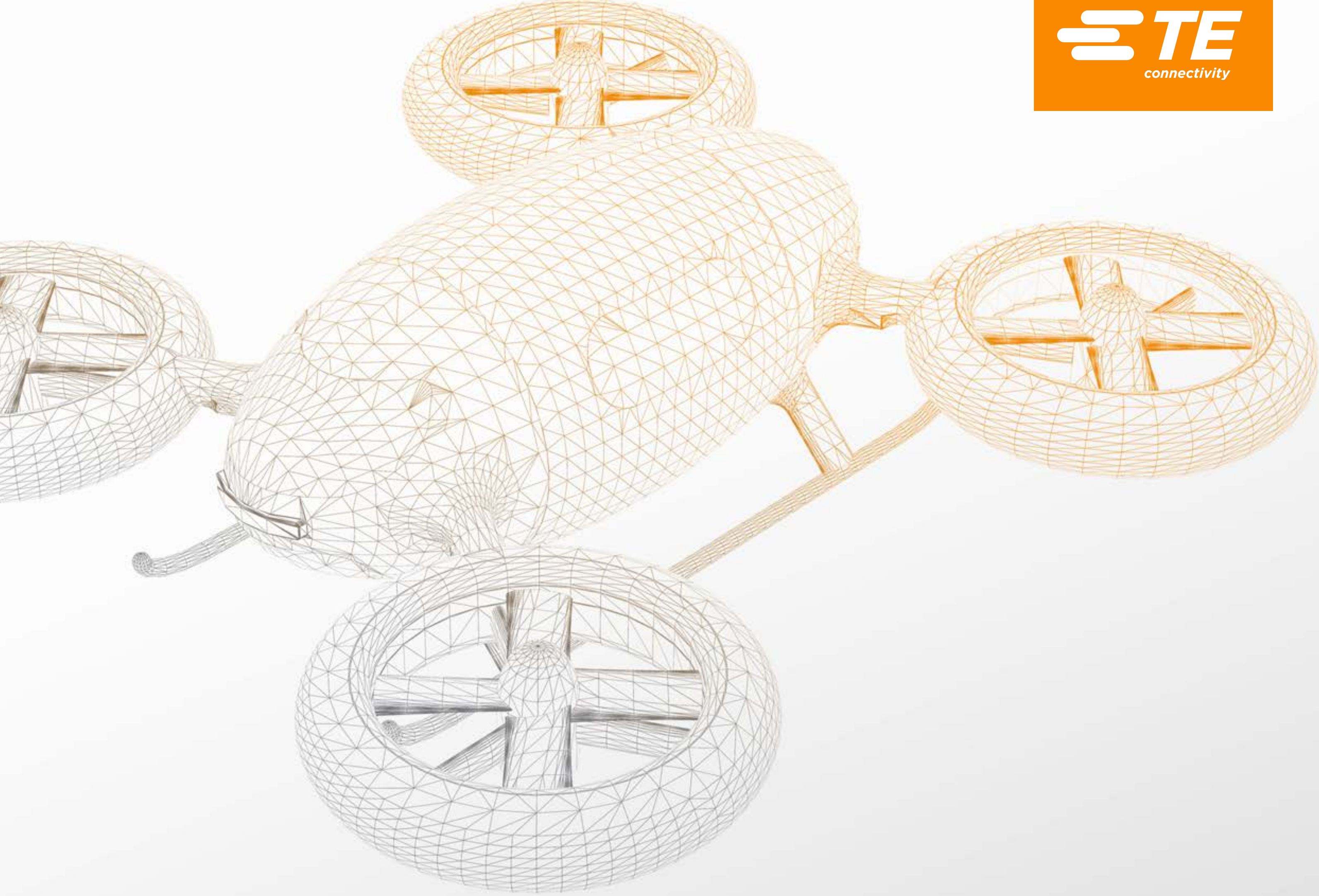

WHITEPAPER

CONNECTING THE FUTURE OF FLIGHT

Enhancing Urban-Air-Mobility (UAM) avionics with faster, smaller, and electrically optimized interconnection technologies.

by: Martin Cullen, Robert Moore, Clint Schlosser, Mark Benton

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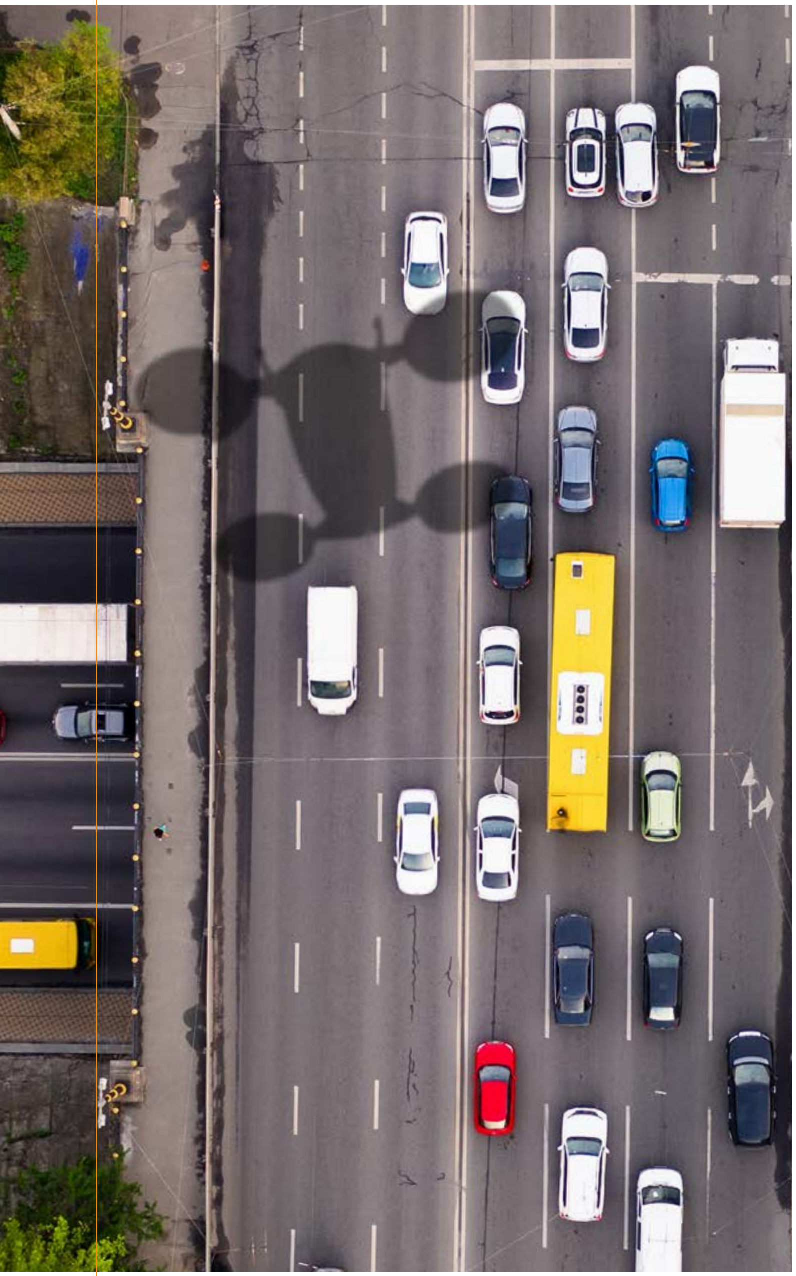
Enabling connectivity solutions for avionics in UAM and electric-powered vertical takeoff (eVTOL) aircraft.

This is the second in a series of white papers from TE Connectivity (TE) on connectivity technologies for urban-air/advanced-air mobility (UAM/AAM) projects. (The previous white paper addressed power-management solutions.) For over 75 years, the global technology and manufacturing leadership of TE has been empowering customers with a wide range of connectivity and sensing products for aviation, aerospace, automotive, and defense applications. As a go-to innovation partner, TE offers this overview of an evolving portfolio of products to enable solutions for the connectivity challenges of electric flight.

1. Opportunities



The future of electric-powered vertical flight is looking up—from 150 meters to 4 kilometers (500 feet to 2.5 miles) above ground level. That's where urban-air/advanced-air mobility (UAM/AAM) aircraft, low-altitude personal air vehicles (PAVs), and air taxis can transport cargo and passengers far above traffic snarls.

UAM and electric-powered vertical-takeoff-and-landing (eVTOL) aircraft promise a greener, cleaner alternative to hydrocarbon-fueled cars and conventional rotorcraft. But to make UAM a reality before 2030, project design teams must solve many avionics challenges in fly-by-wire and autonomous flight systems. In the 1990s, rotorcraft safety significantly improved with the development of Prognostic Health Management (PHM) and Health Usage Monitoring Systems (HUMS). Now, those technologies, along with data flow from autonomous flight control systems, impose significant connectivity challenges. Avionics designers and electrical-wiring-interconnect-system (EWIS) engineers benefit by understanding how a "follow-the-wire" approach using TE technologies and expertise can help significantly advance UAM avionics.

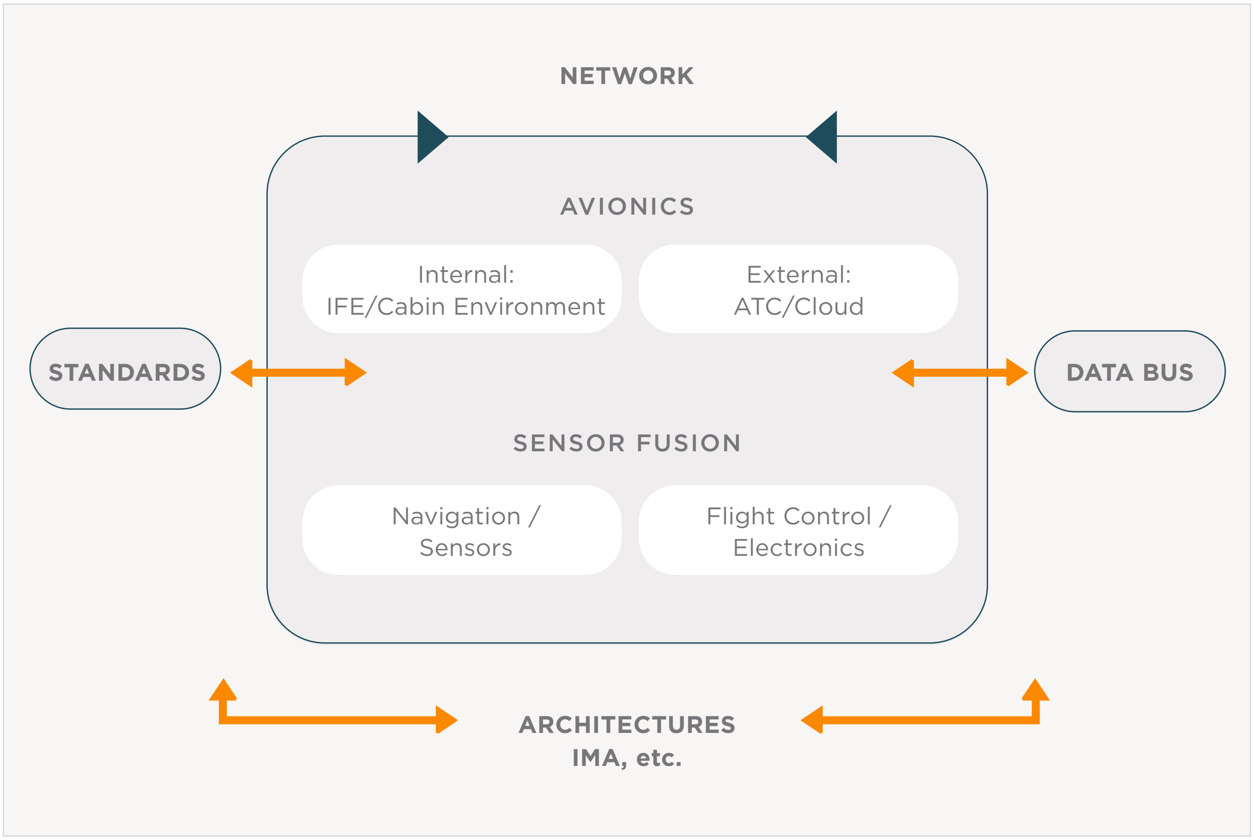
2. Scope of Challenges

It's valuable for avionics system designers and EWIS engineers to view interconnects holistically as part of a system where EVERY CONNECTION COUNTS. As eVTOL aircraft designs rapidly iterate and proliferate, project teams encounter a wide range of connectivity challenges (Figure 1 on page 3).

Areas covered in this white paper include:

- *Network solutions,* which encompass cabling and connectors, wiring harnesses, and terminations that transmit data and signals. Different protocols, topologies, and bus types are used depending on the avionics application, such as inflight-entertainment and communication (IFC), cabin environment control, navigation, and flight-management-and-control systems.
- *Architectures/electronic packaging levels,* which in this white paper covers Level 2 printed circuit boards (PCB), Level 3 board assemblies, Level 4 modules and assemblies integrated into an enclosure, Level 5 subsystems connected with a system's input/output (I/O) interface, and Level 6 network connections from box to box.
- *Sensor fusion,* which encompasses various radio frequency (RF) and electro-optical sensor technologies that provide inputs integrated with radar and signal processing along with other I/O from sensor nodes and networks.
- *Standards,* which include aviation-specific Aeronautical Radio, Inc. (ARINC) standards, Society of Automotive Engineers (SAE) aerospace standards (AS), network communication standards (e.g., Ethernet IEEE 802 and serial CANbus standards), and even military specifications (MIL-SPEC). In recent years, connectivity products have been introduced that are defined by new or emerging standards alongside commercial-off-the-shelf (COTS) technologies suitable for electric flight.

FIG 1: UAM connectivity challenge areas. (Courtesy TE Connectivity)



3. Network Solutions

Single-Pair Ethernet for Mbps Speed and Low Swap

VALUE

Ethernet is more than a protocol that connects homes and businesses to the Internet. Aviation applications can also use it for passenger connectivity, lighting control, cabin interior, and more. Additionally, Ethernet is the basis for the predominant commercial-aviation data network standard—the Avionics Full-Duplex Switched Ethernet (AFDX) implementation of the ARINC 664 part 7 standard. AFDX is a deterministic version of Ethernet that can deliver data packets to their destination at the required time—a necessity for flight-critical avionics systems.

Deterministic data delivery is not needed for connecting passenger electronics and other non-critical applications. Accordingly, the Cabin Systems Subcommittee (CSS) SAE Industry Technologies Consortia developed a non-deterministic version of Ethernet known as the ARINC 854 Cabin Equipment Network—sometimes classified under the umbrella terms “single-pair Ethernet” (SPE) and “Aviation Ethernet.” The ARINC 854 standard for SPE defines 100 Mbps data rates over two-way (full-duplex) links using lightweight twisted-wire pair cable in lengths up to 15 m (49 ft).

The ARINC 854 standard references a protocol developed in the automotive industry—the 100BASE-T1 standard known as “Automotive Ethernet.” The 100BASE-T1 standard is among several SPE standards positioned as a platform for the Industrial Internet of Things (IIoT). It will also enable “Industry 4.0” connectivity with developments aiming to deliver data and remote power (Power-over-DataLine) over a two-wire cable simultaneously, which would be useful for avionics applications.

PERFORMANCE

For UAM avionics, ARINC 854-compliant SPE offers many advantages:

Bandwidth and Data Rates

It will be qualified for 200 MHz and 100 Mbps operation over 15 m (49 ft) link lengths in accordance with ARINC 854 adoption of 100BASE-T1 specifications. Anticipating further developments as future market needs emerge, TE’s product roadmap envisions eventual support for 1 Gbps and 10 Gbps data speeds. The roadmap also envisions link lengths up to 40 m (131 ft), frequencies over 750MHz, and new connector designs to accommodate higher frequencies and speeds—anticipating 1000BASE-T1 capabilities will eventually be adopted.

Signal Integrity

ARINC 854-conforming links have passed 100 Mbs testing over a total of six connections and passes. Impedance, propagation delay, insertion loss (IL), and return loss (RL) all comport with 100BASE-T1 requirements.

Crosstalk

There is no crosstalk within an SPE cable due to the inherent crosstalk immunity of a single twisted-wire pair (not so with two pairs of wire in quadrax or four pairs with traditional Cat 5e or 6a cables). Alien crosstalk—i.e., crosstalk between two adjacent cables—poses little concern if shielded cables are used by offering the same crosstalk-noise-reduction properties obtainable with 100BASE-T1 links depending on the shield configuration. Immunity to electromagnetic interference (EMI) aligns with 100BASE-T1 specifications.

SWAP APPLICABILITY

Compared to heftier, enterprise-grade Ethernet 100BASE-TX (100 Mbps), 1000BASE-T (1 Gbps), and 10GBASE-T (10 Gbps) networks that use four unshielded twisted wire pairs (UTP), a two-wire SPE cable weighs nearly 50 percent less. The resulting weight savings in civilian aircraft is significant. For example, take the case of a wide-body commercial jet, such as a Boeing B747-400 aircraft, flying a 5,000 nautical-mile average stage length for 3,000 flight hours per year.

If the total weight of all wiring and connectors is calculated to be 1,814 kg (4,000 lbs), then hauling that mass consumes nearly 60,000 gallons of jet fuel annually. The annual fuel cost value for that amount of fuel comes to $115,800 USD. The annual CO_2 emissions from burning that much fuel amount to 2,785,200 kg (1,266,000 lbs) annually—the equivalent of automobile emissions from 124 passenger vehicles.[1]

The effect of weight on eVTOL aircraft is different. In conventional aircraft, weight is optimized for long-range endurance. Approximately one-third of takeoff mass is lost during fuel burn at takeoff. In battery-powered eVTOLs, weight remains constant for the entire flight (some weight variance occurs in hybrid UAM aircraft). Payloads weigh less, and passengers are fewer. The range is shorter, covering distances over city blocks or a cityscape.

FIG 2: Sources of system weights (in pounds) in various UAM aircraft. [2]

UAM/AAM AIRCRAFT TYPE	QUADROTOR	SIDE-BY-SIDE	TILTWING
Number of passengers	1	6	15
Trapped fluids	5	10	20
Automatic flight control	40	40	40
Instruments	10	10	10
Mission equipment	40	40	40
Electrical (10lb Plus 10lb/Person)	20	70	160
Environmental	15	90	225
Furnishings	31	178	443
Total system weight	161	438	938
Percent system weight contributed by electrical/electronic components	68%	37%	27%

Accordingly, the aircraft is smaller, and the amount of wiring in a UAM airframe is significantly less than for civilian aircraft. Nevertheless, depending on the eVTOL design, electrical and electronic components contribute from 27% to 68% of non-passenger, non-structural system weight.

The ability to shave weight is critical in UAM aircraft design. As aircraft maximum takeoff mass (MTOM) increases, the required battery mass increases significantly. The relationships between weight and other design variables have a cascading effect: Increasing eVTOL mass increases disk loading on rotors, which increases the power needed to maintain rotor speed, which increases battery size.

Implementing two-wire SPE for electronics connectivity reduces weight by a small fraction of total eVTOL mass. Nevertheless, that reduction can significantly contribute to overall power-to-weight effectiveness due to the positive cascading effects of losing several pounds of useless weight.

TE TECHNOLOGIES FOR SINGLE PAIR ETHERNET

Mini-ETH

As a CSS member of the SAE Industry Technologies Consortia, TE developed a family of 100BASE-T1 products that meet ARINC 854 specifications. The Mini-ETH interconnection system from TE is an end-to-end, point-to-point, ARINC 854-compliant SPE solution that helps deliver significant SWaP and performance advantages for UAM aircraft. The same TE expertise that developed MATEnet automotive interconnects—and a host of ARINC compliant interconnects for aircraft—is embodied in Mini-ETH technology. The result is a two-wire SPE platform to enhance bandwidth and data rates while enabling UAM aircraft to fly smarter and lighter.

Bandwidth and Data Rates

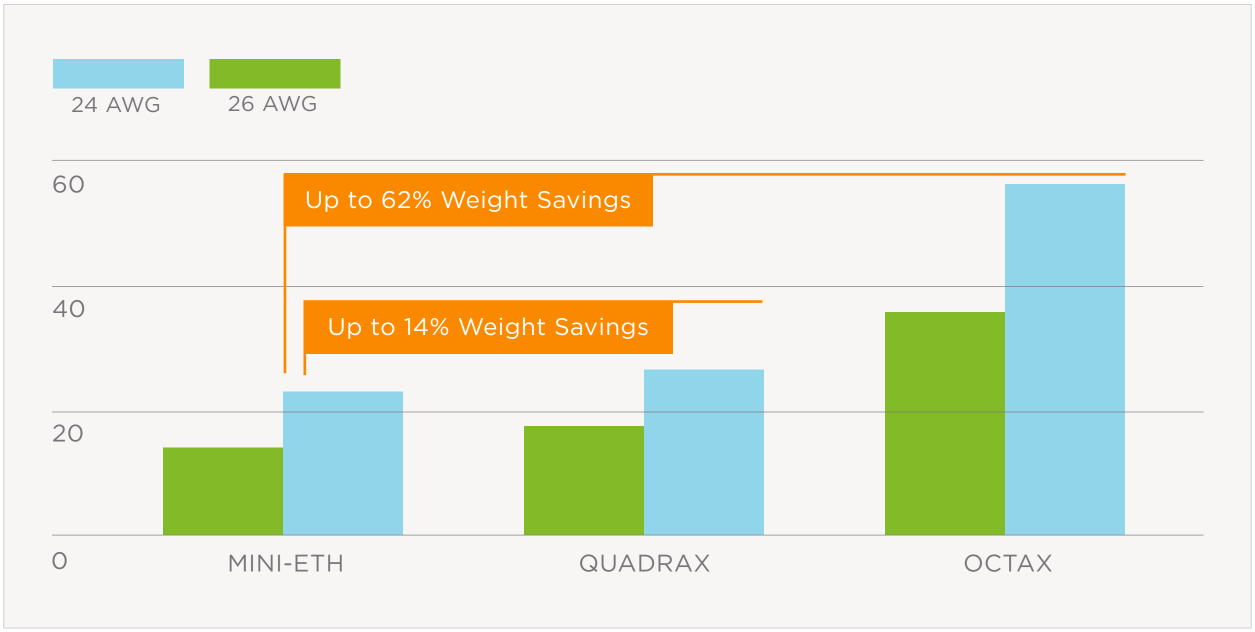
The bandwidth and data rate obtainable with a Mini-ETH solution are well suited to non-flight-critical UAM connectivity. Complying with ARINC 854 adoption of 100BASE-T1 specifications, the Mini-ETH interconnection system is qualified for 200 MHz and 100 Mbps operation at 15 m (49 ft) link lengths.

Current Mini-ETH interconnects are described under ARINC 854 specifications for the Cabin Equipment Network Bus. Compatible connectors and cables are described under ARINC 800 Part Two and Part Three specifications, respectively.

Cabling

Compared to 4-wire quadraxial cable commonly used for 100 Mbs Ethernet or octal cable with eight 24 AWG wire used in common Category 5e and 6a cable, two-wire Mini-ETH cable provides up to 62 percent weight savings (Figure 3 on page 7). The smaller dimensions of Mini-ETH cables with 26 AWG wire help improve space utilization. For example, switching from a quadraxial cable with four 24 AWG wires to a Mini-ETH cable with two 26 AWG wires shrinks cable diameter by approximately 15 percent. Mini-ETH cable's jacket construction is based on TE's long experience with its Raychem precision-extruded, high-temperature foamed dielectrics. Jacket materials are low smoke, meet the flammability requirements of Federal Aviation Regulations (FAR) Part 25, and the toxicity requirements imposed by major aircraft manufacturers.

FIG 3: Mini-ETH Cable Weight Comparison (pounds/100 feet)



TE TECHNOLOGIES FOR SINGLE PAIR ETHERNET (CONT.)

Looking forward, the TE Mini-ETH roadmap anticipates support for 1 Gbs and 10 Gbps data speeds, links up to 40 m (131 ft) long, and frequencies over 750MHz. The roadmap also includes new connector designs to accommodate higher frequencies and speeds—and already envisions 1000BASE-T1 for aerospace over longer run lengths. Given likely developments in ARINC standards, Mini-ETH cables are also provisioned for future operation up to 1,000 Mbps.

Connectors

Complementing the weight savings of two-wire cabling, Mini-ETH connectors reduce weight as much as 41 percent weight savings compared to typical D-sub connectors.
The Mini-ETH connector design is based on the success of TE's 369 series connectors, a family of EWIS-compliant rectangular connectors that provide a robust solution in a small envelope. This design was based on TE's DEUTSCH DMC-M series connectors, the classic modular cabin and avionics design used in aerospace applications for nearly three decades.
In addition to compactness, the 369 series connector design features internal latching and an ergonomic push-button feature that reduces installation time.

Mini-ETH connectors employ standard Mil-Spec AS39029 contacts and utilize a miniaturized, robust design intended for harsh environments and high vibration. These miniaturized contacts are particularly robust against vibration.
The connector shell is constructed from rugged materials with strength similar to steel but 40 percent lighter. The combination of composite materials and machined contacts accommodates temperatures between -55 °C (131 °F) and up to 175 °C (347 °F) for use inside and outside a cabin at altitudes up to 16,764 m (55,000 ft).

CANbus SERIAL COMMUNICATIONS for real-time control with low data rates

VALUE

For transmitting altitude, velocity, position, motor parameters, and other flight-critical data, commercial aircraft use the Controller Area Network (CAN) bus serial interface to connect LRUs (line replaceable units) with inertial measurement units (IMUs). CANbus microcontrollers and devices—such as a temperature sensor—can communicate with electronic control units (ECUs)—such as an engine ECU—without a host computer. The deterministic CANbus protocol handles fly-by-wire electronic control for flaps, trim, engine controls, and autopilot systems in place of direct mechanical linkage between the flight controls and flight surfaces. And in glass cockpits, CANbus connects radio system control panels on the flight deck to radio system LRUs, engine control interfaces, and LCD flight instrument displays.

Used in point-to-point wiring, shielded-twisted-pair CANbus cable is compact, saving space and minimizing weight in an eVTOL airframe.

PERFORMANCE

Originally developed in the 1980's by Bosch GmbH for automotive control systems, CANbus was subsequently adopted for aircraft—notably the Airbus A380—with physical interfaces, data formats and other features suited for avionics systems. CANbus provides distributed real-time control by broadcasting transmissions to all nodes. There is no explicit address in the message frame. Intelligence in a CAN node's software or acceptance filtering applied by a CAN hardware controller processes the transmitted message's ID to receive relevant return messages.

Bandwidth and Data Rates

The classic CAN frame format handles short messages with up to an 8-byte data payload. Available in different versions, the maximum bit-rate of "high speed" CANbus (ISO 11898) is 1 Mbit/s. The CAN arbitration method limits the length of the network link. At 1 Mbps, a theoretical length of 40 meters can be maintained. But practically, cabling, connectors, and other physical-layer components necessitate shorter lengths. Slower bit rates allow longer cables.

A recently introduced format, the CAN Flexible Data (CAN FD) protocol accommodates 64-byte payloads and faster bit rates for up to 600 percent higher throughput. ARINC 825 Supplement 4 defines enhanced capabilities for CAN FD technology, which accommodates 4 Mbps data rates and increases payload size from 8 byte to 64 bytes.

TE TECHNOLOGIES FOR CANbus

For CANbus implementations, TE can provide the full physical-layer solution, including cables, connectors, and terminations, as well as the ability to manufacture finished point-to-point harnessing. Raychem SAE J1939-compliant CANbus cables support speeds up to 1 Mbps. Shielded and unshielded variations are available in wire weights from 18 to 26 AWG allowing flexible construction for easier routing through the confined spaces in UAM airframes.

HIGH-SPEED COPPER
for Gigabit to 10 Gigabit Ethernet and beyond

VALUE

For data-intensive functions, the 4-Mbps speed of CAN FD can be too slow by over three orders of magnitude. Operating at far faster speeds, 10 Gigabit Ethernet using high-speed Cat 6a copper cabling can provide real-time, non-deterministic data transmission for avionics, flight-control, and cabin-management systems. However, this solution requires over-provisioning the network with a huge amount of bandwidth. Over-provisioning allows even worst-case network contention to be resolved quickly. To calculate the margin level between link performance and application limit, the designer must account for cable and connector impedance and environmental variables (temperature, humidity, aging). By providing a large margin for error, the designer can implement a 10 Gigabit Ethernet network without needing complex and expensive ARINC 664 hardware.

PERFORMANCE

High-speed Cat 6a copper cabling can support 10 Gigabit Ethernet at 83 m (272 ft), versus 36 m (118 ft) for a Cat 6 cable. Cat 6a cable is available in size 24 AWG or smaller 26 AWG wire sizes to minimize size and weight.

To mitigate insertion loss, crosstalk, and other signal-degrading due to faster I/O, the designer must use high-speed ARINC 600-compliant connectors. Proprietary, circular connectors are also available to handle extreme environments, offer flexible speed and size range, and provide metallic or composite-shell options for weight reduction.

TE TECHNOLOGIES FOR HIGH-SPEED COPPER

TE can provide a full physical-layer solution for high-speed copper applications based on extensive, high-performance-connectivity experience with 100- and 200-Gbps speeds for next-generation applications. Standards-based link components include:

- *Fully shielded Raychem Cat 6a* four-pair cables with AS6070 qualification. Fluoropolymer cable construction supports ANSI/TIA-568-C specifications for stability in extreme conditions.
- *Compact CeeLok FAS-T connectors* are 10G Ethernet, field-terminable I/O connectors widely used in aerospace and defense applications. Substantial size and weight savings are obtainable due to a small shell size 8 form factor. Electrical resistance meets ≤1.0 mΩ requirement of AS85049/128.
- *CeeLok FAS-T Nano circular connectors* combine 10 Gigabit rates with factory terminated, environmentally sealed assemblies 30 AWG Turbo Twin cable saves space and weight. Close impedance matching provides high-frequency headroom to tolerate noisy environments.
- *CeeLok FAS-X connectors* employ AS39029 crimp contacts designed for rugged environments. These connectors are significantly smaller than RJ45 in M38999 connectors (shell size 11 versus shell size 19).

FIBER OPTICS for real-time data transmission at light speed

VALUE

While flying at slower speeds and shorter distances than commercial aircraft, UAM vehicles still generate high-speed, high-volume data for aircraft management, navigation, collision avoidance, and other functions that make autonomous flight possible. With high-speed copper cabling, a shift from 100 Mbps to 10 Gbps Ethernet requires bigger, heavier cables as conductors jump from four to eight. In contrast, fiber optics offers clear advantages, which include:

- *High bandwidth:* Multimode fiber can support data rates of 10 Gbps and much higher using parallel optics transceivers that support multiple channels in little space.
- *Lightweight:* A fiber-optic cable is nearly 78 percent lighter than equivalent lengths of generic Cat 6a Ethernet cable.
- *Noise immunity:* Optical fibers are made of dielectric materials; they neither emit nor receive EMI. Cable shielding is not required.

IMPLEMENTATION

Physical Contact (PC) Connectors

A PC connection uses ferrules mated within a precision sleeve that assures radial alignment to minimize optical misalignment losses (Figure 4). The termini and mating sleeves can be incorporated into standard circular and rectangular connectors to provide multichannel operation. PC connections offer:

- Lowest insertion loss
- Lower reflection
- Compact format

While most PC connectors use a ceramic ferrule for a single fiber, a mechanical transfer (MT) ferrule is a multifiber variation typically holding 12 or 24 fibers.

FIG 4: Physical contact (PC) connector. (Courtesy TE Connectivity)

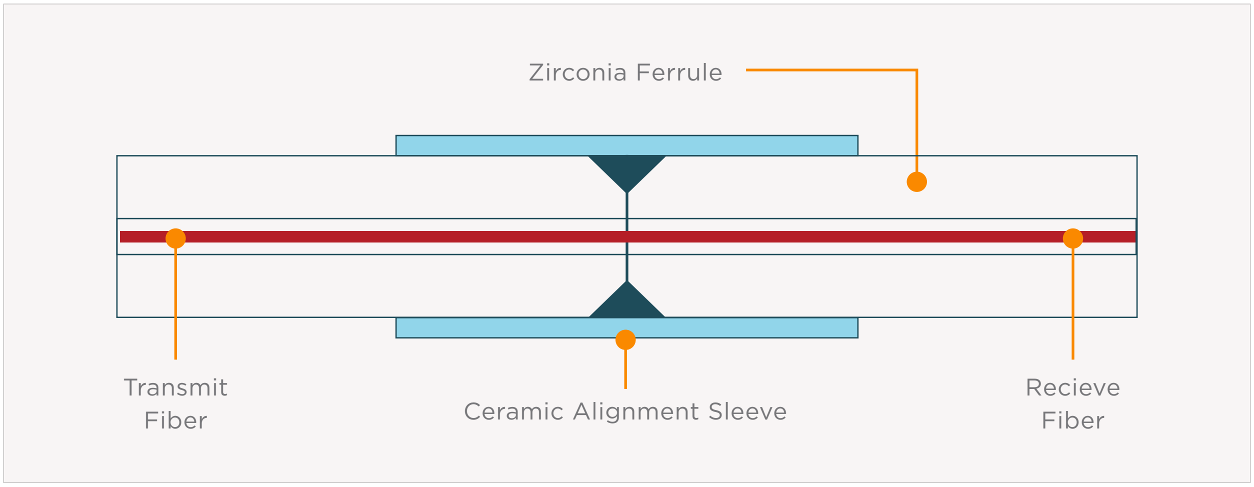
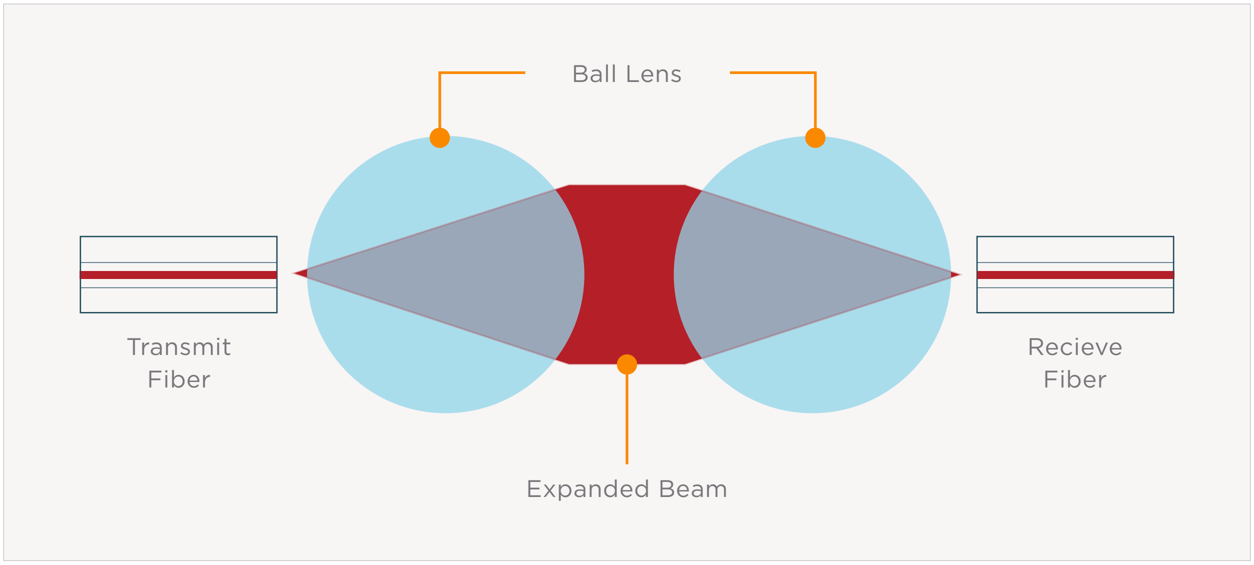


FIG 5: Expanded beam (EB) connector. (Courtesy TE Connectivity)



Expanded Beam (EB) Connectors

EB connectors expand and re-focus light at the fiber end faces and allow an air gap in the optical pathway (Figure 5). The EB concept uses optical lenses (typically a 3-mm ball lens for dedicated inserts or 1.25-mm lens for EB16 termini) to expand and collimate the beam emitted from the launch fiber.

Without physical fiber contact, EB connectors are suited to demanding environments by offering:

- Sealed optical interface
- High vibration and shock resistance
- High mating-cycle durability
- Tolerance to dirt and debris
- Easy cleaning

The expanded beam remains collimated across the mechanical interface until the receiving lens focuses the beam onto the receiving fiber. Standard channel counts for EB-specific connectors are 1, 2, 4 and 8. When used in rugged and tactical environments, EB connectors are usually terminated on robust, metal-tubed, and avionics/flight-grade cable.

Innovative EB16 optical termini employ the same technology from well-established dedicated inserts into termini that can be used in 38999 Series III and EN4165 size 16 cavities to allow for flexibility and higher fiber counts.

Fiber and copper can coexist in many applications by selecting appropriate media converters, transceivers, and hybrid termini.

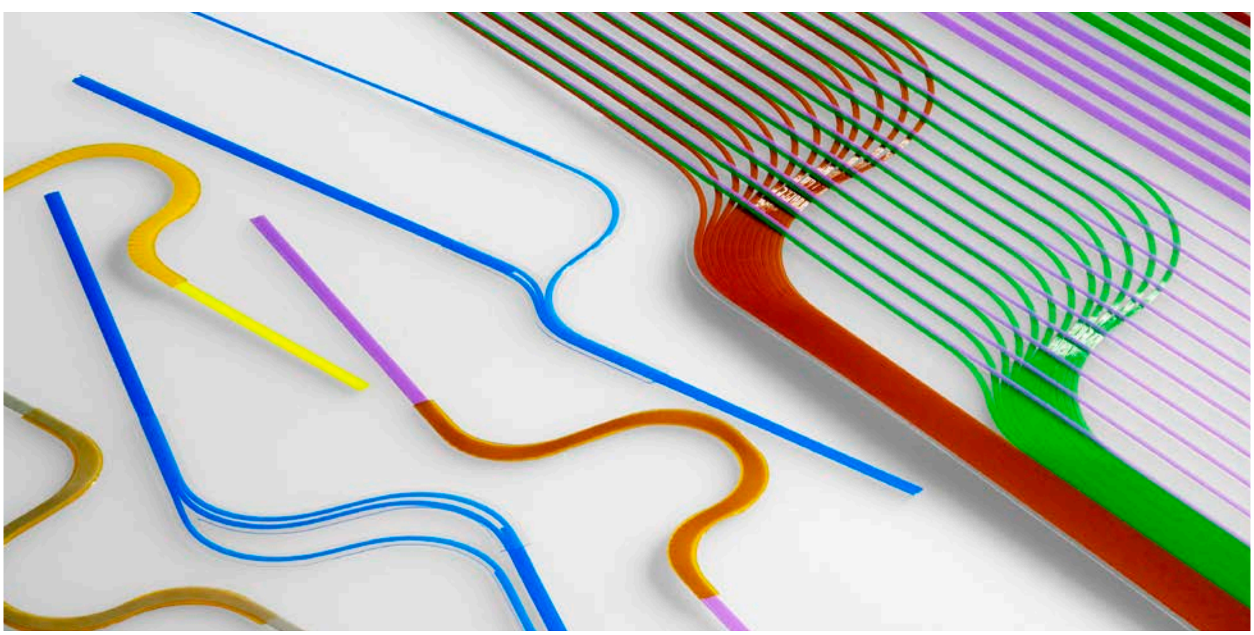
TE TECHNOLOGIES FOR FIBER OPTICS

Even with the inherent advantages of fiber optics, optimum system performance depends on properly integrating appropriate active and passive technologies. As a vertically integrated company, TE enables a complete end-to-end solution with a product roadmap for active and passive optical technologies that support next-generation applications. When evaluating a transition from copper to fiber or vice versa, designers can consult with TE subject matter experts on the best path forward.

Cabling, termini, optical transceivers, and fiber connectivity products from TE include:

- *Single mode and multimode cabling* in tight-buffered and loose-tube constructions with low-smoke, zero-halogen versions to support safety.
- *Optical inserts* supporting ceramic ferrules, expanded beam termini, and MT ferrules complying with ARINC, MIL-SPEC, and other specifications.
- *High-performance optical termini* featuring precision ceramic ferrules as small as 1.25 mm, MT array ferules, and expanded beam.
- *Optical flex circuits* in symmetrical and asymmetrical designs can be utilized for card-to-card or backplane applications and offer the designer multiple options in cable assembly design, connectorization, and routing (Figure 6).
- TE can provide fiber optic transceivers featuring a modular 1 x 12 industry-standard MT optical interface. Also supports board mountable SMT, pluggable mezzanine connector interface, and blindmate to VITA 66 compatible interface, through our partnership with Reflex Photonics.

FIG 6: Fiber optical flex circuits (Courtesy TE Connectivity)



4. Architecture Solutions

Integrated Modular Avionics (IMA) for embedded and edge computing

VALUE

There are two main avionics architectures:

1. Federated architecture for distributed avionics that are packaged as self-contained units, such as LRUs.
2. Integrated modular avionics (IMA) architecture for a partitioned environment where multiple avionics functions varying in criticality are hosted on a shared computing platform. By enabling resource sharing, IMA makes it possible to use fewer computing resources to reduce weight and power requirements.

With either approach, electronics must be packaged to provide structural integrity, environmental protection (e.g., thermal, radiation), secure Circuit Card Assembly (CCA) attachment points, thermal relief paths, and structural stability.

STANDARDS

The evolution of ARINC standards has facilitated the move to IMA architecture.

ARINC 600

In the 1970s, the Aeronautics Radio, Inc. (ARINC) 404 standard defined "black box" enclosures and racks within aircraft. The ARINC 600 standard—which defined a Modular Concept Unit (MCU)—is the basic building block module for conventional Integrated Modular Avionics (IMA). An ARINC 600 metal enclosure can hold up to 12 MCUs, allowing a lot of computing power to be placed in a centralized "box."

A centralized IMA approach offers:

- Reduced size and weight
- Easier maintenance with standardized cards that are easily replaceable.

However, a big box can be a problem in UAM airframes where electronics must fit in tight enclosures in any orientation and where the center of gravity (COG) of the airframe must be carefully tuned.

ARINC 800

ARINC 800 standards respond to the embedded-computing trend using a distributed architecture of loosely coupled boxes with fixed functions. Processors are embedded on miniaturized printed circuit boards (PCBs) that can be deployed locally within the airframe to handle higher data loads. ARINC 800 standards define modules for embedded processors to reduce package weight and size, improve thermal management, and push intelligence closer to the point where control decisions are made.

Edge computing is another trend that brings processors equipped with artificial intelligence (AI) software to the data source at the so-called "edge" of the network. With edge-computing architecture, cable weight, connector count, and device mass and volume are greatly reduced. This approach helps designers meet design and center-of-gravity (COG) constraints by simplifying how components integrate into the airframe. It also enhances reliability by reducing repair points for connections and cards.

ARINC 836A

Embedded systems, edge computing, and truly distributed architecture are combining to push IMA to the next level. The ARINC 836A standard supports this effort by establishing a mini modular rack principle (MiniMRP) for avionics packaging. The advantages of MiniMRP for UAM avionics include:

- Significantly reduced size with as much as 40% smaller packaging and 60% weight savings
- Enhanced flexibility and simpler configuration with a less costly commercial-off-the-shelf (COTS) selection approach
- Secure attachment of modules and boards with robust latches and interconnects

PERFORMANCE

By implementing edge intelligence in miniaturized electronics packaging, the avionics designer can implement navigation, communications, and other intelligent functions locally without being wired back to a central microcomputer. With edge computing, processing occurs at sensor or control nodes to enable nearly instant decision-making in support of autonomous control. Embedded-edge intelligence can act as if it is a Remote Interface Unit on the airframe extremity that converts sensor signals into ARINC 429-compliant digital packets transmitted over fiber optics to mission computers.

EWIS engineers benefit from more bandwidth for monitoring and flight-system control—while enjoying size and weight reductions to minimize disk loading and optimize battery life. Finally, edge intelligence can also function as an Internet of Things (IOT) device that connects to the “cloud” for high-order functions, such as predictive analytics.

FIG 7: ARINC 600 box compared to ARINC 836A MiniMRP enclosures. (Courtesy TE Connectivity)

TE TECHNOLOGIES FOR IMA

MiniMRP Modules

By supporting miniaturized, standardized modules that can be mixed and matched within a high-speed network, a TE MiniMRP solution provides the flexibility that UAM avionics designers and airframers need for avionics placement and cabling.

Flexibility

ARINC 836A MiniMRP modules from TE are available in four compact size combinations: single-width (42 mm/1.6 inches) or double-width (84 mm/3.3 inches), and single-height (112.3 mm/4.4 inches) or double-height (224.8 mm/8.8 inches) variations. Lightweight composite materials replace traditional heavy metal enclosures. Advanced composite formulations — including base materials and fillers — can be selected to meet application needs. Fillers range from carbon fibers to microsphere and nanotubes. Composites can be selectively plated to add shielding, circuit elements, and other features, such as embedded antennas. Previously considered expensive, composite enclosures are now more cost-effective thanks to advanced manufacturing techniques.

Configuration

With MiniMRP avionics, a big box in the avionics bay can be replaced with small enclosures distributed on a fiber optic or copper backbone (Figure 8).

Modules can be used singly or combined as needed for specific functionality and external environmental factors. MiniMRP packaging encompasses connecting hardware, including bus-structured modules, interfaces, and power supplies. Standardization allows designers to take advantage of COTS components to lower costs and accelerate the design cycle. Modules are designed for quick, tool-less installation. Changes, maintenance, and upgrades can be accomplished by simply swapping out modules.

Rack Interconnects

Avionics designers often face tight constraints with PCBs; modular racks provide design flexibility using European Standard EN4165-mateable interconnects for modular racks. With a fully-integrated MiniMRP design, PCB connector modules and boxes can be securely latched to protect against pull-out and torsion. The preferred connector for MiniMRP modules is the classic DEUTSCH DMC-M series connector that conforms to demanding avionics specifications, including EN4165. The DMC-M family offers many contact arrangements and insert layouts in both multi-cavity and single-module configurations. Sizes include 8, 12, 16, 20, and 22 gauges. Contacts can be crimped on copper wire, aluminum wire, or PCB mounting.

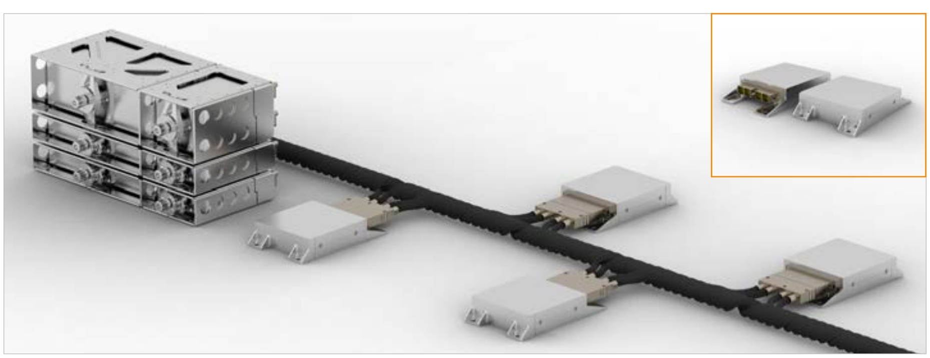


FIG 8: MiniMRP modules, standardized in ARINC 836A and conforming to IMA packaging, are distributed on a fiber or copper backbone. (Courtesy TE Connectivity)

TE TECHNOLOGIES FOR IMA (CONT.)

Cabling for MiniMRP

In distributed avionics, a large number of links are shorter than 83 m (272 ft). Consequently, high-speed 10G Ethernet copper cable or fiber optics can be employed as discussed above. For high-speed Cat 6a links less than 60 m (197 ft), 26 AWG cables may be used for smaller and lighter harnesses. Cat 6a cable can be terminated with small, high-speed ARINC-compliant circular connectors.

Transceivers for MiniMRP

In MiniMRP applications, copper and fiber can easily coexist. Each medium brings specific advantages, from the comfortable familiarity of copper to the high-bandwidth and EMI immunity of fiber. Avionics designers who are challenged by bandwidth-hungry processes can employ transceivers accommodating both optical fiber and copper to meet an array of high-speed connectivity needs, from box to box, box to backbone, and box to server.

- *ParaByte transceivers* employ a robust parallel optical design capable of achieving 10+ Gbps while also meeting MIL-SPEC standards for robustness. The small and dense ParaByte Transceiver design allows multiple transceivers to fit easily inside a single MiniMRP module.

Connectors for MiniMRP

- *DEUTSCH DMC-M connectors* are commonly used for MiniMRP modules. DMC-M connectors offer both multi-cavity and single-module configurations and composite housings, as well as aluminum wire capability, fiber optics, higher densities, and shunting configurations.
- *CeeLok FAS-T circular connectors* offer a true 100-ohm impedance design compatible with Cat 6a cable. A compact size 8 shell reduces SWaP (size, weight, and power) requirements. Crimp-snap contacts allow easy termination and field repairability. An integral backshell enables 360-degree shield termination. Minimal crosstalk and high signal integrity are achieved with a T-shaped contact pattern that provides noise cancellation and decoupling.
- *CeeLok FAS-X circular connectors* (Figure 9) are available in a small size 11 shell in a M38999 profile for one 10 Gbps Ethernet channel (size 25 shell for four channels). Contacts employ a proven AS39029 design for rugged environments. An innovative shielding arrangement shields each contact pair through the connector for improved impedance matching and crosstalk elimination. CeeLok FAS-X connectors are also qualified to MIL-DTL-32546.

FIG 9: CeeLok FAS-X connectors employing rugged, MIL-SPEC components for robust 10G Ethernet connectivity. (Courtesy TE Connectivity)

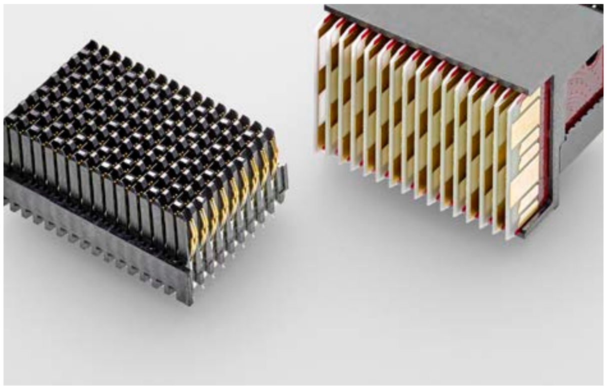
VPX and Open VPX standards for ultimate bandwidth

VALUE

While commercial aviation looks to IMA packaging and ARINC standards, the defense-aviation industry utilizes VPX form factors and interconnect standards developed by the VME International Trade Association (VITA) Working Group and the Sensor Open Systems Architecture (SOSA™) Consortium.

Incorporating high-speed-switch-fabric technology, VPX and OpenVPX backplanes enable immense bandwidth—for example, up to 900 Gbs duplex data throughput for optical interconnects that conform to the forthcoming VITA 66.5 standard. This level of bandwidth exceeds the needs of commercial avionics applications. Nevertheless, given the ever-expanding appetite of bandwidth-hungry autonomous-control applications, it's valuable for UAM avionics designers to be familiar with interconnects defined by VPX and OpenVPX standards.

FIG 10: MULTIGIG RT 3 high-speed backplane connectors meet the interface dimensions for VITA 46 VPX connectors and support up to 32 Gbps baud rates. (Courtesy TE Connectivity)



TE TECHNOLOGIES FOR VPX AND OPENVPX STANDARDS

Board-to-board connectors

The VITA 46 standard defines the primary digital connector for VPX backplanes and is based on the MULTIGIG RT platform developed by TE.

- *MULTIGIG RT 2 interconnect family* is comprised of stackable modular components and guide-pin assemblies enabling pinless, board-to-board interconnection supporting Ethernet, Fibre Channel, InfiniBand applications, PCIe and Serial RapidIO high-speed protocols. MULTIGIG RT 2-R is a ruggedized version suited to high-vibration environments.
- *MULTIGIG RT 3 family* supports 25-32 Gbps baud rates that meet OpenVPX and SpaceVPX standards, while maintaining mating compatibility with MULTIGIG RT 2 and 2-R systems (Figure 10). Four points of contact (compared to two for MULTIGIG RT 2) provide redundancy for contacts between the receptacle and the wafers, which is suited for extreme environments.

Ruggedized backplane connectors

These connectors are available for next-generation packaging in VPX avionics boxes needing

TE TECHNOLOGIES FOR VPX AND OPENVPX STANDARDS (CONT.)

the robustness found in military-ground-vehicle applications.

- *Fortis Zd Connector Modular backplane connector* system combines the highest performance for mil/aero applications while supporting 10 Gbps+ data rates. The Fortis Zd LRM (line replaceable module) solution combines with power, RF, and optics modules proven in VPX applications.

Coaxial interconnects

VITA 67 (ANSI/VITA 67.0-2019) standard defines the coaxial interconnect for connecting high-speed analog and RF signals directly to the backplane. Coax contacts are populated in multi-position modules to enable RF signaling between VPX plug-in modules and the chassis backplane pass-through interface.

- *NanoRF modules and contacts* provide a rugged, high-frequency nano-miniature coax system supporting frequencies up to 70 GHz (Figure 11).

External interconnects

VITA 87 is a draft standard for circular optical MT connectors. Just as the optical interface to the backplane is growing in fiber density, VITA 87 accommodates multiple MT ferrules in proven circular M38999 shells for high-density external cabling (Figure 12).

- *MC801 connector family* combines high-performance ARINC 801 optical termini with the rugged MIL-DTL-38999 Series III connector style where weight, electromagnetic interference (EMI), and ruggedness are issues.

FIG 12: 38999 Series III Style circular connectors with up to four MT ferrules accommodating up to 96 optical channels. (Courtesy TE Connectivity)

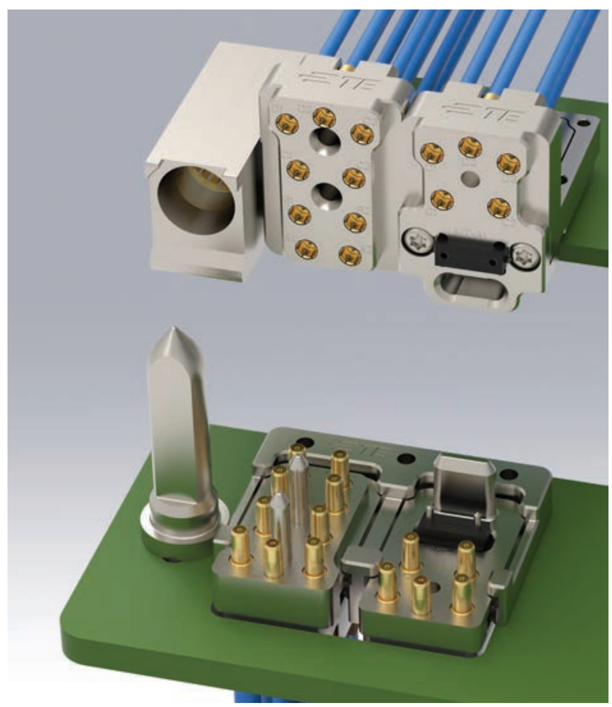


FIG 11: NanoRF/optical module using a floating insert within the backplane module that can pre-align MT ferrules and RF contacts. (Courtesy TE Connectivity)

5. Sensors

Sensor Fusion

VALUE

Autonomous flight control systems require multi-sensor data fusion that can handle movement in three dimensions.

Inputs from different RF and electro-optical sensors must be integrated with radar and signal processing technologies along with I/O from multiple wired and wireless sensor nodes and networks. Integrating inputs from all sensors (sensor fusion) enables more accurate and dependable UAM prototype testing during takeoff, hovering, forward flight, and landing.

TE TECHNOLOGIES FOR SENSORS

- *Multisensor AmbiMate sensor module MS4 series* is an application-specific set of sensors on a ready-to-attach PCB assembly for easy integration into a host product. The design process is accelerated by integrating the MS4 series pre-engineered with a four-core sensor solution for motion/light/temperature/humidity into the product.
- *Pressure sensor products* encompass sensing elements with system packaging for harsh environments. Standard and custom pressure sensors are available from board-level components to fully amplified and packaged transducers. Based on piezoresistive Micro-electromechanical systems (MEMS) and silicon strain gauge (Microfused, Krystal Bond) technology.
- *Rate, inertial & gyro sensors* are employed in electronic test and measurement systems, such as inertial sensors, rate sensors, and rate gyroscopes for demanding robotics, biomechanics, and other testing environments.
- *Temperature-sensor* offering includes negative temperature coefficient (NTC) thermistors, resistance thermometer detectors (RTDs), thermocouples, and thermopiles
- *Antenna products* include a wide range of antenna types, many available in moldable composite forms. Multiband, wideband antennas yield fewer antennas per platform. Wi-Fi 6E antenna product portfolio supports triple bands, including the new 6 GHz band, along with widely used 2.4 GHz and 5 GHz Wi-Fi frequency bands.

6. Implementation


Power Feeder Cables

High Voltage DC Relays and Contactors


Harnessing and Cable Management


High Performance Wire and Cable


Sensors


High Speed I/O Connectors


High Power Connectors


Fiber and Copper Cable Assemblies

With deep expertise in automotive, aviation, defense, and aerospace connectivity, TE offers innovative solutions to help meet the most demanding requirements.

Our broad product portfolio assists UAM designers and EWIS engineers by providing options for achieving the optimum balance between performance, cost, SWaP, and time to market. And our end-to-end breadth covers designing, customizing, manufacturing, and implementing components all along the wire of eVTOL aircraft: sensors, monitors, circuit breakers, wiring, assemblies, and more.
Use our extensive resources in avionics connectivity to control your UAM project's path—from demonstration to certification to production to flight.

Additional Resources

TE Urban Air Mobility Homepage

Contact One of Our Experts

References

1. "Advancing Aircraft Connectivity With A Single Pair Ethernet Solution," TE Connectivity white paper. https://www.te.com/content/dam/te-com/documents/aerospace-defense-and-marine/aerospace/global/spe-whitepaper.pdf. Accessed February 17, 2021.

2. Wayne Johnson, Christopher Silva, and Eduardo Solis, "Concept Vehicles for VTOL Air Taxi Operations." Paper presented at the AHS Technical Conference on Aeromechanics Design for Transformative Vertical Flight, San Francisco, CA, January 16-19, 2018. Table adapted from page 7. https://rotorcraft.arc.nasa.gov/Publications/files/Johnson_2018_TechMx.pdf. Accessed February 17, 2021.

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