



[www.ozeninc.com](http://www.ozeninc.com)

[info@ozeninc.com](mailto:info@ozeninc.com)

(408) 732 4665

1210 E Arques Ave St 207

Sunnyvale, CA 94085

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# From Signal Integrity to Product Integrity

## EXECUTIVE SUMMARY

We're in the midst of an electronics-centered innovation boom that has transformed the way we communicate, work, learn and entertain. Virtually no product is exempt from these improvements. In your home and office — around the globe, in obvious and not-so-obvious applications — there are ultra-smart phones, fiber-optic and wireless networks, computers that fit into a pocket, LED screen displays that mimic paper and even tracking chips in pets. Second-millennium automobiles are filled with electronic communications devices that control engine functions, keep wheels from skidding, help avoid accidents and direct our route of travel. Aviation electronics include radar, fly-by-wire systems and airborne communications. Electronics innovations have been adopted in industrial and military applications: Smart electronics are redefining everything from just-in-time manufacturing to homeland security. It's obvious that these devices are affecting the quality of our lives. What's not so apparent is how interconnected products have become and how they impact our safety.

For companies that develop products, the implications of this electronics boom are significant. Never before has the opportunity to differentiate in the marketplace been so pronounced. At the same time, the downside risk of product failure and its consequences can be catastrophic: One estimate for a single product recall is \$8 million-plus — in direct costs only. More significantly, a brand that took decades to build can be destroyed in seconds.

The behavior that underlies product failure is complex and difficult to physically test. For instance, electronics create a large amount of stray electromagnetic emissions that can cause complications. When a signal is sent down a wire, it resonates and emits electromagnetic fields that interfere with other components in the product — as well as other products that happen to be in the area.

*“The potential impact of simulation is limited only by imagination. Increasingly detailed simulation models and more powerful computers will make possible problem solving that otherwise could not be done.”*

— Stefan Thomke, Professor of Technology and Operations Management, Harvard Business School

Product designers must wrestle with this challenge — often referred to as cross talk, signal integrity or electromagnetic interference (EMI) — which is difficult to predict and replicate as well as expensive to detect or measure. But the issue goes beyond EMI. Even if unintended, phenomena related to structural mechanics, heat transfer, fluid flow and electromagnetics can interact and lead to product failure. Your company's mission, then, is to anticipate the “system effect” of a modern product whose whole is far greater (and more volatile) than the sum of its parts. How do you study all the possibilities to reach product integrity?

A test-and-build approach is expensive, time-consuming and iterative. Specific to EMI complexities, physical experiment fails to explain how and why, so the next product iteration may fail as well, delaying development and further increasing costs. The proven alternative is engineering simulation, which enables engineers to virtually test performance of a design



under a wide range of scenarios, some of which may be impossible to replicate experimentally. Simulation enables an engineer to understand exactly how and why a design performs in any given scenario. Using simulation, top performers get products to market an average of 158 days sooner with \$1.9 million lower development costs.

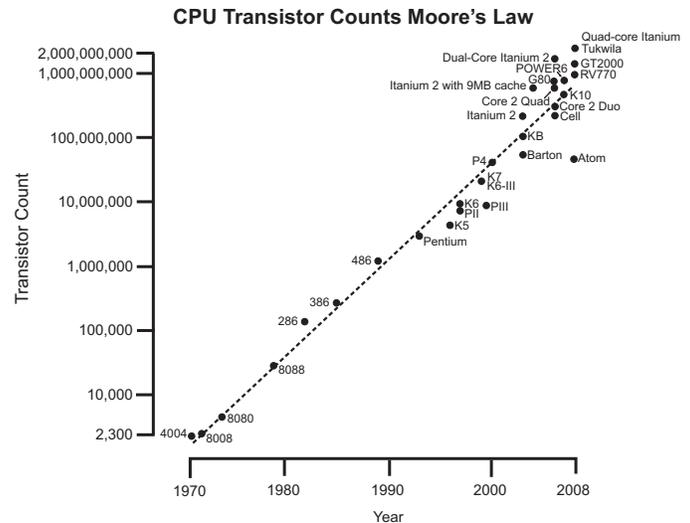
This white paper explores the factors behind the electronics explosion, how the potential for product failure puts your company at risk, how simulation can help your company move from signal integrity to product integrity, as well as parameters important to realize accurate simulation results — and product success.

## EXPONENTIAL GROWTH

As developers build additional electronics content into their product designs, the challenge of maintaining product integrity becomes much more difficult. At the center of the revolution is the semiconductor industry, which has followed Moore's Law and doubled the amount of transistors on an integrated circuit (IC) every 18 months. The result is an exponential increase in the amount of data that can be inexpensively processed or stored in today's chips. Case in point: Intel's latest Itanium® chip, targeting the high-end server markets, will have more than 2 billion transistors compared with chips that carried less than 1,000 in 1970.

There also has been an exponential increase in the speed at which these chips operate. The rise of semiconductor electronics, and the underlying manufacturing technology for them, is among the most important global developments in the history of the past half-century. Integrated circuits — silicon chips — have transformed communication, transportation, commerce, military force and culture. The end result is that huge numbers of product features can be added to new and existing products — many of them features that did not exist in the past.

To illustrate, *BusinessWeek* magazine and Chetan Sharma Consulting analyzed innovation in the wireless, networking and communications field. A high-end cell phone in 2005 typically used about 100 MB of broadband data per month, mostly for voice call and limited web browsing. Today's newest capabilities — including net radio, YouTube® and smart phone networks — consume about 1,000 MB of broadband data per month. This consumption will steadily increase as consumers around the world use more and more complex devices, such as the tablet computer with improved video- and book-download capabilities. The possibilities for further hand-held device enhancements have been a major driver of innovation throughout the semiconductor industry — and have spread to networking devices such as high-end routers, servers and fiber optic networks.



Moore's Law describes how the amount of transistors on an IC has doubled every 18 months.

### Timeline of Electronics Applications and Products

1970s	1980s	1990s	2000s
Email	Wireless email	Instant message	Bluetooth®
PC	Laptop	DVD/DVR	Smart phone
Mobile phone	Walkman®	MP3	iPod®
VCR	CD	Wi-Fi	Wireless network
		iMac®	Blu-ray™
		Digital camera	Broadband internet
			Hybrid/ electric car
			HD and 3-D TV
			GPS
			E-reader
			Tablet computer
			Fiber optics
			RFID
			Xbox® gaming
			Auto stability and accident control

As electronics capabilities expand, the technology is being incorporated into more and more innovative products. Each holds the opportunity for electromagnetic interference — along with product failure.

In the 1970s, signal integrity was not so great a design challenge: An electrical signal sent down a wire would travel to its destination and perform its intended task without affecting any other part of the circuit. But the electronic signals in today's products — such as iPod, smart phone, laptop and networking equipment — travel at much higher speeds. Furthermore, the increasing bandwidth and smaller sizes have changed everything. Now, when the higher-frequency signal is sent, the wire still carries the signal to its destination, but it also resonates and emits electromagnetic fields that interfere with other components in the product — as well as other products that happen to be in the area. In complex systems such as cars and airplanes, electronic and electromechanical components are developed by multiple vendors, increasing the opportunity for signal interference.

What are the consequences? Products become much more complicated when they include several electronics components operating at high-signal processing rates. The vast majority of the unintended signals flying around the product are likely to appear as noise that has no effect on the product's operation. But can your company withstand even one product failure? "Signal integrity is a whole new field," said Professor of Electrical Engineering Paul G. Huray at the University of South Carolina, "and the signal integrity engineer is becoming the crown jewel of the company."

## THE GROWING COSTS OF PRODUCT FAILURES

Even a few isolated product failures can damage an organization in the form of reputation, sales, stock price, warranty claims, legal costs and credit rating. Product integrity is emerging as a potential problem at a time when the cost of delivering a faulty product to customers has never been higher. The American Society for Quality estimates that each **product recall costs an average \$8 million-plus** in direct costs alone. The indirect costs add greatly to the total. That's only the beginning. The Consumer Product Safety Commission can impose **fines of up to \$15 million** for failing to report potential product safety violations or defects. U.S. companies spend a combined total of over **\$2 billion a year defending product liability lawsuits** according to the Public Services Research Institute. This number does not include

*"In the future, we will have to change the way we do things. Hardware product developers want to sell computers that operate at 10 GHz in the next generation, then probably 30 GHz after that, and 100 GHz after that."*

— Dr. Paul G. Huray, Professor of Electrical Engineering, University of South Carolina

## The Permutations of Cross Talk

Few products today are immune from the domino effect of interconnected systems and physical components each talking over the other.

### Cars

More than 40 percent of the value of next-generation automobiles is expected to come from onboard electronics and electromechanical components, including devices intentionally designed to talk to each other: drive by wire, ABS, engine control, navigation and hands-free mobile communication. A large proportion of these devices are designed by multiple vendors. Driver and passengers can bring aboard their favorite devices from the thousands of models of cellular phones, MP3 players, video players, GPS systems and more — each inviting the opportunity for electromagnetic interference. With 400-plus car models available each year (in the United States alone), the permutation of interactions may run into many trillions.

### Planes

Modern aircraft have many electronics devices, such as fly-by-wire systems, communication and navigation devices, radar, antennas and passenger entertainment systems. Many planes offer satellite-enabled cell phone service. Furthermore, a typical Boeing airliner can carry up to 280 passengers, a large percentage of whom carry cell phones, laptop computers and personal audio devices. A NASA report, "Personal Electronic Devices and their Interference with Aircraft Systems," details that "14 years of incidents reported by pilots to the Aviation Safety Reporting System showed that interference was caused, or suspected to be caused, by passenger electronic devices. Mobile phones were the most frequently identified source of interference, with laptop computers a close second."

### Consumer Products

Beyond web-enabled smart phones and laptops, a host of other consumer products have the potential to interact with each other in ways that were never imagined by their designers: kitchen appliances, wireless routers, RF-tagged products, HD and 3-D TVs, game and entertainment consoles, Wi-Fi, Bluetooth, net books, e-readers, GPS location devices ... With billions of such devices in use today and thousands of new electronics products coming to market every year, is it possible to test the interaction of your next product with all of the gadgets it might come into contact with?

actual settlements or jury awards, which average about \$700,000 each. But the greatest cost of all may be the effect on a company's reputation if consumers believe that its products are not safe.

Consider the impact of product integrity on just one industry. In the United States, there are more than 6 million car accidents and a resulting 40,000 deaths every year. The total cost of these accidents, as estimated by the American Automobile Association, is \$164 billion. In the last few years, more than 10 million vehicles have been recalled in the United States. How many of these product defects and accidents are related to unanticipated malfunction in hardware or software electronics components? The causes are not readily identifiable, since historically it has been difficult to conduct physical tests for EMI and quantify risks.

The estimated cost of running a component EMI study in a testing facility can be up to \$10,000. For a larger and very complex system — such as a typical automobile that comprises components from a variety of manufacturers — costs can increase substantially, up to \$1 million per test. Is it possible for your company to physically test every use scenario — considering that the myriad electronics comforts passengers bring aboard might interfere with the automobile's critical electronics? And if your product fails EMI testing, will the analysis tell you why it failed or provide insight for the next design iteration?

## SIMULATION TO THE RESCUE

So how should your company rule out product designs with the potential to fail? In many cases, the least costly, most effective and most insightful way to ensure product integrity is with engineering simulation. Unlike traditional prototype testing, simulation enables engineers to virtually test how a given product design will perform — well before any physical model is built — against a wide range of scenarios, some of which may be impossible to replicate experimentally. Simulation can be used at any point in the design process, but it is especially beneficial in the early stages when changes can be efficiently and cost effectively implemented.

“The ability to run massive experiments via simulation has become critical in many fields,” said Stefan Thomke, professor of technology and operations management at Harvard Business School and author of books on product innovation. “The potential impact of simulation and other experimentation technologies now and in the future is limited only by imagination. Increasingly detailed simulation models and more powerful computers will not only allow researchers and engineers to run analysis ‘in silico’ [via computer] faster and cheaper but also will make possible problem solving that otherwise could not be done. In this way, computer modeling and simulation will continue to advance our knowledge in many ways we cannot anticipate today.”

## MAKING SENSE OF DESIGN TRADE-OFFS

Simulation is a proven way to move your design beyond mere signal integrity to whole-system product integrity. Design engineers must carefully consider a wide range of intended or unintended interacting parameters — electrical, thermal and mechanical. Obviously, powerful electronics components, crammed into tighter-than-ever-before spaces, must not be allowed to overheat. On the mechanical front, how do shock and vibration loads affect a component's reliability? Each part of a product must be optimized based on electrical, thermal and mechanical parameters.

Just as important is system integrity. The entire product design community faces an escalating challenge to anticipate the “system effect” of a modern product whose whole is far greater (and more volatile) than the sum of its parts. Untangling the risks is complex, but the best simulation processes go beyond solving problems to developing innovative solutions.

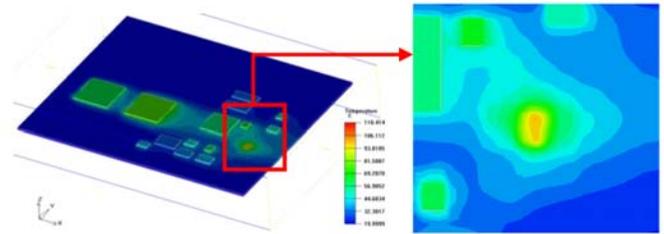
*“Simulation is being taken into account as part of corporate strategy in bringing more innovative products to market and more revenue to the company's bottom line.”*

— James Croscheck, Structural Engineer and President of consulting firm Effective Engineering Solutions

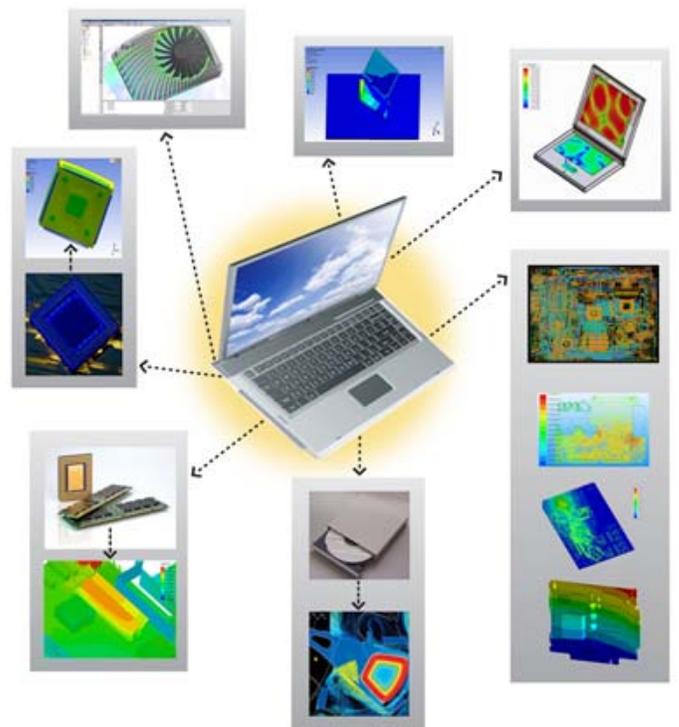
For example, in designing a laptop computer, a team responsible for signal and power integrity (SI/PI) might design a printed circuit board layout that minimizes signal interference along the high-speed channel. But this same layout might lead to two high-power components operating in close proximity to one another, causing significant overheating. Similarly, a thermal engineer might add a thermal connection, specifically a thermal via, under a high-power device to improve conductive heat transfer, but that might lead to significant interference with the signal entering or leaving the IC. EMI/EMC engineers might want to reduce the size of an air vent to decrease electromagnetic emissions from the product. But reducing vent size will make it harder for hot air to escape the product, creating the risk of overheating and product failure. In the same way, the group responsible for thermal design might add a heat sink atop an IC to improve heat transfer, but this puts increased weight on the IC, which can result in damage during shipment. The heat sink also can act as an internal antenna that increases electromagnetic emissions. The cycle continues: Adding a fan to improve air circulation can increase noise and power consumption, increase the size and weight of the device, and reduce product reliability due to fan failure. Changing the laptop's overall dimensions, or even the materials it is made of, may reduce costs and weight but expose the computer to damage from shock and vibration that occur during regular usage. System interdependencies make it essential that electrical and mechanical engineers work together to optimize system performance rather than each optimizing the product for their particular component or discipline.

## SIMULATE WITH THE BEST TOOLS TO ENSURE PRODUCT INTEGRITY

Choose your simulation software wisely, however, as not all simulation tools are equal. To help ensure that your product designs succeed in the market, engineering and design teams must accurately predict how complex products will behave in a real-world environment — one that changes continuously and involves the interaction of multiple types of physics. Only multiphysics simulation allows users to create virtual prototypes of their designs operating under such real-world conditions, predicting the interactions between structural mechanics, heat transfer, fluid flow and electromagnetics. In EMI simulation, for example, your portfolio must deliver integrated 3-D solvers along with circuit-level tools. A single, unified engineering simulation environment harnesses the core



Chip size reduction and speed improvements together result in power densities that can create hot spots on the chip and in the surrounding PCB circuitry.



An integrated engineering simulation solution can help your company meet product integrity and innovation challenges, interdependently addressing issues including SI/PI, EMI/EMC, RF/MW, thermal and mechanical. Simulation also encourages innovation design.

*“With the help of simulation, top performers on average were able to get the most complex products to market 158 days sooner with \$1.9 million lower development costs.”*

— Aberdeen Group

physics and enables their interoperability, which is critical for a quality solution. It also provides common tools for interfacing with your unique CAD system, in-house codes and data management tools.

The best simulation software spans the design continuum to fuel open communication between diverse engineering teams — from electrical and mechanical to thermal and fluid dynamics. Software that incorporates deep and broad multiphysics tools built on a single, integrated platform helps to ensure that no detail is missed, no potential risk factor is overlooked, and no product is released before it is ready. Barriers to true collaboration are shattered. As a result, product developers are inspired to design, develop and deliver only performance-tested, market-ready products.

A portfolio that makes it easy to explore what-if questions is essential for robust design, wherein a product performs optimally over its lifetime despite environmental variables. For example, what happens if you need to improve functionality (speed) by 20 percent to meet customer demands? What if you reduce overall weight by 10 percent? Or try to improve manufacturability by reducing the number of parts? Using simulation software with robust design capabilities, engineering teams can readily evaluate alternative designs, gain valuable insight into product behavior, make intelligent trade-off decisions, and test the feasibility of way-out ideas — especially important as organizations try to incorporate customer demands. This approach is much faster than physical testing, so engineers can evaluate many more design alternatives subject to a plethora of scenarios than would be possible using conventional methods. Your engineering team can move faster than competitors in adding innovative features and quantifying risk — before the product leaves the manufacturing plant and without running the risk of product failure.

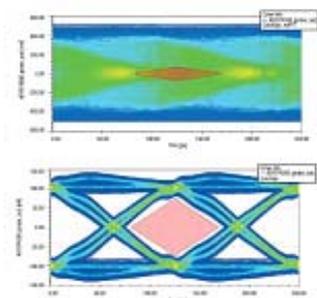
These proven benefits certainly are well documented. In the recent “Simulation-Driven Design Benchmark Report,” the Aberdeen Group found that 100 percent of best-in-class manufacturers — those meeting cost, revenue, quality and launch-date targets 86 percent or more of the time — use simulation in the design phase. They average 1.6 fewer prototypes than all other manufacturers. With the help of simulation, these top performers, on average, were able to get the most complex products to market 158 days sooner with \$1.9 million lower development costs. Manufacturers with the simplest products shortened launch times by 21 days and saved \$21,000 in development costs.

“Simulation empowers engineers and designers to envision and develop better designs — in which better might mean lighter, cheaper or stronger,” said Tim Morris, chief executive of NAFEMS. “While companies might need to cut back on manufacturing in times of recession, smarter companies will not cut back too much on design or research but, rather, will use the opportunity to improve both

## Simulation@Work

### NVIDIA Brings Simulation into Product Design Process

NVIDIA is a world leader in visual computing technologies and the inventor of the GPU, a high-performance processor that generates breathtaking, interactive graphics on workstations, personal computers, game consoles and mobile devices. One of the hardest challenges when designing such graphics solutions is ensuring that the communication link is clear between the pixel generation and pixel display. That means the signal originating at one part of the system needs to propagate undistorted to another area so it may be detected without errors. Ansoft Designer software from ANSYS enables NVIDIA engineers to assemble each piece of the channel as a black box model. These models may comprise measured data, simple circuits, SPICE components or dynamic links into any of the ANSYS circuit extraction tools. These individual models may be rearranged, bypassed or parametrically varied, providing the engineer with the ability to test all possible configurations. This high-level schematic approach also allows the design to be easily shared among different groups, which then can quickly see what is being modeled and provide input into the design. “Given that there is a finite amount of time and machine resources, the statistical approach gives engineers systematic coverage without running an astronomical number of simulation corners. Using the statistical methodology allows engineers to make judgment calls between cost and production yield,” said Ting Ku, NVIDIA’s director of signal integrity.



Simulation eye diagrams, which show whether the received data is able to be detected error free

products and design processes. Continued investment in simulation will continue to bring rewards in terms of making companies more competitive and should allow these businesses to emerge from the recession in a stronger state, and quite probably with fewer competitors. What we do know, from independent research that we have been involved with, is that the best-in-class companies are often those that make the greatest use of simulation.”

## SIGNAL AND PRODUCT INTEGRITY SIMULATION IN ACTION

Simulation to address signal integrity — and electronics design in general — can begin as soon as engineers have designed the electronics circuits and long before a physical prototype exists. The engineering team can use a circuit simulator to model the behavior of the circuit down to the level of the amplitude and timing of individual pulses. Then, after the physical layout is complete, they can perform a 3-D electromagnetic simulation to identify all of the radiation that is released by the prospective design. Next, these stray signals can be added back to the circuit simulation to determine their precise effect on the operation of the product.

Other simulation tools address a variety of issues involved in product design, such as electronics cooling and structural integrity during normal loading and vibration or during an accidental drop. In the best-practice scenario, these simulation tools can be harnessed together to simultaneously determine the effect, for example, of how changing the size of a vent will impact the product's electromagnetic compatibility, thermal design, mechanical reliability, weight, cost or function.

“Until now, analysis has been done almost as an afterthought at many companies, performed apart from design and out of the product development loop,” noted James Croscheck, a retired structural engineer with Deere and Company and now head of the consulting firm Effective Engineering Solutions. “Advances in technology and processes notwithstanding, the single most important factor in bringing simulation into the mainstream of product development is a radical shift in attitude. In engineering departments, simulation tools are now more commonly being regarded as an integral part of design instead of an outside service used only on a limited basis. And at the executive level, simulation today is being taken into account as part of corporate strategy in bringing more innovative products to market and more revenue to the company's bottom line.”

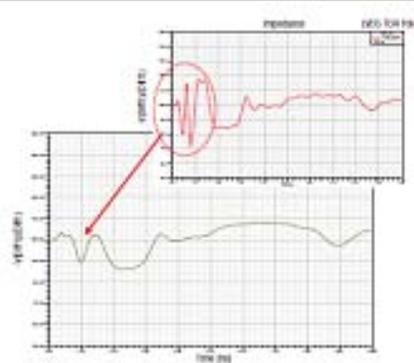
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— Tim Morris, Chief Executive, NAFEMS

### Simulation@Work

#### Panasonic Optimizes Design Process and Product

In a unique network camera device that permits remote visual monitoring for surveillance applications, Panasonic used a standard Ethernet connection to transmit video and audio signals, allowing remote monitoring from any location. Panasonic used ANSYS engineering simulation software in creating a methodology that enabled engineers to simulate complex high-speed PCBs and meet challenging signal integrity and product design specifications. By adopting a circuit and 3-D electromagnetic cosimulation approach, the design team saved about two months on a second prototype build and about one month on lab measurements. “The high-level schematic approach allows the design to be easily shared among different groups, which then can quickly see what is being modeled and provide input into the design,” said Hiroshi Higashitani of Panasonic Electronic Devices Co.



A comparison of impedance maps for two PCB designs

## YOUR NEW PRODUCT DESIGN IMPERATIVE

Your product development efforts should meet these critical requirements to ensure innovation along with the integrity of your product development process:

*See the true possibilities of product innovation.* The fundamental value of simulation is not in terms of doing what you did yesterday 20 percent more effectively, it's in exploring new possibilities, doing things in completely different ways, breaking the status quo, jumping to the next curve. The unrivaled what-if capability of computer-based simulation can expand your design horizons and help you to create products you might not have known were possible. Look for a simulation partner that offers robust design along with the ability to simulate entire systems, thus enabling product success — not just product design.

*Your design tools should be as smart as the products you develop.* Consumers are demanding more features, more functions, in as sleek and elegant a design as possible. The advanced electronics capabilities designers put into today's products result in higher user functionality but increasingly smaller footprints fraught with design challenges. Your products are only as good as the software tools that test them for performance, reliability and safety — before they hit the market. So choose an established supplier whose years of experience translate into a world-class reputation. Make sure that the portfolio you're planning to invest in delivers high-fidelity, accurate and real-world results.

*You shouldn't design in a vacuum.* Tight collaboration between engineering teams means less risk of misunderstandings that can negatively impact the real-world performance of your products. The right simulation tools span the design continuum to fuel open communication between your diverse engineering teams — from electrical and mechanical to fluids designers and engineers. With the barriers to true collaboration shattered, your product developers can be inspired to design, develop and deliver performance-tested, market-ready products. A simulation solution that offers deep physics within disciplines encourages engineers to drill down to solve a wider range of problems as well as deal with more complex scenarios. But tools alone are not enough; your organization must modify and streamline processes to produce a more collaborative product development model.

*Socialize your smart devices.* Evaluating risk is not as simple as identifying cause and effect: It involves untangling the interrelationships between the disparate technologies used in a given product. Engineering teams must evaluate how your product interacts with its environment. Consider the average car, today's modern kitchen or the cockpit of an airplane: These real-world environments are littered with smart devices that either directly or indirectly talk to each other. Your product's performance, even after rigorous testing, can be compromised once it leaves the development lab.

Testing your design across the various engineering disciplines and within different ecosystems at the system, component and circuit levels is critical to identifying and correcting potential problems in your products before they reach the market. Using the right engineering simulation means your engineers will be able to look beyond the symptoms and common operating conditions and into a better definition of the design space. Choosing a broad and coupled multiphysics simulation program — one that includes far more than electromagnetic 3-D solvers and circuit-level tools — enables you to move from mere signal integrity to product integrity.

### Simulation@Work

#### ZTE Takes R&D Capabilities to Next Level

ZTE is China's largest listed telecommunications equipment provider of customized network solutions. Using ANSYS signal and power integrity analysis software, engineers there are able to predict radiated emissions and induced interference from printed circuit boards (PCBs) and to examine multiple PCBs within a cabinet to determine trends for system-level emission. The new design methodology has allowed ZTE to eliminate expensive build-test-repeat iterations in their design cycle. "Our engineers are very experienced in PCB design and needed to expand capabilities for EMI/EMC. Previously, we were using expensive and time-consuming prototyping and testing to make sure the design performance met requirements," said Zhu Shunlin, chief engineer of the EDA group at ZTE. "The ANSYS design methodology helped us solve this issue, improve product performance, reduce cost and speed our time to market. We have taken our R&D team's capabilities to the next level."

*Failure to predict problems can damage more than your product.* It can ruin your career and your company. So don't risk your brand by tolerating even one product failure. Finding the right product testing and simulation partner is critical to preventing serious product failures that can damage your image. Even the best companies in the world can struggle with the complexity of product problems that span EMI to fluid dynamics. Simulation can help you identify potential problems and product risks so your customers never will.

Your company's reputation is its most valuable asset. It takes years to build a quality image, and only seconds to damage it. Protect it by choosing wisely.



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About ANSYS, Inc.

ANSYS Inc., founded in 1970, develops and globally markets engineering simulation software and technologies widely used by engineers, designers, researchers and students across a broad spectrum of industries and academia. The Company focuses on the development of open and flexible solutions that enable users to analyze designs directly on the desktop, providing a common platform for fast, efficient and cost-effective product development, from design concept to final-stage testing, validation and production. The Company and its global network of channel partners provide sales, support and training for customers. Headquartered in Canonsburg, Pennsylvania, U.S.A., with more than 60 strategic sales locations throughout the world, ANSYS, Inc. and its subsidiaries employ more than 1,600 people and distribute ANSYS products through a network of channel partners in over 40 countries. Visit <http://www.ansys.com> for more information.

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Southpointe	1.866.267.9724
275 Technology Drive	Toll Free Mexico:
Canonsburg, PA 15317	001.866.267.9724
U.S.A.	Europe:
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