Intel Platform and Component Validation

A Commitment to Quality, Reliability and Compatibility

How does Intel ensure leading quality, reliability and compatibility for its processors, chipsets, motherboards and platform software? – by maintaining the industry's most advanced and comprehensive testing environment. Over 2,500 employees in 20 facilities around the world are dedicated to validation testing, and to delivering the world's most reliable and compatible PC platforms.

Executive Summary

The internal complexity of the personal computer has grown to a staggering level. Today's most advanced processors and chipsets incorporate millions of transistors, and must be compatible with dozens of operating systems, hundreds of platform components and thousands of hardware devices and software applications. To ensure leading performance, reliability and compatibility in this complex environment, Intel invests over $300 million annually in component and platform validation.

Intel's validation process begins during the first stages of component design – and continues throughout pre-silicon and post-silicon development. All core platform components are exhaustively tested, both independently, and with an enormous variety of third-party hardware and software components. Operating conditions and performance demands are pushed to extreme limits. Issues are unearthed and resolved, and the findings are used to drive constant improvement in Intel's design and manufacturing processes.

Intel's design and validation engineers also work closely with leading hardware and software vendors throughout the industry to coordinate development and testing efforts. This helps to ensure that new technologies are integrated quickly and reliably into next-generation products, so users can rely on the highest level of platform functionality.

The results of this unprecedented commitment to quality are better products and faster time to market, important advantages for the many businesses and users who depend on the performance, reliability and compatibility of Intel platforms and components.

This paper provides an overview of Intel's validation program. It describes some of the key tools and processes that are essential in ensuring that validation testing provides deep and comprehensive coverage, and that Intel platforms and components continue to offer leading reliability and performance in the widest possible range of operating environments.

The Validation Challenge

Ten years ago a typical Intel chipset had about 50 thousand gates. Today, these core platform components have as many as 4 million gates, and are growing in complexity with each new generation. During this same period, the number of transistors in Intel desktop processors has increased from about 3 million to over 40 million. Intel's current chipsets and processors also support more functions, operate at faster frequencies and must be compatible with far more hardware devices and software components than ever before.

The Importance of Validation

PC reliability and compatibility issues can be costly for users. For businesses, typical on-site support costs range from about $150 for an average service call to as much as $600 to replace a system. Consumers face even greater difficulties, since many lack technical expertise, and may not have immediate access to experienced troubleshooting or repair services. For both businesses and consumers, the cost of resolving a compatibility or reliability issue can quickly escalate beyond the original price of the PC. Intel's comprehensive validation program plays a critical role in helping to keep these costs down, reducing customer risk, and increasing the long-term value of newly purchased PCs.

The internal complexity of a processor or chipset creates an astronomical number of possible test sequences. Yet that complexity is just one measure of the validation challenge. Each component will be manufactured by the millions, and will be used in an enormous variety of platform configurations. It will have to interoperate with many different motherboards, components, peripherals, operating systems and applications. It will also face various extremes of temperature, voltage and clock frequency. This variability in the number of platform configurations and operating environments raises the number of test conditions to near infinite levels.

Clearly, there is no way to test every conceivable possibility in full detail. Yet advanced testing facilities and carefully engineered, automated test suites enable very deep testing across a large range of variables.

The Industry's Most Comprehensive Validation Program

Intel invests over $300 million annually in component and platform validation. Over 2,500 employees are dedicated to this task in 20 facilities around the world. Though the scope of the effort has increased over the years, this testing has been a major, ongoing effort since Intel's earliest days. The constant interaction between validation engineers and design engineers has helped to create a cycle of constant improvement.

> **Integrated Platforms Enhance Reliability**
>
> Unlike other hardware vendors, Intel develops and provides most core PC components, including processors, chipsets, motherboards and software elements, such as BIOS and drivers. All of these components are designed cooperatively and tested extensively, both individually and together. The result is a higher level of integration capability, compatibility and reliability, plus industry-leading support for emerging PC standards, many of which are initiated and championed by Intel itself.

Compatibility and reliability issues are found and resolved early, and the results are used to further refine Intel's design and manufacturing tools and processes. As a result, the quality and reliability of Intel platforms and components have improved steadily, even as performance and complexity have continued to climb.

There are basically eight stages in Intel's comprehensive validation program (Figure 1):

Pre-Silicon

- Stage 1: DIQR Methodology
- Stage 2: Component Design
- Stage 3: Pre-Silicon Simulation
- Stage 4: System Level Emulation

Post-Silicon

- Stage 5: System Validation
- Stage 6: Analog Validation
- Stage 7: Compatibility Validation
- Stage 8: Software Validation
- Stage 9: Product Qualification
- Stage 10: Silicon Debug

Much of the testing takes place in software, before a physical component is ever created. Extensive validation testing continues during the post-silicon phases of development. By the time an Intel component reaches the marketplace, the design has been validated over more than one hundred trillion bus cycle combinations

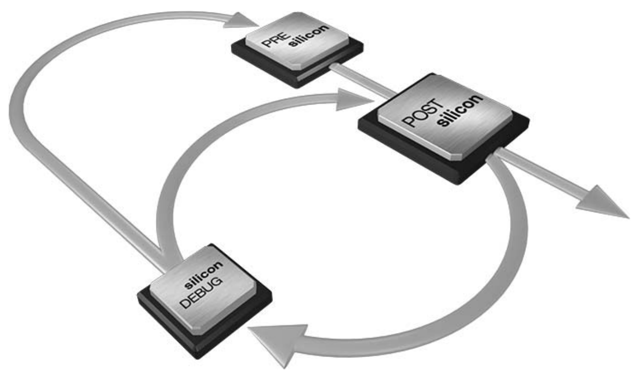

Figure 1. *Intel's comprehensive validation process accelerates product development while improving the quality, reliability and compatibility of Intel platforms and components.*

Stage 1: Intel's Design in Quality and Reliability (DIQR) Methodology

Intel's validation program is based on a documented methodology that makes quality and reliability core objectives in all planning, design and manufacturing processes (Figure 2). This is a major departure from traditional quality assurance programs, which are typically implemented as a final stage prior to product delivery. A fully integrated process is far more effective. It helps Intel keep development efforts on track, reduce the number of design iterations, and deliver complex products on more predictable timelines.

Intel's DIQR methodology covers three key areas of the development process.

Technology Readiness

As Intel engineering teams develop product roadmaps, they look closely at new technologies, to ensure they deliver capabilities that are important to users, and can be implemented in accordance with the highest levels of platform and component quality. Feasibility studies are conducted, focusing primarily on power, performance, size and cost factors. Results are compared with documented customer expectations based on Intel studies of business and consumer needs. No new technology is integrated into Intel's product roadmap until it meets strict DIQR requirements. This early investment in quality pays for itself many times over through higher component quality and accelerated development.

Front-End Development

Once a technology is added to the roadmap, DIQR hooks are designed and integrated into the logical and physical designs of each product, so quality and reliability testing can be performed efficiently at every stage. The DIQR methodology impacts all major design processes, including RTL (Register Transfer Level) synthesis, integrated circuit layout and cell library choices. The earlier a problem is discovered, the easier it is to fix, so formal validation at each stage is an efficient and cost-effective strategy.

Execution

Quality and reliability monitoring continue during circuit routing and final design validation. Even minor design modifications are carefully evaluated to ascertain their impact on DIQR variables.

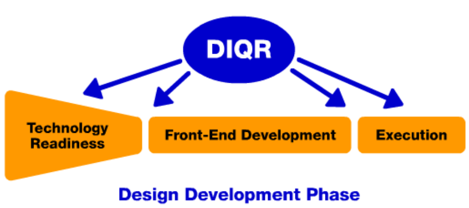

Figure 2. *Intel's Design in Quality and Reliability (DIQR) methodology helps to ensure that quality and reliability are core considerations in every phase of product development, from the evaluation of proposed technologies to final execution.*

Stage 2: Component Design

Intel design and validation engineers work closely together throughout product development and testing. This cooperation begins during the first stages of component design, in order to develop validation tools and processes that are efficient and thorough. This close cooperation is especially important today, as higher frequencies and increasing complexities continue to push the limits of existing technologies. Intel brings especially strong resources to this critical process.

Experience

For over 30 years, Intel has been a leader in the drive toward better and more affordable computing solutions. With sophisticated tools, mature processes and some of the most experienced people in the business, Intel has unparalleled resources for developing and manufacturing the industry's leading platforms and components.

Vision

Intel devotes considerable resources toward understanding and addressing next-generation platform requirements. Research and development teams are always planning 3-5 years ahead, with a close eye on usage trends and industry developments. As a result, Intel platforms and components are typically among the first to incorporate important new technologies[1]. This can be an important advantage, especially for businesses that deploy thousands of PCs. It helps them to support a wider range of new applications and technologies on their existing client base. As a result, they can deploy new applications and processes more quickly, with less need for expensive PC upgrades and replacements.

Industry Collaboration

Intel works together with a broad range of industry leaders to coordinate development efforts. This helps to ensure comprehensive, cost-effective and compatible PC solutions. It also helps the PC community develop, adopt and implement new technologies more quickly, which increases the power and value of the PC for both businesses and consumers.

[1] Past examples include the PCI bus, the Universal Serial Bus (USB), and the Accelerated Graphics Port (AGP).

Stage 3: Pre-Silicon Simulation

By employing some of the industry's most advanced simulation tools, Intel begins validating component design long before the first silicon prototypes are produced. The digital design is first simulated in software, and then tested under an enormous variety of operating conditions. Tests are designed to provide comprehensive validation coverage at all levels.

Unit Level

Intel validation engineers test the internal workings of each major subsystem within the component. Using customized software tools, they can control and monitor all subsystem interfaces, enabling a higher level of testing than is possible in hardware. Problems can be detected earlier and resolved more quickly to accelerate product development.

Chip Level

Component performance is also tested with all subsystems operating simultaneously. Here again, all interfaces are tightly controlled and monitored, and functionality is validated under an enormous variety of conditions.

System Level

At the system level, the simulated component is tested in a full operating environment to ensure that it works flawlessly in tandem with other platform components. Operation is also tested against industry bus standards, to validate compatibility in virtually any environment that adheres to appropriate standards.

Stage 4: System Level Emulation

During system-level emulation, the software model of the design is extended to determine how the component will perform in a real physical system. State-of-the-art hardware emulators run the software model in a full platform environment that includes actual hardware components, operating systems and Intel software drivers.

Altogether, Intel has invested over $30 million in advanced hardware emulators to enable realistic, pre-silicon validation of physical designs. Each emulator can model up to 4 million gates at emulation frequencies ranging from 500 kHz to 2 MHz. Intel engineers have developed fast, proprietary interfaces to accelerate the testing process in order to enable more comprehensive pre-silicon validation.

Though expensive to implement, emulation helps to ensure very high design quality before the first silicon prototypes are manufactured, a benefit that more than pays for itself in later stages of development. Engineers not only validate the logic functionality of the design, but also debug BIOS and software drivers, and verify the quality of the tools and processes that will be used in post-silicon testing.

Emulation also plays an important role during post-silicon validation. If a component fails a test, a proposed fix can be implemented and tested through emulation, before stepping to a new silicon version. This enables Intel engineers to verify that the original bug has been fixed, to uncover any additional bugs and to verify that no new bugs have been introduced. In both pre-silicon and post-silicon stages, the advantages of emulation are instrumental in improving overall quality and reducing time-to-market.

Stage 5: System Validation

System validation puts the actual component through a comprehensive suite of tests in a real platform environment. Hundreds of test systems run 24 hours per day for up to three months, throwing an incredibly varied assortment of random and focused tests at the component and its subsystems. As these test suites are applied to the Intel CPU, chipset and graphics subsystem, frequency and temperature conditions are intensified to test performance at the extreme corners of the component's specifications.

CPUs

System validation stresses both the architectural and micro-architectural features of the processor, with a focus on cache coherency and multiprocessor environments. Both systematic and random tests are used to cover very deep data space and intensive floating-point demands. System validation tests for the Intel® Pentium® 4 processor offer a good example of the scope and intensity of the process:

- 2,450 CPU feature tests; 2,000 ancestral architectural tests
- Random instruction testing, 1 trillion instructions per week

- Focused tests (I/O stress testing, millions of chipset feature permutations)
- Manipulate any piece of memory by any CPU in a multiprocessor environment.

Chipsets

All chipset features are tested using custom-built system validation boards and test cards running custom software to stress each interface of the chipset. Performance parameters are pushed to extreme limits on all cards and busses concurrently, to validate performance limits and to verify bus compatibility.

Graphics

Specialized tools and test suites are employed for validation testing of the graphics subsystem in all Intel chipsets with integrated graphics. Special test images are created to ensure a rigorous baseline for automated testing. If a test reports even a single wrong bit, the root cause is determined by a validation engineer, so that the problem can be fully resolved to ensure outstanding visual quality with no defects.

Stage 6: Analog Validation

As PC performance demands continue to climb, the electrical integrity of processors and chipsets is vital to ensure reliable operation at high frequencies. Intel's analog validation testing finds failures that can happen in just trillionths of a second. Components are stressed to failure at the extremes of temperature, voltage and frequency. Issues are resolved, and findings are shared with design and production engineers, so they can continue to improve Intel's design and production methods. There are two major aspects to analog validation: Circuit Marginality Validation and Analog Integrity Engineering.

Circuit Marginality Validation (CMV)

During CMV, the test suites that were used during pre-silicon simulation of Intel processors are applied again, but this time with a focus on reliability and performance under extreme operating conditions. Both commercial and custom tests are used to test voltage, frequency and temperature extremes, and to ensure reliable operation within the product's specifications.

Analog Integrity Engineering (AIE)

AIE tests the integrity of the chipset, to make sure the entire platform is electrically robust. Performance is validated under a wide variety of worst-case scenarios. Intel works especially closely with PC manufacturers during this process, providing simulation models, correlating models to silicon and working with specific customers to validate electrical robustness under the most demanding real world conditions.

Stage 7: Compatibility Validation

A key advantage of Intel architecture is its wide compatibility with third-party hardware components, software applications and operating systems. Intel components and platforms undergo exhaustive compatibility, stress and concurrency testing with over 20 operating systems, numerous motherboards and add-in cards, more than 150 peripherals, and more than 400 applications.

OS testing includes multiple versions of Microsoft Windows*, NetWare*, SCO*, UNIXware* and Linux*. Application testing includes many of the world's most popular business and multimedia programs, as well as numerous games, industry benchmarks and industry hardware tests. A comprehensive suite of tests is also applied to the component in a heavily networked environment. Massive file transfers and broadcasts test performance and data coherency using a wide range of protocols, including Ethernet, Fast Ethernet, Gigabit Ethernet, and FibreChannel*.

In addition to these well-known hardware and software products and protocols, the component is tested with specially designed cards that push test parameters beyond conventional limits, to ensure superior performance under worst-case conditions. For example, multimedia traffic is increased to the bandwidth limit of the PCI bus, to verify that audio and video signals do not break up under peak workloads.

Stage 8: Software Validation

Intel develops all core software components for its PC and server platforms. This includes the BIOS and the drivers that are used for graphics, storage and LAN connectivity. More than 100 people in 4 validation sites are dedicated to thoroughly testing and validating these software stacks. Over 250,000 stress tests are performed in realistic test environments that include 7 operating systems, 27 languages, and over 300 English and international applications.

Throughout this process, software validation is tightly integrated with hardware validation to ensure that hardware and software components operate smoothly together. This is essential to validate that the total platform will deliver top performance and reliability in the widest possible range of environments.

Intel's many years of experience are instrumental in developing automated test suites to validate driver reliability and compatibility. Over the years, Intel has shipped over 100 million integrated graphics chipsets, and developed a highly mature and comprehensive test environment in the process.

Microsoft WHQL* Certification testing is performed on all Intel software that is specified for use in a Microsoft Windows operating environment. The WHQL test suite is used in addition to Intel's proprietary tests, to certify Intel drivers and to ensure exceptionally strong validation with Microsoft applications and operating systems. Thanks to Intel's software validation expertise and established processes, WHQL certification throughput has been reduced from weeks to days on most driver releases.

Stage 9: Product Qualification

High quality design is not enough to ensure that a component delivers the value and reliability that customers have come to associate with the Intel brand. Manufacturing materials and processes must also meet strict standards to ensure that the quality of the design carries over into real devices that perform reliably for extended periods under a wide variety of environmental conditions. This is the goal of the Intel Product Qualification methodology. During this final stage, component capabilities are also compared with current end-user expectations. If a product successfully passes Product Qualification testing, it is ready to enter the marketplace.

Market Segment Requirements

Intel gathers, interprets, and documents performance, functionality, quality and reliability expectations for each major market it serves. The results are used to define validation parameters during Product Qualification. Both new and existing products are continuously evaluated to ensure they meet customer expectations. As discussed earlier, the results of these studies are also instrumental in evaluating new technologies for inclusion in Intel's product roadmap.

The Product Qualification Methodology

Extensive qualification tests are performed covering a wide variety of categories (Table 1). As with all Intel validation processes, methods and results are fully documented and carefully reviewed. This provides a foundation for designing next-generation processes, and fuels a constant cycle of improvement in the business and technical processes used to achieve qualified and shippable products.

When a new component fully passes this phase of testing, it is ready for high-volume manufacturing and sales. If not, another design iteration is required, after which the product component reenters the validation process at stage 5 (Systems Validation). If minor design issues are discovered at this—or any other—post-silicon stage, Intel engineers use advanced silicon debugging tools to correct the problem (see stage 10, below). However, even minor silicon adjustments are followed with substantial revalidation to ensure the quality and reliability of the final product.

Evaluation Category	Purpose of Tests
Design Quality	To validate the quality of the product design prior to manufacturing. Example: *ESD (Electrostatic Discharge)*
Materials Quality	To confirm the quality of procured parts and materials used in the manufacturing process. Example: *Product Procurement*
Manufacturing Quality	To verify that manufacturing tools and processes deliver high-quality, useable and reliable parts. Examples: *Statistical Process controls, Fault Grading*
Environmental Quality and Reliability	To validate performance and reliability under a wide variety of environmental conditions. Example: Thermal Moisture
Operating Reliability	To evaluate the reliability of the product over time. Example: Infant Mortality (Burn-in)

Table 1. *During final product qualification, yet another set of tests are performed validate the quality of the manufactured component. Only products that pass this final phase are ready for high-volume manufacturing and sales.*

Stage 10: Silicon Debug

A vital component of Intel's validation environment is the ability to look "inside the pins." This means that Intel engineers can examine physical and electrical characteristics at the transistor level – while exercising components at full speed. They can also perform "silicon surgery," to repair hardware defects as they are located. As a result, fixes can be implemented and tested before stepping to a new silicon version, a capability that greatly improves design and validation efficiency. Because Intel technology advances more rapidly than the industry infrastructure, Intel works with the industry to develop the necessary tools for this critical process. Three tools are essential.

Laser Voltage Probe

The laser voltage probe enables Intel engineers to observe the physical and electrical characteristics of a single transistor out of the many millions in a processor or chipset. Performance can be inspected in complete detail during full-speed operation, so logical and electrical problems can be traced to specific physical causes.

Laser Chemical Etcher

Processors and chipsets are three-dimensional, with multiple layers of transistors, interconnect wiring and protective material. The laser chemical etcher enables validation engineers to isolate areas of interest and expose them for testing and repair.

Focused Ion Beam

With the focused ion beam, Intel engineers can add, delete or modify transistors and wires to adjust timing parameters. They can also add or bypass logic cells to alter digital functionality. Multiple edits can be performed on a single die. The component can then be re-tested to validate the edited design before stepping to a new silicon version.

Using these three tools, Intel validation engineers can pinpoint, isolate and fix problems in a matter of days rather than weeks, and they can verify that their fixes will work under demanding, realistic conditions. This combination of quick-fix capabilities and an exhaustive test environment significantly reduces the number of silicon iterations required to go from an initial design to a final, fully-tested component. For Intel, this means a less costly development process and a faster and more reliable time to market. For customers, it means better and more reliable products at more affordable prices.

Conclusion

Intel platforms and components are subjected to the most rigorous and comprehensive testing environment in the computing industry. Over $300 million are invested in this program annually, with over 2,500 Intel employees working in 20 facilities around the world. Equally important is the experience and expertise Intel brings to this vital task. For over 30 years there has been continuous feedback between Intel's design and validation teams, which has fueled a constant cycle of improvement. As a result, the performance and functionality of Intel components and platforms have increased dramatically – and so have their reliability and compatibility.

A wide array of individuals and organizations benefit from this intense commitment to quality, from the thousands of hardware and software companies that develop compatible solutions, to the millions of businesses and consumers who depend on the performance, reliability and compatibility of Intel-based PCs.

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