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AEM Testing Innovation

Assuring Cabling Infrastructure Readiness:

Advanced Cable Testing for Standard and Single-Pair Ethernet

Steve Cowles, RCDD/NTS

CINI4.0 Conference Day
16/06/2022, Gent

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We Are AEM

We Are Testing Innovation

AEM's mission is to provide the most comprehensive semiconductor and electronics test solutions based on the best-in-class technologies, processes and customer support.

Test Cells Solutions

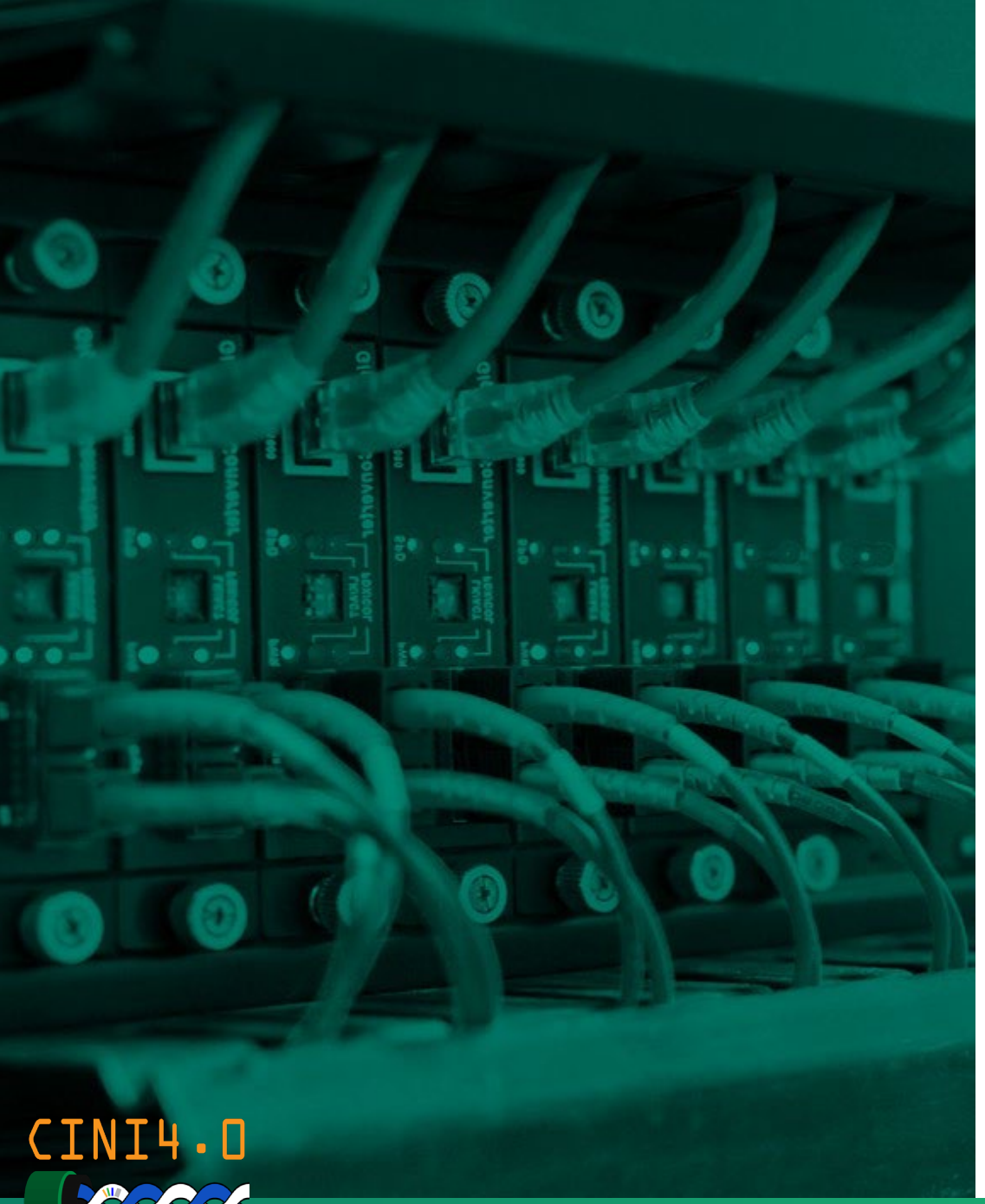
System Level Test Solutions >

Wafer Level Test Solutions >

Instrumentation

ATE Solutions >

Test & Measurement Solutions >



Presentation Agenda

- Cable Certification Testing basics
  - Required, optional and informational test parameters
  - Common causes of test failures
  - Additional testing considerations
- Single Pair Ethernet
  - Environments
  - Standards
  - Topology
  - Power over Single Pair (PoDL and SPoE)
  - SPE testing

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Cable Certification Testing Basics

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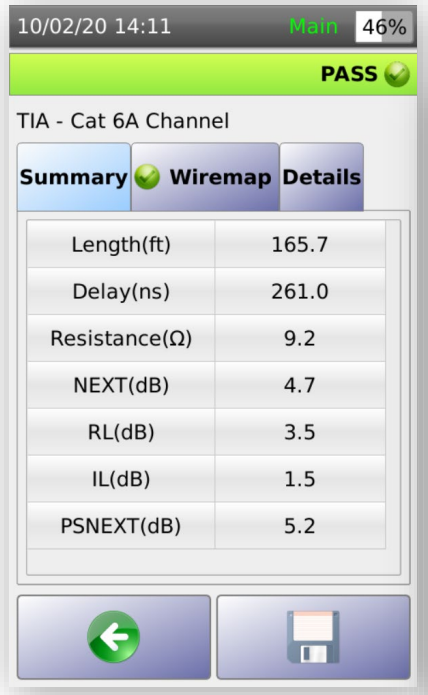
Cabling Certification Test Parameters

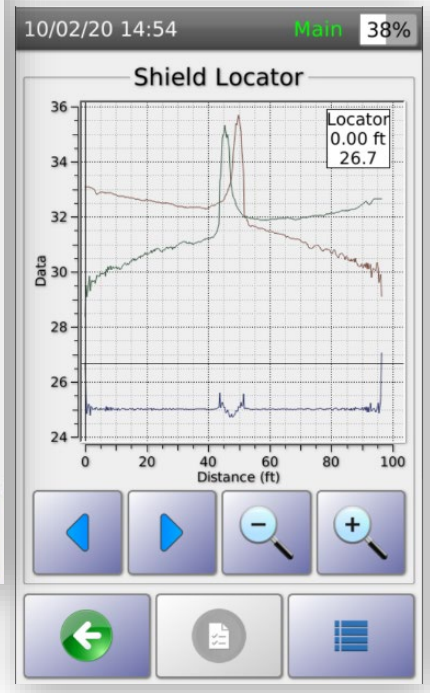
Pass/Fail Criteria

- Length
- Delay
- Delay Skew
- Loop Resistance
- Insertion Loss
- Return Loss
- NEXT
- PSNEXT
- ACRF
- PSACRF

Informational

- Network Compliance
- Resistance Unbalance P2P*
- Resistance Unbalance in Pair*
- TCL*
- ELTCTL*
- ACRN
- PSACRN
- Impendence
- RL Locator TDR
- NEXT Locator TDR
- Shield Locator TDR

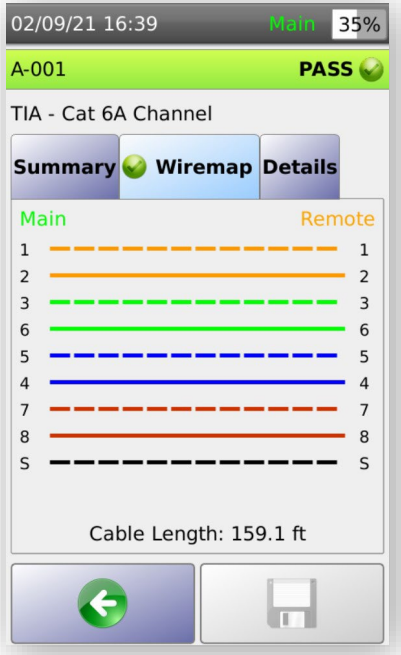


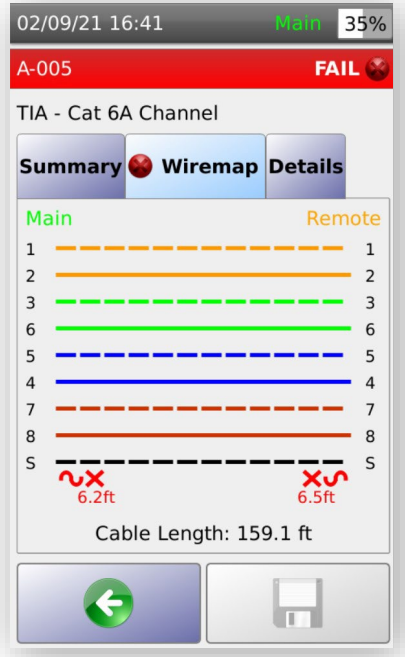


* - Parameter can be included as pass/fail using alternate test limits

Wiremap

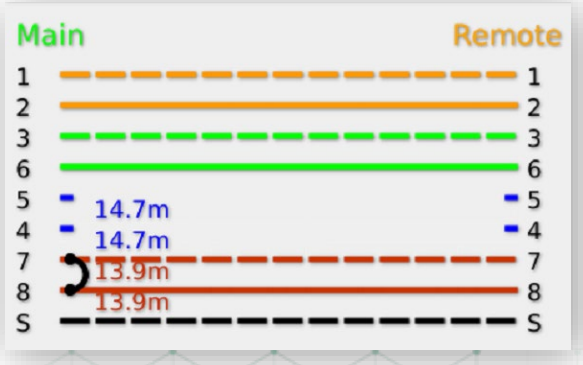
- Wiremap shows
  - Pair continuity
  - Opens
  - Shorts
  - Crossed pairs
  - Split pairs
  - Shield continuity (if applicable)
- Open – unconnected/unterminated wire, cut/broken wire
- Short – when two or more copper conductors have physical contact together, sometimes due to wire stripping error or defective insulation on conductors
- Crossed pairs – wire pairs are attached to a specified pair of pins at one end, but terminated to a different set of pins at the other end
- Split pairs – wires terminated to the connector pins specified for a single pair are split up through two separate pairs in the cable.



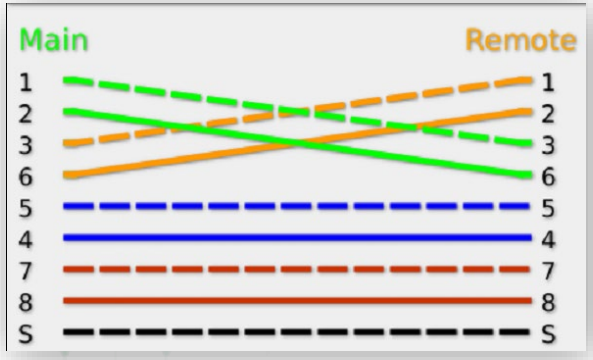


Shield Discontinuity

Open - 5/4 and Short - 7/8

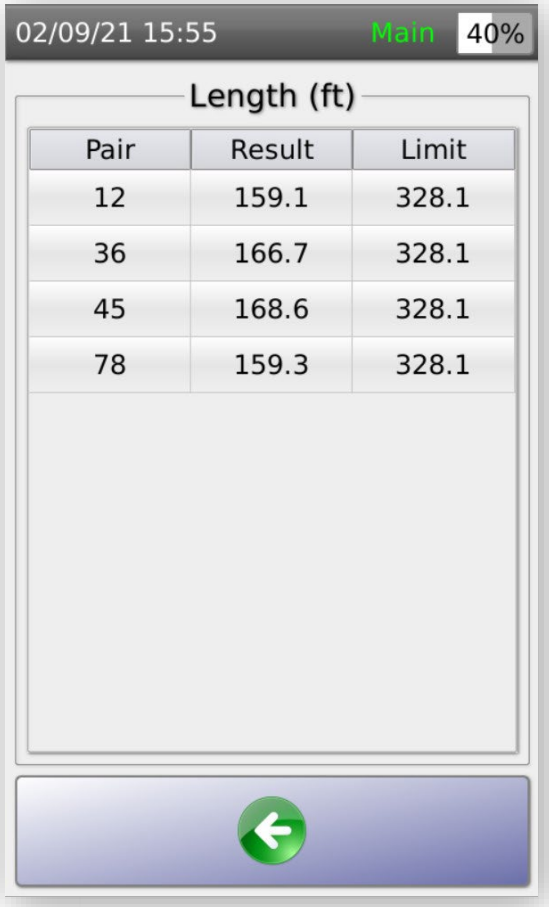


1/2 and 3/6 Crossed



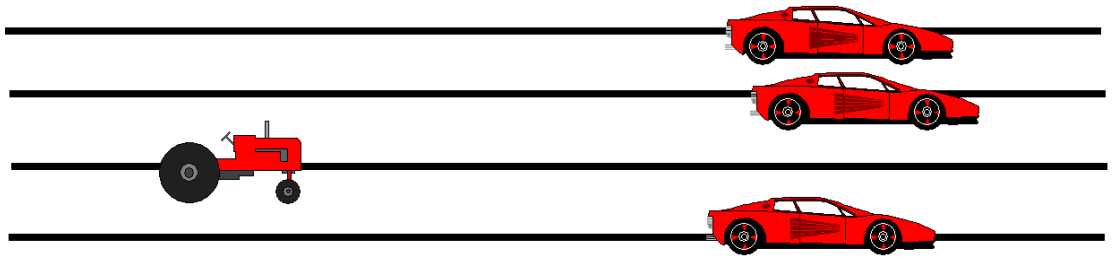
Length Measurement

- Most common failure due to incorrect NVP setting.
  - Nominal Velocity of Propagation - speed at which electrical signals travel through the cable
  - Expressed as a percentage of the speed of light
  - Use built-in cable library to avoid NVP-based length errors
  - Verify NVP value with cable manufacturer's documentation
- Length test for certification uses the shortest length of the 4 pairs, but all pairs are included in test details
- Standards allow for a 10% buffer in length measurement for pass/fail criteria



Propagation Delay and Delay Skew

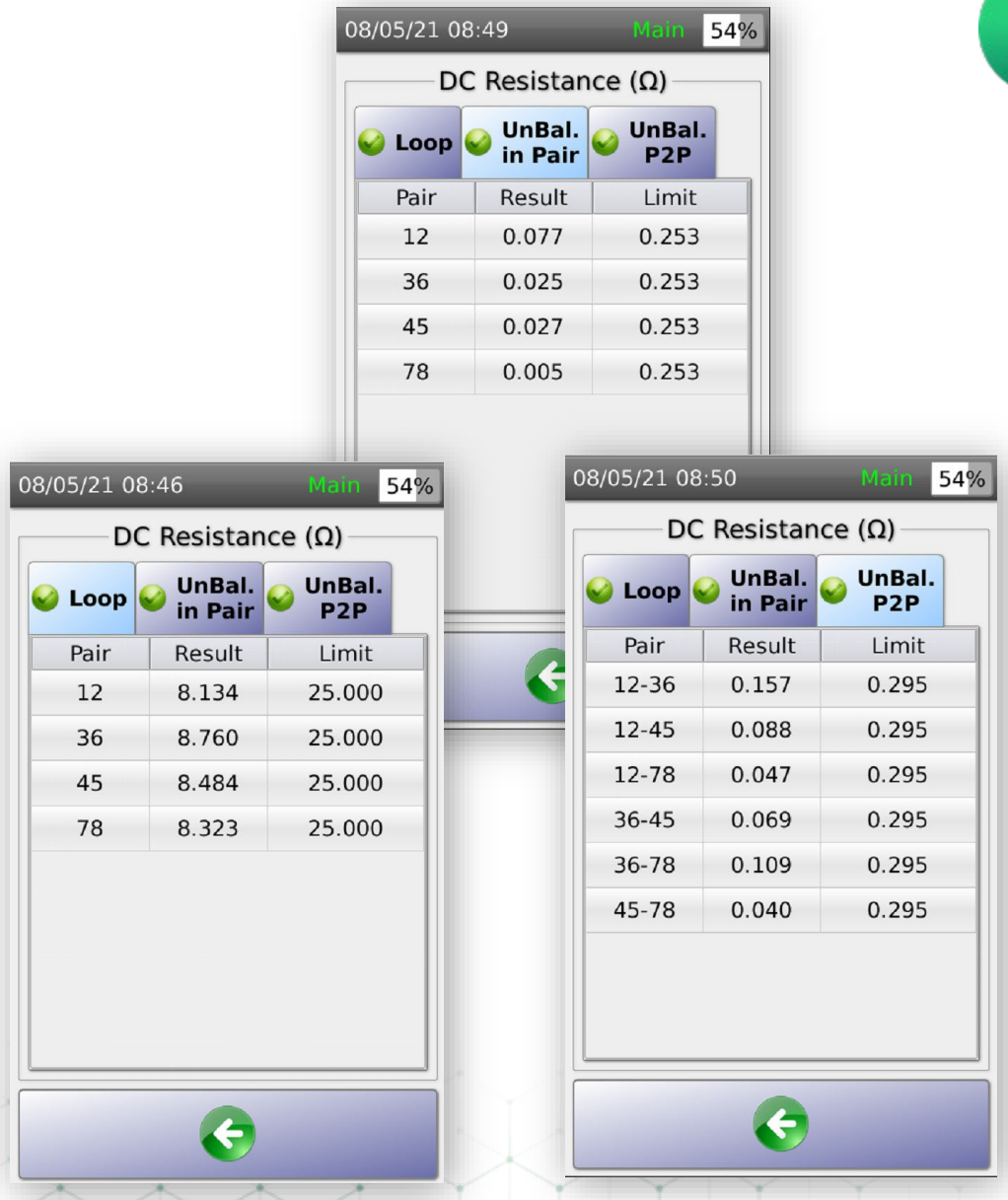
- Propagation Delay – the time required for a signal to travel from one end of the transmission path (cable pair) to the other
  - Most common cause of failure – length exceeds maximum allowed under the standard
  - Defective cable due to manufacturing deficiencies can also result in failure
- Delay Skew is the difference in propagation delay between any two pairs within the same cable sheath
  - Critical for Gigabit Ethernet and other application which use all 4 pairs
  - Most common cause of failure – cable damage or manufacturing problem
  - Substandard connection components or patch cords can also cause failure



3 + 1 Cable Skew

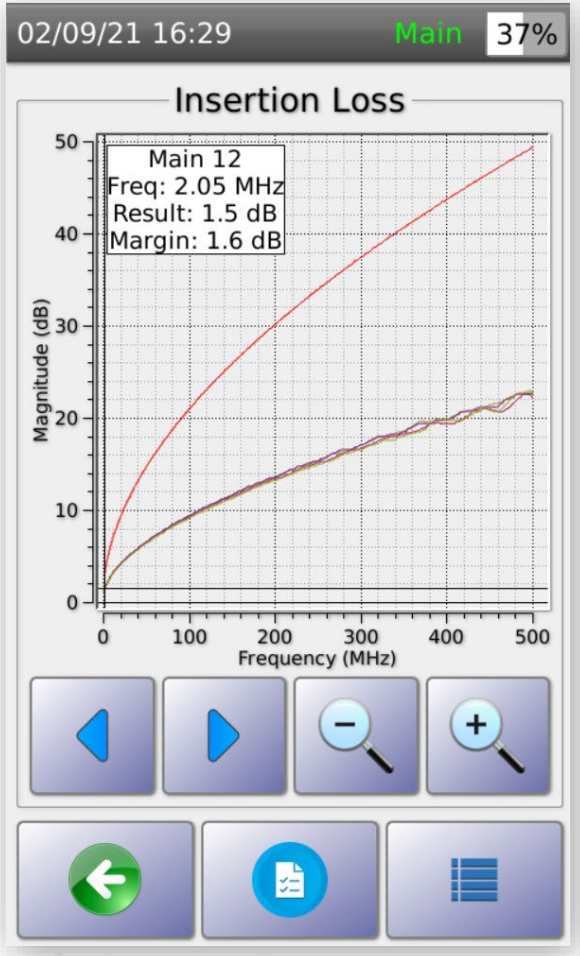
DC Resistance

- DC Loop Resistance
  - Round trip resistance measurement of the pair
- DC Resistance Unbalance In-Pair (not required)
  - Compares the resistance of each of the conductors in the pair
- DC Resistance Unbalance Pair-to-Pair (not required)
  - Compares the resistance of each pair to all other pairs
- As specified in ANSI/TIA-568.2-D and TIA TSB-184A D3.0
  - DC Loop Resistance for Cat3/5e/6/6A shall not exceed 25 Ohms
  - DC Resistance Unbalance <200mOhms or <3% of Unbalance in pair (750mOhms)
  - DC Resistance Unbalance between pairs <200mOhms or <7% of unbalance between pairs



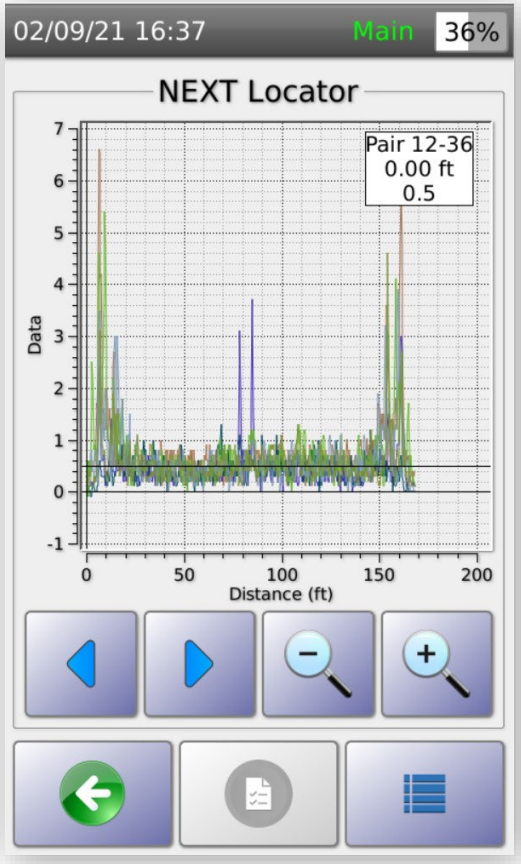
Insertion Loss (IL)

- Insertion Loss (aka attenuation) is the loss of power of a transmitted signal as it travels along the cable
- Result measured in decibels (dB)
- Increases with distance (length), temperature and frequency
- Failures
  - Most common cause is excessive length
  - Rarely seen in isolation, typically eliminated once other faults are corrected
  - Wrong wire gauge or category of cable can also be the culprit – cable under test may not be suitable for the application
  - Incorrect equipment patch cable (channel test) – patch cables are an often-overlooked cause of trouble
  - If IL failure is isolated to a single pair, it is likely a termination issue – try re-termination



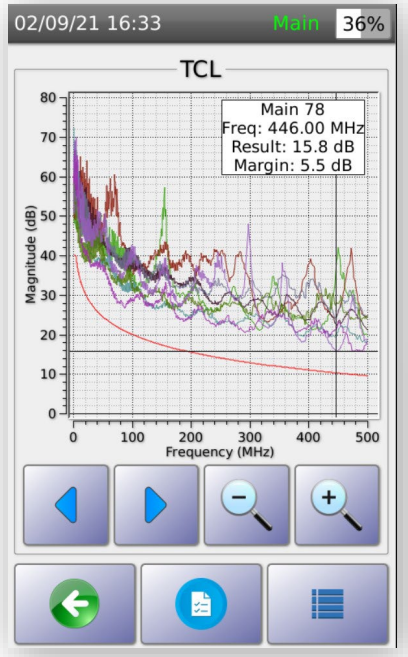
Near-End Crosstalk (NEXT)

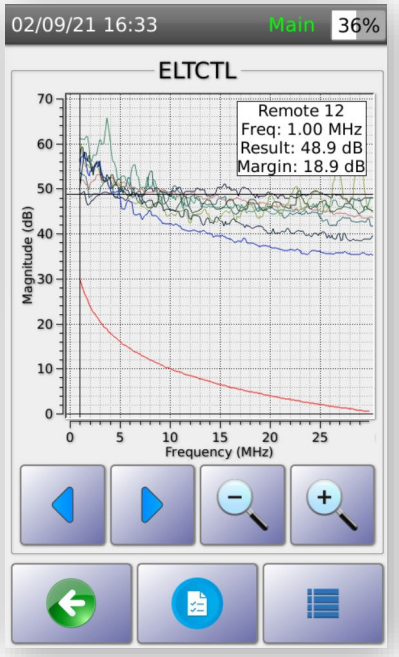
- NEXT is the unwanted signal coupling between pairs
- Measured at the end of the cable nearest transmission
- "Back-in-the-day" example – hearing other people conversing over a landline phone, hence the name "crosstalk"
- PSNEXT – the combined crosstalk on a tested pair from all other operating pairs, calculated using the results of other crosstalk measurements
- Failures
  - Mixed categories of cabling/termination hardware/patch cables
  - Improper termination
  - Split pairs
  - Incorrect/substandard components
  - Incorrect or defective test cables or test adapters
  - Excessive EMI in the environment
  - Excessive compression by cable ties or supports on cable bundles
  - Cable kinked/damaged during installation
  - Excessive force used when installing cable
  - Use NEXT Locator (TDR) to pinpoint location of crosstalk
  - Use visual inspection to check workmanship



TCL and ELTCTL (not required)

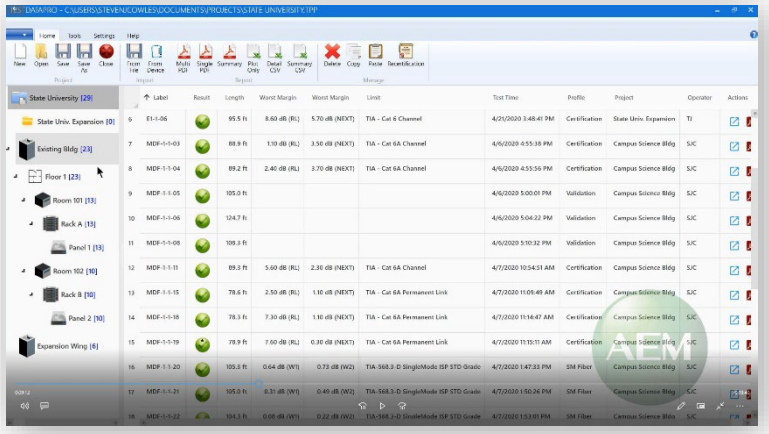
- TCL – Transverse Conversion Loss
- ELTCTL – Equal Level Transverse Conversion Transfer Loss
- Not required for field testing, these are done by the manufacturers to ensure conformance
- Signal noise is injected into the cable and the measurements indicate the level of noise immunity to show the cable will perform adequately in noisy environments such as external sources in an industrial environment or alien crosstalk from adjacent cables for 10GBase-T applications
- This is included as an optional test

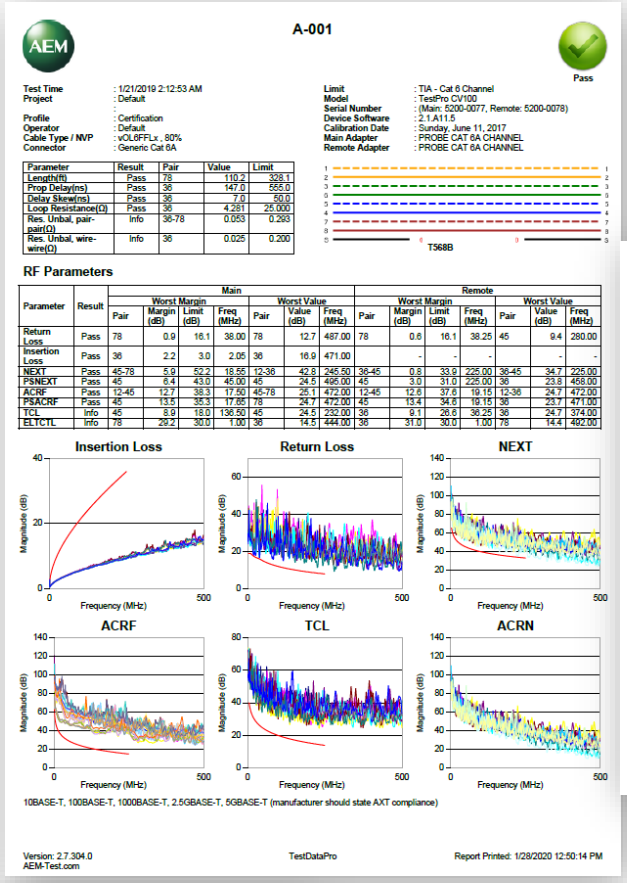


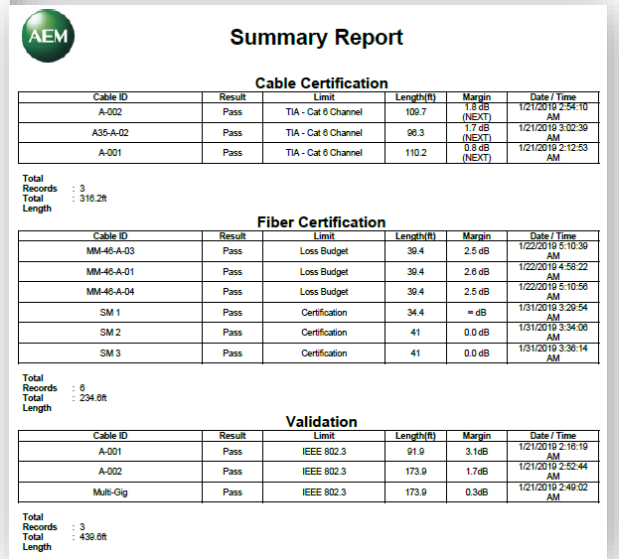


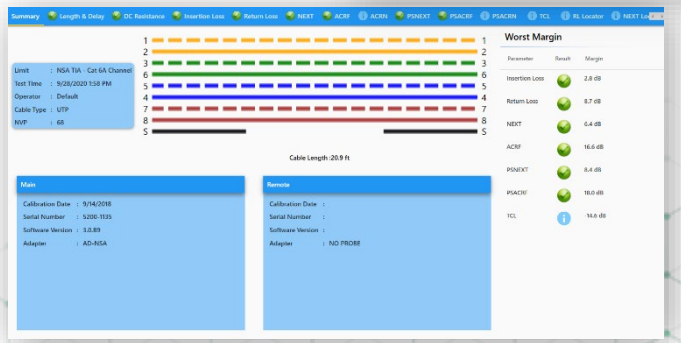
Test Documentation

- Provides the end customer a proof of quality
- Protects the installer
- Supports manufacturer's system warranty
- Includes complete test results, details about the test equipment used, test configuration and application compatibility



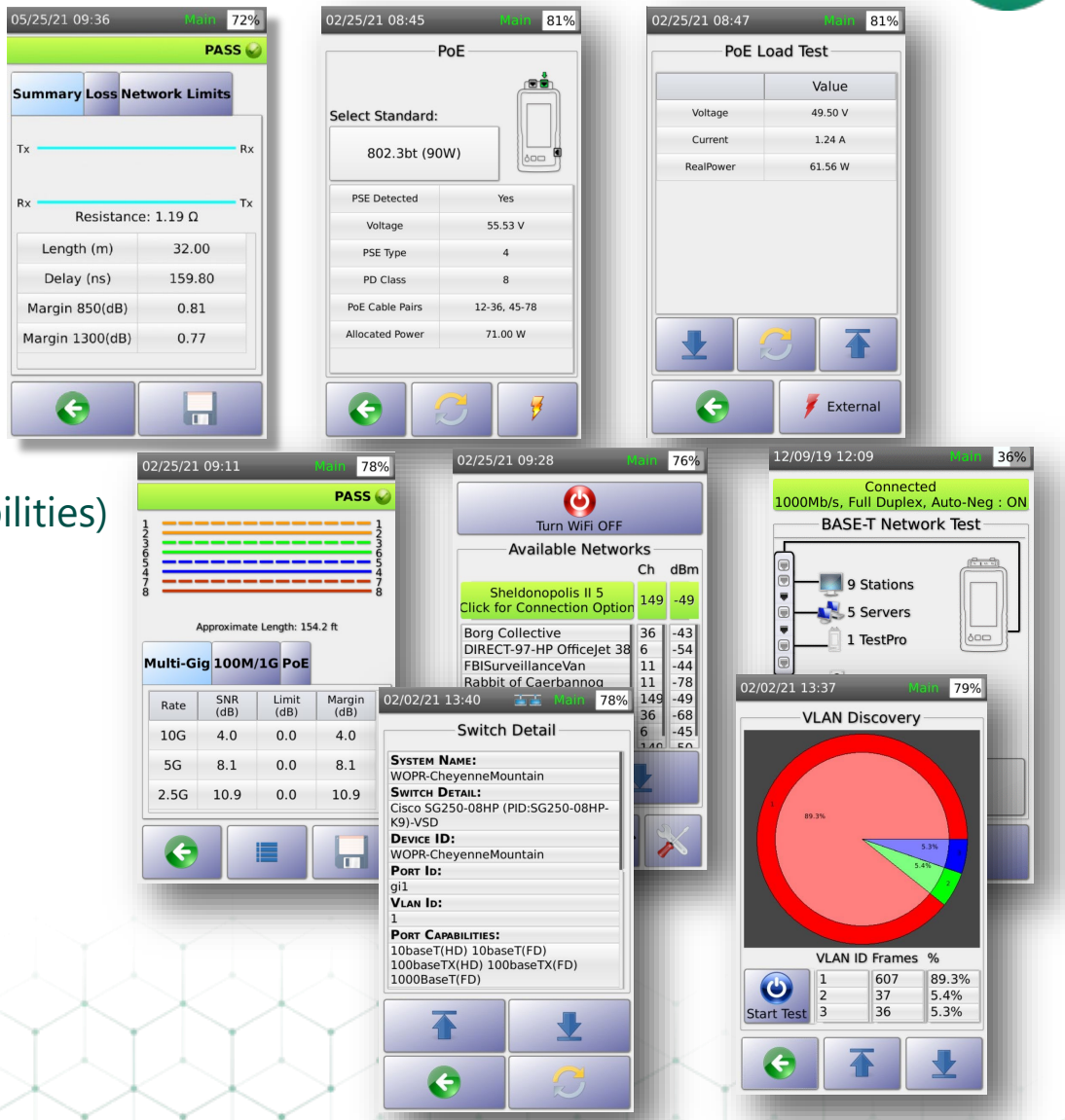






Other Testing Considerations – going beyond physical copper cable tests

- Fiber Optic Loss, including hybrid powered fiber
- PoE – Power Over Ethernet validation with true load test
- MultiGigabit SNR testing up to 10GigE data rates
- Network Connectivity Testing – wired/wireless
  - Discovery of IP/MAC addresses
  - Connection details (DNS, DHCP, subnet, etc)
  - Switch Detail (switch ID/make and model, port/VLAN/port capabilities)
  - Ping
  - Traceroute
  - SSID discovery and WiFi Signal Strength testing



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Single Pair Ethernet

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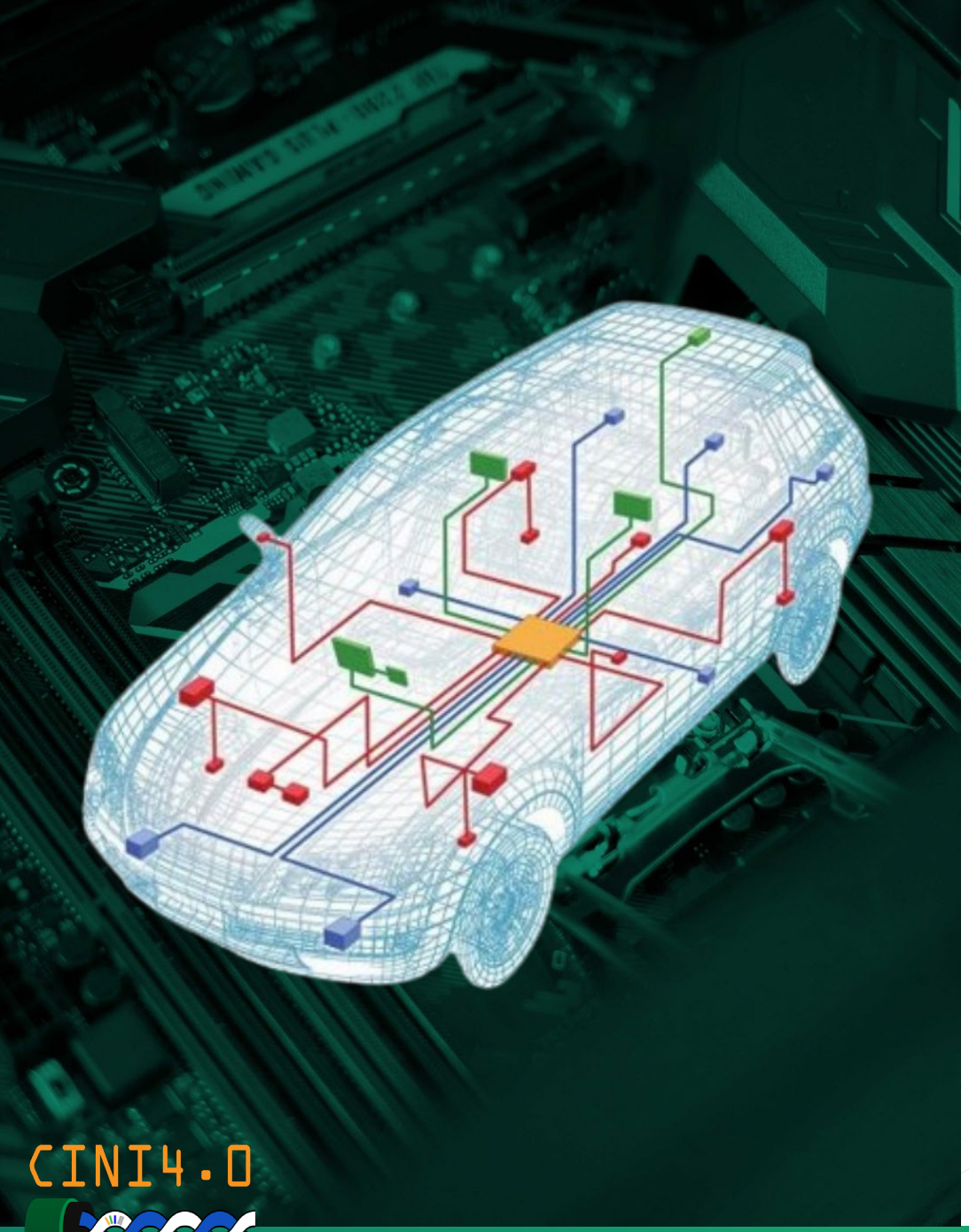


SPE Adoption – First Automotive

Automotive and Transportation Environments

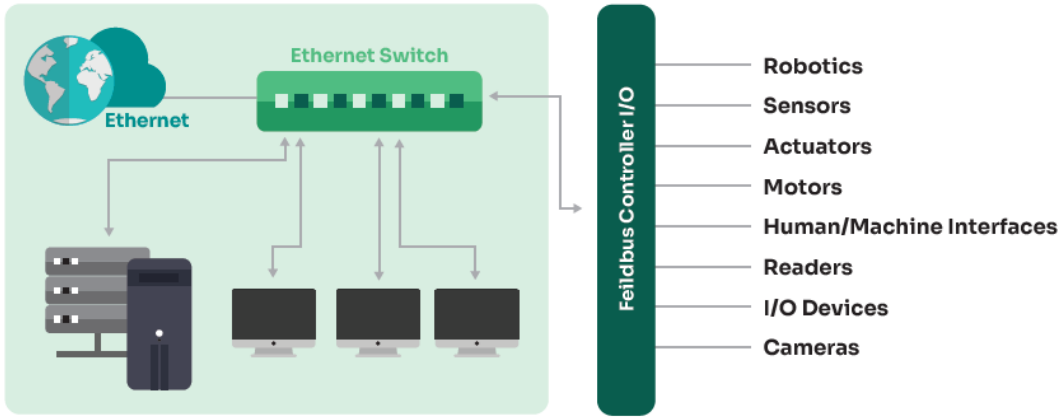
- 802.3bw-2015 – 100BASE-T1
  - 15 meters – 100Mbps
- 802.3bp-2016 – 1000BASE-T1
  - 15 meters – Cars, 1Gbps
  - 40 meters – Aircraft, Railway, Bus, Heavy Trucks, 1Gbps

Power delivery over one pair

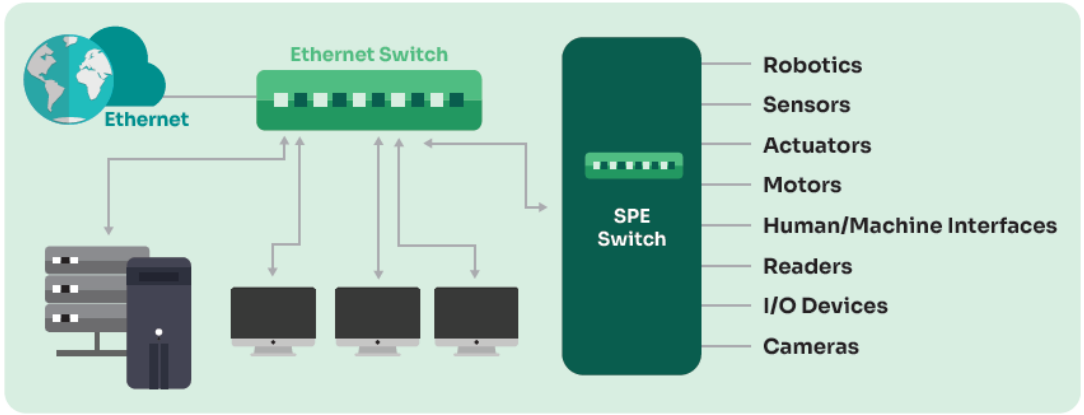
- 802.3bu-2016 – Power over Data Lines (PoDL)
  - Pronounced “poodle”
  - Also referred to as SPoE
  - Up to 52W of power

SPE Adoption | Then Industrial

Fieldbus Topology



Single Pair Ethernet Topology



The industrial Internet of Things (IIoT) is a major use case.

SPE can replace many instances of Fieldbus or other non-Ethernet automation networks.

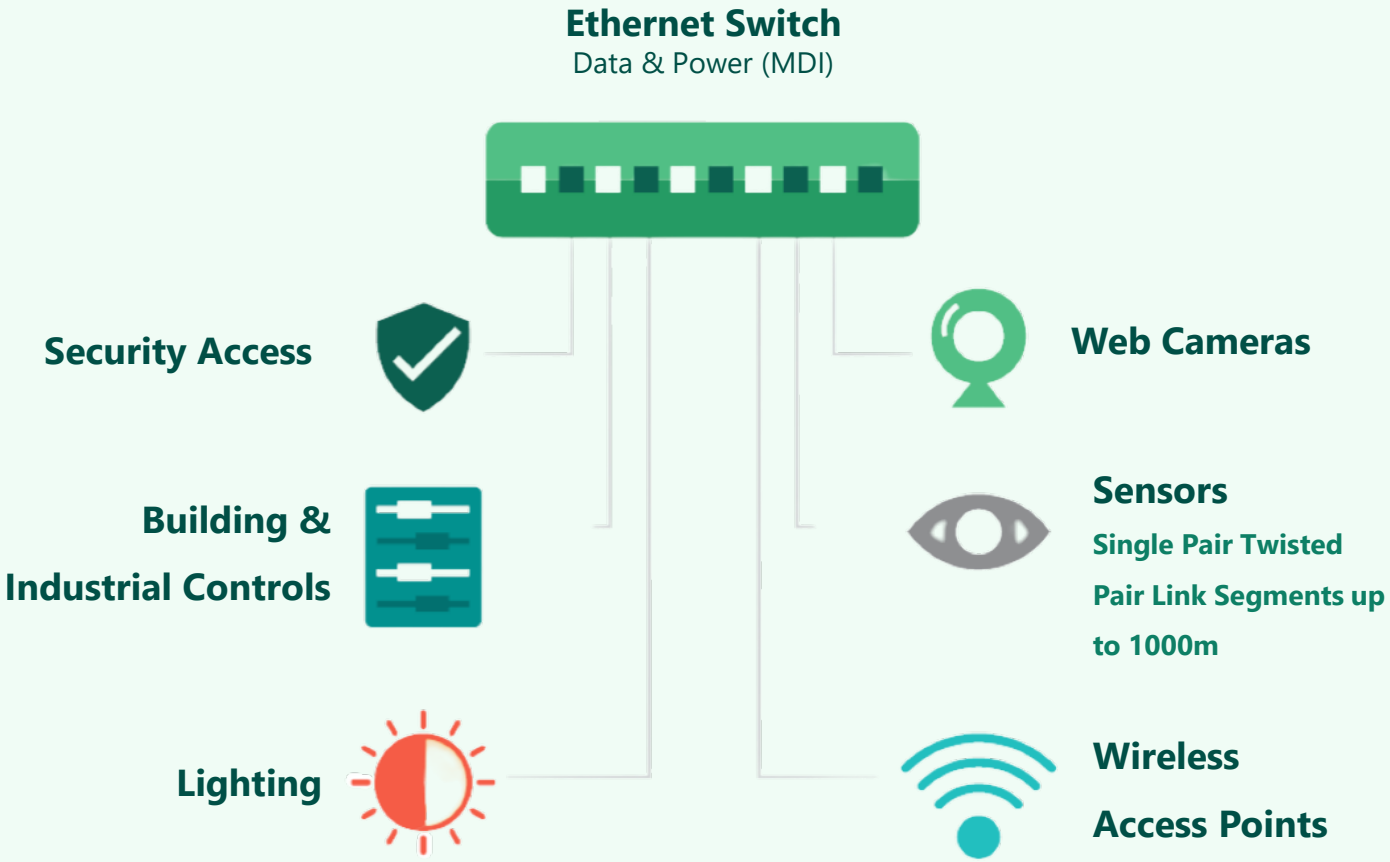
SPE is perfect for sensors and devices that need limited power and bandwidth but do require efficient, fast, reliable transmission.

On 18 AWG wire, 7.7W of power can be delivered over 1000m

Now | SPE is coming to a building near you

802.3cg

Single-Pair Ethernet 10Mbits/Sec and Power



Single Pair Ethernet General Topologies

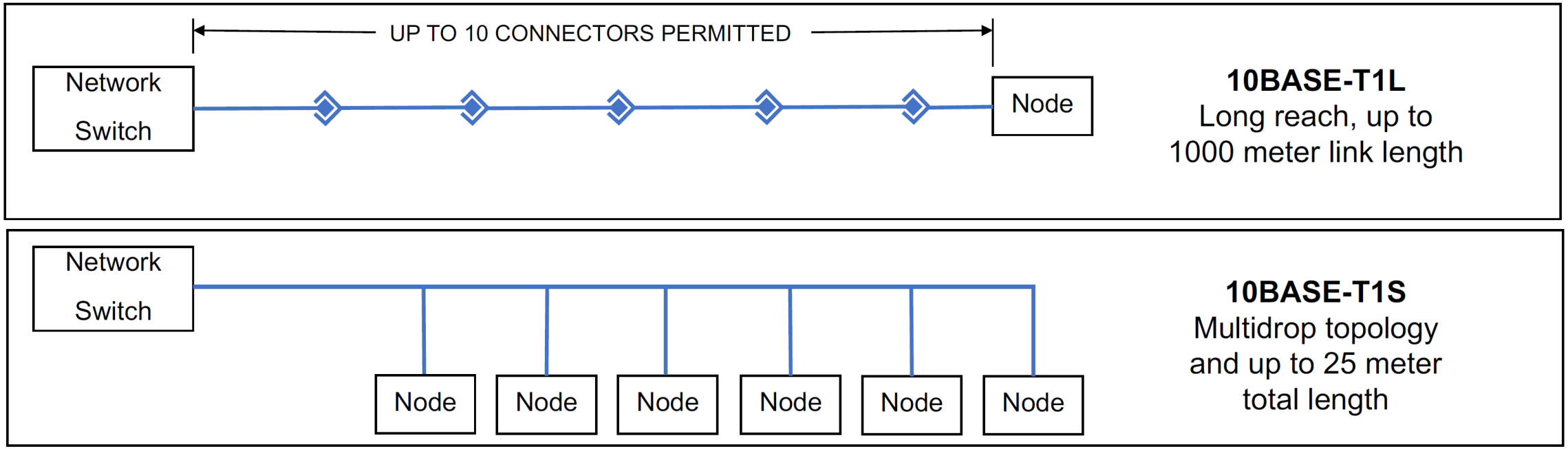
Network Switch

"closet end"

SPE connectors and media

Controlled Device

"device end"

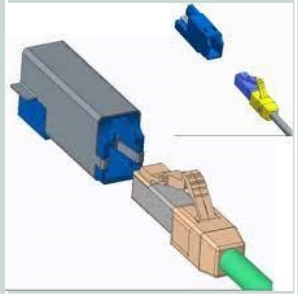
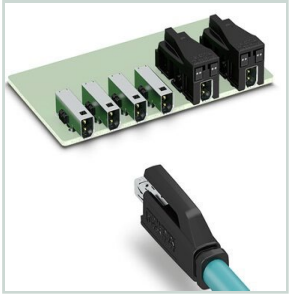


Source: TIA Single Pair Ethernet Consortium standards update Sept 2021

SPE Power Delivery (SPoE)

Distance	AWG	No. of Connectors	Max Power
1000m / 3280ft	18	10	7.7W
451m / 1480ft	18	10	20W
187m / 614 ft	18	2	52W
58m / 190 ft	23	2	52W

SPE Connector variants

	IEC 63171-1	IEC 63171-2	IEC 63171-3	IEC 63171-4	IEC 63171-5	IEC 63171-6	IEC 63171-7
							
Type	LC - Style	Rectangle	TERA 1P	Square	M8/M12	Rectangle/M 8/Push Pull	M12/Power
# Pairs	1	1	1/4	1	1/4	1	1
Company	CommScope	RdM, PxC, WM	Siemon	BKS	PxC, WM, RdM	Harting	PxC, TE

Source : ISO/IEC 63171

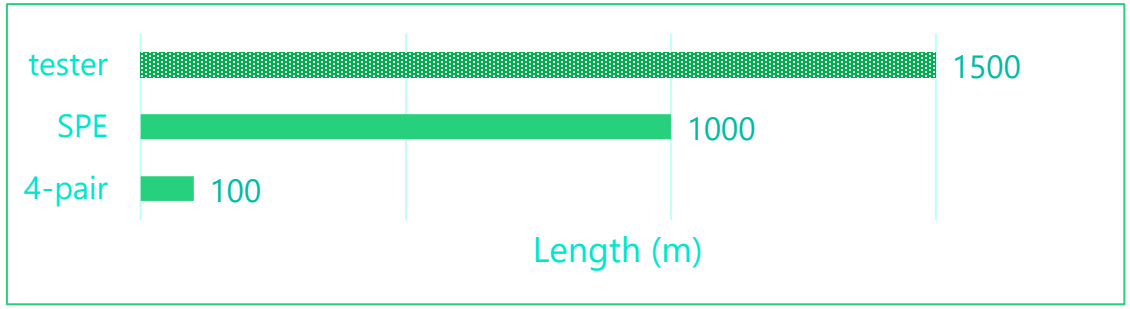
Single Pair Ethernet

Single Pair Ethernet Field Testing

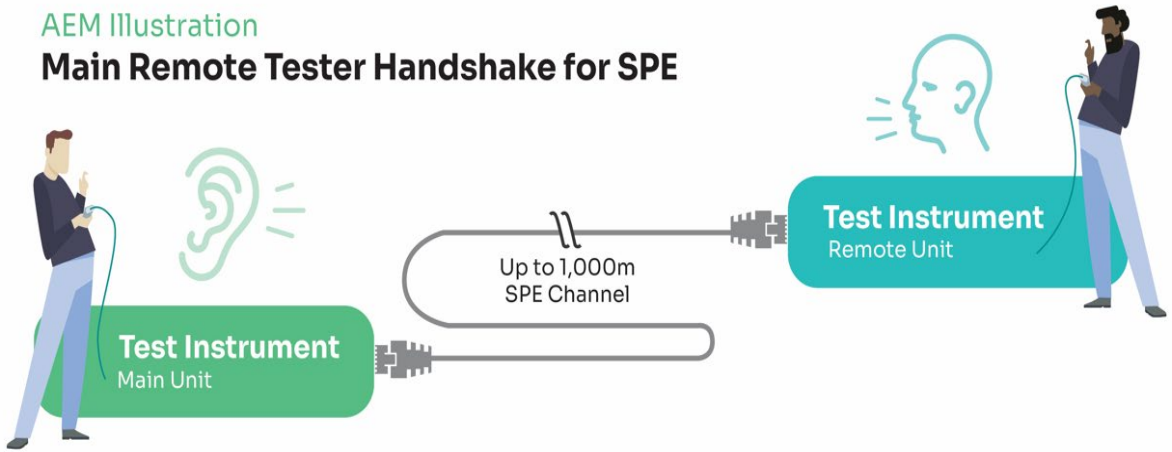
- ✓ Only when we can test an installation, can we be assured that it is all done correctly
- ✓ Field testing is an important piece in SPE rollout
- ✓ In next few slides, we review the current status of field testing SPE links

Single Pair Ethernet vs 4-Pair Cabling Test Requirements

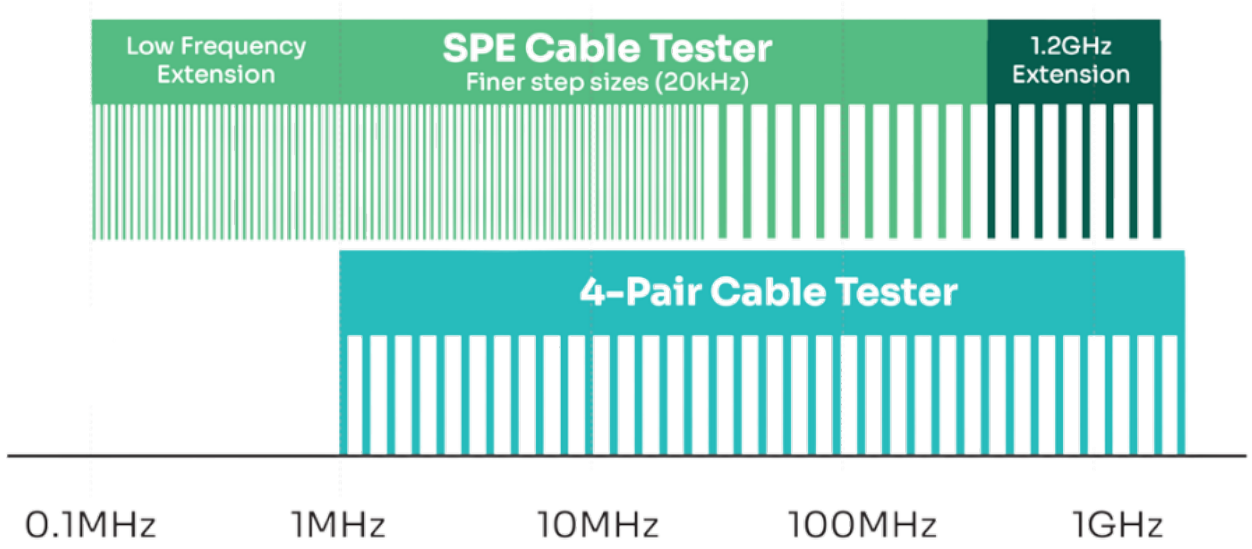
SPE cabling standard specifies 1,000m; but test instruments are expected to work with even longer link lengths (~1,500m)



Test equipment main and remote units must perform end-to-end synchronization and communication over long single-pair DUTs



Single Pair Ethernet vs 4-Pair Cabling Test Requirements



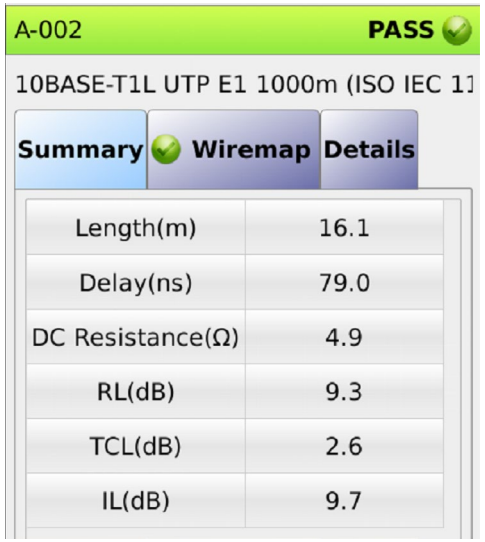
Lower range of frequencies
extended to 0.1MHz instead of 1MHz

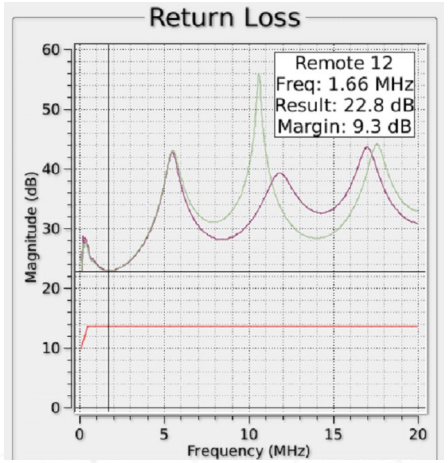
Finer frequency resolution
to locate faults over longer lengths

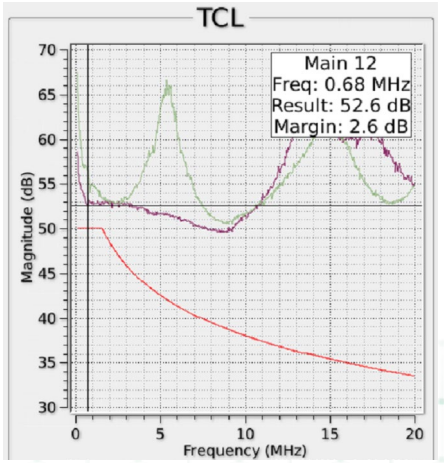
- **20kHz (TBD) minimum step size compared to 150kHz for 4-pair cable tester**

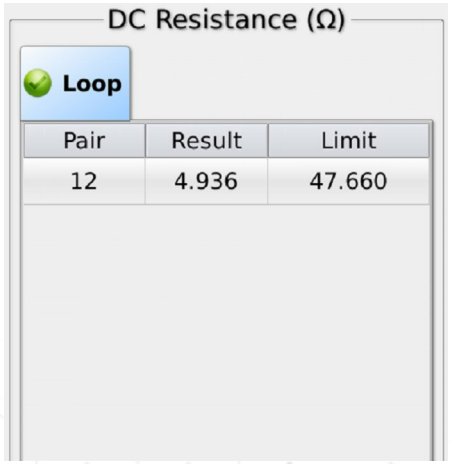
Single Pair Ethernet Standard parameters from Field Testing perspective

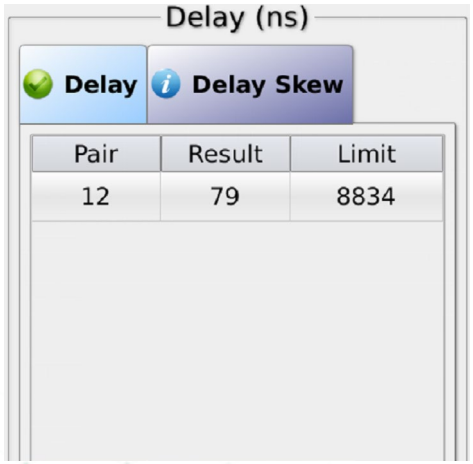
	Parameter	IEEE 802.3cg	ANSI/TIA-568.5
1	Insertion Loss	✓	✓
2	Return Loss	✓	✓
3	TCL (UnShielded)	✓	✓
4	DC Loop Resistance	✓	✓
5	Delay	8834ns (AWG 14 @ 1589m)	5559ns (AWG 18 @ 1000m)



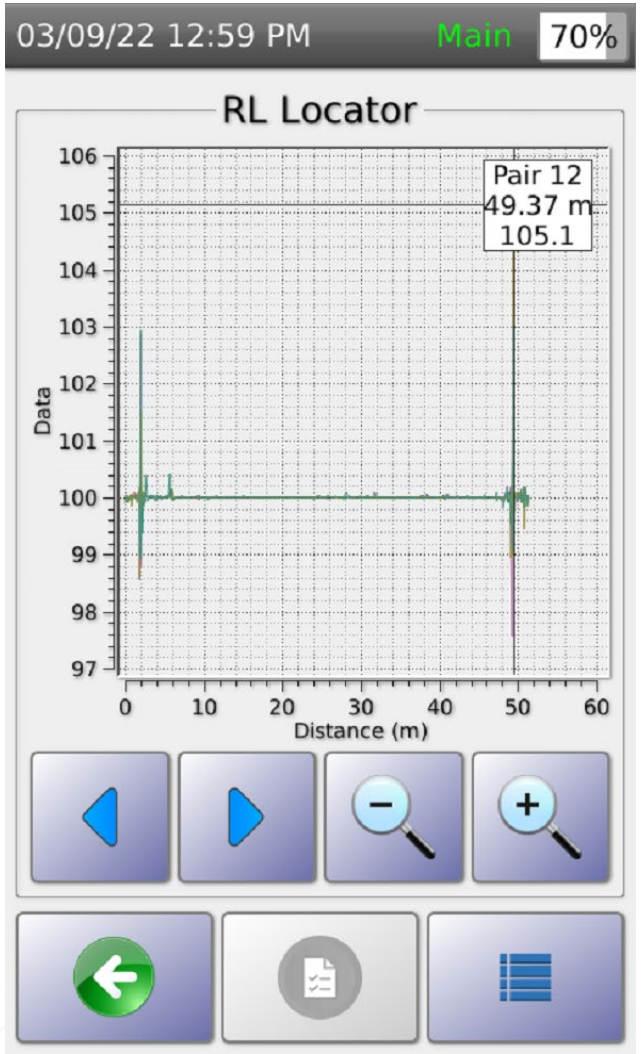


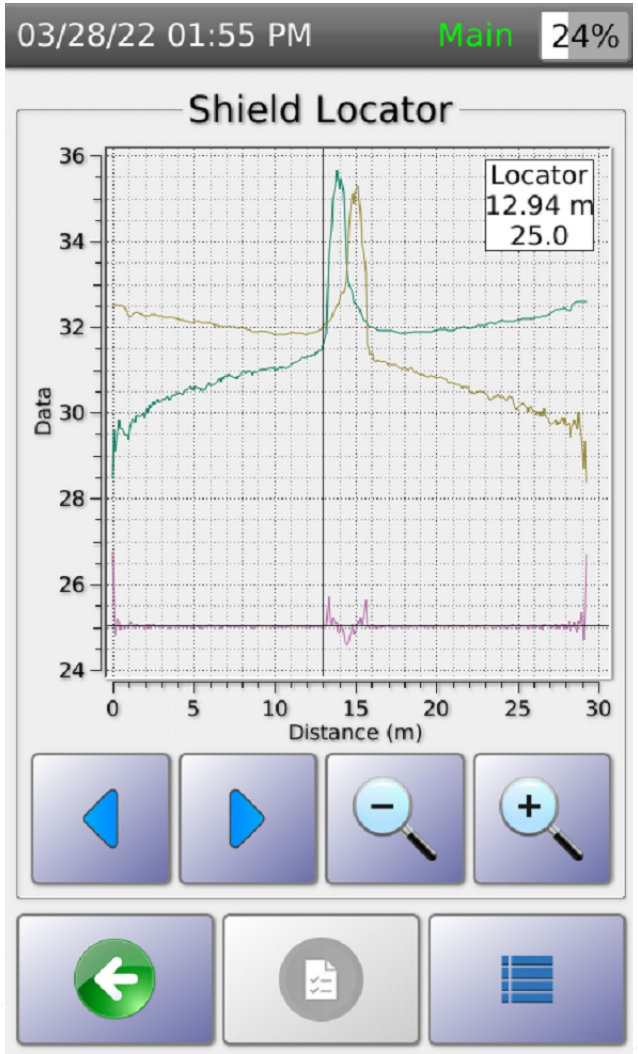






Troubleshooting Tools – locate the point of failure





Connectivity & DC test for SPE

Shield Continuity Measurement

End-to-end shield presence test

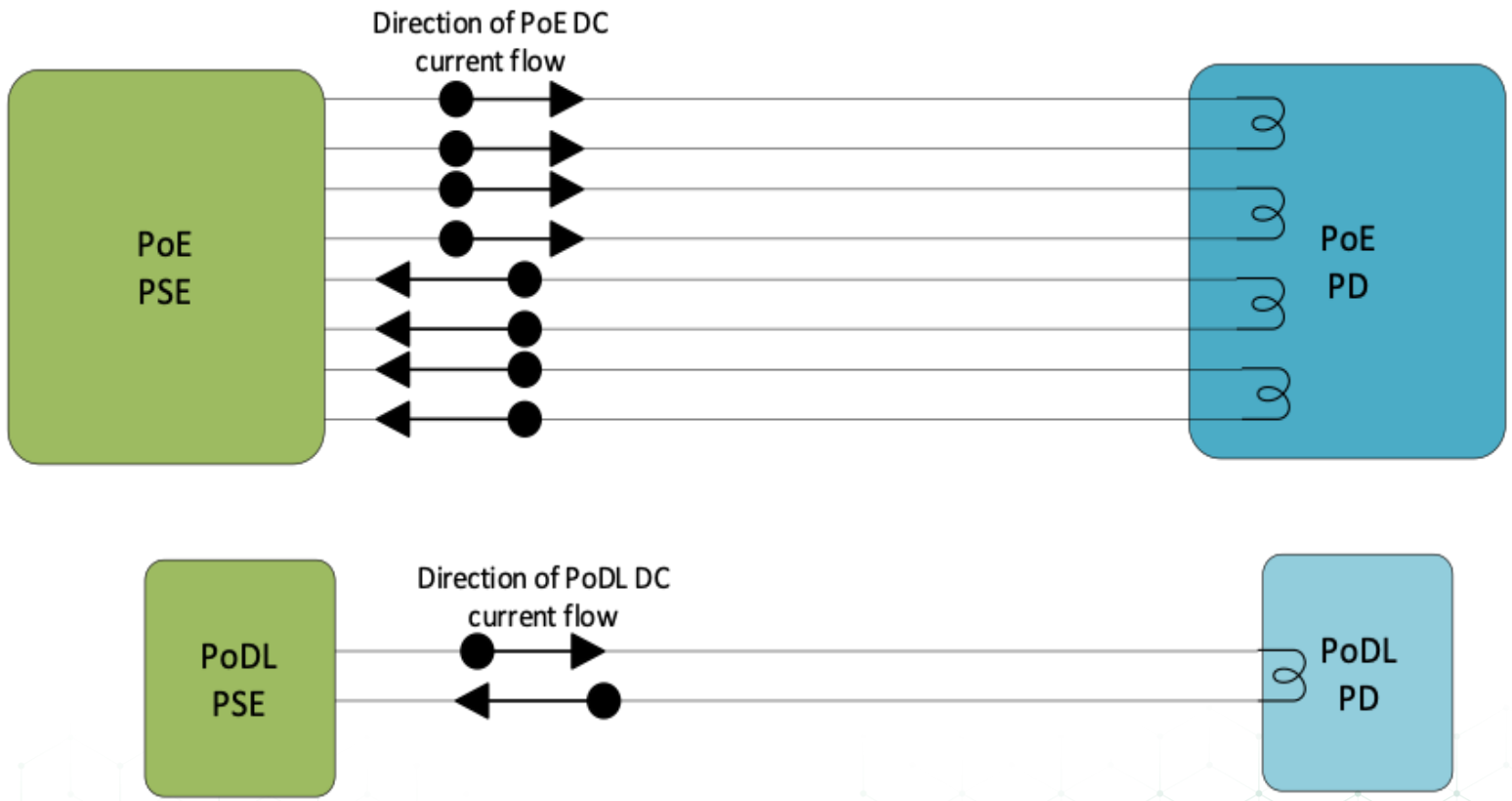
Resistance Measurement

DC loop resistance

Resistance Unbalance Measurement

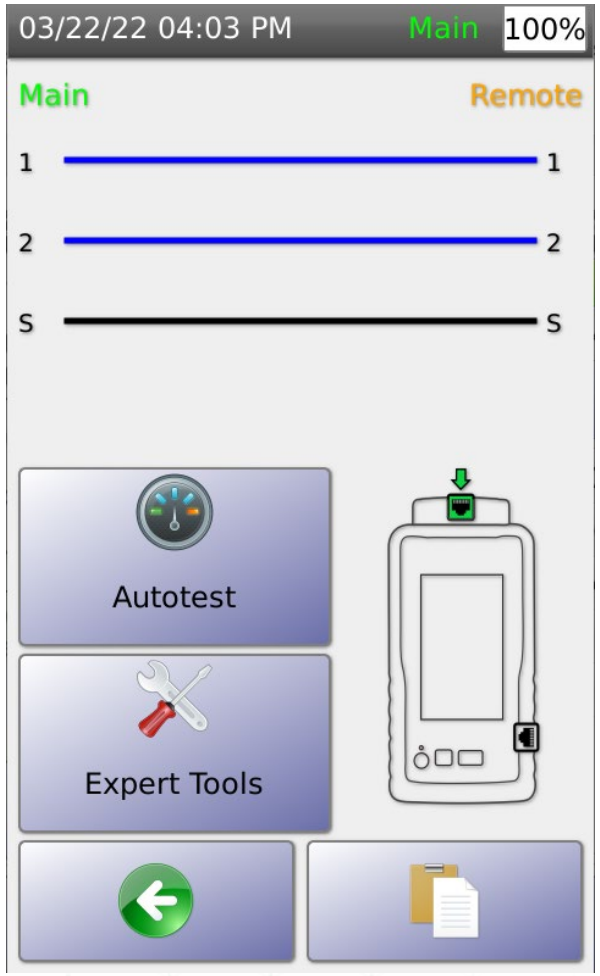
Only shielded SPE cables can be tested for resistance unbalance between two signal wires

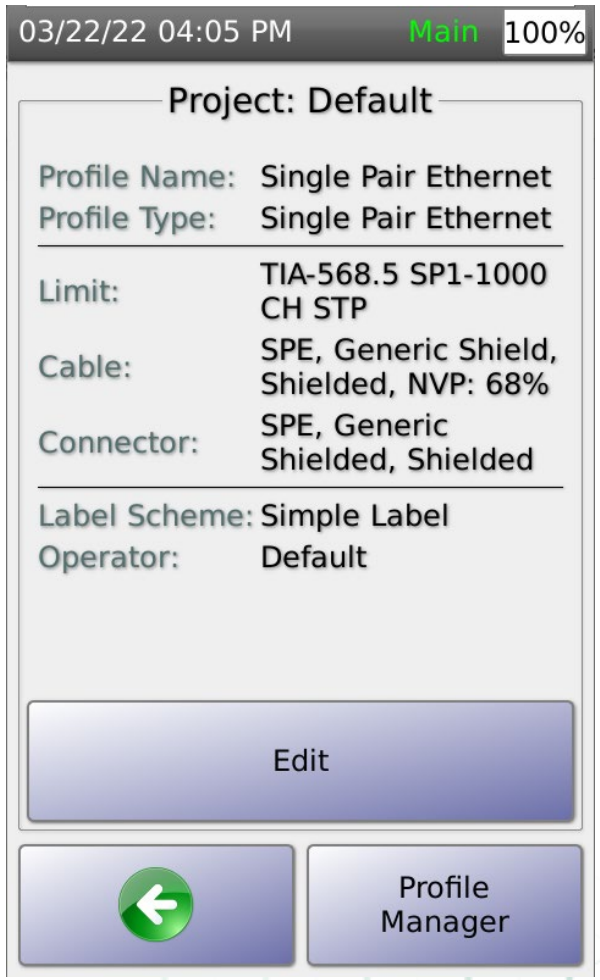
DC Powering
SPE vs 4-Pair Cabling

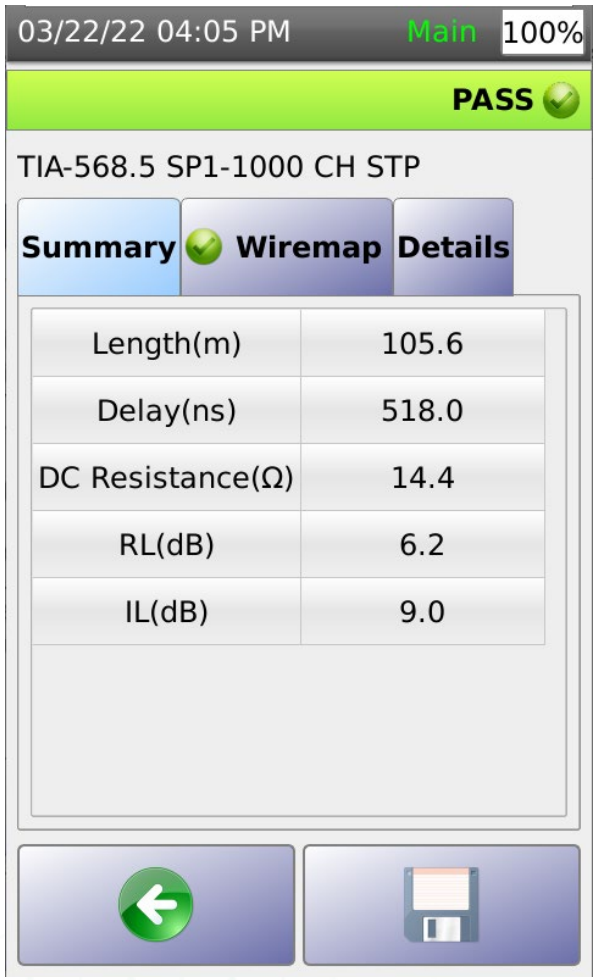


Resistance unbalance is not as big a concern for SPE because **PoDL current flows in opposite directions in transformer magnetics (unlike PoE)**

TestPro Single Pair Ethernet Test Example







Single Pair Ethernet Test Equipment

SPE testers may be available in one of two varieties:

- Existing cable certifiers with new adapters for SPE

New testers specifically for SPE

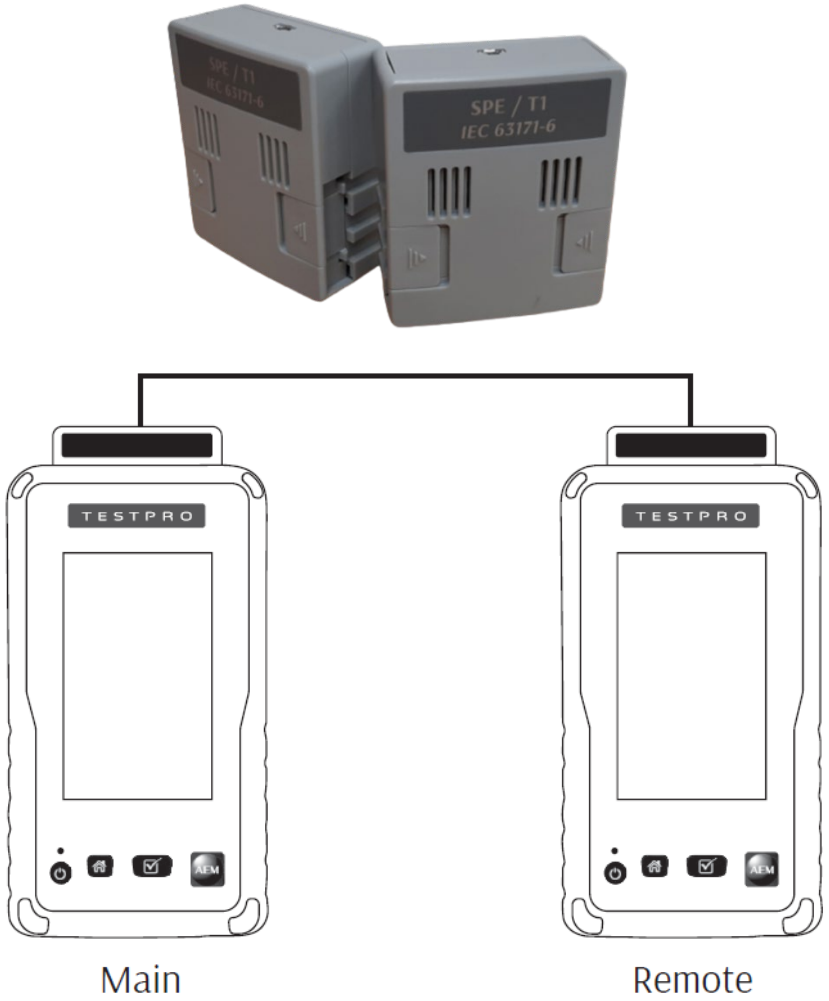
Single Pair Ethernet Field Test Equipment

Advantage of existing field testers support for **SPE testing vs new testers**

Significantly lower cost of ownership with adapter based enabling of new test needs

A single test platform covering needs for **4-pair and SPE cable testing**

Easily scale to requirements ranging from **20MHz to 1.2GHz** max frequency



SPE Summary

Single Pair Ethernet for a common intelligent Building Network

- ✓ Extends Ethernet network to new systems and devices
- ✓ Offers the potential to quickly deploy and power building IoT devices

SPE cables will have the capability to safely deliver power to all kinds of new devices

Single Pair Ethernet cabling will be tested in familiar ways using existing testers with new adapters

CINI4.0

Thank You!

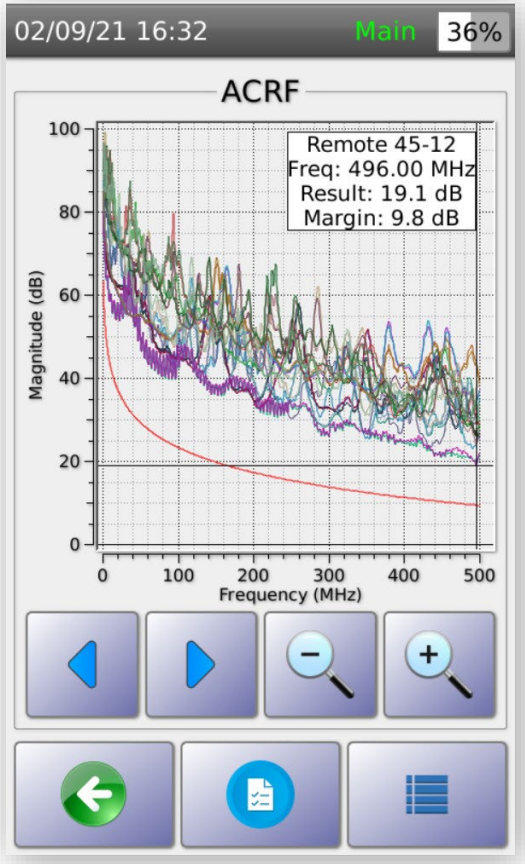
Please visit the AEM/Heynen stand for live demonstration.

Interested in a demo?
Heynen is local partner for AEM test within the Benelux region.
Account manager Heynen nv: Joris Schreurs,
joris.schreurs@heynen.be

Additional Slides on SPE

ACRF and PSACRF

- Attenuation-to-Crosstalk Ratio
  - NEXT minus IL = ACR
- ACRF is Attenuation-to-Crosstalk Ratio Far End
  - Far End ACR minus IL = ACRF (formerly known as ELFEXT)
- PSACRF is Power Sum Attenuation-to-Crosstalk Ratio Far End
  - Calculation of the combined ACRF on a tested pair from the three remaining pairs
- Bandwidth is determined by using ACR measurements
- Impacted by same factors as NEXT, including incorrect or substandard cable/components, improper termination, mismatched patch cords
- TestPro's Autotest also includes the Near-End tests of ACRN and PSACRN for informational purposes



What's driving the demand?

- Bandwidth consumption by personal IoT devices
- Expected growth to 75 billion by 2025
- Low bandwidth devices can be offloaded to SPE
  - Access controls
  - Lighting
  - Cameras
  - Sensors
  - Industrial controls

Single Pair Ethernet Standards

IEEE

IEEE 802.3cg. – 10Mb/s (2019)

- 10BASE-T1S – Link segment (point-to-point), 4 connections, 15m reach, PoDL power
- 10BASE-T1L – Link segment (point-to-point), 10 connections, 1000m reach, PoDL power
- 10BASE-T1S – Mixing segment (multidrop), 8 nodes, 25m reach

IEEE 802.3da. – 10Mb/s (TBD) **Multidrop Enhancements**

IEEE 802.3bu. – 10Mb/s (2016) **Power Over Data Line (PoDL)**

- Power delivery over single twisted-pair segment

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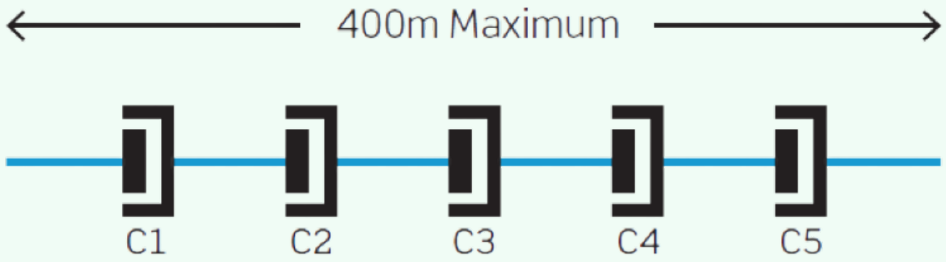
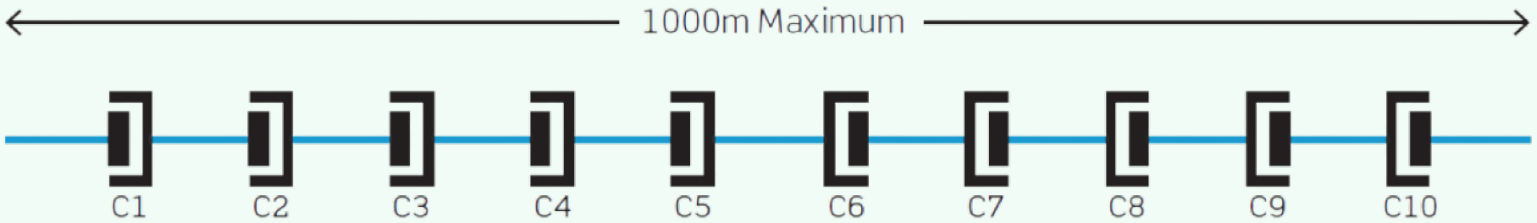
Single Pair Ethernet Topologies – Wire Size Matters

SP1-400 Channel (23 AWG)



SP1-100 Channel (18 AWG)



Single Pair Power Over Ethernet – PoDL vs SPoE

- IEEE 802.3 originally standardized powering over a single pair of conductors at 100Mb/s and 1000Mb/s in IEEE 802.3bu, known as Power over Data Lines (PoDL).
- IEEE 802.3cg extended the specification to support 10Mb/s for OT environments.
- In practice there are two variants of single-pair powering, SPoE and PoDL.
  - SPoE is used to describe the classification-based implementation utilized in OT networks
  - PoDL is used in engineered networks, e.g., in-car networks

Source: Ethernet Alliance
Tech Brief SPE/SPoE
July 2021

SPE Adapters
Variants Roadmap