GO BEYOND THE WAVEFORM
ADVANCED SPICE ANALYSIS

EMA Design Automation®

WHY SIMULATE?

Simulation modeling enables engineers to visualize the operation of their designs and clearly demonstrate the ability or inability to meet performance objectives.

Utilizing SPICE simulation early in the design increases the likelihood of meeting design requirements the first-time and helps finalize the design and verify circuit functionality. This safe-guard approach to ensure correct circuit functionality before moving to production is important; however, it really only scratches the surface of what you can do with simulation to drive product success. So how can you scale your SPICE simulation capabilities to answer important design questions such as:

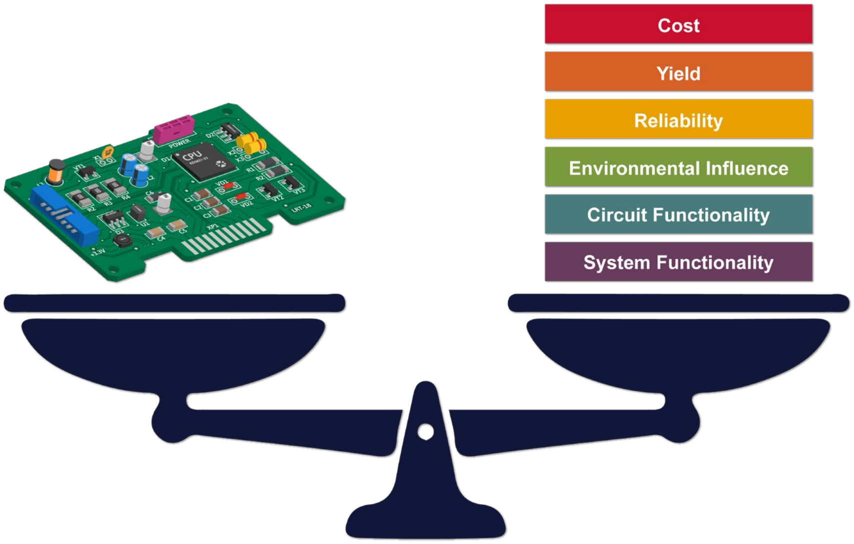
- How do my design choices affect functionality?
- How can I reduce field failures?
- How can I ensure & improve reliability?
- How do I increase product yield?
- How do I ensure system level success?
- How do I maximize profitability without sacrificing performance?
- How do I reduce time to market?
- **What is the optimal configuration for my design across all these requirements?**

The answers to these questions are often determined through manual methods, trial and error, and lessons learned from previous designs. As deadlines shorten and product complexity increases, the time commitment required to conduct these analyses through manual and iterative processes become untenable; products start to fail, costs go up, and the company suffers. With nearly infinite possibilities and design options, how do you ensure the right choices are made?

EVERY DESIGN CHOICE AFFECTS THE ONE AFTER IT

The ultimate goal of PCB design is achieving a balance between:

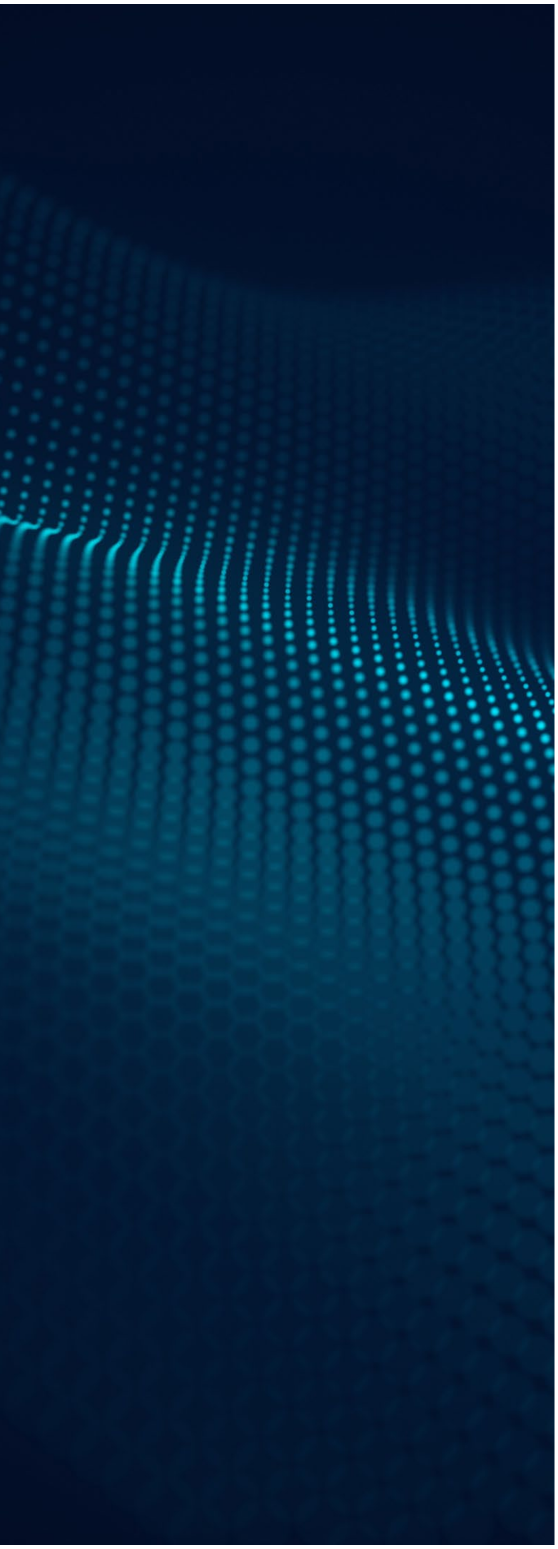
- Cost
- Environmental Influence
- Reliability
- Circuit Functionality
- Yield
- System Functionality



Every decision made in each of these categories not only has direct implications on its own outcome but can also influence the others. For example, choosing specific components to help mitigate cost can affect functionality, etc. Informed design choices are required to achieve the desired design results; however, since every choice made is compounded during the design process, achieving success is complicated.

> **"EVERY DECISION MADE IN EACH OF THESE CATEGORIES NOT ONLY HAS DIRECT IMPLICATIONS ON ITS OWN OUTCOME, BUT CAN ALSO INFLUENCE THE OTHERS."**

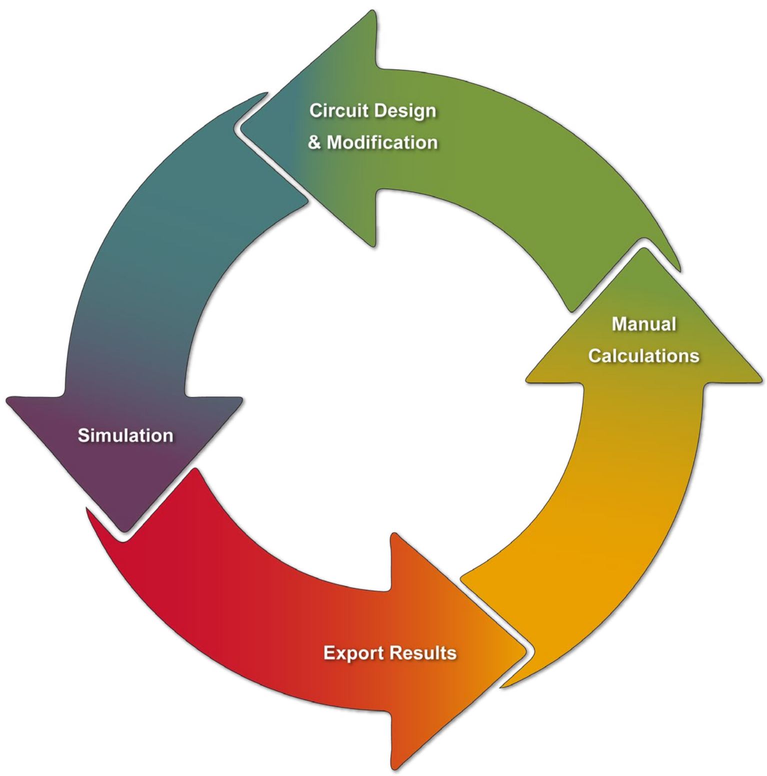
HOW TO FIND THE BEST SET OF CHOICES FOR YOUR DESIGN



Simulation can be performed to evaluate endless scenarios and options including:

- **Component values**
- **Component stress**
- **Component tolerance**
- **Temperature effects**

However, completing this analysis with individual SPICE simulations is a labor-intensive process consisting of setting up and running thousands of simulations, exporting results, and performing manual calculations, modifying the design, and doing it all over again.



While simulation answers functionality questions so educated design choices can be made, simulation can be taken further to provide additional insights into your design and scale it to better assess macro problems.

Advanced SPICE simulation can be leveraged to scale analysis methods with:

- Component Tolerance Variation
- Automatic Identification of Critical Components
- Automatic Evaluation of Temperature Variation Effects
- Exhaustive Component Stress Analysis
- Automatic Design Optimization
- Automatic Calculation of Yield
- Integrated Electro-Mechanical Analysis

Incorporating these methods allows engineers to access multiple design scenarios and outcomes simultaneously enabling a real-world determination of how a circuit behaves in a variety of scenarios. Engineers can then evaluate, optimize, and ensure reliability of designs before prototype and efficiently make trade-off decisions to positively impact business outcomes.

This eBook will dive into descriptions and examples of how you can scale your simulation capabilities to ensure you can meet your overall design goals across cost, performance, reliability, yield, and overall system performance BEFORE prototype.

BALANCING PERFORMANCE AND COST

Every project has a specific budget that must be followed. This budget must account for:

- **Development Time**
- **Stakeholder Salaries**
- **Components**
- **Fabrication & Assembly**
- **Mechanical Enclosures**
- **Testing**

To maximize profitably, costs should be reduced wherever possible. While many of these budget allocations are fixed, components aren't. Component selection contains a wide variety of factors which can be fine-tuned to improve purchasing and reduce costs:

Packaging

How the component is packaged can have an affect on the price. For example, prices for tape and reel, tube, tray, etc. often vary.

Quantity

Discounts are often available when purchasing components in bulk. For example, purchasing a pack of 10 is sometimes less expensive than purchasing 6 single components.

Distributor

Distributors offer competitive pricing. Shopping around can often be an effective way to save on overall component costs.

Component Parameters

When a component requires a higher temperature rating, or is designed for a specific application (high-speed, high-power, etc.), the cost increases.

Tolerance

Component cost increases when tolerance ratings are stricter as the production process requires higher precision. For example, a component with a 5% tolerance will be less expensive than a component with a 1% tolerance.

Note: It is crucial engineers use caution when loosening component tolerance as this can affect circuit performance.

EXAMPLE
ANALYZING COMPONENT TOLERANCES

Using simulation, the effect of component tolerance on circuit behavior can be analyzed. Standard simulation allows you to vary the component tolerance, run the simulation, and view the effects on circuit behavior. For comprehensive analysis, this process must be completed for each passive component in the design to determine the critical components.

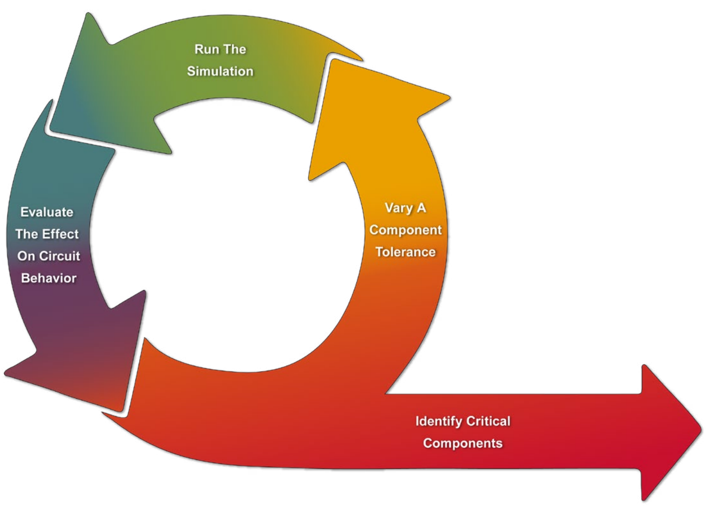


Image		
Mfr Part #	08053C104KAT4A	08053C104MAT2A
Mfr	KYOCERA AVX	KYOCERA AVX
Supplier	KYOCERA AVX	KYOCERA AVX
DK Part #	478-13052-2-ND 478-13052-1-ND 478-13052-6-ND	478-7947-2-ND 478-7947-1-ND 478-7947-6-ND
Description	CAP CER 0.1UF 25V X7R 0805	CAP CER 0.1UF 25V X7R 0805
Price	$0.10000	$0.15000
Stock	92,500 Factory Stock	51,985 Factory Stock
Min Qty	1	1
Series	-	-
Package	Tape & Reel (TR) Cut Tape (CT) Digi-Reel®	Tape & Reel (TR) Cut Tape (CT) Digi-Reel®
Product Status	Active	Active
Capacitance	0.1 µF	0.1 µF
Tolerance	±10%	±20%
Voltage - Rated	25V	25V
Temperature Coefficient	X7R	X7R
Operating Temperature	-55°C ~ 125°C	-55°C ~ 125°C

Identifying critical components which require tighter tolerances (often more expensive) and loosening tolerances of non-critical components guarantees circuit performance while reducing overall cost. For example, loosening only the tolerance specifications on a 0.1uF capacitor can save 5 cents. If this could be done for all 0.1uF capacitors in the design across the entire PCB production significant cost savings can be achieved without affecting performance (example: $0.05 savings * 50 capacitors * 10,000 boards = $25,000).

Designing for Cost AND Performance

Advanced SPICE analysis completes this iterative process more efficiently with automation. By varying component parameters simultaneously and automatically identifying critical components in a single analysis run, engineers can quickly evaluate trade-off decisions for cost and performance, finding an optimal configuration.

ACCOUNTING FOR ENVIRONMENTAL CONDITIONS

Environmental conditions can affect how a PCB performs. With the end product being used in a variety of environments (and not in a controlled lab environment) outside influences must be considered. Typically, this is achieved by prototyping the design and performing a variety of tests in chambers that replicate harsh environmental conditions. Introducing extreme high and low temperatures to the PCB and analyzing the performance will guarantee the end product functions correctly in any environment.

To meet regulatory requirements, this testing is required before a product launch. However, due to the laborious and costly process associated with prototyping and testing, iterations should be reduced wherever possible to keep the project on budget and on time.

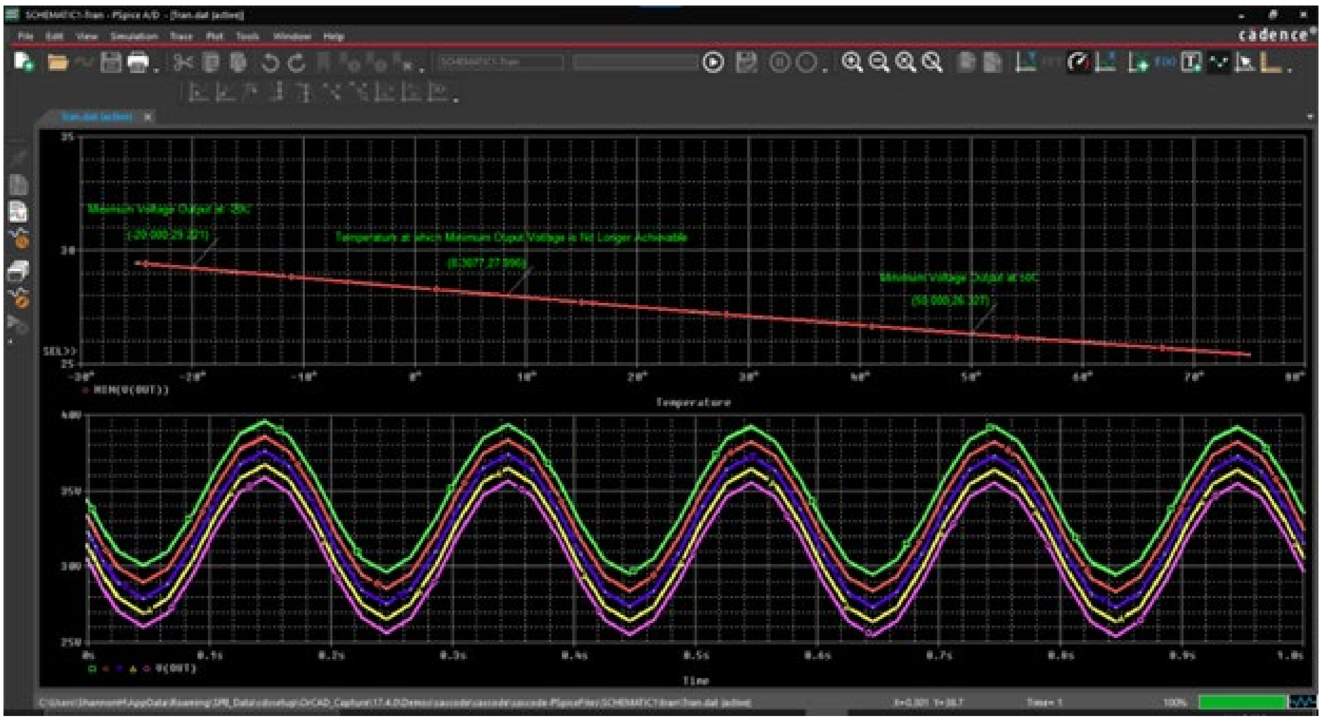
Utilizing simulation to evaluate environmental conditions during the schematic phase will:

- **Minimize the number of prototypes**
- **Reduce Testing Iterations**
- **Save Money**
- **Reduce Time**
- **Increase product success in the field**

Outside and environmental influences must be considered for all designs; however, this is especially important for industries where field failure is not an option such as military applications. Devices made for aerospace and defense are often exposed to extreme environmental conditions and must adhere to additional regulatory standards.

Note: The chart on the right is only for example purposes and is not an exhaustive list of every certification/ standard required for that specific industry.

EXAMPLE
EXPLORING CIRCUIT PERFORMANCE UNDER TEMPERATURE



Standard simulation allows the ambient temperature of the simulation to be defined and varied with each simulation run. Engineers can then perform multiple simulations, changing the temperature, to ensure adequate circuit function despite severe conditions.

For example, military applications are often utilized in deserts which can see extreme temperatures of up to 49°C during the day and drop to -18°C at night. These crucial applications, this temperature swing cannot have an extreme effect on circuit functionality. If a minimum output voltage of 28V is required for guaranteed circuit functionality, advanced SPICE simulation can pinpoint the temperature at which this requirement is no longer achieved as well as analyze the performance over the temperature drop and extreme limits.

Experience and Understand Environmental Effects Before You Build

Taking analysis a step further with advanced SPICE capabilities, engineers can automatically analyze the circuit behavior over multiple simulation runs and plot the variation in circuit behavior to quickly correlate changes in circuit behavior as it relates to temperature. This ability will help you understand expected field conditions and circuit behavior early and significantly reduce costs due to failures and in-lab testing.

KNOW YOUR CIRCUITS LIMITS AND ENSURE RELIABILITY

Ineffective circuit design is often caused by a lack of insight into how the design and components will behave in the field. This prevents engineers from making educated design choices, often leading to issues found once a design is completed or worse, when a product is released to market. As circuit failures commonly occur when a product exceeds safe operating limits, without exhaustive circuit analysis the risk of product failures and recalls increases.

Product recalls and failures can have a detrimental impact on a company through:

Increased Project Costs

Companies must replace and fix defective products as well as reimburse customers, significantly increasing the project cost.

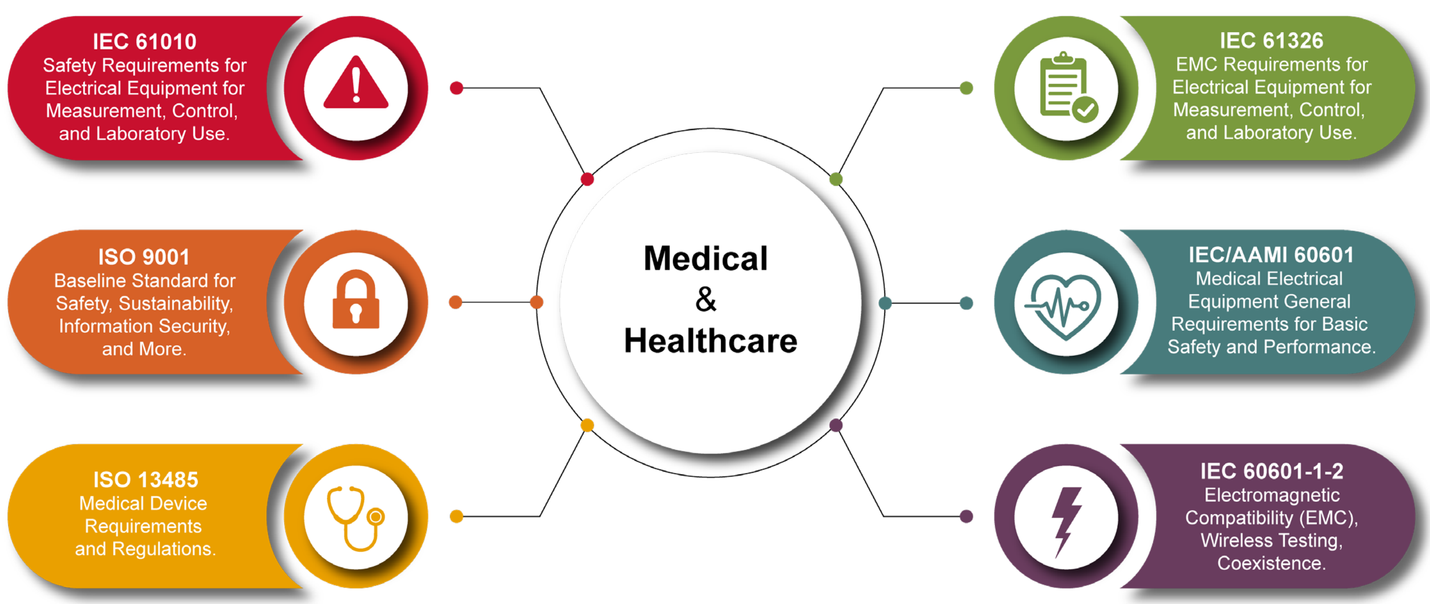
Decreased Market Performance

Due to a loss of trust in product quality, customers will be less likely to purchase the product again.

Tarnished Company Reputation

Customers will be less inclined to trust the company to purchase future products in light of recalls.

While increased costs and tarnished reputations are not ideal, the consequence of circuit failure becomes dire for life-dependent technologies including medical devices. To combat this, additional reliability standards are required:



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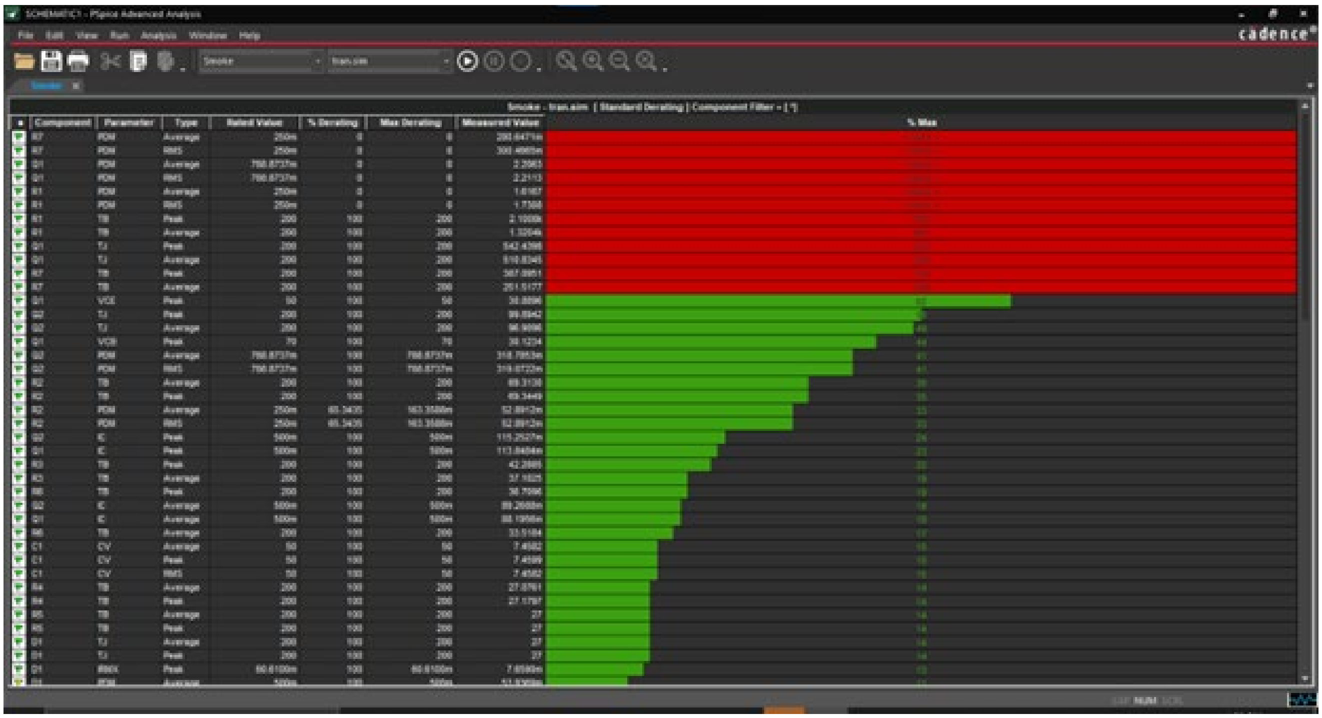
Even with standards in place to help guarantee safety and reliability, without exhaustive simulation it's possible for mistakes to slip through the cracks. For example, take a blood pumping console that temporarily takes over the function of the heart and lungs during surgery. In 2021, the FDA issues a Class 1 recall due to:

- User interface going blank
- Burning odor during use
- Electrical failure causing the device to stop
- Smoke coming from the device

This electronic failure resulted in the possibility of insufficient blood flow, blood clots, neurological dysfunction, or death for patients utilizing the 93 units sold. Could the tangible and intangible cost of this product recall (responsible for death or injury, refunding the 93 units, possible lawsuits, etc.) be potentially mitigated with a more thorough simulation and analysis? While no one will know for sure, simulation can provide additional verification checks and peace-of-mind.

EXAMPLE

PERFORMING CIRCUIT STRESS ANALYSIS



Reliability and longevity can be tested by analyzing the stress a component experiences over time to determine:

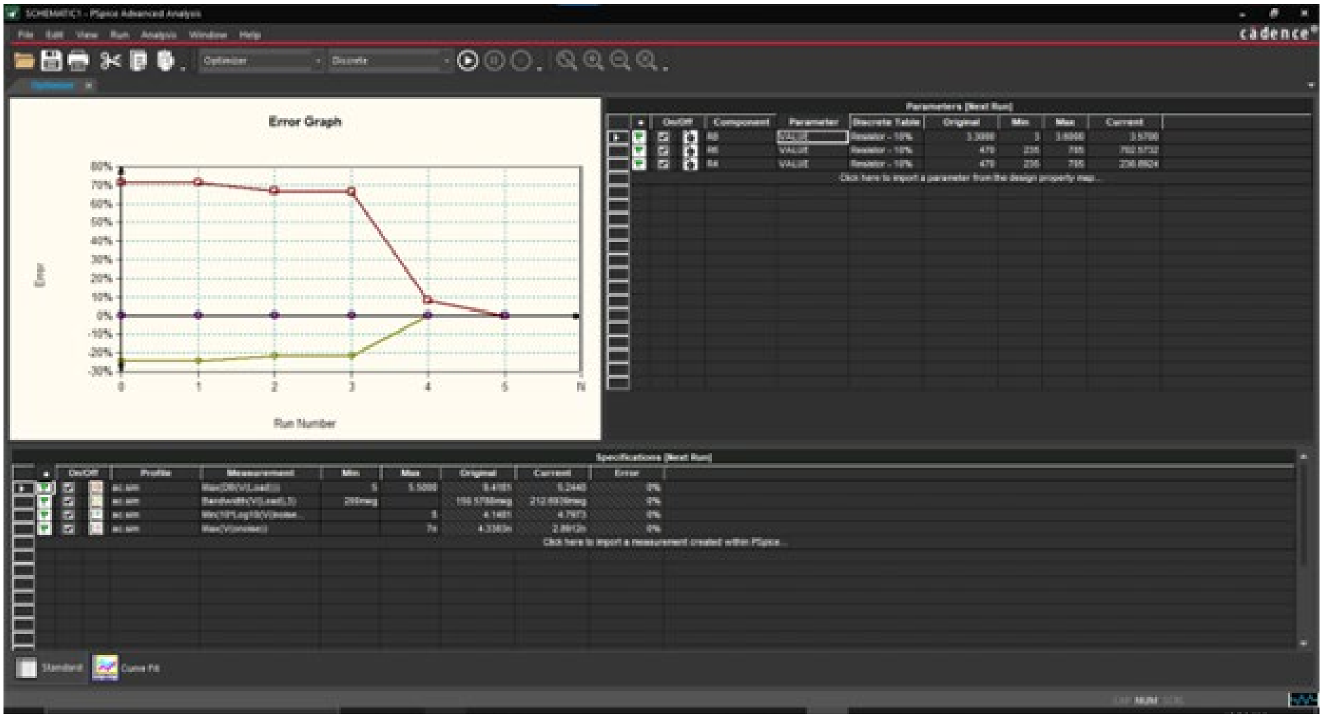
- Breakdown voltage across device terminals
- Maximum current limits
- Power dissipation for each component
- Secondary breakdown limits
- Junction temperatures

With advanced SPICE capabilities, engineers can easily pinpoint components that are experiencing too much stress and have the possibility of failing or overheating.

Identify Unreliable Components Before Failure

Component stress and smoke analysis seamlessly incorporates maximum operating conditions and derating factors (often supplied by vendors and designers) into the simulation. The required measurements are automatically calculated and adherence to safe operating limits is reported for quick identification and replacement of unreliable components.

OPTIMIZE DESIGNS WHEN THE COST OF CHANGE AND RISK IS LOWEST



Project requirements define the desired outcome of a PCB and electrical engineers are tasked with creating a circuit to produce those results. Determining the component values is typically completed manually through pen and paper calculations during circuit design; however, precisely matching the ideal circuit output is difficult due to the volume of components in the design. Every component has a purpose, and each value has a direct effect on circuit functionality, some more than others. If a non-ideal value is chosen for a critical component, design specifications will not be met and circuit functionality will suffer through poor performance and circuit malfunction.

For example, a popular smart watch, which can detect atrial fibrillation, was alerting consumers of a concerning heart rhythm. For the Mayo Clinic alone, only 30 of the 264 patients who sought treatment due to the concerning notification received a cardiac diagnosis in a 6-month period. The remaining 234 false positives resulted in additional patient stress and anxiety while consuming vital emergency medical resources. While these false positives could have been caused by any number of issues in the watch design, it's possible they could have been prevented if the watch was fine-tuned and optimized for peak circuit performance.

Achieve Peak Performance

Advanced simulation capabilities help fine-tune circuit behavior by automatically identifying the ideal, purchasable component values required to meet the desired output. Achieving peak performance is important in any design but is increasingly crucial as technology evolves.

UNDERSTANDING AND INCREASING PRODUCT YIELD

Every mass production will see inconsistencies in the final yield, either due to variations in the manufacturing process or components. Inspection and testing processes are implemented to identify and resolve inevitable manufacturing inconsistencies; however, variations in components are more difficult to pinpoint. With hundreds or thousands of components on the PCB, identifying the problem components in the lab is almost impossible. Every discrete component is produced with an associated tolerance, specifying the possible value range. If even one component is placed on the board with a value at the extreme limits of the tolerance range, board failure can occur. Component variation is unique to each board in the production and therefore requires exhaustive testing to guarantee a functional end product- testing 1 out of 10 boards is ineffective as failure can still occur on the other nine untested PCBs.

Determining the occurrence of an outcome when a situation has intrinsic uncertainty creates endless scenarios that are difficult to analyze. Monte Carlo analysis was developed to address this issue and can be utilized in electrical simulations to predict the results of mass production and determine PCB yield.

PCB cost varies greatly depending on the board complexity, size, layer count, number of components, etc. Let's take a look at an average scenario:

PCB Fabrication:
$35/board

+

PCB Components:
$150/board

+

PCB Assembly:
$50/board

Total Cost of an Individual PCB: $235

Once a board is produced it needs to be verified and tested. Thorough in-circuit testing can vary from $10,000 to $60,000 which would increase the overall cost for each board. If a board doesn't meet the desired functionality and fails testing, engineers will often need to troubleshoot the design (~$50/hr). These costs are often wasted as the likelihood of finding the problem component is slim. Each failed PCB assembly costs hundreds of dollars ($235 in this example), affecting the bottom line of the project and often increases the price of the product for the end user. By predicting the yield using simulation and ensuring the board functions as intended when components are pushed to their tolerance extremes, these costs can be reduced. So, how can you ensure high yield for your circuits effectively?

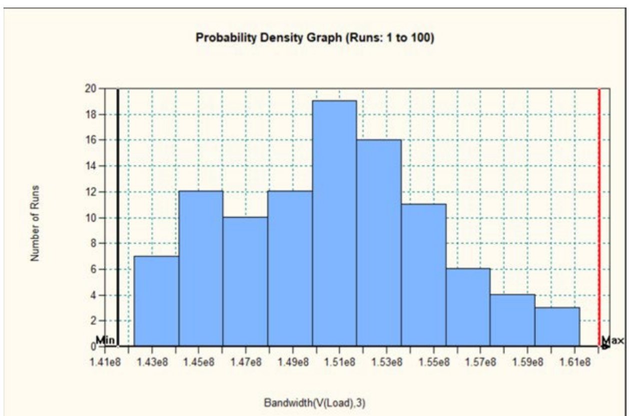
FUN FACT: First developed for a nuclear weapons project where secrecy was of the utmost importance, the analysis was given the code name Monte Carlo, after a casino in Monaco.

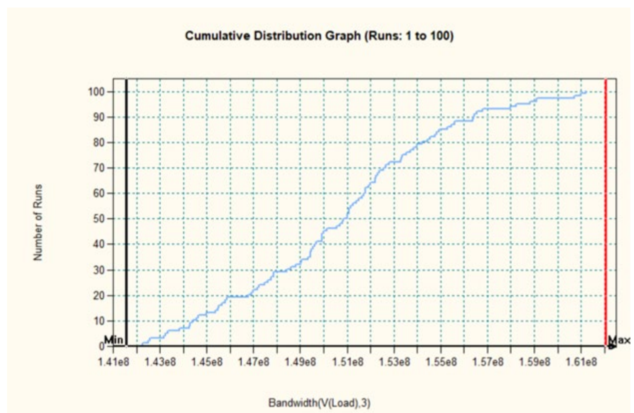
EXAMPLE
ENTER MONTE CARLO ANALYSIS

Monte Carlo predicts the behavior of a circuit statistically when part values are varied within their tolerance range. These simulation iterations can then be manually transformed into a probability density graph to evaluate the likelihood of certain outputs.

Taking this a step further, we can efficiently complete Monte Carlo Analysis and provide comprehensive results with:

- Statistical models of circuit behavior
- Automatic calculation of statistical data
- Automatic calculation of yield based on specifications
- Integrated measurements with graphical displays
- Immediate graphical results to evaluate possible outcomes





The **Probability Distribution Function** (PDF) graph shows the possible output measurements and likelihood of them occurring when the tolerance of components is varied within the specified range. The probability distribution is displayed as a bar chart with the range of measurements along the x-axis and number of runs along the y-axis.

The **Cumulative Distribution Function** (CDF) graph displays the probability distribution as a cumulative stair-step plot. Mathematically, the CDF is the integral of the PDF.

Increase PCB Yield

Performing Monte Carlo analysis gives the insight needed to ensure mass productions will deliver a high yield of functional PCBs, even when components are pushed to manufacturer-defined tolerance extremes.

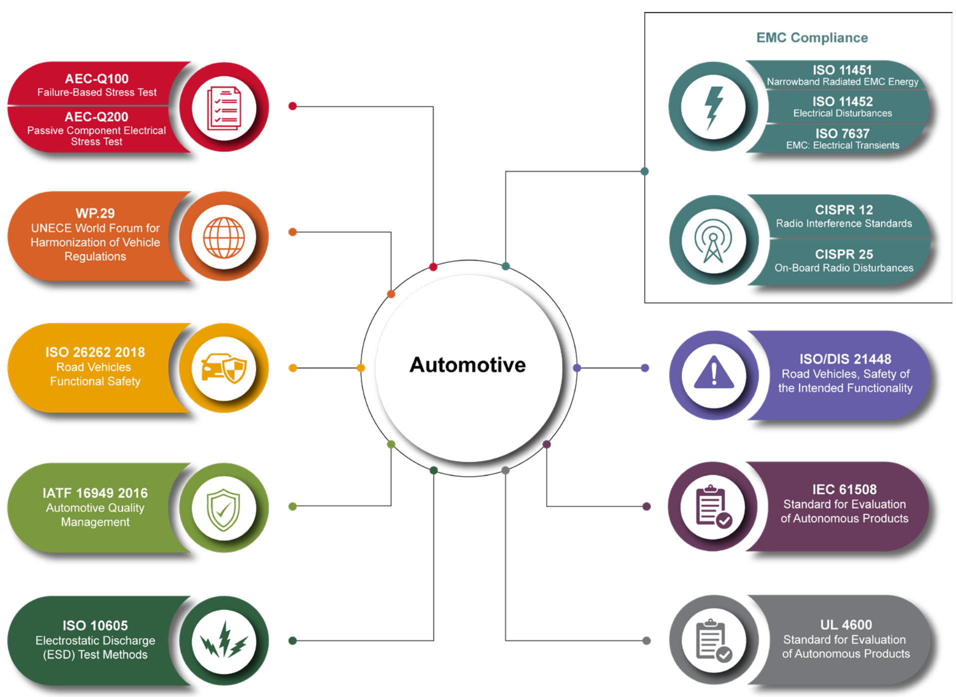
SOLVING FOR SYSTEM-LEVEL DESIGN SUCCESS

Today's electronics are frequently incorporating motion devices, sensors, MEMS, power electronics, and circuits for information processing and system control. Electronic components are a portion of the larger design, making it harder to understand and analyze the full-system functionality before production. Ensuring these electro-mechanical systems will function as intended introduces additional challenges to engineers. This is partly due to disjointed communication between software tools and various engineering teams.

Therefore, multiple design elements must be combined into one cohesive system to analyze complete functionality:

Digital Circuits	Analog Circuits	Electro-Mechanical Components	Software-Defined Hardware	Mixed-Signal Simulation

This is especially apparent in the automotive industry with autonomous and electric vehicles becoming more common. Recently, numerous accidents have been attributed to autopilot systems that can steer, accelerate, and brake on their own. Currently being investigated by two federal agencies, drivers relying on assisted-driving devices drove into parked emergency vehicles, ran through stop signs or red lights, and struck pedestrians. With this evolution of technology and reliance on automation, additional safety standards must be developed and adhered to.



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EXAMPLE

PERFORMING COMPREHENSIVE SYSTEM ANALYSIS

Autopilot and assisted-driving technologies are intricate systems consisting of sensors, electro-mechanical devices, and electronics. Systems must be simulated as a whole to ensure functionality of inter-dependent devices.

Virtually prototyping the design with MATLAB and PSpice generates a complete multi-physics analysis of the electro-mechanical system with:

A Seamless Co-simulation Environment

Ensure an accurate analysis by incorporating the electrical simulation into the physical system.

Incorporating Functions

Effectively model system behavior by incorporating mathematical expressions, Laplace transformations, logarithmic functions, and more into the simulation.

Visualizing Results

Advanced plotting capabilities allow for the quick transformation of waveform results into Polar Plots, 3D Plots, and more.

Advanced Waveform Analysis

Incorporate measurement functions to evaluate the characteristics of waveforms after simulation is completed.

This comprehensive system analysis increases the likelihood of first-pass compliance to performance, reliability, and safety standards. By analyzing functionality of the entire system before production, engineers can identify errors early in the design process, debug the system virtually, and reduce development time.

CONCLUSION

ADVANCED SIMULATION IS VITAL TO DESIGN SUCCESS

By mimicking the behavior of the designs, SPICE simulators provide designers with the information needed to determine if design and compliance requirements are being met. Advanced simulation capabilities automate the techniques required to scale your SPICE simulation capabilities and answer important design questions. Multiple scenarios can be assessed efficiently, trade-off decisions can be quickly analyzed, and informed design choices can be made to achieve a balance between cost, performance, and dependability. This leads to fast and effective problem-solving of complex design issues when change is easiest.

The advanced analysis features in OrCAD PSpice Designer Plus quickly provides additional insights into your design to better assess macro problems and positively affect business outcomes with:

Performance Analysis

Analyze how the circuit performs over varying temperatures to guarantee circuit functionality despite harsh environmental conditions.

Smoke Analysis

Examine the electrical stress of components over time to ensure the longevity of the design.

Sensitivity Analysis

Understand the effect of component tolerance on circuit behavior to ensure functionality and reduce component cost.

Optimization

Fine-tune circuit behavior by automatically determining the ideal, purchasable component values to meet the required circuit output.

Monte Carlo Analysis

Statistically model circuit behavior and predict production yield.

Electro-Mechanical Co-Simulation

Incorporate electrical and mechanical simulation to perform a comprehensive system analysis with bi-directional co-simulation between PSpice and MATLAB/Simulink.

More Information on PSpice:

go.ema-eda.com/PSpice

info@ema-eda.com

TRIAL

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