A Comparison of the Cooling Efficiency of Popular Tablets in a Natural Convection Environment

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Advancements in Thermal Management
August 6-7, 2014   Denver, Colorado
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Abstract

Since the Apple iPad opened up and legitimized the tablet market, tablets have become the fastest selling new product in the electronics market. This study explores the limits of natural convection cooling for handheld devices based on both testing and simulation and proposes a figure of merit for the efficiency of heat dissipation.

The factors affecting the maximum possible power dissipation are the available surface area and surface finishes, selection of the outer shell materials, thermal interface materials, heat spreaders and air gaps. In most cases, the limiting factor in the thermal design of these devices is not the temperatures of the internal components but the temperature of the external surfaces since these are in direct contact with the skin of the user.

There have been studies that address the maximum allowable comfortable touch temperature of a handheld device. This study presents a method for analyzing the quality of the thermal design of these devices.

The study presents the results of testing four popular tablets under similar conditions of computational and graphical stress and compares their natural convection thermal solutions against each other and to the theoretical optimum thermal design for their size.
Handheld devices are increasingly capable of running applications that used to require laptop and desktop computers. The requirement that these devices provide similar performance with a smaller form factor presents significant challenges, especially when one considers that passive cooling is almost a requirement.

Thermal design of next generation handheld tablet devices will need to address both a comfortable surface touch temperature and maximum temperature limitations of internal critical components while also meeting aggressive industrial design requirements.
Power Dissipation and Surface Temperature
Surface Temperature of a 10 Inch Vertical Isothermal Tablet
In a 25°C ambient condition, the maximum total power dissipation is calculated with a requirement that the surface temperature does not exceed a touch temperature of 41°C (16°C Temperature Rise). This is the maximum aluminum enclosure comfort touch temperature as presented by Berhe (2007). Use of low conductivity case materials has the effect of increasing the maximum comfortable touch temperature by about 5°C.

The chart on the right shows the surface temperature rise of an isothermal tablet vs power dissipation when the device is suspended vertically in midair with heat transfer occurring from all surfaces.

These calculations assume perfect heat spreading and a surface emissivity of 1.0. In actual practice, there will be hot spots on the device which have the effect of lowering the maximum allowable power.

Over half of the power is dissipated by radiation.
If the power dissipation at 41°C maximum touch temperature is calculated using CFD for three devices ranging from smart phone size through mini tablet size and a full-size tablet, the power dissipation versus surface area is shown for the device in both the vertical position and the horizontal position with an adiabatic lower surface.
Surface-to-Air Thermal Resistance vs Surface Area

From the power and temperature rise computations, it is now possible to calculate the surface-to-air thermal resistance of a vertical, isothermal tablet as a function of the exposed surface area. The results are shown in the chart on the right.
Tablet Teardown
iPAD Teardown

Frame removal
iPAD Teardown

The touch screen display removal
iPAD Teardown

The touch screen display removal
The touch screen display removal
iPAD Internal Components

- Batteries
- Camera
- Cabling
- Speaker

The touch screen display has been removed

Main PCB with EMI Shields over ICs
iPAD Cabling

Cabling to Main PCB
PCB Components
Instrumentation of the Tablet’s Internal Components
Experimental Results Compared to CFD Modeling
Natural Convection Tablet
Internal Surface Temperatures
Natural Convection Tablet
IR Imaging vs FloTHERM Simulation

IR Camera Image, Emissivity = 0.90
Numerical Simulation
Use of Heat Spreaders to Increase Power Dissipation
Use of Heat Spreaders

Heat spreaders may be either internal or part of the case structure. Through the use of high-conductivity heat spreaders, the maximum hot spot temperature is reduced. Due to reducing hot spot temperature, the average case temperature may be raised allowing increased power dissipation while not exceeding the maximum surface temperature requirement.

The following screen captures show the effect of increasing the thermal conductivity of a 0.8 mm thick case from 0.2 W/mK (plastic) to 200 W/mK (aluminum).

This study assumes an internal power dissipation of 8.9 watts and an ambient temperature of 24C. The tablet is in the vertical orientation.
Temperatures of Back Surface of Case

K = 0.2 W/mK

K = 2.0 W/mK
Temperatures of Back Surface of Case

K = 20 W/mK

K = 200 W/mK
## Effect of Case Thermal Conductivity

<table>
<thead>
<tr>
<th>k (W/mK)</th>
<th>Hot Spot (°C)</th>
<th>Case Center (°C)</th>
<th>CPU (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>81.3</td>
<td>34.6</td>
<td>99.1</td>
</tr>
<tr>
<td>2</td>
<td>69.9</td>
<td>35.5</td>
<td>87.9</td>
</tr>
<tr>
<td>20</td>
<td>51.2</td>
<td>35.7</td>
<td>73.3</td>
</tr>
<tr>
<td>200</td>
<td>39.9</td>
<td>34.9</td>
<td>64.2</td>
</tr>
</tbody>
</table>
Effect of Case Thermal Conductivity
Effect of Case Thermal Conductivity

Effect of Conductivity on Tablet Power Dissipation
41°C Hot Spot Temperature, 24°C Ambient, Vertical Orientation

Tablet Power Dissipation (W)

Heat Spreader Thermal Conductivity (W/mK)
Experimental Testing
Thermocouple and IR Measurements
Three Tablets Under Stress

Hotspot temperatures and power consumption are being measured while the tablets are running Riptide GP.
Shown below are infrared images of the back side of four different models of tablet. The tablets were running a game called Riptide GP which measures the graphics and computational capabilities of mobile devices. Ambient air temperature at the time of the test was recorded for each tablet to determine the temperature rise of the hot spot. The dark area running up the center of tablet A is from the support that was holding that tablet in the vertical position.
Heat Spreading Efficiency
Figure of Merit
Figure of Merit for the Quality of the Thermal Solution

Since heat spreading is the most important factor for dissipating heat from the outer surface of the tablet and reducing the temperature of hot spots, the authors propose the following figure of merit to determine the effectiveness of the thermal design of the tablet. The thermal heat spreading efficiency of the tablet can be defined as the ratio of the ideal thermal resistance of an isothermal tablet divided by the measured or simulated thermal resistance of the actual tablet. The thermal resistance of an isothermal tablet with emissivity equal to 1.0 is the very best that can be achieved on a theoretical basis. The isothermal thermal resistance is calculated by dividing the temperature rise ($\Delta T_i$) above ambient by the dissipated tablet power for an isothermal tablet. The actual thermal resistance is calculated by dividing the temperature rise ($\Delta T_a$) of the hot spot above ambient by the dissipated tablet power

Heat Spreading Efficiency = $\frac{R_i}{R_a}$

$R_i = \frac{\Delta T_i}{Q_i}$  \hspace{1cm} \text{Thermal resistance of an ideal isothermal tablet}$
$R_a = \frac{\Delta T_a}{Q_a}$  \hspace{1cm} \text{Thermal resistance of an actual tablet}$

Where:

$\Delta T_i = \text{Temperature rise above ambient for an ideal isothermal tablet with } e = 1.0$
$Q_i = \text{Power dissipation of the ideal isothermal tablet}$
$\Delta T_a = \text{Temperature rise of the hot spot above ambient for the actual tablet}$
$Q_a = \text{Power dissipation of the actual tablet}$
The following table summarizes the results of the testing for the four tablets and calculates the heat spreading efficiency of the thermal design for each tablet.

<table>
<thead>
<tr>
<th>Heat Spreading Efficiency</th>
<th>Tablet</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ambient Temperature (C)</td>
<td></td>
<td>23.7</td>
<td>19.0</td>
<td>20.0</td>
<td>20.0</td>
</tr>
<tr>
<td>Hot Spot Temperature (C)</td>
<td></td>
<td>44.4</td>
<td>36.9</td>
<td>35.4</td>
<td>36.0</td>
</tr>
<tr>
<td>Actual Delta T (C)</td>
<td></td>
<td>20.7</td>
<td>17.9</td>
<td>15.4</td>
<td>16.0</td>
</tr>
<tr>
<td>Power (W)</td>
<td></td>
<td>8.8</td>
<td>6.88</td>
<td>7.2</td>
<td>5.24</td>
</tr>
<tr>
<td>Ra (C/W)</td>
<td></td>
<td>2.35</td>
<td>2.60</td>
<td>2.14</td>
<td>3.05</td>
</tr>
<tr>
<td>Delta T iso (C)</td>
<td></td>
<td>16.0</td>
<td>16.0</td>
<td>16.0</td>
<td>16.0</td>
</tr>
<tr>
<td>Power iso (W)</td>
<td></td>
<td>13.9</td>
<td>13.9</td>
<td>13.9</td>
<td>9.5</td>
</tr>
<tr>
<td>Ri (C/W)</td>
<td></td>
<td>1.15</td>
<td>1.15</td>
<td>1.15</td>
<td>1.68</td>
</tr>
<tr>
<td>Efficiency</td>
<td></td>
<td>0.49</td>
<td>0.44</td>
<td>0.54</td>
<td>0.55</td>
</tr>
</tbody>
</table>
The maximum power dissipation of the internal components is not only governed by the size of the tablet but is a strong function of how well that heat is spread internally to reduce hot-spot temperatures. Few engineers realize the importance played by radiation in dissipating the heat from the exposed surfaces of a tablet. It is not until precise calculations are made that the importance of radiation is realized in the thermal design of the tablet. If the emissivities of the various surfaces are high, over half of the heat transfer to the surroundings is due to radiation. Overall heat transfer is maximized by reducing hot spot temperatures and spreading the heat so that all surfaces are effectively providing maximum heat transfer through convection and radiation.

Introduced in this presentation is the Heat Spreading Efficiency figure of merit that measures the actual cooling efficiency of a tablet against the theoretical maximum cooling efficiency. The perfect thermal design for a tablet cooled under natural convection has a Heat Spreading Efficiency of 1.0. Most of the current tablets on the market achieve an efficiency of around 0.5. However, tablet thickness and weight have to be traded off against efficiency to produce a viable product.
References


