Aspects of IIoT for Industry 4.0
-
Focus on Single Pair Ethernet

08/11/2023 – ISEP, Porto

Philippe Saey

KU Leuven

Outline

- The CINI4.0 project
- Aspects of IIoT for Industry 4.0 (covered in CINI4.0)
- Focus on Single Pair Ethernet (SPE)

2

The CINI4.0 project

Converging **I**ndustrial **N**etworks for **I**ndustry **4.0**
New challenges for wired Ethernet

Philippe Saey
Jos Knockaert

KU LEUVEN · GHENT UNIVERSITY · inIT · TH OWL · Fraunhofer IOSB-INA · FE Forschungsvereinigung Elektrotechnik beim ZVEI e.V.

IGF 309 EN (01/08/2021-31/07/2023) – HBC.2020.2998

cornet

AiF · AGENTSCHAP INNOVEREN & ONDERNEMEN · Supported by Federal Ministry for Economic Affairs and Energy on the basis of a decision by the German Bundestag

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CORNET

- Applied research – limits & feasibility studies
- Technology transfer

CINI4.0

- Funding Organizations:
    - AiF (German Federation of Industrial Research Associations**)**
    - Vlaio (Vlaams Agentschap Innoveren & Ondernemen)
    - Co-financing by the Belgian User Committee members

4

CINI4.0 · KU LEUVEN

CINI 4.0

- **Project Partners:**

  - KU Leuven, Campus Gent   (C, "coordinating association")
  - UGent, Campus Kortrijk   (R, "research performing organization")
  - TH-OWL / inIT (Lemgo)   (R)
  - Fraunhofer IOSB-INA (Lemgo)   (R)
  - FE ZVEI   (A, "Association")

5

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CINI 4.0

- CORNET project

  - **User group**

Phoenix Contact NV/SA	(Zaventem)
Prokorment VOF	(Delft, The Netherlands)
Bintz NV/SA	(Zaventem)
Prolink Engineering BV	(Deinze)
ArcelorMittal Belgium NV/SA	(Zelzate/Gent)
Linkworx BVBA	(Aalter)
Volvo Cars Gent	(Oostakker/Gent)
iBA Benelux BVBA	(Gent)
VMA NV/SA	(Sint-Martens-Latem)
Agoria vzw	(Brussel)
Siemens NV/SA	(Huizingen)
Endress+Hauser SE+Co. KG	(Maulburg)
Hilscher Gesellschaft für Systemautomation GmbH	(Hattersheim am Main)
Indu-Sol GmbH	(Schmölin)
Perinet Gmbh	(Berlin)
rt-solutions.de GmbH	(Köln)
ZVEI e.V	(Frankfurt am Main)
R. STAHL Schaltgeräte GmbH	(Waldenburg)
TOSIBOX Gmbh	(Lemgo)
ESR Pollmeier GmbH Servo-Antriebstechnik	(Ober-Ramstadt)
InnoRoute Gmbh	(München)
Lenze SE	(Aerzen)

6

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CINI4.0 — **C**onverging **I**ndustrial **N**etworks for **I**ndustry **4.0**
New challenges for wired ethernet

- Background: merging IT and OT

- Technologies:
  - SPE & APL
  - TSN
  - OPC UA

- Questions:
  - Feasibility
  - Limits
  - Design tools for network planning
  - Robustness (redundancy, EMI)
  - Training

- Methods:
  - Survey of solutions
  - Develop test cases
  - Demonstrate & measure at component level and at system level (lab and industry)
  - Develop workshops and courses

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7

Outline

- The CINI4.0 project
- **Aspects of IIoT for Industry 4.0 (covered in CINI4.0)**
  - Time-Sensitive Networking
  - OPC UA and TSN
  - Single Pair Ethernet
- Focus on Single Pair Ethernet (SPE)

- **Not** in the CINI4.0 project:
  - WiFi 6
  - 5G
  - … for industrial applications
- Topics for a future CORNET !
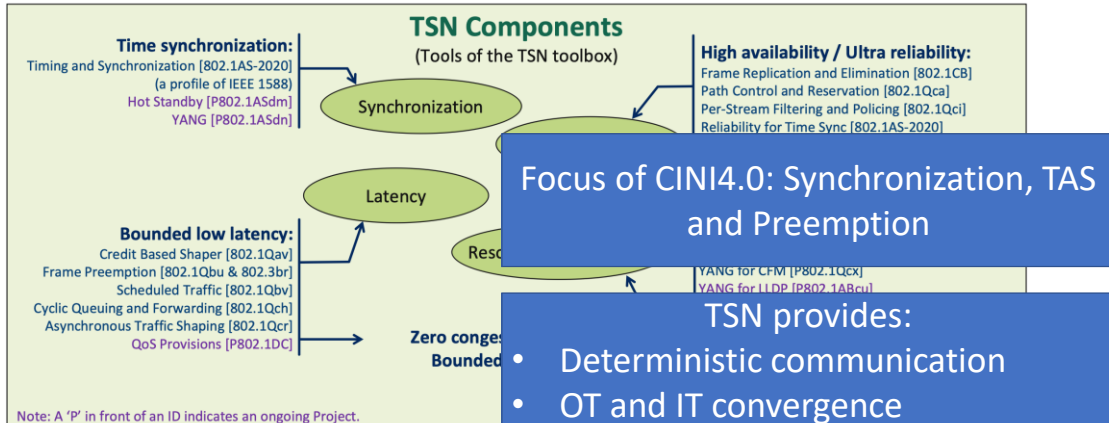
Co-funded by the Erasmus+ Programme of the European Union   HEIn4.○   KU LEUVEN

9

About the demonstrators … Time-Sensitive Networking

Siemens BANY XM400
Best-Effort netload generator (0-100%)

Siemens SIMIT
48 Simulated PN IO-devices

PN over TSN domain

PxC TSN switch 1   PxC TSN switch 2   PxC TSN switch 3

IO-controller

TAP1

IO-device 1

TAP2

IO-device 2

PROFITAP PROFISHARK
Preempted frame analysis

Hilscher netANALYZER

Fraunhofer TSN Monitor
CH1: Frame passes TAP1
CH2: Frame passes TAP2

Best-Effort
PROFINET
PROFINET +
Best-Effort

About the demonstrators … Time-Sensitive Networking

TSN – Demonstrator 2

Converged network - example

- TSN, PLC-PLC I-device communication, IP
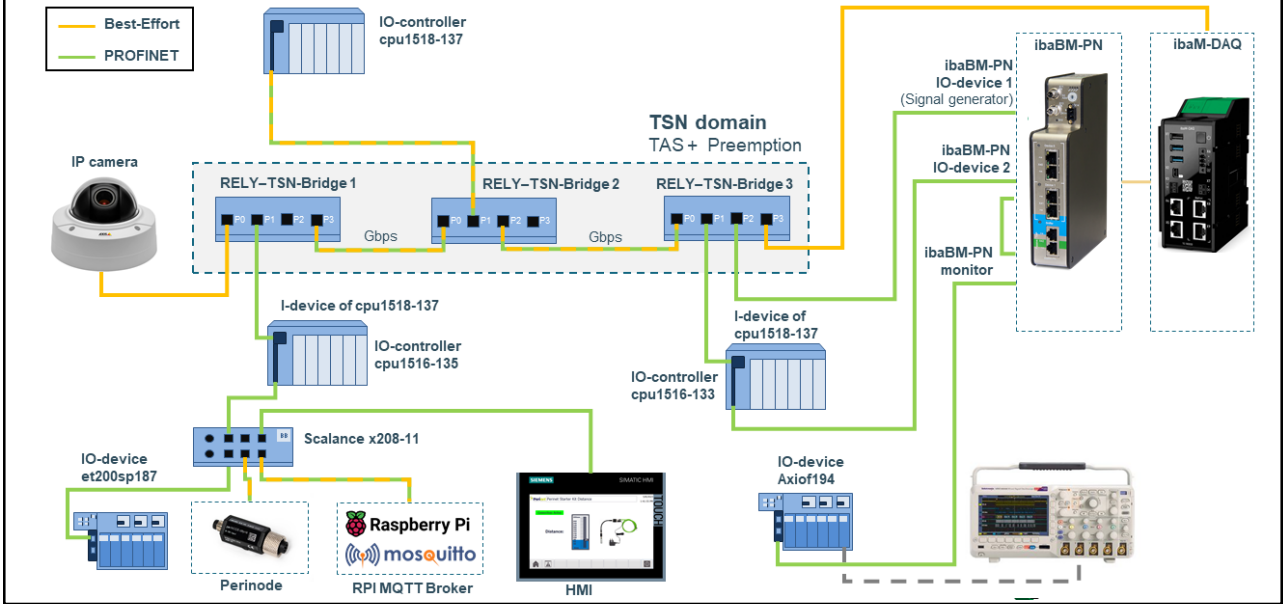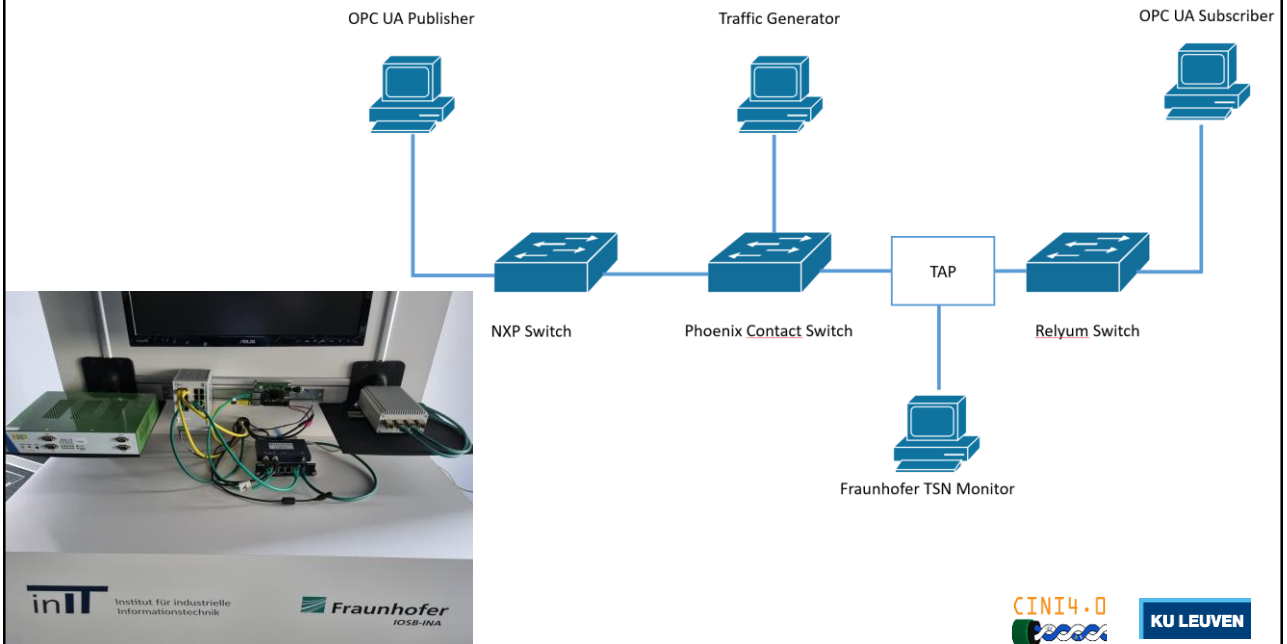 Camera, Data-acquisition, MQTT and hybrid SPE

TSN Configuration

- TAS Configuration   (802.1Qbv – Time Aware Shaper)
  - 125 Mbps reserved for PROFINET
    - 12,5 μs = 12500 ns
  - 875 Mbps PROFINET + BE
    - 87,5 μs = 87500 ns
- Preemption enabled in TSN domain

About the demonstrators … Time-Sensitive Networking

About the demonstrators … OPC UA + TSN

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Aspects of IIoT for Industry 4.0
-
Focus on Single Pair Ethernet

08/11/2023 – ISEP, Porto

Arne Verhoeven
Dimitri De Schuyter
Mathieu Troch
Philippe Saey (lecturer)

Outline

- Introduction
  - What is Single Pair Ethernet?
  - Advantages of Single Pair Ethernet
  - Some thoughts on "What is?"
  - Single Pair Ethernet Standards
- SPE: full duplex over one single twisted wire pair – How?
- Ethernet frame – Signal encoding
- Power over Data Line (PoDL)
- Cabling and Connectors
- Ethernet Advanced Physical Layer (APL)
- Conclusion

18

Single Pair Ethernet
ISEP, Porto – 08/11/2023

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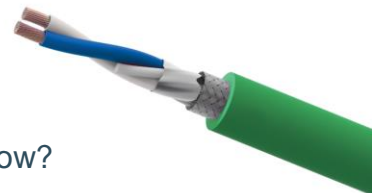
What is Single Pair Ethernet?

From 2 pair 100 Mbps
(e.g. PROFINET)
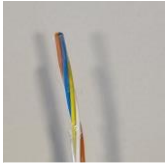
To 4 pair 1000 Mbps
(1 Gbps, difficult confection)

To 1 pair 10 – 100 - 1000 Mbps

Single Pair Ethernet (SPE) provides full duplex transmission (and power delivery) over a single balanced twisted wire pair

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What is Single Pair Ethernet?

- SPE affects only the physical layer
  - Just like optical fiber, WiFi…

- Layers 2-7 remain unchanged

802.3 Standard Ethernet

Application	• End User layer • HTTP, FTP, IRC, SSH, DNS
Presentation	• Syntax layer • SSL, SSH, IMAP, FTP, MPEG, JPEG
Session	• Synch & send to port • API's, Sockets, WinSock
Transport	• End-to-end connections • TCP, UDP
Network	• Packets • IP, ICMP, IPSec, IGMP
Data Link	• Frames • Ethernet, PPP, Switch, Bridge
Physical	• Physical structure • Coax, Fiber, Wireless, Hubs, Repeaters

SPE Specific

Advantages of Single Pair Ethernet

- Smaller connector + reduced footprint
- Lighter, more compact, cheaper and simpler cabling
- Simpler field assembly of connectors (1)
- Power + data over 1 wire pair
- Full duplex communication over 1 wire pair
- High bandwidth – up to 1000 Mbps (40 m)
- Low bandwidth (10 Mbps) over 1000 m
  - With optional intrinsic safety
  - With optional re-use of existing fieldbus cabling
- No gateways required, all is Ethernet (e.g. PN / PB PA)
  ➜ Implemented in different standards!
  (1) About 6-8% of 1 Gbps Ethernet connectors assembled in the field are not working or are of bad quality (Belden).

SPE (10BASE-T1L) PCB
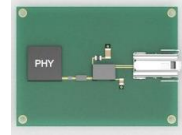
RJ45 PCB
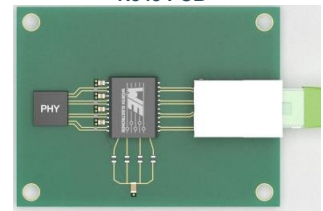
Some thoughts on "What is?"
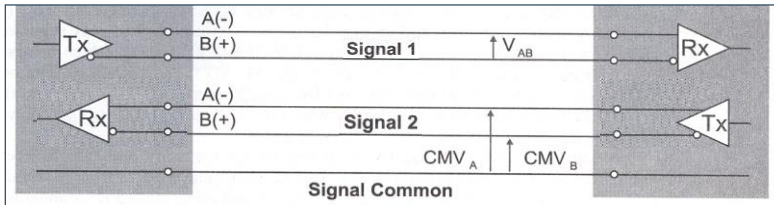
Balanced (or differential) signals:
- **Unbalanced** = referred to the same common ground (e.g. RS232c)
- Balanced/differential: e.g. RS485, Ethernet
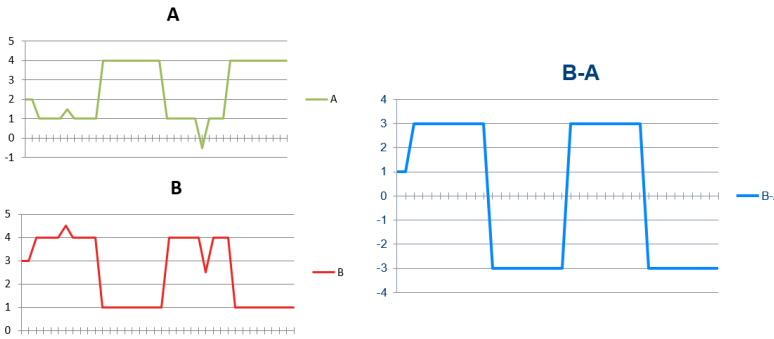
The (common mode) disturbance is not present in the differential signal

Some thoughts on "What is?"

Balanced (or differential) signals:

- Unbalanced = referred to the same common ground (e.g. RS232c)
- **Balanced/**differential: e.g. **RS485**, Ethernet

The (common mode) disturbance is not present in the differential signal

23   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

Some thoughts on "What is?"

Reduction of inductive coupling
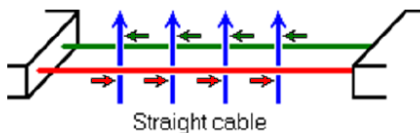
Without twisted pair:
Magnetic field induces a current
→ The two currents strengthen each other
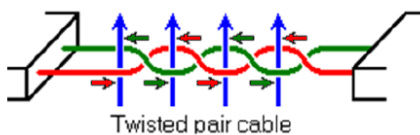
Twisted pair:
Magnetic field induces a current
→ Currents from 2 loops neutralise each other

Twisted:

- <> EMI (reduces radiation from the pair, improves rejection of external EMI, reduces crosstalk between neighboring pairs)

(**Equalizing** (each in turn the closest to the maximum disturbance) and **cancelling** (induced currents in each "loop"))

24   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

Some thoughts on "What is?"

Full duplex:

- TX/RX possible at the same time
- **Your PROFINET cable has 4 wires, 2 wire pairs: TX and RX are nicely separated!**
- Measurement on 65 m PN cable, voltage signals on TX and RX at switch (CH1+2) and IO-Device (CH3+4) sides:
  - <u>**Always**</u> **signals on both wire pairs!** (Unlike e.g. RS232c or RS485)
  - Attenuation of the voltage levels; it's only 65 m
- Refer to "The Ethernet physical layer: signals, cables, connectors and TAPs for 100 and 1000 Mbps"

Single Pair Ethernet
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Some thoughts on "What is?"

Full duplex:

- TX/RX possible at the same time
- **Your PROFINET cable** has 4 wires, 2 wire pairs: TX and RX are nicely separated!
- Measurement on <u>100 m</u> PN cable, voltage signals at switch and IO-Device sides:
  - Always signals on both wire pairs! (Unlike e.g. RS232c or RS485)
  - **Attenuation of the voltage levels, after 100 m of cable**

26

Single Pair Ethernet
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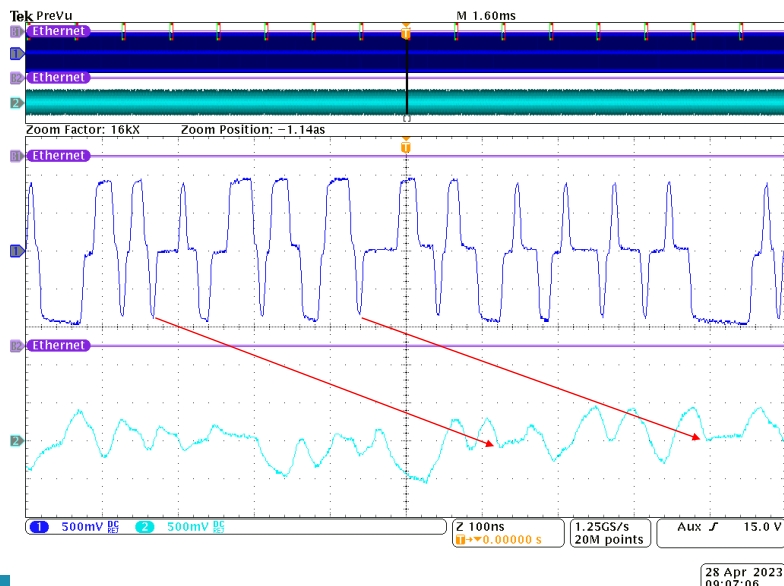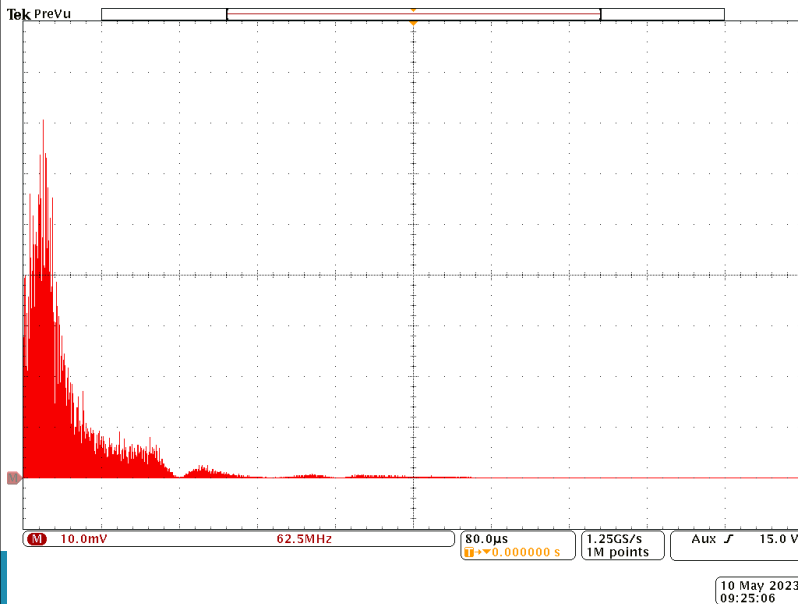

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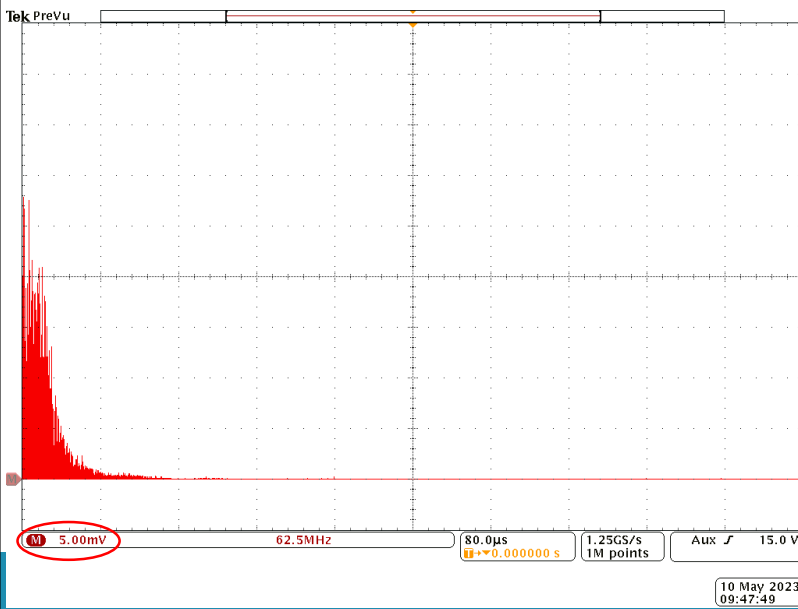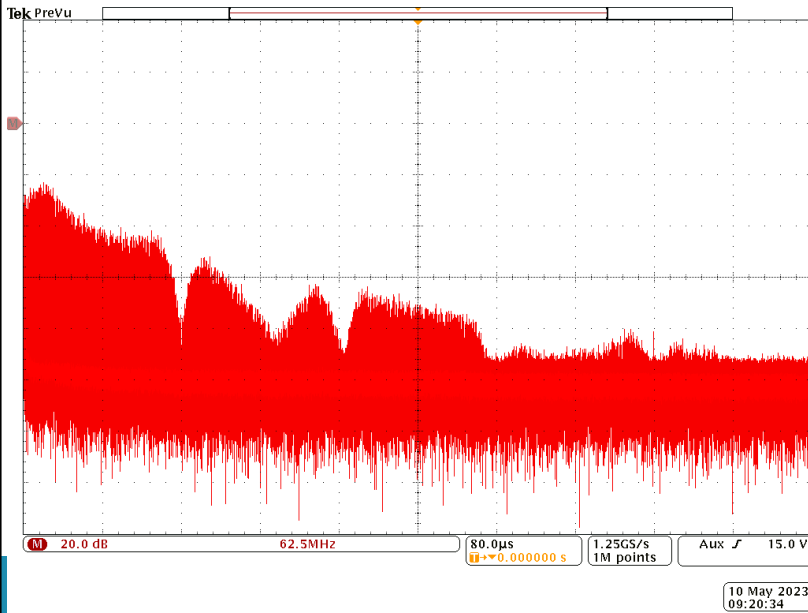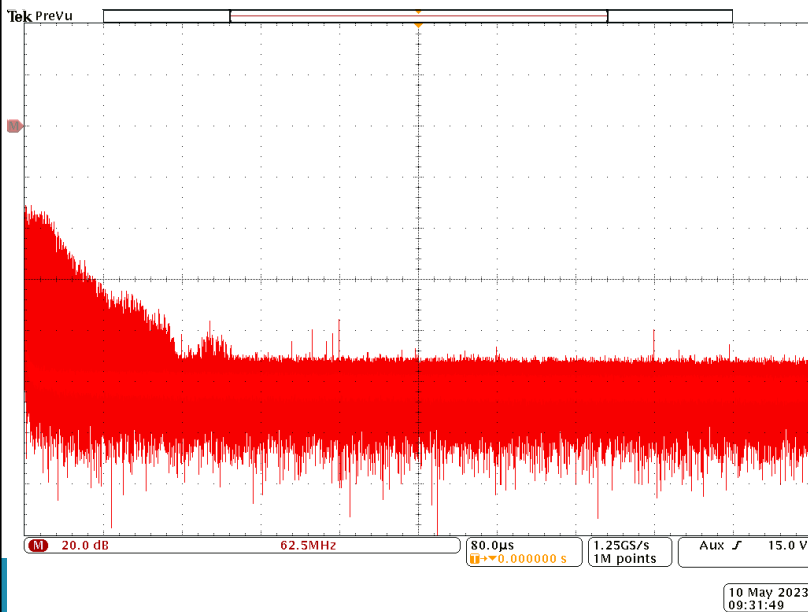 - **Attenuation of the voltage levels, after 100 m of cable**

Some thoughts on "What is?"

- Single Pair Ethernet (SPE) provides full duplex transmission (and power delivery) over a single balanced twisted wire pair

- **Interpretation - Challenges**:
  - Balanced
  - Twisted
  - **Full duplex**
  - **Over *one* wire pair?**
    - **Signals**
    - **Power**

Over one wire pair ???
- **Superposition of signals** as these are always present
- Large one from the "near end" superimposes on the small one coming from the "far end"
- Some types of SPE cable are a 1000 m long … up to 60 dB less signal (depending on the frequency)
- We see on both sides reflections ("echo") because of small changes in characteristic impedance along the way (passive connections, different cable types, ageing and wear, …)
- We pick up disturbances along the way
- And … PoE requires 4 wires …

31 Single Pair Ethe
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Some thoughts on "What is?"

Background: reflection ("echo") – RS485 example

Open line $(R_t > Z_o)$

Tek stop Single Seq 100MS/s
Ch1 Zoom: 1.0X Vert 1.0X Horz
Ch1 2.00 V   M 500ns Ch1   5.68 V
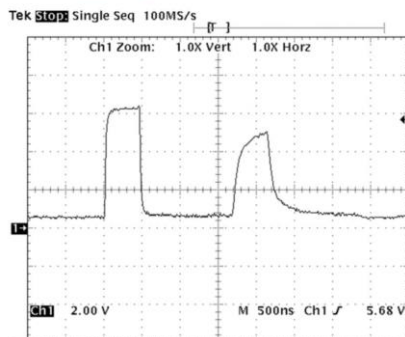
Reflection coefficient

- The way how a signal will be reflected can be calculated by the reflection coefficient:

$$\Gamma = \frac{Z_L - Z_S}{Z_L + Z_S}$$

- For short circuited lines:
A reflection coefficient of -1 = total and negative reflection

$$\Gamma = \frac{0\,\Omega - 150\,\Omega}{0\,\Omega + 150\,\Omega} = -1$$

- For open lines:
A reflection coefficient of +1 = total and positive reflection

$$\Gamma = \frac{\infty\,\Omega - 150\,\Omega}{\infty\,\Omega + 150\,\Omega} = 1$$

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SPE Standards in short

- **10BASE-T1S**
  - Half duplex, point-to-point or multidrop, 25 m
- **10BASE-T1L**
  - Full duplex, 1000 m, power, intrinsic safety
- **100BASE-T1**
  - Full duplex, power, 40 m
- **1000BASE-T1**
  - Full duplex, power, 40 m

Automotive

Industrial

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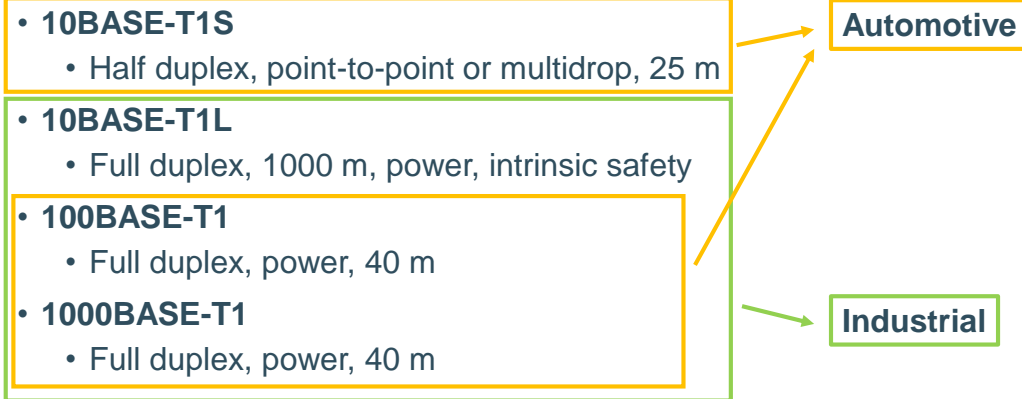
SPE Standards - Properties

	10BASE-T1S	10BASE-T1L	100BASE-T1	1000BASE-T1
Standard	802.3cg-2019	802.3cg-2019	ISO/IEC/IEEE 8802-3:2017/Amd 1-2017	ISO/IEC/IEEE 8802-3:2017/Amd 4-2017
Duplex type	Half duplex	Full duplex	Full duplex	Full duplex
Max. unshielded cable length (m)	15 (point-to-point) 25 (multidrop)	/	15	15
Max. shielded cable length (m)	15 (point-to-point) 25 (multidrop)	1000	40	40
Max peak-to-peak voltage level of transceiver (V)	1	1, 2.4	2.2	1.3
PoDL	Point-to-point: Yes Multidrop: in progress	Yes	Yes	Yes
Extra features	Multidrop	Ethernet-APL with intrinsic safety for process industry		

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Standards – SPE & APL (Advanced Physical Layer)

- Single Pair Ethernet is discussed now:
  - 100 & 1000 BASE-T1
  - 10BASE-1S
  - *10BASE-T1L long reach*
- Ethernet-APL is made up of:
  - Single Pair Ethernet (IEEE 802.3cg-2019, 10BASE-T1L)
  - 2-WISE: 2-Wire Intrinsically Safe Ethernet (IEC 60079) (compare to FISCO)
  - Type A fieldbus cable (IEC 61158-2, for intrinsic safety).

- The SPE standard defines a "channel" (its properties), not a specific "cable".

35   **Single Pair Ethernet**
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  - Advantages of Single Pair Ethernet
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  - Single Pair Ethernet Standards
- **SPE: full duplex over one single twisted wire pair – How?**
- Ethernet frame – Signal encoding
- Power over Data Line (PoDL)
- Cabling and Connectors
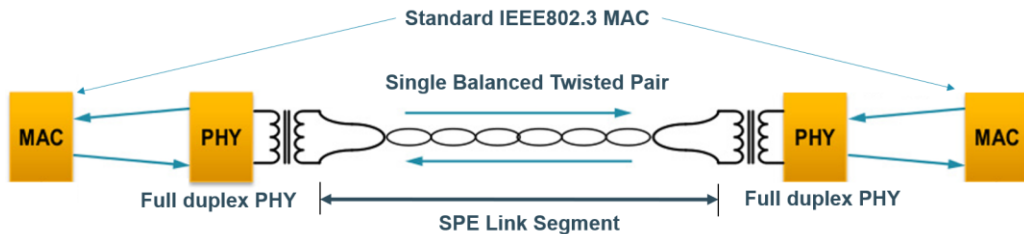- Ethernet Advanced Physical Layer (APL)
- Conclusion

36   **Single Pair Ethernet**
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SPE: full duplex over one single twisted wire pair

- SPE affects only the physical layer
  - Just like optical fiber, WiFi…
- Layers 2-7 remain unchanged

- PHY interfaces with data link "MAC" layer using the standardized Media Independent Interface (MII)   =>
  also here reuse of (part of) the existing electronic design

Standard IEEE802.3 MAC

Single Balanced Twisted Pair

MAC — PHY — Single Balanced Twisted Pair — PHY — MAC

Full duplex PHY — SPE Link Segment — Full duplex PHY

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SPE: full duplex over one single twisted wire pair
Interfacing SPE PHY with standard 802.3 MAC

802.3 Standard Ethernet

OSI REFERENCE MODEL LAYERS:
- APPLICATION
- PRESENTATION
- SESSION
- TRANSPORT
- NETWORK
- DATA LINK
- PHYSICAL

SPE Specific

ETHERNET LAYERS:
- HIGHER LAYERS
- LLC (LOGICAL LINK CONTROL) OR OTHER MAC CLIENT
- MAC (MEDIA ACCESS CONTROL)
- RECONCILIATION
- *MII
- PCS
- PMA — PHY
- MDI
- MEDIUM
- 100 Mb/s link segment

MDI = MEDIUM DEPENDENT INTERFACE
MII = MEDIA INDEPENDENT INTERFACE
* Physical instantiation of MII is optional.

PCS = PHYSICAL CODING SUBLAYER
PMA = PHYSICAL MEDIUM ATTACHMENT
PHY = PHYSICAL LAYER DEVICE
PMD = PHYSICAL MEDIUM DEPENDENT

Media Independent Interface (MII)
- Standardized connection between MAC and different PHYs
- Standard 100 Mbit/s MII
  → transmits 4 bit nibbles at 25 MHz

Physical Coding Sublayer (PCS) and Physical Medium Attachment (PMA)
- Converts data received from MAC to the suitable physical signal
- Places physical on MDI

Media Dependent Interface (MDI)
- Physical interface
  = connectors + cabling

38 — Single Pair Ethernet — *ISEP, Porto – 08/11/2023* — CINI4.0 cornet KU LEUVEN

SPE: full duplex over one single twisted wire pair

- Both transmitters send simultaneously → signals are superimposed on cable
- PHY must separate transmitted and received signal → **hybrid** circuit
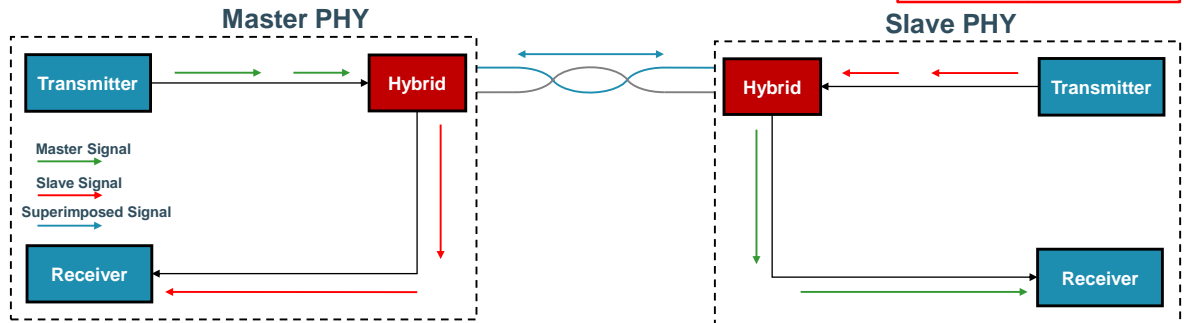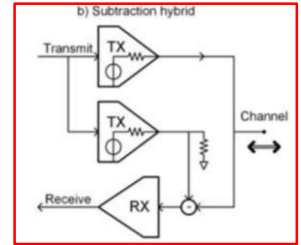
Single Pair Ethernet
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SPE: full duplex over one single twisted wire pair

- But… impedance mismatches exist → part of transmitted signal is reflected: "echo"
- Echo should not be interpreted as a received signal from partner PHY
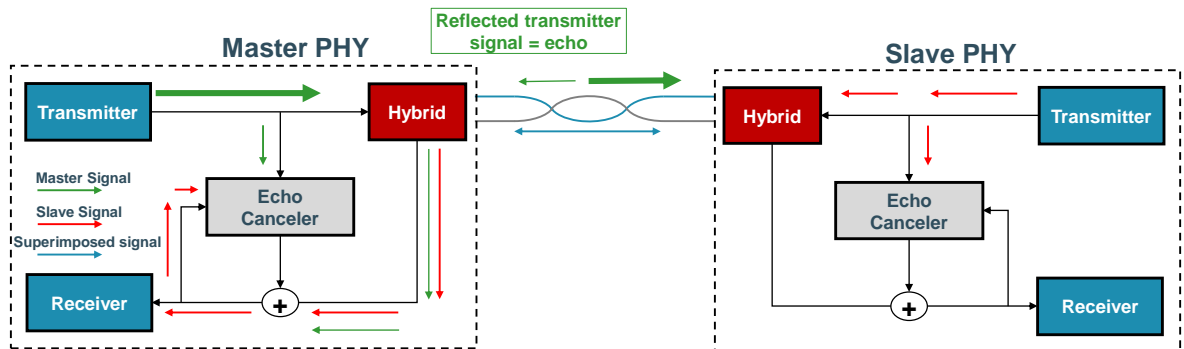   → **Removed by Echo Canceler** (signals drawn only on Master side)

Single Pair Ethernet
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SPE: full duplex over one single twisted wire pair

- How do 100BASE-T1 signals look like?

CH1 - Voltage measured at master

CH2 - Current measured at master

Math13 - Near end signal at master

Math14 - Far end signal at master
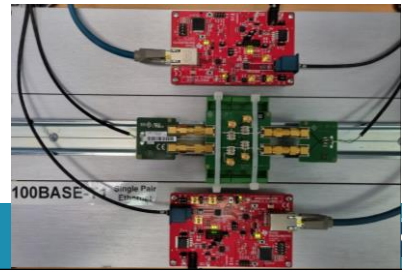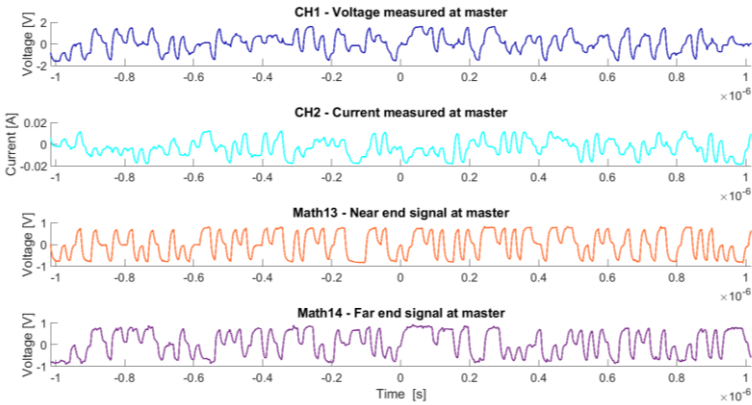
Measurements with 8 CH Tektronix, TEK specific measuring principle

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SPE: full duplex over one single twisted wire pair

- Surprise: it's nothing new …
- Your 1 Gbps Ethernet uses … SPE signaling

Use all four pairs with full-duplex transmission on each pair. (Requires hybrid.)

1000BASE-T uses DSP-based adaptive filtering to cancel the effects of echo, crosstalk and noise

Outline

- Introduction
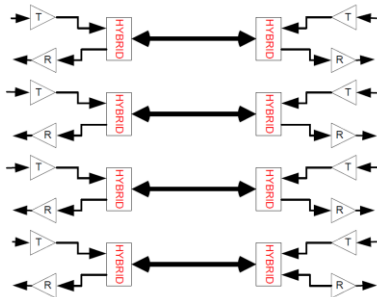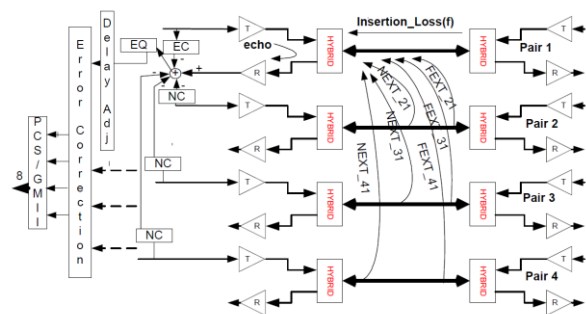 - What is Single Pair Ethernet?
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- Power over Data Line (PoDL)
- Cabling and Connectors
- Ethernet Advanced Physical Layer (APL)
- Conclusion

43

Single Pair Ethernet
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The Ethernet Frame

- The Ethernet frame remains the same, except preamble and Inter Frame Gap (IFG)
  - **S**tart- and **E**nd-of-**S**tream **D**elimiter added (SSD and ESD)

Also in e.g. PRP redundancy and "in the wireless phase" in WiFi you get a header/trailer: invisible for the end user

# bytes	7	1	6	6	2	46-1500	4	12
	Preamble	SFD	Destination address	Source address	Length/ Ethertype	Data	FCS	IFG

Ethernet II frame

Header

Byte: 0   6   12   14   60-1518
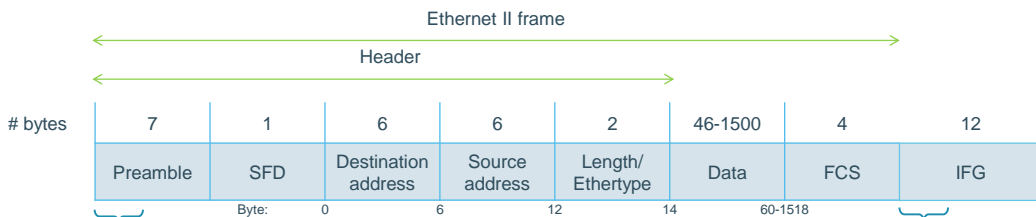
Start-of-Stream Delimiter (SSD)
- Replaces first x bits of preamble
  - 10BASE-T1L: 16 bits
  - 100BASE-T1: 9 bits
  - 1000BASE-T1: 9 bits

End-of-Stream Delimiter (ESD)
- Replaces first y bits of IFG
  - 10BASE-T1L: 16 bits
  - 100BASE-T1: 9 bits
  - 1000BASE-T1: 9 bits

44

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100BASE-T1 Signal Encoding

- Different standards = different physical signals
- But... they share common encoding principles (except 10BASE-T1S)

Example: 100BASE-T1

Sort data stream in blocks of specific bit length →	4B/3B-coding
Randomize data stream →	Scrambling
2-level to 3-level signal →	3B/2T-coding
3-level Pulse Amplitude Modulation →	PAM3

3B/4B-coding
Descrambling
2T/3B-coding
PAM3

Physical signal — **cable**
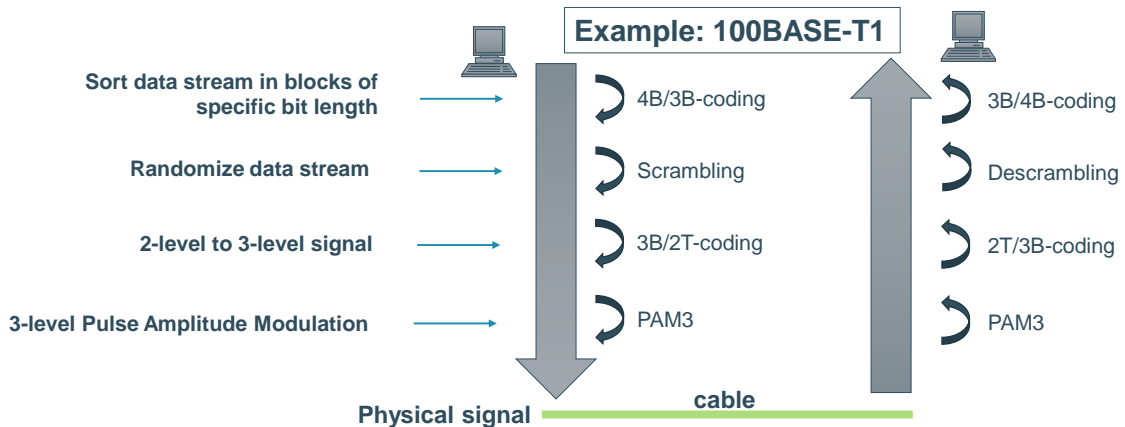
100BASE-T1 Scrambling

- Data stream scrambled using a pseudo-random code
- Prevent loss of synchronization between PHYs
- Spread transmit power over frequency band
- Reduces DC portion of signal
- Reduces electromagnetic interference
- Reduces radiated emissions

4B/3B-coding	3B/4B-coding
Scrambling	Descrambling
3B/2T-coding	2T/3B-coding
PAM3	PAM3

cable

Physical signal
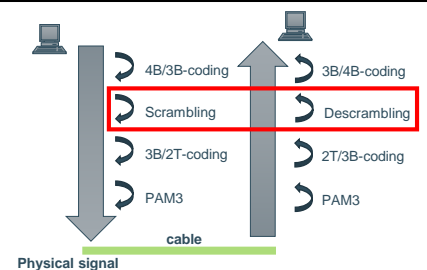
Scrambler function

PAM3-Modulation

*Measurement methods discussed during demo

- Data stream from MAC layer → 4-bit nibbles at 25 MHz
- Convert to 3-bit blocks at 33,3 MHz
- 3-level Pulse Amplitude Modulation (PAM3)
  - 3 amplitude levels (Ternary) → -1, 0, 1
- Transmitted at 66,6 MHz, 1 ternary every 15 ns

Superimposed signal*

Separated signal*

47

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100BASE-T1 Summary

4B/3B-coding
Scrambling
3B/2T-coding
PAM3

3B/4B-coding
Descrambling
2T/3B-coding
PAM3

cable

Physical signal

4B Data	0101	1000	1111	1001	1010	0011		MII
3B Data	010	110	001	111	100	110	100	011
2T	-1 1	1 -1	0 1	0 -1	1 0	1 -1	1 0	0 1

Scrambling →

4B/3B Encoding

3B/2T Encoding

+1 V

PAM 3 0 V

-1 V

MDI

PAM3-Modulation

66.66
Msps

33.33
MHz
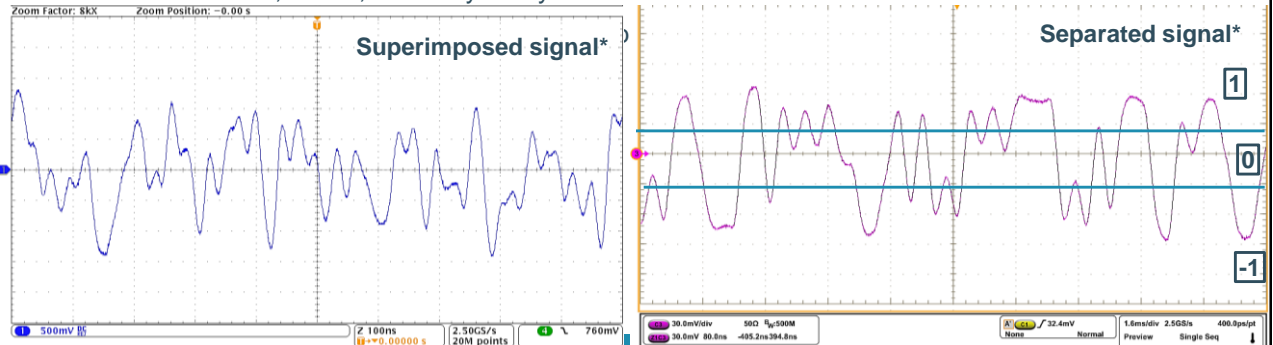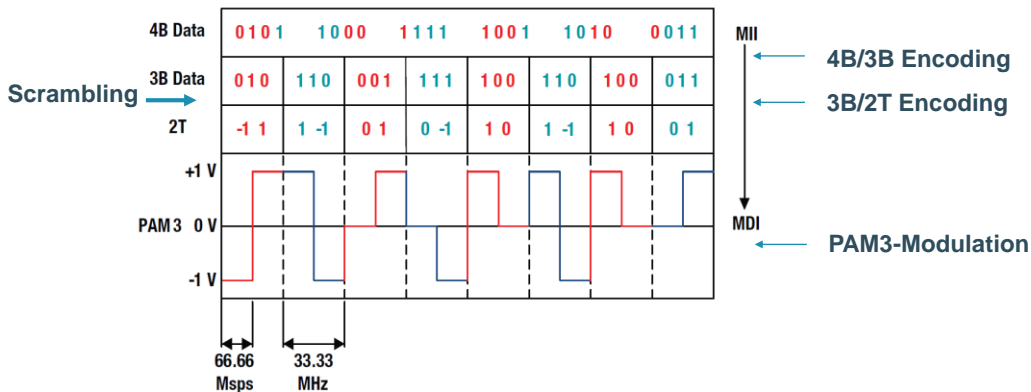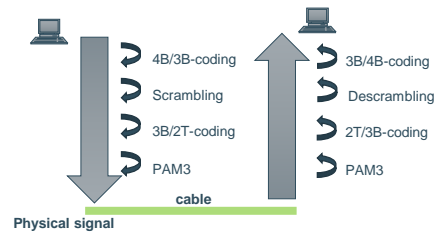
48

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10BASE-T1L Encoding

10BASE-T1L Physical signal

- **2 amplitude options: 1 V_{ptp} and 2.4 V_{ptp}**

- Max cable length: 1000 m

- Encoding systems
  - Scrambling, Disparity handling, 4B3T, PAM3
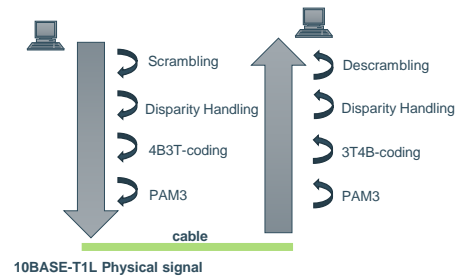
- Disparity = difference between number of transmitted "+1" and "-1" symbols
    (Aim: the long-term ratio of ones and zeros transmitted should be exactly 50%)
- Disparity handling
  - **Goal** → Achieve DC-free PAM3 transmission = DC-free 4B3T coding
  - **How** → Change 4B3T coding table based on disparity

10BASE-T1L Clause 164 Rev. D

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The Ethernet frame @ 10BASE-T1L

- Ethernet frame remains the same, except preamble and Inter Frame Gap (IFG)

- Typical PROFINET frame is 6.72 µs @100 Mbps => 10x shorter @1Gbps, but 67.2 µs @10 Mbps

- But in PROFINET networks there are also longer frames (startup, alarms … LLDP, SNMP …)

- Longest (standard) frame is 125 µs @100 Mbps => 12.5 µs @1Gbps, *but 1.25 ms @10 Mbps*

- An update time of at least 2 ms for devices connected via 10BASE-T1L

- Limited line depth (…)

Maximum line depth with update time			
Update time	1 ms	2 ms	4 ms	8 ms
Line depth	7	14	28	58

- Typical layout: switch with higher speed backbone, and a number of T1L-ports

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Outline

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  - Single Pair Ethernet Standards
- SPE: full duplex over one single twisted wire pair – How?
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- Cabling and Connectors
- Ethernet Advanced Physical Layer (APL)
- Conclusion

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PoE and PoDL Principles

*Power to device

2 Types of devices
- Load: **P**owered **D**evice **PD**
- Source: **P**ower **S**ourcing **E**quipment **PSE**

- **Power over Ethernet (PoE)**
  - PSE and PD connected through transformer center taps
  - 44-57 V
  - Max. 25,5 W* (802.3at, **4-wire cabling**)

- **SPE – Power over Data Line (PoDL)**
  - PSE and PD Connected through highpass/lowpass band splitting network
  - 12, 24, 48 V
  - Max. 50 W (802.3bu)

"A Quick Walk Around the Block with PoDL", D. Dwelly. IEEE P802.3bu Power over Data Lines Tutorial – November 2015 IEEE 802.3 Plenary

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PoDL power classes (802.3bu)

Class	12 V Unregulated PSE		12 V Regulated PSE		24 V Unregulated PSE		24 V Regulated PSE		48 V Regulated PSE	
	0	1	2	3	4	5	6	7	8	9
$V_{PSE(max)}$ (V)	18	18	18	18	36	36	36	36	60	60
$V_{PSE\_OC(min)}$ (V)	6	6	14.4	14.4	12	12	26	26	48	48
$V_{PSE(min)}$ (V)	5.6	5.77	14.4	14.4	11.7	11.7	26	26	48	48
$I_{PI(max)}$ (mA)	101	227	249	417	97	339	215	461	735	1360
$P_{Class(min)}$ (W)	0.566	1.31	3.59	6.79	1.14	3.97	5.59	12	35.3	65.3
$V_{PD(min)}$ (V)	4.94	4.41	12	10.6	10.3	8.86	23.3	21.7	40.8	36.7
$P_{PD(max)}$ (W)	0.5	1	3	5	1	3	5	10	30	50

$V_{PSE(max)} \rightarrow$ Maximum allowed voltage at the PSE PI over the full range of operating conditions
$V_{PSE\_OC(min)} \rightarrow$ Minimum allowed open circuit voltage measured at the PSE PI
$I_{PI(max)} \rightarrow$ Maximum current flowing at the PSE and PD PIs except during inrush or an overload condition
$P_{Class(min)} \rightarrow$ Minimum average available output power at the PSE PI
$P_{PD(max)} \rightarrow$ Maximum average available power at the PD PI

IEEE802.3bu

53

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Extended SPE power classes for 10BASE-T1L (802.3cg)

Class	10	11	12	13	14	15
$V_{PSE(max)}$ (V)	30	30	30	58	58	58
$V_{PSE\_OC(min)}$ (V)	20	20	20	50	50	50
$V_{PSE(min)}$ (V)	20	20	20	50	50	50
$I_{PI(max)}$ (mA)	92	240	632	231	600	1579
$P_{Class(min)}$ (W)	1.85	4.8	12.63	11.54	30	79
$V_{PD(min)}$ (V)	14	14	14	35	35	35
$P_{PD(max)}$ (W)	1.23	3.2	8.4	7.7	20	52

$V_{PSE(max)} \rightarrow$ Maximum allowed voltage at the PSE PI over the full range of operating conditions
$V_{PSE\_OC(min)} \rightarrow$ Minimum allowed open circuit voltage measured at the PSE PI
$I_{PI(max)} \rightarrow$ Maximum current flowing at the PSE and PD PIs except during inrush or an overload condition
$P_{Class(min)} \rightarrow$ Minimum average available output power at the PSE PI
$P_{PD(max)} \rightarrow$ Maximum average available power at the PD PI

* Single-pair Power over Ethernet (SPoE) use these classes. Refer to Ethernet Alliance.

IEEE802.3cg
https://ethernetalliance.org/wp-content/uploads/2021/07/EA_TechBrief-SPE-SPoE_FINAL.pdf

54

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Outline

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- Power over Data Line (PoDL)
- **Cabling and Connectors**
- Ethernet Advanced Physical Layer (APL)
- Conclusion

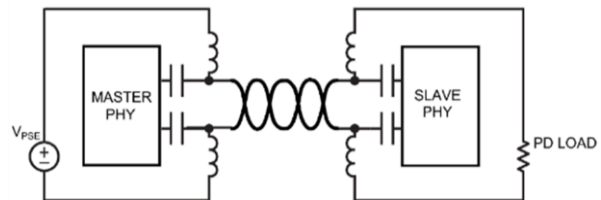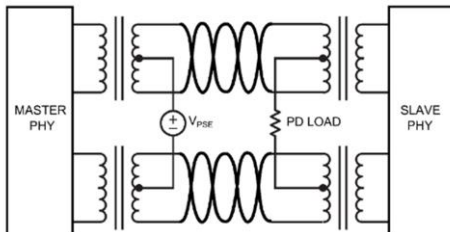**Single Pair Ethernet**
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(Industrial) Cabling for Single Pair Ethernet

"The standard makes the impossible possible in terms of utilizing Ethernet for two-wire long-distance communications" (TI [1])

- **100BASE-T1, 1000BASE-T1**

    (1) Application Report: Extend Network Reach with IEEE 802.3cg 10BASE-T1L Ethernet PHYs, Texas Instruments

    - 40 m
    - Shielded
    - Defined in IEC 61156-11 (fixed installation) and IEC 61156-12 (flexible installation)
    - 600 MHz bandwidth required
    - 100 Ω characteristic impedance

- **10BASE-T1L**
    - (Minimum) 200 m (1 V_{ptp}), 1000 m (2.4 V_{ptp})   *(TI: 1000 m (1 V_{ptp}), up to 2000 m (2.4 V_{ptp}))*
    - Shielded
    - 20 MHz bandwidth required
    - Cabling requirements fit Fieldbus type A cable (e.g. PROFIBUS PA, Foundation Fieldbus) !
    - 100 Ω characteristic impedance

Single Pair Ethernet
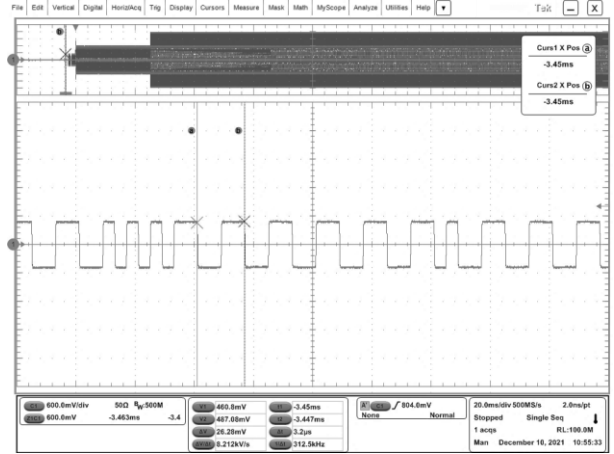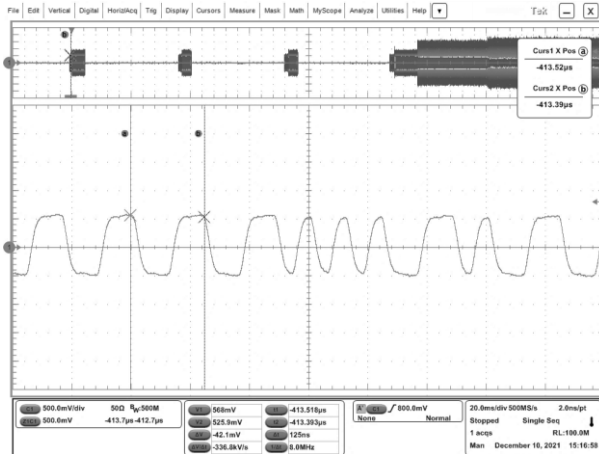*ISEP, Porto – 08/11/2023*

Negotiation phase has different properties !

100BASE-T1 negotiation
Lowest frequency 8 MHz

10BASE-T1L negotiation
Lowest frequency 312,5 kHz

- (Long) Brownfield cables with high insertion losses around 500 kHz may limit the T1L length
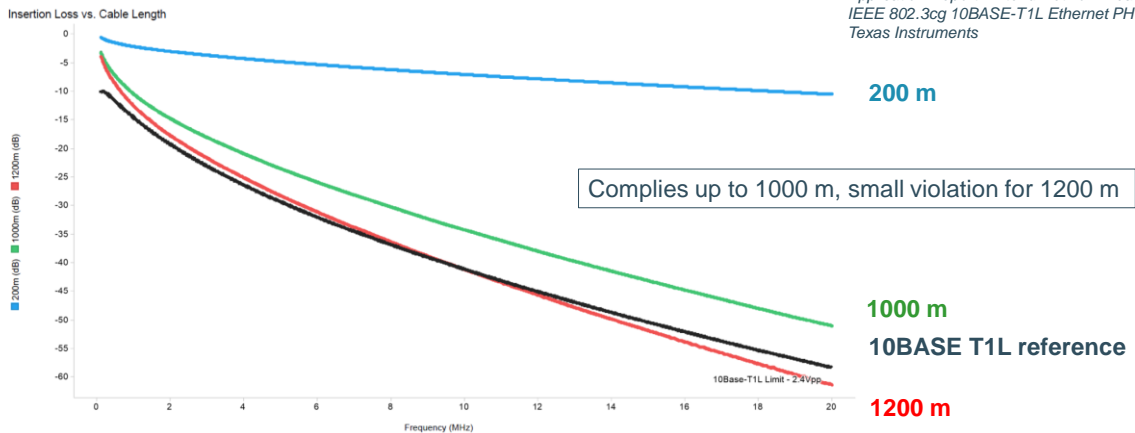

57   Single Pair Ethernet
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Cabling Parameters – Measurement example

- Insertion loss measurements on brownfield fieldbus cable *(Texas Instruments)*
- Black is the reference. Cable complies (also for auto-negotiation), until 1000 m (and up to 2000 m in forced mode for "negotiation")

Siemens 6XV1830-5EH10 Cable

Application Report: Extend Network Reach with IEEE 802.3cg 10BASE-T1L Ethernet PHYs, Texas Instruments

Insertion Loss vs. Cable Length

200 m

Complies up to 1000 m, small violation for 1200 m

1000 m
10BASE T1L reference

1200 m

58   Single Pair Ethernet
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Cabling Parameters – Measurement example

- Insertion loss measurements on brownfield fieldbus cable *(Texas Instruments)*
- Black is the reference. Cable does not comply for these lengths (for auto-negotiation until 260 m OK), and up to 600 m in forced mode "negotiation".

Belden 3076F Cable

Complies up to 400 m

600 m

800 m ● 10BASE-T1L Reference

Application Report: Extend Network Reach with IEEE 802.3cg 10BASE-T1L Ethernet PHYs, Texas Instruments
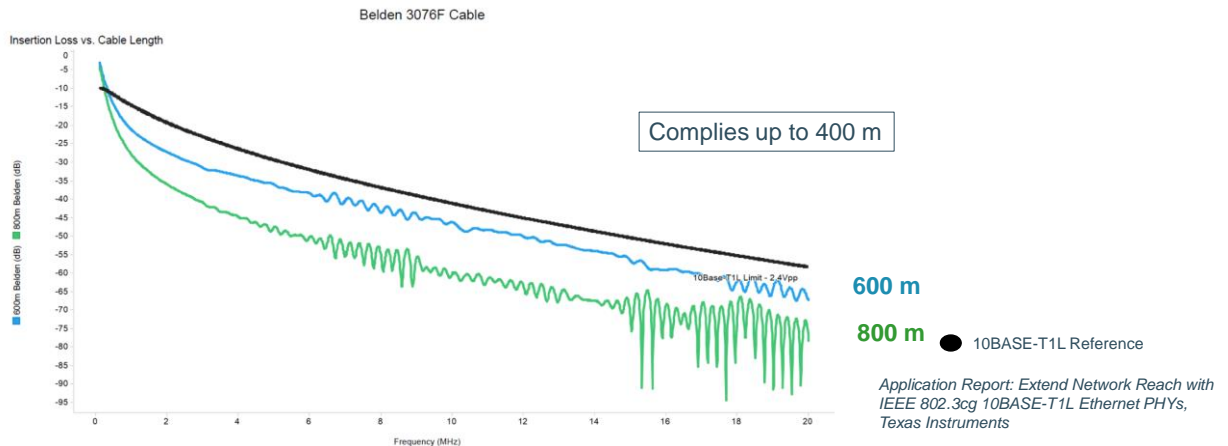
59   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

(Industrial) Cabling for Single Pair Ethernet

- **Dedicated SPE cable**
- **Profibus PA-test**
  - Cabling requirements fit Fieldbus type A cable (e.g. PROFIBUS PA, Foundation Fieldbus)
  - Legacy PA cable can be used (cf. CINI4.0 tests)
- **EMC-test by Pepperl+Fuchs**
  - Connections can be used !
  - (Minimum) 200 m (1 V_{ptp}), 1000 m (2.4 V_{ptp})   *(TI: 1000 m (1 V_{ptp}), up to 2000 m (2.4 V_{ptp}))*
- **Update:** Nexans is designing a passive connector converting a CAT7 cable into 4 SPE cables.

60   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

Industrial connectors for SPE

- Defined in IEC 63171
- IP20-IP67
- M8, M12, Plugin connectors
- 4-wire hybrid connectors with 2 data and 2 power pins exist (e.g. Perinet, member of the CINI4.0 User Committee)

61   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

Industrial connectors for SPE

ISO/IEC 63171   **CONNECTORS FOR ELECTRICAL AND ELECTRONIC EQUIPMENT**

	IEC 63171-1	IEC 63171-2	IEC 63171-3	IEC 63171-4	IEC 63171-5	IEC 63171-6
Company	Commscope	PxC, WM, RdM	SIEMON	BKS	PxC, WM, RdM	Harting
Picture						
Type	LC-Style	Rectangle	TERA IP	Square-shaped	M8 / M12	Rectangle / M8 / Push Pull
#Pairs	1	1	1 / 4	1	1 / 4	1
Degree of protection	IP20	IP20	IP20	IP20	IP67	IP20 / IP67

62   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

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63

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Ethernet – APL (Advanced Physical Layer)

- Ethernet-APL is more than just Single Pair Ethernet.
- Ethernet-APL is made up of
    - Single Pair Ethernet (IEEE 802.3cg-2019, 10BASE-T1L) (extended power classes)
    - 2-WISE: 2-Wire Intrinsically Safe Ethernet (IEC 60079) (compare to FISCO)
    - Type A fieldbus cable (IEC 61158-2, for intrinsic safety).
- The Ethernet-APL cable specification is important because end users can potentially re-use existing installed Type A fieldbus cable.
    - Characteristic impedance 100 Ω.
    - Type A two-wire cable with shielding is polarity independent to reduce installation errors.
    - Up to 10 connections:

        SP1-100 Channel (18 AWG)

        1000m Maximum
        C1 C2 C3 C4 C5 C6 C7 C8 C9 C10
    - Few tools (screwdriver, wire preparation tools to physically connect) needed.
    - Analog Devices showed on the HM 2022 combined T1L and TSN in one device, including cable "ageing and wear" detection. Also refer to Lapp (and Helmholz), Igus, Indu-Sol for "ageing and wear" detection.
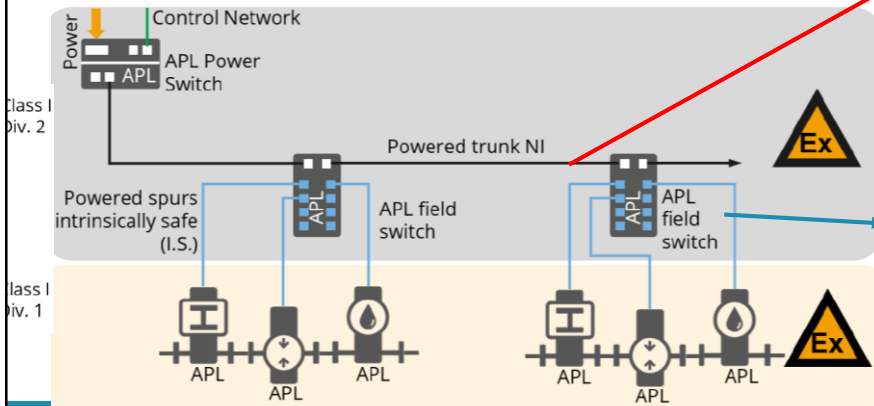
64

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APL Topology – Link Types

"Bring Ethernet to the field"

➢ 1 Ethernet network for Field and Control level

➢ Facilitate IIoT and Industry 4.0

➢ Allow easy migration from existing brownfield

Trunk line
- APL power- & field switches
- 1000 m
- 2.4 V_{ptp}
- High power (up to 57.5 W)

Spur line
- APL field switch & field device
- 200 m
- 1 V_{ptp}
- Low power (up to 1.1 W)
- Strictest IS classification

65   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*   CINI4.0 cornet KU LEUVEN

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66   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*   CINI4.0 cornet KU LEUVEN
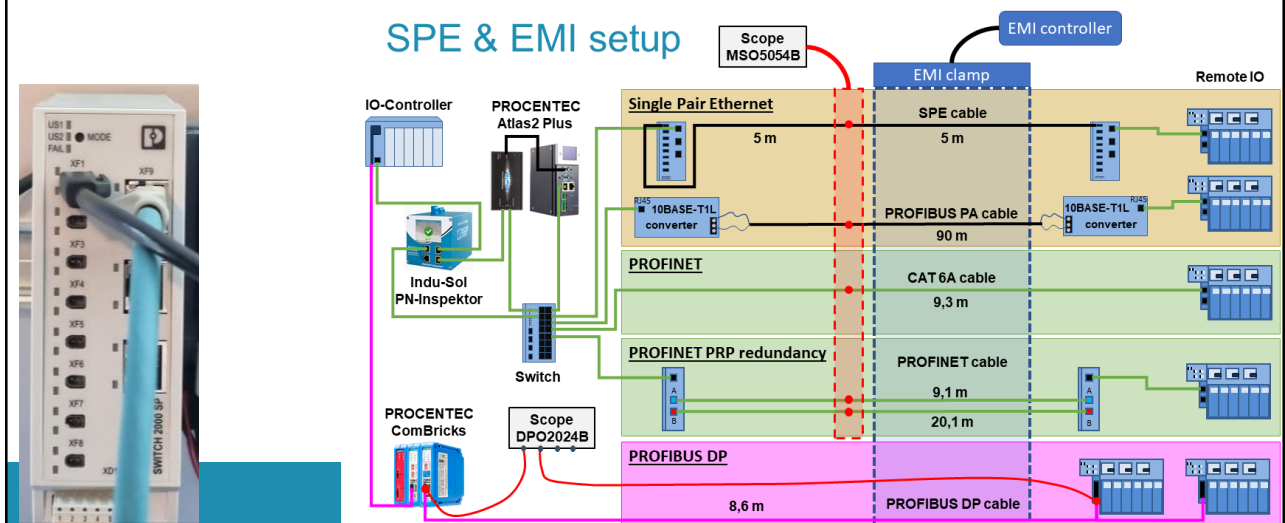
Single Pair Ethernet

- SPE provides another physical layer that can be used by the network design engineer

- ... But with some distinct advantages!
  - Smaller, lighter, simpler cabling and connectors, simpler field assembly
  - Nothing changes in the OSI Layer 2-7
  - No gateways needed anymore

- Different SPE standards allow for flexible network design
  - High bandwidth
  - Very long distance, with potential reuse of existing type A fieldbus cable
  - Power over Data Line
  - Ethernet-APL
  - …

67   **Single Pair Ethernet** *ISEP, Porto – 08/11/2023*

About the demonstrators … Single Pair Ethernet (SPE)

SPE & EMI setup

About the demonstrators … Single Pair Ethernet (SPE)

SPE & EMI setup

Questions?

Single Pair Ethernet
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