TMS320C6x Thermal Design Considerations

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TMS320C6x Thermal Design Considerations

Abstract

This document discusses thermal analysis and heat sink selection for the Texas Instuments (TI™) TMS320C6x digital signal processor (DSP). A simplified approach us offered to select a heat sink that matches a particular operating environment. Examples are included to demonstrate the method for selecting a heat sink for a typical design.

Product Support

Related Documentation

The following list specifies product names, part numbers, and literature numbers of corresponding TI documentation.

- *Document title*, Literature number SXXX0000
- *Document title*, Literature number SXXX0000

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Design Problem

Thermal analysis and heat sink selection for the TMS320C6x.

Solution

Like most high-performance processors, the ‘C6x dissipates some thermal energy during normal operation. The high level of integration, high clock frequency, and large on-chip memory arrays have an increased effect on the silicon junction temperature (Tj) compared with a lower performance DSP. To ensure proper operation and device reliability, the silicon junction temperature must not exceed maximum junction temperature (related to maximum case temperature Tc_{max}). Under normal operating conditions, system level thermal management is needed to assist with dissipating the heat away from the chip package. A passive heat sink provides a reliable and cost effective method for removing the excess heat. The size and shape of the heat sink depend on the operating conditions of the ‘C6x device and the characteristics of the system within which it operates.

Most of the current consumed by CMOS devices is Alternating Current (AC), which charges and discharges the capacitance of internal nodes, pins, and external pin loads. The current flowing through the ‘C6x causes the temperature of the silicon die to rise. To maintain device reliability and proper operation, the junction temperature must not exceed the maximum specified junction temperature. As the heat is transferred from the die to the package, the case temperature of the package also rises. The junction-to-case thermal resistance $R\Theta jc$, together with the maximum junction temperature, are parameters that determine the maximum case temperature Tc_{max}. Because of these factors, the specification of temperature is given in terms of Tc_{max} in the Thermal Analysis section of this document.

The heat typically flows from the case to the surrounding air up through the heat sink and down through the pins and the board. The heat dissipation through the board material largely depends on the number of power and ground layers inside the board. The portion of the power that is dissipated by the heat sink must first propagate through the case-sink joint. The thermal resistance of case to sink joint can vary depending on the type of joint used, such as thermal epoxy or double-sided adhesive pads. The rate at which the heat is transferred from the sink to the ambient air depends largely on the velocity of the air at the heat sink. The heat flow from the sink rises with the speed of the airflow.

The examples in this section present a method for first order approximation of the size of the heat sink needed to keep the maximum case temperature from exceeding Tc_{max} during maximum system operating conditions. Following heat sink installation, the actual case temperature should be measured to verify that it doesn't exceed the Tc_{max} value.

Heat transfer analysis can be a complex task depending on the degree of accuracy required in the modeling of system components. A number of computational fluid dynamics and heat transfer tools are available to provide highly accurate results. Experimental methods can be used as well for analyzing heat flow.

This document uses a simplified approach to select a heat sink that matches a particular operating environment. The driving parameter in determining the heat flow is the maximum case temperature that must stay below Tc_{max} at all times during device operation. The system parameters that have first order effect on the case temperature are

- Average device power dissipation
- Ambient air temperature
- Air approach velocity

The choice of the heat sink largely depends on those factors, as shown in the following examples. Other factors that can affect heat dissipation include board design/materials and the case to sink attachment method. The relatively long Time Constant of the case/sink combination (around 2 minutes) can effectively smooth out any power peaks that may occur. To validate proper operation of the heat sink, a small hole should be drilled in the center of the sink to place a miniature thermocouple directly on the case (center top surface) to measure the actual case temperature under system's maximum expected operating conditions.

Thermal Considerations

'C6x device operating conditions that can affect power dissipation:

- Operating frequency
- Use of power-down (idle) modes
- Amount of on-chip activity
- Number of functional units exercised every cycle
- Frequency of the internal data memory accesses

- Frequency of the internal program memory accesses
- Activity level of on-chip peripherals (DMAs, Serial Ports, etc.)
- Rate at which data is being driven on and off the chip

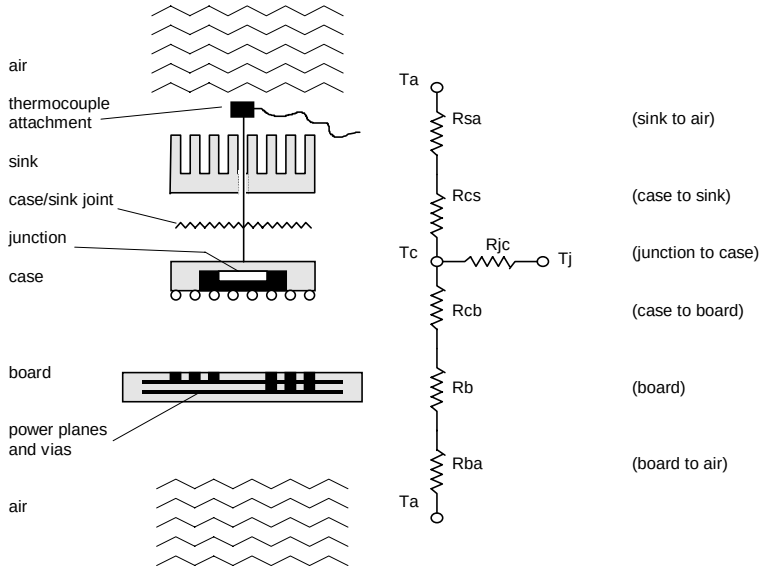
System considerations for choosing a heat sink:

- Air flow rate over the board housing the ‘C6x
- ambient air temperature
- Area / type of joint between package and the heat sink
- Board design and layout

Thermal Analysis and Heat Sink Selection

The following examples demonstrate the method for selecting a heat sink for a typical design. Figure 1 shows the thermal model of the ‘C6x mounting.

Figure 1. Thermal Model Used for Heat Flow Analysis



Example 1:

- Specify operating conditions (this system reflects a typical PC operating environment)

Pa = 4.2 W	average power dissipated by the case
Ta_{max} = 40 ºC	ambient air temperature
Va_{min} = 85 LFM	air approach velocity (linear feet per minute)
h_{max} = 9mm	height limit for the heat sink (system requirement)
RΘcs = 0.5 ºC/W	case to sink thermal resistance (using thermal epoxy)
Tc_{max} = 90 ºC	case temperature

- Estimate the total power that needs to be dissipated by the heat sink, Ps.

  Ps = Pa -1W (assume 1W dissipation through the board)

  Ps = 4.2 - 1 = 3.2 W

- Compute the maximum heat sink to air thermal resistance RΘsa that will maintain the case temperature below Tc_{max} for the operating conditions specified above.

  RΘsa + RΘcs = (Tc -Ta) / Ps

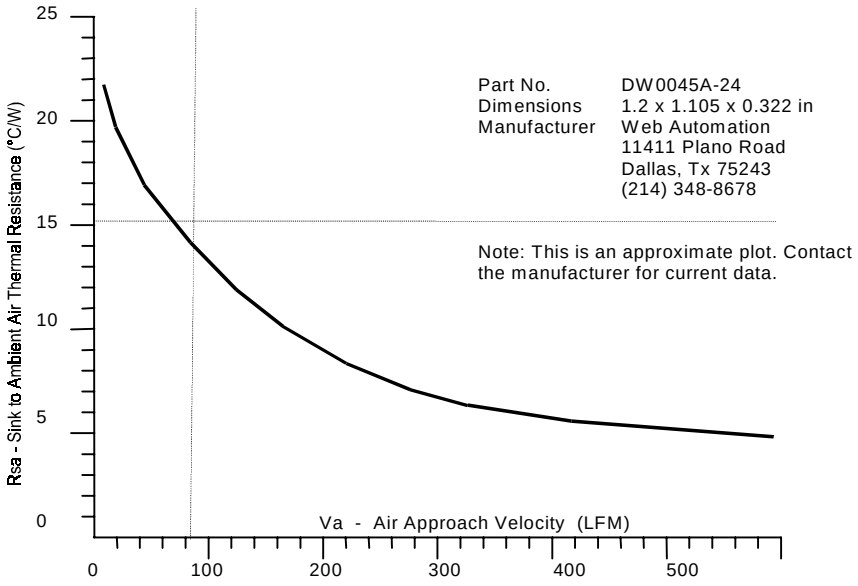
  RΘsa = {(Tc -Ta) / Ps} - RΘcs

  RΘsa = {(90 - 40) / 3.2} - 0.5

  RΘsa = 15.1 ºC/W

- Choose the heat sink based on the computed maximum sink to air resistance RΘsa and the minimum air approach velocity inside the enclosure. The heat sink performance plot below verifies that at 85 LFM minimum air velocity, the sink to air thermal resistance will indeed stay at or below the Rsa value of 15.1 ºC/W that is required to maintain the case temperature below Tc_{max} for the listed operating conditions. Actual experimental measurement of the case temperature should be performed next to verify heat sink performance. Figure 2 gives the performance plot of a heat sink that would satisfy the requirements of the system in Example 1.

Figure 2. Heat Sink Performance Plot



Example 2:

- Specify operating conditions

Pa = 6.9 W	average power dissipated by the case
Ta_{max} = 55 ºC	ambient air temperature
Va_{min} = 140 LFM	air approach velocity (linear feet per minute)
h_{max} = 17mm	height limit for the heat sink (system requirement)
RΘcs = 0.2 ºC/W	case to sink thermal resistance (using thermal grease)
Tc_{max} = 90 ºC	case temperature

- Estimate the total power that needs to be dissipated by the heat sink, Ps

  Ps = Pa - 2W (assume 2W dissipation through the board)

  Ps = 6.9 - 2 = 4.9 W

- Compute the maximum heat sink to air thermal resistance RΘsa that will maintain the case temperature below Tc_{max} for the operating conditions specified above.

  RΘsa + RΘcs = (Tc -Ta) / Ps

  RΘsa = {(Tc -Ta) / Ps} - RΘcs

  RΘsa = {(90 - 55) / 4.9} - 0.2

  RΘsa = 6.9 ºC/W

- Choose the heat sink based on the computed sink to air resistance RΘsa and the minimum air approach velocity inside the enclosure. The heat sink performance plot below verifies that at 140 LFM minimum air velocity, the sink to air thermal resistance will indeed stay at or below the Rsa value of 6.9 ºC/W that is required to maintain the case temperature below Tc_{max} for the listed operating conditions. Actual experimental measurement of the case temperature should be performed next to verify heat sink performance. Figure 3 gives the performance plot of a heat sink satisfying the requirements of the system in Example 2.

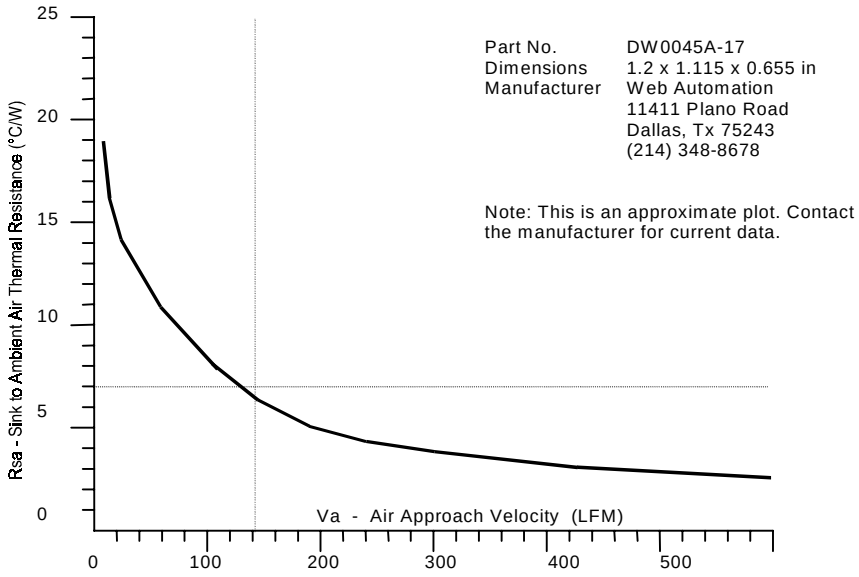



Figure 3. Heat Sink Performance Plot