Thermal Measurement and Modeling of Multi-Die Packages


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OVERVIEW OF CHARACTERIZATION OF TYPICAL MULTI DIE PACKAGES

Package: 144LQFP

Figure 1: Two test dies stacked in a 144 LQFP package.
Multiplying this matrix with the vector of any combination of $pi$ powers applied at the chips, one can obtain the corresponding vector of the $\tau_i$ temperature responses at all dies.
OVERVIEW OF CHARACTERIZATION OF TYPICAL MULTI DIE PACKAGES

Figure 3: Frequency-domain representation of the thermal impedance matrix of the stacked die package

Time domain function:

$$Z_{ik}(\omega) = \frac{1}{p} \int_0^\infty a_{ik}(t)e^{-j\omega t} dt$$

Frequency domain function:
OVERVIEW OF CHARACTERIZATION OF TYPICAL MULTI DIE PACKAGES

Figure 4: P-TO263-15-1 package, internal leadframes, footprint and tab numbering (H1, H2, H3).

Figure 5: Comparison of complex loci in still-air setup. Curves $Z_{11}$, $Z_{12}$ measured with junction on H1 driven, $Z_{22}$, $Z_{21}$ measured with junction on H2 driven.
MODELING ISSUES–Compact model

**Figure 6:** Non-reciprocal steady-state compact model of a two-die package.

**Figure 7:** A dynamic compact model of stacked die package.
MODELING ISSUES—
Structure functions for validation of detailed models

DCP-1: heat sink at the top and bottom surface of the package, sides and leads insulated.

DCP-2: heat sink at the bottom surface, top surface insulated by plastic spacer, sides and leads insulated.

DCP-3: heat sink at the top surface, bottom surface insulated by plastic spacer, sides and leads insulated.

DCP-4: heat sink at the leads, all other surfaces thermally insulated.

MODELING ISSUES - Structure functions for validation of detailed models

Figure 8: Suggested flow of validation of detailed models with the help of structure functions.
CASE STUDY—
Testing a two die stack in different test environments

![Diagram showing two die stack configurations](image)

Figure 9: DCP1 and modified DCP1 setup of the package of Figure 1.
CASE STUDY— Testing a two die stack in different test environments

From Figure 10 ($R_{thja}$)

- $R_{th, mylar sheet} = 10 \text{ K/W}$
- $R_{th, pedestal} \approx 5 \text{ K/W}$. 

![Figure 11: Structure functions obtained from DCP1 and modified DCP1 measurement results when the top die is heated and when the bottom die is heated.](image-url)
CASE STUDY– Testing a two die stack in different test environments

Figure 12: Structure functions obtained from DCP1, 2 & 3 measurement results when the top die is heated.

Figure 13: Structure functions obtained from DCP1, 2, 3 and DCP4 measurement results when the bottom die is heated.
CASE STUDY—
Extension of the DELPHI topology to stacked die packages

Figure 14: Suggested model topology for DELPHI style BCI compact model for stacked die packages.

Combine fig.6

Figure 15: Model topology for DELPHI style BCI compact model for stacked die packages accounting for non-reciprocal coupling among dies.
CASE STUDY—An opto-coupler device in a plastic DIL package
CASE STUDY –
An opto-coupler device in a plastic DIL package

Figure 17: Measured thermal impedances with detector driven in “low power” samples. Still-air environment, low conductance (LCB) and high conductance (HCB) board.

Figure 18: Cumulative structure functions of driving point thermal impedances in the same arrangement.
CASE STUDY–
An opto-coupler device in a plastic DIL package

Figure 19: Identification of $R_{\text{thJC}}$ values for the second series of devices ($R_{\text{thJC}}$ for the detector chip).

Figure 20: Cold-plate setups for the identification of the $R_{\text{thJP}}$ value for the “high power” type of devices ($R_{\text{thJP}}$ for the detector chip).
CONCLUSIONS

• Several measurement examples have demonstrated that coupling between different chips in multi-die packages may show asymmetry.

• This asymmetry necessitates the use of network elements which have been unusual in compact thermal models.

• Temperature controlled heat-flux generators can be used to properly model the nonreciprocal behavior observed in measurements.