Understanding Temperature Specifications: An Introduction

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Associated Project: No
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AN4017 gives a basic understanding of the temperature specifications found in Cypress's product datasheets. There are many factors that affect the thermal operation of a device. This application note also gives you an understanding of the thermal parameters and temperature specifications of the device.

1 Introduction

Power is required to operate integrated circuits (ICs). This power is provided to the IC in the form of voltage and current through power supply pins. The consumption of power creates heat and results in junction temperatures different from the surrounding ambient temperature. There are several factors that affect the junction temperature:

- Heat from neighboring ICs
- Airflow
- IC packaging material
- IC packaging technique (example flip chip versus wire bond)
- Number of leads on the IC package
- Printed circuit board (PCB) materials
- Ambient temperature

The air temperature ($T_A$) dictates the minimum temperature at which the device operates. No matter how much heat sinking or airflow is supplied, the device will not get colder than the surrounding air. Once the IC begins to dissipate power the junction temperature ($T_J$) increases above the ambient temperature. You can reduce the junction temperature by adding airflow or heat sinks, but as long as the power is dissipated, the junction rises to a temperature above $T_A$.

Thermal resistance is the ability for a given device to dissipate the internally generated heat, expressed in units of °C/W. Basically, the thermal resistance is derived to show how much the $T_J$ increases based on the power dissipated by the device.
2 Definitions

The following are some important definitions that pertain to the operating condition of the devices.

\( T_A = \) Ambient temperature. This is the temperature of the environment, still air.

\( T_C = \) Case temperature. This is the temperature of the case of the semiconductor device.

\( T_J = \) Operating Junction temperature. This is the temperature of the device circuit itself under given operating conditions. \( T_J \) must be calculated or inferred from the case and/or ambient temperature.

\( T_{J_{\text{max}}} = \) Maximum Junction temperature. This is the maximum temperature that the device tolerates to guarantee reliable operation. The system designer needs to ensure that \( T_J < T_{J_{\text{max}}} \) to guarantee reliability.

Table 1. Maximum Junction Temperature

<table>
<thead>
<tr>
<th>SRAM Type</th>
<th>( T_{J_{\text{max}}} )</th>
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<tbody>
<tr>
<td>Sync SRAMs</td>
<td>125 °C</td>
</tr>
<tr>
<td>( nVSRAM )</td>
<td>150 °C</td>
</tr>
<tr>
<td>Async SRAM</td>
<td>150 °C</td>
</tr>
<tr>
<td>Dual port RAMs and FIFOs</td>
<td>125 °C</td>
</tr>
<tr>
<td>( F-RAM )</td>
<td>125 °C</td>
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</table>

Max junction temperature is listed in Table 1 for various Cypress memory devices.

\textbf{Power Dissipation (P_d)} = This is the power consumed while the device is in operation and this power consumption creates heat. It is typically expressed in Watts.

\textbf{Airflow} = The movement of air over and around a device that is used to remove heat from the system.

\textbf{Thermal Resistance} = An empirically derived set of constants that describe the heat flow characteristics of a given system, expressed in °C/W. Thermal resistance is a measure of the ability of a package to transfer the heat generated by the device inside a package to the ambient. Some factors that affect thermal resistance include: (1) the die size of the IC chip, (2) the mold compound, and (3) lead frame / substrate design. \( \theta_{JA} \) (junction-to-ambient thermal resistance), \( \theta_{JC} \) (junction-to-case thermal resistance), \( \theta_{CA} \) (case-to-ambient thermal resistance), and \( \theta_{JB} \) (junction to board) are the thermal parameters generally used to characterize a package.

\( \theta_{JA} \) value is available in the datasheet of the device.
θJC is the junction-to-case thermal resistance. θJC is defined as the temperature difference between the junction and a reference point on the package when the device is dissipating 1 W of power. θJC (expressed in °C / W) = (TJ – TC)/Pd. It is mainly a function of the thermal properties of the materials constituting the package. θJC value is available in the datasheet of the device.

θJB is the junction-to-board thermal resistance. θJB is defined as the temperature difference between the junction and the board when the device is dissipating 1 W of power. θJB (expressed in °C/W) = (TJ – TB)/Pd. TB is the temperature of the PCB board taken at a predefined location near the die. θJB can be provided upon request.

θCA is the case-to-ambient thermal resistance. θCA is defined as the temperature difference between a reference point on the package and the ambient temperature when the device is dissipating 1 W of power. θCA (expressed in °C/W) = (TC – TA)/Pd. θCA is mainly dependent on the surface area available for convection and radiation and the ambient conditions, among other factors. This can be controlled by using heat-sinks, providing greater surface area and better conduction path, or by air or liquid cooling.

The junction-to-ambient thermal resistance is the sum of the thermal resistances of junction-to-case and case-to-ambient. In other words, the relationship between the thermal parameters can be expressed as: θJA = θJC + θCA

3 Calculating the Junction Temperature

When the junction-to-ambient thermal resistance (θJA) and the ambient temperature are given, you can calculate the junction temperature of the chip after calculating the power dissipated by the device, as follows:

TJ = Pd × θJA + TA

Where,

θJA = Junction-to-ambient thermal resistance

TA = Ambient temperature

Pd = Core power + I/O switching power + ODT Power

Core power = VDD(max.) × IDD and

I/O switching power = α × f × C_L × V^2 × (number of I/Os that are switching),

where:

α is the activity factor, or the ratio of frequency at which outputs toggle to the clock frequency

= 0.5 for single data rate devices like Std Sync, NoBL™- SRAMs;

= 1 for double data rate devices (such as DDR/QDR™ SRAMs)

f = operating frequency

C_L = external load capacitance

V is output voltage swing,

For example,

= Vddq for unterminated load

= Vddq/2 for a terminated load with pull-up termination
ODT Power is the power dissipated in the input on die termination resistors. For Non-ODT parts this power is zero. See Figure 2 for a description of ODT Power consumption.

If the driver source impedance is R, the input on die termination resistors are 2R as shown below.

Figure 2. ODT Power Consumption

Depending on whether the source is driving a “1” or “0” either Path-1 or Path-2 is active. In either case the Power dissipated in the ODT resistors is

ODT Power = \( \frac{5}{16} \times V_{ddq}^2 \times \frac{1}{R} \times \text{(number of inputs with ODT resistors)} \), where:
- \( V_{ddq} \) is I/O voltage
- \( 2R \) is the termination resistor, used for pull-up and pull-down termination

See AN42468 for derivation of the ODT Power Equations.

4 SRAM Example

Let us look at an example using the 100-lead SRAM TQFP device (specifically, part number CY7C1381D). The thermal resistance is 28.66 °C/W for a 4-layer board with 0 ft/s of airflow. Assuming the device is running at 100 MHz with a 40-pF capacitive load and all I/Os switching, the power dissipated is calculated as follows:

\[ P_d = \text{Core power} + \text{I/O switching power} + \text{ODT power} \]

Core power = \( V_{DD(max)} \times I_{DD} = 3.6 \times 175 \times 10^{-3} = 0.63 \) W

I/O switching power = \( \alpha \times f \times C_L \times V_d^2 \times \text{(number of I/Os that are switching)} = 0.5 \times 100 \times 10^6 \times 40 \times 10^{-12} \times (3.6)^2 \times 36 = 0.93 \) W

ODT power = 0, as there are no input ODT resistors.

Therefore total power dissipated, \( P_d = 1.56 \) W

The junction temperature increase is then calculated using the thermal resistance value:

\[ T_J = T_A + (\text{Thermal resistance} \times \text{Power}) \]

\[ = T_A + (\theta_{JA} \times P_d) \]

\[ = T_A + (28.66 °C/W \times 1.56 W) \]

\[ = T_A + 44.71 °C \]

Note: \( \theta_{JA} \) used is a referenced value and will vary by device.
If the application is rated for commercial temperature range, we can have an ambient temperature from 0 °C to 70 °C. Assume a typical environment within the system is 30 °C, the resulting junction temperature is:

\[ T_J = 30 \, ^\circ C + 44.71 \, ^\circ C \]
\[ = 74.71 \, ^\circ C \]

If the same system had airflow, the junction temperature would be lower.

In a worse-case scenario, we can have \( T_A = 70 \, ^\circ C \):

\[ T_J = 70 \, ^\circ C + 44.71 \, ^\circ C = 114.71 \, ^\circ C \]

However, note that a typical application will have boards with more layers and better heat sinking characteristics. We see that the temperature at the junction will be much higher than the temperature of the air around it, and that airflow and board construction have a large impact on the junction temperature.

For more information, see the online tool for calculating the junction temperature for Synchronous SRAM products.

## 5 Temperature Specifications

The thermal parameters exhibit worst-case values when there is no airflow. Also, with higher temperatures the thermal performance becomes even more critical. Because of this, as we move from commercial temperature ranges to industrial or automotive temperature ranges, temperature specifications become much higher.

To ensure good thermal management, it is essential that the junction temperature remains well below the maximum rated value \( T_{J\text{max}} \). This is because an increase in junction temperature (\( T_J \)) can adversely affect the long-term operating life of a device.

## 6 System Considerations

The major part of the heat travels through the PCB only. There are essentially four paths for heat to transfer out of the chip into the PCB:

1. The small amount of heat transfer from case to ambient through the air around the device.
2. Heat transfer into the PCB through the top layer.
3. Heat transfer to the internal dielectric material and copper layers through via array.
4. Finally, the heat that travels through via array below the chip and into the PCB’s bottom-most copper layer.

The manner in which an IC package is mounted and positioned in its surrounding environment has significant effects on operating junction temperatures. These conditions are controlled by the system designer and are worthy of serious consideration in the PC board layout and system ventilation and airflow features.

Forced air cooling significantly reduces thermal resistance. Airflow parallel to the long dimension of the package is generally a little more effective than airflow perpendicular to the long dimension of the package.

External heat sink applied to an IC package can improve thermal resistance by increasing heat flow to the surrounding environment. Heat sink performance will vary by size, material, design, and system airflow. In general, they can provide a substantial improvement.

Package mounting can affect thermal resistance. For example, surface mount packages dissipate significant amounts of heat through the leads that attach to the traces.

The metal (copper traces) on PC boards conduct heat away from the package and dissipate heat to the ambient; thus the larger the trace area the lower the thermal resistance.

The dielectric material used in the PCB with higher thermal conductivity can also help to get the lower thermal resistances. For example, the thermal resistance from junction to board (\( \theta_{JB} \)) is about 10% lower in the case of RT/duroid 6035HTC (Rogers) than FR-4.[3]

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[1] Based on Cypress’ 72M QDR-II+ and JEDEC standard PCB board thermal resistance measurement simulation results.

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The other most effective conduction path is vias. The more the number of vias under the chip, the lower the thermal resistances; as a result, the junction temperature of the chip will be reduced. Optimized conduction paths from vias to copper layers and dielectric material through accurate design of the via array provides the most efficient paths in the design for removing heat from the chip.

Also, as package sizes shrink and more devices are mounted on the board the thermal characteristics become a major concern.

7 Measurement of $T_J$

Measurement of junction temperature to confirm whether it is well below the specification is a possible but difficult procedure.

A practical and easier method is to measure the case temperature. The measurement can be done through a direct measurement — such as a thermocouple or resistance temperature detector (RTD) placed in contact with the device under test — or with a noninvasive method, such as an infrared heat detector. Once $T_C$ is known, $T_J$ can then be calculated using the junction-to-case thermal resistance and the power as mentioned in the previous example.


In general, the case temperature will be within a few degrees of the junction temperature so the calculation will not be necessary. Therefore it is advisable to measure the case temperature, and ensure it is below the maximum rated junction temperature. If it is higher than the maximum specified junction temperature, the junction will be even hotter and the application will be running outside of specification.

8 Summary

The thermal characteristics of a device have been and will continue to be a major concern for board designers. It is crucial that the thermal parameters, especially junction temperature, are well below the specified limit. This is because an increase in junction temperature can adversely affect the long term operating life of a device. As it is impractical to measure junction temperature directly, it is better to measure the case temperature of the device and then calculate the junction temperature. Some factors affecting $T_J$ are controlled by the IC manufacturer and others are controlled by the system designer. Also, temperature specifications as well as thermal management become a major concern to board designers as package sizes shrink and board density increases.
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Document Number: 001-15491

<table>
<thead>
<tr>
<th>Revision</th>
<th>ECN</th>
<th>Orig. of Change</th>
<th>Submission Date</th>
<th>Description of Change</th>
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