Digital Thermal Sensors and the DTS based Thermal Specification for the Intel® Core™ i7 Processor (Bloomfield)

Benson Inkley

Intel® Microarchitecture (Larrabee) Technical Marketing

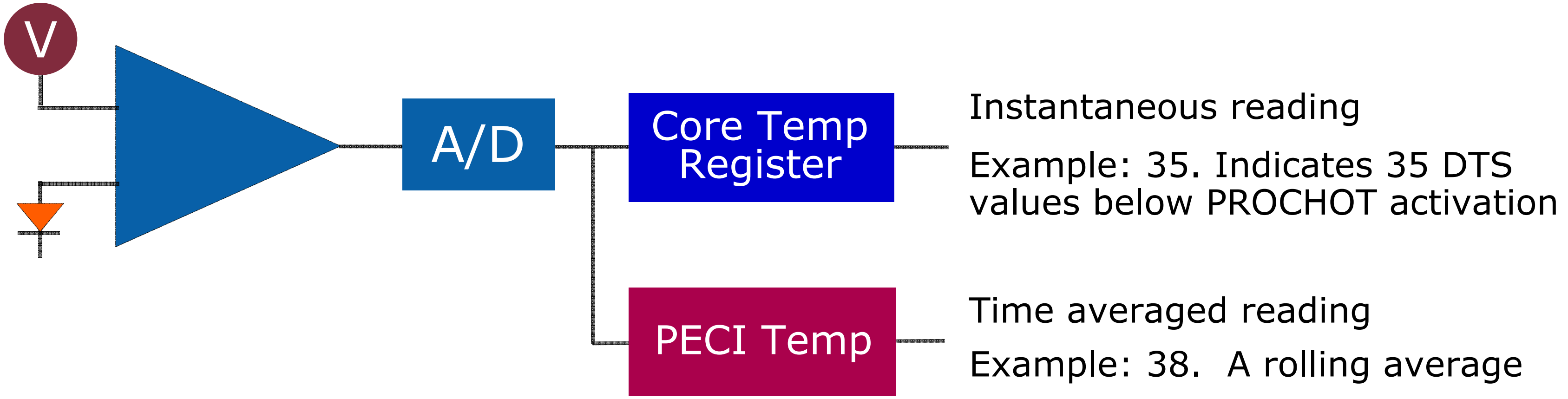
TPWS002

Agenda

- Digital Thermal Sensors
- Intel Processor Temperatures
- Thermal Specification Review
- Intel® Core™ i7 processor DTS Thermal Specifications

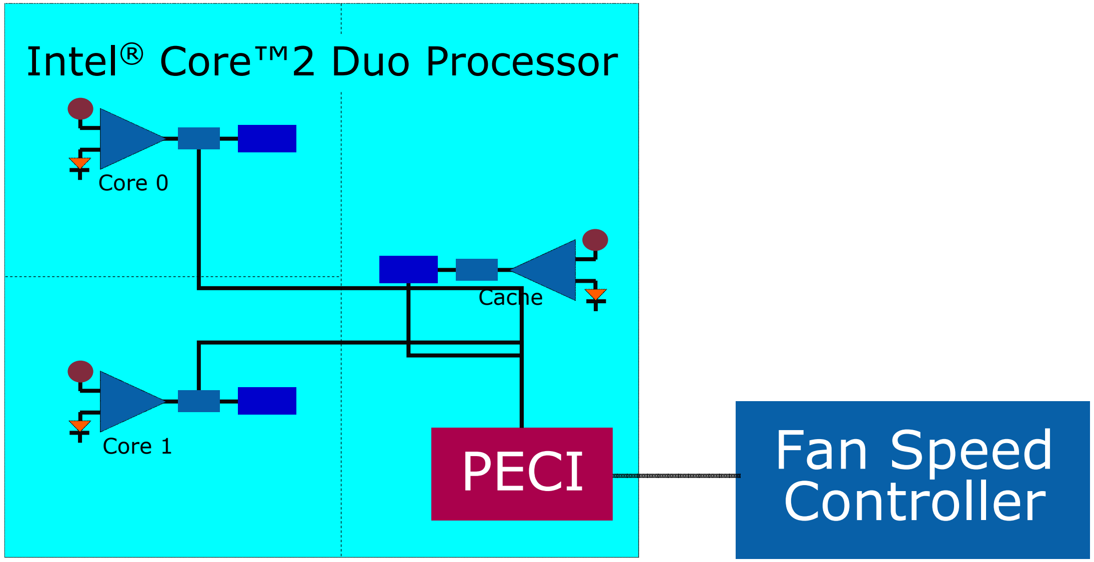
Digital Thermal Sensors (DTS)

- Intel processors contain a Digital Thermal Sensor
  - Converts analog signal to digital value
  - Reports temperatures as a relative offset from 0
  - When DTS = 0, PROCHOT# is activated
- Data stored in an internal register and PECI averaging register
  - Internal registers are software visible
  - PECI is bi-directional single pin interface to processor registers



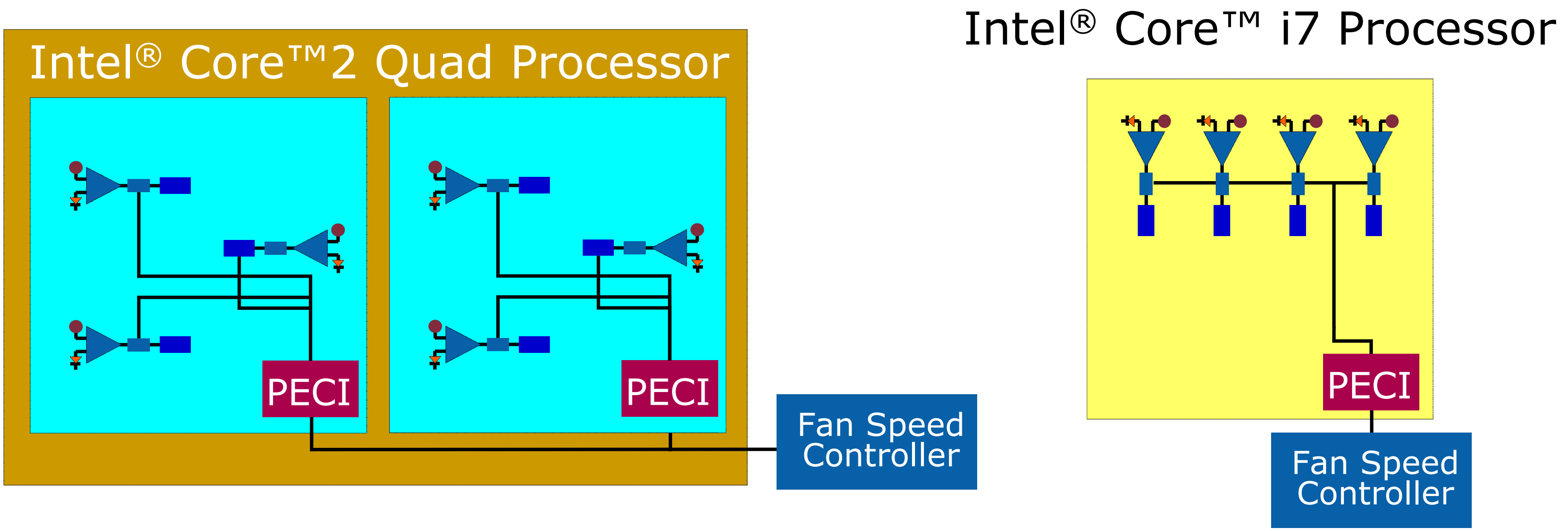
Dual-Core DTS Implementation

- Multiple DTS sensors per processor die
- Software only has access to the core temperature register
- PECI monitors all sensors and selects the highest temperature
  - Temperature is a rolling average of previous high temperatures
  - $T_{CONTROL}$ specifications are relative to the PECI temperature



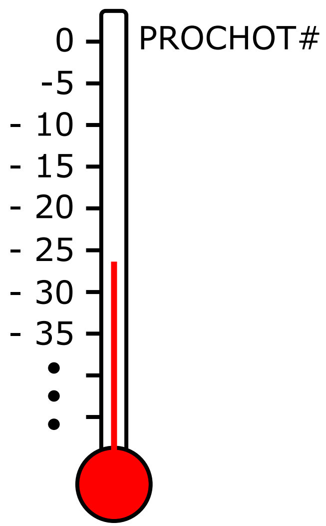
Quad-Core DTS Implementations

- Dual die quad-core processors have 2 PECI domains
  - Fan speed control must use PECI to access DTS on both die
  - Hottest die is used to determine fan speed
- Monolithic quad-core processor has only one PECI domain

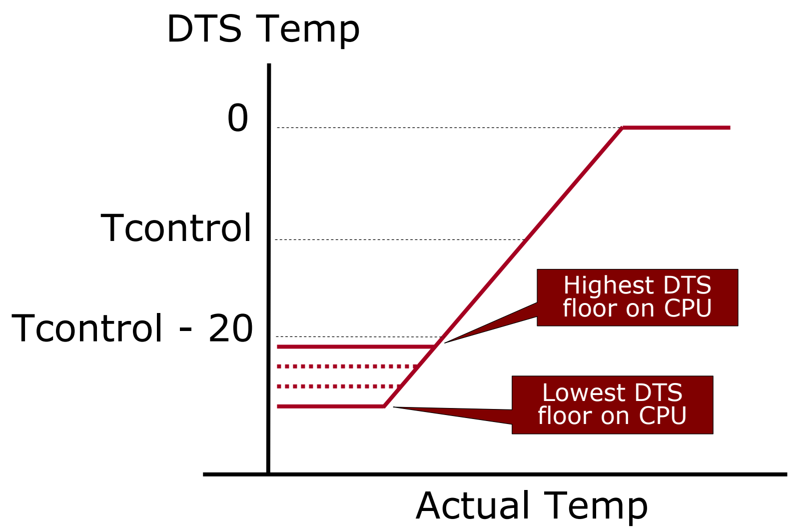


DTS Range

- DTS circuit is designed for a reasonable operating range
  - DTS may 'bottom out' when temperatures are ~20 C below Tcontrol
  - Lower limit depends on characteristics of each DTS



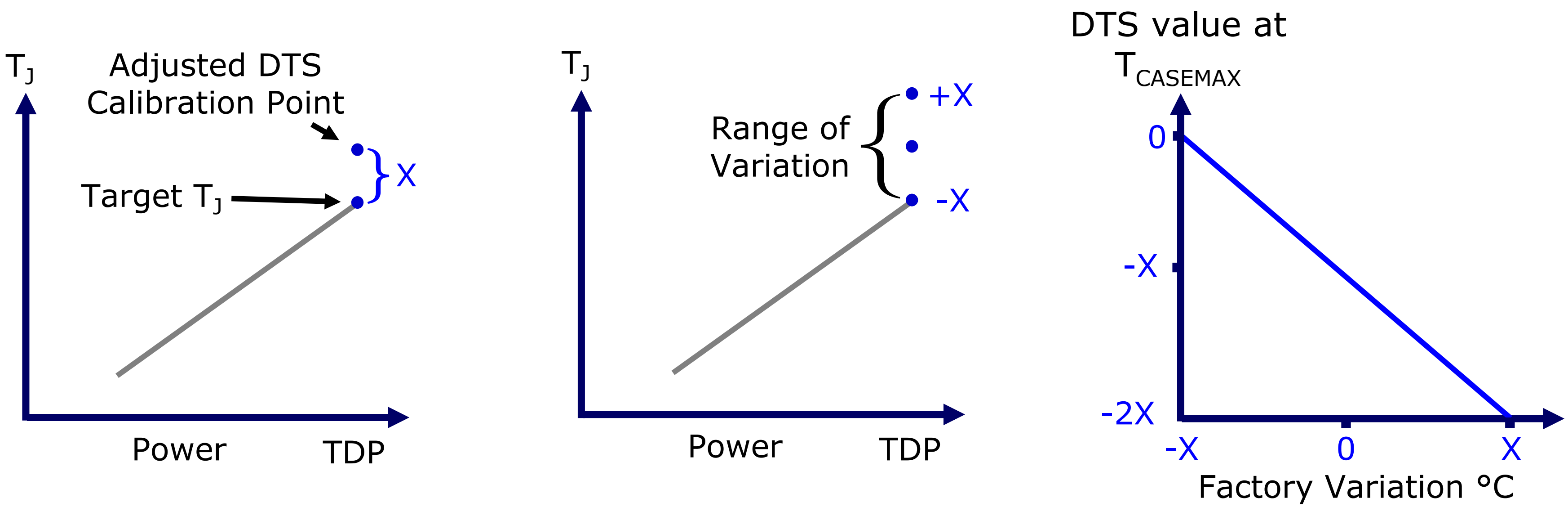
DTS reported as offset from Zero



DTS Range Limits

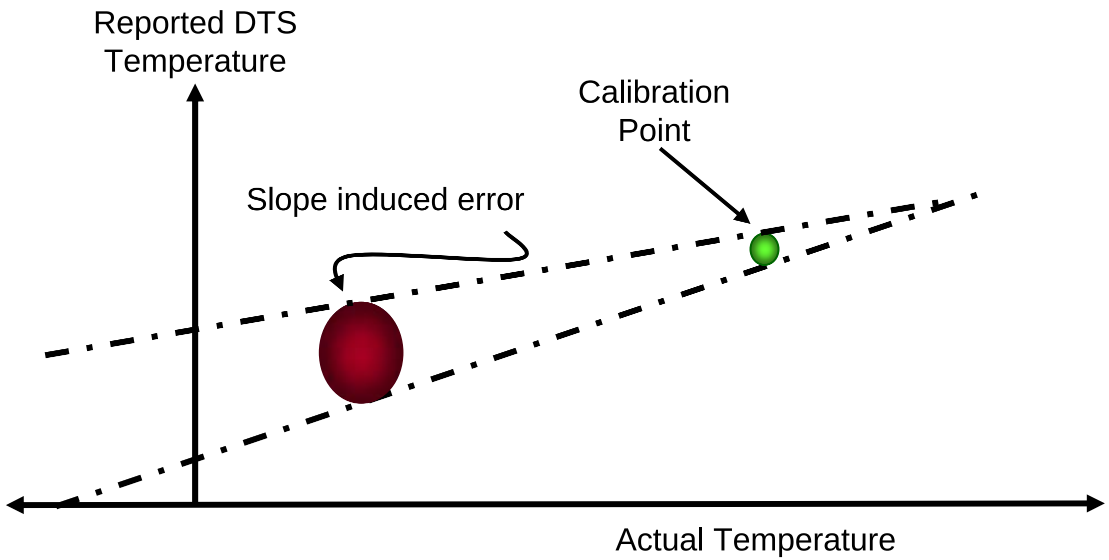
Sensor Calibration

- Each device is individually calibrated
  - Normal factory variation influences the accuracy
  - PROCHOT# trip temperature will vary from part to part
- DTS calibration point adjusted higher than target $T_{JUNCTION}$
  - Minimizes potential for PROCHOT# activation below $T_{CASEMAX}$
  - Influences reported DTS temperature at $T_{CASEMAX}$
- This is one reason why DTS cannot be used to predict T_{CASE}



DTS Slope

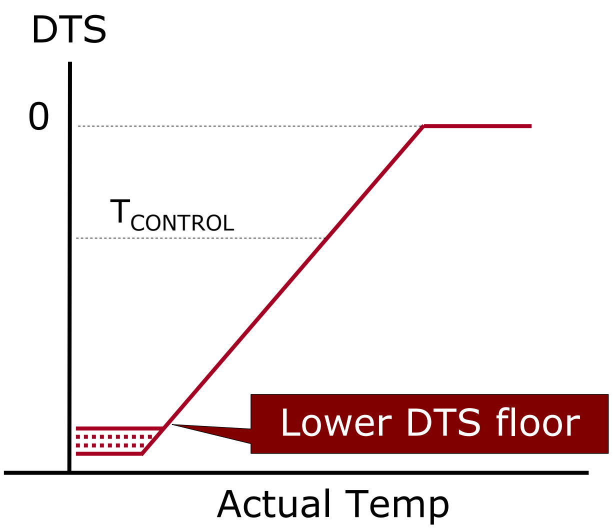
- 1 °C change in temperature may not cause DTS to change by 1
  - Slope error overshadows calibration error at lower temperatures
  - 2nd reason why DTS cannot be used to predict T_{CASE}
- Accuracy works well for intended uses
  - Fan speed control
  - Thermal solution failure detection

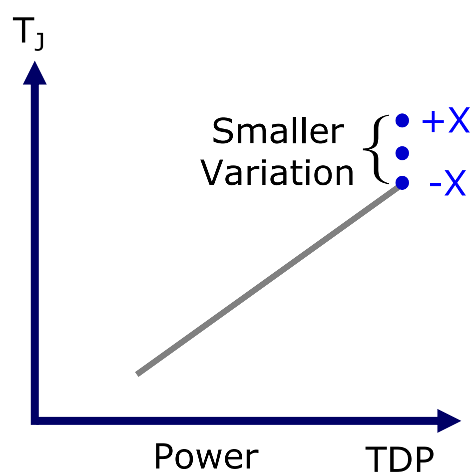


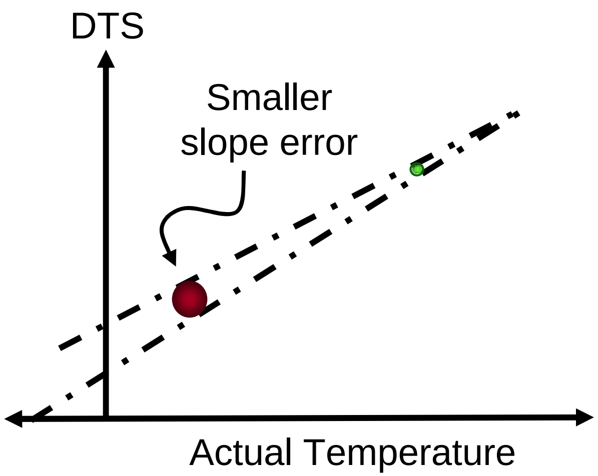
DTS Enhancements

- Nehalem has improved the Digital Thermal Sensor circuit
  - Expanded temperature range – unlikely to 'bottom out'
  - Calibration accuracy is improved
  - Slope error is reduced

- Future processors may report temperatures in °C



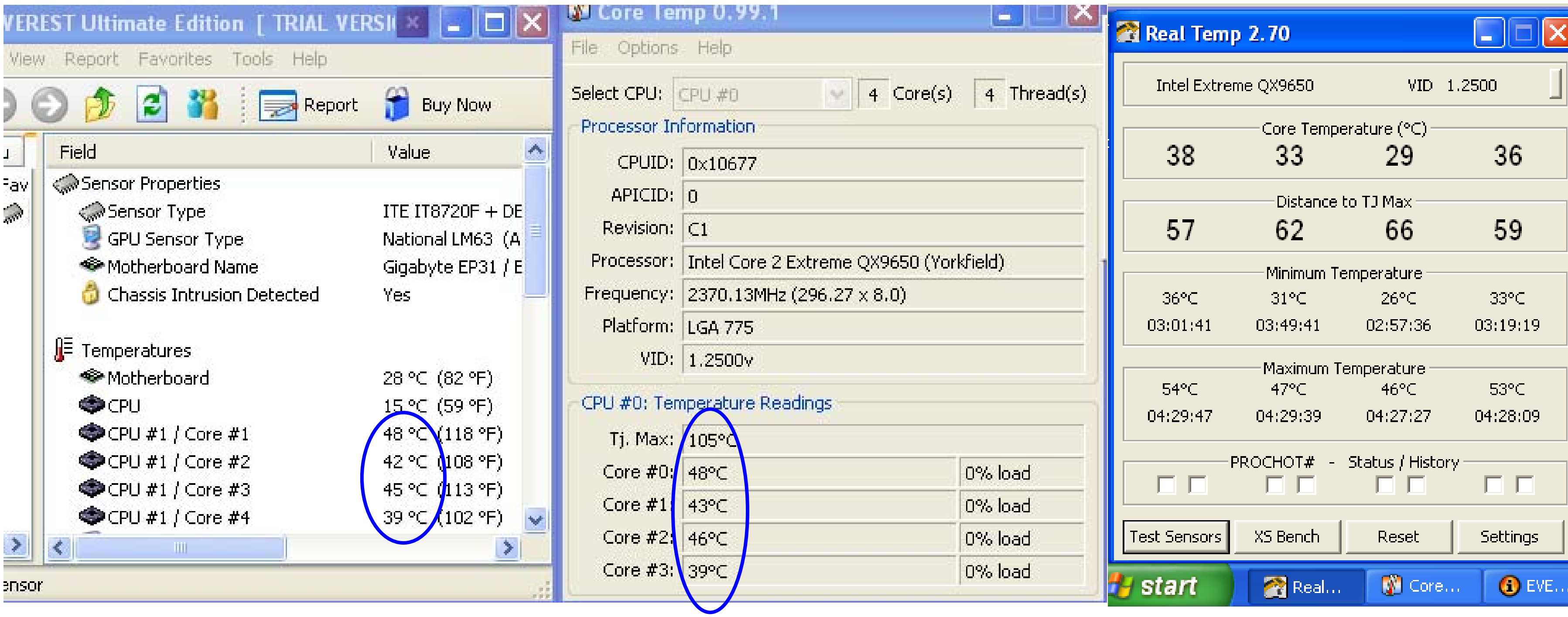




T_J For Mobile Processors

- Mobile Datasheet specifies T_J: 85, 100, 105 °C, etc.
- Which T_J to use is determined by Bit X in Register Y
- This mechanism does not apply to Desktop or Server processors
  - Bit X in Register Y for these processors is undefined
  - It may be 0 or might be 1
  - Depends on the design of that particular product family
- Applications that use this mechanism will report invalid temperature data

Temperature Utility Update



- Most temperature reporting utilities have been updated with 45nm desktop T_J information from San Francisco IDF
- 65nm and Xeon® processor information available today

Agenda

- Digital Temperature Sensors
- Intel Processor Temperatures
- Thermal Specification Review
- Intel® Core™ i7 processor DTS Thermal Specifications

Processor $T_{JUNCTION}$ Targets

- The values listed for T_J Target are not specifications
- Remember, as described earlier, in most cases the DTS calibration point will be higher than the T_J Target values
- Intel reserves the right to change the T_J targets at any time without notice
- If T_J targets change, Intel will provide an appropriate update
- Thermal solutions must be designed to meet the Thermal Profile as defined in the processor Datasheet

T_J For 45nm Desktop Processors

45nm Desktop Dual-Core Processors	Target T_J
• Intel® Core™2 Duo processor E8000 and E7000 series	100 °C

45 nm Desktop Quad-Core Processors	
• Intel® Core™2 Quad processor Q9000 and Q8000 series	100 °C
• Intel® Core™2 Extreme processor QX9650	95 °C
• Intel® Core™2 Extreme processor QX9770/9775	85 °C

T_J For 65nm Desktop Processors

65nm Desktop Dual-Core Processors	Stepping:	B2	G0
• Intel® Core™2 Duo processor E6000/E4000 series		70	80 °C
• Intel® Core™2 Extreme processor X6800		75	85 °C
65 nm Desktop Quad-Core Processors			
• Intel® Core™2 Quad processor Q6000 series		80	90 °C
• Intel® Core™2 Extreme processor QX6000 series		80	90 °C
• Intel® Core™2 Extreme processor QX68XX		80	80 °C
65 nm Intel® Celeron® Processors	Stepping:	L2	M0
• E1000 series		75	85 °C

- T_J increased on G0 stepping to enable lower cost heatsinks or quieter systems (slower fan speed)

Intel® Xeon® Processors

- Intel Xeon processors are available for many applications
  - Tele-communications: switches, mobile phone infrastructure
  - High performance computing: molecular research, rendering
  - Transaction processing: banking systems, airline reservations
  - File sharing: corporate email, web based social networking
  - Many others
- Each of these have different environmental requirements
- Intel provides many versions of Xeon processors to meet the needs of each market segment
- As a result, there are many more Tj numbers for Xeon processors than there are for desktop processors
  - It may not be possible to use <u>software</u> to identify exactly which device is installed in the system
  - Consequently, <u>software</u> may not be able to determine the appropriate Tj for each part

45nm Intel® Xeon® Processors 7400

45nm Intel® Xeon® Processors 6-Core	Target T_J
• Intel Xeon processors X7460	85 °C
• Intel Xeon processors E7450	85 °C
• Intel Xeon processors L7455	85 °C
45nm Intel® Xeon® Processors Quad-Core	
• E7440, E7430, E7420 Series	90 °C
• Intel Xeon processors L7445	80 °C

65nm Intel® Xeon® Processors 7000

65nm Intel® Xeon® Processors Quad-Core	Target T_J
• X7350	90 °C
• E7340, E7330, E7320, E7310	80 °C
• L7345	80 °C

65nm Intel® Xeon® Processors Dual-Core	
• E7220, E7210	80 °C
• 7100 series	100 °C

45nm Intel® Xeon® Processors 5400

45nm Intel® Xeon® Processors Quad-Core	Target T_J
• X5492, X5482, X5472, X5470, X5460, X5450	85 °C
• E5472, E5462, E5450/40/30/20/10/05	85 °C
• L5408	95 °C
• L5430, L5420, L5410	70 °C

45nm Intel® Xeon® Processors 5200

45nm Intel® Xeon® Processors Dual-Core	Target T_J
• X5282, X5272, X5270, X5260	90 °C
• E5240, E5220, E5205	90 °C
• E5205, E5220	70 °C
• L5240	70 °C
• L5238, L5215	95 °C

65nm Intel® Xeon® Processors 5000

65nm Intel® Xeon® Processors Quad-Core	Target T_J
• Intel Xeon processors X5000	95 °C
• Intel Xeon processors X5000	90 °C
• Intel Xeon processors E5000	80 °C
• Intel Xeon processors L5000	70 °C
• L5318	95 °C

65nm Intel® Xeon® Processors Dual-Core	Stepping:	B2	G0
• 5080, 5063, 5060, 5050, 5030		80	90 °C
• 5160, 5150, 5148, 5140, 5130, 5120, 5110			80 °C
• L5138			100 °C

45nm Intel® Xeon® Processors 3000

45nm Intel® Xeon® Processors Quad-Core	Target T_J
• X3370/60/50/30/20	95 °C
• L3360	90 °C

45nm Intel® Xeon® Processors Dual-Core	
• E3120, E3113, E3110	95 °C
• L3110	95 °C

45nm Intel® Xeon® Processors Single-Core	
• L3014	95 °C

65nm Intel® Xeon® Processors 3000

65nm Intel® Xeon® Processors Quad-Core		Target T_J
• XEE		80 °C
• XE		90 °C
• X3230, X3220, X3210		90 °C

65nm Intel® Xeon® Processors Dual-Core	Stepping:	B2	G0
• 3085, 3075, 3070, 3065, 3060/50/40		80	90 °C

Intel® Core™ i7 Processor T_J Target

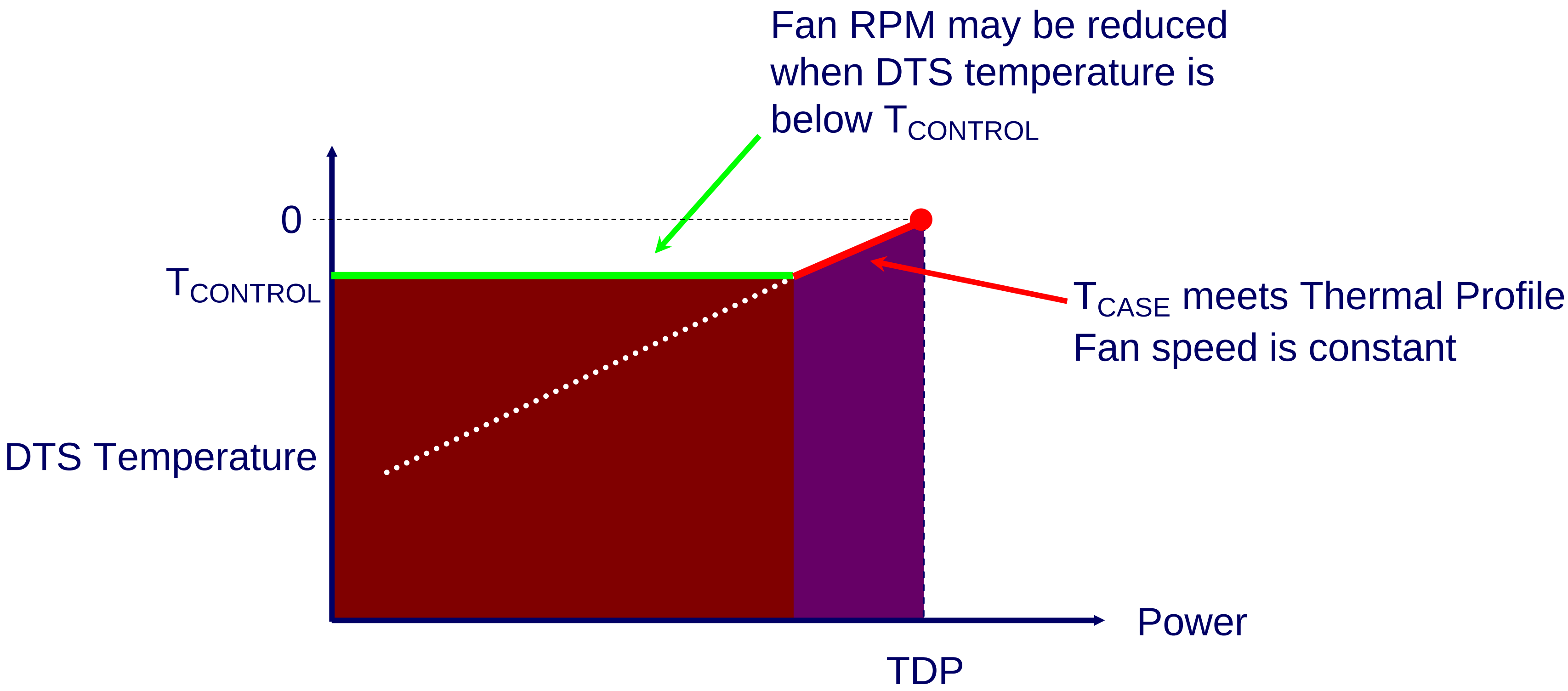
- Software visible register contains the target T_J
  - A new feature in the Intel® Core™ i7 processor is a software readable field in the IA32_TEMPERATURE_TARGET register that contains the minimum temperature at which PROCHOT# will be asserted. The PROCHOT# activation temperature is calibrated on a part-by-part basis and normal factory variation may result in the actual activation temperature being higher than the value listed in the register. PROCHOT# activation temperatures may change based on processor stepping, frequency or manufacturing efficiencies.
- IA32_TEMPERATURE_TARGET register
  - MSR 1A2h Bits [23:16]
  - Data format is decimal degrees C

Agenda

- Digital Temperature Sensors
- Intel® Core™2 Duo and Quad Processor Temperatures
- Thermal Specification Review
- Intel® Core™ i7 processor DTS Thermal Specifications

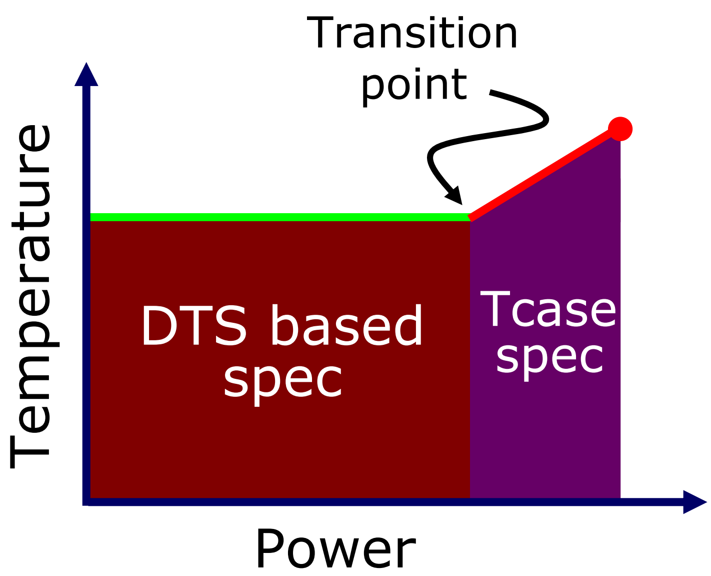
Existing Thermal Profile Review

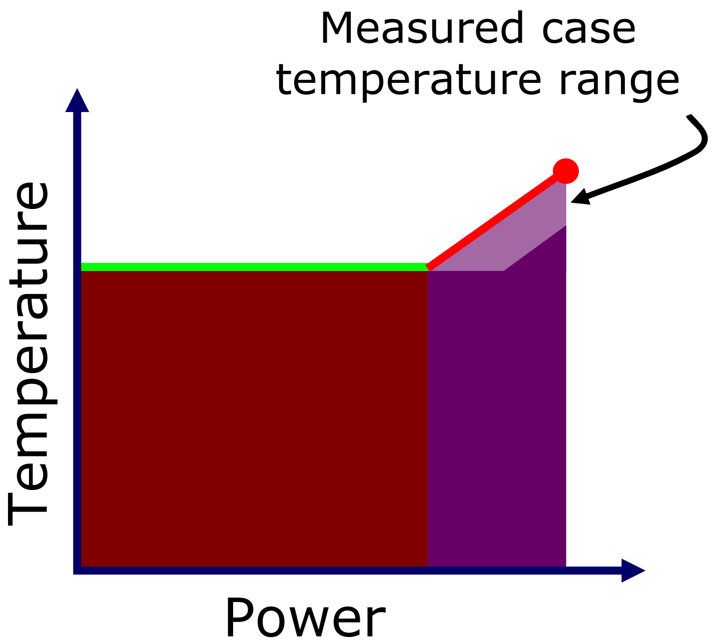
- Thermal Profile specifies relationship between T_{CASE} and Power
- $T_{CONTROL}$ defines the DTS temperature for fan speed control
- Temperature specification uses both T_{CASE} and DTS



T_{CASE} When DTS > $T_{CONTROL}$

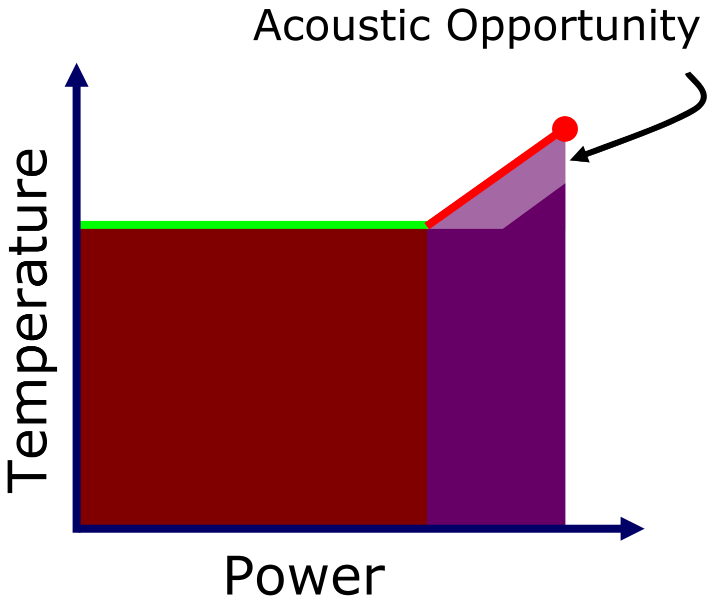
- Thermal spec transitions from DTS to T_{CASE} when DTS > $T_{CONTROL}$
- T_{CASE} will be ≤ to Thermal Profile spec when DTS ≥ $T_{CONTROL}$
  - Parts may be over cooled
  - Result of calibration errors, ambient temperature, other variables
- Fan RPM could be reduced if Power and T_{CASE} could be measured





How To Always Run At $T_{CASEMAX}$?

- System acoustics could be reduced if T_{CASE} could always be right on the Thermal Profile
- No practical way to measure T_{CASE} in high volume systems
- A real time feedback mechanism is needed



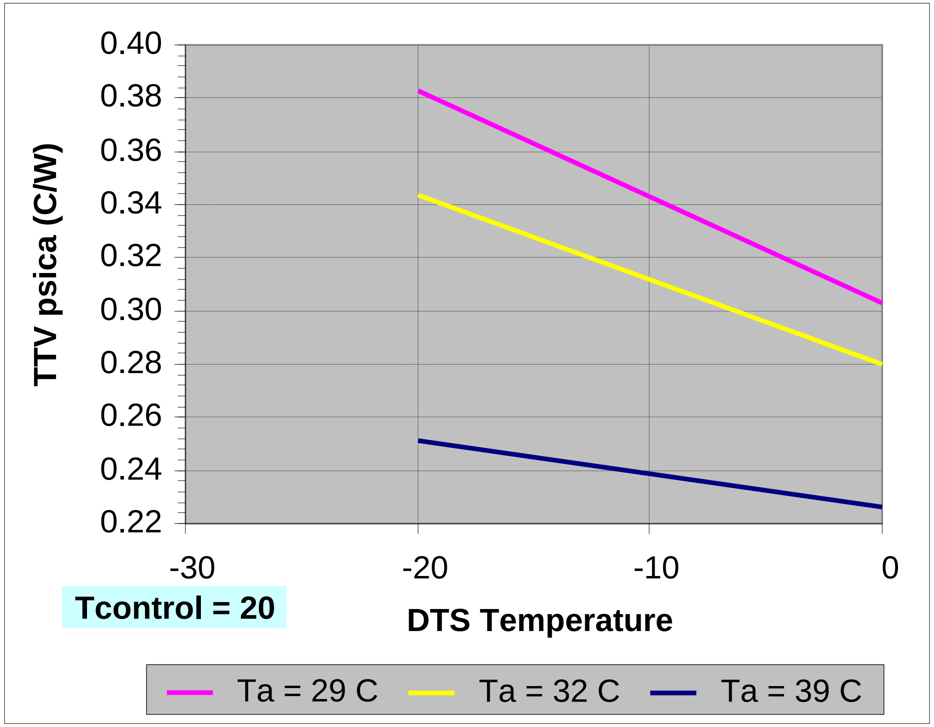
Intel Developer FORUM

Agenda

- Digital Temperature Sensors
- Intel® Core™2 Duo and Quad Processor Temperatures
- Thermal Specification Review
- Intel® Core™ i7 processor DTS Thermal Specifications

DTS Based Thermal Profile

- Thermal spec will be written to use only the DTS
- No transition to T_{CASE} when DTS is higher than $T_{CONTROL}$
- The Ψ_{CA} and $T_{AMBIENT}$ necessary to run at the optimal acoustic point will be specified



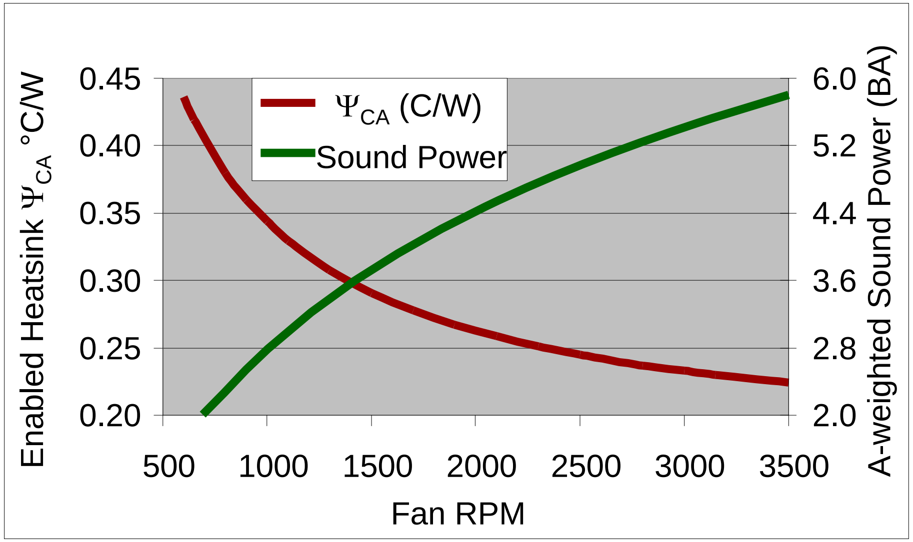
DTS Based Thermal Profile

- Intel® Core™ i7 processor specifications
- Ψ_{CA} is defined for each value of DTS between Tcontrol and -1
  - Ψ_{CA} decreases linearly with increasing DTS
  - Fan control makes appropriate RPM adjustments
- When DTS < Tcontrol, fans are at min RPM
- Customer has choice of fan control scheme
  - Previous generation fan control still works
  - Meets spec, but does not take advantage of acoustic opportunity
- Further details will be available in the *Thermal and Mechanical Design Guide*

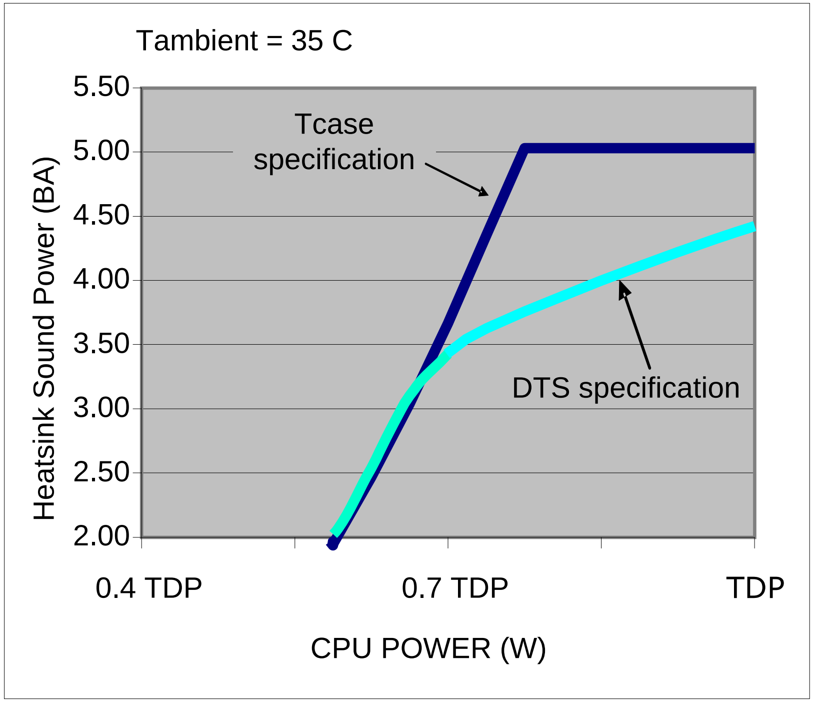
Tambient	Ψ-ca at DTS = Tcontrol	Ψ-ca at DTS = -1
43.2	0.190	0.190
42	0.206	0.199
41	0.219	0.207
40	0.232	0.215
39	0.245	0.222
38	0.258	0.230
.	.	.
.	.	.
.	.	.
.	.	.
.	.	.
24	0.440	0.338
23	0.453	0.345
22	0.466	0.353
21	0.479	0.361
20	0.492	0.368
19	0.505	0.376
18	0.518	0.384

Acoustic Benefit of DTS Specification

- DTS spec enables ~1.0BA of acoustic benefit vs. Tcase spec



Ψ_{CA} and Acoustics vs. Fan RPM for Intel enabled thermal solution



Acoustic noise comparison between Tcase and DTS Thermal Specifications for Intel enabled thermal solution

Summary

- Proper use of DTS can provide valuable thermal information about a processor

- Use the correct T_J values when converting from DTS value to °C

- New sensor based thermal specification for Intel® Core™ i7 processor enables acoustically optimized systems

Session Presentations - PDFs

The PDF for this Session presentation is available from our IDF Content Catalog at the end of the day at:

https://www.apacidf.com/idf/twn/fall2008/training/tracks.htm

Or

https://intel.com/idf
Content Catalog under IDF Taiwan conference resources

Legal Disclaimer

- INFORMATION IN THIS DOCUMENT IS PROVIDED IN CONNECTION WITH INTEL® PRODUCTS. NO LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE, TO ANY INTELLECTUAL PROPERTY RIGHTS IS GRANTED BY THIS DOCUMENT. EXCEPT AS PROVIDED IN INTEL'S TERMS AND CONDITIONS OF SALE FOR SUCH PRODUCTS, INTEL ASSUMES NO LIABILITY WHATSOEVER, AND INTEL DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY, RELATING TO SALE AND/OR USE OF INTEL® PRODUCTS INCLUDING LIABILITY OR WARRANTIES RELATING TO FITNESS FOR A PARTICULAR PURPOSE, MERCHANTABILITY, OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT. INTEL PRODUCTS ARE NOT INTENDED FOR USE IN MEDICAL, LIFE SAVING, OR LIFE SUSTAINING APPLICATIONS.
- Intel may make changes to specifications and product descriptions at any time, without notice.
- All products, dates, and figures specified are preliminary based on current expectations, and are subject to change without notice.
- Intel, processors, chipsets, and desktop boards may contain design defects or errors known as errata, which may cause the product to deviate from published specifications. Current characterized errata are available on request.
- Code names featured are used internally within Intel to identify products that are in development and not yet publicly announced for release. Customers, licensees and other third parties are not authorized by Intel to use code names in advertising, promotion or marketing of any product or services and any such use of Intel's internal code names is at the sole risk of the user
- Performance tests and ratings are measured using specific computer systems and/or components and reflect the approximate performance of Intel products as measured by those tests. Any difference in system hardware or software design or configuration may affect actual performance.
- Intel, Xeon, Core and the Intel logo are trademarks of Intel Corporation in the United States and other countries.
- *Other names and brands may be claimed as the property of others.
-

Risk Factors

This presentation contains forward-looking statements that involve a number of risks and uncertainties. These statements do not reflect the potential impact of any mergers, acquisitions, divestitures, investments or other similar transactions that may be completed in the future. The information presented is accurate only as of today's date and will not be updated. In addition to any factors discussed in the presentation, the important factors that could cause actual results to differ materially include the following: Demand could be different from Intel's expectations due to factors including changes in business and economic conditions, including conditions in the credit market that could affect consumer confidence; customer acceptance of Intel's and competitors' products; changes in customer order patterns, including order cancellations; and changes in the level of inventory at customers. Intel's results could be affected by the timing of closing of acquisitions and divestitures. Intel operates in intensely competitive industries that are characterized by a high percentage of costs that are fixed or difficult to reduce in the short term and product demand that is highly variable and difficult to forecast. Revenue and the gross margin percentage are affected by the timing of new Intel product introductions and the demand for and market acceptance of Intel's products; actions taken by Intel's competitors, including product offerings and introductions, marketing programs and pricing pressures and Intel's response to such actions; Intel's ability to respond quickly to technological developments and to incorporate new features into its products; and the availability of sufficient supply of components from suppliers to meet demand. The gross margin percentage could vary significantly from expectations based on changes in revenue levels; product mix and pricing; capacity utilization; variations in inventory valuation, including variations related to the timing of qualifying products for sale; excess or obsolete inventory; manufacturing yields; changes in unit costs; impairments of long-lived assets, including manufacturing, assembly/test and intangible assets; and the timing and execution of the manufacturing ramp and associated costs, including start-up costs. Expenses, particularly certain marketing and compensation expenses, vary depending on the level of demand for Intel's products, the level of revenue and profits, and impairments of long-lived assets. Intel is in the midst of a structure and efficiency program that is resulting in several actions that could have an impact on expected expense levels and gross margin. Intel's results could be impacted by adverse economic, social, political and physical/infrastructure conditions in the countries in which Intel, its customers or its suppliers operate, including military conflict and other security risks, natural disasters, infrastructure disruptions, health concerns and fluctuations in currency exchange rates. Intel's results could be affected by adverse effects associated with product defects and errata (deviations from published specifications), and by litigation or regulatory matters involving intellectual property, stockholder, consumer, antitrust and other issues, such as the litigation and regulatory matters described in Intel's SEC reports. A detailed discussion of these and other factors that could affect Intel's results is included in Intel's SEC filings, including the report on Form 10-Q for the quarter ended June 28, 2008.