Large Format FPC Conductors as a platform technology:

Enabling the next generation of electrified, intelligent, and multifunctional systems.

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Wiring is no longer just connectivity

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CONNECTING TECHNOLOGY

Executive Summary

For more than a century, electrical systems have been built around discrete wires routed between isolated components. While this approach supported the industrial and electronic revolutions, it now limits the performance, manufacturability, and scalability of modern electrified and intelligent systems. As whole industries move toward automation, distributed sensing, lightweight structures, and software-defined architectures, traditional wiring harnesses have become a major bottleneck in weight, reliability, and bandwidth.

Large-format FPC technology offers a different approach. Instead of having thousands of individual conductors together in a single wiring loom, electrical functionality is provided by a continuous, precisely controlled, flexible surface. Power delivery, high-speed data exchange, sensing, heating, and diagnostics all within a single laminated architecture. This creates a platform that is inherently compatible with emerging Software-Defined Physical Layer (SDPL) technologies, which require stable, low-loss, continuous transmission paths rather than point-to-point wiring.

Across multiple industries, including aerospace, EVs, robotics, superconductor systems, medical devices, and large-scale scientific infrastructure, the same demands are emerging. They are all requiring their electrical architecture to have reduced mass, simplified assembly, improved reliability, higher functional density, and the ability to embed intelligence directly into the physical structure. As systems become more autonomous, sensor-rich, and software-defined, long-length multilayer FPCs are becoming the go-to passive substrate for the next generation of high-performance electrical harnesses.

The end of the traditional wiring model.

Traditional wiring systems evolved in an era when machines were relatively simple, rigid, and rarely had complicated instrumentation. Modern systems, on the other hand, have become more electrified, intelligent, and densely sensed as each year passes. Aerospace platforms can contain hundreds of kilometres of cable; EVs carry heavy, complex harnesses, which limit range and complicate manufacturing; battery packs require extensive management, monitoring and instrumentation; medical devices struggle to miniaturise due to conductor routing limits and the volume of instrumentation and reporting requirements; and superconductor systems demand embedded diagnostics within tight geometries.

These are not just practical inconveniences. Point-to-point wiring can be heavy, and as demands increase, so do associated assembly costs, maintenance burdens, and reliability risks. And as length and complexity increase, it also carries a greater risk of a fragmented, discontinuous electrical environment, poorly suited to emerging software-defined signalling. High-bandwidth, deterministic physical layers require continuous, predictable transmission lines with stable impedance and low dispersion over long distances - conditions that traditional harnesses cannot consistently deliver.

Flexible PCB harness replacements directly deal with these issues by replacing bundles of discrete wires with a continuous conductive layer engineered into a flexible substrate. Because the electrical pathways are manufactured as a single integrated surface, they provide the uniformity, shielding continuity, and geometric stability required for both today's high-speed electronics and tomorrow's SDPL-enabled systems. In this way, the interconnect ceases to be a collection of assembled subsystems and becomes a unified part of the structure itself.

From wires to fully functional flexible surfaces.

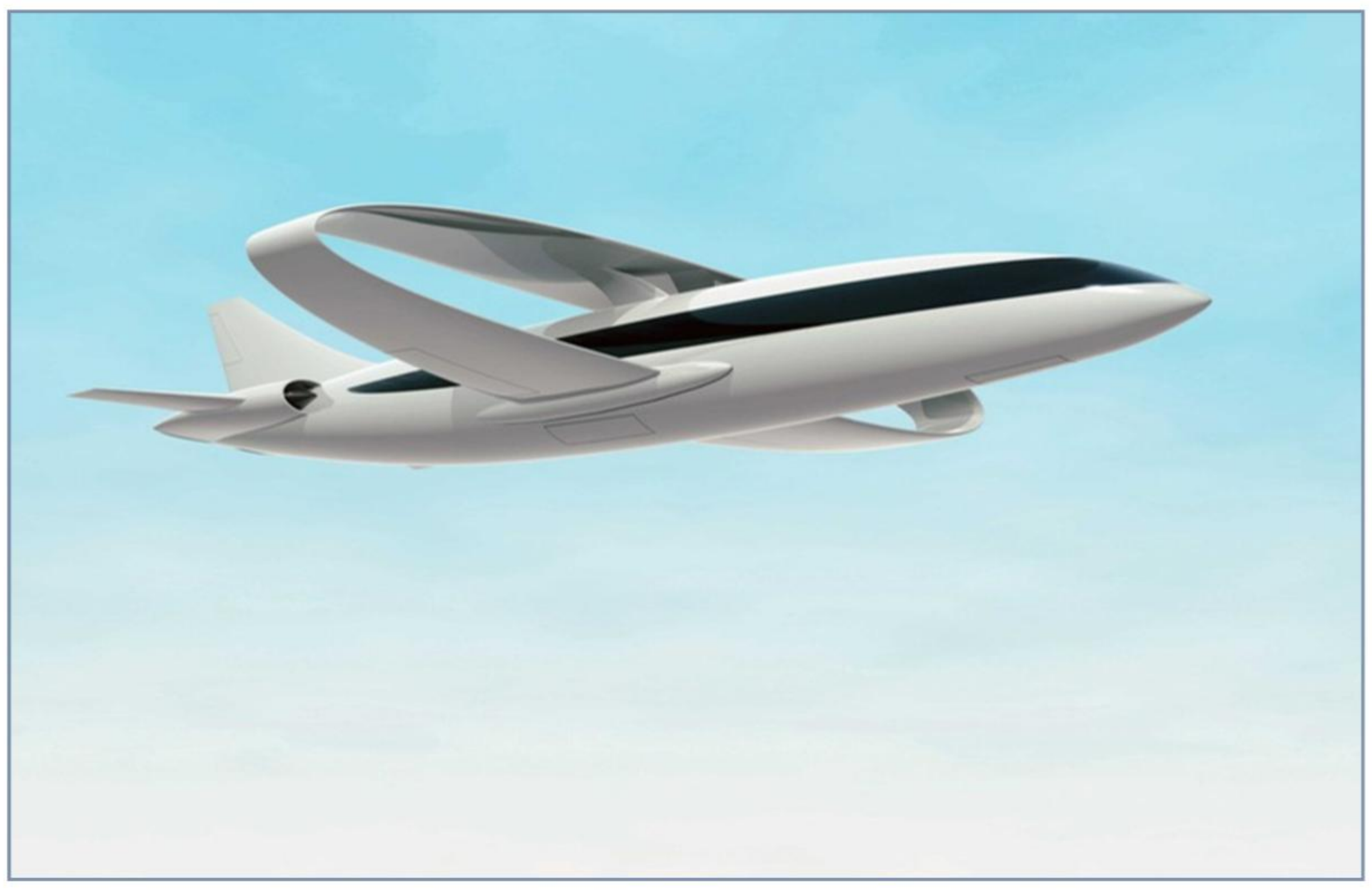
One of the most significant aspects of long-length multilayer FPC technology is that it collapses multiple traditionally separate subsystems into a unified architecture. A single large format FPC laminate may simultaneously provide power distribution, data transmission, thermal management, sensing, shielding, and diagnostics.

This transition can be seen elsewhere in advanced engineering. In many situations, mechanical structures are becoming aware, and their surfaces are becoming electrically active. The materials themselves are increasingly expected to sense, communicate, and respond, and all that requires interconnect technology to provide solutions.

Large Format FPCs fit naturally into this evolution because they allow intelligence and functionality to be distributed continuously across large areas rather than concentrated at isolated nodes.

This development is especially useful where mass, volume, and reliability is essential.

For example, in aerospace applications, wiring harnesses represent both a substantial weight and manufacturing complexity, which is only increasing over time. Routing thousands of wires through limited spaces is labour-intensive and difficult to automate. Long flex systems enable laminated electrical architectures to be integrated directly against, or even into, fuselage structures, wings, or interior surfaces. Connector counts can be dramatically reduced, installation simplified, and reliability improved by eliminating many mechanical interconnects.



Saving both space and weight to improve performance and range.

The same principles apply in other industries - automotive zonal architectures, robotic systems, industrial equipment, and large-scale infrastructure, for example. In each case, replacing discrete harnesses with integrated conductive surfaces enables both simplification of manufacture and installation, and increased functionality.

Thermal systems and large-area heating.

The benefits of long flex become even more apparent with respect to thermal management. The traditional approach of wound resistance wire or thick-film ceramic assemblies can be difficult to fit into non-linear layouts and can be challenging to control uniformly over larger areas.

The nature of long flex heater architectures means that they can replace discrete elements with distributed resistive patterns integrated directly onto supporting structures. This allows the conductor geometry to be engineered precisely to the required shape and enables thermal profiles to be controlled across large surfaces. All this means that heat can be distributed as required, mass can be kept low, and flexibility high.

In cases where thermal conditioning is required across large, lightweight structures, such as aerospace applications, this function is becoming increasingly important. Aircraft wing deicing, spacecraft thermal management, cryogenic tank conditioning, and battery warming systems all benefit from lightweight distributed heating architectures that can conform to the supporting structure.

Long-length multilayer FPCs go beyond what was commonly available with the more traditional approach through integrating sensing layers into the systems, allowing them to become intelligent. With temperature monitoring embedded directly in the heating structure, closed-loop control and real-time diagnostics can be enabled.

The result of these evolutions means the distinction between the heater, sensor network, and wiring system begins to disappear.

Spacecraft solar arrays & deployable power systems

As in aerospace, spacecraft systems can also gain substantially from the mass reduction and structural integration enabled by long flex conductors. Traditional solar arrays for spacecrafts tend to depend on fixed frameworks, discrete interconnects, and complex deployment mechanisms. These, although proven technology, introduce cost, weight, and reliability concerns.

Large-format FPC architectures enable engineers to approach space power systems differently. Integrating photovoltaic interconnects into flexible conductor backplanes, along with power routing, sensing, and deployment-strain monitoring, turns them into continuous, lightweight structures that can be folded or rolled for launch, only to be deployed effortlessly when required.

With the developing trend towards roll-out and deployable solar arrays for space systems, satellites, lunar infrastructure, and deep-space systems, this technology seems to be an ideal solution. The electrical pathways are distributed across flexible surfaces rather than concentrated in rigid harnesses, therefore flexibility is increased dramatically, the packaging efficiency improves, and, due to roll-to-roll manufacturing, failure points are reduced.

Img src. Smithsonian

As in aerospace, a similar environment where space is of increasingly high value, there is a move towards recognising the benefits of embedded sensing. Distributed thermal and strain monitoring can provide continuous awareness of degradation, radiation effects, deployment integrity, and localised faults. This promotes flexible PCB harness technologies from simply an incumbent replacement that reduces system mass, to one that creates more observable and resilient spacecraft architectures.

HTS magnet systems and fusion energy

High-temperature superconducting (HTS) magnet systems are another area where long flex conductor tapes are ideally suited. Applications such as fusion energy systems, particle accelerators, MRI platforms, and other strong-field magnets all require increasingly sophisticated conductors operating under harsh mechanical and electromagnetic states.

Long-length multilayer conductor tapes provide one key element of multifunctional superconducting magnet structures where superconducting tapes, stabilisers, sensing elements, and thermal pathways are integrated into unified laminated assemblies. Distributed voltage taps, quench detection networks, and temperature sensing layers can be embedded directly alongside the current-carrying conductors.

For fusion systems in particular, manufacturability may become one of the defining financial restrictions in commercialisation. Technologies that simplify conductor integration and instrumentation at scale could play an important role in allowing practical large format, high-field fusion architectures.

Long-Flex as the Passive Foundation for Software-Defined Physical Layers (SDPL)

As electrical systems evolve toward software-defined architectures, the physical interconnect is now not simply a passive carrier of signals but a programmable medium. Software-Defined Physical Layer (SDPL) technologies depend on transmission paths that are continuous, uniform, and electrically predictable over long distances - characteristics that traditional wire harnesses cannot consistently provide. Large format FPC conductor technology naturally delivers this environment because it is manufactured as a single, uninterrupted electrical surface with tightly controlled impedance, low-loss dielectrics, and integrated shielding.

- At SDPL Level 1, long-length multilayer FPC delivers a stable, reliable, deterministic transmission line suitable for the off-the-shelf high-speed transceivers often used in robotics, EV subsystems, and other environments where distributed sensing is required.

- These distributed sensing architectures are increasingly relevant to aerospace structures, industrial process systems, cryogenic infrastructures, wind turbines, smart buildings, and data centres.

- At SDPL Level 3, large-format FPC becomes the go to substrate for multi-tap, software-defined network architectures, where power, data, sensing, and diagnostics all exist as part of a single flexible surface, enabling distributed intelligence across large structures.

By providing the passive electrical accuracy demanded for SDPL architectures, long-length multilayer FPC technology becomes a key enabler for the next generation of intelligent, lightweight, and software-defined systems.

Distributed intelligence in large format FPCs

The ability to deliver distributed sensing systems is arguably one of the most game changing aspect of long flex technology. Conventional sensing architectures rely on discrete sensors connected through extensive wiring networks. This limits sensor density and introduces complexity that scales poorly as systems become larger and more instrumented. Long flex systems instead enable sensing to become continuous.

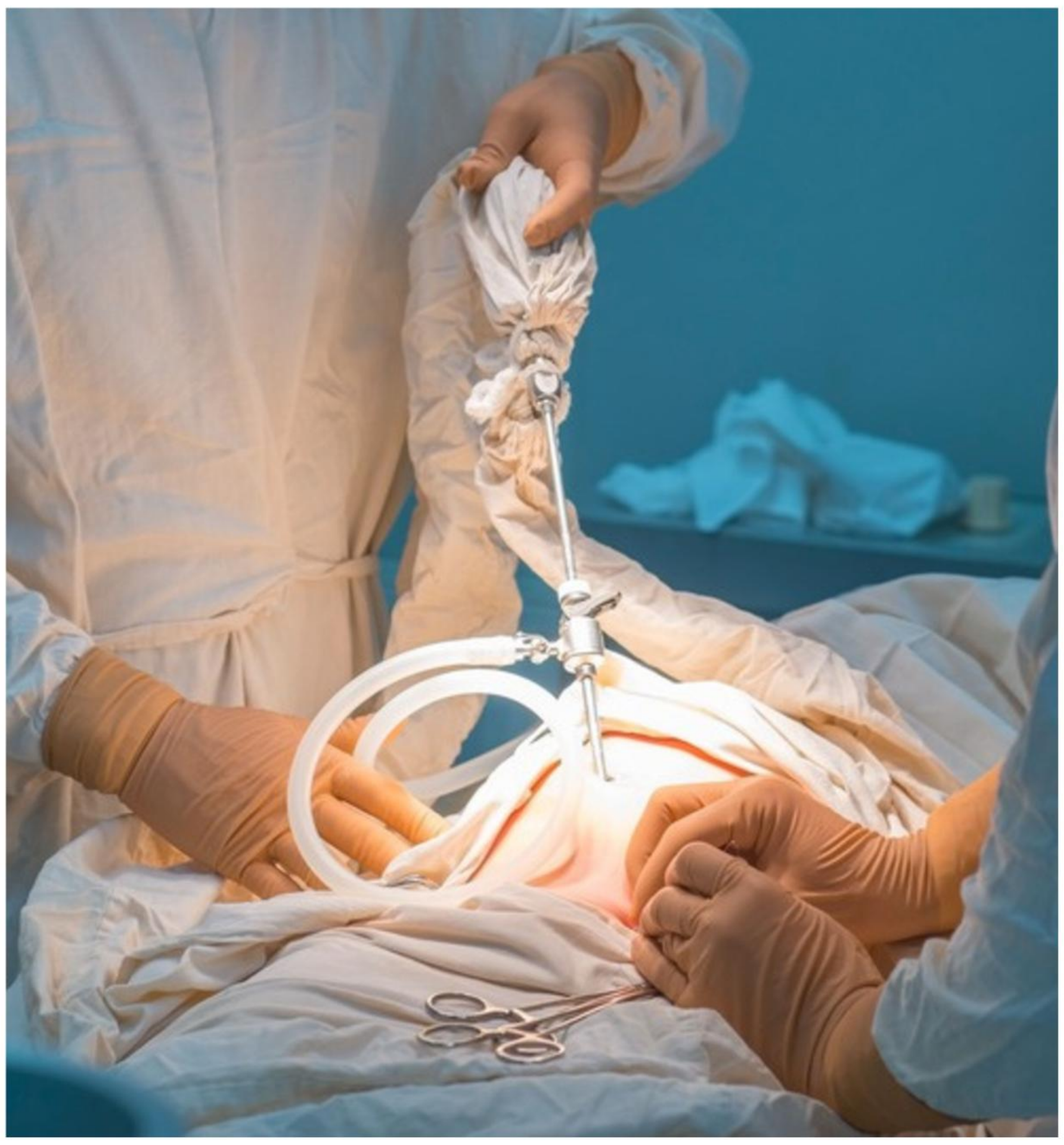
Temperature sensing, strain monitoring, pressure detection, and electrical diagnostics can all be integrated directly into flexible conductive surfaces. Rather than monitoring isolated points, systems gain the ability to observe entire thermal or structural fields in real time.

This function is especially important in battery systems. Modern battery packs require dense instrumentation during development, validation, manufacturing, and operation. Conventional thermocouple wiring becomes increasingly cumbersome when scaled. Long flex sensing layers, however, can be laminated directly into modules or pack structures, which enables distributed temperature and voltage monitoring throughout the system with vastly reduced wiring complexity.

These distributed sensing architectures are increasingly relevant to aerospace structures, industrial process systems, cryogenic infrastructures, wind turbines, smart buildings, and data centres. The system itself effectively becomes a sensing platform.

Medical catheters and intelligent interventional devices

The MediTech sector is a prime example of how demands in electrical functionality are increasing exponentially in order to facilitate its integration into minimally invasive devices. Traditionally, catheters rely on bundles of discrete microwires, each calling for individual stripping, routing, and termination. As functionality increases, this approach becomes time-consuming, difficult to scale, and increasingly constrained by size, flexibility, and assembly complexity.



Conductive layers can be embedded directly into catheter walls

Modern catheters are evolving into highly demanding technical systems with requirements to sense, image, navigate, and deliver precision therapy. However, as higher conductor counts lead to bulkier shafts, reduced flexibility, and greater variability in manufacturing, the microwire is becoming less optimal as a solution.

Long-length multilayer FPCs provide a fundamentally different approach. Instead of assembling individual wires, flex circuits deliver a single, pre-terminated structure made from a finely etched conducting layer - replacing complex microwire bundles with a compact, high-density interconnect. Conductive layers can also be embedded directly into catheter walls, enabling advanced electrical functionality within extremely small, flexible geometries.

The flexibility and miniaturisation allows power delivery, imaging, sensing, electrode arrays, and localisation systems to coexist as one single structure, improving both device capability and manufacturing consistency, and at volume, cost of manufacture . In applications such as cardiac mapping, higher channel densities can be achieved without increasing catheter size. Similarly, RF ablation devices benefit from integrated temperature sensing, supporting more precise energy delivery and improved safety.

As robotic-assisted interventions become more common, the requirement for integrated sensing and localisation will increase. Long-length multilayer FC provides a scalable, manufacturable platform that overcomes the limitations of classic microwire-based designs.

Manufacturing, scalability, and the future of intelligent structures

A major advantage of large-format FPC technologies is found in their compatibility with scalable manufacturing techniques. Roll-to-roll processing, printed electronics, additive conductor deposition, and automated lamination allow these systems to be manufactured continuously rather than assembled conductor by conductor.

This creates the possibility of transitioning from labour-intensive electrical assembly toward highly automated functional surface manufacturing.

The implications are considerable. Electrical systems become lighter, more reliable, and easier to install. Sensors become effectively ubiquitous. Thermal management becomes integrated rather than appended. Structures themselves become electrically intelligent, and with this, the distinction between structure, wiring, sensing, and computation will blur.

The future is clear: tomorrow's systems are going to have greater dependence on continuous, multifunctional electrical surfaces rather than relying on discrete, interlinked components if they are to keep up with what is required of them.

Conclusion

Large formant FPC technology embodies far more than an incremental improvement in wiring. It is an architectural shift that transforms electrical functionality into a continuous, integrated surface capable of carrying power, high-speed data, sensing, heating, and diagnostics within a single lightweight structure. As electrified systems grow in complexity - from EVs with dense ADAS sensor suites to aerospace platforms with extreme weight limitations - traditional point-to-point harnesses increasingly limit performance, manufacturability, and reliability.

Across every sector, the same pressures are converging: the need for high-bandwidth data transmission, robust EMI/EMC behaviour, lightweight interconnects, thermal and mechanical endurance, and simplified assembly. These demands are pushing systems away from bulky cable bundles and toward continuous electrical surfaces that offer predictable electrical behaviour and dramatically reduced failure modes. Long-flex architectures meet these requirements by eliminating connectors and transitions, enabling distributed sensing, and delivering a scalable manufacturing pathway through roll-to-roll processing.

As machines become more autonomous, sensor-rich, and structurally integrated, long-flex conductors provide a foundation for the next generation of intelligent infrastructure. They allow electrical, thermal, and diagnostic functions to be built directly inside the fabric of the system itself. This shift isn't optional - it is the natural evolution required for future aerospace, automotive, medical, energy, and industrial platforms to meet their performance, reliability, and manufacturing challenges.

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