CARTS USA 2011 Presentation

Power Efficiency Improvement for Low Ohm Current Sense Resistor

Akhlaq Rahman, Fred Olinger, Mike Howieson

Thin Film Technology Corporation
North Mankato, Minnesota
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

- 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

Low Side current sensing technique
Necessary Improvement

- 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

Low Side current sensing technique
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

- 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

- 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

- Surface temperature result and thermal profile
- Condition: Power = 1 Watt, 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

- Surface temperature of resistor 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

- 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**
  - Passivation layer
  - Termination
  - Resistive material
  - Substrate
  - Land pad
  - PC board

- **New Resistor Layout**
  - Alumina substrate
  - Resistive thin film
  - Termination
  - Land pad
  - PC board
  - Passivation layer

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

**Equivalent Resistor Value**
Power Efficiency Improvement

- 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