

XMA-SOLO: Extending High-Performance FTI to Remote and Distributed Environments

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Abstract

Flight testing a prototype aircraft requires a significant number of additional sensors, data acquisition units (DAU) and wiring harnesses. Today, new technologies enable the remote deployment of data acquisition modules across the entire aircraft to increase installation flexibility, to reduce cabling constraints, and to open new possibilities for complex aeronautical applications. Power over Ethernet allows acquisition modules from mature flight proven data acquisition unit to operate in remote mode which offers more distributed Flight Test Instrumentation (FTI) architectures. This paper presents the technology, the main design principles and illustrates several representative architectures potentially combined with wireless links to unleash possibilities.

Keywords: Instrumentation, Modularity, Low-SWAP, Scalability, Power-over-Ethernet, Wireless

Background and problem statement

Flight test instrumentation is important for aircraft development and certification because it allows data to be collected during real flight conditions. As aircraft become more integrated and more constrained, adding instrumentation is becoming more difficult.

Key challenges include added **weight**, limited installation **volume**, **thermal** management, and the need for late-stage **adaptability** to accommodate evolving measurement requirements. In parallel, the instrumentation chain must provide accurate measurements, time **synchronization** and strong **deterministic** behavior to ensure coherent and repeatable data acquisition across all channels.

Wireless is a technology brick that can help, but it cannot be used in all situations, such as compartmentalized areas, interference issues, or susceptibility concerns.

To address these constraints, **weight**, **volume**, **wiring intrusiveness** and late-stage **adaptability**, new FTI architectures leverage distributed, modular acquisition units that can be installed close to sensors while still operating within a coherent, deterministic network.

Among the technological enablers of this evolution, **Power over Ethernet** (PoE) plays a central role: it allows rugged flight-proven data acquisition modules to be deployed remotely, powered and synchronized over the same

Ethernet cable used for data, reducing separate power and timing wiring effort and cost.

The following sections describe PoE fundamentals, its basic principle, wiring options, power-management modes and network topologies, before showing how these concepts are applied in SAFRAN Data Systems FTI solutions, illustrated by centralized versus decentralized architectures and the XMA and XMA-SOLO product families.

What is Power-over-Ethernet

Power over Ethernet (PoE) enables the simultaneous transmission of electrical power and data over standard Ethernet cabling. Although the concept was introduced in the late 1990s, its widespread adoption has primarily occurred over the last decades, driven by increasing demand for simplified infrastructure and scalable network deployments such as network cameras, wireless access points, and industrial sensors.

How does PoE work?

First, consider how Ethernet cables operate. When copper-based, they consist of 8 conductors organized into 4 twisted pairs, where each pair carries a differential voltage signal between its two wires.

A key advantage is immunity to DC bias. Differential signaling is particularly advantageous because the transmitted data depends only on the voltage difference within

each pair, not on the absolute voltage level of the individual conductors.

For example, if one set of twisted pairs has a DC bias of 57V, and another has a DC bias of 0V, then while the differential signals are left unaffected, the DC voltage across the two twisted pairs will always have a 57VDC difference. Then, it becomes possible for a special filter circuit to separate both the AC and DC signal components of all the cables, allowing data to be read by a controller, while the power circuit extracts power from the DC bias.

A PoE link typically involves two elements: the **power sourcing equipment (PSE)** also called injector and the **powered device (PD)**.

Wiring options

PoE offers several wiring options (Figure 1), depending on the standard used (802.3af/at, 802.3bt “4PPoE”), the speed (10/100Mb/s vs Gigabit).

There are three common ways to route power on the cable:

Alternative A: Power and data share the same two pairs (pins 1–2 and 3–6) that carry data in 10/100-Mbps Ethernet.

Alternative B: Two dedicated pairs carry power (pins 4–5 and 7–8), while the other two pairs carry data only.

4PPoE: All four pairs carry both data and power simultaneously, enabling high power levels and full-speed Gigabit connectivity

Pins at switch	T568A color	T568B color	10/100 mode B, DC on spares	10/100 mode A, DC & data	1000 mode B, DC & bi-data	1000 mode A, DC & bi-data	1000 mode A+B (4PPoE), DC & bi-data ^[Note 1]
Pin 1	green stripe	orange stripe	Rx +	Rx + DC +	TxRx A +	TxRx A + DC +	TxRx A + DC +
Pin 2	solid green	solid orange	Rx -	Rx - DC +	TxRx A -	TxRx A - DC +	TxRx A - DC +
Pin 3	orange stripe	green stripe	Tx +	Tx + DC -	TxRx B +	TxRx B + DC -	TxRx B + DC -
Pin 4	solid blue		DC +	Unused	TxRx C + DC +	TxRx C +	TxRx C + DC +
Pin 5	blue stripe		DC +	Unused	TxRx C - DC +	TxRx C -	TxRx C - DC +
Pin 6	solid orange	solid green	Tx -	Tx - DC -	TxRx B -	TxRx B - DC -	TxRx B - DC -
Pin 7	brown stripe		DC -	Unused	TxRx D + DC -	TxRx D +	TxRx D + DC -
Pin 8	solid brown		DC -	Unused	TxRx D - DC -	TxRx D -	TxRx D - DC -

Figure 1 : Wiring options [1]

Power management

Power over Ethernet can be implemented in two main ways: active PoE (standard, IEEE-based) and passive PoE (non-standard). The key difference lies in whether the power source “talks” to the device before delivering full

voltage or just sends power continuously, regardless of the device’s capability

Active “signature” refers to the IEEE 802.3af/at/bt detection behavior where the PD presents a controlled 25 kΩ signature and associated capacitance during a defined low-voltage probing interval, enabling the PSE to decide whether to apply PoE power. Figure 2 summarizes the comparison of key Power-over-Ethernet parameters across the different IEEE 802.3 standards.

Official name in IEEE 802.3	Type 1	Type 2	Type 3	Type 4
Common name(s)	PoE	PoE+	PoE++ / 4PPoE	
Defining IEEE document	802.3af	802.3at	802.3bt	
Power available at PD	12.95 W	25.50 W	51 W	71.3 W
Maximum power delivered by PSE	15.40 W	30.0 W	60 W	90 W
Voltage range (at PSE)	44 / 57V	50 / 57V		52 / 57V

Figure 2 : Comparison of PoE parameters [1]

Passive “signature” for so-called passive PoE solutions is effectively absent; the PSE applies a fixed voltage without any signature-based detection.

Topologies

In PoE, “topology” usually refers to how the PSE and PD are connected in the network, rather than classic bus/ring/mesh patterns. The main practical PoE topologies are star, in-line, daisy chain.

Star topology

A PoE-enabled switch is at the center, each powered device connects directly to the switch via a separate Ethernet cable. Figure 3 below presents a PoE system implemented in a star topology.

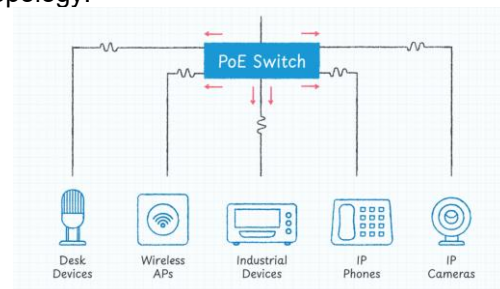


Figure 3 : Star topology [2]

In-line topology

A non-PoE switch feeds a PoE injector that sits between the switch and the PD; the injector adds power onto the cable without modifying the switch and the bi-directional data flow. Figure 4 below presents a PoE system implemented in in-line topology



Figure 4 : Topology in-line [3]

Daisy-chain topology

A PoE-capable device receives PoE on one port and then passes both data and power to the next PoE device on its downstream port, forming a chain. Figure 5 below presents a PoE system implemented in a daisy-chain topology.

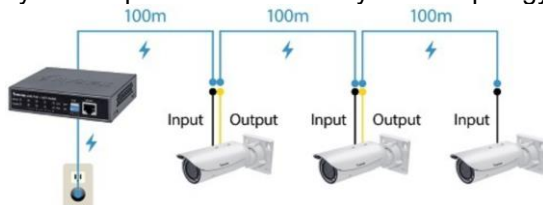


Figure 5 : Topology Daisy-chain [4]

Understanding the FTI architecture is key to appreciating the new integration possibilities enabled by PoE technologies.

Legacy centralized topology: characteristics and drawbacks

In the centralized FTI model a central Data Acquisition System concentrates analogue and digital front-ends, timing and recording; long multipair harnesses routed through the test vehicle to connect each sensor, increasing weight, installation time and maintenance burden. The mechanical and electromagnetic intrusiveness of this harness forced numerous structural penetrations and bespoke fixings, with consequent sealing and EMI/EMC challenges and limited sensor placement options in compact aircraft zones (e.g., leading edges, avionics bays, rotor hubs). From the test-engineer perspective this topology reduced adaptability of the measurement plan: adding or re-locating channels often required major harness rework, extended aircraft downtime, and potentially new structural interventions if routing access was not available. Figure 6 below presents a centralized topology. Harnesses between the DAU and sensors are shown in green.

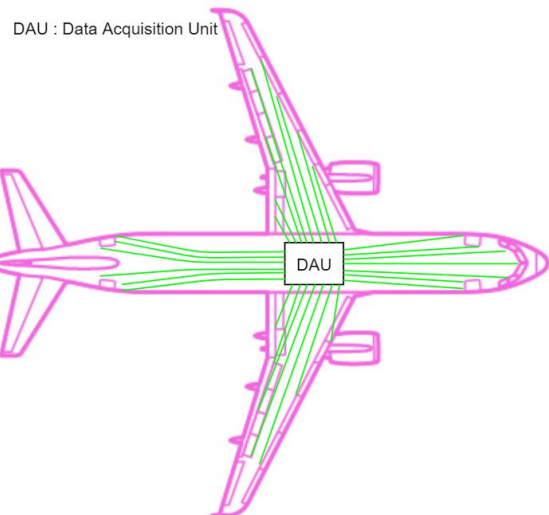


Figure 6 : Legacy centralized topology

Remote topology: current practice

Today's FTI architectures are significantly less centralized: the number of sensing channels grows while acquisition modules become smaller, more modular and more widely distributed across the test vehicle, enabling acquisition to occur closer to sensors and digitization at the edge. These modules are designed to be rugged, compact and network-ready, supporting digital outputs (Ethernet, UDP, IRIG Chapter formats) and synchronization protocols (IEEE-1588, IRIG) to maintain deterministic timing and allow streaming, recording and telemetry integration. The result is reduced wiring weight and intrusion, improved access to previously inaccessible zones, and enhanced scalability: networked telemetry and merging functions allow virtually unlimited growth of channel counts without a proportional increase in central DAU size or harness complexity. Figure 7 presents a decentralized topology. Ethernet cables between DAUs are shown in blue.

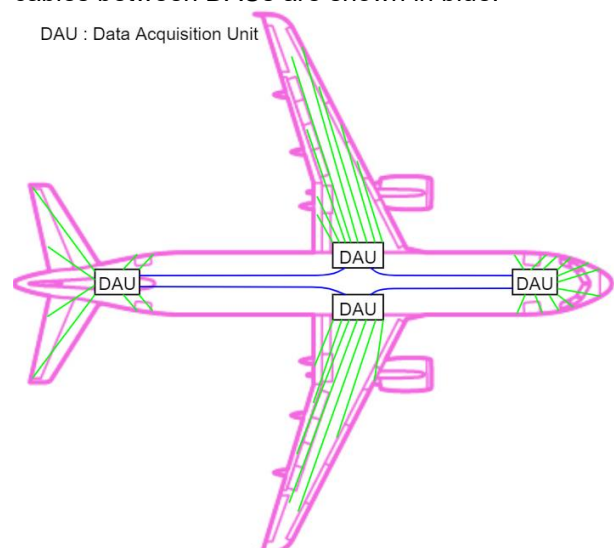


Figure 7 : Current remote topology

Ultra-remote topology: new practice

The next evolution of FTI architectures may be described as an ultra-remote topology, where acquisition nodes are no longer only distributed across the vehicle, but deployed as fully autonomous network endpoints powered directly through the communication infrastructure. Leveraging PoE technology, both data transmission and electrical power are conveyed over a single Ethernet cable, significantly simplifying installation and enabling highly compact remote DAUs to be positioned in previously inaccessible or constrained areas of the test vehicle. Figure 8 below presents an Ultra-remote topology.

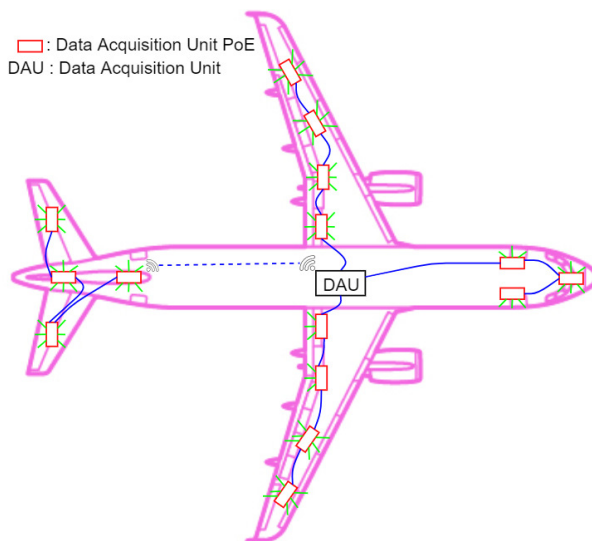


Figure 8 : Ultra-remote topology

Power-over-Ethernet: one implementation selected for the FTI

Merging data and power

Based on the "Alternative A" wiring scheme, 10/100 Mbit/s bi-directional data transmission, power and data are combined within the same wires, using only two twisted pairs. This reduces the total wiring cross-section and harness weight, directly contributing to lower cable-routing intrusiveness inside the test vehicle and minimizing the number of holes and fixings required. Considering that the electrical harnesses are a significant part of the FTI budget, the benefit is not only axed to weight capitalization but also induces cost reduction. To further enhance installation robustness and flexibility, Ethernet switches are configured with **Auto MDI-X** capability, allowing automatic detection and adaptation to cable type, while the implementation of a **diode bridge** at the PD interface ensures polarity independence. This design choice simplifies cabling operations and mitigates the risk of wiring errors during

installation and maintenance. Figure 9 below presents a PoE wiring for FTI.

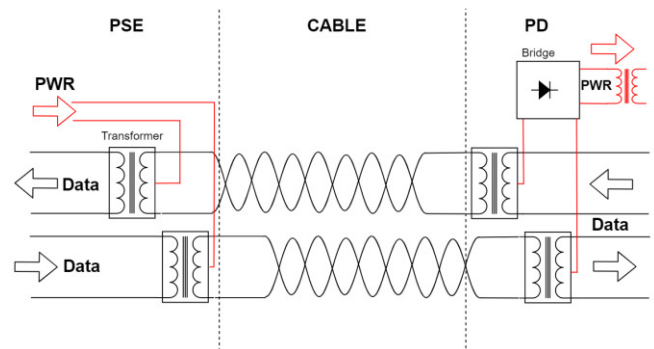


Figure 9 : PoE 10/100Mbits/s wiring for FTI

Passive signature

The solution is based on passive PoE, where the power sourcing equipment continuously applies a fixed voltage without performing an IEEE-type signature negotiation. This approach ensures a consistent, **deterministic** power-on behavior of the acquisition modules, which is critical for flight-test applications and is more resilient to abnormal situation.

Daisy-chain topology

A daisy-chain topology is used, in which each PoE-capable acquisition unit receives power and data on one port and passes them to the next unit downstream. This reduces the number of cable runs from the power source and the amount of cabling routed through the test vehicle, lowering both **weight** and mechanical/electrical intrusiveness. **Thermal** management is also positively impacted, since the heat load of the powered units is distributed along the chain rather than concentrated in a single location, enabling a more homogeneous thermal profile in critical aircraft zones.

XMA as an enabling family for remote acquisition

The XMA family illustrates the remote-module approach for airborne FTI: ultra-compact, highly rugged cores accept a wide portfolio of analog, digital and specialized modules (recorder, GNSS receiver, Wireless gateway, on-board processing or telemetry transmitter, etc.), providing high channel density per volume and state-of-the-art measurement accuracy for harsh environments. XMA's mechanical form factor, module interoperability and environmental hardening (wide temperature, shock, vibration, fluid proof and EMI/EMC compliance) make it particularly suited to distributed telemetry and remote acquisitions where space and protection are constrained. Its integrated network capability (Ethernet connectivity, UDP output, merging modules and

standard synchronization) supports both onboard recording and telemetry transmission, enabling system architectures that blend local recording, processing and networked streaming with centralized supervision. Figure 10 below presents an XMA stack.



Figure 10 : XMA stack

XMA-SOLO spreads XMA stack into PoE remote unit

XMA-SOLO represents a new concept born from the combination of the XMA modular architecture and Power over Ethernet. It is a compact, autonomous “holder” that can accommodate any XMA-module from the portfolio, such as analog acquisition, recorder, GNSS receiver, Wireless gateway, on-board processing or telemetry transmitter remaining fully compatible with the larger XMA-based network. Thanks to PoE, XMA-SOLO receives both power and Ethernet connectivity over the same cable, enabling precise synchronization via IEEE-1588 Precision Time Protocol (PTP) and seamless integration with other XMA stack and remote units, with no need for separate power or timing infrastructure. The module keeps the same mechanical / electrical interfaces (mounting, power, data, synchronization,...), firmware and configuration / monitoring behavior as larger XMA stacks. Managed through the standard eZ software suite and the Management/Control Console, so that whether deployed as an autonomous remote node or as a regular stack within the network, it delivers identical measurement integrity, deterministic timing and centralized supervision. Furthermore, XMA-SOLO is daisy-chainable, it offers 2 PoE ports so multiple units can be connected in series over the same Ethernet backbone, simplifying cable routing, reducing the number of switch ports needed and enabling instrumental growth capability. Figure 11 below presents an XMA-SOLO that is composed of 2 parts, the holder (XMA-DOK) and an analogue acquisition unit (XMA-ANA).



Figure 11 : XMA-SOLO : ~30 x 50 x 100mm

Benefit in terms of FTI cabling

Considering this new capability, the following sections study the benefit in terms of FTI cabling. The following models are defined to compare the weight impact between a **Remote** architecture and an **Ultra-remote** architecture with 8 sensors.

Architecture model

The remote configuration consists of a base stack composed of one Power Supply (PWR), one ANalog Acquisition unit (ANA), and one Computer Processing Ethernet unit (CPE). 8 sensors are installed x meters from the base stack. Each sensor interface uses one differential pair for excitation and one differential pair for measurement therefore the interconnection harness requires 16 (8 x 2) shielded pairs.

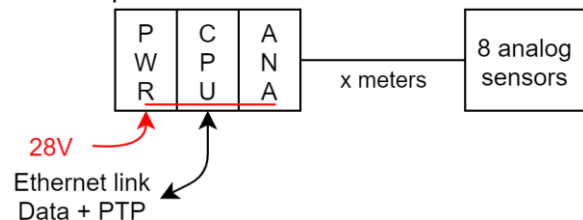


Figure 12 : Remote architecture model with 8 sensors

The same model can be extended by adding an additional set of 8 sensors, resulting in a total of 16 sensors, installed x meters from the first sensor set.

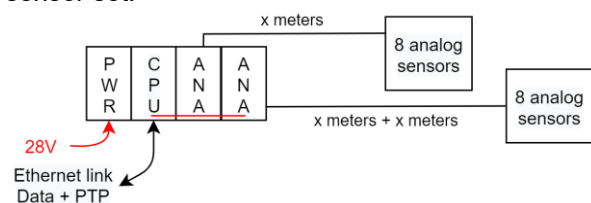


Figure 13 : Remote architecture model with 16 sensors

Ultra-Remote architecture model

The ultra-remote configuration consists of a base stack composed of one Power supply, one PoE injector, and one Computer Processing Ethernet unit. A remote stack, composed of one XMA-SOLO and one ANalog Acquisition unit, is installed X meters away from the base stack. The interconnection harness between the base stack and the remote stack requires only 2 shielded pairs. The 8 sensors are installed in close proximity to the remote stack.

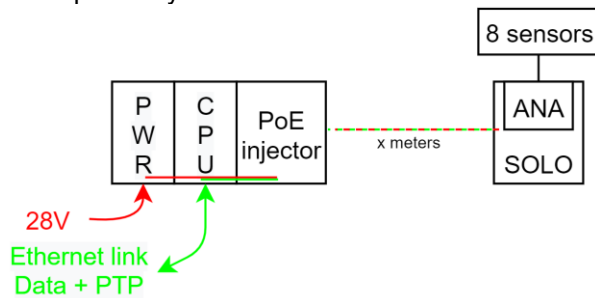


Figure 14 : Ultra-Remote architecture model with 8 sensors

The same model can be extended by adding an additional set of 8 sensors, resulting in a total of 16 sensors, installed at a distance of x meters from the first sensor set.

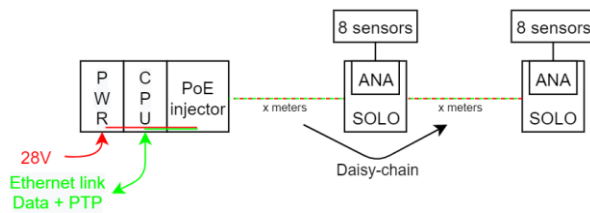


Figure 15 : Ultra-Remote architecture model with 16 sensors

Equipment differences between architectures

The main equipment differences between the remote and ultra-remote architectures are summarized below:

Function	Equipment	Remote Architecture	Ultra-Remote Architecture
Power supply	XMA-PSI	1	1
Analog Acquisition unit	XMA-ANA	1 located in the base stack	1 located in the remote stack
Processor ethernet capable unit	XMA-CPE	1	1
SOLO	XMA-DOK	None	1
PoE Injector	XMA-POE	None	1
Sensor location	-	X meter away from base stack	Close to the ultra-remote stack
Interconnection cable	-	16 shielded pairs	2 shielded pairs
Power / data transmission	-	Dedicated wiring	Combined through PoE for FTI

Table 1 : Equipment Differences Between Architectures

Figure 16 shows the **saving** between the two topologies for configurations with 8 and 16 sensors. Considering the commonly use of the shielded AWG#24 wires, as soon as the sensor set is located more than 1 meter away from the base stack, the remote architecture using PoE technology becomes significantly more advantageous solution in terms of weight. At a distance of 5 meters, the weight reduction achieved with the remote architecture is 2.3 kg for the 8 sensor configuration and 7.9 kg for the 16 sensor configuration. At 10 meters, the weight reduction increases to 5 kg for 8 sensors and 16.5 kg for 16 sensors.

Although the remote architecture requires additional equipment, such as an XMA-SOLO (~250g) module and a PoE injector (~110g), it enables a significant reduction in harness weight.

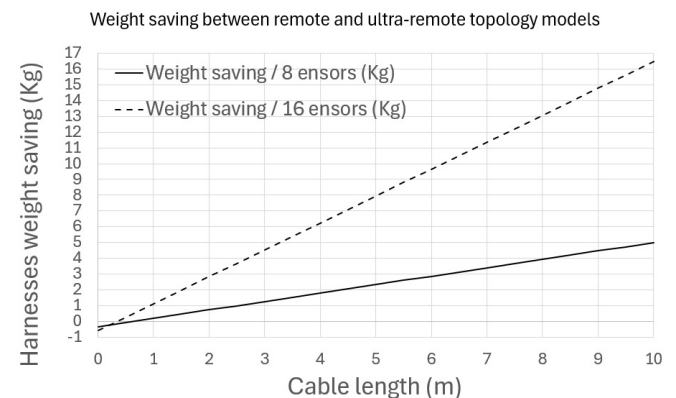


Figure 16 : Weight saving between remote and ultra-remote topology models

Flexibility and last-minute measurement integration

In the event of late integration of additional measurements, the remote architecture provides increased flexibility. An XMA-SOLO module associated with an XMA-ANA can be rapidly added to the system.

As the PoE implementation of the XMA-SOLO is based on the IEEE802.3 standards, other PD can be connected to it. As such the SAFRAN microMA DAU, which provides a compact low-Size-Weight-and-Power (SWaP) acquisition capability. For configurations requiring fewer than four additional measurements, the microMA equipped with the PoE option remains fully compatible with the XMA environment, enabling a near plug-and-play deployment within the FTI architecture. (Figure 17).

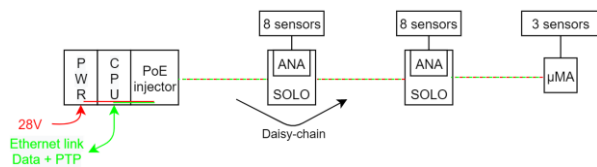


Figure 17 : Flexibility and Last-Minute Measurement Integration

Getting more with XMA-SOLO

Tomorrow's FTI architectures can evolve toward networks of small independent units, such as XMA-SOLO, being not only dedicated to acquisition.

XMA-SOLO + wireless module:

A quick add-on of a wireless FTI Ultra-Remote gateway can be easily achieved by docking a Wireless module (XMA-WLS) in an XMA-SOLO. This allows to implement a wireless "hop" in the FTI architecture where cables are prohibited (e.g. pressurized - unpressurised transition, instrumentation of moving parts,...)

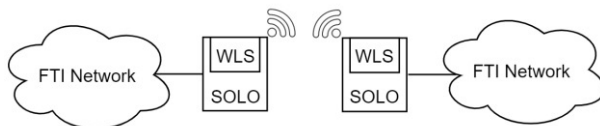


Figure 18 : Ultra-Remote FTI gateway

XMA-SOLO + recorder module:

A quick add-on of a standalone FTI Ultra-Remote recorder can be easily achieved by docking a Recorder module (XMA-RCD) in an XMA-SOLO. This creates a small device easily integrated with its recording media being easily accessible (e.g. cockpit, avionics bay,...)

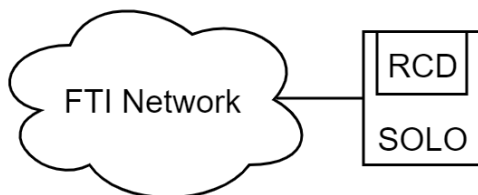


Figure 19 : Ultra-Remote FTI recorder

XMA-SOLO + On-Board Processing module:

A quick add-on of a wireless FTI Ultra-Remote on-board processing can be easily achieved by docking an On-Board Processing module (XMA-OBP) in an XMA-SOLO. This extends the processing and user-customization capabilities including the local command and control of third-party devices via the various input/output interfaces available (e.g. GPIO, Serials, Ethernet,...)

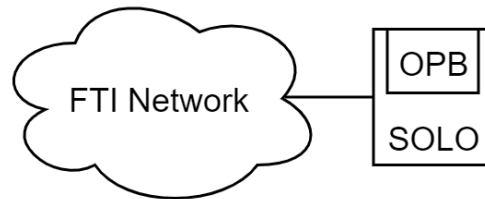


Figure 20 : Ultra-Remote On-Board Processing

Conclusion

The combination of modular DAUs and PoE extensions unleashes new capabilities for next-generation FTI architectures. The ultra-remote topology, by relocating DAUs closer to the sensors, significantly reduces dedicated power and signal harnessing, resulting in lower system weight, reduced aircraft intrusiveness, and decreased integration effort and installation cost. In addition, late-stage instrumentation changes and measurement extensions are greatly simplified, enabling unprecedented deployment agility in flight-test operations.

References

- [1] en.wikipedia.org/wiki/Power_over_Ethernet
- [2] www.belfuse.com/resource-library/blog/power-over-ethernet-explained-how-poe-powers-data-and-devices
- [3] www.fastcabling.com/2022/01/28/utilize-power-over-ethernet-with-poe-injector
- [4] ipvm.com/reports/vivotek-poe-extender-cameras