Optimized for Atom: Choosing Atom or Atom XL - is the industrially rated chip worth it?

How the temperature range of the commercial grade Intel® Atom™ processor CPU can be extended, and what issues are associated with application of Atom chipsets with Atom level power consumption but industrial temperature specifications.

Whitepaper

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Abstract

The low power Intel® Atom™ CPU is not just for laptops and MIDs- it is beginning to be applied as the center of single board computers for general industrial, medical and commercial applications. This has increased the demand for operation under extended and industrial temperature regimes either by up rating the commercial Atom processor, or by using the new Atom XL CPU. For ten years the Columbia, MD design center of Eurotech has up rated ARM and other CPU architectures, and we compared uprating of the standard Atom part to the Atom XL, which is rated for either extended temperature (-20°C to +70°C) or Industrial Temperature (-40°C to +85°C). We performed some thermal tests to verify extended temperature range and to further discuss the design and manufacturing issues associated with the industrial temperature rated x86 chips.

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Introduction to Up Rating

For more than ten years we have been supplying extended temperature range single board computers, often based on semiconductor components not rated for extended temperature service. This effort has been driven by cost only as a secondary issue as very often the desired high performance chips were not provided in extended temperature versions at all. Up rating is not a simple matter of trying a commercial chip at industrial or extended temperatures; it is a specific process originally defined by the FAA for in-flight avionics. To perform this up rating, we most often used the services of the University of Maryland CALCE lab[1]. Now, with the Intel Atom processor becoming a popular low power solution, we ran some tests to see if it could be up rated, and if so, how far.

Before detailing the tests conducted, it is important to discuss the process of up rating and the nature of operating at extended temperature ranges. Physics is what counts, and the physics at the semiconductor junction is most important. The specs at each semiconductor junction (like rise time, fall times, setup time, hold time, propagation delay) vary with temperature. In an up rated design, the degraded specs can be measured and the design carried out within those limits. For example, MOS memory, which is basically a series of capacitors, may not have the same charge retention and hold time at elevated temperatures that it does at commercial temperatures, mandating extra refresh cycles in the code. This junction temperature is quite different from the ambient temperature specified for the chips. For low temperature operation, chips self heat, and at the low end it is sometimes possible to let a cold chip heat itself until the junction is at operating temperature range. On the other hand, at high temperature the heat transfer of the chip package must be studied with thermographic camera limits to verify that the silicon junction temperature is not too hot to function.

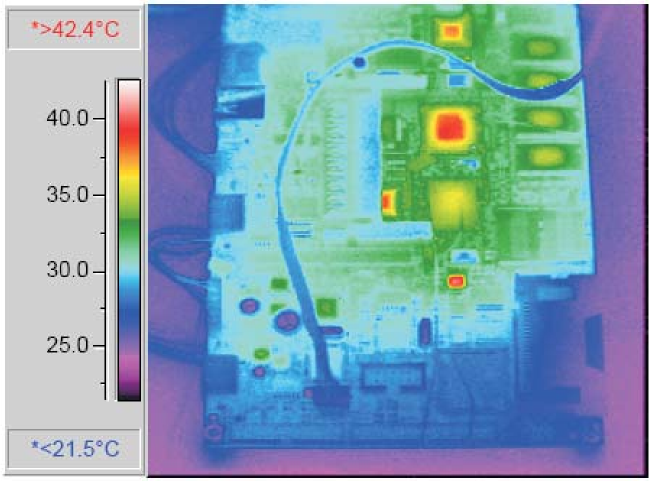

Figure 1- A thermograph camera catches the chip surface temperatures of an operating board in an oven.

Extending the temperature range for Intel Atom Processor and Companion Chip

For years Intel® Architecture processing systems have been synonymous with high power, heat sinks, and fans that were originally designed for server and desktop applications. The new 45nm process combined with advanced packaging technology changes all the rules and allows a new generation of Intel processors (specifically Intel Atom) to operate in free air with no heat sinking. This low power dissipation and excellent thermal conductivity poses the question: is there now a new paradigm for up rating commercial devices to run over the extended temperature range?

In previous generation systems, after being cold-soaked, devices could be turned on, held in reset and allowed to self heat until the case or the junction temperature met the minimum operating temperature. This process allowed a system designer to make a trade-off between turn-on time and minimum operating temperature. If the turn-on time was too long and not acceptable, the designer was forced to use industrial grade components. This low temperature operation is surprisingly critical and difficult to achieve.

[1] See http://www.eurotech-inc.com/embedded-lab-certifications.asp

First, many people want to deploy Intel Atom processor-based systems in vehicles. These vehicles might be left outdoors in a cold North Dakota winter. A cold boot from -40 degrees is not an abstract requirement. Second, the internal logic of the chip is extremely complex, and the start up contains time-dependent 'intra-processor' steps that could be made non-deterministic if some piece of logic runs fast because it is colder than another piece. Third, the Intel Atom processor, like virtually all high performance commercial chips, is manufactured in a process where specs are parameterized after 'the die is cast,' meaning chip-to-chip variation (within spec limits) is to be expected. Outside of spec limits, however, this variation might be serious enough to impair function.

When Eurotech began the design of the Intel Atom processor-based Catalyst Module, the project design guidelines required that all specified support ICs (such as regulators, crystals, logic, etc.) would be required to operate over the industrial temperature range. This was an easy requirement to meet as most of these types of devices are specified and guaranteed by the manufacturer to operate from -40°C to +85°C. This left just the Intel Atom processor, its companion chip, the Intel® System Controller Hub US15W (Intel® SCH US15W), and DDR-2 DRAMs as devices that could be specified as either commercial or industrial. When Intel first released the Intel Atom processor and SCH US15W in the smaller packages and only in the commercial temperature range, many manufacturers had to scramble to offer extended temperature range processor modules based on a perhaps untested process of self qualification. At Eurotech, however, we will not imply the components' performance without repeatable testing.

Therefore, we ran a test to see if the low temperature limit of the Atom processor and SCH US15W chip could be extended by using self heating. With the Atom setting new levels of low power operation and low power consumption, its ability to self heat to extend low temperature operation cannot be assumed.

Test Organization and Result

The tests were run on a Eurotech Catalyst Module mounted on a Catalyst EC connector card. The unit was placed into a Thermotron temperature chamber and allowed to soak at -10, -20, -30 and -40 degrees Celsius for thirty minutes. The scenario implemented was to cold-soak the card for 30 minutes, then apply power with the system in reset and measure the warm-up time for the Atom processor and SCH US15W to reach their minimum operating temperature. An on-die thermal diode was used to measure the temperature to get an accurate reading of the actual die temperature. Scenarios were run from cold-soak temperatures of 0, -10, -20, -30 and -40 degrees Celsius.

The on-board microcontroller that monitors the die temperature holds the processor in reset mode until the specified low end temperature is met, thus allowing the operating system to boot. The microcontroller reports its data via a serial port to a PC running a standard terminal program to capture the on-die temperature warm-up profile at one second intervals with a resolution of one degree.

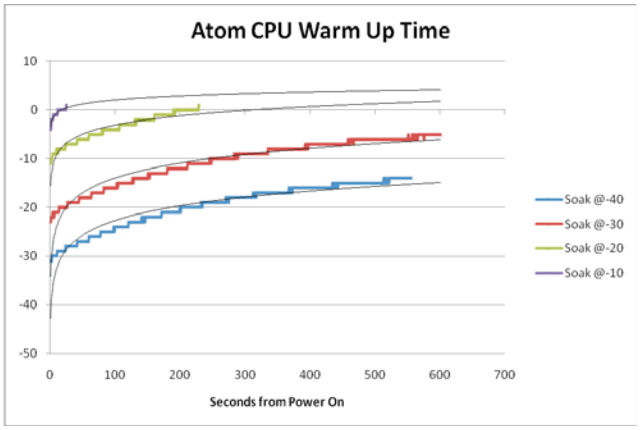

Figure 2- Atom Processor Warm-Up Time Test Results, December 2008

As seen from the graph in Figure 2, the excellent thermal characteristics of the Intel Atom processor packaging and the low power dissipated under a reset condition do not allow the die to reach the recommended operating temperature within an acceptable warm-up time (less than one minute). Temperature rises of 5° to 6°C within one minute are achievable, but warm-up temperatures from below -10°C are just not achievable without some type of heating assistance, an undesirable function for battery or solar powered equipment.

Design with the Intel Atom XL

The Atom chip packaged for industrial temperature range is quite different than the commercial temperature version. In particular, the Atom XL is build on 1 mm ball pitch centers which make the carrier board easier to build, at the expense of board real estate. So the OEM faces two costs to use the industrial temperature part: component cost and board cost.

Figure 3- Side by side comparison of commercial and industrially rated Catalyst Module platforms (commercial temperature range on right; notice much smaller chip package). These are complete computers, with everything but connectors and boot media. Both are the same size, same the pin out configuration.

There is a real tradeoff here. Some money can be saved if the commercial Atom components are used. With the investment of a little time, some up rating can be accomplished. With the investment of considerable time to perform a FMEA analysis, more up rating might be possible, even to the extended temperature or industrial temperature ranges. However, for many OEMs the cost point favorable for up rating might be at higher volumes that expected.

Eurotech decided to give its OEMs the option to offer either, or both, industrial and standard temperature components. Both the commercial-grade Catalyst Module and industrial-rated Catalyst Module XL are designed in the same 67 x 100 mm package. This flexibility in module offerings allows an OEM customer to trade off cost versus environmental performance as he likes, or to even offer both options to his customer.

Conclusion

Our tests show that, at least for low temperature operation, an Intel-qualified industrial-grade Atom processor would be well advised. A heater could be placed on the chip to speed warm up, but this same heater would perhaps cause heat transfer problems at the high end of the temperature range. It is also possible that most Atom chips will start up cold a majority of the time, but we would not recommend out-of-spec application unless the system was specifically accessed via a formal Failure Mitigation and Effects Analysis (FMEA) process.

We recommend companies design around an Atom module that can host either the commercial or industrially related component. This flexibility gives them the option of using the current commercial-grade Intel Atom processor with the expectation of changing to industrial temperature when needed.

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