CARTS USA 2011 Presentation

Power Efficiency Improvement for Low Ohm Current Sense Resistor

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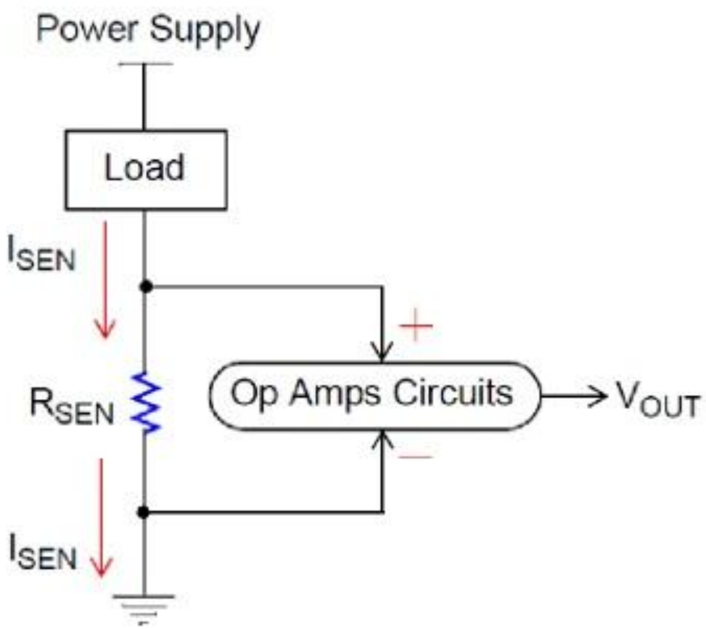
Outline

- *Motivation*
- *Review of Current Sense technique in the system*
- *Applied techniques to enhance power handling capability*
- *Result of enhance power handling capability from manufactured product test data*
- *Product improvement to prevent failure due to thermal fatigue*
- *Product specification improvement with unique construction*
- *Power efficiency improvement while detecting current with enhanced package layout technique*
- *Summary and conclusion*
- *Acknowledgement and Future work*

Motivation

- Power efficiency is becoming significantly important in present day’s system design
- To minimize power loss, “Current” needs to be measured and monitored accurately throughout the system
- Typically current sense resistor is used to detect the current
- These current sense resistors need to be very low ohm value with higher rated power
- Research is done to improve power handling capability without size increment
- Increased product efficiency with unique package layout

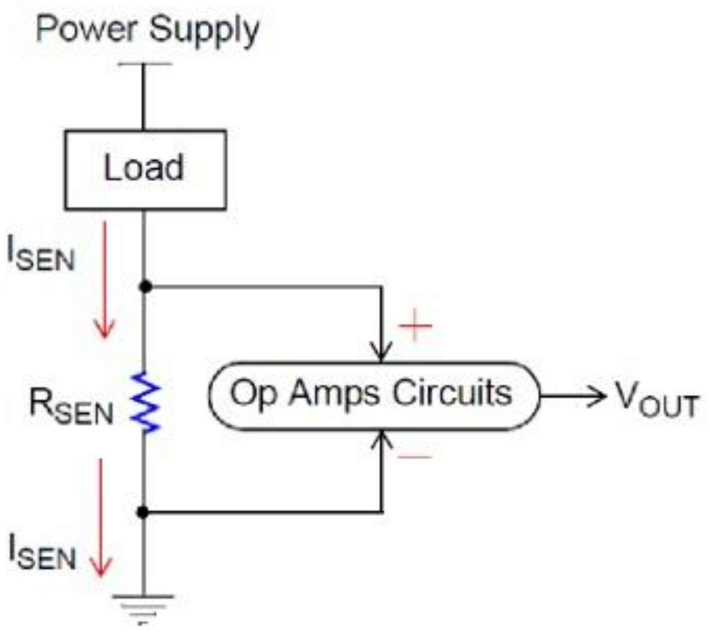
Review: Current Sense Technique



Low Side current sensing technique

- Voltage drop across R_{SEN} is amplified with Diff. Amp
- Vout is measured as detection of Current through the Load
- From Vout result, applied power can be controlled for the Load

Necessary Improvement



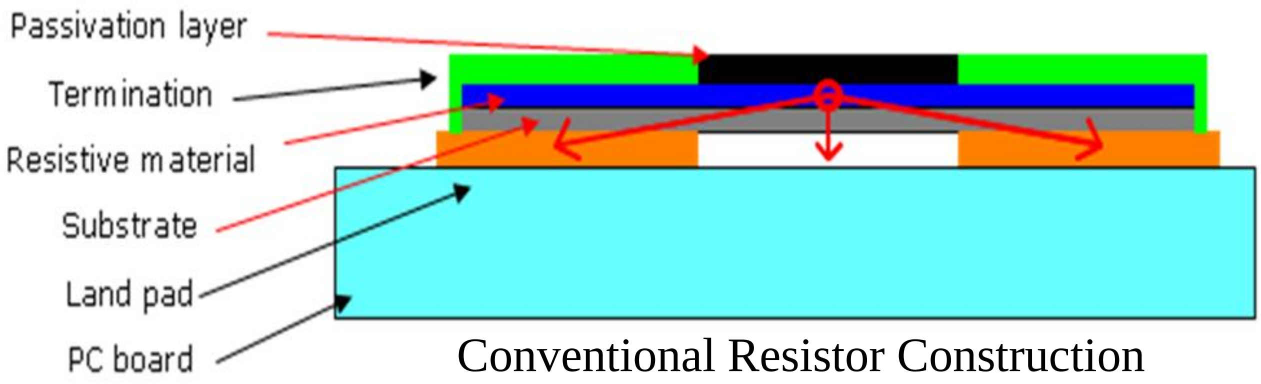
Low Side current sensing technique

- ❑ Current sense resistor parameters
  - ❑ Low ohmic value
  - ❑ Enhance power handling capability
- ❑ Other resistor parameters
  - ❑ Tighter tolerance
  - ❑ Lower TCR value
  - ❑ Lower ESL value
  - ❑ Smaller size
  - ❑ Cost effective

Enhance Power Handling Capability

- Higher applied power generate higher temperature
  - Electro migration phenomenon takes place
  - Make crack in the resistor material on the substrate
  - Resistor value goes up, Resistor opens up
  - Long time Excessive heat can cause irreversible damage to resistor product
  - Component Reliability gets significantly reduced
- Thermal Management
  - Must reduce excess heat from resistor
  - Can not let the generated heat stay in the resistive material for prolonged period of time
- Biggest challenge to enhance power handling capability is to efficiently disperse generated heat

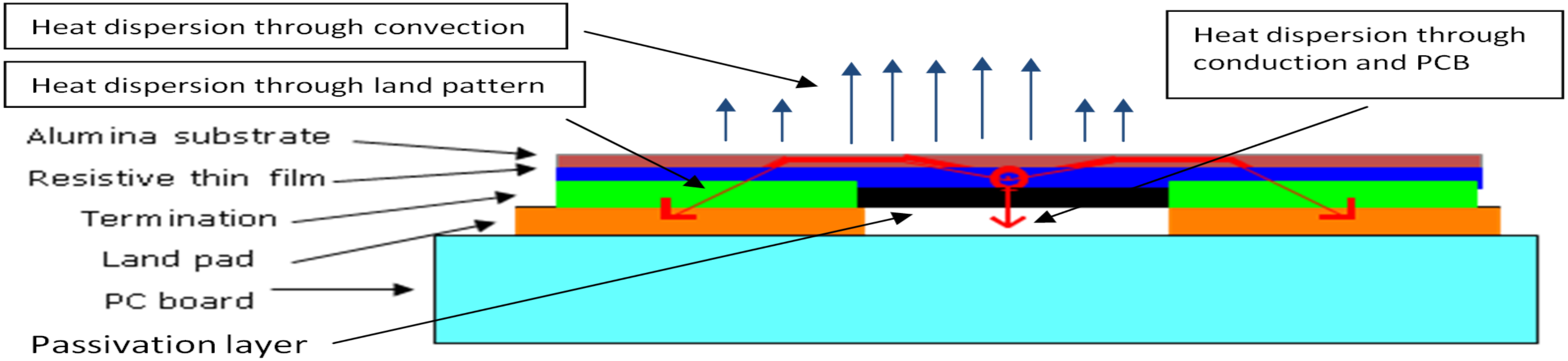
Enhance Power Handling Capability



Conventional Resistor Construction

- Heat Dispersion from resistor product
  - Conduction through the circuit board, ultimately by convection from circuit board
  - Through pattern then substrate then through land pad termination to circuit board
  - Gradual radiation to air through surface material and cover

Enhance Power Handling Capability



New Resistor Construction

- Improved Heat Dispersion
  - Changed the construction
  - Passivation is at the bottom side,
    - No direct heat transfer to the PCB
    - No heat dissipation through PCB
    - Minimizing risk of permanent thermal damage to PCB

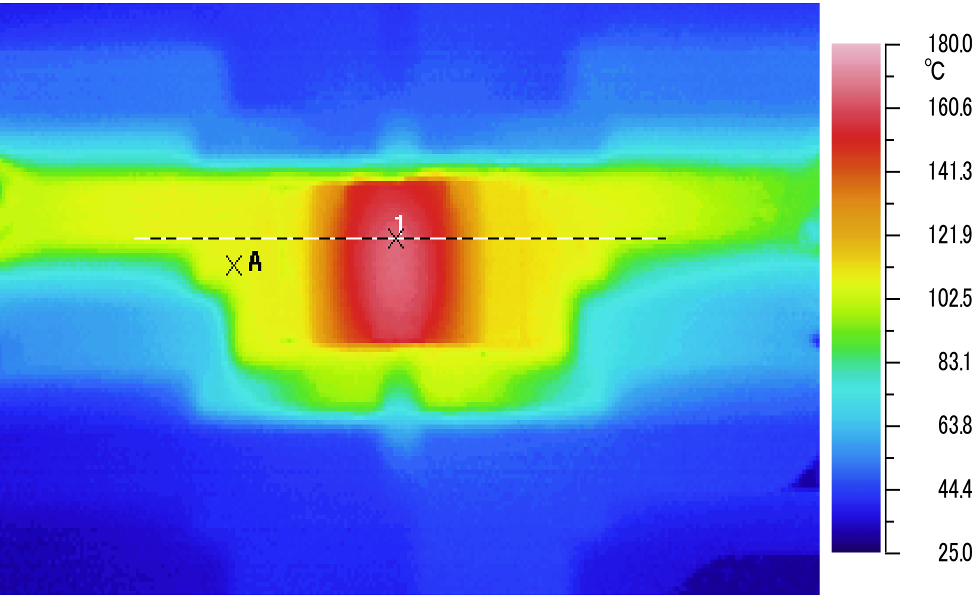
Enhance Power Handling Capability

- Uniform Heat Distribution
  - Resistive area as big as possible
  - Eliminated one peak surface temperature
  - Surface temperature is uniformly distributed
  - Power specification does not need to depend on one single hot spot
- Improve Current Density
  - Maximum current density – Maximum tolerated current per unit of cross sectional area
  - Used NiCr as resistive material; NiCr has high current density limit
  - Bigger resistive area also improves current density
  - Reduced electro migration effect

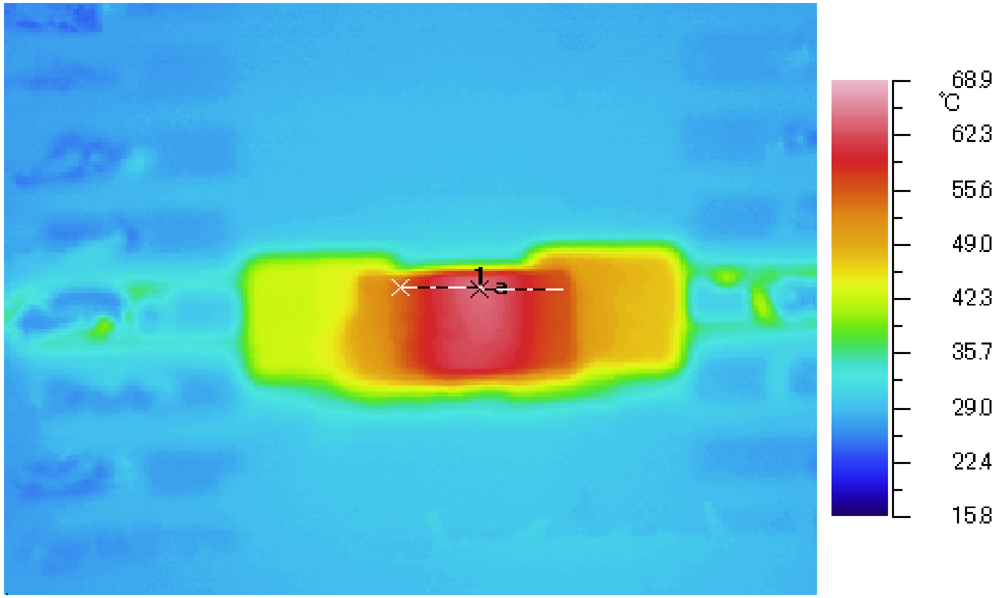
Enhance Power Handling Capability

- Improve Heat transfer rate through Footprint
  - Lowered thermal resistance interface from resistor to circuit board
  - NiCr is deposited directly to substrate, resulting less thermal resistance between material and substrate
  - Maximized termination electrode's size
  - Used high purity, high thermal conductivity material for terminal footprint
  - Special design is considered to ensure balance distribution of generated heat
  - Improved heat transfer rate through the termination material
  - Used AlN as substrate for better thermal properties

Thermal Profile Comparison and Result



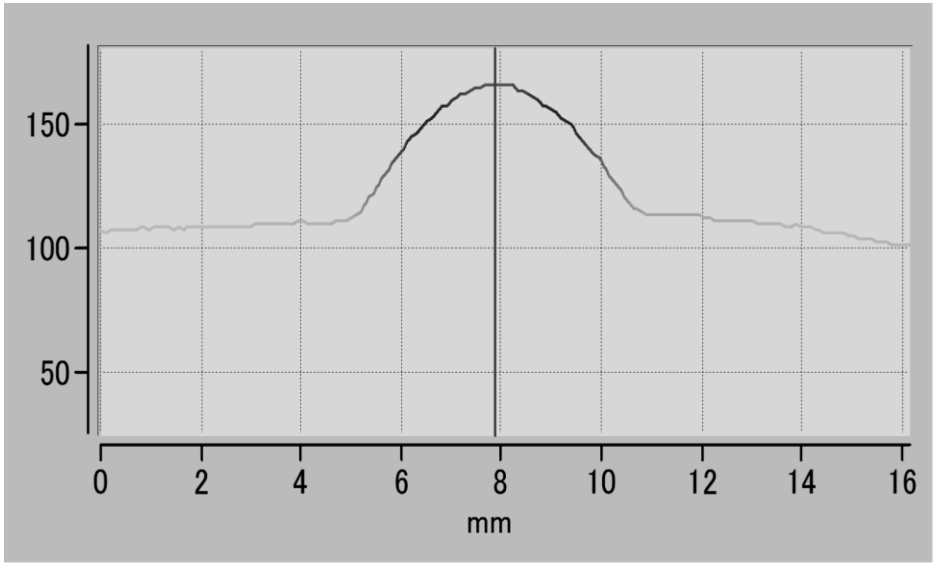
Conventional Resistor



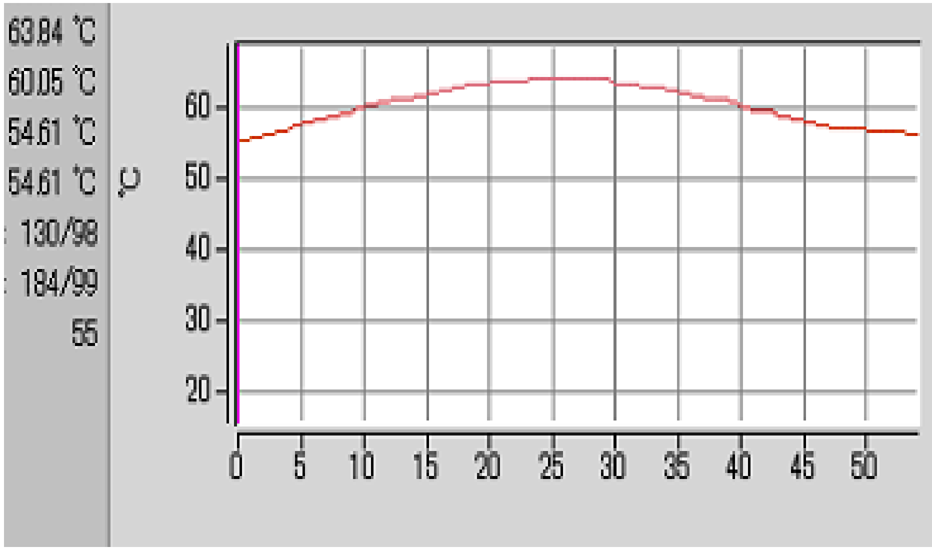
New Resistor

- Surface temperature result and thermal profile
- Condition : Power = 1Watt, Chip size = 2512, Resistor value = 3 mΩ
- Convention Resistor Temperature: Res. = 165˚C; Termination = 107˚C; PCB = 75˚C
- New Resistor Temperature: Res. = 65˚C; Termination = 44˚C; PCB = 31˚C
- Thermal Resistivity : Conventional Res. = 57˚C/Watt; New Res. = 19˚C/Watt

Thermal Profile Comparison and Result



Conventional Resistor



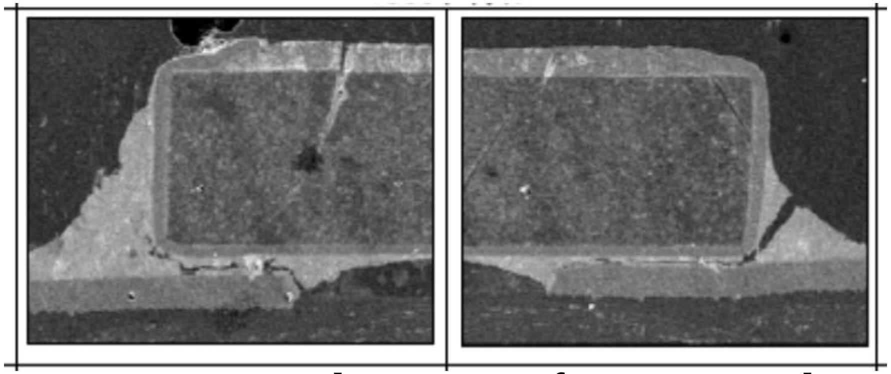
New Resistor

- Surface temperature of esistor and PCB
- Less temperature variation from resistor and PCB
- Convention Res. = 50˚ C temp. difference for 4 mm distance from the resistor
- New Res. = 10˚ C temp. difference for 25 mm distance from the resistor

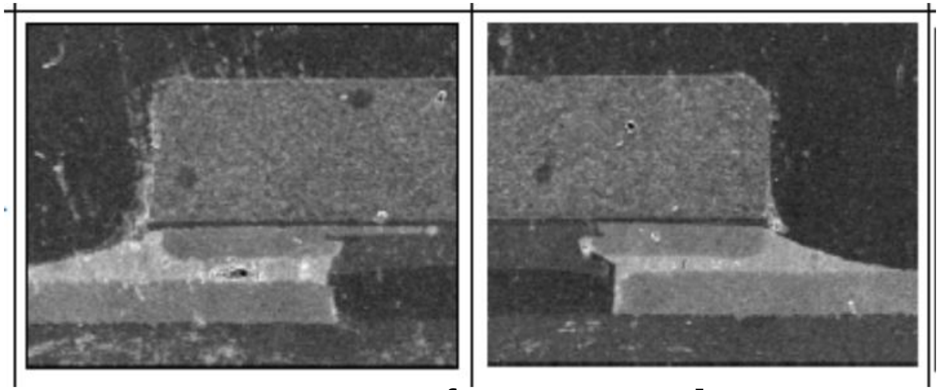
Reduce Thermal Fatigue

- Thermal Fatigue
  - High temperature can exceed melting point of mounting solder
  - It can potentially create crack in the solder joint
    - Causes irreversible damage to resistor, Changes resistor value
    - Decreasing resistor reliability, Potential damage to PCB
  - Depending on the applied power, temperature rise and fall
    - PCB and Resistor expands and contracts
    - Different expansion and contraction rate of both material can make crack in solder joint
- Reduced Thermal Fatigue
  - Used termination material with similar CTE value as PCB
  - Termination electrodes and PCB expands and contracts in same rate

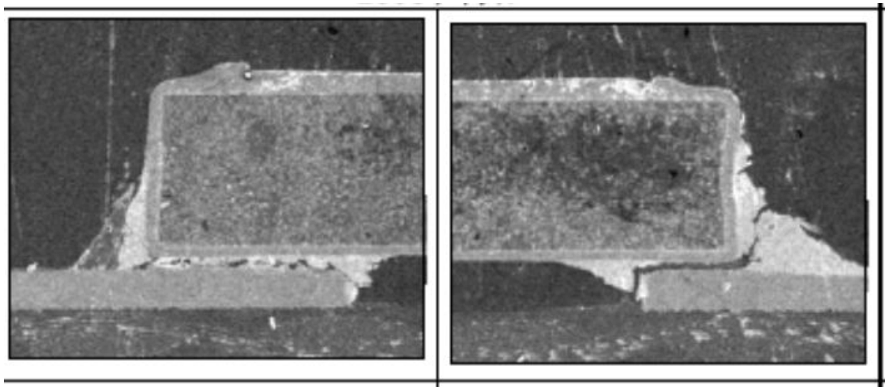
Reduce Thermal Fatigue



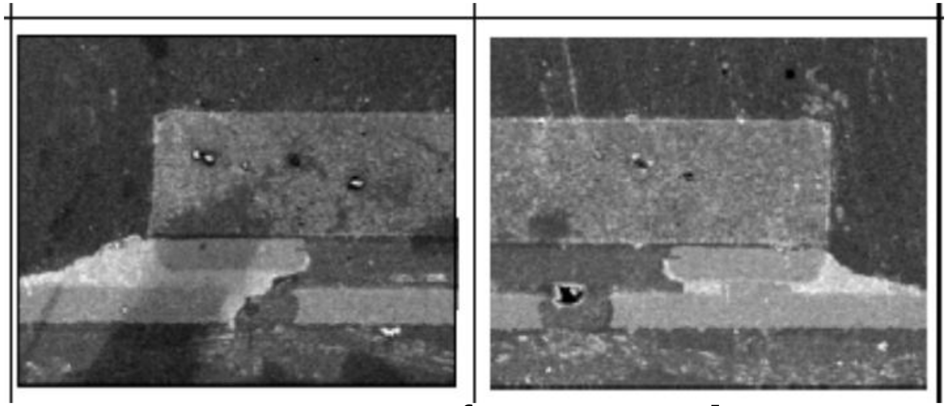
Conventional Resistor after 1000 cycle



New Resistor after 1000 cycle



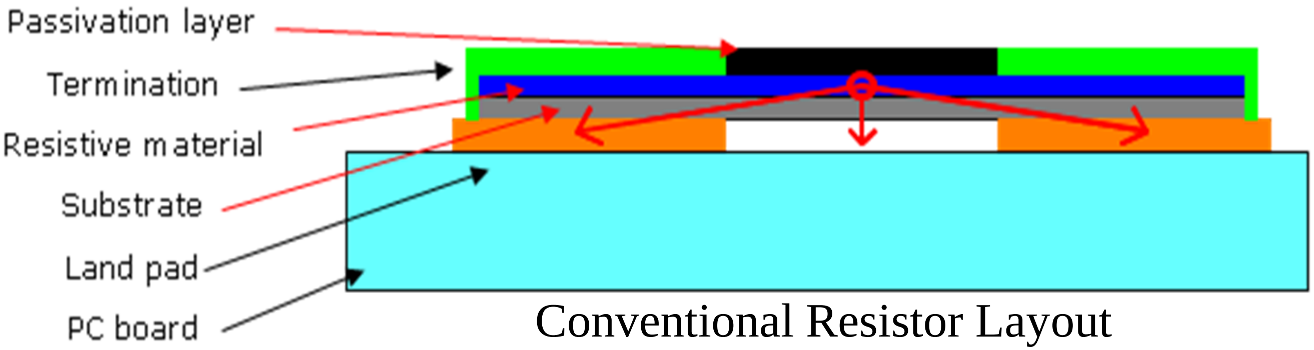
Conventional Resistor after 2000 cycle



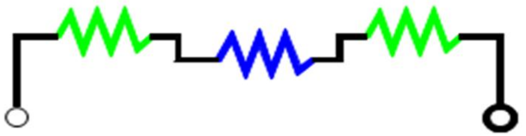
New Resistor after 2000 cycle

- ❑ Thermal Fatigue result phenomenon comparison
- ❑ Condition = +155˚C for 30 min, Room temp for 3 min, -55˚ for 30 min

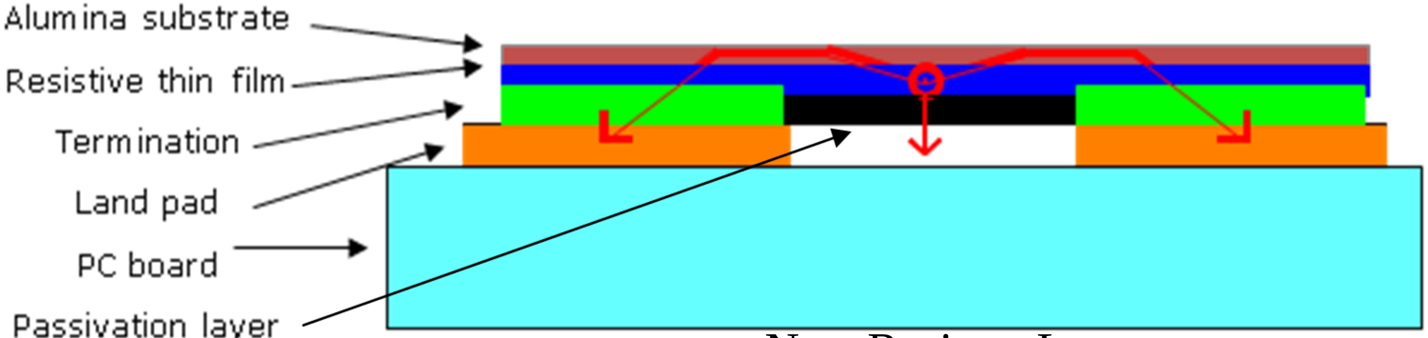
Efficient Resistor Construction



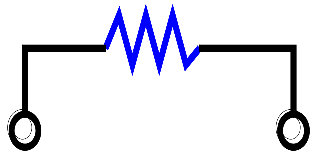
Conventional Resistor Layout



Equivalent Resistor Value



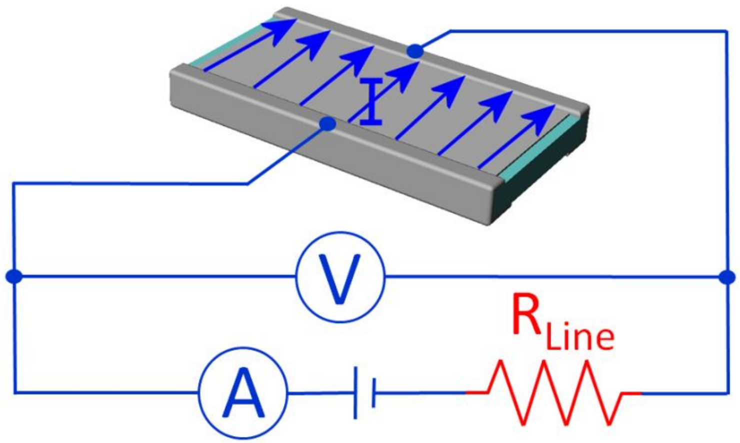
New Resistor Layout



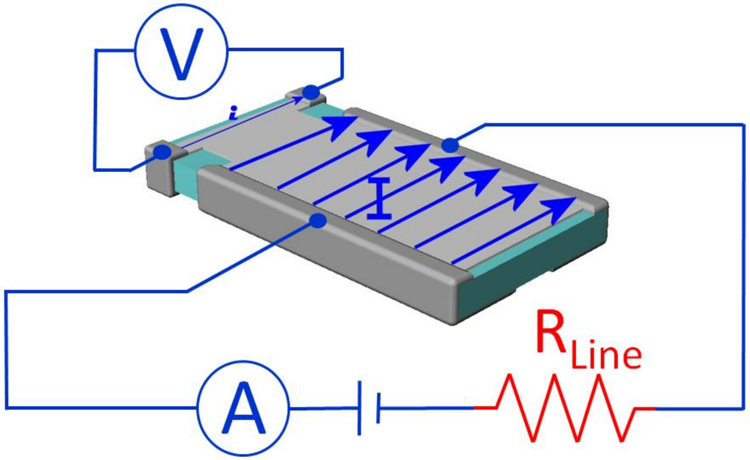
Equivalent Resistor Value

- Parallel Package Layout
  - Electrode and termination laid out parallel
  - Reduced contact resistance, improved tolerance level

Power Efficiency Improvement



2 Terminal Resistor Package Schematic



4 Terminal Resistor Package Schematic

- 4 Terminal Resistor Designed
  - Structure optimally for current sensing purpose
  - Voltage measurement is separated from flowing current
  - Improved power efficiency
  - Less noise from Line Resistor

Summary and Conclusion

- Research was done to enhance power handling capability of low ohm current sense resistor
- Effective thermal management reduced peak surface temperature
- Thermal profile illustrated heat dispersion improvement
- Using termination material with similar CTE of PCB to prevent failure due to thermal fatigue
- Enhanced long time reliability with thermal fatigue reduction
- Reduced contact resistance by using parallel package layout
- Four terminal package layout technique was used to improve power efficiency

Acknowledgement and Future Work

- Future Work
  - Research work will be done on lowering resistance value
  - Power handling capability can be enhanced more
  - Enhance component tolerance value
  - Enhance TCR level
  - Size reduction
- Acknowledgement
  - We would like to thank Yokohama Denshi Seiko Co. for sharing valuable knowledge and resource

Thank you for your time and attention