TECHNOLOGY WHITE PAPER

Understanding Intel® Processor Throttling for Defense Applications

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Introduction

Intel Core™ processors automatically throttle their performance based on the processor workload and their thermal environment, reducing power consumption and also protecting hardware from overheating if not adequately cooled. However, for demanding defense applications where predictability is essential, performance throttling may have adverse effects. This paper presents the basics of Intel processor throttling, and the advanced cooling techniques needed to ensure consistent performance for defense applications.

Basic Concepts of Processor Throttling

Processor throttling (sometimes called 'dynamic frequency scaling') is used in computer architectures to adjust the clock frequency, or instructions executed per unit of time, of a processor. Simply put, the processor's clock is slowed down. Throttling back the clock frequency causes a processor to run more slowly, do less work, use less power and, as a consequence, generate less heat.

The benefits of throttling are directly related to these reductions. Reduced power use will extend battery life for laptops and decrease energy costs for IT systems. Decreases in heat generation reduce cooling costs and can also reduce environmental noise when demands on cooling systems (fans and air conditioning) are reduced.

Most significantly, reduced heat generation due to throttling may allow systems to avoid catastrophic failure from overheating. This is one of the primary reasons for introducing throttling into processor architectures like the Intel x86 and why it is often a 'hard-wired' certainty for some processors. When the die temperature reaches a given 'imminent failure' threshold, throttling is initiated with no user or system programming control. However, most x86 processors have multiple levels of performance throttling below this 'imminent failure' threshold where throttling is within programming control.

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Processor Throttling: Commercial vs. Defense Environments

Today's Intel x86 processors are very attractive to defense designers for two primary reasons:

1. industry leading price vs. performance, which continues to set the pace with recent additions of multiple processing cores, AVX2 vector (math) processing engines and powerful integrated Graphics Processing Units (GPUs), and;
2. broad software support, including commonly used operating systems, middleware and tools.

Fundamental to the architecture and functionality of Intel processors is that they are heavily optimized for commercial markets, not necessarily for professionally designed real-time, embedded, mission-critical defense applications. In the consumer IT world, processor throttling can be carefully managed to extend battery life. Since the small amount of extra time needed to load a document or navigate through e-mail on a throttling processor is not likely to be measured, the reduction in performance is rarely noticed by a user. However for real-time applications where processor performance is highly optimized to ensure consistent results, the effects of throttling can be catastrophic. Deterministic systems that must process real-time data in a specific time interval rely on an expected level of performance. Reduced throughput and responsiveness due to processor throttling is often unacceptable, as it may compromise mission viability.

There are key benefits and as well as drawbacks to processor throttling in a particular application environment. It is imperative that defense designers fully understand processor throttling characteristics in order to effectively use Intel processors in time-critical embedded applications.

Beneficial Uses for Processor Throttling

The most beneficial use of processor throttling is to reduce overall system power consumption. For a battery-operated laptop computer, dynamic throttling has a significant effect on battery life. To illustrate the effect of processor frequency on power consumption, Table 1 summarizes the Intel 4th Generation Core i7 Quad-Core "Haswell" processor power consumption at various clock frequencies and core usage.

TABLE 1 Intel 4th Gen Core i7 Quad-Core Processor power vs. clock frequency and core usage

# ACTIVE CORES	CLOCK FREQUENCY (GHz)	PROCESSOR POWER CONSUMPTION (Watts)
4-core	2.4	36
	1.8	25
	1.2	17
	0.8	12
1-core	2.4	13
	1.8	10
	1.2	8
	0.8	6

Note: typical for 100% CPU, 0% GPU, 100% memory @ 25°C

For a laptop computer, the power saving opportunity is considerable. If the operating system can control processor throttling, it can reduce power during periods of low use, and increase performance as required to perform more complex work. In a larger IT environment, where power consumption is a significant factor in operating costs, the resultant financial savings during periods of light processing loads can be substantial.

Defense applications can also benefit from a reduction in overall system power consumption. For example, an airborne ISR system traveling to or from an area of interest could be throttled back to reduce power demand on the platform. This power savings can translate to longer airborne mission time, a clear advantage for all ISR missions.

Another advantage of processor throttling is to safeguard against thermal runaway. In modern electronics, power consumption is also linked to temperature. As the temperature of IC chips increases, the power consumption also increases, which in turn increases the temperature further. This can lead to a thermal runaway condition, with catastrophic consequences.

Intel has designed a thermal safeguard into their Core processors called SpeedStep technology, whereby the processor monitors its internal operating temperature, and if the temperature reaches a pre-defined thermal limit, the processor will override any programmatic throttling controls and will throttle clocks to reduce power consumption, in turn reducing the processor internal temperature. In a commercial industry where low cost (and low reliability) components such as cooling fans are prevalent, this safeguard offers a reassuring measure of protection to the consumer.

Detrimental Consequences of Processor Throttling

In a critical real-time application, processor performance is carefully controlled to ensure critical tasks are completed in a predetermined amount of time. Often, a processor is chosen due to its match of performance against cost or power: there is no need to over-design a processor's performance if it meets the real-time requirements. However, if a processor begins to throttle when it is not expected to, its performance will drop and critical tasks may not be completed in their allotted time.

The key to using Intel's high performance Core processors is to understand the conditions in which the processor throttling is no longer under the control of the operating system or the application. This condition is directly related to the system's thermal performance. If the processor temperature can be kept below its preset throttling limit, then throttling will not interfere with the application's performance settings.

For Intel's 4th Gen Core i7 processor, this hard-set internal processor thermal limit is 100°C. For a rugged embedded single board computer designed to operate at a worst-case card-edge temperature of 85°C, this leaves an extremely challenging 15°C budget to cool the processor from the card edge to the internal silicon of the processor.

Curtiss-Wright's Intel-based Single Board Computers

Curtiss-Wright is an industry leader in thermal management. Having designed Single Board Computers (SBCs) for embedded applications for over 30 years, Curtiss-Wright uses many specialized techniques to ensure critical electronics are not compromised by temperature extremes.

Each design is different. In the case of Intel-based SBCs, Curtiss-Wright may use a combination of aluminum or copper heat spreaders, phase-change thermal interface material, or highly effective heat pipes to pull heat out of the processor, efficiently reducing the processor's operating temperature.

Curtiss-Wright also provides detailed thermal performance data, and correlates this with Intel processor clock speeds and throttling characteristics. This data allows the system designer to clearly identify what system conditions may cause a processor throttling action, or put another way – to design a system with confidence that the processor will not throttle under normal operating conditions. As an example, Figure 1 below shows the processor clock performance against board card-edge temperature for a 6U VPX Intel 3rd Gen Core i7 ("Ivy Bridge") single board computer.

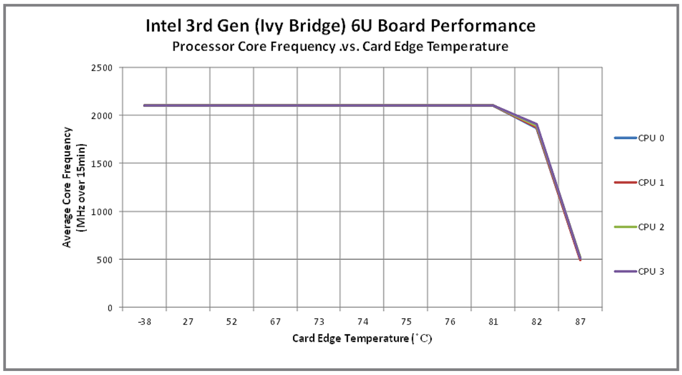

Figure 1: 6U VPX board performance with Intel's 3rd Gen Core i7 Processor
Processor clock .vs. card edge temperature

In this worst-case example (100% CPU on all 4 cores/8 threads, 100% GPU) , the board performs at 100% target clock frequency of 2.1 GHz until the card edge reaches approximately 81°C. At this point, the processor begins to reduce the CPU clock speed to ensure the processor temperature does not exceed its preset limit. At a card edge temperature of 85°C, the clock has been reduced to 1.2 GHz and continues to reduce down to 500 MHz at a card edge temperature of 87°C. A system designer must maintain a card edge temperature below 81°C to ensure full performance without unwanted processor throttling. This example is worst-case with a 100% CPU and 100% GPU workload. With reduced work load (CPU or GPU), the performance curves will be different.

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Summary

Today's high performance Intel Core processors offer significant processing power at reasonable price and power levels. However, due to the processor's ability to throttle its clock and reduce performance based on thermal operating conditions, it is critical that when used for real-time data processing, the system designer pays careful attention to thermal design to ensure the processor does not reduce its performance and cause undesired consequences.

Curtiss-Wright has incorporated unique thermal cooling techniques into our Single Board Computer designs to ensure optimal processor cooling, and we fully characterize the thermal and throttling performance of our Intel-based SBCs.

For additional information, please contact Curtiss-Wright.

Learn More

VME-1908 is our VME form factor Intel 4th Generation Core i7 Single Board Computer

VPX6-1958 is our 6U VPX form factor Intel 4th Generation Core i7 Single Board Computer

VPX3-1258 is our 3U VPX form factor Intel 4th Generation Core i7 Single Board Computer