

Product Tuning for Reliability on Intel® Processors for Edge

Processor Reliability

Processor reliability is the ability of a computer chip to consistently and accurately execute its functions over time without experiencing failures. This aspect is vital for maintaining performance and stability within computer systems, especially for such applications as industrial controllers, medical devices, security appliances, and others where downtime or errors can lead to significant consequences.

However, a processor may become less reliable and potentially fail over time due to semiconductor aging as well as wear and tear associated with regular usage. Understanding and modeling the reliability characteristics of processors is essential.

Processor reliability can be quantified by the probability of failure (P_{fail}) over a period of usage (T) from the start. This is defined as:

$$P_{fail}(T) = N_{fail}(T)/N_{total}$$

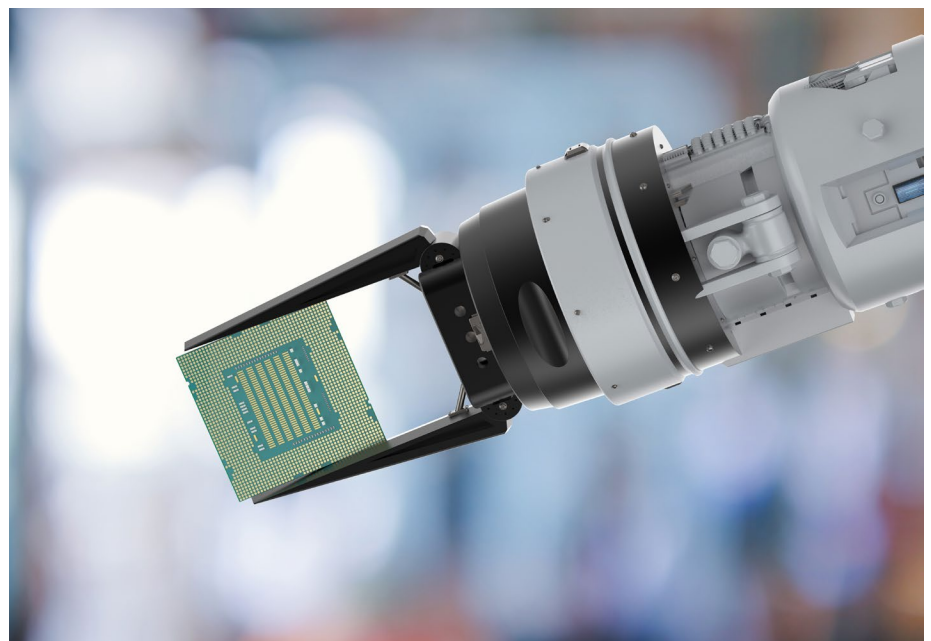
where N_{fail} represents the number of parts that fail out of N_{total} number of parts in use over time period T .

The reliability of an Intel processor is typically specified in terms of a reliability profile, which consists of multiple P_{fail} values projected over various periods of usage from the start, e.g.,

$$\text{Reliability Profile} = \{ P_{fail}(1\text{yr}), P_{fail}(3\text{yr}), P_{fail}(5\text{yr}), \dots \}$$

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Use Conditions for Reliability Assessment

Processor reliability generally depends on several factors, with key elements including:

- **Processing speed:** the rate at which the processor executes instructions
- **Active percentage:** the percentage of time the processor is in a busy state executing instructions
- **Thermal cooling:** the efficiency of dissipating heat generated during operation
- **Time in use:** total time the processor has been in operation

The reliability of an Intel® processor is assessed and qualified against a predefined "use condition." At a high level, this use condition prescribes the active percentage of operation over a target lifespan.

Shown below are the typical use conditions applicable to Intel processors suitable for embedded, IoT, and edge applications.

Use Condition	Active Percentage	Target Lifespan
PC/Client	Moderate	Several years
Embedded	High	Several years
Industrial	Maximum (with Turbo Frequency off)	Extended number of years

These use conditions reflect varying levels of usage over different lifespans, providing a generalized framework for use requirements across multiple vertical segments.

Product Reliability Specifications

For Intel processor products, their specifications available on ark.intel.com may feature a "Use Conditions" property indicating the specific use conditions for which the products have been qualified.

For instance, the Intel® Core™ i7 processor 14700 information on ark.intel.com reveals that it supports the PC/Client use condition by default.

Supplemental Information	
Marketing Status	Launched
Launch Date	Q1'24
Embedded Options Available	Yes
Use Conditions	PC/Client /Tablet, Workstation

To pass reliability qualification, a processor SKU's projected failure rates must not exceed predefined targets, assuming the usage level and lifespan prescribed by the use condition. In the example shown above, the Intel Core i7 processor 14700 is projected to meet a preset failure rate criterion when subject to the PC/Client use condition.

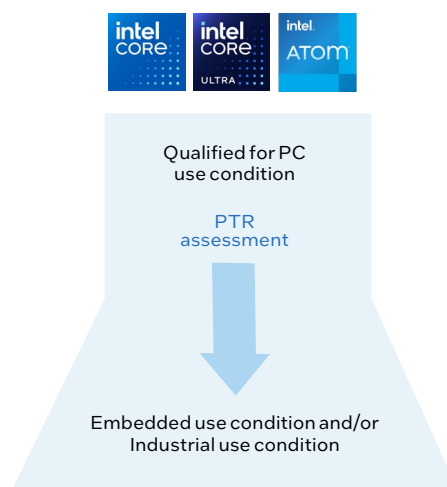
Further reliability information for a product SKU can be found in its Product Release Qualification (PRQ) report (accessible under nondisclosure agreement). A PRQ report typically encompasses multiple SKUs from a product family. It specifies the use conditions for which the SKUs have been qualified and presents projected failure rate data that apply to all SKUs covered by the report. For instance, the PRQ report for the Intel Core i7 processor 14700 confirms that the part has been qualified for the PC/Client use condition, with projected failure rates not exceeding preset targets over one-year, three-year, and five-year periods, respectively.

Product Tuning for Reliability

A considerable number of product SKUs in Intel's "edge" processor portfolio have been qualified for PC/Client use conditions by default. However some of them may be suitable for Embedded and/or Industrial use conditions without compromising reliability. This expansion is possible because the SKU's reliability profile for the default use condition has sufficient headroom below the target ceiling.

Additionally, in cases of less headroom, it might be possible to apply frequency tuning to expand the product's reliability for higher usage levels. This tuning involves making minor adjustments to one or more of the frequency settings for the processor. Often, lowering the maximum CPU Turbo Frequency by 0.1 or 0.2 GHz is sufficient. Frequency reductions, as such, are restricted to a small range to minimize impact on processor performance.

Based on these principles, Product Tuning for Reliability (PTR) is a practice to support "expanded use reliability" for processors initially qualified for the PC/Client use condition, thereby enabling their application in designs that demand Embedded or Industrial use conditions.



At the core of the PTR practice is post-manufacturing assessment of the reliability of PC/Client-qualified SKUs when subject to an expanded use condition, such as Embedded and/or Industrial use conditions. On a per-SKU basis, the process entails: 1) analyzing the SKU's reliability behavior for the expanded use condition, 2) determining whether frequency tuning is required and to what degree, and 3) projecting the resulting failure rates. This is accomplished through reliability modeling based on the product's manufacturing data.



The possible outcomes from the post-manufacturing reliability assessment of a processor SKU against an expanded use condition are as follows:

Feasible without tuning: The SKU can be used as originally specified for the expanded use condition while still meeting qualification goals.

Feasible with tuning: The SKU can be used for the expanded use condition, provided it operates at reduced frequencies, while still meeting qualification goals.

Not feasible: The SKU is unsuitable for the expanded use condition due to excessive reliability degradation that cannot be mitigated with reasonable frequency adjustments.

Reliability Application Note for PTR

Beginning with Intel® Core™ Ultra processors (Series 1) within Intel's edge processor portfolio, the SKU-specific product specifications on ark.intel.com include a "Product Tuning" property to indicate whether PTR is supported for the SKU in question. This is a quick way of finding out if a product SKU has been evaluated for expanded use reliability or not.

For instance, the specifications list for the Intel Core Ultra 7 265H processor has "Product Tuning" marked as "Yes." In fact, the same is true for other SKUs in the same product family. This indicates that although this product family was initially qualified for PC/Client use conditions during manufacturing, PTR analysis was conducted post-manufacturing to assess whether individual SKUs can be utilized for higher usage levels.

Supplemental Information

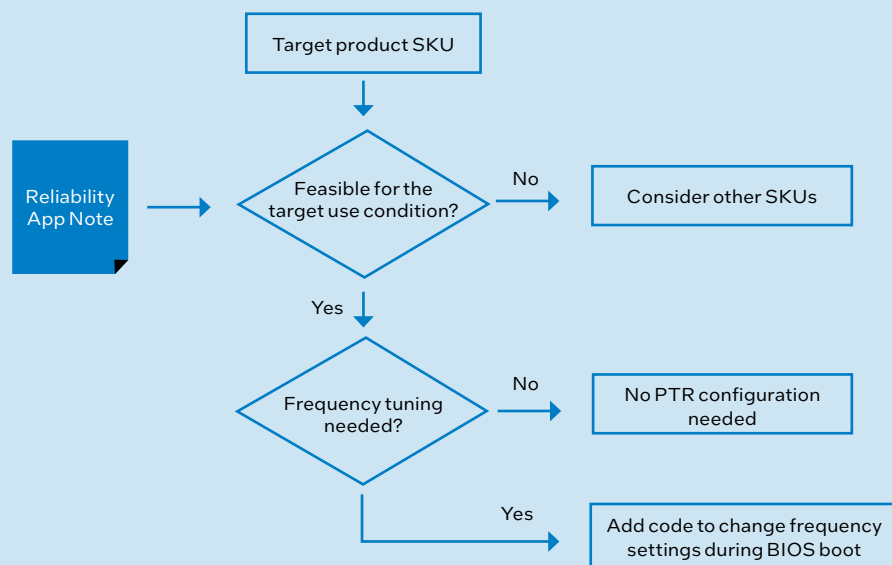
Marketing Status	Launched
Launch Date	Q1'25
Embedded Options Available	Yes
Product Tuning (Embedded Uses)	Yes

Details of the PTR assessment results are disclosed through the product's Reliability Application Note (RAN) document (accessible under nondisclosure agreement). Typically released several weeks after the product goes into production, the RAN document identifies the expanded use condition(s) under consideration and provides the following information on a per-SKU basis:

- Suitability for use under the expanded use condition
- Any frequency adjustments needed
- Failure rate projections over different time intervals

For instance, according to the RANs for Intel Core Ultra processors (Series 2) with LGA socket types, most SKUs in the product family can operate reliably under Embedded use condition without needing frequency adjustments. The Intel Core Ultra 9 285 processor is the only exception: For it to be suitable for the Embedded use condition, its Performance-core Max Turbo Frequency needs to be slightly reduced. The RANs also provide one-year, three-year, and five-year failure rate projections for each of these SKUs under the prescribed usage.

SKU	Feasible for Embedded use condition?	Frequency adjustment needed?
Core Ultra 9 285	Yes	Yes
Core Ultra 9 285T	Yes	No
Core Ultra 7 265	Yes	No
Core Ultra 7 265T	Yes	No
Core Ultra 5 245	Yes	No
Core Ultra 5 245T	Yes	No
Core Ultra 5 225	Yes	No
Core Ultra 5 225T	Yes	No



Design-In Expanded Use Reliability

There are two approaches to applying PTR in designs to achieve expanded use reliability with Intel edge processors.

Approach 1: RAN-Guided Configuration

Begin by reviewing the RAN for the specific product SKU to check its feasibility for the desired use condition and to decide if the projected failure rates are acceptable. If the SKU can meet the use reliability requirements without needing frequency adjustments, no special configuration is necessary. Otherwise, if frequency tuning is needed, it is implemented through BIOS boot code by writing the frequency value(s) to the appropriate Model Specific Register(s) (MSRs).

Approach 2: Easy Button Configuration

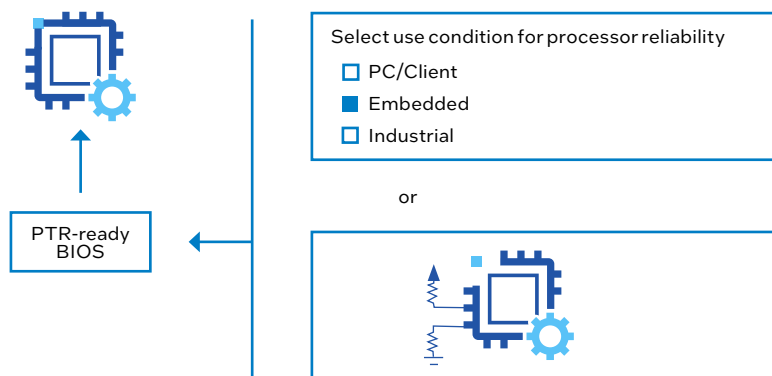
Aiming to simplify the application of PTR in the field, this approach abstracts away PTR implementation details from OxMs' processor design-in considerations. It allows OxMs to explicitly select an expanded use condition and rely on

the BIOS to automatically and accurately apply any required frequency adjustments upon system bootup according to the processor SKU. Called "Easy Button," this approach necessitates a PTR-ready BIOS and a method for selecting use conditions.

PTR-ready Reference BIOS

Incorporated in the PTR-ready Reference BIOS are PTR data extracted from the RAN(s) for the product. It also has a built-in PTR function that accepts the use condition as an input. Upon invocation, this function references the PTR data to determine the frequency settings for the specified use condition and subsequently configures the relevant MSRs to establish any necessary frequency adjustments.

For products with PTR support, their Reference BIOS will be updated and released with this capability within one or two quarters after the product goes to production. ODM and/or IBV partners may use the PTR-ready Reference BIOS to develop custom production BIOS with Easy Button support. They have the choice of using a BIOS menu or GPIO pins for intake of use condition selection.

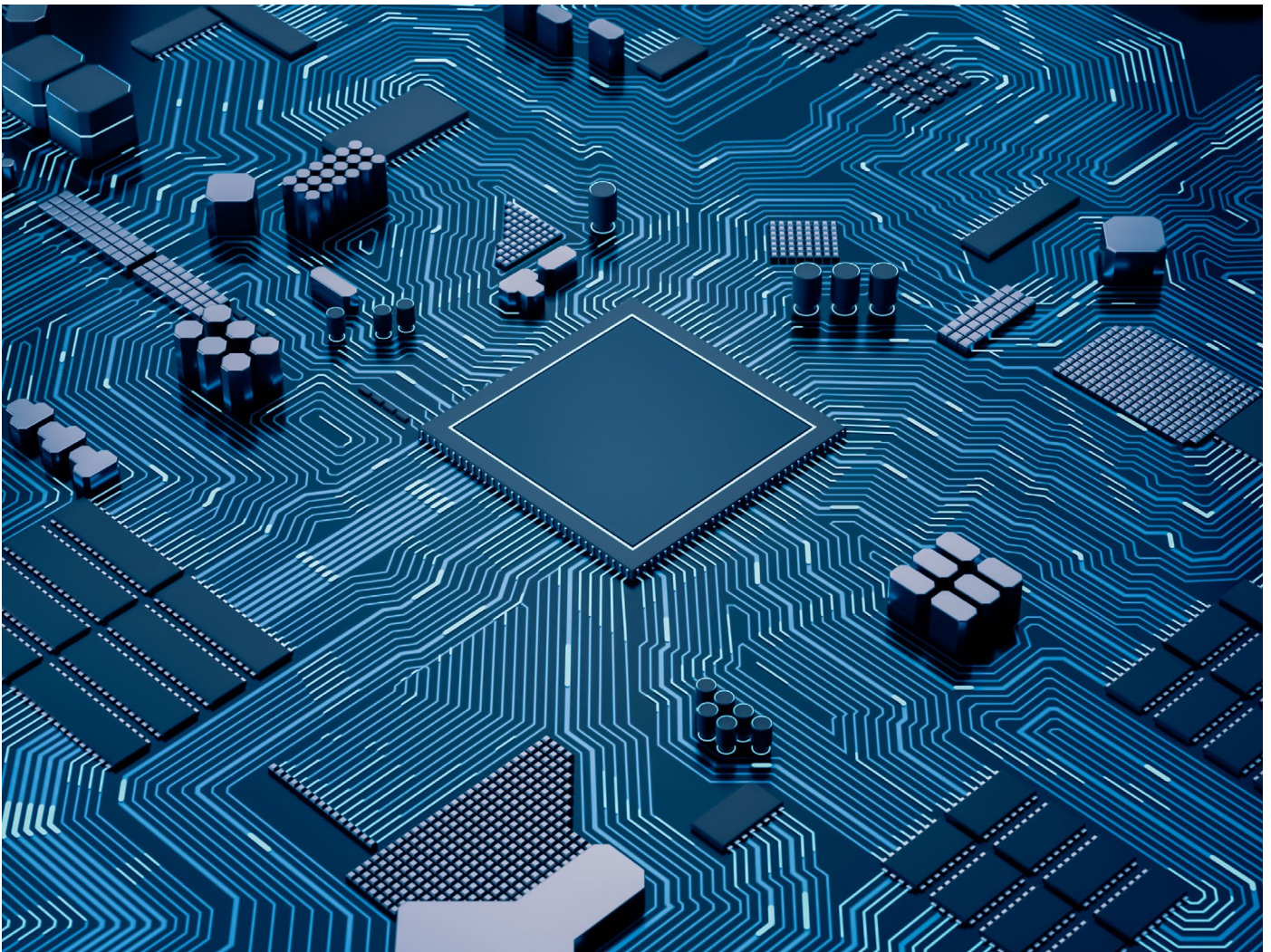


Easy Button: Using BIOS Menu for PTR Configuration

Use condition selection can be configured through a BIOS menu, offering options such as PC/Client, Embedded, and/or Industrial, depending on the PTR profile for the product SKU. This method requires inclusion of a use condition menu and BIOS boot code to read the menu selection and invoke the PTR function with the selected use condition as the input parameter. A sample implementation of this method is included in the PTR-ready Reference BIOS corresponding to the product of interest. Incidentally, to prevent tampering in the field, the use condition menu should be hidden or locked once the configuration is finalized.

Easy Button: Using GPIO Pins for PTR Configuration

Rather than exposing use condition selection on a soft menu in BIOS, one or two available GPIO pins on the processor can be designated for this purpose. Essentially, the selection is hardwired by soldering pull-up and/or pull-down resistors to those pins, following a chosen binary encoding scheme to represent PC/Client, Embedded, and/or Industrial use conditions. As such, the BIOS boot code should include a routine to read and decode the GPIO pins and invoke the PTR function accordingly.



Conclusions

Intel processors are qualified against predefined use conditions to ensure reliability. A majority of the products in Intel's edge processor portfolio are, by default, qualified for the PC/Client use condition. Product Tuning for Reliability (PTR) is a practice aimed at expanding the reliability of these processors in designs that require Embedded and/or Industrial use conditions. It encompasses reliability modeling and analysis on individual product SKUs post-manufacturing. Recent results have shown that many PC/Client-qualified product SKUs can withstand higher levels of usage without compromising failure rates, and other SKUs may do the same with slight frequency adjustments. Detailed information on PTR feasibility, including frequency settings and projected failure rates, is provided in the Reliability Application Notes (RANs) associated with the product SKUs. For design integration, PTR can be enabled in BIOS through the "Easy Button" method, or direct access of MSRs when frequency tuning is needed.

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