Power Electronic Module Packaging for Commercial, Construction and Agricultural Vehicle (CAV) Traction Drives

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Introduction

Two challenges - Smaller size and lower cost

Technical issue - How to manage temperature cost effectively

For power electronics:

- Reduce losses at source
- Packaging for high frequency switching
- Shrinking silicon size
- Alternative topologies
- Cooling system
- Module options
Power Losses.

Approximately 90% of the power loss is in power silicon
Static and dynamic losses

Loss In Watts

Switching frequency in kHz

Conduction Loss
Switching Loss
Improvements in Vcesat levels for reduced conduction losses

It is getting more difficult to get significant gains in Vce sat voltage.
Opportunities for reduction in switching losses

- Optimize silicon for application
- Use of SiC
- Improved module packaging
- Negative effects of high frequency switching
Different loss distribution for different silicon types

- Conduction Loss - Fast Silicon
- Switching Loss - Fast Silicon
- Conduction loss - Slow Silicon
- Switching Loss - Slow Silicon

![Graph showing loss distribution for different silicon types.](image-url)
600V Si-IGBT Inductive Switching: Turn-On @ $T_J = 175 \, ^\circ C$

**Losses at 20A 400V**

- **Fast Silicon Diode**
  - $E_{onIGBT}$: 450 $\mu$J
  - $E_{offDiode}$: 75 $\mu$J

- **SiC Diode**
  - $E_{onIGBT}$: 125 $\mu$J
  - $E_{offDiode}$: 5 $\mu$J

The reduction in turn on reverse recovery current not only reduces switching losses but can reduce turn on EMI.
Inductance Plates vs. parallel wires

Inductance does not mix well with high di/dt levels in silicon.

How to reduce system inductance?
Strip line design module inductance reduction

Reduction of inductance by 75% is possible

Prototype module

Current density
Alternate topologies. Three level NPC2 or Matrix

Active rectifier

Output phase

Matrix topology for AC to AC conversion.
Why the drive to make chips smaller

Smaller chips and larger wafers = reduced cost + increased power density.

Consequences?

- 1990 Area 100%
- 1994 Area 65%
- 2000 Area 44%
- 2007 Area 36%
- Next Generation
New technology for high temperature packaging

**Chip to substrate**
- Si chip
- DCB

**Chip top side**
- Si chip
- DCB

**Substrate to baseplate**
- Si chip
- DCB
- base plate

**Standard Technology**
- Soft soldering with SnAg paste
- Al wedge bonding
- Soft soldering with SnAg pre form

**New Technology**
- Diffusion soldering
- Cu wedge bonding
- High reliability system soldering
Diffusion soldering

- Very thin, Sn based solder
- $T_{\text{melt}} > 400^\circ\text{C}$
- Comparable to discrete component assembly
- Fast process, highly integrated, high volume compatible

Schematic comparison of a standard solder joint (left) and a diffusion soldered joint (right).
The future of bond wiring – Copper

Top side metallization of chips allows for copper bonding
High reliability system soldering

- Base plate modules have thermal advantages for thermal management in vehicle drives
- Improvements in soldering process and alloys

![Existing solder after 400 TST](image1)

![Improved solder after 2000 TST](image2)
Delamination image of solder layer

DCB to baseplate solder layer at end of design life thermal cycles
Power cycling life data curves

How are these generated and what are their limitations?
From mission profile to design life

Mission profile

Module Electrical model

Thermal model: module + cooling system

Matlab/Simulink Simulation
From mission profile to design life

**Mission profile**

- DC voltage
- Motor voltage
- Motor current

**Losses**

- IGBT losses
- Diode losses
- Total losses

**Simulation**

- IGBT
- Diode
- Solder layer temperature profile

**Temperatures in detail**
From mission profile to design life

Junction and solder temperatures

Summation of design life wear in %

Design life wear in %

IGBT

Diode

Solder

Rainflow
Pin-fin modules for improved cooling

Copper or AlSiC pin fin construction?

HybridPack 1 and 2 modules with direct pin-fin cooled base plate
Module Selection some options

Non standard products
Design a custom package with optimized pin out, silicon and topology

Use an existing package and pin out; but, use specific silicon or topology

High volume - Long time to market

Medium volume - Short time to market

Standard products

• AQS 1002 qualified

• 200A – 800A parts available.
• 650V and 1200V.

• Module series qualified for CAV applications - high vibration and temperature cycling capability
• 100A – 1400A parts available
• 650V, 1200V and 1700V
ENERGY EFFICIENCY COMMUNICATIONS SECURITY

Innovative semiconductor solutions for energy efficiency, communications and security.