Thermal-Mechanical Considerations for In-Vehicle Infotainment

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January 2009
Executive Summary

The thermal design power (TDP) for Embedded Menlow is low, approximately 4.5W for the kit - the lowest kit TDP produced by Intel in recent history, but it is not low enough to overcome thermal issues in some In-Vehicle Infotainment (IVI) applications. Until TDP decreases, another way to meet automotive requirements is to provide package-level thermal enhancements that allow for reliable operation in thermally restrictive IVI systems.

The packaging for Embedded Menlow XL allows for enhanced thermal performance and reliable operation and under extreme usage conditions.

To address the thermal-related requirements of IVI, larger packaging of Embedded Menlow was offered, now referred to as Embedded Menlow XL. The processor includes an integrated heat spreader (IHS) which allows the processor to run approximately 14 °C cooler, and below specification, in an IVI system. In addition to the thermal enhancements, Embedded Menlow XL also allows provides:

- An industrial temperature rating: -40 to 85 °C, and a higher Tj-max rating: 110 °C.
- Mechanical isolation of the critical thermal interface thereby minimizing the risk of TIM1 separation during shock and vibration events.
- Lower cost of ownership; seamless integration into existing manufacturing processes.
The packaging of Embedded Menlow XL was driven by automotive requirements, but it is also well suited for other rugged applications like military and industrial. The packaging for Embedded Menlow XL allows for enhanced thermal performance and reliable operation under extreme usage conditions.
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Background

In an effort to provide product differentiation and attract customers, In-Vehicle Infotainment (IVI) has become a selling point for the automotive industry. The typical feature set of Intel® architecture is well suited to meet the rich content that IVI demands. Historically, with respect to IVI, Intel® processors and chipsets dissipated too much power, had relatively low operating temperatures and did not meet reliability requirements. To bridge that gap, the Embedded & Communications Group considered adopting the Menlow platform (Intel® Atom™ processor and Intel® US15W System Controller Hub) for IVI, which already had a low kit thermal design power (~4.5W). To meet the higher operating temperature and reliability requirements, changes were made to factory testing and screening process to produce components that can reliably operate in an automotive environment.

As the Embedded Menlow platform began to attract the attention of the IVI industry, closer scrutiny of the Embedded Menlow platform revealed that thermal performance was lacking in the typical IVI application. Although TDP is low, the very small die size of the Intel® Atom™ processor leads to very high thermal interface resistances and to excessively high die junction temperatures. The high thermal interface resistance is inherent to the system-level thermal/mechanical design, where gap pads are used for thermal coupling and shock isolation. To address the thermal issues, a larger and thermally enhanced package change was required. The following content details the key issues that were resolved and led to the new larger package definition of Embedded Menlow, commonly referred to as Embedded Menlow XL.

Embedded Menlow & Menlow XL

The thermal solution options for the Intel® Atom™ processor and Intel® System Controller Hub US15W Chipset are dependent upon system-level packaging requirements. Typical IVI head units have common sizes, where the front panel size is governed by an industry-wide specification (1-DIN or 2-DIN) while the depth of the IVI module can vary. The head unit is packed with functionality: radio (FM/AM/Satellite), GPS – navigation, Audio, Video, LCD, CD/DVD, HDD, to name a few. As such, there is very little room, if any, for component heatsinks or fans; Figure 1 below shows the basic size of the Intel® Atom™ processor and Intel® System Controller Hub US15W Chipset. For components that need a heatsink, such functionality can be integrated into the chassis. In these cases a gap pad is used as the thermal interface between the component and the chassis, which is a relatively poor conductor but a good option for shock/vibration isolation and high volume manufacturing.
Chassis Conduction

When the primary heat transfer path, junction-to-chassis, is by conduction the Intel® Atom™ processor and Intel® System Controller Hub US15W Chipset (and other components potentially) interface to the chassis wall through a gap pad. The chassis acts as the sink for the components as the chassis conducts heat to mounting brackets and the local ambient (behind the dashboard) by natural convection/radiation. Figure 2 below shows a simple mechanical stack-up of the Printed Circuit Board (PCB) package, gap pad and chassis.
Overall thermal performance is highly dependent on the gap pad thermal interface. The thickness of the gap pad is determined by the height tolerances of the component packages and the mechanical standoffs that control the gap between the PCB and the chassis, and the working range of the gap pad itself (max. and min. compression). From the above example, the nominal gap pad thickness is 1.65 +/- 0.15mm.

**Preliminary Thermal Analysis**

As an initial estimate on thermal performance, a one-dimensional thermal model can be used to assess the thermal impact of the gap pad. Table 1 below illustrates the impact of die size on gap pad temperature difference when the gap pad is at a maximum material condition (1.80mm thk.).

<table>
<thead>
<tr>
<th>Component</th>
<th>Die Area (cm²)</th>
<th>Gap Pad Impedance (°C-cm²/W)</th>
<th>Gap Pad Resistance (°C/W)</th>
<th>TDP (W)</th>
<th>ΔT @ TDP (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atom</td>
<td>0.26</td>
<td>19.8</td>
<td>2.2</td>
<td>43</td>
<td></td>
</tr>
<tr>
<td>SCH</td>
<td>1.18</td>
<td>5.1</td>
<td>4.4</td>
<td>2.3</td>
<td>10</td>
</tr>
</tbody>
</table>

- Gap pad: 1.80 mm thk., k = 3.5 W/mK

If the allowable junction temperature is specified at 110 °C and the max. ambient temperature is 70 °C, the allowable temperature rise, ambient-to-junction, is only 35 °C. Based on this simple analysis, where the temperature rise in the gap pad alone is 43 °C, a potential thermal issue exists, calling for a more detailed analysis. With regard to the Intel® System Controller Hub US15W Chipset, the gap pad temperature rise is only 10 °C despite having
slightly more power. The Intel® System Controller Hub US15W thermal solution appears to be much more manageable at this stage.

**Detailed Thermal Analysis: Intel® Atom™ Processor**

As shown above, the very small die area of Intel® Atom™ processor leads to a very large gap pad resistance and corresponding temperature delta. However, the effect is overstated based on the conservative assumptions of the analysis. The fact of the matter is that not all of the processor heat will go through the die and into the gap pad. In a system configuration that depends on natural convection/radiation, conduction through the package and into the PCB can account for 15% to 40% of the overall heat transfer.

To get a better estimate of the true thermal performance, a 3-D conduction model of Intel® Atom™ processor with automotive boundary conditions was created. The chassis temperature is approximately 95°C and the PCB is approximately 105°C, which accounts for the mutual heating effects of nearby components.

**Figure 3. Intel® Atom™ Processor Conduction Model with Automotive Boundary Conditions**

The approximate temperature drop across the gap pad, junction-to-chassis, is 25°C – significantly less than the estimate from the 1-D model since less power is conducted through the gap pad (appx. 1.7W). From a resistance point of view, the gap pad resistance in the 3-D model is $\theta_{jc} = 14.6°C /W$, less than the 1-D model value of $19.8°C /W$ since spreading resistance is accounted for.
Improving Thermal Performance

Although the conduction model gives a better representation of gap pad thermal behavior, unfortunately the die temperature is still too high, approximately 11 °C over the $T_{j,max}$ limit of 110°C. Gap pad improvements are limited since the thickness is a function of the mechanical tolerances and gap pad working range. Improvements in gap pad material conductivity would have to be at least 5X better, which is possible but cost prohibitive.

Another option is to introduce a high conductivity heat spreader between the die and gap pad, which would effectively lower the die heat flux at the gap pad interface. As seen with the 1-D model, the Intel® System Controller Hub US15W Chipset has ~4.5X the die area and a correspondingly lower heat flux: 2.0 W/cm² for the SCH vs. 8.5 W/cm² for the Intel® Atom™ processor.

Figure 4. Intel® Atom™ processor with heatspreader

The conduction model was updated by adding a copper heatspreader between the die and gap pad. The copper heatspreader is 0.5 mm thick and has the same footprint as the package (13 mm x14 mm). A new thermal interface material (TIM1) is introduced between the die and heat spreader; it is assumed this material has an impedance of 0.40 °C-cm²/W.

Figure 5. Intel® Atom™ Processor Conduction Model with Copper Heatspreader
Although a second interface material has been added (TIM1), an intermediate heat spreader allows for a \( \sim 12 \) °C improvement in \( T_j \), now 109 °C which is below specification. Comparing Figures 3 and 5, the gap pad isotherms in Figure 5 indicate that much more of the gap pad is “working” as compared to Figure 3. The nearly uniform temperature of the heatspreader, coupled with its area (1.82 cm\(^2\)) – about 7X that of the Intel® Atom™ processor die, minimizes the thermal impact of the gap pad.

**Embedded Menlow XL Packaging**

In the previous section it was shown that Intel® Atom™ processor could work in an IVI system if a copper heatspreader was added between the die and gap pad. Thermally this works, but it may be an unwanted assembly step in manufacturing and may pose a reliability risk if the heatspreader separated from the die, compromising TIM1, during a shock or vibration event. To address these pressing issues, a larger package definition was implemented although it took away the small foot print advantage of Menlow. Figure 6 below shows the basic package sizes of Embedded Menlow XL. The Menlow kit area is 666 mm\(^2\) while the Menlow XL kit area is 1890 mm\(^2\).

**Figure 6. Menlow XL Package Definition**
Detailed Thermal Analysis: Menlow XL Processor

With the bigger package the integrated heatspreader (IHS) size for the Menlow XL processor is 16.5 mm x 15 mm with a nominal thickness is 0.8 mm. The thermal interface between the die and IHS is 0.40 °C-cm²/W, which represents the expected “end of life” TIM1 performance.

Figure 7. Menlow XL Thermal Model

As seen in Figure 7, the maximum die temperature is approximately 107 °C, about 2 °C less than the Intel® Atom™ processor example with a heatspreader. With respect to the earlier analysis where the temperature drop from junction-to-chassis was approximately 25 °C, this model indicates the same temperature drop is now approximately 11 °C, so quite an improvement despite the addition of a second interface material and copper heatspreader (gap pad thickness of 1.80 mm remained the same).

Thermal-Mechanical Improvements with Menlow XL

The Menlow XL packaging includes an integrated heat spreader (IHS) for the processor. Primarily for the thermal performance improvements as noted above, the IHS provides these additional advantages:

- Mechanical isolation of critical thermal interface between die and IHS; minimizes the risk of TIM1 separation.
- Protects the processor thin die (the Intel® System Controller Hub US15W Chipset has a relatively thick die).
- Allows for higher compressive loads if a heatsink is used.
- Lower cost of ownership – does not need secondary heatspreader.
• The processor and Intel® System Controller Hub US15W Chipset are approximately the same height (within 0.06mm) – common heatspreader designs could be simple plates instead of machined or stamped heatspreaders; difference in height could be made up by gap pads.

It should be noted that the IHS surface area (1.82 cm²) is not large enough to be a viable surface for convection/radiation alone – some kind of heatsink or chassis integration will be needed for the extreme environments seen in automotive, industrial and military. Outside of those applications it may not be necessary to attach a heatsink if the PCB is large enough, overall system power is low and the local ambient is low (~35°C or less).

Conclusion

The automotive in-vehicle infotainment market has unique environmental and packaging requirements, where temperature specifications may be as high as those seen in military environments, but at the same time system designs must be low-cost and conform to the rules of high volume manufacturing. These constraints present significant challenges for thermal solution design, where options may be limited to conduction to the chassis, through gap pads, as the primary component heat transfer path.

Embedded Menlow appeared to be a good fit for IVI with its low power product offering. However, despite its low TDP the very small die of the Intel® Atom™ processor leads to a high gap pad thermal resistance, creating a system-level thermal issue. This can be resolved by adding a heatspreader between the Intel® Atom™ processor die and gap pad, but this creates an additional assembly step and creates a new risk, TIM separation, that’s likely to appear in the IVI shock/vibe environment.

To address these issues, the Embedded Menlow XL package was offered, where a larger package with an integrated heat spreader is used to achieve the package- and system-level thermal performance required. In addition to meeting thermal requirements, the larger package with IHS provides a lower cost of ownership and high reliability as compared to the Intel® Atom™ processor. The Embedded Menlow XL packaging is well suited for the rigors of automotive markets, as well as industrial and military markets, wherever reliable, high temperature operation is required.
## Authors

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## Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tbody>
<tr>
<td>DIN</td>
<td>Deutsches Institut fur Normung (German Institute for Standardization)</td>
</tr>
<tr>
<td>IHS</td>
<td>Integrated Heat Spreader</td>
</tr>
<tr>
<td>IVI</td>
<td>In-Vehicle Infotainment</td>
</tr>
<tr>
<td>SCH</td>
<td>System Controller Hub</td>
</tr>
<tr>
<td>TDP</td>
<td>Thermal Design Power</td>
</tr>
<tr>
<td>TIM1</td>
<td>Thermal Interface Material One: interface between die and IHS</td>
</tr>
<tr>
<td>TIM2</td>
<td>Thermal Interface Material Two: interface between IHS and system thermal solution (chassis, sink, heatspreader, etc.)</td>
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