BM difference amplifier with gain error = $\pm 0.01\%$ max is a good choice. Instead of using a voltage reference, drive the input of the INA117 with a $\pm 5V$, 10Hz sine or triangle wave (see AN-165, Fig. 46 for a suitable triangle generator circuit). Connect one input of the INA105 to the driven INA117 input. Connect the other input of the INA105 to the INA117 output. Adjust the 5kΩ gain trim pot for zero AC at the INA105 output. Using the AC technique allows you to distinguish between offset and gain error.

If you want to adjust both gain and CMR, use the circuit shown in Figure 8.