TECHNICAL NOTE

Voltage Measurement Using Current Sensing Resistor

§0. Abstract

Generally speaking, a resistor of several mΩ or below is used in current sensing. In the voltage measurements using resistors of low resistance values, the voltage measurements can often be affected by the resistance of copper foil pattern and the temperature coefficient of resistance as well as by the current path and voltage measuring position used. The following is the design reminders in minimizing these effects.

§1. Effects of Resistance of Copper Foil Pattern and Temperature Coefficient of Resistance

The resistivity of copper foil used as pattern on a printed board is about 1.7 μ Ωcm. In the design of general electronic circuits, therefore, it is not necessary to pay particular attention to the resistance of copper foil pattern or the temperature coefficient of resistance. However, for the circuits that use resistors of several mΩ or below of resistance value, it is important to correctly grasp the effects of copper foil pattern and apply appropriate design.

Fig. 1 shows the simulation result of the influence of resistance of copper foil pattern. A copper foil pattern of a thickness of 35μm is placed in between the Center electrode and peripheral electrode. The voltage drop of the copper pattern when 1A is applied is shown in the right-hand side of Fig.1.

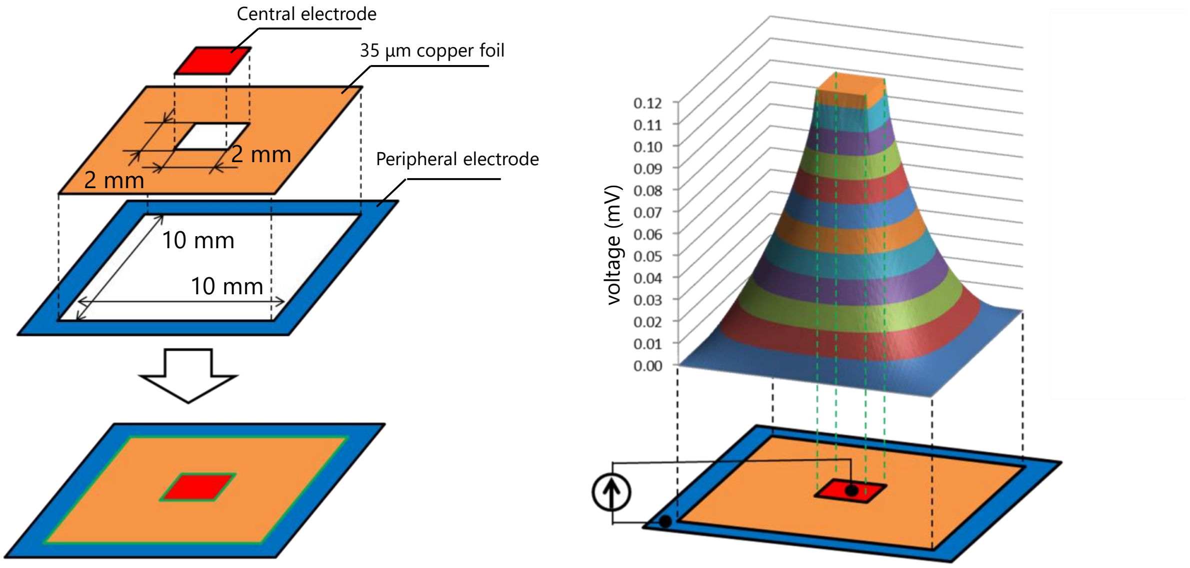


Fig. 1 Voltage drop of copper foil pattern

According to the right-hand side of Fig.1, there is a voltage drop of 0.12mV. Since the applied current is 1A, the resistance value of the copper foil pattern is 0.12 mΩ.
The resistance value of 0.12 mΩ of this copper foil pattern is equivalent to 12% of that of a resistor of 1 mΩ, for instance. The value is of a level significant enough that the effects cannot be ignored.
It is also necessary to take into consideration the effects of copper foil pattern on the temperature coefficient of resistance. The temperature coefficient of resistance of a current sensing resister is mostly 200ppm/K or below. In contrast to this, the temperature coefficient of resistance of copper foil pattern is as high as about 4000 ppm/K.
The influence from temperature coefficient of resistance of the copper foil pattern will be larger when the ratio of voltage drop of the copper foil pattern in the measured voltage becomes larger.
When a resistor with a resistance value of several mΩ or below is used, the effects of copper foil pattern must be taken into account in deciding on the voltage measuring position.

In measuring the voltage across a resistor, it is a general practice to employ a four-terminal (Kelvin) connection.

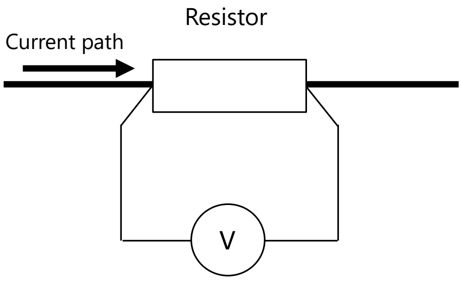


Fig. 2 Voltage measurement by 4-terminal (Kelvin) connection

In an ideal 4-terminal connection, the voltages at the connecting points between the current path and the resistor are measured, and thus the voltage across the resistor can be measured accurately without being affected by the effects voltage drop in the measuring system.
However, it is difficult to measure the voltage unaffected by the copper pattern because in reality, the copper foil pattern on the board and the resistor is connected by a plane. Additionally, accurate voltage measurement of both ends of the resistor will be obstructed because of the variation of amount of voltage drop depending on the path which the current flows into the resistor.Fig.3 shows a recommended current flowing and voltage measuring position when the resistor used is a Metal Plate Chip Type Low Resistance Resistor TLR.

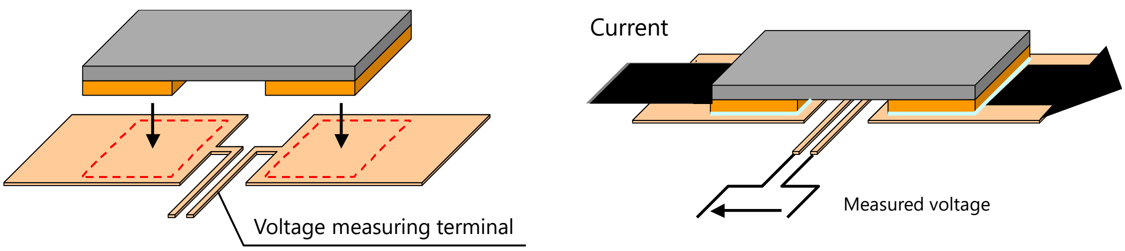
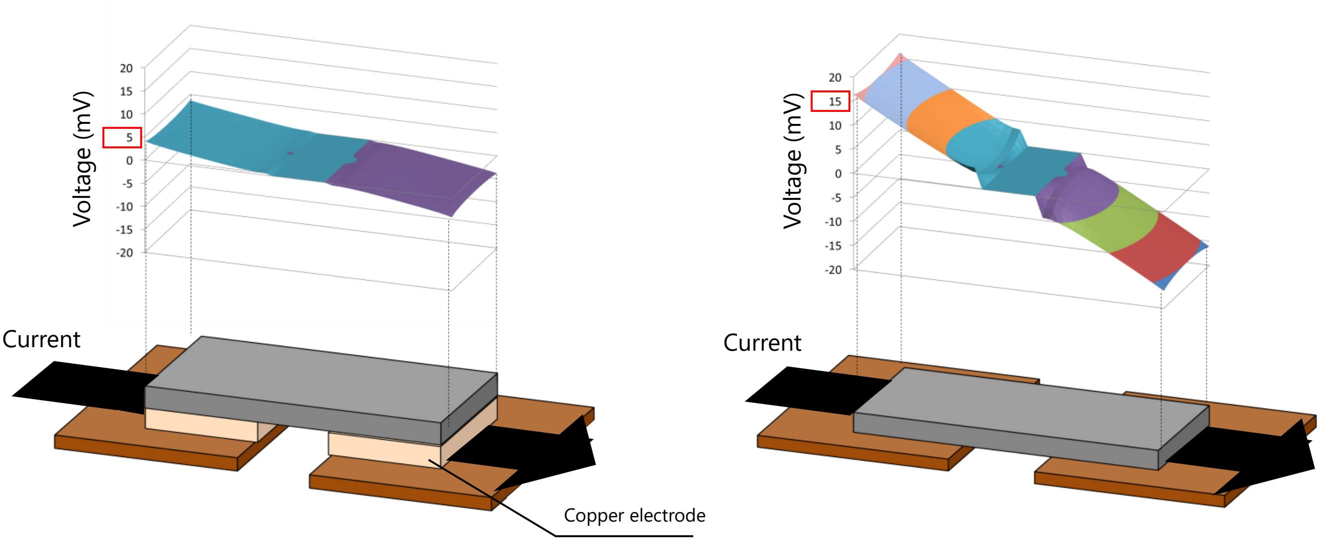


Fig. 3 Recommended current path and voltage measuring position

To minimize the effects of copper foil pattern, the resistor must be arranged such that the current passes straightly, and the voltage measuring position must be located at the midportion inside the component-mounting land.
it is necessary to comprehend the cause of the increasing effects of copper foil pattern and then design so as to reduce the influence as small as possible. The following are the points to note in carrying out such a design.

§2. Effects of Electrodes of Current Sensing Resistor

The existence of the electrode of current sensing resistors have great influence to the error of the measured voltage.
Fig. 4 shows the results of a simulation of voltage drop in the electrode part. In the case of (a), the resistor is 6332 size TLR, 1 mΩ, and the copper foil pattern is 35 μm thick. It can seen that the TLR is reducing the voltage drop in the electrode part by introducing the copper electrode.



(a) With copper electrode (TLR)

(b) Without copper electrode

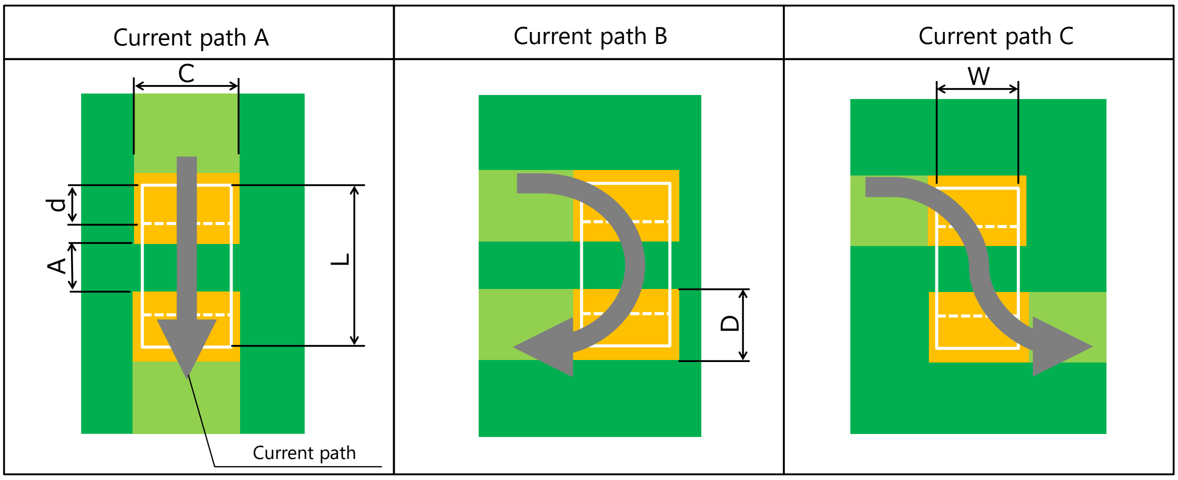
Fig.4 Difference in voltage drop from the existence of copper electrode

In this manner, use of a resistor with copper electrodes can reduce the errors in measured voltage. KOA's current sensing resistors are mostly provided with copper electrodes, thus reducing the effects of voltage drop. However, attention must be paid to the fact that the reduction in voltage drop can vary with the thickness of copper electrodes and the resistance value of the resistor.

§3. Effects of Current Path and Voltage Measuring Position

The effect of copper foil pattern will be strengthened when the current path is not straight even if the voltage measurement position is located inside and center part of the component mounting pad.
The error of the measured voltage and the difference of the temperature coefficient of resistance will be explained for the following three examples: current flows through the resistor in a straight line (Current direction A), current enters the resistor from the right-angle and flows out in the same direction (Current direction B) and current enters the resistor from the right-angle and flows out in the opposite direction (Current direction C).

Fig. 5 shows the simulation models. The current sensing resistors used were TLR3AP of 0.5 m, 1 mΩ, 5 mΩ, 10 mΩ, respectively. It is to be noted that TLR3AP has different external dimensions according to the resistance value. And therefore the differences in external dimensions are reflected in the simulation models. Also, the copper foil pattern used was 70μm thick, and the temperature coefficient of resistance of the resistor was 0ppm/K.



(mm)

		L	W	d	A	C	D
TLR3AP 	0.5mΩ	6.35	3.18	2.275	0.8	3.83	3.375
	1mΩ			2.2	1.45		3.05
	5mΩ			1.2	3.45		2.05
	10mΩ			0.77	4.4		1,575

Fig. 5 Simulation models

When the voltage measuring position is shifted to the left and right from the center (X=0 mm) of the resistor as in Fig. 6, the errors in measured voltage are as shown in Fig. 7, and the temperature coefficients of resistance are as shown in Fig. 8

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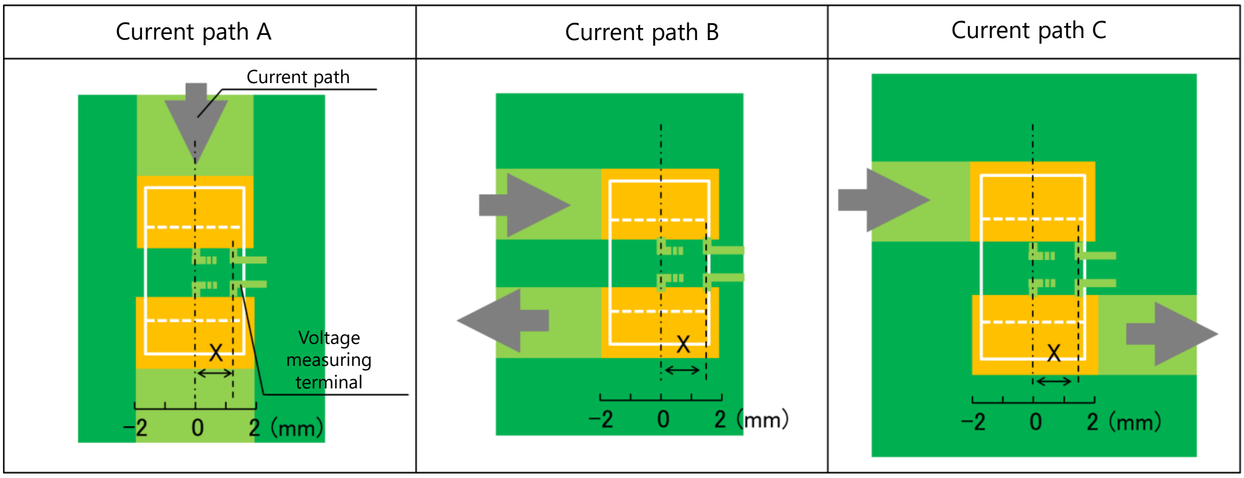

Fig. 6 Voltage measuring position

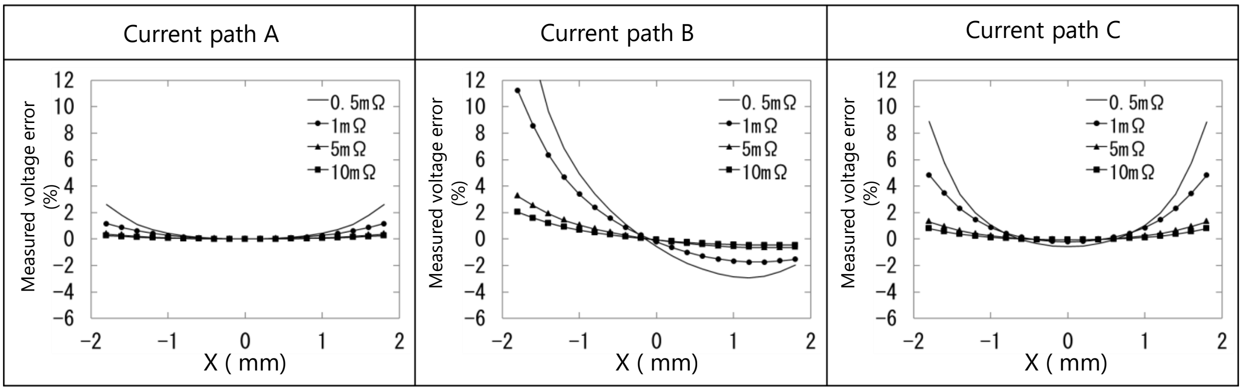

Fig. 7 Changes in Measured voltage error relative to current path and voltage measuring position

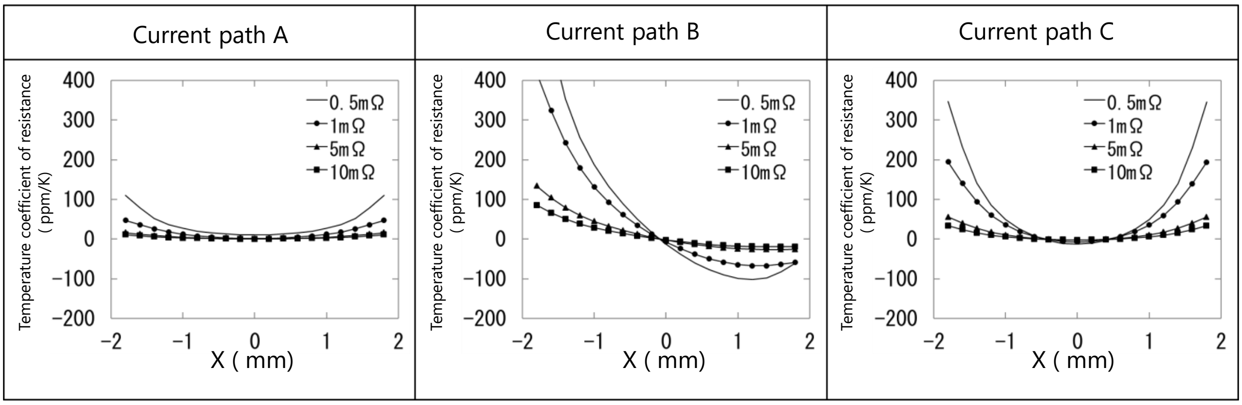

Fig. 8 Temperature coefficient of resistance relative to current path and voltage measuring position

The influence of the copper foil pattern increases as the resistance value of the resistor becomes lower for all three current paths.
It can be seen that the effects of voltage measuring position vary with the current path. For current path A, the error in measured voltage and the temperature coefficient of resistance become minimum when the voltage measuring position is X=0 mm, and more significant effects of copper foil pattern are seen when the voltage measuring position is farther away from X=0 mm. For current path B, the effects of copper foil pattern vary greatly depending on whether the voltage measuring position is on the right or left, and the effects become minimum not at X=0 mm but in a position shifted to the left. For current path C, the effects become minimum when the voltage measuring position is in positions shifted to the right and left from X=0 mm.
Therefore, for current paths B and C, the effects of copper foil pattern are far greater than those for current path A, when the connecting points of voltage measuring terminals are away from the optimum point.
From the above observation, design is recommended such that an optimum voltage measuring position be selected using a simulation when the current path is not straight.

§4. Influence of position gap in mounting process

There are cases where the effects of voltage drop in copper foil pattern increase due to manufacturing errors of the PC board or dislocation of mounting positions even when the current path or the connecting positions of voltage measuring terminals are designed properly.

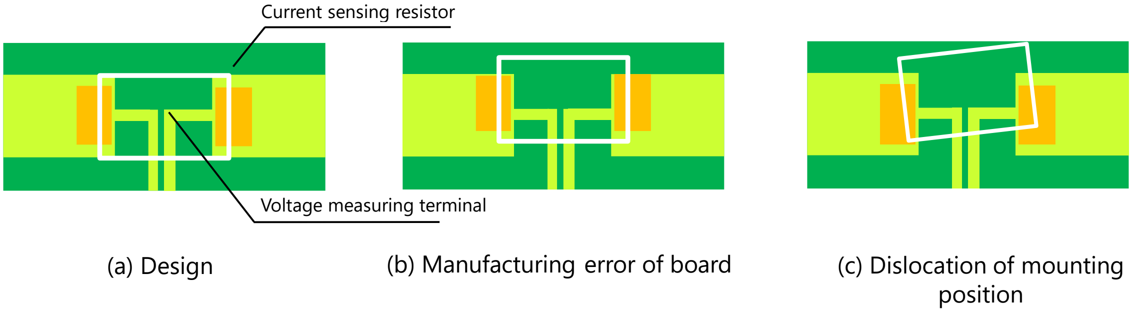

Fig. 9 Errors in connecting position of voltage measuring terminal away from design

The manufacturing errors of the board are mainly relative to the positioning accuracy of solder resists. And the dislocation of mounting positions depends mainly on the accuracy of the component mounting machine. The smaller the size of the resistor, the greater the effects of these errors will be on the accuracy of measured voltage. Therefore, in selecting the resistor size, attention must be paid not only to the power rating but to the manufacturing accuracy of the printed board and the accuracy of the component mounting machine.

§5. Conclusion

It is necessary to take care of the following notes when the voltage is measured by a current sensing resistor with resistance value lower than few mΩ.

The current path for a resistor should be designed as straightly as possible. The position of the voltage measuring terminal should be in the middle position inside the component-mounting land when the current path is straight or otherwise in a position that minimizes the measured voltage error and the temperature coefficient of resistance.
If the current path and the voltage measuring position cannot be optimized, it is advised that a resistor provided with copper electrodes at the terminals is used.
The effects of errors in measured voltage and the temperature coefficient of resistance of copper foil pattern are reduced for higher resistance values of resistors. Therefore, it is recommended that a higher resistance value is selected so long as power consumption is permissible.
In selecting the size of the resistor, attention must be paid not only to the power rating but also to the manufacturing accuracy of the printed board and the accuracy of the component mounting machine.

It is also necessary to consider the parasitic inductance when the change of the current is fast.
For notes on the effects of parasitic inductance, please refer to our Technical Note : "Effects of Parasitic Inductance of Current Sensing Resistor".

It is effective to use simulation for defining the optimum connection position of the voltage measurement terminal. If there are any request of review or suggestion, please send us the design information such as pattern chart, copper foil pattern and thickness for verification.