APPLICATION NOTE

ST6x86 Thermal Design Considerations

1.0 Introduction

This Application Report serves as a guide in the thermal design of a personal computer that uses the SGS-Thomson ST6x86 Microprocessor. A simplified thermal model is presented that utilizes thermal resistances to describe heat flow from the CPU. Two case studies are included to show how to measure the thermal performance of the ST6x86 microprocessor in a typical computer enclosure. Additional examples illustrate the calculation of case temperatures at the maximum and nominal power levels. The D.C. Specifications and thermal data in the ST6x86 Microprocessor Data Book are expanded and updated in the Appendix in this Application Report.

1.1 Heat Flow

The ST6x86 CPU dissipates as much as 25 Watts of power depending on the CPU clock frequency. The CPU is mounted up-side-down in a PGA package (Figure 1). Most of the heat is concentrated at the surface of the semiconductor chip and is transferred to the package through three main paths:

1.) Through the bulk of the silicon chip to where the chip is mounted to the package.

2.) Through the bond wires to the package.

3.) Through radiation across the void between the chip and the bottom of the package.

The package is cooled by radiation, convection, and conduction. Some heat is conducted through the pins and the socket, but most of the heat passes from the package into the flowing air stream where it is transferred out of the equipment enclosure. The transfer of heat from the package to the ambient air can be greatly enhanced with the use of a heatsink. Our thermal model will concentrate on the heat flow from the case and heatsink to the surrounding air.

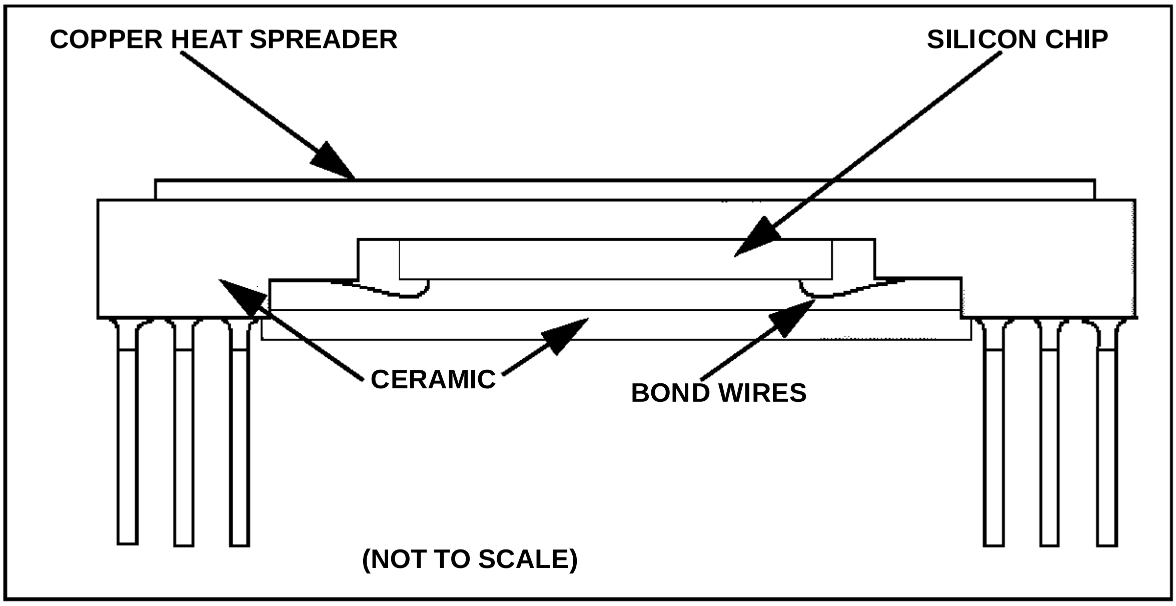

Figure 1. ST6x86 PGA Package Cross-Sectional View

This is advanced information on a new product now in development or undergoing evaluation. Details are subject to change without notice.

1.2 Thermal Resistance Model

As heat flows from a heat source to a cooler object, the resulting temperature drop (T_0 - T_1) which is similar to the voltage drop (E) across an electrical resistor. Electrical power (P) dissipated by the chip generates heat. Heat flows away from the source analogous to an electrical current (I). By dividing the temperature drop (T_0 - T_1) by the power (P) producing the heat, we obtain thermal resistance (θ) expressed in degrees Celsius (^oC) per Watt (W).

$$\theta = \frac{(T_0 - T_1)}{P} \; ^oC/W$$

[Similar to: Resistance = E (Potential Difference) / I (Current Flow)]

1.2.1 Thermal Resistances

Three thermal resistances (Figure 2) can be used to idealize the heat flow from the case of the ST6x86 CPU to ambient:

θ_{CS} = thermal resistance from case to heatsink in $^oC/W$.

θ_{SA} = thermal resistance from heatsink to ambient in $^oC/W$.

$\theta_{CA} = \theta_{CS} + \theta_{SA}$ = thermal resistance from case to ambient in $^oC/W$.

1.2.2 Temperatures

T_C = case temperature (top center) in ^oC.

T_S = heatsink temperature in ^oC.

T_A = ambient (free air) temperature in ^oC.

1.2.3 Power Dissipation

The power (P) dissipated by the CPU is given by

$P = V_{CC} * I_{CC}$ Watts (W).

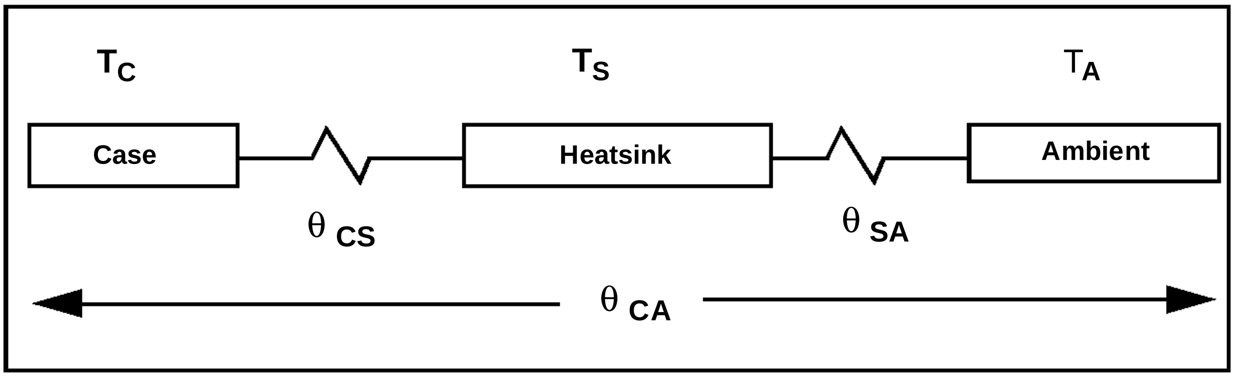

Figure 2. Thermal Resistor Model for Case to Ambient Thermal Resistance

1.3 Controlling the Case Temperature

Before power is applied, the case temperature is at ambient.

$T_C = T_A$

When power is applied, the case temperature rises as a function of the power applied and of the amount of heat lost to the ambient from the case.

$T_C = T_A + (P * \theta_{CA})$

The case temperature of the ST6x86 CPU must be controlled in such a way as to maintain a 70°C maximum temperature. The case temperature can be reduced by:

- Decreasing the case to ambient thermal resistance (θ_{CA}) through the use of a heatsink or a heatsink/fan.
- Increasing the air flow in the electronic enclosure to decrease the ambient temperature (T_A) .

1.4 Heatsinks and Heatsink/Fans

The case to air thermal resistance (θ_{CA}) can be greatly decreased through the use of a heatsink. Heatsinks improve radiation and convection efficiency. Using a heatsink, the thermal resistance (θ_{CA}) becomes the sum of the case to heatsink thermal resistance (θ_{CS}) and heatsink to ambient thermal resistance (θ_{SA})[1].

$\theta_{CA} = \theta_{CS} + \theta_{SA}$.

To take advantage of the heatsink, it is important to provide a good case to heatsink fit. Using sufficient clamping force between the heatsink and case and the application of thermal grease can reduce θ_{CS} to about 0.01 $^oC/W$. This allows the following approximation to be made:

$\theta_{CA} \cong \theta_{SA}$.

The heatsink to ambient thermal resistance can be improved by a factor of about three by using a heatsink/fan combination. A heatsink/fan reduces θ_{CA} by increasing the airflow across the heatsink.

1.5 Required Case to Ambient Thermal Resistance

If the maximum ambient temperature $T_{A(MAX)}$ inside the electronic enclosure is known, the required case to ambient thermal resistance can be calculated. The results of this calculation can be used to select which type of heatsinks or heatsink/fan is required. The equation below calculates the thermal resistance of a heatsink required for a particular application.

$$\theta_{CA} = \frac{T_{C(MAX)} - T_{A(MAX)}}{V_{CC(MAX)} * I_{CC(MAX)}} \quad ^oC/W$$

Note:

1. Some manufacturers use the symbol $R\theta_{SA}$ instead of θ_{SA} .