Power Efficiency Improvement for Low Ohm Current Sense Resistor by Optimum Thermal Management

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Abstract

To improve power efficiency, design engineers need to detect current throughout the circuit to minimize power loss. Low ohm current sense resistors are used to detect current to measure and monitor power. These components need to handle higher power to achieve optimal performance. In this work, we extensively studied to improve the power handling capability of low ohm current sense resistors, while maintaining smaller size. We optimized power dissipation by applying innovative thermal management techniques. Employing novel packaging technique, we optimized heat dispersion and minimized the peak surface temperature rise. Using proprietary thermal protection material, we avoided direct heat transfer from component to PC board and minimize the risk of thermal damage against PCB and extreme thermal cycle. We extensively discussed the thermal fatigue of resistor termination structure. Solid metal package construction leads to solder cracks due to thermal fatigue, hence decreases resistor reliability. We improved the packaging footprint and significantly reduced the chance of solder cracking. We optimized the resistor structure for current sensing and shunting purpose. We laid out electrodes and termination in parallel and minimized the contact resistance. Considering these parameters, we manufactured low ohm current sense resistor of 0.5 milli ohm to 100 milli ohm values with up to 5W rated power with tolerance as low as 0.5%.

Introduction:

Current sensing is one of the essential functions for any circuit that needs to monitor the current. Conventional current sensing methods insert a resistor in the path of the current to be sensed. Due to the resistor's presence in the circuit path, there is a voltage drop across the resistor. A control circuitry detects this voltage drop and measures the current through the path. It is very important to minimize the power consumption by the current sense resistor, so maximum power can be delivered to other part of the circuit. Therefore, the resistor needs to be very low resistance value, in the order of less than 10 mΩ. Accurately sensing current is very important to lot of electrical systems. As sensing current can help effectively provide current for the system's functions, and reduce unnecessary power consumption. Therefore this current sense low ohm resistors needs to have capability to handle high power and in rush current. Several research works have been done on increasing power handling capability in smaller size low ohm current sense resistors. A current sensing principle that exploits copper trace was discussed in [1]. High gain amplification can be achieved by considering low side current sense resistor [2]. Several advanced current sensing techniques for power electronic converters were explored [3]. In this work, we studied how to improve the power handling capability of low ohm current sense resistor while keeping the size smaller. We investigated how to manage the power efficiently, so power handling capability can be improved. One of the eminent reasons of resistors failure, due to high power, is not being able to keep surface temperature below the level where permanent damage can occur to the component. We analyzed how to remove the heat as the component's surface temperature increases. We explored techniques on efficiently heat dissipation through the resistors. We discussed several innovative ways to efficiently remove heat from the component surface, resulting lowering peak surface temperature. We improved heat transfer rate and prevented thermal fatigue of the termination electrodes. Then we applied these efficient heat removal techniques for low ohm current sense resistors. We tested conventional and our new current sense resistor products for thermal fatigue and power handling capability. The results suggest that the new current sense resistor significantly outperforms conventional resistor in both tests. We also reduced unwanted resistor from electrodes and termination by laying out materials in parallel compare to ordinary surface mount wrap around resistor's construction technique. As the resistance value is intended to be very low, new construction technique helps keep the resistor value with higher tolerance level. Illustrated pictures clearly demonstrate the effectiveness of new construction technique. We kept the product very low profile and cost effective.

Heat dispersion:

The biggest challenge to improve power efficiency in chip resistor is effective heat removal. As the power gets increased, the product gets extremely hot and starts to degrade its performance. Excessive generated heat can change the resistor value during hot temperature. If the power resistor is extremely hot for a longer period of time, the heat can cause irreversible change in the resistor product. Resistors eventually start entering in the failure mode and finally quit performing. Therefore, efficient thermal dispersion is very important for the integrity of the product.

Generally heat removes through three different ways from the resistor. One is gradual radiation to the air through the surface material and cover. Another way is by conduction through the circuit board from which heat is removed from the larger area of the board, ultimately by convection. The third way is through land pattern then through substrate and finally through the termination. Figure 1 shows three different ways of heat removal from chip resistor.

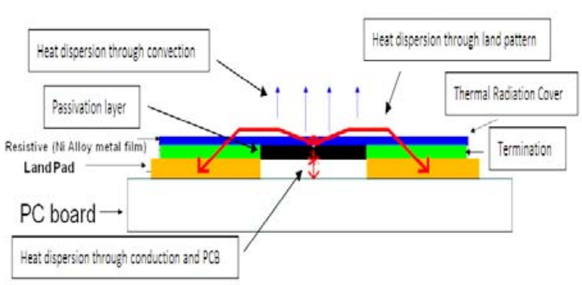

Figure 1. Heat dispersion ways from chip resistor

Out of three ways, heat dispersion through conduction to PCB significantly increases the temperature of PCB. This excessive heat damages the circuit board. If the heat stays there for long period of time, then it can cause permanent damage to the board. We created a passivation layer in between the resistive material layer and the air pocket. Figure 1 shows the passivation layer's existence. This layer prevents any heat going through the PCB. Therefore, heat can only removes from the top of the resistor and through the termination. This way we created dual thermal paths and blocked any heat escape through the PCB. Consequentially, we minimized the risk of any permanent thermal damage against PC board due to extreme thermal cycle.

Current density improvement:

The dominant form of resistor damage is occurred while peak surface temperature rise in certain level. Generally surface temperature is not uniform throughout the surface. Due to the different pattern of the resistive material, temperature is different at different spots of the surface. Some part of the surface can experience very low heat while other part can experience significantly higher heat. To prevent resistor from damaging by overheating, it is recommended to specify the power handling capability of the resistor in a very conservative way. However, if the resistor surface temperature can be distributed uniformly then the whole surface experiences similar temperature rise; therefore the product does not need to depend on one single spot. We significantly enlarged the resistive material area in the chip to uniformly distribute the heat in all part of the resistor. As a result, we eliminated one single point of heat transfer. Using distinctive thin film sputtering process, we maximized the resistive portion of the component, therefore resistive material is distributed uniformly throughout the product. Consequently, heat is removed throughout the product instead on one single point.

Thermal fatigue prevention:

We studied to improve the heat transfer rate through the component termination footprint. We realized that the faster the heat can transfer from the electrodes, the less time the heat has to keep the electrodes hot. If the heat cannot move faster through the electrodes and more heat is generating in the chip resistor, then the electrodes keep getting hotter. As the temperature rise, at some point the surface temperature could exceed the melting point of the mounting solder and potentially makes a crack in the solder joint. This phenomenon can potentially causes irreversible changes in resistance – as well as potential damage to the printed circuit board. This significantly decreases the reliability of the resistor. Moreover, as the temperature rises and falls in the board and resistors termination material, both experience physical expansion and contraction. If the expansion and contraction rate is different for board material and termination material then it also makes crack in the solder joint.

We significantly improved the rate of heat transfer through the termination electrodes. We minimized the existence of heat in the termination material. Heat flows efficiently from the resistor to the board as the product gets hot. We also used termination material that has similar value of coefficient of thermal expansion (C.T.E) as the circuit board. Consequentially, temperature change in same rate for printed circuit board and the resistor termination material. As a result, due to presence of heat, PCB and resistor termination expands and contracts in same rate. Hence it minimizes the probability of solder joint crack. As PCB, we considered FR4, as it is mostly used in the industry.

Figure 2 illustrates the result of material expansion and contraction due to thermal fatigue. It illustrates that excessive heat can make the temperature rise more than the melting point of mounting solder and different rate of expansion and contraction of the PCB and termination material can make a crack in the resistor joint. As a result the product can enter into failure more.

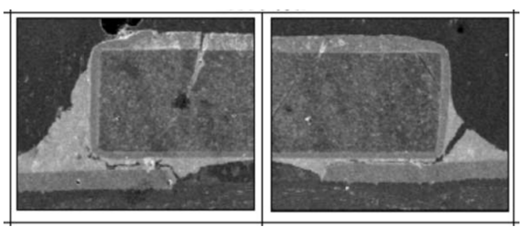

Fig 2 a. Conventional power resistor after 1000 cycle

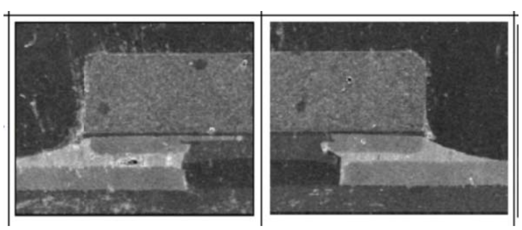

Fig 2 b. TFT power chip resistor after 1000 cycle

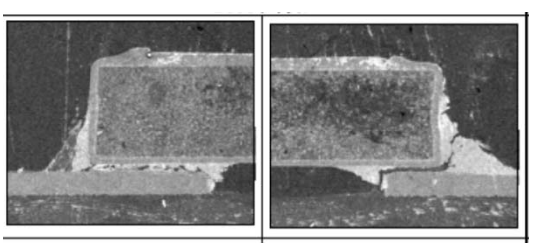

Fig 2 c. Conventional power resistor after 2000 cycle

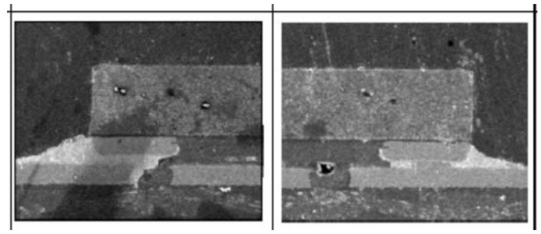

Fig 2 d. TFT power chip resistor after 2000 cycle

Figure 2a and Figure2c represent conventional chip resistor where heat transfer rate and thermal fatigue is ordinary. It shows the effect of thermal fatigue, which make cracks in the solder joint and failed the long life reliability test. Figure 2b and Figure 2d represents our new improved chip resistor, where heat transfer rate is optimized and termination material C.T.E is kept very close to the PCB's C.T.E. This figure demonstrates that for exact same heat, generated from applied power, there is no change in the solder joint. As a result, no damage is done in the chip resistor. This result shows the robust package of our new improved chip resistor prevents solder joint cracks and improved long life and reliability characteristics. For this test, we used thermal shock cycles. Test condition was -55˚ temperature applied for 30 min , followed by room temperature applied for 3min followed by +155°C applied for 30min, followed by room temperature applied for 3min, repeating to 1000 cycles and 2000 cycles on FR4 0.6mm thickness PC board.

Thermal profile comparison:

After implementing the several innovative techniques to efficiently remove heat from the resistor we made the product very robust to handle excessive power while keeping the temperature significantly low. After the theoretical analysis, we fabricated the low ohm current sense chip resistor. Then we compared the temperature differences between conventional low ohm current sense chip resistor and our new current sense chip resistor. We have applied 1 Watt power to 2512 size low ohm current sense resistor.

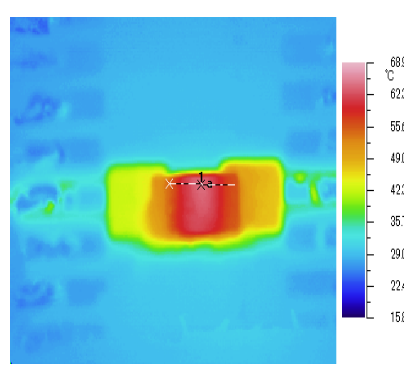

Fig 3a. Thermal profile of new low ohm resistor

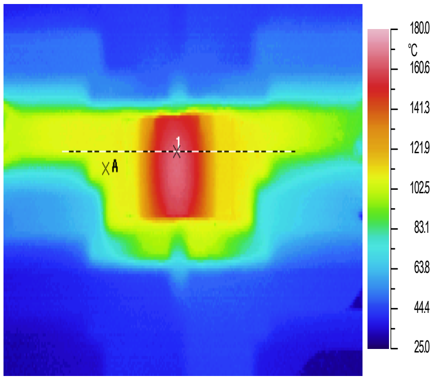

Fig 3b. Thermal profile of standard low ohm resistor

Figure 3a and Figure 3b illustrate surface temperature thermal profile of new current sense resistor and conventional current sense resistor respectively.

Figure 3 demonstrates that for 1 watt applied power, surface temperature of the new resistor rose to 63.8˚C, while surface temperature of conventional resistor rose to 164.1˚C. Moreover, surface temperature of PCB with conventional current sense resistor rose much higher than new resistor. PCB surface temperature with new resistor rose to 44.0˚C, while PCB surface temperature with conventional resistor rose to 107.1˚C. We also measured that thermal resistance for new low ohm current sense resistor is 19˚C/Watt, and for conventional resistor it is 57˚C/Watt. These figures exhibit that the temperature rises significantly with conventional low ohm current sense resistor while in new improved resistor it is very low. As a result, power handling capability of new resistor is appreciably improved.

Conclusion:

In this work, we studied low ohm current sense resistors and importance of power handling capability of the resistor. We explored several innovative techniques to improve power handling capability of the resistor. We investigated different novel approach to efficiently remove heat from the resistor surface, resulting minimizing peak surface temperature to a level that will not cause resistor to enter in failure mode. We removed the heat by efficiently dual thermal dispersion technique, uniformly distributed the heat around the chip surface area and improving thermal resistivity. By enhancing packaging technology, we improved the thermal fatigue characteristics of the resistor, resulting increased long life and reliability of the product. By showing thermal profile comparison with conventional low ohm current sense resistor, we demonstrated the outstanding power handling capability of our new low ohm resistor. Finally we showed the new laying out technique and equivalent resistor circuit of our product. By laying out the resistor material, electrodes and termination in parallel, we eliminated unwanted resistor and improved resistor tolerance of the new low ohm current sense resistor product

References:

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