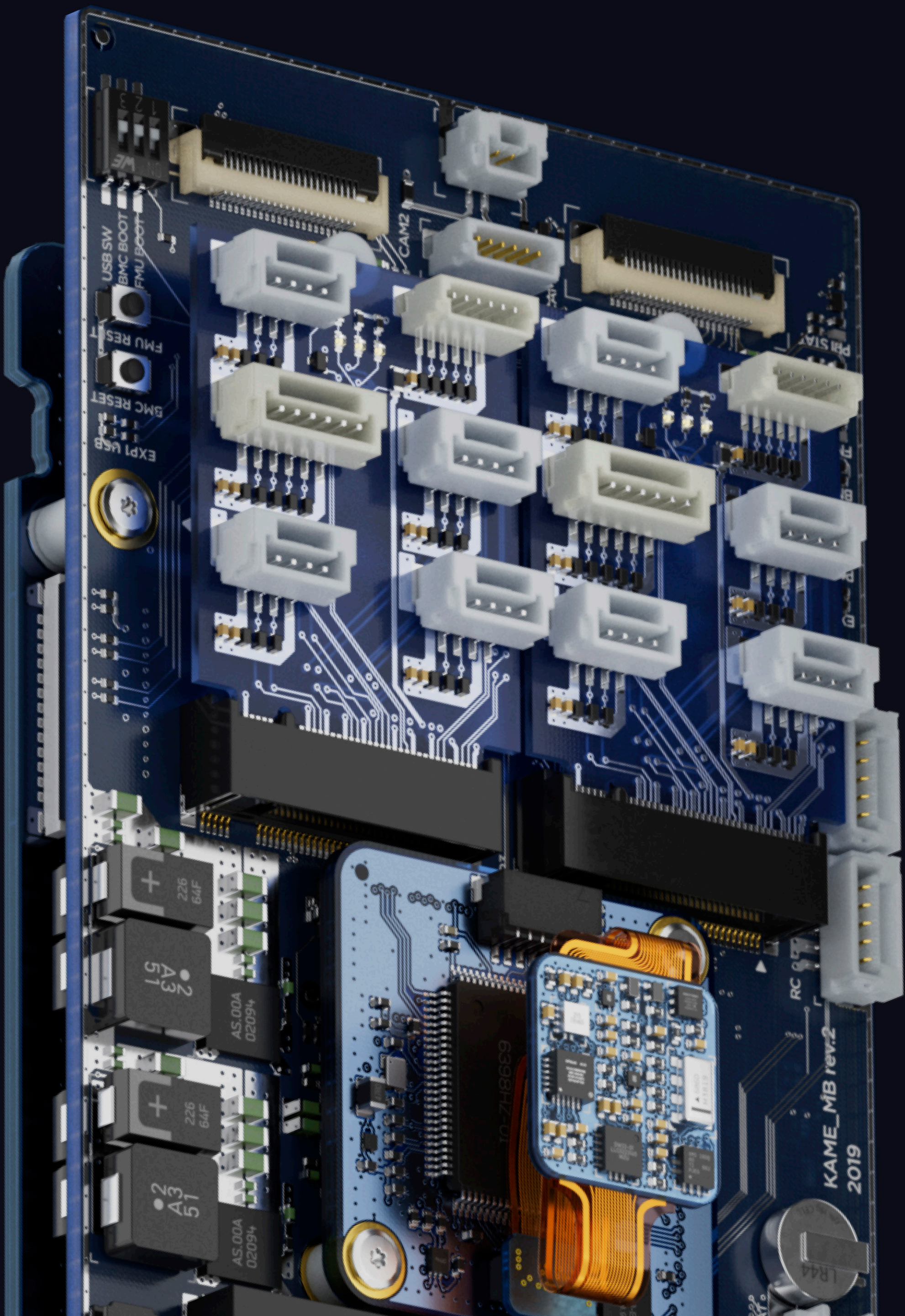
Altium

Digital Thread for Electronics:

Synchronizing PCB, Multi-Board, & Harness Design



Executive Summary

As the complexity of electronic products continues to accelerate, so too does the demand for multi-board systems and intelligent harness integration. While PCB design tools have matured over the last decade, the methodologies and tooling for system-level design, where multiple boards, connectors, and cables must work as one, have failed to keep pace. The result is a widening gap between system intent and implementation, increasing the risk of errors, rework, and delays in product development.

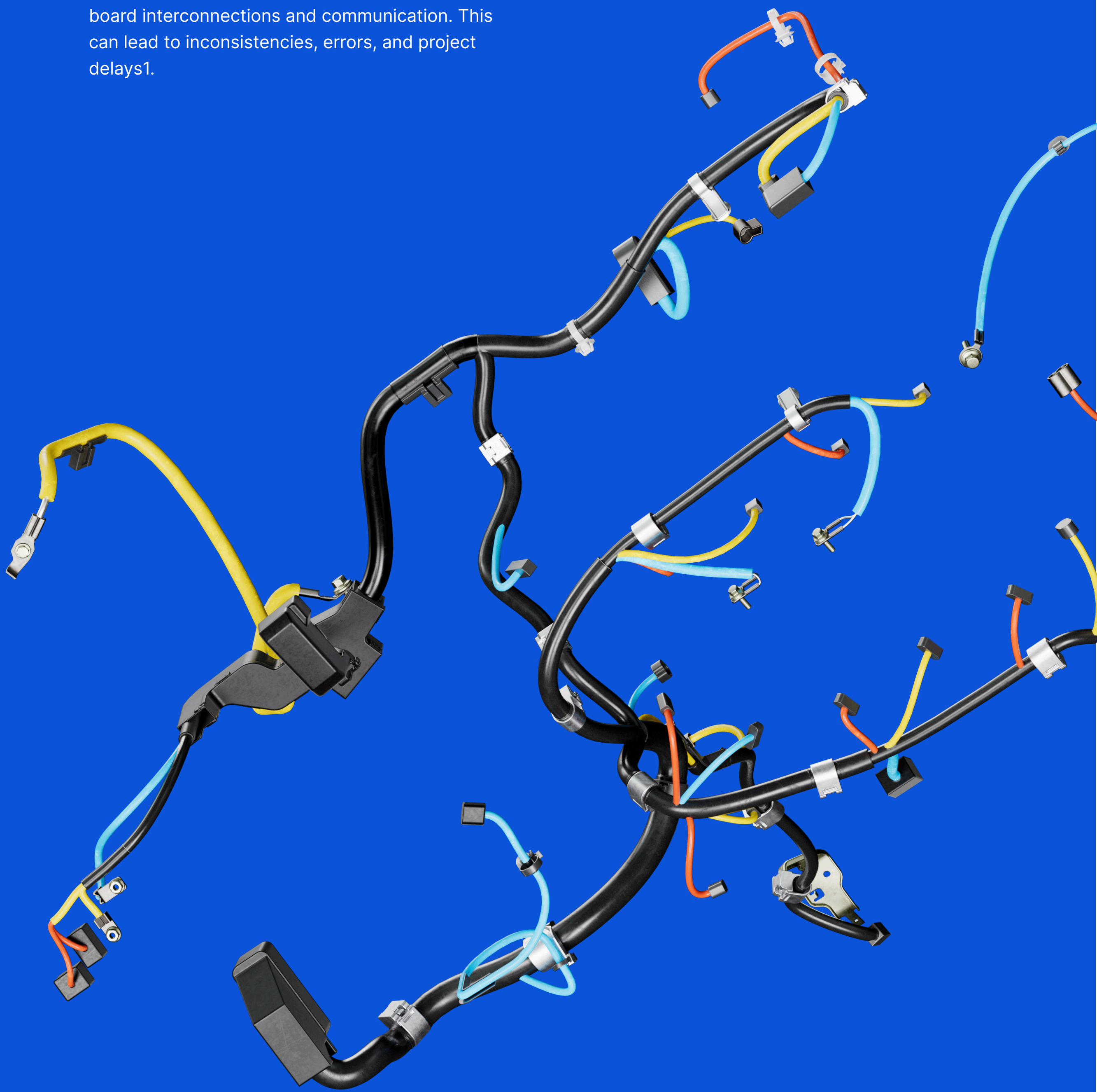
This whitepaper examines the unique challenges of multi-board and harness design, identifies the limitations of conventional workflows, and outlines a vision for a modern, integrated approach to these challenges. Practical insights are offered into how this methodology can be implemented, with examples drawn from modern engineering tools and practices.

Introduction: Designing Beyond the Board

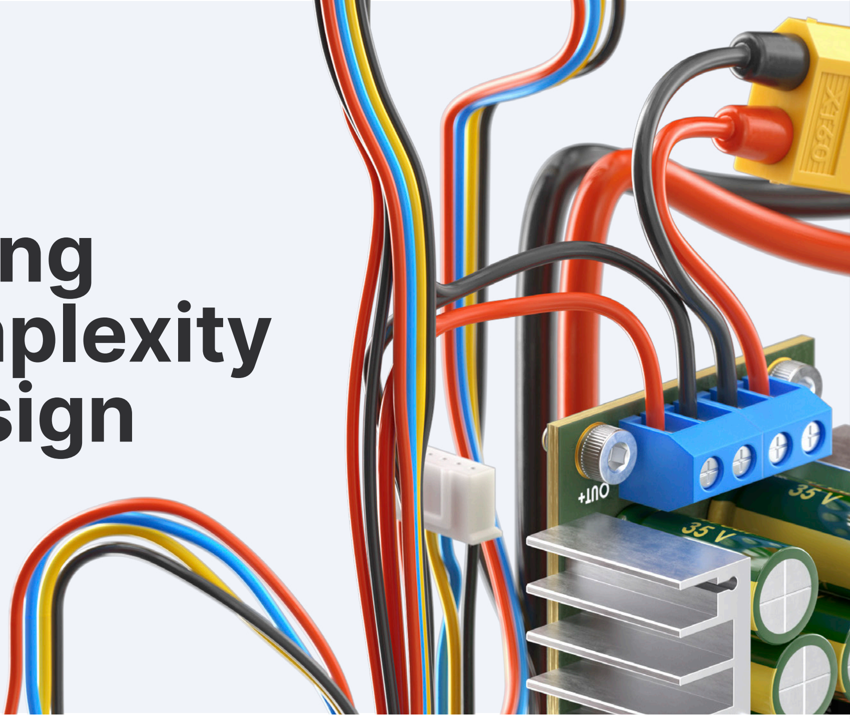
Designing modern electronics now goes beyond single PCBs. Products, from small consumer devices to aerospace systems, commonly integrate multiple boards for specific tasks, connected by harnesses. Managing this system-level complexity is crucial for design success.

While single-board design tools have advanced, the system-level design process is often fragmented and manual. Teams frequently use spreadsheets, 2D drawings, and separate CAD files to define board interconnections and communication. This can lead to inconsistencies, errors, and project delays1.

System-level design requires a fundamental change in approach. Instead of viewing a product as an individual board, it must be seen as an integrated system of interconnected subsystems designed for cohesive operation. This mandates the synchronization of logical, physical, and mechanical constraints across the entire product, moving beyond isolated component verification.



Understanding System Complexity Through Design Layers



Modern electronic products are rarely built around a single board. They are made up of interconnected elements that span different layers of design responsibility. Understanding these layers helps teams plan, partition, and validate systems more effectively:

Off-Board Components (COTS):

These are individual components or small assemblies that perform a specific task, such as sensing, computing, or power conversion.

Module/Board:

A single printed circuit board (PCB) typically hosts multiple functional modules and serves as a self-contained platform for a defined portion of the product's behavior.

Integrated Multi-Board Systems:

A standalone complex unit or product, this electronic-centric system comprises multiple interconnected PCBs, COTS components (such as sensors and actuators), and the necessary cables and/or connectors to deliver its features and capabilities.

Complex Systems of Systems:

More sophisticated applications, such as automotive platforms, aerospace assemblies, or industrial automation systems, require multiple independent systems to work together effectively. This integration of interdependent systems creates a new, more complex system, introducing a new tier of complexity in managing communication, timing, power domains, and mechanical integration across these systems.

Layers of Electronic Design

- Complex Systems of Systems: Multiple independent systems working together (e.g., automotive platforms, aerospace assemblies)
- Integrated Multi-Board Systems: Standalone electronic-centric unit comprising multiple interconnected PCBs, COTS components, and cables/connectors
- Module/Board: A single PCB hosting multiple functional modules
- Off-Board Components (COTS): Individual components or small assemblies that perform a specific task, such as sensing, computing, or power conversion

Reliable electronic product design requires mastery of each level, as each layer builds upon the one below it. Furthermore, it requires ensuring seamless integration—electrically, mechanically, and logically into a coherent system.

Industry Challenges in Multi-Board and Harness Design

Designing a product with multiple boards and interconnected cables introduces a level of complexity that goes beyond traditional PCB design. As product architectures evolve to incorporate multiple PCBs, interconnects, and harnesses, the design process shifts from single-board layout control within an EDA environment to a more system-centric approach. This transition significantly increases the potential for integration challenges.

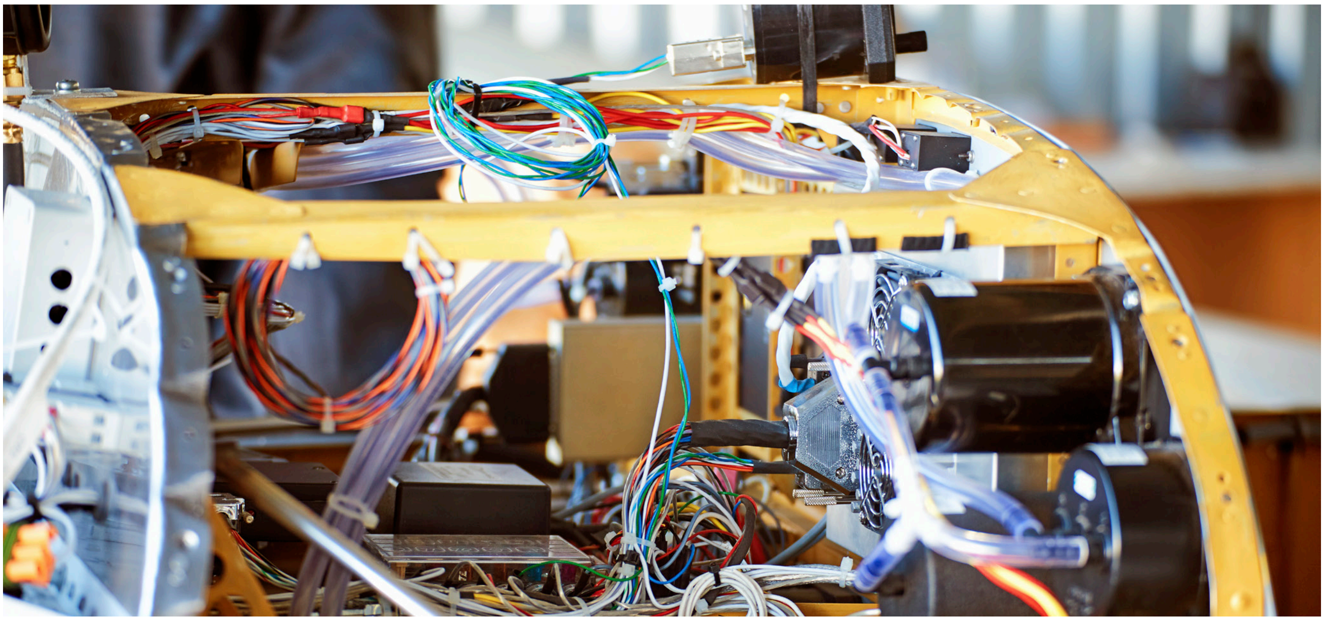
Interconnect Complexity and Signal Integrity

When signals exit a PCB, they face challenges such as impedance mismatches, EMI, voltage drops, and timing issues as they travel through connectors and cables. For high-speed interfaces and Ethernet, maintaining precise impedance control and length matching across connectors and harnesses is critical. A signal that performs correctly on the board can degrade or fail completely if it travels through a cable that is improperly routed or has a mismatched connection. Therefore, designers must holistically consider shielding, pair matching, and propagation delay. Manually tracking such complexities or separating them from the design intent increases the system's vulnerability to faults[3].

Connector Mismatches and Miswiring

The most common source of failure in multi-board systems is incorrect use of connectors. Teams may define connectors separately for each board, assuming they're wired identically. However, pin ordering, orientation, ground placement, and mating halves are often handled manually, leading to pin reversals, swapped signals, or wrong mating connector types.

These errors may not be discovered until the system is assembled. At that point, fixing a reversed pair or a shifted pinout may require re-spinning boards or redesigning harnesses, which can take weeks or more.



Mechanical Constraints and Fit Issues

A connector may be placed appropriately electrically, but may fail to mate physically due to interference from an enclosure wall or poor board alignment. Cables may be too short or forced into tight bends that violate bend radius requirements, increasing wear and failure risk.

If cables are not modeled and validated within the mechanical context, teams often encounter routing conflicts, tension issues, or packaging failures late in the design process[4].

Harness Design: An Isolated and Late-Stage Activity

Harness design is frequently delayed or outsourced until the rest of the design is «final.» Harness engineers rely on hand-annotated schematics, spreadsheets, and board exports that may already be outdated. This introduces a high risk of error and often requires redesigns to reflect the latest signal maps or connector types.

Because harnesses are treated as physical routing artifacts rather than logical circuit elements, they're not part of the simulation or validation process, leaving a critical gap in system assurance. NASA's testing found that over 50% of avionics boxes returned for service had no actual fault—the issue lay in harnesses or interconnects[2,8].

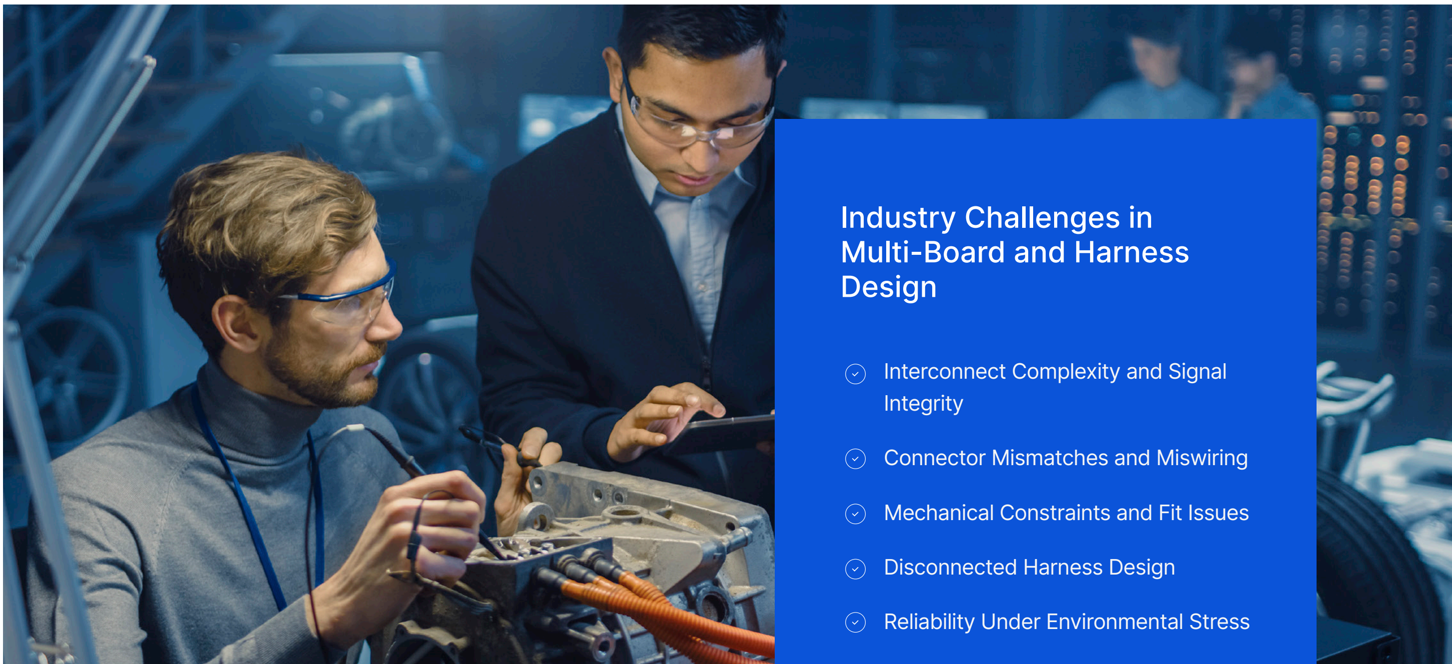
Reliability Under Environmental Stress

Cables and connectors in automotive, aerospace, and industrial systems are susceptible to heat, vibration, humidity, and motion. Neglecting early design-stage simulation of strain relief, mechanical mounting, and insulation can lead to long-term wear and latent product failures. In a rugged military system, field reports revealed recurring system faults that were traced back to intermittent cable disconnections caused by poor routing and inadequate strain relief. The harness met electrical specs but failed in real-world conditions.

Power and Grounding Across Boards

Multi-board systems often distribute power from a central supply through connectors or power harnesses. Improper planning of ground return paths, voltage drop, or load distribution can result in marginal supply conditions, board resets, or overheating.

The issue is compounded when power domains are not clearly defined across the system. A harness may inadvertently tie together separate domains or ground planes, creating loop currents or violating EMI constraints[3].



Industry Challenges in Multi-Board and Harness Design

- Interconnect Complexity and Signal Integrity
- Connector Mismatches and Miswiring
- Mechanical Constraints and Fit Issues
- Disconnected Harness Design
- Reliability Under Environmental Stress
- Power and Grounding Across Boards

Limitations of Traditional Workflows

Despite the increasing need for multi-board and harness design, many organizations still rely on outdated and disconnected workflows.

Siloed Tools and Teams

Board designers work in ECAD. Mechanical designers work in MCAD. Harness engineers use specialized tools—or worse, spreadsheets—to define cabling. These tools rarely share a unified data model, and synchronization across domains is manual.

Manual Data Entry and Version Drift

Connectors, pins, and signals are often documented multiple times: in schematics, harness drawings, mechanical layouts, and spreadsheets. This increases the risk of data entry mistakes and version mismatches.

There's also no built-in traceability across domains. If a pin is moved in the PCB, the harness engineer may not know until the error is discovered during testing.

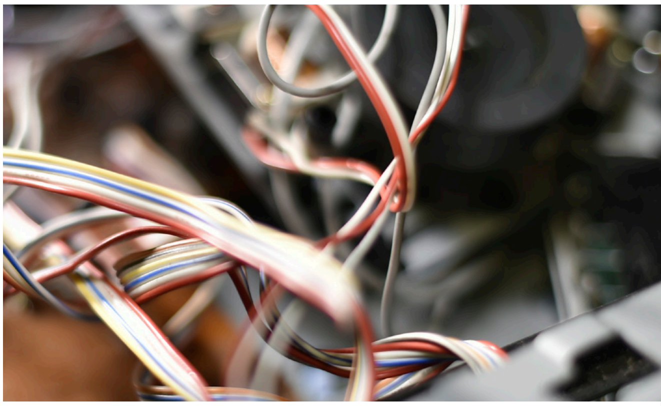
Incomplete Validation

Board-level DRCs catch electrical issues, but system-level DRCs are typically nonexistent. There's no way to ensure that signals match across connector pairs, that wire gauges meet power delivery needs, or that cable paths avoid mechanical conflicts[4].

Time-Consuming Change Propagation

When a net is renamed, a connector changed, or a board repositioned, all downstream artifacts—schematics, harness drawings, cable lengths, BOMs—must be updated. In traditional workflows, this means manually editing multiple documents or files.

Each of these manual steps is a potential failure point, especially under tight schedules or in environments with rapid iteration[5].



A Vision for Integrated System-Level Design

A better methodology starts with a fundamental shift: viewing the product not as a collection of boards and cables, but as an integrated system defined at the architectural level. In this model:

System-Level Abstraction Comes First

Engineers begin by defining the system's logical architecture—boards, functional domains, and signal paths—before diving into schematic or layout. This top-down approach enables better planning, clearer interface definitions, and reusable design patterns[6].

Unified Data Model Across Domains

Electrical, mechanical, and harness design share a common, synchronized model. When a signal changes, its implications ripple automatically across schematics, harnesses, 3D models, and documentation. Everyone works from the same source of truth[7].

Seamless ECAD-MCAD Collaboration

Integrated environments allow electrical and mechanical engineers to co-design in real time. A connector moved in the PCB can be instantly visualized in the enclosure. A harness reroute can be validated for bend radius, clearance, and stress—all within the 3D model[4].

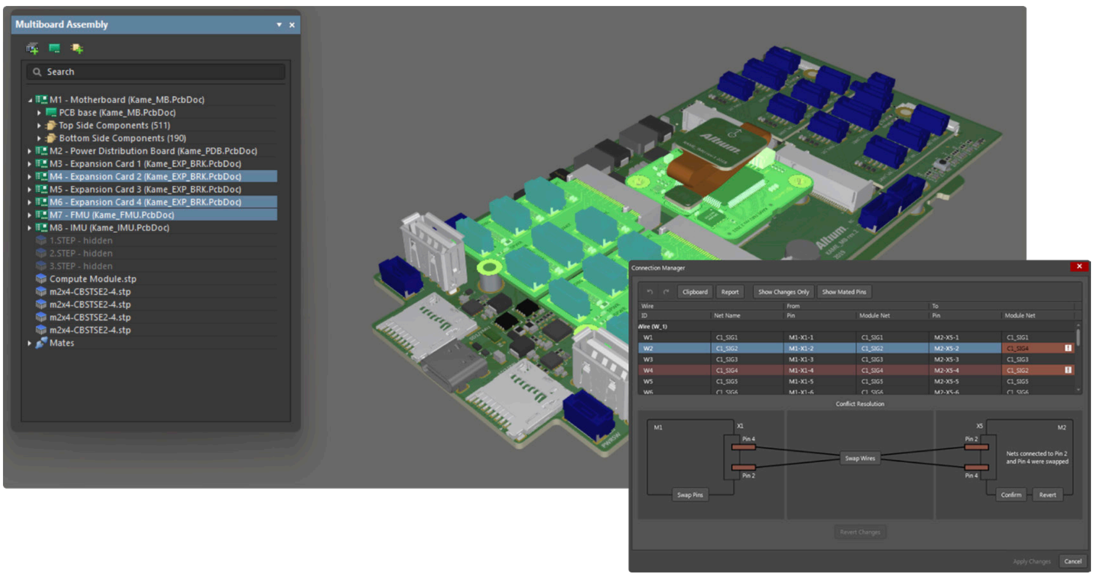
Harnesses as First-Class Design Objects

Harnesses are derived from logical connectivity, not drawn from scratch. Engineers can define inter-board signals, then automatically generate wire tables, connector pinouts, and harness documentation[5].

Because the harness shares the system model, it remains synchronized as designs evolve. There's no need to re-document or reconcile harness data manually.

Intelligent Validation and Simulation

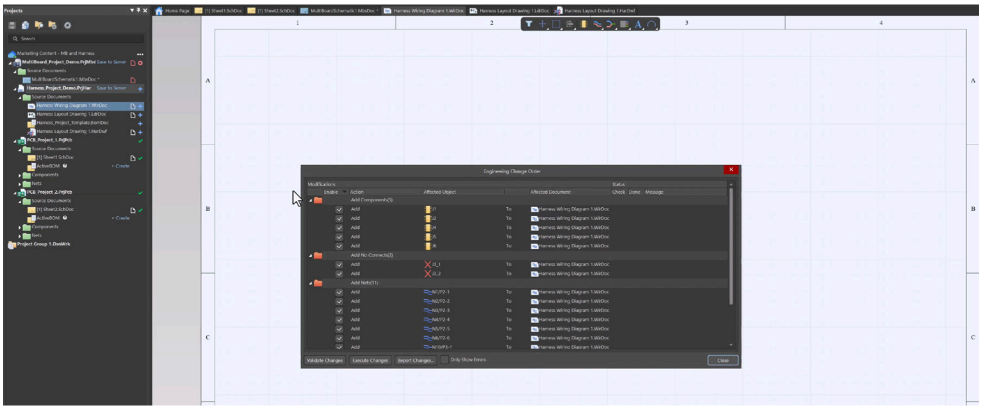
System-aware DRCs catch mismatches between board connectors, detect duplicate pin assignments, or flag missing grounds. Signal integrity tools can analyze cable paths. 3D verification ensures fit, clearance, and assembly constraints are met[6].



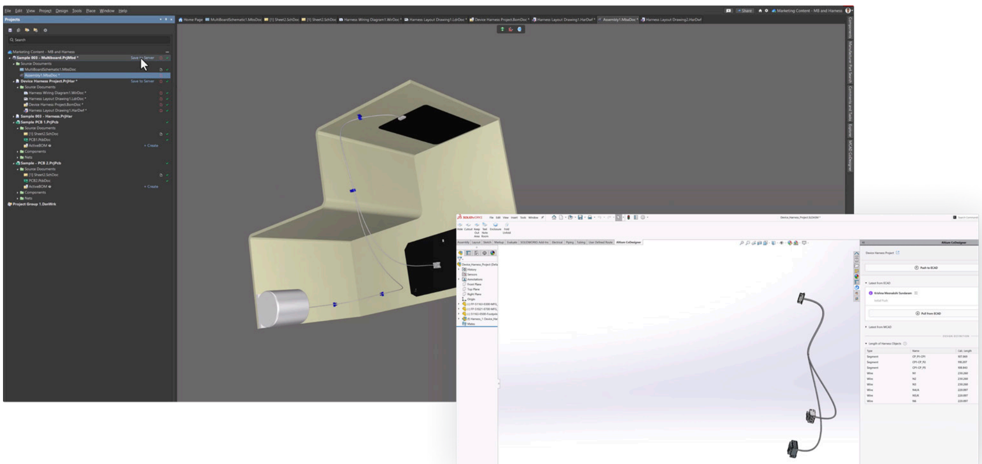
Implementing the Approach in Practice

In practice, this methodology is increasingly supported by design platforms that integrate system capture, board layout, harness design, and MCAD collaboration.

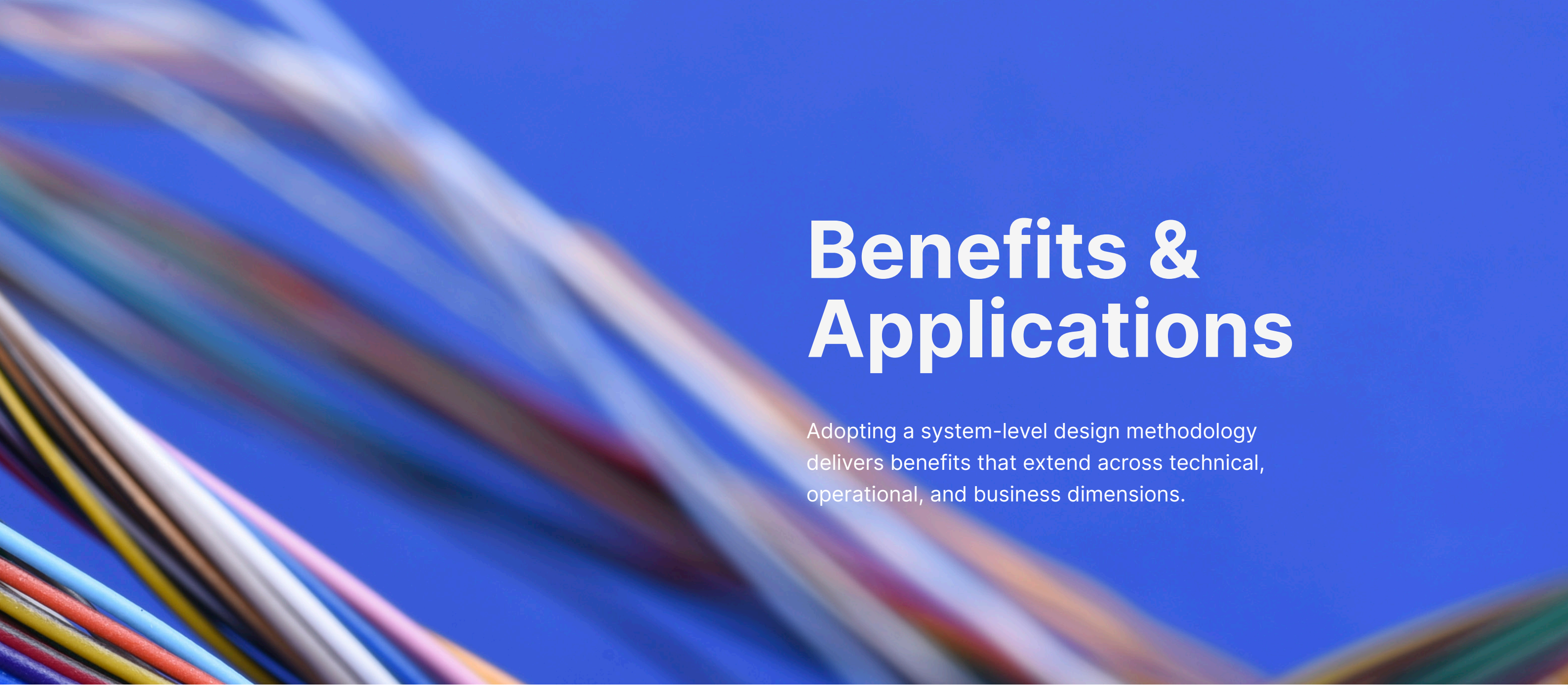
Engineers start with a system diagram that defines each board, its function, and its interfaces. Logical connections drive harness generation, PCB signal assignment, and documentation. When one board changes, those updates ripple throughout the system automatically.



In advanced platforms, 3D models validate connector alignment and cable paths. Cable lengths, bend radii, and mechanical interference are verified digitally. Designers can simulate the full mechanical assembly—including boards and harnesses—prior to any prototyping.



In addition, integrated data management ensures that all team members are working with current data. When an engineer updates a pinout, that change is visible to the system architect, harness engineer, and MCAD designer—instantly. This closes the feedback loop and enables concurrent engineering across domains.



Benefits & Applications

Adopting a system-level design methodology delivers benefits that extend across technical, operational, and business dimensions.

Reduced Errors and Rework

Synchronization between logical and physical design drastically reduces common mistakes—such as miswired connectors, out-of-date harness drawings, or mismatched interfaces.

Faster Development Cycles

Changes propagate automatically across the project, reducing manual effort and enabling parallel work.

Improved Collaboration

Shared environments improve visibility between ECAD, MCAD, and manufacturing teams.

Stronger System Validation

With 3D modeling and digital twins, engineers can catch problems in the design phase—before hardware is built.

These benefits are already being realized across aerospace, automotive, consumer electronics, and industrial sectors where complexity is increasing and time-to-market is shrinking.

What are the benefits of system-level design methodology?

- Reduced Errors and Rework
- Faster Development Cycles
- Improved Collaboration
- Stronger System Validation

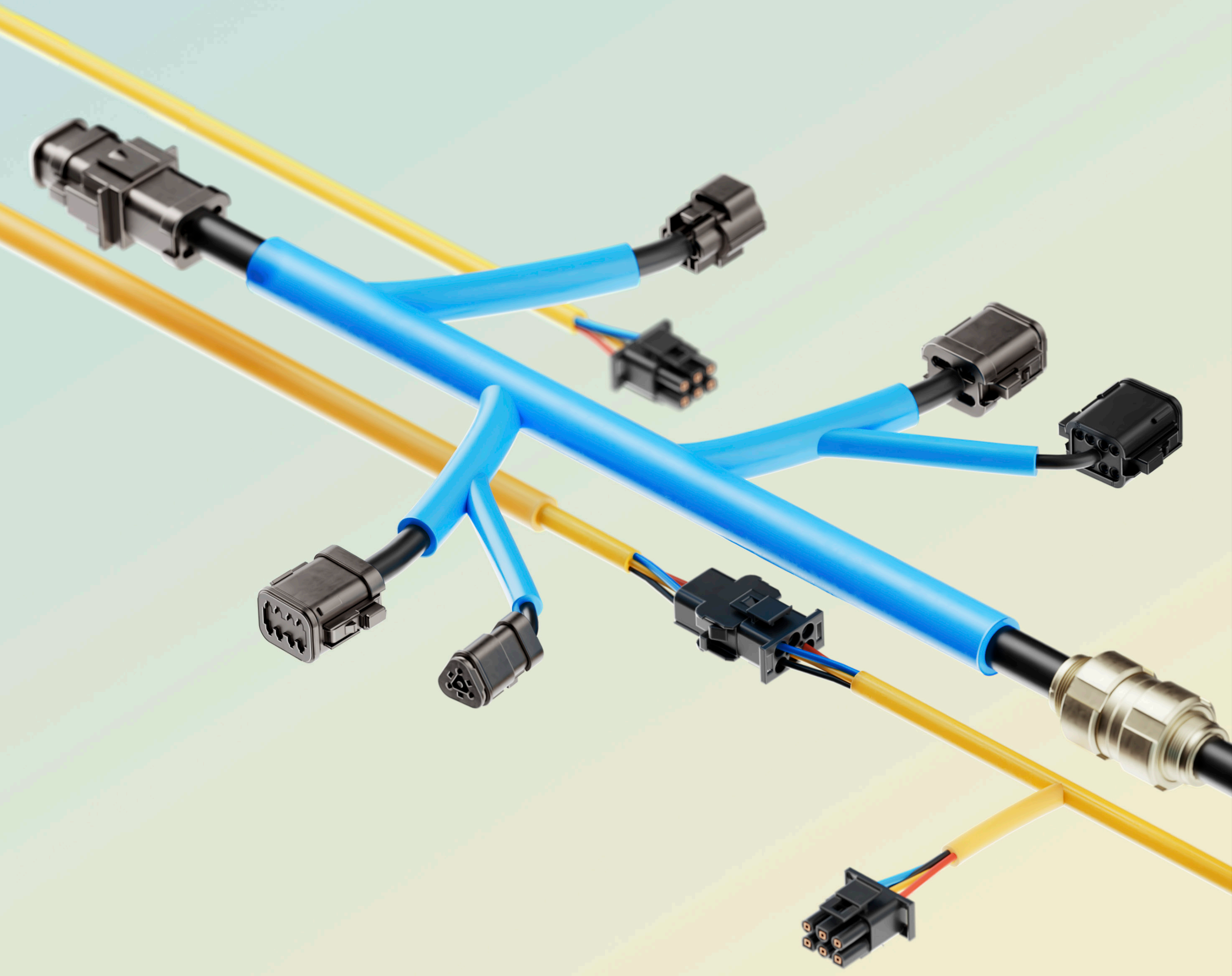
Conclusion

Multi-board and harness design has become the norm, not the exception. As electronic products grow in complexity, the limitations of fragmented, manual workflows are increasingly exposed. Integration errors, delayed projects, and rising costs are not technical inevitabilities. They are the result of outdated processes.

To move forward, teams need a methodology that unifies system planning, board design, harness development, and mechanical integration. This paper has outlined such an approach: one grounded in system-level abstraction, automated synchronization, and cross-domain collaboration.

Tools that support this vision are already changing how engineers design, allowing them to model the whole system from the start, rather than stitching it together at the end. The result is higher-quality products, delivered faster, with greater confidence.

In a world where complexity is only going to increase, the ability to design at the system level is no longer optional. It is essential.



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