

The Ethernet physical layer revisited

CINI4.0 - Converging Industrial Networks for Industry 4.0

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Outline

- Technology classes Copper cable
- The 100 Mbps Ethernet voltage signals
- Signal and packet measurement methods
- Conclusion



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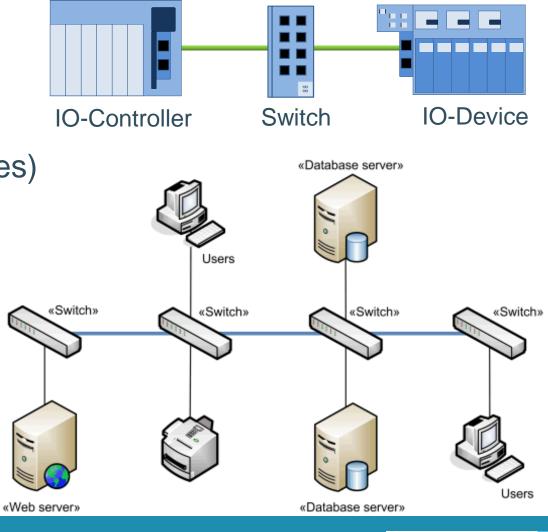
Technology classes

Physical media



Technology classes – Switched/Fast Ethernet

- 100 Mbps
- Point-to-point links
- Full duplex => min 2 wire pairs (4 wires)
- Intelligent switching => collision free
- Topologies:
 - Star
 - Line
 - Tree
 - Ring



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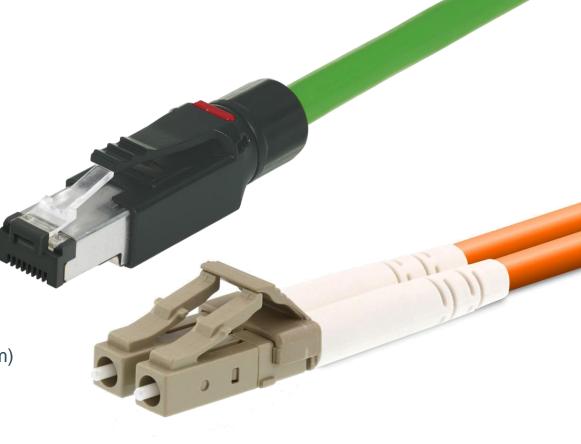
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Technology classes

- Copper wire (100BASE-TX) (IEEE 802.3u)
- Fiber Optical Cable (100BASE-FX) (IEEE 802.3u)
 - Plastic Optical Fiber (50 m)
 - Hard Clad Silica (100 m)
 - Glass Fiber multi-mode (2 km) and single-mode (14 km)
- Wireless:
 - Wi-Fi (IEEE 802.11g) => limited to 54 Mbps & half duplex
 - Bluetooth (IEEE 802.15.1) => limited bandwidth either half-duplex or full-duplex

Typically industrial ethernet communication only uses 5 to 10% bandwidth of 100BASE-TX => Wireless bandwidth can be sufficient but introduces more jitter and a less reliable medium

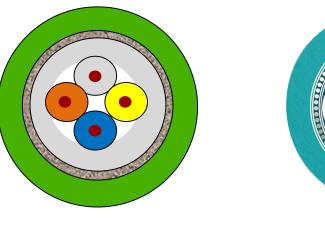


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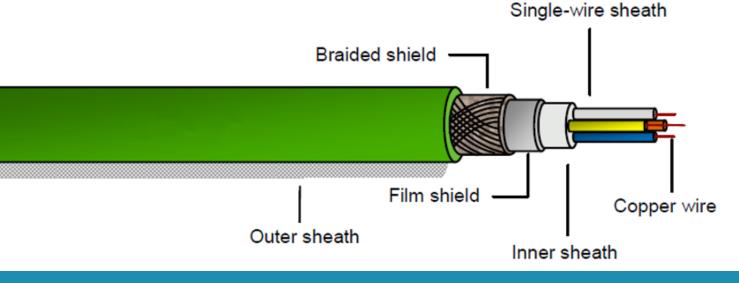
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Technology classes: copper cable

- 4 core cable
 - 2 wire pairs -> Full duplex
 - Allows Power over Ethernet (Mode A)
 - Star-quad cable or Twisted pair
- Typically Shielded for Industrial use



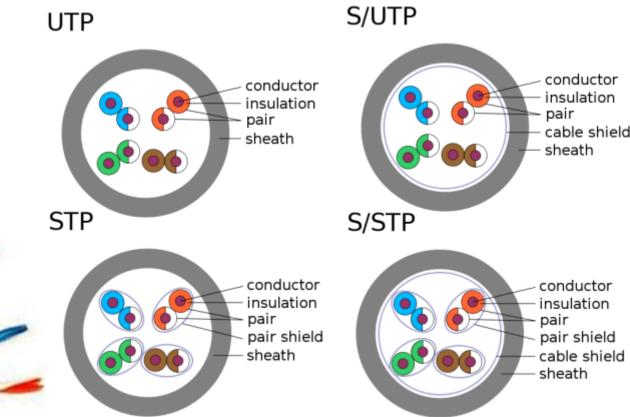






Technology classes: copper cable

- 8 core cable
 - 4 wire pairs -> Full duplex
 - Allows for 1Gbps communication and Power over Ethernet (Mode B and 4-pair mode)
 - Twisted pair
- Shielded (S/STP or S/UTP)



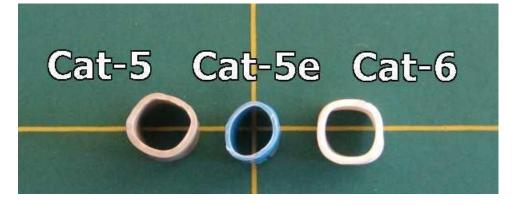


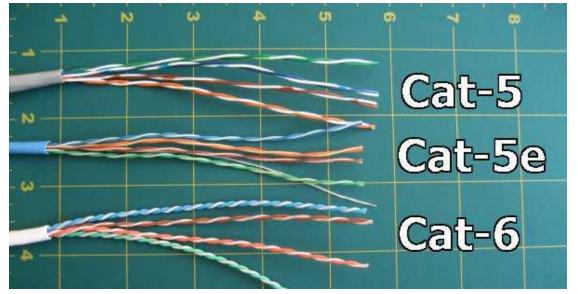
Technology classes: cable categories (CAT)

Higher category means:

- Less crosstalk (XT), less alien crosstalk (AXT) and less near end crosstalk (NEXT)
- Higher speed/bitrate due to higher bandwidth

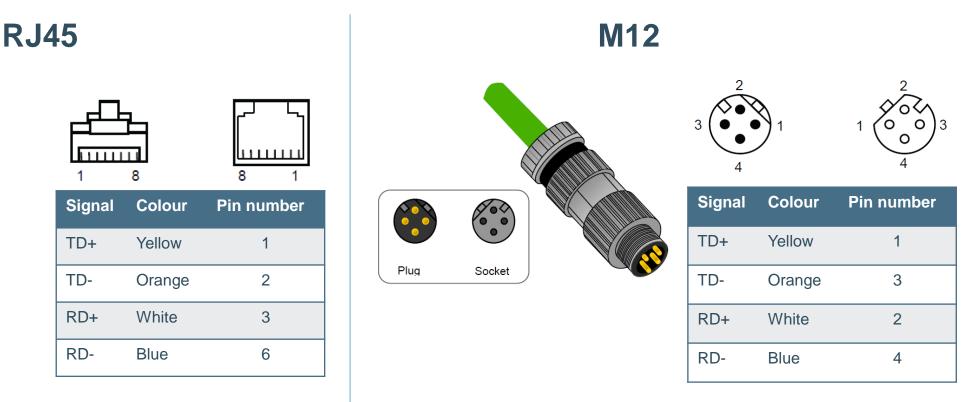
Category	Length (meters)	Speed/bitrate	Bandwidth (MHz)		
Cat-5	100	Up to 100 Mbps	100		
Cat-5e	100	Up to 1 Gbps	100		
Cat-6	100 (55m for 10 Gbps)	Up to 10 Gbps	250		
Cat-6a	100	Up to 10 Gbps	500		







Technology classes: copper connector



As we use shielded copper cables the connectors need to be shielded for a correct interconnection of the shielding

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The 100 Mbps Ethernet voltage signals



Ethernet signal decoding – Ethernet II frame format

- Data is sent in frames, also called packets
- Frames consist of bytes (groups of 8 bits)
- MAC-address communication at switch level (Data link layer)
- Payload depends on protocol used (TCP/IP, UDP/IP, ...)

	8 bytes		6 bytes	6 bytes	4 bytes	2 bytes	42 to 1500 bytes	4 bytes
Prea	amble	SFD	Destination Address	Source Address	VLAN TAG	Type / Length	Data / Payload	Frame Check Sequence (CRC)

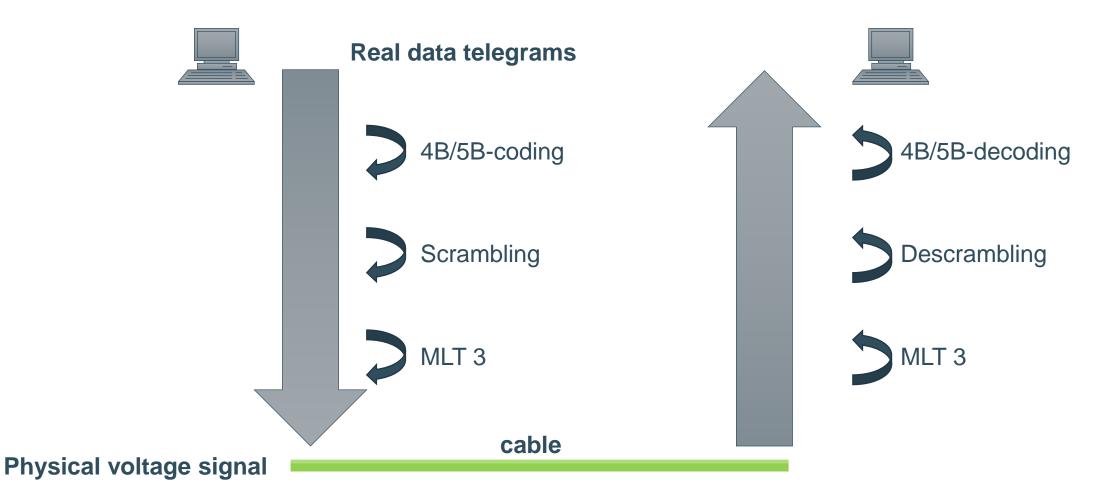
Situating Ethernet in the OSI model

Application	End User layerHTTP, FTP, IRC, SSH, DNS
Presentation	Syntax layerSSL, SSH, IMAP, FTP, MPEG, JPEG
Session	 Synch & send to port API's, Sockets, WinSock
Transport	End-to-end connectionsTCP, UDP
Network	PacketsIP, ICMP, IPSec, IGMP
Data Link	FramesEthernet, PPP, Switch, Bridge
Physical	 Physical structure Coax, Fiber, Wireless, Hubs, Repeaters

SFD = Start of Frame Delimiter CRC = Cyclic redundancy check



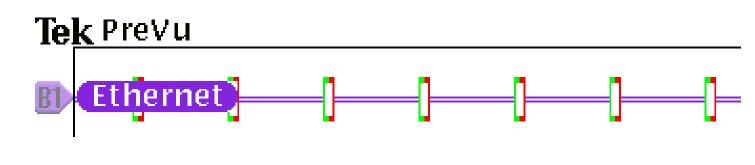
Ethernet signal decoding - overview





4B/5B-coding

- Raw IO-data: possible loss of synchronisation For long series of '0': possible loss of synchronisation between transmitter and receiver
- 4 data bits = 5 bits on the line
- Extra signalling codes possible
- Resulting in 125 Mbps

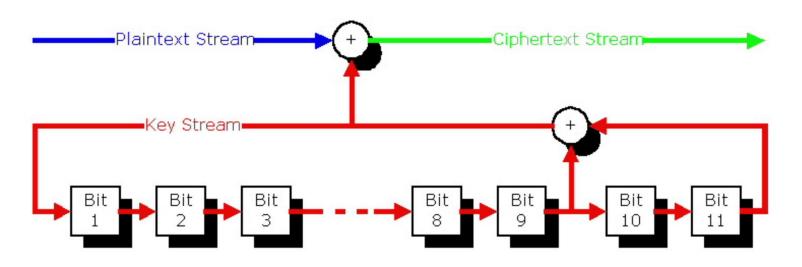


Bin 4b	Code	Bin 5b	Description
0000	0	11110	Data
0001	1	01001	Data
0010	2	10100	Data
0011	3	10101	Data
0100	4	01010	Data
0101	5	01011	Data
0110	6	01110	Data
0111	7	01111	Data
1000	8	10010	Data
1001	9	10011	Data
1010	А	10110	Data
1011	В	10111	Data
1100	С	11010	Data
1101	D	11011	Data
1110	E	11100	Data
1111	F	11101	Data
	I.	11111	Idle
	J	11000	SSD (Part 1)
	K	10001	SSD (Part 2)
	L	01101	ESD (Part 1)
	R	00111	ESD (Part 2)
	Н	00100	Transmit Error



Scrambling

- Reduce number of signal transitions -> lower signal frequency
- More robust data communication
- Using pseudo-random seed
- Through an 11 bit XOR shift register





Scrambling **IO-Device IO-Controller** Switch Signal after switch **Signal before switch** PREAMBLE SFD 000E 8CFD 00E7 PREAMBLE SFD _FL, 14 1.00 44, m

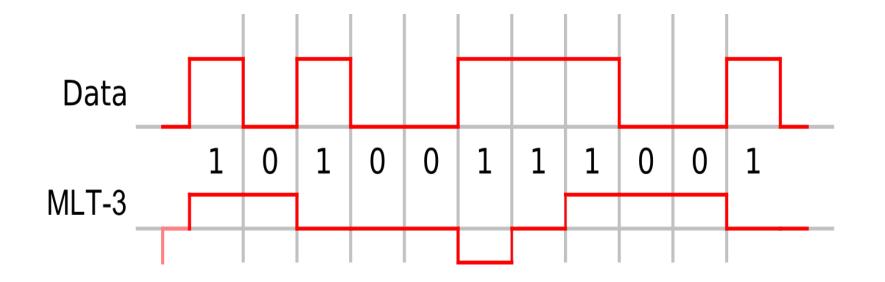


00:0E:8C:FD:00:E7

MLT 3

- Multi-Level Transition 3: Working principle
 - Logic high bit = Signal transition
 - Logic low bit = Constant signal level

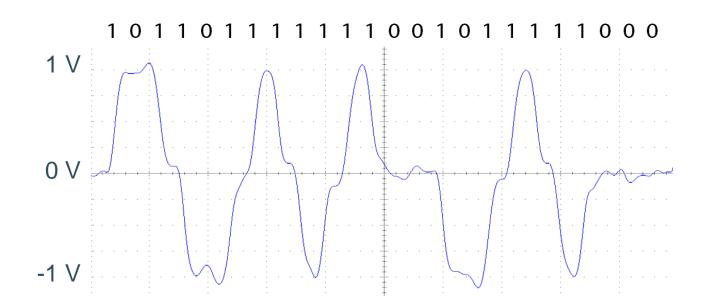
Voltage levels: -1, 0, 1 V





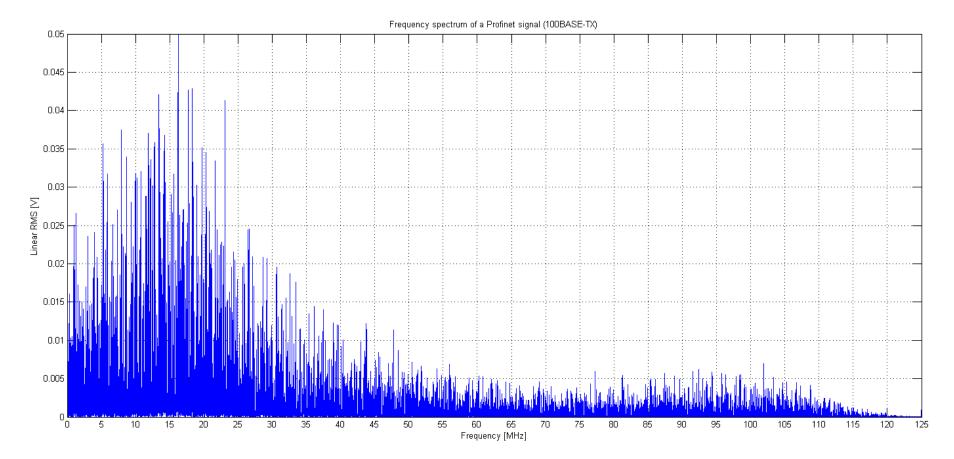
MLT 3

- Multi-Level Transition 3
- Reduces the maximum signal frequency
- Differential voltage measured on 1 wire pair





Frequency components



Peak amplitude at a frequency of 15,625 MHz



Outline

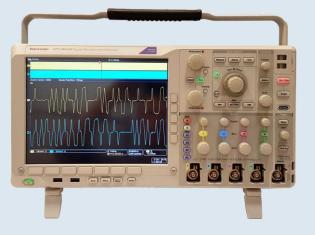
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Signal and packet measurement methods for industrial applications

Wireshark

Oscilloscope







Wireshark – a free software tool

- High level diagnostics
- Short loggings
- Measure all Ethernet traffic
- Where to measure?
 - Connect to normal switch port
 - Connect to mirror port (Throughput & switching priorities)
 - Use Ethernet tap
 - Export pcap-file from diagnostic devices

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Ар	ply a di	splay filt	ter <	Ctrl-/>											* E	xpression	.
No.		Time			Source			Destinat	tion		Protoco	l Lengt	th	Info			
	1	14:4	5:23,2	220224	10.128.2	4.71		10.128	3.24.2	54	DNS	9	90	Standard query 0xca	47 A	mobile	
	2	14:4	5:23,2	223557	10.128.2	4.254		10.128	3.24.7	'1	DNS	10	96	Standard query resp	onse	0xca47	
	3	14:4	5:23,2	273625	Cisco_0b	:8e:e4		Broado	ast		ARP	6	50	Who has 10.128.27.0	? Te	11 10.1	
	4	14:4	5:23,3	313781	10.128.2	4.200		10.128	3.31.2	55	BROWS	ER 24	43	Host Announcement P	CGEN	T20735,	
	5	14:4	5:23,3	333730	10.128.2	4.71		10.128	3.31.2	55	NBNS			Name query NB WPAD<			
	6	14:4	5:23,3	333908	10.128.2	4.71		224.0.	0.251		MDNS			Standard query 0x00			
				334161	10.128.2	4.71		224.0.	0.252		LLMNR			Standard query 0x47			_
				334312	10.128.2	4.71		224.0.	0.252	!	LLMNR			Standard query 0x40			
				425302	10.128.2			10.128			NBNS			Name query NB ISATA	P<00	>	
			-	431668	204.79.1			10.128	3.24.7	'1	TLSv1			Application Data			
				431709	10.128.2			204.79			TCP			57989 → 443 [ACK] S			
Г				479475	10.128.2			54.152			TCP			[TCP segment of a r	easse	embled	
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Website: https://www.wireshark.org/

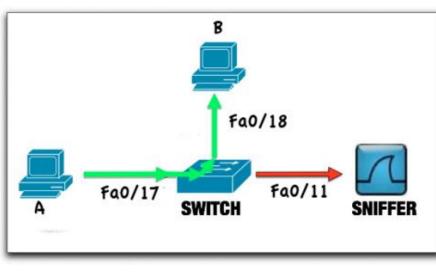


Wireshark – Where to measure

Using a switch

- Connect to normal switch port
- Connect to mirror port

Inaccurate timestamps!







Examples of industrial switches



Wireshark – Where to measure

Using an Ethernet TAP (Terminal Access Point)

- As USB connected ethernet adapter
- Or connected directly to a PC's ethernet port





Examples of Ethernet TAPs



Wireshark – Where to measure

Using Diagnostic devices

- Passive connection in the network
- Permanently monitors the communication
- Snapshot are taken on specific trigger conditions
 Snapshots can be exported as pcap-files (Wireshark format)
- Allows for packets to be mirrored to a dedicated port





Examples of diagnostic devices



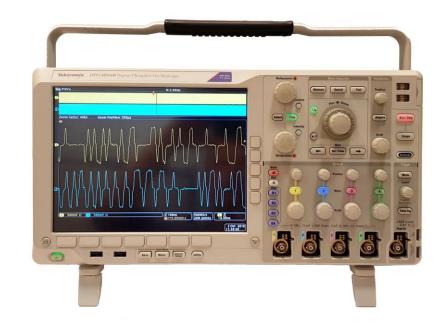
Oscilloscope

• Why?

Visual voltage signals and accurate timestamps Allows measurement on multiple locations in the network Combination of analog signals and network frames

• Waveform can be seen

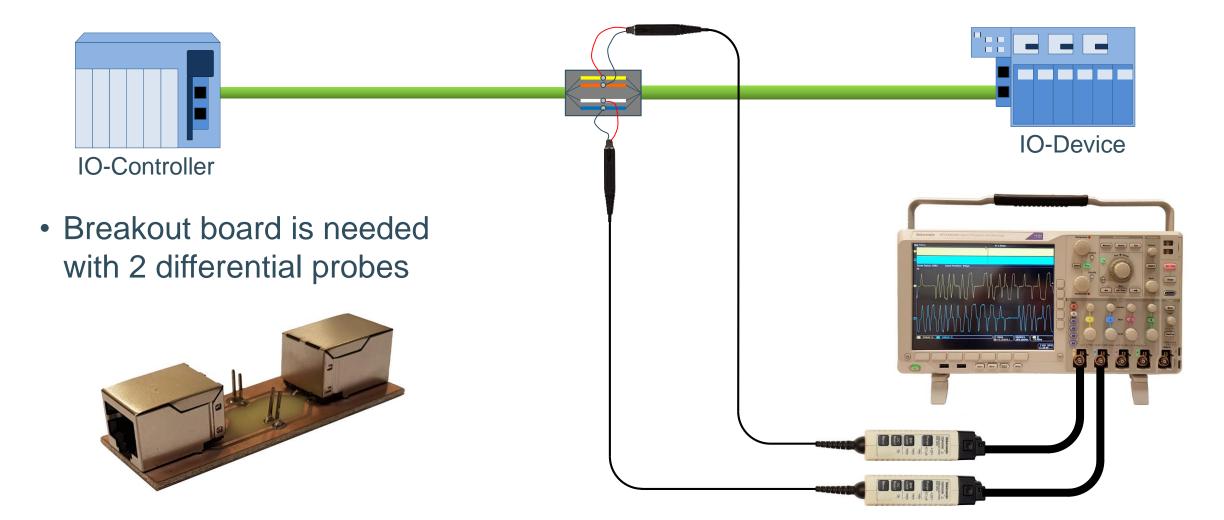
- But can't be decoded by hand
- Amount of data can be measured/analysed at once
 - 500 MS/s, 20 MS/ch => 40 ms
 - 500 MS/s, 125 MS/ch => 250 ms
- Useful for highly accurate timing measurements
- Decoding possibilities
 - Some scopes can decode a clean and distortion free ethernet voltage signal



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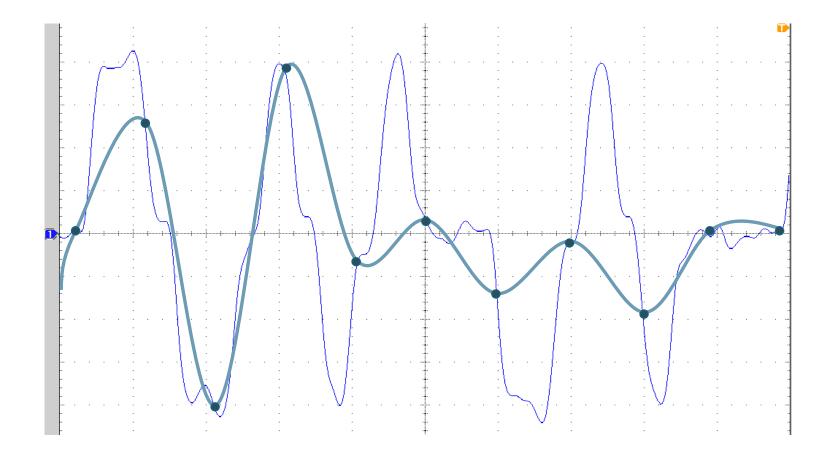
Oscilloscope – How and where to measure





Oscilloscope - Effect of the sampling rate

Low sampling rate
 → Wrong signal

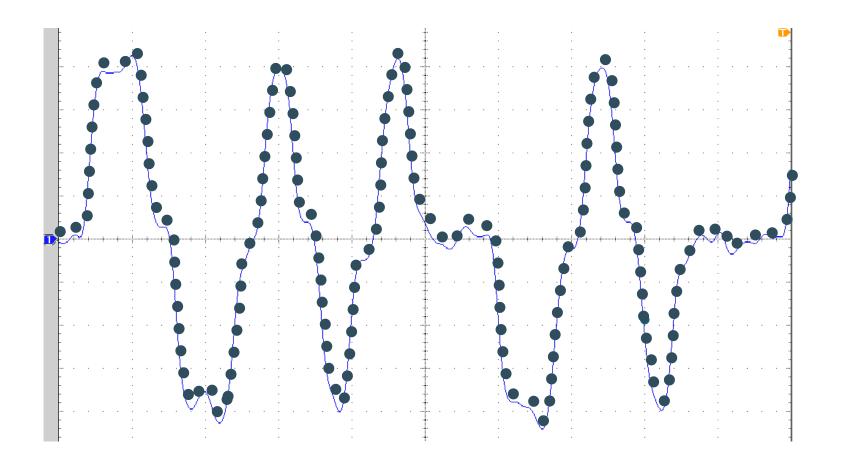




Oscilloscope - Effect of the sampling rate

- Low sampling rate
 → Wrong signal
- High sampling rate
 → Correct signal

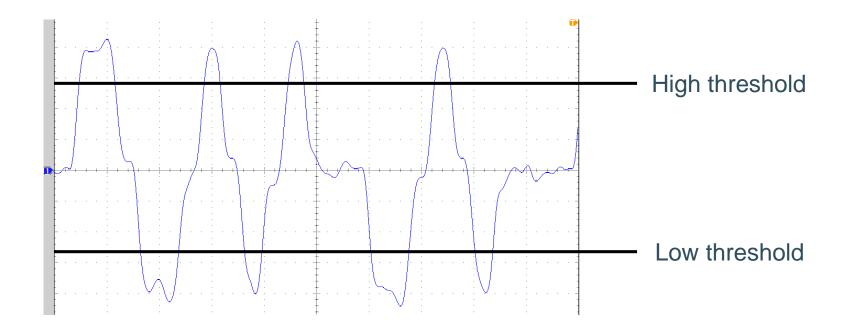
In practice: 500 MS/s





Oscilloscope – Setting signal levels for decoding

- Determine voltage levels
- When will the signal be seen as a high/low level?

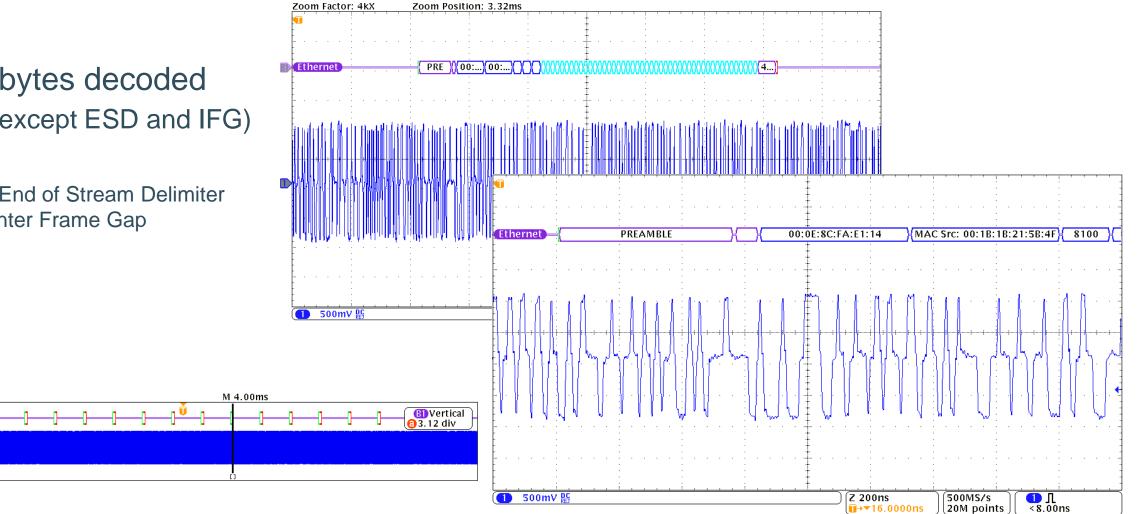




Oscilloscope – **Decoding**

 All bytes decoded (except ESD and IFG)

ESD = End of Stream Delimiter IFG = Inter Frame Gap





Tek PreVu

B Etherne

Oscilloscope – Decoding

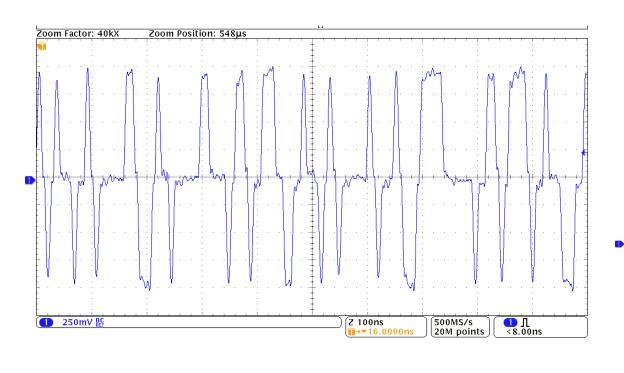
- All bytes decoded (except ESD and IFG)
- Event Table

Tek P	reVu				M 200µs					
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									4.54 UIV	4
	· · · · ·				-					
2>										
Zo	om Factor: 20	X Zoom P	osition: 491µs							
4			/ /							·
ED 🗧 🛛	Time	Destination	Source	Length	Data	FCS/CRC	Errors			<u> </u>
i.	1 mile	(hex)	(hex)	(hex)	(hex)	(hex)	LIIUI3	1		
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-	L				0000 0000 0000 0000				Event Tabl	е
4					0000 0000 80EF 2735					
<u>e</u> /					00				On Of	f
	240.5µs	000E8CE85B1C	00A04534E3CF	8892	Qtag: 8100C000	E59B6B27				_
	L				8061 8080 8080 0000				Q.131	
					8080 D982 0000 0000					
-					0000 0000 0000 0000				File Details	5
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					0000 0000 0000 0000			. i		
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Conclusion from measurements Effect of too many connectors

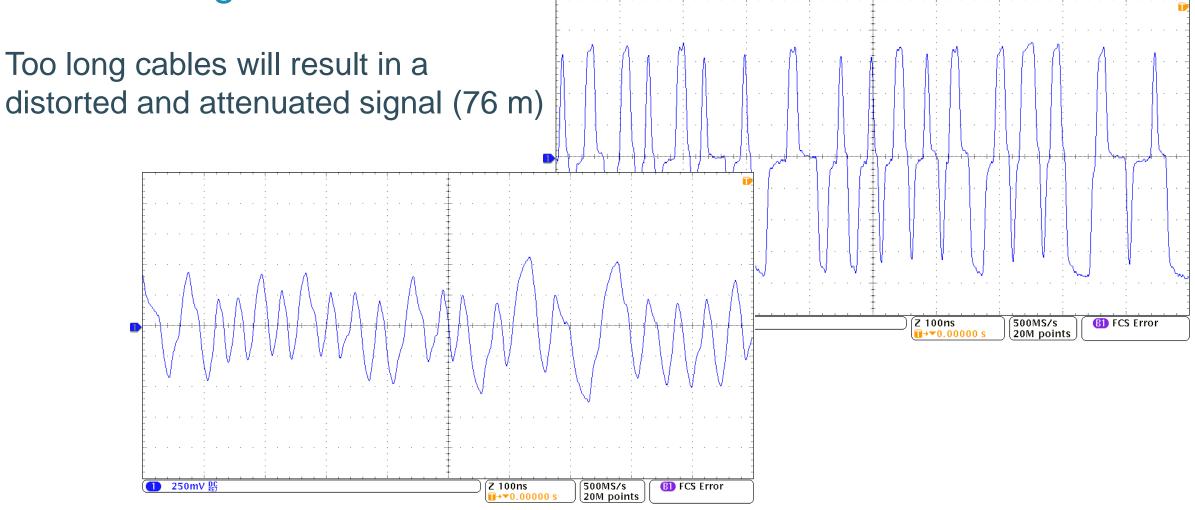
Too many connectors





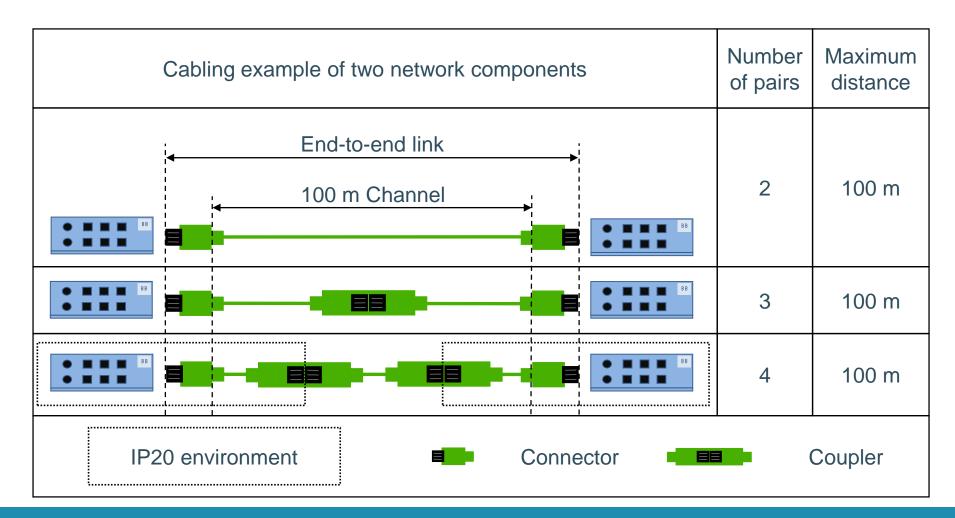


Conclusion from measurements Effect of long cables





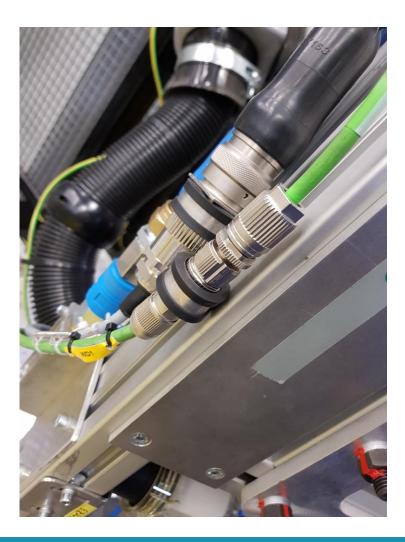
Copper cable and connectors guideline





Pay attention – Design guideline







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Conclusion

Physical layer on copper has been discussed

- MLT3 and Scrambling reduce the frequency of the voltage signal on the lines
- Voltage signals are not easily interpreted
- Cable length and amount of connectors have a measurable influence on signal quality
- Consult the Design Guidelines of the implemented Industrial Ethernet Protocol

A number of measuring methods have been discussed

- Measuring method will depend on application and the to-acquire data
- In most cases Wireshark will suffice for analysis of packets and communication
- An oscilloscope can be used for accurate timing measurements



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Questions?

