Reference Design Material for Current Sensing

Reference Board for
Low-side Current Sensing Circuit
REFSENS002-EVK -001

The reference design for low-side current sensing circuits is achieved by using shunt resistors, an op-amp, and external components to configure a low-side current sensing circuit to be used for functions including current (voltage) control, over current limiting, and remaining battery level detection in the areas of automotive and industrial equipment. The low-side current sensing circuits can be incorporated most simply at a lower cost compared with other methods.

Reference board REFSENS002-EVK-001 is configured with an op-amp and shunt resistors for industrial equipment, enabling current detection up to 100 A.

Features
• The current detection circuit is configured with the simplest circuit using shunt resistors and an op-amp
• The circuit uses PSR series shunt resistors (PSR400, 2mΩ, 4 in parallel), which are ideal for current detection in large current circuits
• The circuit uses a low noise LMR1802G CMOS op-amp, which is ideal for high precision sensing
• Current detection range: max. 100 A
• Proper thermal design enables operations with a detection current of 100 A and the ambient temperature at 85°C

Electrical characteristics
The electrical characteristics of REFSENS002-EVK-001 are shown below.

<table>
<thead>
<tr>
<th>Item</th>
<th>Min</th>
<th>Typ</th>
<th>Max</th>
<th>Unit</th>
<th>Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection current range</td>
<td>–</td>
<td>100</td>
<td>A</td>
<td></td>
<td>R11/12=2kΩ, R21/22=120kΩ</td>
</tr>
<tr>
<td>Sense voltage</td>
<td></td>
<td>50</td>
<td>mV</td>
<td></td>
<td>RS = 0.5mΩ</td>
</tr>
<tr>
<td>Sensing precision</td>
<td></td>
<td>7</td>
<td>%</td>
<td></td>
<td>Iin=50A</td>
</tr>
<tr>
<td>Operating voltage range</td>
<td>2.5</td>
<td>5.5</td>
<td>V</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Operating temperature range</td>
<td>-40</td>
<td>85</td>
<td>°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage</td>
<td>3.0</td>
<td></td>
<td>V</td>
<td></td>
<td>Iin=100A, Vdd=5.0V</td>
</tr>
<tr>
<td>DC Gain</td>
<td></td>
<td>60</td>
<td>V/V</td>
<td></td>
<td>R11/12=2kΩ, R21/22=120kΩ</td>
</tr>
</tbody>
</table>

Table 1. Electrical characteristics of REFSENS002-EVK-001
Appearance of evaluation board

The appearance of the REFSENS002-EVK-001 board is shown below.

<table>
<thead>
<tr>
<th>Board name</th>
<th>REFSENS002-EVK-001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Board size</td>
<td>90mm × 80mm × 1.6mm</td>
</tr>
<tr>
<td>Board structure</td>
<td>FR-4 4-layer board, copper foil thickness per layer: 3 oz, thermal via: ø0.3 mm</td>
</tr>
</tbody>
</table>

Figure 1. Appearance of REFSENS002-EVK-001 board
Example of operating procedure

Necessary devices
• DC power supply: \( V_o=2.5V \sim 5.5V, I_o=100mA \)
• Voltmeter
• Device under test (DUT): circuit with a maximum current of 100 A

The evaluation of the DC items is performed with REFSENS002-EVK-001 according to the procedure below. Other measurements are described in “Measurement circuit diagrams” on page 12.

1. Preset the DC power supply to 5 V and disable the power supply output.
2. Set the DUT to 100 A or less and disable the DUT.
3. Connect the positive and negative terminals of the DC power supply to the VDD and GND terminals, respectively.
4. Connect the positive and negative terminals of the DUT to the +VIN and -VIN, respectively.
5. Connect the positive and negative terminals of the voltmeter to the OUT1 and GND terminals, respectively.
6. Enable the DC power supply.
7. Enable the DUT.
8. Confirm that the reading of the voltmeter is 3.0 V (under a 100 A load).

![Connection diagram]

Figure 2. Connection diagram

Design procedure

In this reference design, the selection of components, design of circuit constants, and setting of sensing precision refer to the application note “Design of Low-Side Current Sensing Circuit”, which is available from the following link.

[Design of Low-Side Current Sensing Circuit]
Circuit diagram

The circuit diagram of REFSENS002-EVK-001 is shown below. The circuit diagram is available from ROHM's website.

Figure 3. Circuit diagram of REFSENS002-EVK-001
Parts list
The parts list of REFSENS002-EVK-001 is shown below. The parts list is available from ROHM’s website.

<table>
<thead>
<tr>
<th>Part</th>
<th>Product name</th>
<th>Value</th>
<th>Footprint</th>
<th>Description</th>
<th>Quantity</th>
</tr>
</thead>
<tbody>
<tr>
<td>C1</td>
<td>GCM155R71H104KE02J</td>
<td>0.1uF</td>
<td>C_1005_0402</td>
<td>Capacitor, Surface Mount</td>
<td>1</td>
</tr>
<tr>
<td>C2</td>
<td>-</td>
<td>open</td>
<td>C_1005_0402</td>
<td>Capacitor, Surface Mount</td>
<td>1</td>
</tr>
<tr>
<td>C11, C12</td>
<td>GCM1552C1H181JA01</td>
<td>180pF</td>
<td>C_1005_0402</td>
<td>Capacitor, Surface Mount</td>
<td>2</td>
</tr>
<tr>
<td>D11, D12</td>
<td>TDZV5.1</td>
<td>5.1V</td>
<td>TUMD2M-SOD_323HE</td>
<td>Zener Diode, Surface Mount</td>
<td>2</td>
</tr>
<tr>
<td>J1</td>
<td>-</td>
<td>-</td>
<td>61300511121</td>
<td>Connector Header1x5,pitch 2.54</td>
<td>1</td>
</tr>
<tr>
<td>R1</td>
<td>MCR01SMQPF</td>
<td>short</td>
<td>R_1005_0402</td>
<td>Resistor, Surface Mount</td>
<td>1</td>
</tr>
<tr>
<td>R2</td>
<td>MCR01SMQPF</td>
<td>short</td>
<td>R_1005_0402</td>
<td>Resistor, Surface Mount</td>
<td>1</td>
</tr>
<tr>
<td>R11, R12</td>
<td>MCR01SMQPF</td>
<td>2kΩ</td>
<td>R_1005_0402</td>
<td>Resistor, Surface Mount</td>
<td>2</td>
</tr>
<tr>
<td>R21, R22</td>
<td>MCR01SMQPF</td>
<td>120kΩ</td>
<td>R_1005_0402</td>
<td>Resistor, Surface Mount</td>
<td>2</td>
</tr>
<tr>
<td>RS1~4</td>
<td>PSR4001TQFJ2L00</td>
<td>2mΩ</td>
<td>10mm x 5.2mm</td>
<td>Resistor, Surface Mount</td>
<td>4</td>
</tr>
<tr>
<td>+VIN</td>
<td>-</td>
<td>-</td>
<td>TP_10P0/7P20</td>
<td>Test Pin, Through Hole</td>
<td>2</td>
</tr>
<tr>
<td>+VIN</td>
<td>-</td>
<td>-</td>
<td>TP_10P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>-VIN</td>
<td>-</td>
<td>-</td>
<td>TP_10P0/7P20</td>
<td>Test Pin, Through Hole</td>
<td>2</td>
</tr>
<tr>
<td>-VIN</td>
<td>-</td>
<td>-</td>
<td>TP_2P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>VDD</td>
<td>-</td>
<td>-</td>
<td>TP_2P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>OUT1</td>
<td>-</td>
<td>-</td>
<td>TP_2P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>GND</td>
<td>-</td>
<td>-</td>
<td>TP_2P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>+IN</td>
<td>-</td>
<td>-</td>
<td>TP_2P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>-IN</td>
<td>-</td>
<td>-</td>
<td>TP_2P0/1P05</td>
<td>Through Hole</td>
<td>1</td>
</tr>
<tr>
<td>U1</td>
<td>LMR1802G-LB</td>
<td>-</td>
<td>SSOP5</td>
<td>CMOS OP-AMP</td>
<td>1</td>
</tr>
</tbody>
</table>

Layout
The PCB layout of REFSENS002-EVK-001 is shown below. This PCB is configured with four layers. The layout data is also available from ROHM’s website.
Figure 5. Top layout (top view)

Figure 6. Second layer layout (top view)
Figure 7. Third layer layout (top view)

Figure 8. Bottom layout (top view)
Reference application characteristics

The reference application characteristics are shown below. Unless otherwise noted, $T_A = 25^\circ C$ and $V_{DD} = 5.0 \, V$

![Figure 9. Error rate of current sensing precision vs. detection current](image1)

![Figure 10. Error rate of current sensing precision vs. ambient temperature](image2)

![Figure 11. Step Response](image3)
Figure 12. Voltage gain and phase vs. frequency characteristics (-40°C)

- $f_c = 7.2\, \text{kHz}$
- $f_{co} = 537.0\, \text{kHz}$
- Phase margin = 67.1°

Figure 13. Voltage gain and phase vs. frequency characteristics (25°C)

- $f_c = 7.2\, \text{kHz}$
- $f_{co} = 562.3\, \text{kHz}$
- Phase margin = 56.7°
Figure 14. Voltage gain and phase vs. frequency characteristics (65°C)

Figure 15. Voltage gain and phase vs. frequency characteristics (85°C)
Figure 16. Phase margin vs. load capacitance characteristics
Measurement circuit diagrams

Figure 17. Measurement circuit diagram for DC Sweep

Figure 18. Measurement circuit diagram for transient analysis (pulse application)

Figure 19. Measurement circuit diagram for AC analysis

Figure 20. Measurement circuit diagram for AC analysis (load capacitance characteristics)
Thermal Design

The following is the result of temperature measurement on the shunt resistors when a detection current of 100 A is applied (at ambient temperature $T_A = 25°C$).

![Temperature distribution of shunt resistors](image)

Figure 21. Temperature distribution of shunt resistors

To apply a large current to the current detection part, it is necessary to maintain the temperature of each component within the specified operating temperature range. The specified operating temperature range for each component is described in the data sheet. The specified operating temperature range is between $-65°C$ and $+175°C$ for PSR400, which is the type of shunt resistor used in this reference design. Reduce the power along the power reduction curve so that the temperature will not exceed the specified operating temperature range.

For ROHM's shunt resistors, the rated power guarantee is specified with the terminal temperature of the product when power is applied, instead of the ambient temperature.

![Power reduction curves](image)

Figure 22. Power reduction curves for PSR400 2.0mΩ (taken from the data sheet)

In Figure 21, the highest terminal temperature is $T_k = 70.0°C$ (at ambient temperature $T_A = 25°C$). If the ambient temperature during actual operations is assumed ($T_A = 85°C$), the terminal temperature is $T_k = 130°C$ (at $T_A = 85°C$). According to the power reduction curves in Figure 22, the power reduction curve for $P_{115°C}$ is applicable if $T_k = 115°C$ or more. Therefore, it is necessary to reduce the power consumption to 3 W or less.
The power consumption of each shunt resistor is calculated to be 1.25 W as shown in the equation below. Therefore, it can be confirmed that the power consumption remains lower than the rated power even at the ambient temperature during actual operations.

\[ P_C = V_{\text{shunt}} \times I_{\text{IN}} = 50 \text{ mV} \times 100 \text{ A} = 5 \text{ W} \quad \text{(1.25 W per resistor)} \]

- \( T_s \): Temperature at center of the shunt resistor terminal
- \( T_a \): Ambient temperature
- \( P_c \): Power consumption
- \( V_{\text{shunt}} \): Voltage produced across the shunt resistor
- \( I_{\text{IN}} \): Detection current

Reference: [High Power Guarantee Using Terminal Temperature Derating](#)
Precautions for use

• In this reference design, the temperature is maintained within the specified operating temperature range by placing four shunt resistors in parallel in order to disperse heat generation.

  Determine the number of parallel shunt resistors according to the detection current, so that the temperature will not exceed the specified operating temperature range.

• Check the absolute maximum rating and the precautions for use described in the data sheets of the op-amp and other components.
Thank you for your accessing to ROHM product informations.
More detail product informations and catalogs are available, please contact us.

ROHM  Customer Support System
http://www.rohm.com/contact/

www.rohm.com
© 2016 ROHM Co., Ltd. All rights reserved.
R1102B