

CINI4.0



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





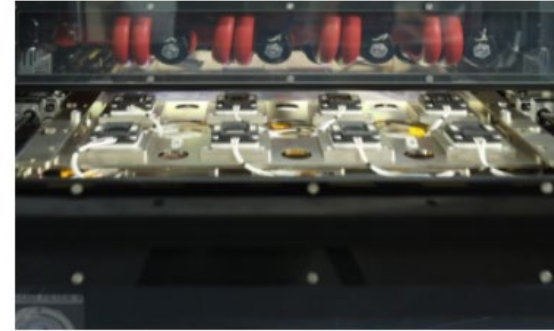
# We Are AEM

## 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.



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System Level Test Solutions >



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### Instrumentation



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## 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



# 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
- Impedence
- RL Locator TDR
- NEXT Locator TDR
- Shield Locator TDR

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

10/02/20 14:11 Main 46%

**PASS**

TIA - Cat 6A Channel

Summary Wiremap Details

Length(ft)	165.7
Delay(ns)	261.0
Resistance( $\Omega$ )	9.2
NEXT(dB)	4.7
RL(dB)	3.5
IL(dB)	1.5
PSNEXT(dB)	5.2

10/02/20 14:27 Main 43%

DC Resistance ( $\Omega$ )

Loop	UnBal. in Pair	UnBal. P2P
Pair	Result	Limit
12-36	0.258	0.519
12-45	1.771	0.519
12-78	0.157	0.519
36-45	2.029	0.519
36-78	0.416	0.519
45-78	1.613	0.519

10/02/20 14:54 Main 38%

Shield Locator

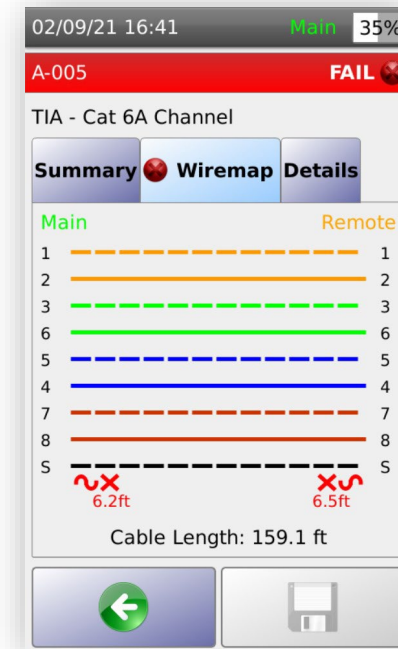
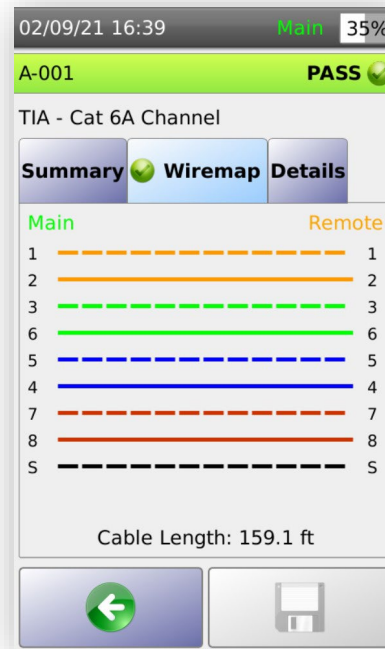
Locator 0.00 ft 26.7





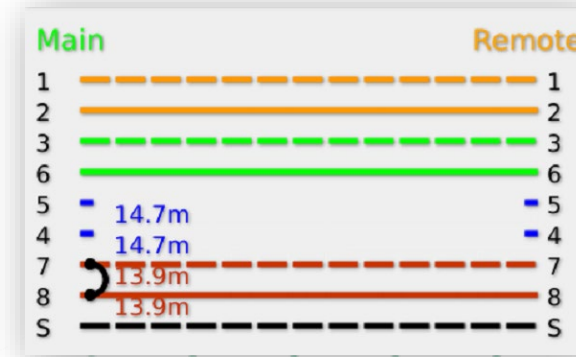
# Wiremap

- 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.

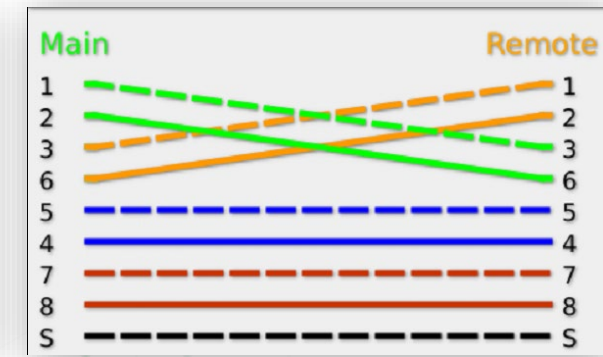


Shield Discontinuity

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

02/09/21 15:55 Main 40%

Length (ft)

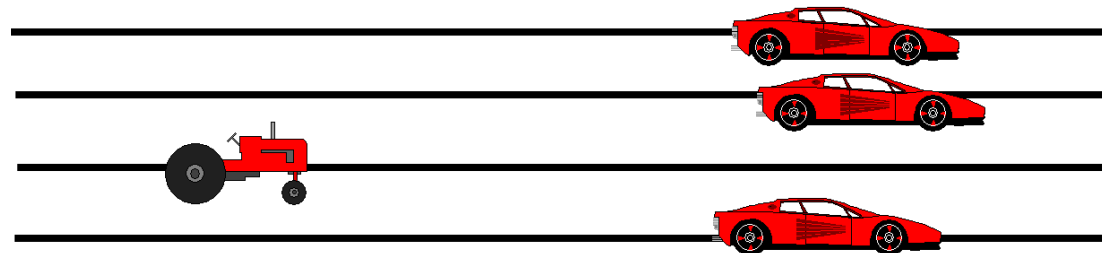
Pair	Result	Limit
12	159.1	328.1
36	166.7	328.1
45	168.6	328.1
78	159.3	328.1

A blue button with a white left-pointing arrow inside a green circle.

# 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

08/05/21 08:49 Main 54%

DC Resistance ( $\Omega$ )

Pair	Result	Limit
12	0.077	0.253
36	0.025	0.253
45	0.027	0.253
78	0.005	0.253

08/05/21 08:46 Main 54%

DC Resistance ( $\Omega$ )

Pair	Result	Limit
12	8.134	25.000
36	8.760	25.000
45	8.484	25.000
78	8.323	25.000

08/05/21 08:50 Main 54%

DC Resistance ( $\Omega$ )

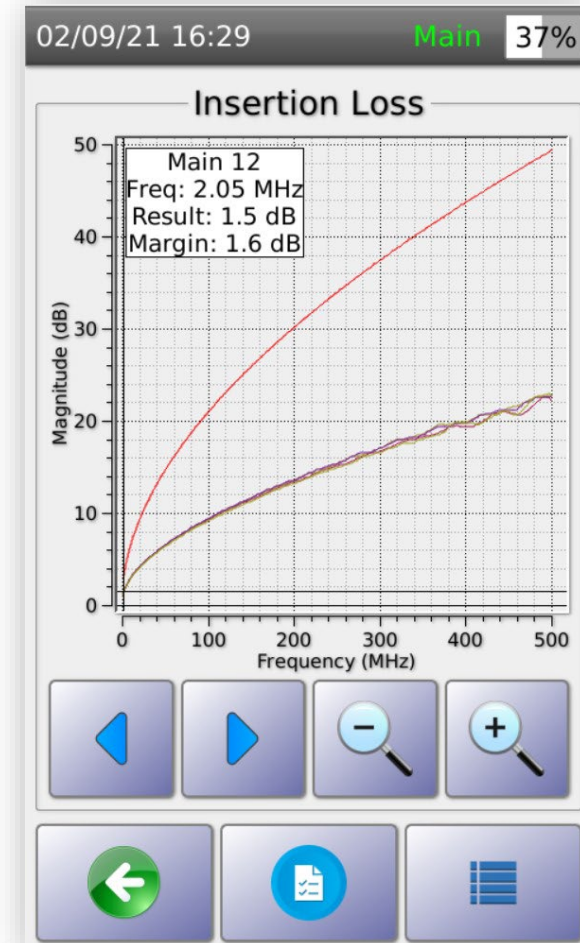
Pair	Result	Limit
12-36	0.157	0.295
12-45	0.088	0.295
12-78	0.047	0.295
36-45	0.069	0.295
36-78	0.109	0.295
45-78	0.040	0.295



# Insertion Loss (IL)



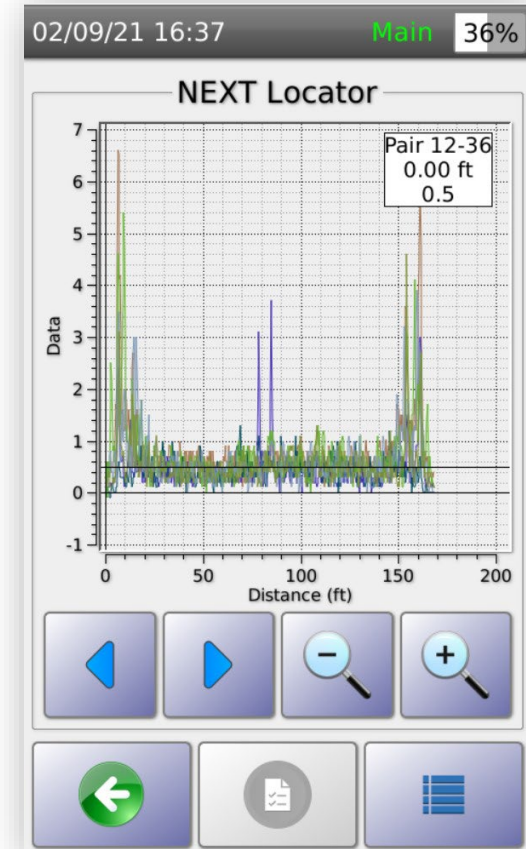
- Insertion Loss (aka attenuation) is the loss of power of a transmitted signal as it travels along the cable
- Result measured in decibels (dB)
- Increases with distance (length), temperature and frequency
- Failures
  - Most common cause is excessive length
  - Rarely seen in isolation, typically eliminated 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

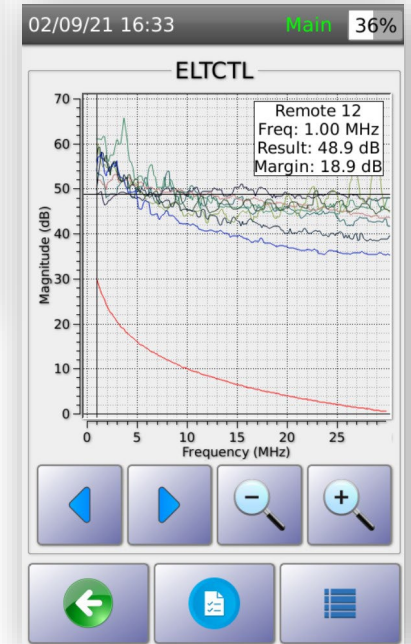
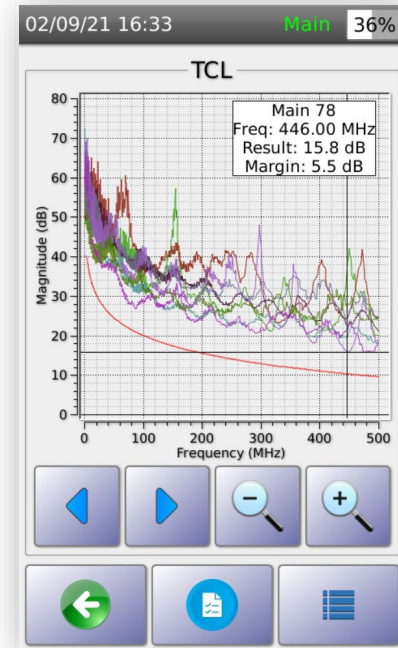




# TCL and ELTCTL (not required)



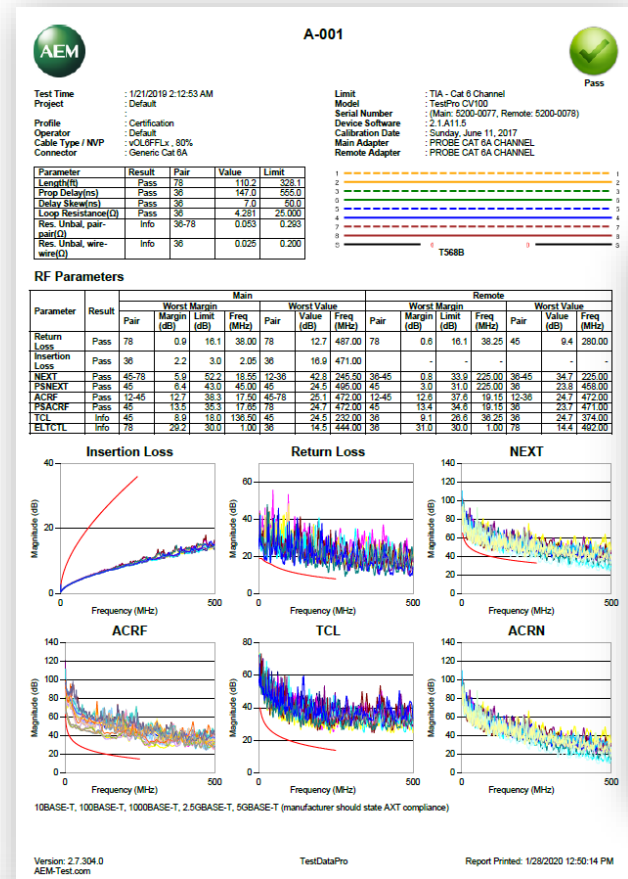
- TCL – Transverse Conversion Loss
- ELTCTL – Equal Level Transverse Conversion Transfer Loss
- Not required for field testing, these are done by the manufacturers to ensure conformance
- Signal noise is injected into the cable and the measurements indicate the level of noise immunity to show the cable 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



**Summary Report**

**Cable Certification**

Cable ID	Result	Limit	Length(ft)	Margin	Date / Time
A-002	Pass	TIA - Cat 6 Channel	109.7	1.8 dB (NEXT)	1/21/2019 2:54:10 AM
A35-A-02	Pass	TIA - Cat 6 Channel	96.3	1.7 dB (NEXT)	1/21/2019 3:02:39 AM
A-001	Pass	TIA - Cat 6 Channel	110.2	0.3 dB (NEXT)	1/21/2019 2:12:53 AM

Total Records: 3  
 Total Length: 316.2ft

**Fiber Certification**

Cable ID	Result	Limit	Length(ft)	Margin	Date / Time
MM-45-A-03	Pass	Loss Budget	39.4	2.5 dB	1/22/2019 5:10:39 AM
MM-45-A-01	Pass	Loss Budget	39.4	2.6 dB	1/22/2019 4:58:22 AM
MM-45-A-04	Pass	Loss Budget	39.4	2.5 dB	1/22/2019 5:10:56 AM
SM 1	Pass	Certification	34.4	= dB	1/31/2019 3:26:54 AM
SM 2	Pass	Certification	41	0.0 dB	1/31/2019 3:34:08 AM
SM 3	Pass	Certification	41	0.0 dB	1/31/2019 3:36:14 AM

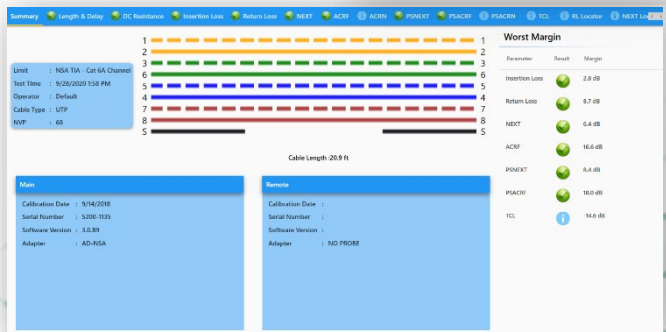
Total Records: 6  
 Total Length: 234.6ft

**Validation**

Cable ID	Result	Limit	Length(ft)	Margin	Date / Time
A-001	Pass	IEEE 802.3	91.9	3.1dB	1/21/2019 2:16:19 AM
A-002	Pass	IEEE 802.3	173.9	1.7dB	1/21/2019 2:52:44 AM
Multi-Gig	Pass	IEEE 802.3	173.9	0.3dB	1/21/2019 2:49:02 AM

Total Records: 3  
 Total Length: 439.6ft

Label	Result	Length	Worst Margin	Worst Margin	Limit	Test Time	Profile	Project	Connector	Actions
E11-3-6	Pass	95.9 ft	8.80 dB (RL)	5.70 dB (NEXT)	TIA - Cat 6 Channel	4/21/2020 3:48:41 PM	Certification	State Univ. Expansion	T1	
MDP-4-1-03	Pass	88.9 ft	1.10 dB (RL)	3.35 dB (NEXT)	TIA - Cat 6A Channel	4/6/2020 4:55:33 PM	Certification	Campus Science Bldg	S/C	
MDP-1-1-04	Pass	89.2 ft	2.40 dB (RL)	3.70 dB (NEXT)	TIA - Cat 6A Channel	4/6/2020 4:55:56 PM	Certification	Campus Science Bldg	S/C	
MDP-1-1-05	Pass	105.0 ft	-	-	-	4/6/2020 5:00:01 PM	Validation	Campus Science Bldg	S/C	
MDP-4-1-06	Pass	124.7 ft	-	-	-	4/6/2020 5:04:22 PM	Validation	Campus Science Bldg	S/C	
MDP-4-1-09	Pass	109.3 ft	-	-	-	4/6/2020 5:10:12 PM	Validation	Campus Science Bldg	S/C	
MDP-1-1-11	Pass	89.3 ft	5.69 dB (RL)	2.35 dB (NEXT)	TIA - Cat 6A Channel	4/7/2020 10:54:31 AM	Certification	Campus Science Bldg	S/C	
MDP-1-1-15	Pass	78.6 ft	3.30 dB (RL)	1.16 dB (NEXT)	TIA - Cat 6A Permanent Link	4/7/2020 11:05:49 AM	Certification	Campus Science Bldg	S/C	
MDP-4-1-18	Pass	78.3 ft	7.30 dB (RL)	1.16 dB (NEXT)	TIA - Cat 6A Permanent Link	4/7/2020 11:16:47 AM	Certification	Campus Science Bldg	S/C	
MDP-1-1-19	Pass	79.9 ft	7.80 dB (RL)	0.37 dB (NEXT)	TIA - Cat 6A Permanent Link	4/7/2020 11:17:01 AM	Certification	Campus Science Bldg	S/C	
MDP-1-1-20	Pass	105.3 ft	0.64 dB (WT)	0.73 dB (NEXT)	TIA-568.3-D SingleMode RP STD Grade	4/7/2020 1:47:33 PM	3M Fiber	Campus Science Bldg	S/C	
MDP-1-1-21	Pass	105.0 ft	0.31 dB (WT)	0.49 dB (NEXT)	TIA-568.3-D SingleMode RP STD Grade	4/7/2020 1:50:26 PM	3M Fiber	Campus Science Bldg	S/C	
MDP-1-1-22	Pass	104.3 ft	0.08 dB (WT)	0.22 dB (NEXT)	TIA-568.3-D SingleMode RP STD Grade	4/7/2020 1:53:01 PM	3M Fiber	Campus Science Bldg	S/C	



# 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

The screenshots display the following test results and configurations:

- Summary Loss Network Limits:** Shows Tx and Rx levels, Resistance: 1.19 Ω, Length (m): 32.00, Delay (ns): 159.80, Margin 850(dB): 0.81, Margin 1300(dB): 0.77.
- PoE:** Select Standard: 802.3bt (90W). PSE Detected: Yes, Voltage: 55.53 V, PSE Type: 4, PD Class: 8, PoE Cable Pairs: 12-36, 45-78, Allocated Power: 71.00 W.
- PoE Load Test:** Voltage: 49.50 V, Current: 1.24 A, RealPower: 61.56 W.
- Multi-Gig 100M/1G PoE:** Table showing Rate, SNR (dB), Limit (dB), and Margin (dB) for 10G, 5G, and 2.5G.
- Available Networks:** List of networks including Sheldonopolis II 5, Borg Collective, DIRECT-97-HP Officejet 38, FBI Surveillance Van, and Rabbit of Caerbannog.
- Switch Detail:** SYSTEM NAME: WOPR-CheyenneMountain, SWITCH DETAIL: Cisco SG250-08HP (PID:SG250-08HP-K9)-VSD, DEVICE ID: WOPR-CheyenneMountain, PORT ID: gi1, VLAN ID: 1, PORT CAPABILITIES: 10baseT(HD) 10baseT(FD) 100baseTX(HD) 100baseTX(FD) 1000BaseT(FD).
- BASE-T Network Test:** Connected 1000Mb/s, Full Duplex, Auto-Neg : ON. 9 Stations, 5 Servers, 1 TestPro.
- VLAN Discovery:** Pie chart showing VLAN ID Frames %: VLAN 1 (607, 89.3%), VLAN 2 (37, 5.4%), VLAN 3 (36, 5.3%).





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# Single Pair Ethernet



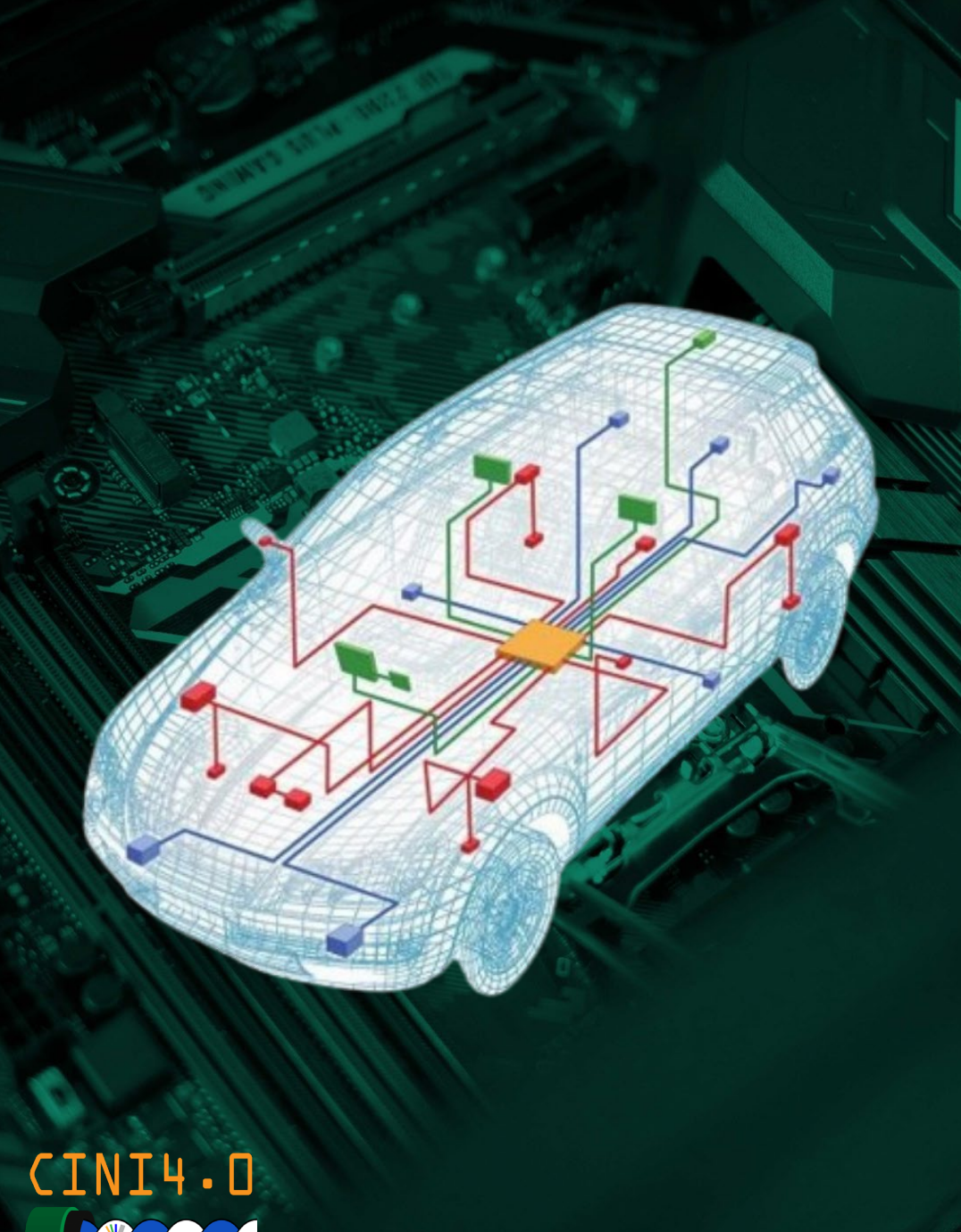
## SPE Adoption – First Automotive

### 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

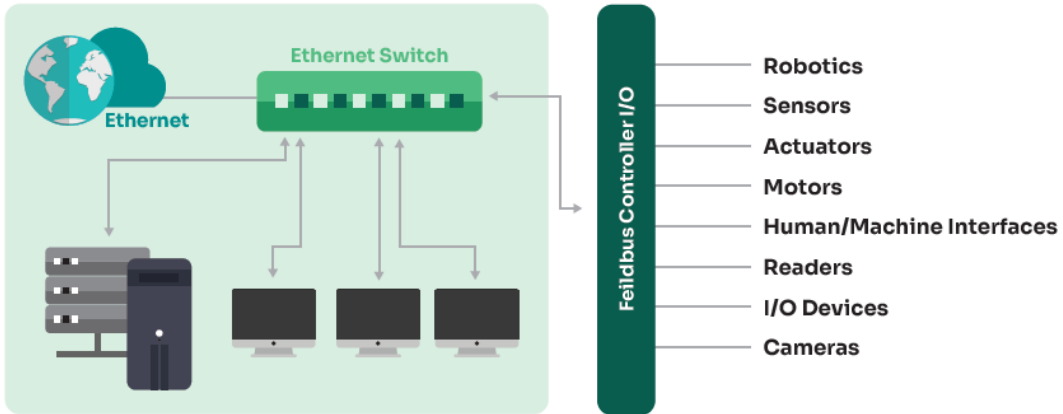
- 802.3bu-2016 – Power over Data Lines (PoDL)
  - Pronounced “poodle”
  - Also referred to as SPoE
  - Up to 52W of power



# SPE Adoption | Then Industrial



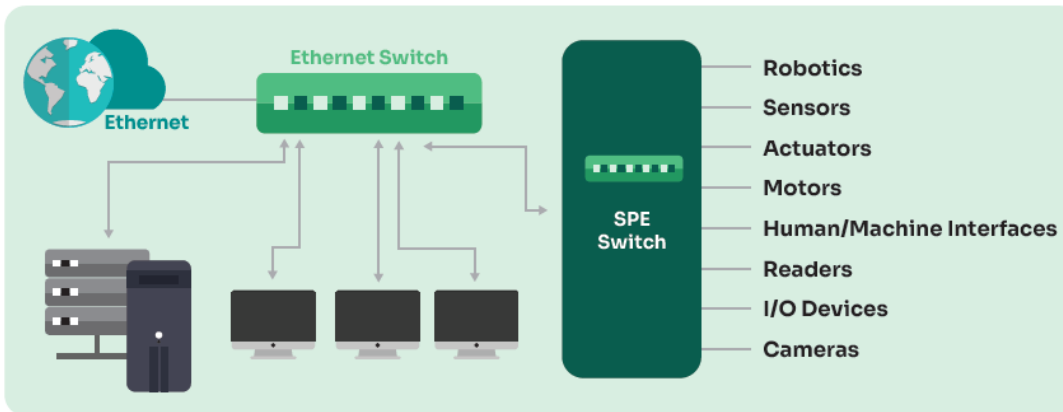
## Fieldbus Topology



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

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

## Single Pair Ethernet Topology



**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



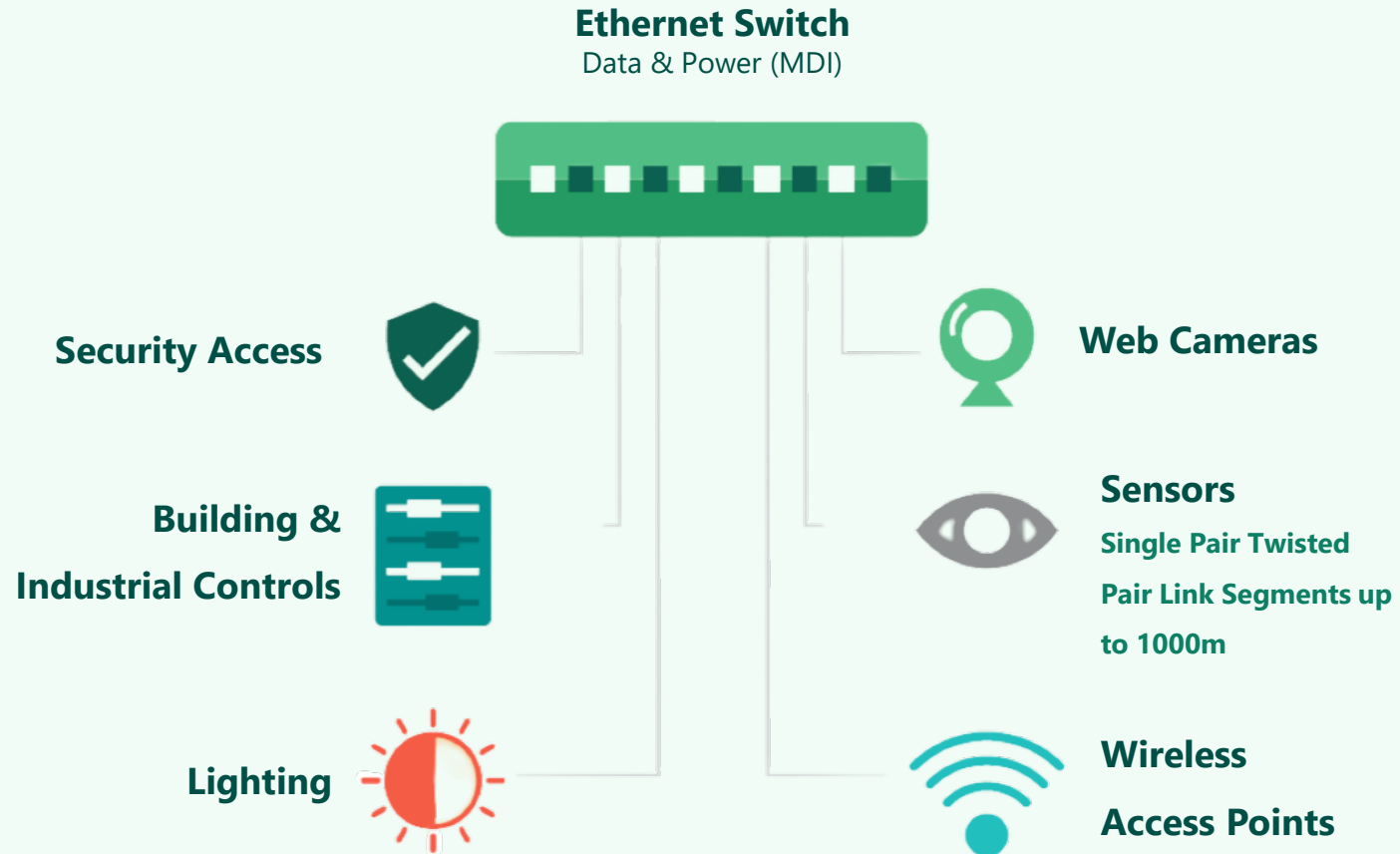


# Now | SPE is coming to a building near you

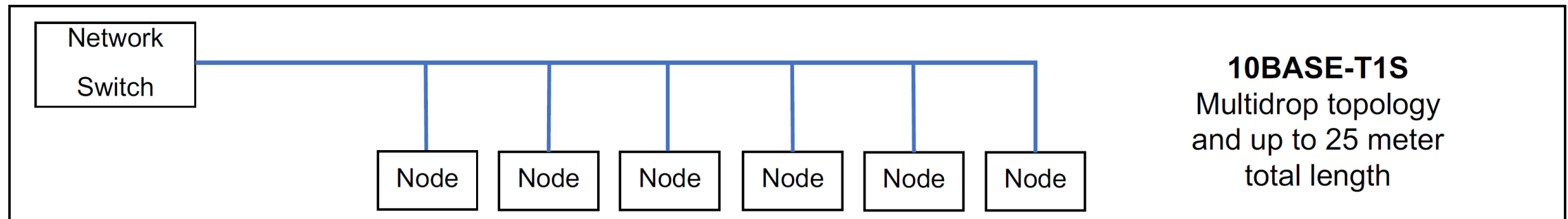
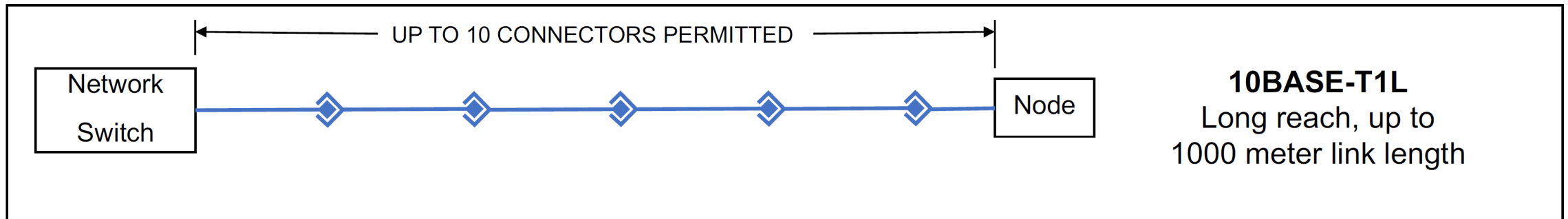


802.3cg

## Single-Pair Ethernet 10Mbps/Sec and Power



# Single Pair Ethernet General Topologies



Source: TIA Single Pair Ethernet Consortium standards update Sept 2021

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CONFIDENTIAL

# 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 Field Testing

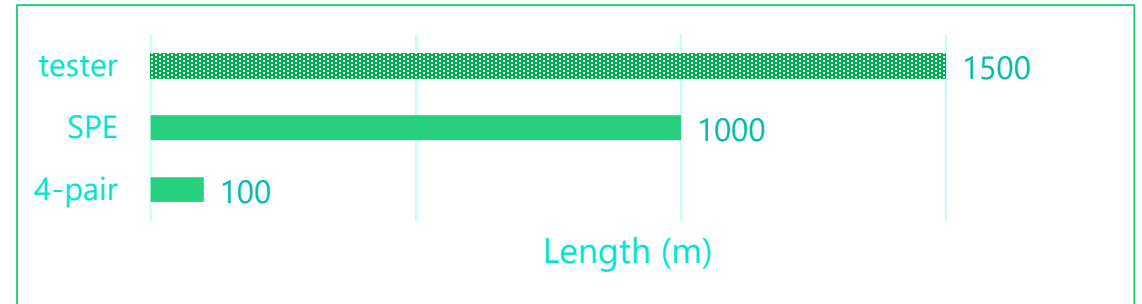
- ✓ Only when we can test an installation, can we be assured that it is all done correctly
- ✓ Field testing is an important piece in SPE rollout
- ✓ In next few slides, we review the current status of field testing SPE links

# Single Pair Ethernet

# Single Pair Ethernet vs 4-Pair Cabling Test Requirements

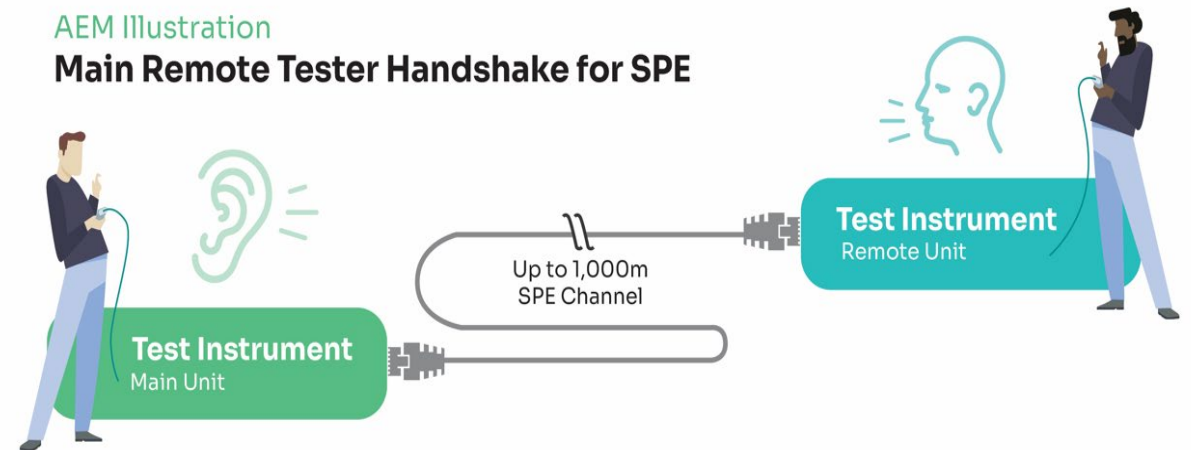


SPE cabling standard specifies 1,000m; but test instruments are expected to work with even longer link lengths (~1,500m)



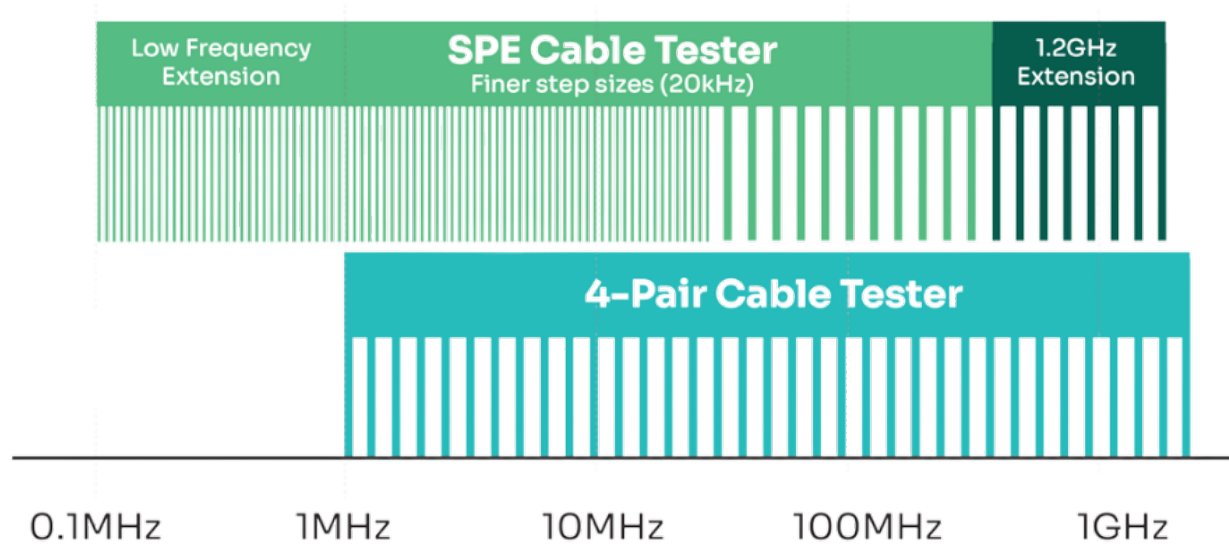
Test equipment main and remote units must perform end-to-end synchronization and communication over long single-pair DUTs

AEM Illustration  
Main Remote Tester Handshake for SPE





# 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



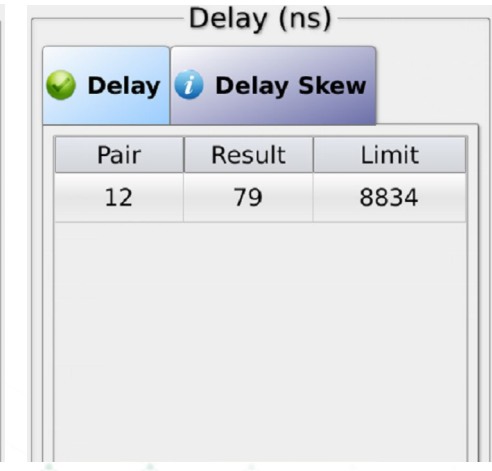
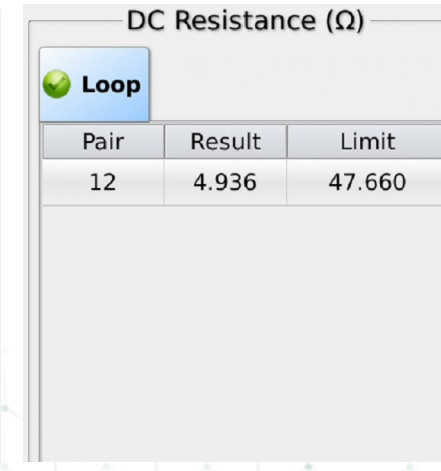
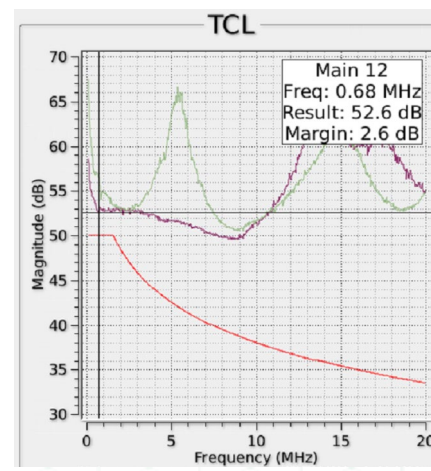
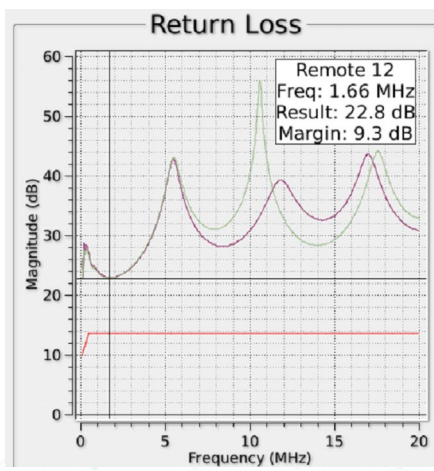
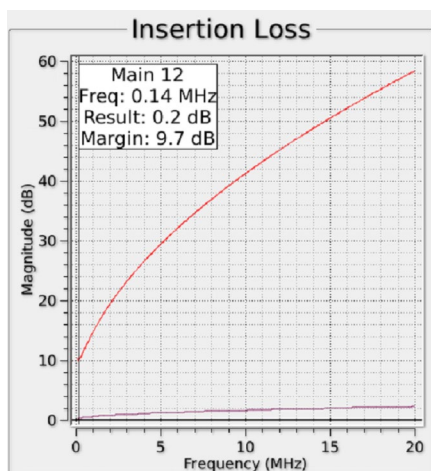
	Parameter	IEEE 802.3cg	ANSI/TIA-568.5
1	Insertion Loss	✓	✓
2	Return Loss	✓	✓
3	TCL (UnShielded)	✓	✓
4	DC Loop Resistance	✓	✓
5	Delay	8834ns (AWG 14 @ 1589m)	5559ns (AWG 18 @ 1000m)

A-002 **PASS** ✓

10BASE-T1L UTP E1 1000m (ISO IEC 11)

**Summary** ✓ **Wiremap** **Details**

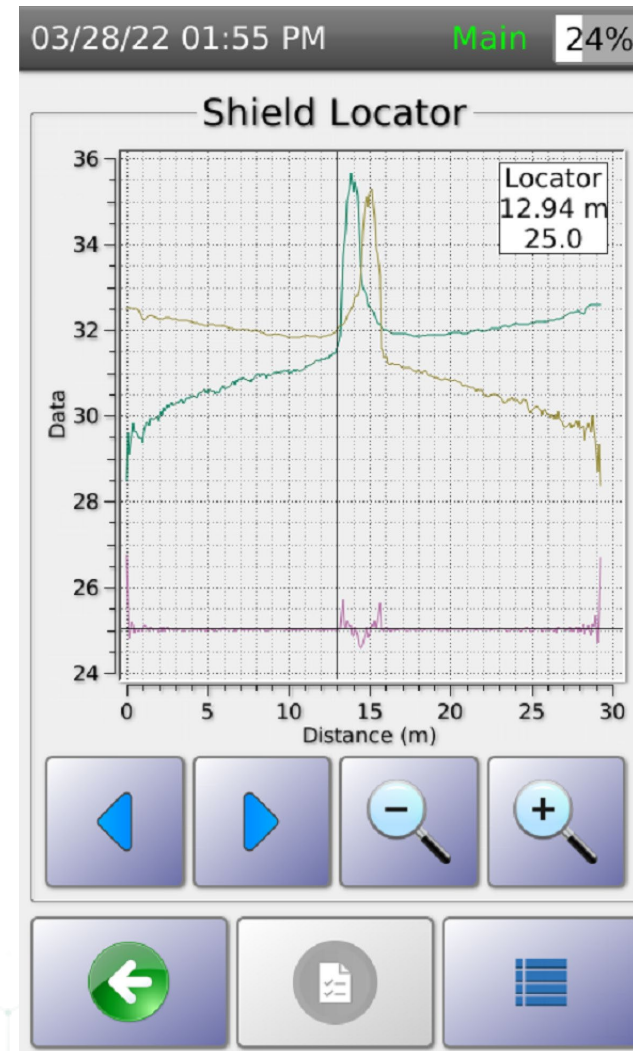
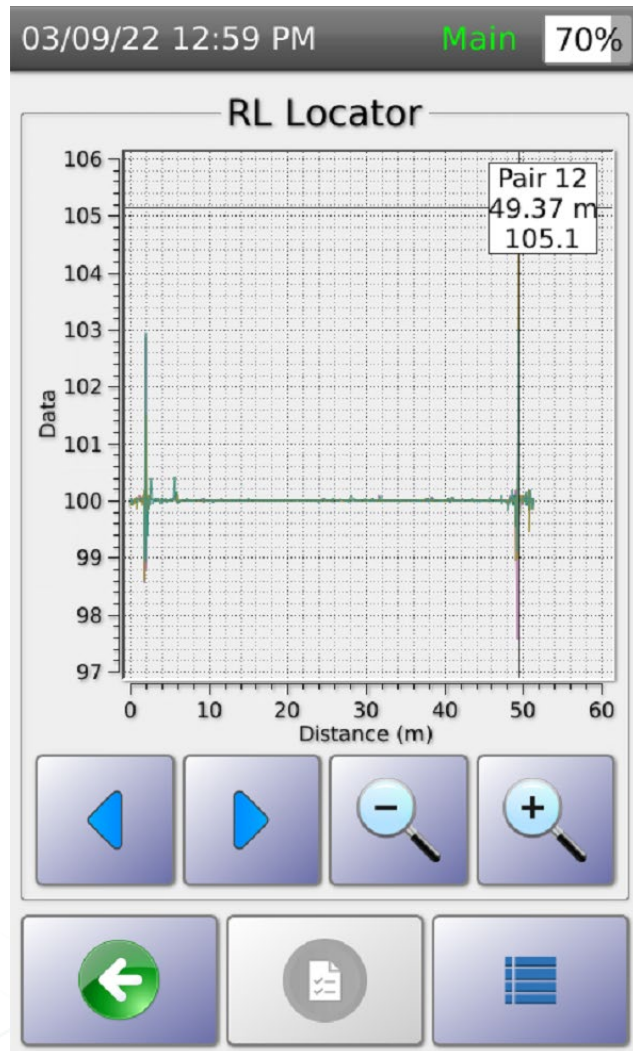
Length(m)	16.1
Delay(ns)	79.0
DC Resistance( $\Omega$ )	4.9
RL(dB)	9.3
TCL(dB)	2.6
IL(dB)	9.7



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# Troubleshooting Tools – locate the point of failure





# Connectivity & DC test for SPE



## Shield Continuity Measurement

End-to-end shield presence test



## Resistance Measurement

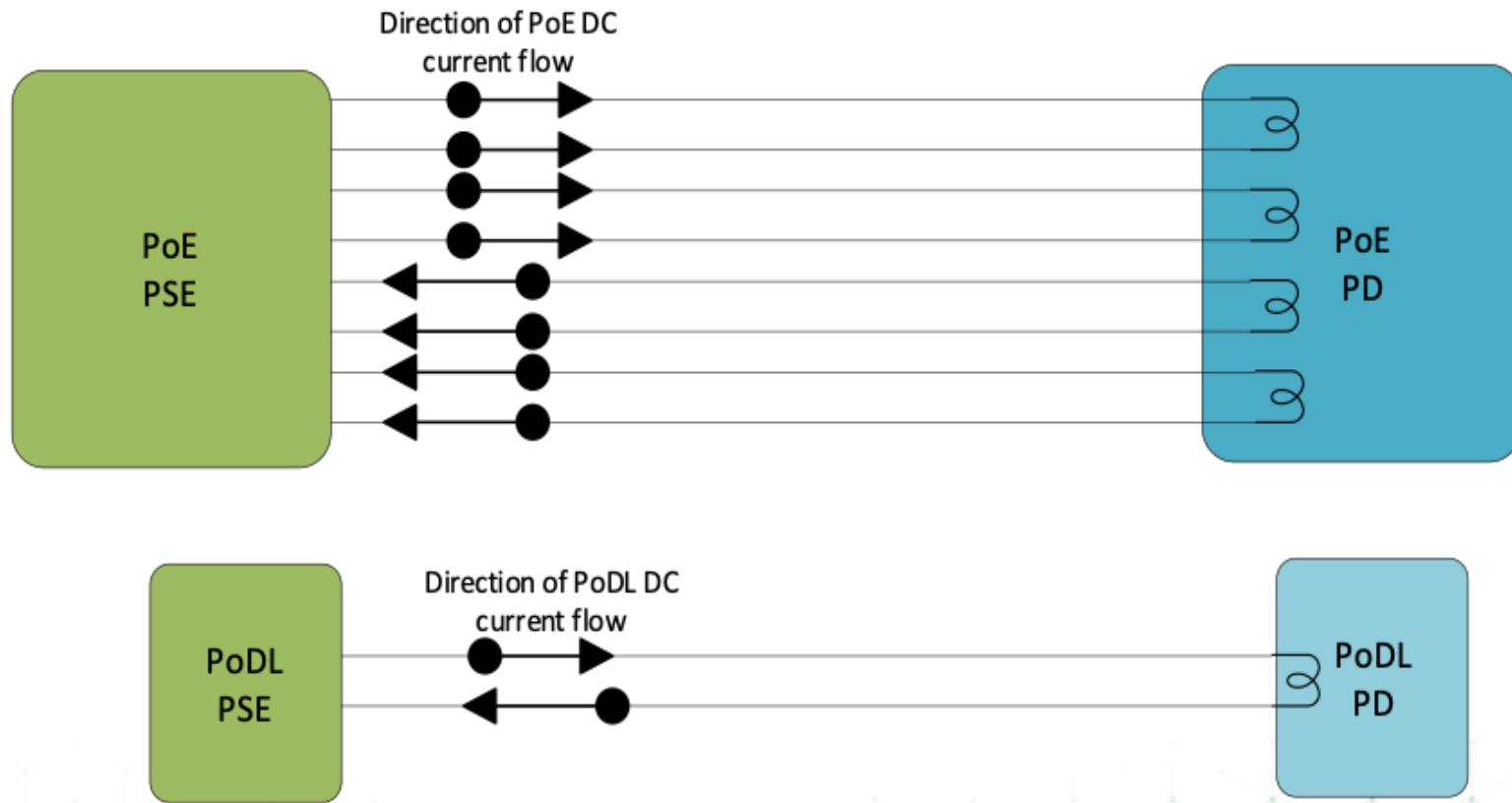
DC loop resistance



## 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



03/22/22 04:03 PM Main 100%

Main Remote

1 1  
2 2  
S S

Autotest

Expert Tools

03/22/22 04:05 PM Main 100%

Project: Default

Profile Name: Single Pair Ethernet  
Profile Type: Single Pair Ethernet

Limit: TIA-568.5 SP1-1000 CH STP

Cable: SPE, Generic Shield, Shielded, NVP: 68%

Connector: SPE, Generic Shielded, Shielded

Label Scheme: Simple Label  
Operator: Default

Edit

Profile Manager

03/22/22 04:05 PM Main 100%

**PASS**

TIA-568.5 SP1-1000 CH STP

Summary Wiremap Details

Length(m)	105.6
Delay(ns)	518.0
DC Resistance( $\Omega$ )	14.4
RL(dB)	6.2
IL(dB)	9.0

Navigation icons: back arrow and save icon







**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 Test Equipment

# Single Pair Ethernet Field Test Equipment

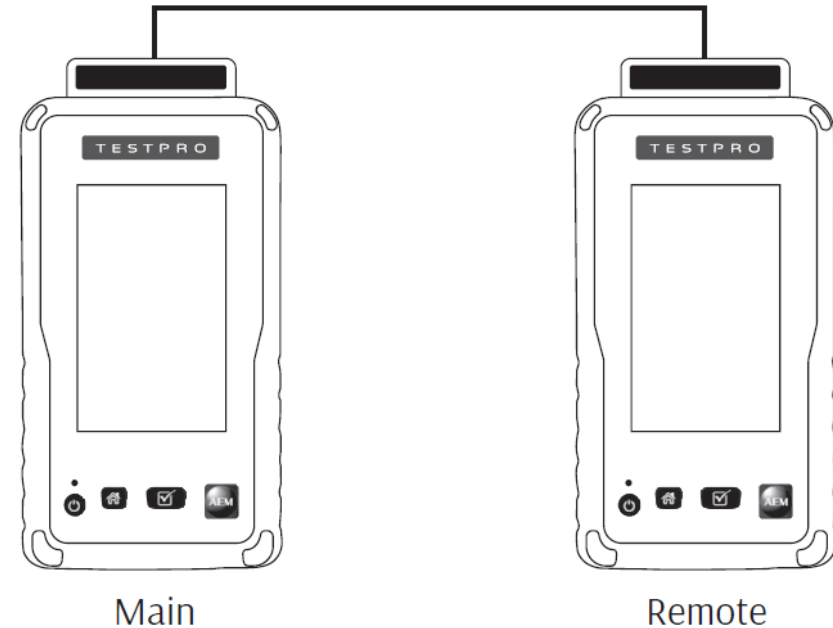


Advantage of existing field testers support for **SPE testing vs new testers**

**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](mailto:joris.schreurs@heyнен.be)





CINI4.0

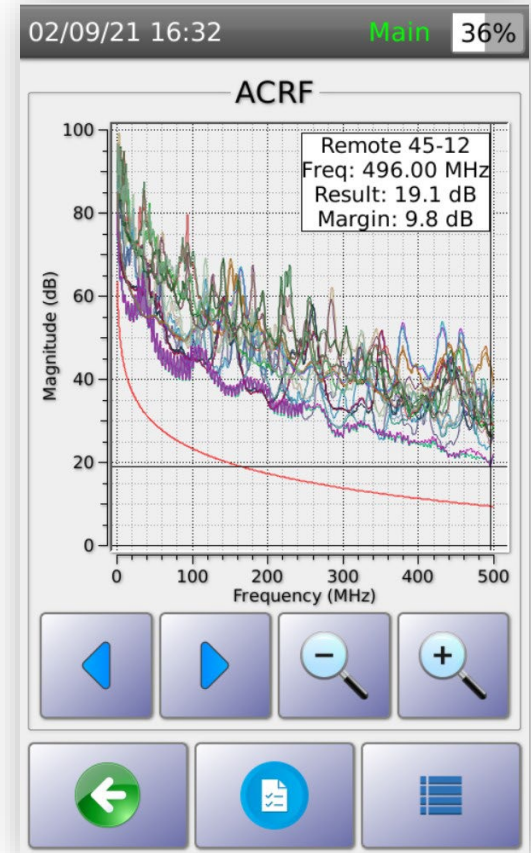


**Additional Slides  
on SPE**

# 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 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



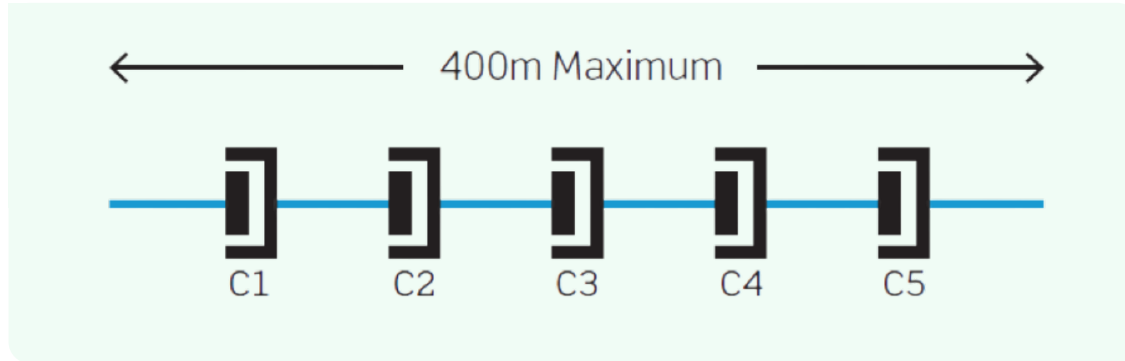


# Single Pair Ethernet Topologies

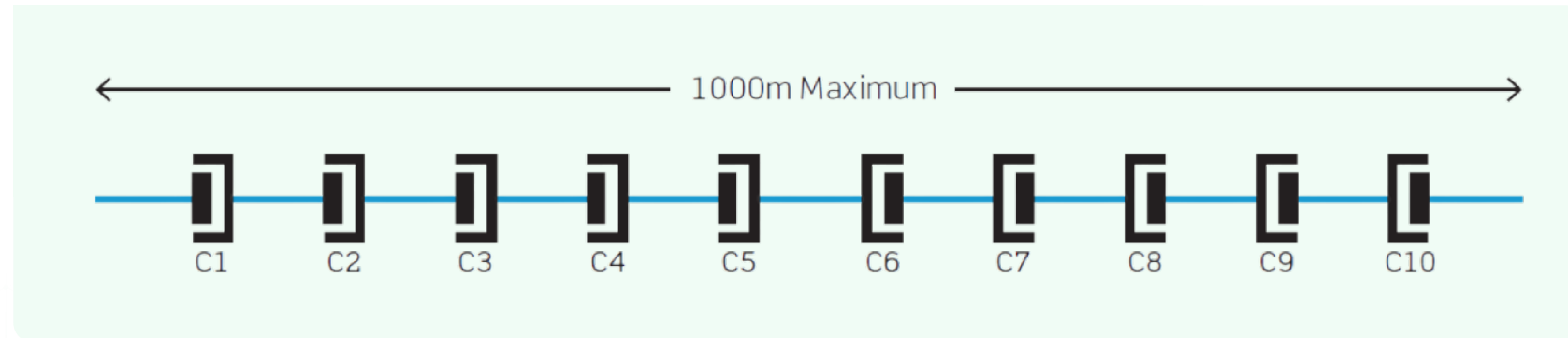
## – Wire Size Matters



### 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

