Actel®

Package Thermal Characteristics

Introduction

Managing heat in CMOS Logic devices is a growing issue for today's system designers. As densities increase and process geometries and form factors shrink, the amount of heat generated on these high-speed circuits creates significant thermal management challenges. Special attention must be paid to power budgets and heat removal needs for today's electronic systems.

While low power and heat dissipation is generally a fundamental design goal for all engineers, systems that leverage FPGAs create some unique challenges in predicting thermal management requirements. Since designers can customize FPGAs and even program them in the field, each customer's design can vary in power as well as physical needs.

Using a low power FPGA solution from Actel is one way of addressing this problem. Actel's single-chip Flash and antifuse FPGAs offer very low power consumption and heat dissipation across every product in the portfolio. Actel also provides a number of tools that help the users estimate power consumption and the associated output during the design cycle. In conjunction with these design aides, it is important for designers to have a fundamental understanding of Actel's package thermal characteristics when using Actel FPGAs.

Thermal dissipation performance must be understood prior to integrating devices on a printed circuit board (PCB) to ensure that any given device is operated within its defined temperature limits. When a device is running, it consumes electrical energy that is transformed into heat. The heat dissipates from the surface of the die to its immediate surrounding environment. It is important that a package is capable of transferring heat to the environment efficiently or the reliability of the device will be weakened. As a result, designers need to carefully estimate the thermal dissipation characteristics of any given device and its package before selecting a solution for their systems.

The power consumption and the associated thermal dissipation can be estimated using the power calculator posted on Actel's website and in Actel's datasheets. As a general rule, when calculating power consumption, users should always ensure that the amount of heat generated during the operation of the device is at least equal to the heat dissipation capability of the package. Package thermal resistance parameters junction-to-air (theta-JA) and junction-to-case (theta-JC) assist the user in estimating the maximum allowable power dissipation and compare with the power consumption of the device. This application note describes this relationship.

Package Thermal Resistance

Package thermal resistance is the measure of the package's heat dissipation capability from a die's active surface (junction) to a specified reference point (case, board, ambient, etc.).

The most commonly documented thermal relationship for IC packages are the junction-to-air thermal resistance (theta-JA) and the junction-to-case thermal resistance (theta-JC).

Theta-JA

Junction-to-air thermal resistance is a measure of the ability of a device to dissipate heat from the surface of the die to the ambient via all paths. It is relevant for packages used without external heat sinks and similar PCB as JEDEC test board. It is determined by:

$$\theta_{JA} = \frac{T_J - T_A}{P}$$

EQ 1

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Where:

T_J = Junction temperature, defined as the maximum temperature on the die, expressed in °C. Usually T_J= 150°C.

T_A = Ambient Temperature, defined as the temperature of the surrounding environment expressed in °C. The temperature range can be found in the recommended operating conditions section of the datasheets.

P = power dissipation from the device while operating.

Theta-JA (θ_{JA}) is determined under JEDEC (JESD-51 series) standard test conditions and boards, which has specific dimensions and layer requirements. It has little relevance in actual performance of the product in real application and therefore should be used with caution. It is useful for comparing the thermal performance of one package to another. Additional evaluation is needed if the application board is different from the JEDEC test board.

A sample calculation of the absolute maximum power dissipation allowed (worst case) for a PBGA 329 pin package at still air is as follows:

$$\text{Maximum Power Allowed} = \frac{\text{Max. junction temp. (°C)} - \text{Max. ambient temp. (°C)}}{\theta_{JA}\text{(°C/W)}} = \frac{150\text{°C} - 125\text{°C}}{17.1\text{°C/W}} = 1.46\text{ W}$$

EQ 2

Where:

θ_{JA} = 17.1°C/W—this comes from the *Package Thermal Characteristics and Weights* document.
T_A = 125°C is the maximum ambient temperature (from the datasheet)

The device's power consumption must be lower than the calculated maximum power dissipation through the package.

The power consumption of a device can be calculated using Actel's power calculator. If the power consumption is higher than the device's maximum allowable power dissipation, then a heat spreader can be attached to the package or the airflow inside the system must be increased.

Theta-JC

Junction-to-case thermal resistance measures the ability of a device to dissipate heat from the surface of the die to the top or bottom surface of the package. It is applicable for packages used with external heat sinks and only applies to situations where all or nearly all of the heat is dissipated through the surface in consideration. Junction-to-case thermal resistance is determined by:

$$\theta_{JC} = \frac{T_J - T_C}{P_{JC}}$$

EQ 3

Where:

θ_{JC} = junction-to-case thermal resistance expressed in °C/W
T_J = junction temperature, defined as the maximum temperature on the die surface expressed in °C. Usually T_J = 150°C.
T_C = temperature of the package taken at a defined location on the body. In most situations it is taken at the primary heat flow path on the package, and will represent the hottest part on the package, expressed in °C. Package case temperature is application dependent.
P_{JC} = total power dissipated from the die to the case

Calculation for heat spreader:

For example, in a design implemented in an FG676 package, the power consumption value using the power calculator is 3.00 Watts. The user-dependent data T_J and T_A are given as follows:

T_J = 110 °C

T_A = 70 °C

From the datasheet:

θ_{JA} = 16.40 °C/W

θ_{JC} = 3.2 °C/W

$$P = \frac{T_J - T_A}{\theta_{JA}} = \frac{110°C - 70°C}{16.4°C/W} = 2.43\ W$$

EQ 4

The 2.43 W power is less than 3.00 W, the design therefore requires a heat spreader or the airflow where the device is mounted should be increased. The design's junction-to-air thermal resistance requirement can be estimated by:

$$\theta_{JA(TOTAL)} = \frac{T_J - T_A}{P} = \frac{110°C - 70°C}{3.00W} = 13.33°C/W$$

EQ 5

Determining the heat spreader's thermal performance:

$$\theta_{JA(TOTAL)} = \theta_{JC} + \theta_{CS} + \theta_{SA}$$

EQ 6

where:

θ_{CS} = 0.37 °C/W = thermal resistance of the interface material between the case and the heat spreader, usually provided by the thermal interface manufacturer

θ_{SA} = thermal resistance of the heat spreader in °C/W

$$\theta_{SA} = \theta_{JA(TOTAL)} - \theta_{JC} - \theta_{CS}$$

EQ 7

$$\theta_{SA} = 13.33°C/W - 3.20°C/W - 0.37°C/W$$

$$\theta_{SA} = 9.76°C/W$$

A heat spreader with a thermal resistance of 9.76°C/W or better should be used. Thermal resistance of heat spreaders is a function of air flow. The heat spreader performance can be improved significantly with the presence of air flow.

Conclusion

Carefully estimating thermal resistance is important in the long-term reliability of an Actel FPGA. Design engineers should always correlate the power consumption of the device with the maximum allowable power dissipation of the package selected for that device using the provided thermal resistance parameters.

Related Document

Package Thermal Characteristics and Weights

http://www.actel.com/documents/Package_Charact_Weights.pdf

List of Changes

Previous Version	Changes in Current Version 51900034-2/2.05*	Page
51900034-1/2.04	EQ 2 was updated.	2

Note: ** The part number is located on the last page of the document.*

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