Using Heat Sinks with Larger CPLDs

Introduction

Increasing operating frequencies and decreasing sizes of semiconductor devices have made heat dissipation and thermal management an important issue. Both the life expectancy and reliability of a device are inversely proportional to its operating temperature. Therefore, it is essential that the operating temperature of a device is kept within the limits set by the device manufacturer.

Heat sinks effectively lower the operating temperature of a semiconductor device by enhancing heat dissipation from the case of the device to the surrounding ambient, usually air. A heat sink lowers the case-ambient heat dissipation barrier by increasing the surface area in contact with the ambient. The main goal of using a heat sink is to keep the operating temperature of a device below the maximum allowable temperature specified by the manufacturer.

This document illustrates the steps taken in choosing a heat sink and provides information on different types, costs and mounting methods of various heat sinks.

How to Choose A Heat Sink

Before discussing how to choose a heat sink, let's look at the basic terms and equations that are commonly used in the topic of heat transfer.

The Basics

Between any two points p and q in a heat dissipation path, the thermal resistance between p and q is defined by Equation 1.

$$\theta pq = \frac{Tp - Tq}{P} \qquad \text{Eq. 1}$$

Where θpq is the thermal resistance in °C/Watt, or, the temperature difference required to dissipate 1 Watt of power:

- Tp is the temperature at point p,
- Tq is the temperature at point q, and
- P is the power that needs to be dissipated as heat.

The lower the thermal resistance a medium has, the more effectively it dissipates heat. Consider the heat dissipation path from the die of an IC device through the case to the ambient without the use of a heat sink (see *Figure 1*).

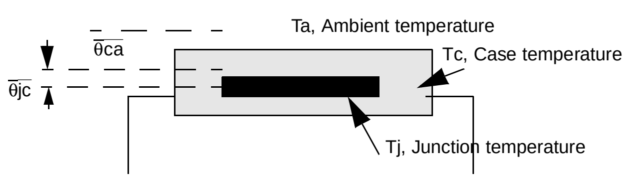

Figure 1. Heat Dissipation Path from Die to Ambient, without a Heat Sink

Without using a heat sink, the thermal resistance from the junction to the ambient is defined in Equation 2.

$$\overline{\theta ja} = \overline{\theta jc} + \overline{\theta ca} \qquad \text{Eq. 2}$$

Where $\overline{\theta ja}$ is the junction-to-ambient thermal resistance in °C/Watt, $\overline{\theta jc}$ is the junction-to-case thermal resistance in °C/Watt, and $\overline{\theta ca}$ is the case-to-ambient thermal resistance in °C/Watt. The overline above the $\overline{\theta}$ represents the thermal resistance when no heat sink is used. In *Figure 2* consider the heat dissipation path from the die of an IC device through the case to the ambient with the use of a heat sink.

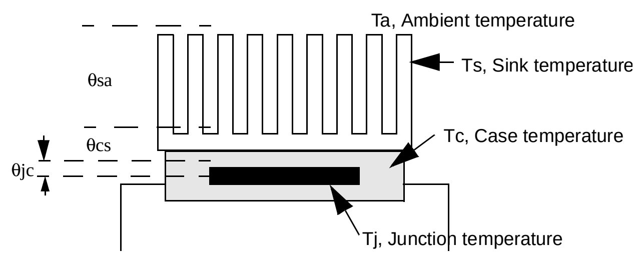

Figure 2. Heat Dissipation Path from Die to Ambient, with a Heat Sink

With a heat sink, the thermal resistance from junction to ambient is defined in Equation 3.

$$\theta ja = \theta jc + \theta cs + \theta sa \qquad \text{Eq. 3}$$

Where θja is the junction-to-ambient thermal resistance in °C/Watt, θjc is the junction-to-case thermal resistance in °C/Watt and is equal to $\overline{\theta jc}$, θcs is the case-to-sink thermal resistance in °C/Watt, and θsa is the sink-to-ambient thermal resistance in °C/Watt. What the heat sink does is to enhance the dissipation of heat from the device to ambient by making Equation 4 true.

$$\overline{\theta ca} > \theta ca \qquad \text{Eq. 4}$$

where

$$\theta ca = \theta cs + \theta sa \qquad \text{Eq. 5}$$

This makes θja for the device with a heat sink lower. Thus the power consumed by the device is dissipated as heat more easily.

Required Heat Sink Thermal Resistance

The manufacturer of a semiconductor device specifies the maximum junction temperature, Tj, beyond which the reliability and life expectancy of the device would be unacceptable. For a device consuming power, P, during operation, we can show that the maximum thermal resistance allowable from the heat sink to the ambient, θsa_{max}, is defined in Equation 6.

$$\theta sa_{max} = \frac{Tj - Ta}{P} - \theta jc - \theta cs \qquad \text{Eq. 6}$$

Where Tj is the maximum junction temperature (provided by device manufacturer), Ta is the ambient temperature (application specific), θjc is the junction to case thermal resistance (provided by device manufacturer), θcs is the case to sink thermal resistance (depends on case-sink interface material), and P is the total power consumed by the device (application specific). θsa_{max}, the maximum allowable thermal resistance from heat sink to ambient determines the types of heat sinks that you can choose for your application. The thermal resistance of the heat sink chosen should not be greater than θsa_{max}. θsa of a given heat sink depends on its material, surface area, surface finish and airflow velocity of the ambient.

Lowering θsa of a Heat Sink by Forced Air Flow

By intuition, we can expect to further lower the junction temperature of a device by attaching a cooling fan to the heat sink. Forced airflow effectively lowers the thermal resistance θsa of a heat sink. *Figure 3* shows the effect of forced air flow on θsa of a typical heat sink.

Negligible Case-to-Sink Thermal Resistance, θcs

θcs depends on the surface finish, flatness, applied mounting pressure, contact area and the type of interface material and its thickness. While the precise value of θcs is difficult to obtain, this value is negligible compared to θsa, assuming that some interface compound is used to remove the air gap between the case and sink. θsa is at least 10 times θcs, even

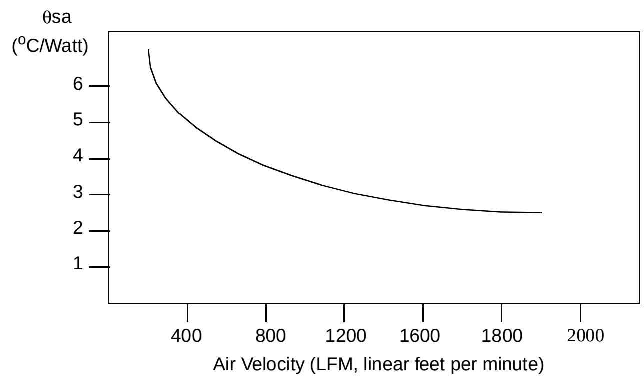

Figure 3. Effect of Forced Airflow on θsa of a Typical Heat Sink

with the help of a very fast cooling fan to lower θsa. In other words, the equation for the maximum sink-to-ambient thermal resistance allowed, θsa_{max}, can be reduced as defined in Equation 7.

$$\theta sa_{max} = \frac{Tj - Ta}{P} - \theta jc \qquad \text{Eq. 7}$$

Where Tj is the maximum junction temperature (provided by device manufacturer), Ta is the ambient temperature (application specific), θjc is the junction to case thermal resistance (provided by device manufacturer), P is the total power consumed by the device (application specific). Typical values for common interface materials are detailed in *Table 1*.

Table 1.Thermal Properties of Interface Materials [1]

Material	Conductivity W/in°C	Thickness inches	Thermal Resistance in^2 °C/W
Ther-O-Link	0.010	0.002	0.19
High Performance Thermal Compound	0.030	0.002	0.07
Kon-Dux	0.030	0.005	0.17
A-Dux	0.008	0.004	0.48
1070 Ther-A-Grip	0.014	0.006	0.43
1050 Ther-A-Grip	0.009	0.005	0.57
1080 Ther-A-Grip	0.010	0.002	0.21
1081 Ther-A-Grip	0.019	0.005	0.26
A-Pli 22o@20psi	0.074	0.020	0.27
1897 In-Sil-8	0.010	0.008	0.81
1898 In-Sil-8	0.008	0.006	0.78

Note:
1. Aavid Engineering, Inc., EDS #117, *Interface Materials*, January 1992

Heat Sink Types

There are 4 packages associated with the larger members (37256, 37384 and 37512) of the Cypress Ultra37000 family of CPLDs, namely:

- 160-pin TQFP -- 24 mm x 24 mm (0.94" x 0.94")
- 208-pin PQFP -- 28 mm x 28 mm (1.1" x 1.1")
- 256-pin BGA -- 27 mm x 27 mm (1.06" x 1.06")
- 352-pin BGA -- 35 mm x 35 mm (1.38" x 1.38")

The type of heat sinks suitable for these packages is the pin matrix heat sink. Pin matrix heat sinks are those commonly used for the Intel Pentium CPUs in PCs. For applications where head room is a major concern, low profile thin fin heat sinks can be used. The thin fin heat sinks can be as thin as 0.01 inches. In the following sections, we will look at an example of how a heat sink can reduce the junction temperature of a device. We will also look at products from some heat sink companies. The heat sinks that we will analyze have a surface size of roughly 1" by 1".

Example Calculation

Suppose we have a 256-macrocell Ultra37256 running at maximum frequency, dissipating 2.5W in a 208-pin PQFP package. Let's find out the junction temperature of the device without a heat sink. Assume that:

- Ambient Temperature = Ta = 70°C (modeling still air temperature in an unventilated enclosed metal case)
- Power Dissipated = P = 2.5W

Also, for a 208-pin PQFP package, it can be found in the "Thermal Management" section of the Cypress Programmable Logic Data Book that:

- Junction-to-Case Thermal Resistance = θjc = 16°C/W
- Junction-to-Ambient Thermal Resistance = $\overline{\theta ja}$ = 39°C/W
- Maximum Junction Temperature = Tj_{max} = 150°C

Note that throughout this example, an overline above a variable such as $\overline{\theta ja}$ indicates that the variable is for the case where a heat sink is not used. Now, let's find the junction temperature of the Ultra37256 without using a heat sink as defined in Equation 8.

$$\overline{Tj} = Ta + P(\overline{\theta ja}) = 70°C + 2.5W(39°C/W)$$
$$= 167.5°C \qquad \text{Eq. 8}$$

Where $\overline{Tj}$ is the junction temperature of the device without a heat sink. We can see that the junction temperature $\overline{Tj}$ (167.5°C) is greater than the maximum allowable junction temperature Tj_{max} (150°C). To lower it, we add a heat sink with a θsa of 12°C/W. Also assume that a certain heat sink interface compound is used to attach the heat sink to the Ultra37256, which has a θcs of 0.5°C/W. The junction temperature of the device with the heat sink now becomes as defined in Equation 9.

$$Tj = Ta + P(\theta jc + \theta cs + \theta sa)$$
$$= 70°C + 2.5W(16°C/W + 0.5°C/W + 12°C/W)$$
$$= 141.25°C \qquad \text{Eq. 9}$$

This is lower than the maximum allowable junction temperature Tj_{max}. Adding a cooling fan can further enhance heat dissipation.

Products of Some Heat Sink Companies

Wakefield Engineering

The 658 series pin matrix heat sinks from Wakefield Engineering are suitable for the 208-pin PQFP, the 256-pin BGA and the 352-pin BGA packages.

Size

The 658 series heat sinks are 1.1" x 1.1". (27.9 mm x 27.9 mm) pin matrix heat sinks. The heights of different members in the series are shown in *Table 2*.

Table 2. Wakefield 658 Heat Sinks

Part #	Pin Height
658-25AB	0.25 in. (6.4 mm)
658-35AB	0.35 in. (8.9 mm)
658-45AB	0.45 in. (11.4 mm)
658-60AB	0.60 in. (15.2 mm)

Mounting

Wakefield suggests using tape adhesive or heat sink compound for mounting the heat sink.

Cost

The cost of each 658 heat sink is around a dollar, depending on quantity. Optional tape adhesive increases the cost by a few cents.

Thermal Characteristic

We will look at an example of the 658-45AB in *Table 3*

Table 3. Thermal Characteristic of Wakefield 658-45AB Heat Sink

Airflow (LFM, linear feet per minute)	Thermal Resistance θsa (°C/Watt)
Still Air	17.2
400	6
800	3.9

Aavid Thermal Technologies

The part numbers of the pin matrix heat sinks from Aavid Thermal Technologies that would fit different packages of the larger Ultra CPLDs are listed in *Table 4*

Table 4. Aavid 3353 Heat Sinks

Part #	Pin Height	Package
3351	0.935 in. (23.7 mm)	160 TQFP
3353	0.450 in. (11.4 mm)	256 BGA
3355	0.600 in. (15.2 mm)	208 PQFP

We will examine the 3353 heat sink in more detail:

Size

The 3353 heat sink measures 1.06” x 1.06” x 0.45” (26.9 mm x 26.9 mm x 11.4 mm).

Mounting

Adhesive tape or heat sink compound.

Cost

The cost of each 3353 heat sink is around a dollar, depending on quantity. Optional tape adhesive increases the cost by a few cents.

Thermal Characteristic

Table 5 lists the θsa values of the 3353 heat sink at different airflow velocities.

Table 5. Thermal Characteristic of Aavid 3353 Heat Sink

Airflow (LFM, linear feet per minute)	Thermal Resistance θsa (°C/Watt)
Still Air	21.5
400	13.7
800	9.8

Contact Information

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Alternative Thermal Management

Before committing yourself to using a heat sink with your product, consider the following alternatives:

Utilize available low-power features of the device. Set a logic block to lower power mode if that is not needed for high speed. For example, some CPLDs such as the Ultra37000 family from Cypress allow you to group signals which are non-speed critical into a logic block. That logic block can then be run in low power mode.

Choose a different device package. Ceramic packages and Ball Grid Array (BGA) packages can dissipate heat more easily. Also a package with a greater number of pins can dissipate more heat to the printed circuit board.

Reduce the number of I/O pins. This can reduce the current used by the device and can lower power consumption.

Modify the design to cut down power. Reducing the amount of circuitry and slowing down portions of the circuit can effectively reduce power used by the device.

Buy low power or low voltage versions of the device.

Conclusion

Heat dissipation and thermal management become an important issue in system reliability as semiconductor devices are running at higher frequencies and smaller sizes than ever. Heat sinks help to lower the junction temperature of semiconductor devices so that high reliability and life expectancy can be achieved.

From the calculation of the junction temperature of a semiconductor device, a designer can evaluate whether his/her application is driving the device over the maximum junction temperature specified by the manufacturer. In case the device overheats and a heat sink is needed, equations are given in this document to calculate the maximum thermal resistance allowed for a heat sink (θsa). The designer can then look for a heat sink that has a lower thermal resistance than the maximum value calculated. Please refer to the appropriate Cypress application notes for calculating power consumption for your particular design.

Besides using a heat sink, there are other alternatives to lower the junction temperature of a device. These alternatives have been briefly discussed in this document. Detailed studies of all possible methods are essential to lower production cost and to achieve the thermal requirements of your design.