Shunt resistor

Guide for PCB Layout of Sensing Lines Using Shunt Resistor

In the areas of automotive and industrial equipment, current sensing circuits are used to enable functions including current and voltage control, overcurrent limiting, and remaining battery level detection. The shunt resistor method is employed in some of these circuits. While the resistor value, power rating, and size are important considerations when using shunt resistors, tolerances that affect the sensing precision must also be considered. These tolerances include the tolerance of the resistor value at room temperature (e.g. Class F: ±1%) and the temperature coefficient of resistance. Furthermore, depending on the position of the sensing lines, the influence of the resistance components of the board wiring and solder could cause an error in the sensing precision. Therefore, to achieve a high-precision current sensing circuit, care must be taken not only in selecting the components and designing the constants but also in arranging the PCB layout. This application note introduces the points that should be noted when arranging the PCB layout and provides verifications through simulations and actual measurements.

Measuring the voltage drop in a shunt resistor

To suppress heat generation and secure a detection current range, shunt resistors with a very low resistor value, generally from several μΩ to several mΩ, are used for current sensing circuits. It is widely known that the 4-terminal method (Kelvin connection) * can be applied to measure the voltage drop in resistors with such a low resistance. When positioning the sensing lines, if the sensing lines are arranged outside the mounting pads of the shunt resistor as shown in Figure 1, an accurate measurement is not possible because the resistance components of the copper foil and solder in the board wiring shown in Figure 2 will be included. As the resistor value of the shunt resistor decreases, the effect is relatively increased, becoming non-negligible as an error factor. Therefore, by arranging the sensing lines so that they are connected inside the mounting pads of the shunt resistor as shown in Figure 3, the measurement can be performed while excluding the unnecessary resistance components. An appropriate PCB layout design is required to secure the sensing precision.

* Four-terminal method (Kelvin connection): Method to eliminate errors in voltage measurement by isolating the voltage measurement terminals from the current conduction terminals.

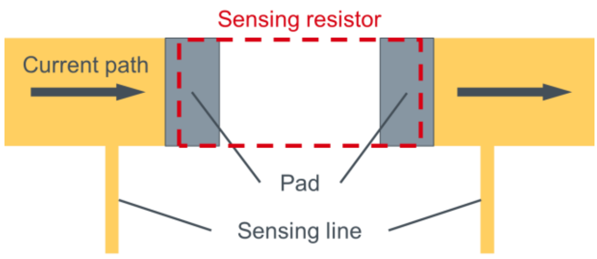

Figure 1. Example of incorrect sensing line layout

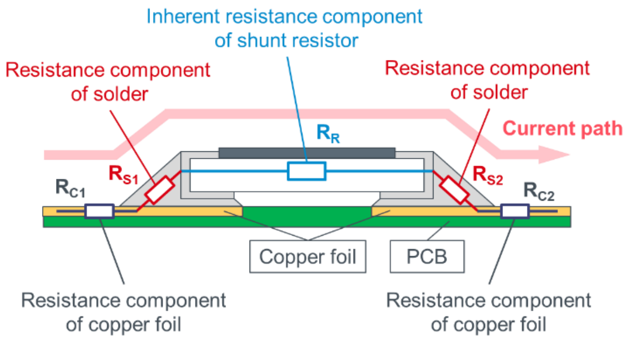

Figure 2. Sectional view of mounting

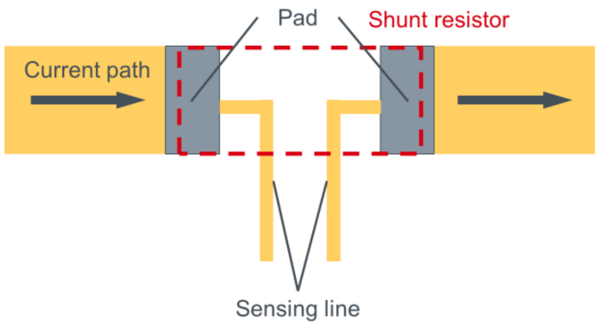

Figure 3. Example of correct sensing line layout

Effect of board wiring resistance

A high-precision voltage measurement can be realized by designing the sensing lines for measuring voltage drop in a shunt resistor so that the resistor components other than that of the shunt resistor are excluded. Several mounting land patterns may be provided if the number of shunt resistors to be connected in parallel is not fixed because the circuit designing is in the initial stage, PCB sharing is being considered, etc. However, if the sensing lines are positioned on each pattern and connected together, a correct voltage drop cannot be measured due to a resistance circuit network formed by the mounting patterns for shunt resistors and the sensing lines.

Specifically, we use the evaluation board (BD1422xG-EVK-001) shown in Figure 4 as an example and check what kind of resistance circuit network is formed on the sensing circuit. In this board design, up to four shunt resistors can be mounted in parallel and the sensing lines are connected inside the mounting pattern for each shunt resistor. We use a resistance circuit network to check how the sensing lines are arranged when a 2.00 mΩ shunt resistor is mounted on position R12 on the center left side of the board as shown in Figure 5. Figure 6 shows the wiring resistance calculated from the pattern shapes of the evaluation board. Figure 7 shows the resistance circuit network configured with the calculated wiring resistance and the resistor value of the shunt resistor. When looking at the terminal of the shunt resistor on one side, a resistance circuit network is included between the terminal of the shunt resistor (red circle) and the voltage measurement terminal (blue circle) as shown in Figure 8. Therefore, the sensing voltage includes not only the voltage drop due to the resistance component of the shunt resistor alone, but also the voltage drop due to the unnecessary resistor components. This may cause errors in the sensing precision.

First, perform a simulation using the resistance circuit network in Figure 7 to check what value of the sensing voltage will be obtained. Simulate the sensing voltage when the current is 1.00 A, the shunt resistor value is 2.00 mΩ, and the values calculated with Equation [1] below based on the pattern shapes are applied to the respective wiring resistances.

$$R\,[\Omega] = (\rho \cdot l)/(t \cdot w) \qquad \cdots[1]$$

ρ: Copper specific resistance [Ω·m], l: Wiring length [m]

t: Copper foil thickness [m], w: Wiring width [m]

The simulation shows that the sensing voltage is 2.21 mV. Since the theoretical value is 1.00 A × 2.00 mΩ = 2.00 mV, an error of 0.21 mV (10.5%) has occurred.

Next, modify the configuration of the resistor circuit network so that the sensing lines are connected only inside the shunt resistor as shown in Figure 9 and perform the same simulation. The result shows the sensing voltage is 2.00 mV. Therefore, the voltage drop due to the resistance component of the shunt resistor alone is detected successfully.

Thus, it can be seen that it is necessary to connect the sensing lines only inside the shunt resistor to be sensed in order to measure the voltage drop in a shunt resistor correctly. When several shunt resistors are connected in parallel or auxiliary patterns are placed on the board, design the sensing lines with great care.

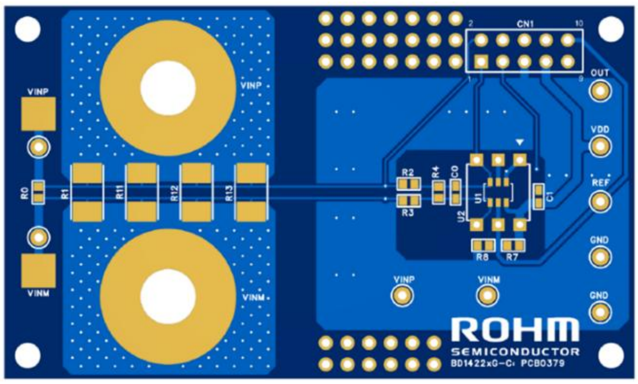

Figure 4. Evaluation board (BD1422xG-EVK-001)

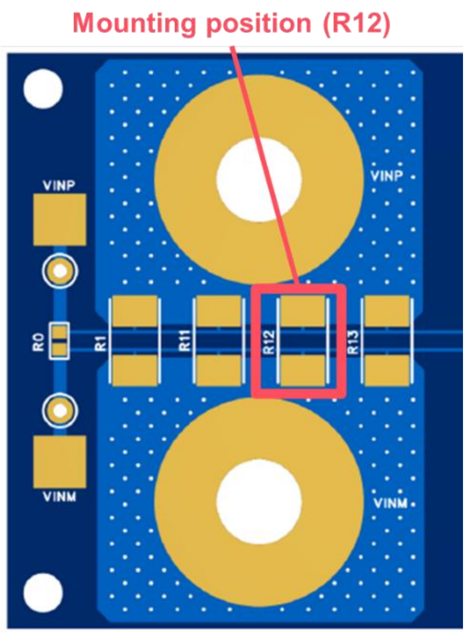

Figure 5. Mounting position of shunt resistor

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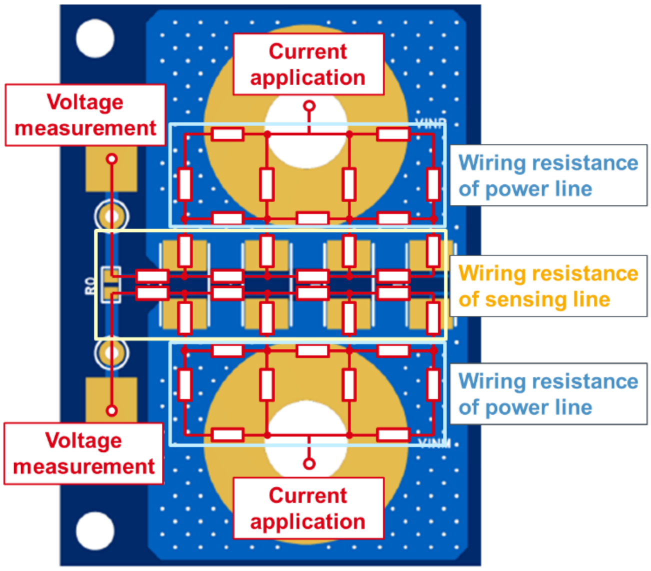


Figure 6. Wiring resistance calculated from evaluation board

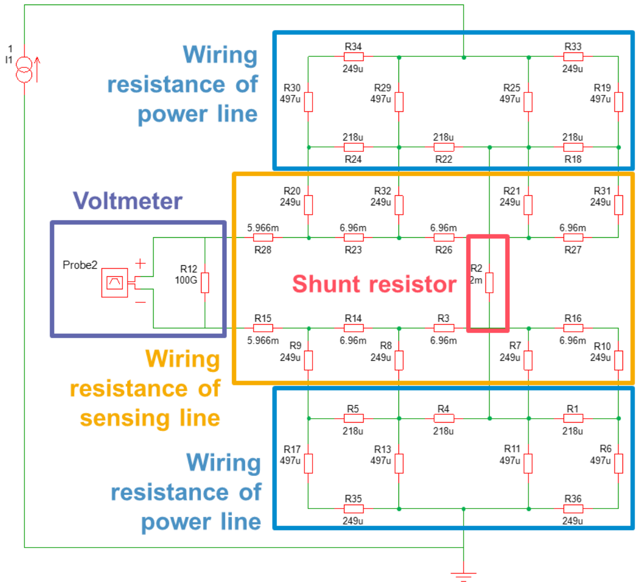


Figure 7. Circuit resistance network when one shunt resistor is mounted

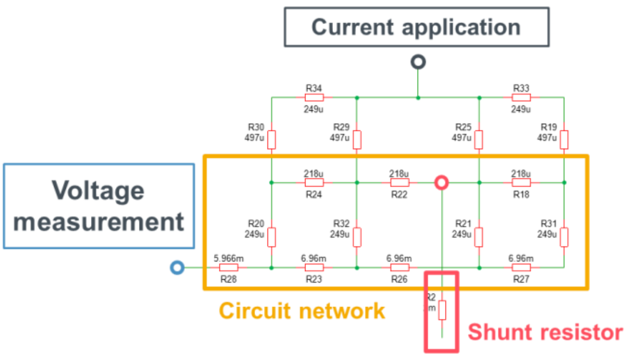


Figure 8. Sensing lines when one shunt resistor is mounted

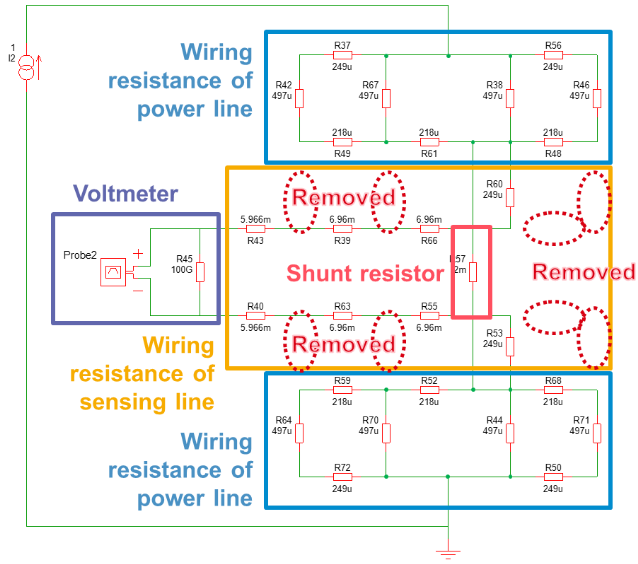


Figure 9. Circuit resistance network after modification of sensing lines

Verification of sensing precision

Use the evaluation board in Figure 4 shown in the previous section to measure the voltage drop when a current is actually applied to the shunt resistor and check the sensing precision. Figure 10 shows the evaluation board with a single shunt resistor (PMR100HZPFV2L00) mounted. As shown in Figure 11, current is applied with the (2) terminals and the voltage drop is measured with the (1) terminals. In Figure 12, the measured values of the voltage drop with applied currents of 5 A, 10 A, 15 A, and 20 A are plotted and compared with the theoretical values. The average resistor value calculated from the measured values is 2.36 mΩ, including the unnecessary resistance components of 0.36 mΩ (18%) relative to the specified resistor value of 2.00 mΩ for the mounted shunt resistor. This result shows that the sensing voltage includes not only the voltage drop in the shunt resistor mounted on the evaluation board, but also the voltage drop due to the unnecessary resistance components. As checked in the previous section, this error is caused due to the sensing lines being connected to several land patterns for parallel connection of shunt resistors.

Next, cut the patterns on the evaluation board at the positions indicated with red circles in Figure 13 so that the sensing lines are connected only inside the mounting pattern of the target shunt resistor, and then perform the same evaluation as described above. The patterns are cut at the sensing line positions to be connected with the land patterns for connecting shunt resistors in parallel. Figure 14 shows the result of the same evaluation using this board. The average resistor value calculated from the measurement results is 2.04 mΩ, indicating that the unnecessary resistance components are decreased to 0.04 mΩ (2%). As can be seen from this result, since the sensing lines are connected only inside the shunt resistor to be sensed, the measured values are closer to the theoretical values compared with the board without the pattern cutting.

Therefore, in addition to the simulation, the evaluation on actual equipment also shows that a high-precision measurement of the voltage drop in a shunt resistor is possible if the sensing lines are connected only inside the land patterns for mounting the shunt resistor to be sensed. However, if the sensing lines are connected with land patterns for parallel connection without mounted shunt resistors, it is confirmed that the board wiring forms a resistance circuit network on the sensing lines, causing an error in the sensing precision. If an actual PCB layout has land patterns for connecting shunt resistors in parallel, it is necessary to carefully consider the effects of the board wiring.

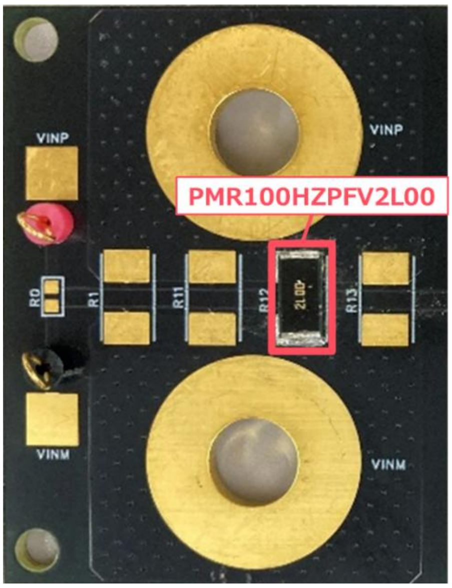
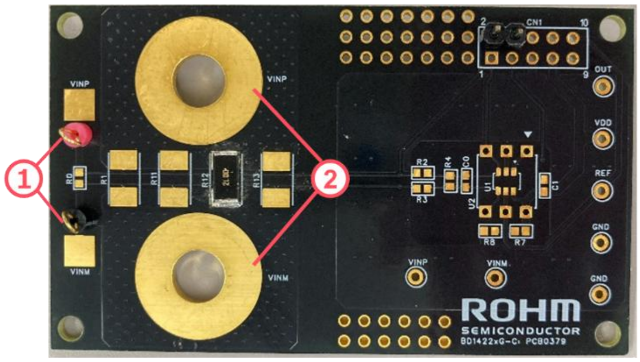


Figure 10. Mounting position of shunt resistor



(1) Voltage measurement (2) Current application

Figure 11. Measurement positions

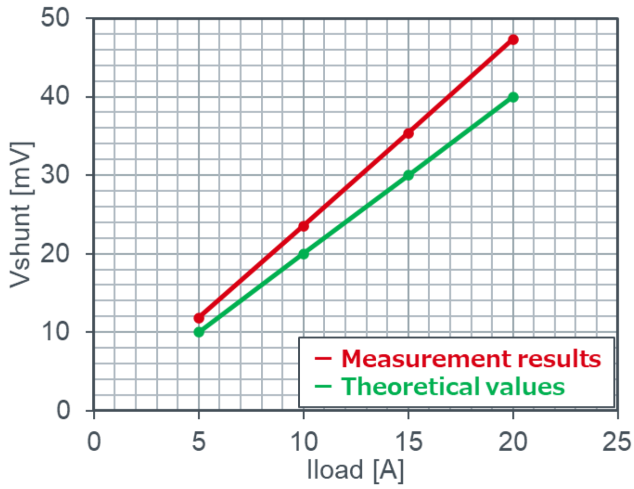


Figure 12. Sensing voltage [mV] vs. applied current [A]

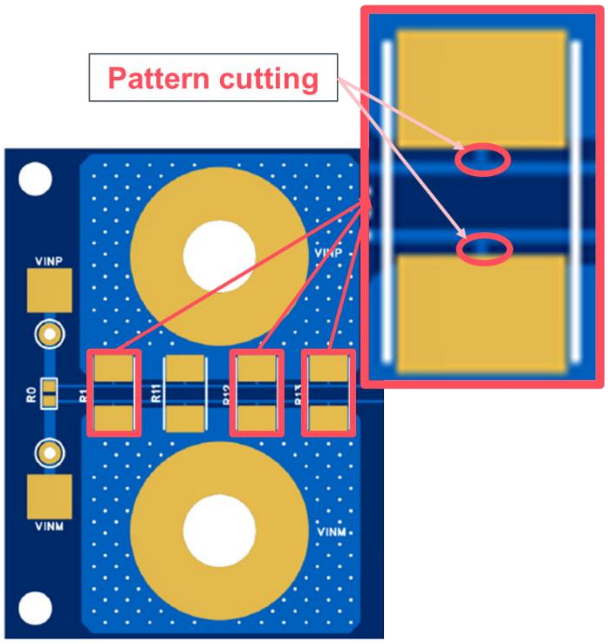


Figure 13. Positions of board pattern cutting

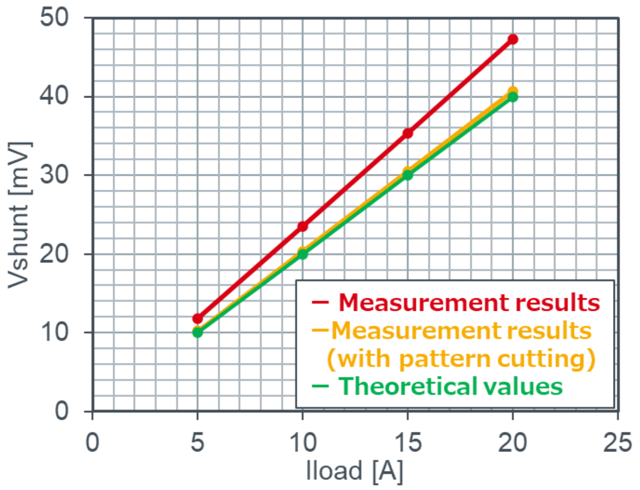


Figure 14. Comparison of measured Vshunt values before and after pattern cutting

Summary

To measure voltage drop in a low resistance component such as a shunt resistor, arrange the layout so that the sensing lines are connected inside the land patterns for mounting the shunt resistor in order to exclude the resistance components of copper foils and solders of the board wiring. Furthermore, position the sensing lines with great care when connecting shunt resistors in parallel. A commonly recommended method for positioning the sensing lines results in an error of 10% or more per shunt resistor.

References

[1] Application Note "Effect of PCB Design on Temperature Coefficient of Resistance", ROHM Co., Ltd.

[2] Application Note "Design of Low-Side Current Sensing Circuit", ROHM Co., Ltd.

[3] Application Note "Current Sensing Using Shunt Resistor Method: Design Guide", ROHM Co., Ltd.

[4] Application Note "Current Sensing Using Shunt Resistor Method: Evaluation of Heat Generation by Shunt Resistor", ROHM Co., Ltd.

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