Gain Error
TI Precision Labs – Current Sense Amplifiers

Quiz
Gain Error – quiz

1. Select all of the following that are true:
   a) Total device gain error consists of gain error for a specified temperature range, gain error drift, and linearity.
   b) Relative gain error is directly proportional to the input sense voltage.
   c) Gain error is the dominant error source at high sense voltages.
   d) Gain error is only valid in the linear output region.
   e) If a CSA device’s gain error is calibrated at room temperature, the only gain error left is gain error temperature drift.
   f) Shunt resistor tolerance can be considered a gain error.
2. Using the following datasheet specifications for the INA302, what is the maximum total device gain error for the A2 variant if ambient temperature can vary from 0°C to 105°C?

a) ±0.215 %
b) ±0.205 %
c) ±0.19 %
d) ±0.18 %

6.5 Electrical Characteristics

at \( T_A = 25^\circ \text{C} \), \( V_{\text{SENSE}} = 0 \text{ V} \), \( V_{\text{REF}} = V_S / 2 \), \( V_S = 5 \text{ V} \), \( V_{\text{IN+}} = 12 \text{ V} \), \( V_{\text{LIMIT1}} = 3 \text{ V} \), and \( V_{\text{LIMIT2}} = 3 \text{ V} \) (INA302) or 2 V (INA303) (unless otherwise noted)

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
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<tbody>
<tr>
<td>OUTPUT</td>
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<tr>
<td>G</td>
<td>A1 versions</td>
<td>20</td>
<td></td>
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<td>V/V</td>
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<td></td>
<td>A2 versions</td>
<td>50</td>
<td></td>
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<td>V/V</td>
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<td></td>
<td>A3 versions</td>
<td>100</td>
<td></td>
<td></td>
<td>V/V</td>
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<tr>
<td>Gain error</td>
<td>( V_{\text{OUT}} = 0.5 \text{ V to } V_S - 0.5 \text{ V}, ) A1 versions</td>
<td>±0.02%</td>
<td>±0.075%</td>
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<td>( V_{\text{OUT}} = 0.5 \text{ V to } V_S - 0.5 \text{ V}, ) A2 versions</td>
<td>±0.05%</td>
<td>±0.1%</td>
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<td></td>
<td>( V_{\text{OUT}} = 0.5 \text{ V to } V_S - 0.5 \text{ V}, ) A3 versions</td>
<td>±0.1%</td>
<td>±0.15%</td>
<td></td>
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<tr>
<td></td>
<td>( T_A = -40^\circ \text{C to } +125^\circ \text{C} )</td>
<td>3</td>
<td>10</td>
<td></td>
<td>ppm/°C</td>
</tr>
<tr>
<td>Nonlinearity error</td>
<td>( V_{\text{OUT}} = 0.5 \text{ V to } V_S - 0.5 \text{ V} )</td>
<td>±0.01%</td>
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</tbody>
</table>
3. A system has performed a two-point calibration at 80°C on the INA185A4 to negate offset and gain error. Using the specifications below, what is the maximum device gain error if the ambient temperature can vary from 60°C to 95°C? Assume the max gain error drift value is ±8 ppm/°C.

### 6.5 Electrical Characteristics

at $T_A = 25°C$, $V_{\text{SENSE}} = V_{\text{IN+}} - V_{\text{IN-}}$, $V_S = 5\, \text{V}$, $V_{\text{REF}} = V_S / 2$, and $V_{\text{IN+}} = 12\, \text{V}$ (unless otherwise noted)

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<thead>
<tr>
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<tbody>
<tr>
<td>Gain error</td>
<td>$V_{\text{OUT}} = 0.5, \text{V}$ to $V_S - 0.5, \text{V}$, $T_A = -40°C$ to $125°C$</td>
<td>±0.05%</td>
<td>±0.2%</td>
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<td></td>
<td>A1, A2, A3 devices</td>
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<tr>
<td></td>
<td>A4 device</td>
<td>±0.07%</td>
<td>±0.25%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Gain error drift</td>
<td>$T_A = -40°C$ to $125°C$</td>
<td>1.5</td>
<td>8</td>
<td>ppm/°C</td>
<td></td>
</tr>
<tr>
<td>Nonlinearity error</td>
<td>$V_{\text{OUT}} = 0.5, \text{V}$ to $V_S - 0.5, \text{V}$</td>
<td>±0.01%</td>
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</table>
Gain Error- quiz

4. The INA253 is a current-sense amplifier with an integrated 2 mΩ shunt resistor so error specifications are slightly different compared to other CSAs. Given the specifications below, what are the worst-case (maximum and minimum) gain values in mV/A for the INA253A2 (200 mV/A typical) if temperature can vary from 0°C to 100°C?

7.5 Electrical Characteristics

at $T_A = 25\,^\circ\text{C}$, $V_S = 5\,\text{V}$, $I_{\text{SENSE}} = IS^+ = 0\,\text{A}$, $V_{\text{CM}} = 12\,\text{V}$, and $V_{\text{REF1}} = V_{\text{REF2}} = V_S / 2$ (unless otherwise noted)

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<tr>
<td>$G$ Gain</td>
<td>INA253A1</td>
<td>100</td>
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<td></td>
<td>mV/A</td>
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<td></td>
<td>INA253A2</td>
<td>200</td>
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<td>mV/A</td>
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<td>INA253A3</td>
<td>400</td>
<td></td>
<td></td>
<td>mV/A</td>
</tr>
<tr>
<td>System gain error$^{(3)}$</td>
<td>$\text{GND} + 50,\text{mV} \leq V_{\text{OUT}} \leq V_S - 200,\text{mV}$, $T_A = 25^\circ\text{C}$</td>
<td>±0.05%</td>
<td>±0.4%</td>
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<tr>
<td></td>
<td>$T_A = -40^\circ\text{C}$ to $+125^\circ\text{C}$</td>
<td></td>
<td></td>
<td>±45</td>
<td>ppm/°C</td>
</tr>
<tr>
<td>Nonlinearity error</td>
<td>$\text{GND} + 10,\text{mV} \leq V_{\text{OUT}} \leq V_S - 200,\text{mV}$</td>
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Answers
Gain Error – quiz

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b) Relative gain error is directly proportional to the input sense voltage.

c) Gain error is the dominant error source at high sense voltages.

d) Gain error is only valid in the linear output region.

e) If a CSA device’s gain error is calibrated at room temperature using a two-point calibration, the only gain error left is gain error temperature drift.

f) Shunt resistor tolerance can be considered a gain error.
2. Using the following datasheet specifications for the INA302, what is the maximum total device gain error for the A2 version if ambient temperature can vary from 0°C to 105°C?

a) ±0.215 %  
b) ±0.205 %  
c) ±0.19 %  
d) ±0.18 %
Gain Error – quiz

2. Using the following datasheet specifications for the INA302, what is the maximum total device gain error for the A2 variant if ambient temperature can vary from 0°C to 105°C?
   a) ±0.215 %
   b) ±0.205 %
   c) ±0.19 %
   d) ±0.18 %

\[
\text{Max total gain error} = E_{G\_Total}
\]
\[
E_{G\_Total} = E_{G\_25C} + \frac{\Delta E_G}{\Delta T} \times \Delta T_A + E_{\text{Linearity}}
\]
\[
E_{G\_Total} = 0.1\% + 10 \frac{\text{ppm}}{\circ C} \times 10^{-4} \times (105\circ C - 25\circ C) + 0.01\%
\]
\[
E_{G\_Total} = 0.1\% + 0.08\% + 0.01\%
\]
\[
E_{G\_Total} = 0.19\%
\]
3. A system has performed a two-point calibration at 80°C on the INA185A4 to negate offset and gain error. Using the specifications below, what is the maximum device gain error if the ambient temperature can vary from 60°C to 95°C? Assume the max gain error drift value is ± 8 ppm/°C.

6.5 Electrical Characteristics

at $T_A = 25°C$, $V_{\text{SENSE}} = V_{\text{IN+}} - V_{\text{IN-}}$, $V_S = 5\, \text{V}$, $V_{\text{REF}} = V_S / 2$, and $V_{\text{IN+}} = 12\, \text{V}$ (unless otherwise noted)

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<td>Gain error</td>
<td>$V_{\text{OUT}} = 0.5, \text{V to } V_S - 0.5, \text{V}$, $T_A = -40°C$ to $+125°C$</td>
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<td>±0.01%</td>
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Answer: Max gain error is ± 0.026 %
3. A system has performed a two-point calibration at 80°C on the INA185A4 to negate offset and gain error. Using the specifications below, what is the maximum total device gain error if the ambient temperature can vary from 60°C to 95°C? Assume the max gain error drift value is ± 8 ppm/°C.

Gain error at the calibrated temperature (80°C) is now limited to just linearity (±0.01%). The maximum temperature change from 80°C is |60°C – 80°C| = 20°C. So the maximum total gain error over the expected temperature range is calculated as:

\[
Max \ total \ gain \ error = \frac{\Delta E_G}{\Delta T_A} \cdot \Delta T_A + E_{Linearity}
\]

\[
Max \ total \ gain \ error = 8 \frac{ppm}{°C} \cdot 10^{-4} \cdot |60°C - 80°C| + 0.01%
\]

\[
Max \ total \ gain \ error = 0.016% + 0.01%
\]

**Answer:** Max total gain error is ± 0.026 %
Gain Error- quiz

4. The INA253 is a current-sense amplifier with an integrated 2 mΩ shunt resistor so error specifications are slightly different compared to other CSAs. Given the specifications below, what are the worst-case (maximum and minimum) gain values in mV/A for the INA253A2 (200mV/A typical) if temperature can vary from 0°C to 100°C?

7.5 Electrical Characteristics

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<td>$V_{\text{OUT}}$ = $V_S - 200 , mV$, $T_A = 25, ^\circ C$</td>
<td>±0.05%</td>
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<td>$T_A = -40, ^\circ C$ to $+125, ^\circ C$</td>
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<tr>
<td>Nonlinearity error</td>
<td>$V_{\text{OUT}}$ = $V_S - 200 , mV$</td>
<td>±0.01%</td>
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Answer: Maximum gain is 201.495 mV/A and minimum gain is 198.505 mV/A
Gain Error- quiz

4. The INA253 is a current-sense amplifier with an integrated 2 mΩ shunt resistor so error specifications are slightly different compared to other CSAs. Given the specifications below, what are the worst-case (maximum and minimum) gain values in mV/A for the INA253A2 (200 mV/A typical) if temperature can vary from 0°C to 100°C?

\[ \text{Max total gain error} = E_{G,\text{Total}} = E_{G,25^\circ C} + \frac{\Delta E}{\Delta T} \cdot \Delta T_A + E_{\text{Linearity}} \]

\[ E_{G,Total} = 0.4\% + 45 \frac{ppm}{^\circ C} \cdot 10^{-4} \times (100^\circ C - 25^\circ C) + 0.01\% \]

\[ E_{G,Total} = 0.4\% + 0.3375\% + 0.01\% \]

\[ E_{G,Total} = 0.7475\% \]

\[ G_{\text{MAX}} = 200 \frac{mV}{A} \times \left(1 + \frac{0.7475\%}{100}\right) = 201.495 \frac{mV}{A} \]

\[ G_{\text{MIN}} = 200 \frac{mV}{A} \times \left(1 - \frac{0.7475\%}{100}\right) = 198.505 \frac{mV}{A} \]

Answer: Maximum gain is 201.495 mV/A and minimum gain is 198.505 mV/A