

The Hidden Network: Why Internal Cables define your hardware

Test Overview

Internal cabling is often the overlooked "last mile" in electronics hardware design, yet it plays a critical role in defining the electrical, mechanical, thermal, and manufacturability aspects of a product. In this use case, we explore why internal cables are foundational to hardware performance and reliability, and investigate whether modern design approaches can minimize or even eliminate internal wiring. The test involves analyzing the impact of cabling on signal integrity, electromagnetic interference (EMI), mechanical stress, thermal management, manufacturing complexity, and serviceability, with a focus on practical design trade-offs and emerging alternatives.

Method & Procedure

We examined internal cabling from multiple perspectives: electrical performance (signal integrity, EMI, power distribution), mechanical and thermal reliability (strain relief, bending, thermal effects), and manufacturing and service considerations (assembly, testing, documentation). This included reviewing structured cabling practices, harness design, and connector technologies, as well as exploring advanced packaging and wireless interconnect alternatives that reduce cable dependency.

Two representative internal cabling scenarios were compared: traditional wire harnesses with discrete cables and connectors, and cable-minimized designs employing flexible printed circuits (FPCs), board-to-board connectors, pogo-pin arrays, and wireless power/data transfer. Specific case studies included industrial automation panels, data center cabling, modular laptops and smartphones, sealed medical devices, and emerging 3D integrated packages.

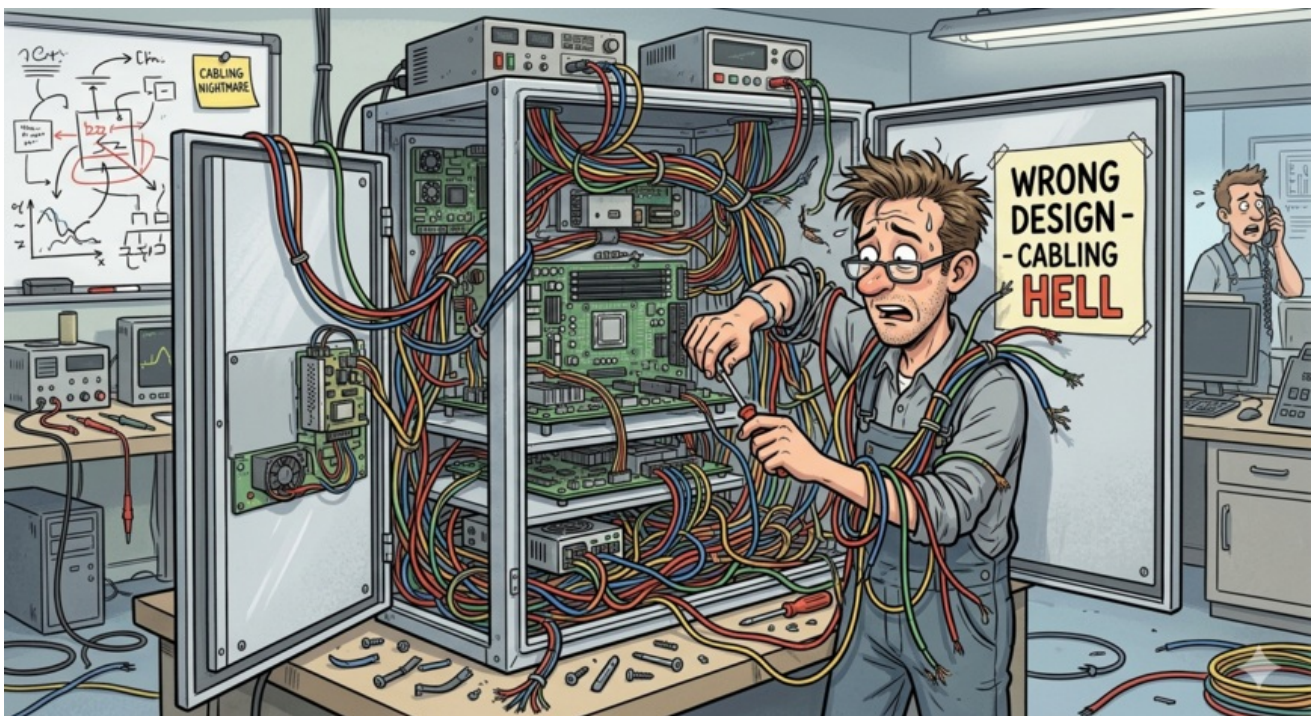


Figure 1: Illustration of problematic internal cabling with tangled wires and poor routing (wrong_design_cabling_hell.png).

Results & Analysis

Electrical analysis confirmed that internal cables significantly affect signal integrity. Poorly routed cables near high-current or noisy circuits introduce crosstalk and EMI, causing intermittent faults and data corruption. Shielded and

twisted-pair cables mitigate these effects but add complexity and cost. Cable length and impedance mismatches degrade high-speed signals, impacting latency and bandwidth, especially in RF and data center environments.

Mechanically, cables subjected to tight bends, vibration, or repeated flexing suffer conductor fatigue and insulation damage, leading to failure. Strain relief and careful routing are essential to extend cable life. Thermal analysis showed that dense cable bundles obstruct airflow, creating hot spots that accelerate component aging and reduce reliability.

Manufacturing studies revealed that preassembled cable harnesses improve assembly speed and reduce wiring errors compared to on-site manual wiring, but harness complexity increases supply chain and documentation overhead. Cable-minimized designs using FPCs, board-to-board connectors, and pogo pins reduced assembly steps and improved modularity but required precise mechanical tolerances and robust connector designs to ensure reliability.

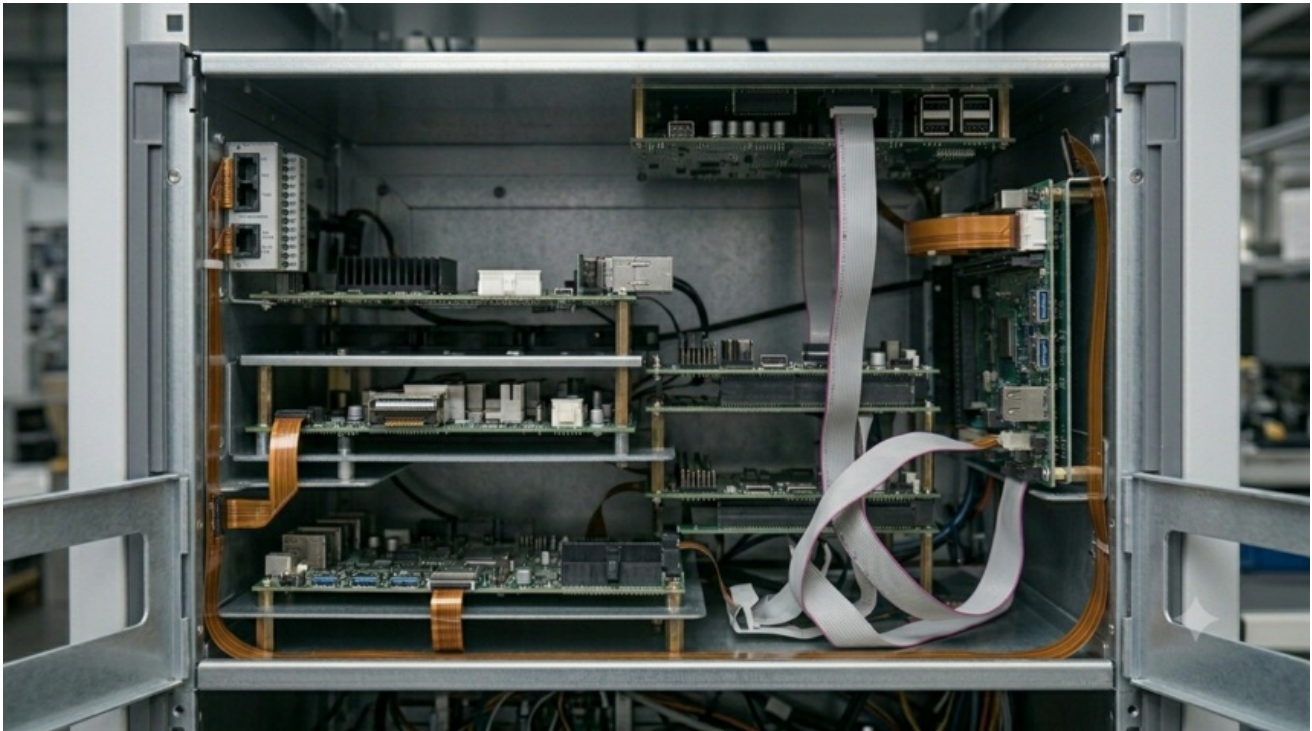


Figure 2: Example of an enclosure designed to minimize internal cables using structured cable routing and modular connectors (Enclosure_minimum_cables_design.png).

Implications

Internal cabling is a critical design domain that influences hardware functionality, reliability, manufacturability, and maintainability. Neglecting cabling early in design leads to costly fixes, increased failure rates, and service challenges. While eliminating internal cables entirely is challenging, modern approaches enable significant reduction through advanced packaging, flexible circuits, blind-mate connectors, and wireless power/data transfer.

Designers must balance electrical performance, mechanical robustness, thermal management, and manufacturing complexity when selecting cabling strategies. Modular architectures with standardized connectors and cable assemblies improve serviceability and upgrade paths. Wireless power and data offer promising alternatives in sealed or hygienic environments but introduce new challenges in EMC, efficiency, and regulatory compliance.

At TrigoPi, we recognize the hidden complexity and importance of internal cabling, and we continually explore innovative solutions that push the boundaries of hardware integration and reliability. It's the kind of challenge that keeps our engineers awake at night—in a good way.

Key Findings

- Signal integrity and EMI are heavily influenced by cable type, routing, shielding, and grounding strategies.
- Mechanical stresses such as bending, vibration, and strain relief critically affect cable lifespan and reliability.

- Thermal management must consider cable bundles as potential airflow obstructions contributing to hot spots.
- Manufacturing efficiency improves with preassembled harnesses and cable-minimized designs but requires precise planning and documentation.
- Serviceability benefits from modular cabling architectures with clear labeling and standardized connectors.
- Designing products with no or minimal cables is feasible using flexible circuits, board-to-board connectors, pogo pins, and wireless power/data transfer, but involves trade-offs in cost, complexity, and regulatory compliance.

Do's & Don'ts

- **Do** plan internal cabling early in the design process alongside PCB and enclosure design.
- **Do** separate power and signal cables physically and use shielding to reduce EMI.
- **Do** implement strain relief and respect minimum bend radii to prevent mechanical failures.
- **Do** use preassembled cable harnesses and modular connectors to improve manufacturing repeatability.
- **Do** consider flexible circuits and blind-mate pogo-pin connectors to reduce cable clutter and improve modularity.
- **Don't** treat internal cabling as an afterthought or late-stage packaging detail.
- **Don't** route sensitive signals near noisy power cables or sources of EMI.
- **Don't** overlook thermal effects of cable bundles inside enclosures.
- **Don't** ignore serviceability – unlabeled, tangled cables increase maintenance time and risk.

Safety & Reliability Notes

Internal cabling must comply with electrical safety standards for insulation, creepage, and clearance distances, especially in high-voltage or medical applications. Connector contacts should be corrosion-resistant and mechanically robust to prevent intermittent failures. Wireless power systems must adhere to EMC and human exposure limits. Regular inspection and testing of cable assemblies and connectors are essential to detect early signs of wear or degradation before failures occur.

For engineers aiming to design with minimal cabling, it is crucial to validate new interconnect methods thoroughly, including mechanical cycling, thermal cycling, and EMC pre-compliance testing, to ensure long-term system reliability.

Call to Action

Understanding and optimizing internal cabling is essential to building robust, high-performance electronic products. At TrigoPi, we love testing the edges of cable management and interconnect design to deliver solutions that balance electrical performance, mechanical resilience, and manufacturability. If you're interested in exploring how advanced cabling strategies or cable-minimized architectures can elevate your hardware designs, we invite you to reach out and learn more about our expertise and services.

References

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