Appendix A: EMC Measurement reports

1. PROFINET Cable

1.1. Cable measurements with LCR

1.1.1. Introduction

This section provides impedance (Z) characteristics of 2 cable types. The intended use of these cables is at 1 Gbps which corresponds to a maximum fundamental frequency of 500 MHz (if the signal was a pure "1"-"0" sequence). Depending on the intended signal protocol, response at 0 Hz (DC) may be of more or less importance; if for example "0" is at - 2.5 V and "1" is at 2.5 V, there is no DC bias. Additionally, the accepted signal distortion will determine the maximum frequency of interest; the more the signal is accepted to resemble a sine wave and less a square pulse, the lower the maximum frequency of interest is i.e. closer to 500 MHz.

1.1.2. Method

General

Wire and input impedance (Z_{in}) measurements were conducted using an LCR instrument (HIOKI IM3536 with a L200 fixture) for DC and a 4 Hz – 8 MHz range, in order to define the cable characteristics that in principle define its behavior at any frequency (f). In order to get a good evaluation of the distributed electrical properties of the cable, a length of nominally 100 m was used. A shorter length (e.g. 5m) would result in the input and termination to affect the measurements to an undesirable extent. However, as a 100 m cable cannot be practically unrolled in a straight line, it is accepted that the unrolled cable properties would in principle differ, as they are free of the crosstalk between cable sections (e.g. between the 2nd meter and the 20th meter of the cable). The rolled cable is shown in Figure 1. It has to be noted that at the frequencies of the intended use, the input and output impedance will almost solely depend on the connector that will be connected at its terminals and not on the cable itself. Already at 6 MHz, strong signs of the terminations was unavoidable as shown as discussed in Section 4.2.

Impedance measurements types

Three Z measurement types were performed. Wire Z-measurements (w) for the pure conductor properties and short- (SC) and open-circuited termination (OC) Z-measurements for the transmission line(TL) characteristics. As the effect of mechanical tension is to be studied, the full set of the cables characteristics was acquired, instead of just of the transmission line that is intended to be used (i.e. the diagonal conductors transmission line as seen in the cable's cross-section). This level of investigation, will allow to study how each individual parameter is affected under mechanical strain, as the equivalent properties of a two-conductor transmission line (2cTL) depend on those of the 5-conductor (5c) cable (4 conductors + shield).

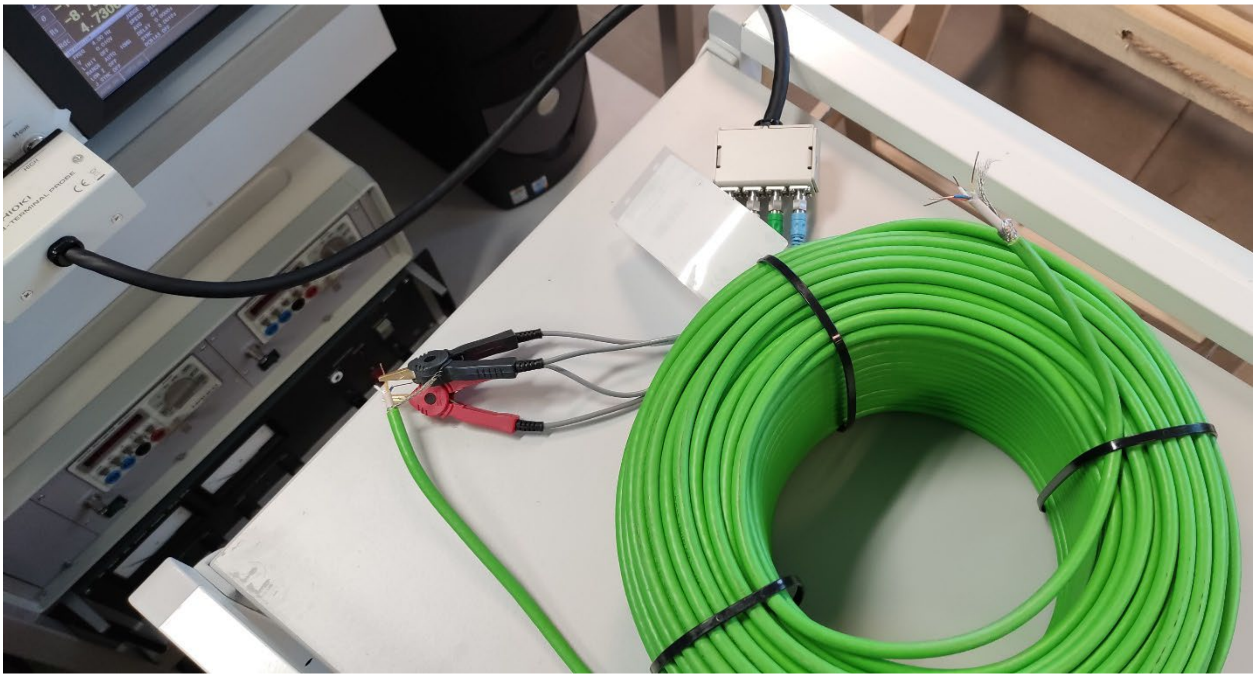


Figure 46. Rolled cable under test (OC measurement).

2.2 Connections

The cable was kept rolled and only a small part (approx. 5cm) was stripped of at each side in order to connect the source (LCR) leads and terminate at the SC measurements, without cutting any conductor length. Wire measurements were performed by connecting the LCR leads one at each side of the wire under test. Transmission line measurements were performed by connecting each 2cTL to the LCR and leaving the TL termination open (OC) or short-circuiting it by twisting the 2cTL wires together while also clamping them. Croc-type connectors at the input of the TL and a clamp at its output ensured a strong connection and thus minimisation of the effect of contact resistance.

2.3 Calibration

The properties of the leads of the LCR-fixture and the internal LCR components were extracted by mathematically uncoupling the TL under test from the source (LCR) characteristics. This was performed by measuring the OC- and SC- characteristics of the LCR and then removing their effect at each point of the frequency sweep, thus fully calibrating and eliminating the impact of the source. The very low resistance (r), inductance (L) and capacitance (C) of the LCR+fixture combination, further improves the measurement. In Figures 2 and 3, the magnitude of Z ($|Z|$) of measurements for the stranded and solid wires cables respectively can be seen.

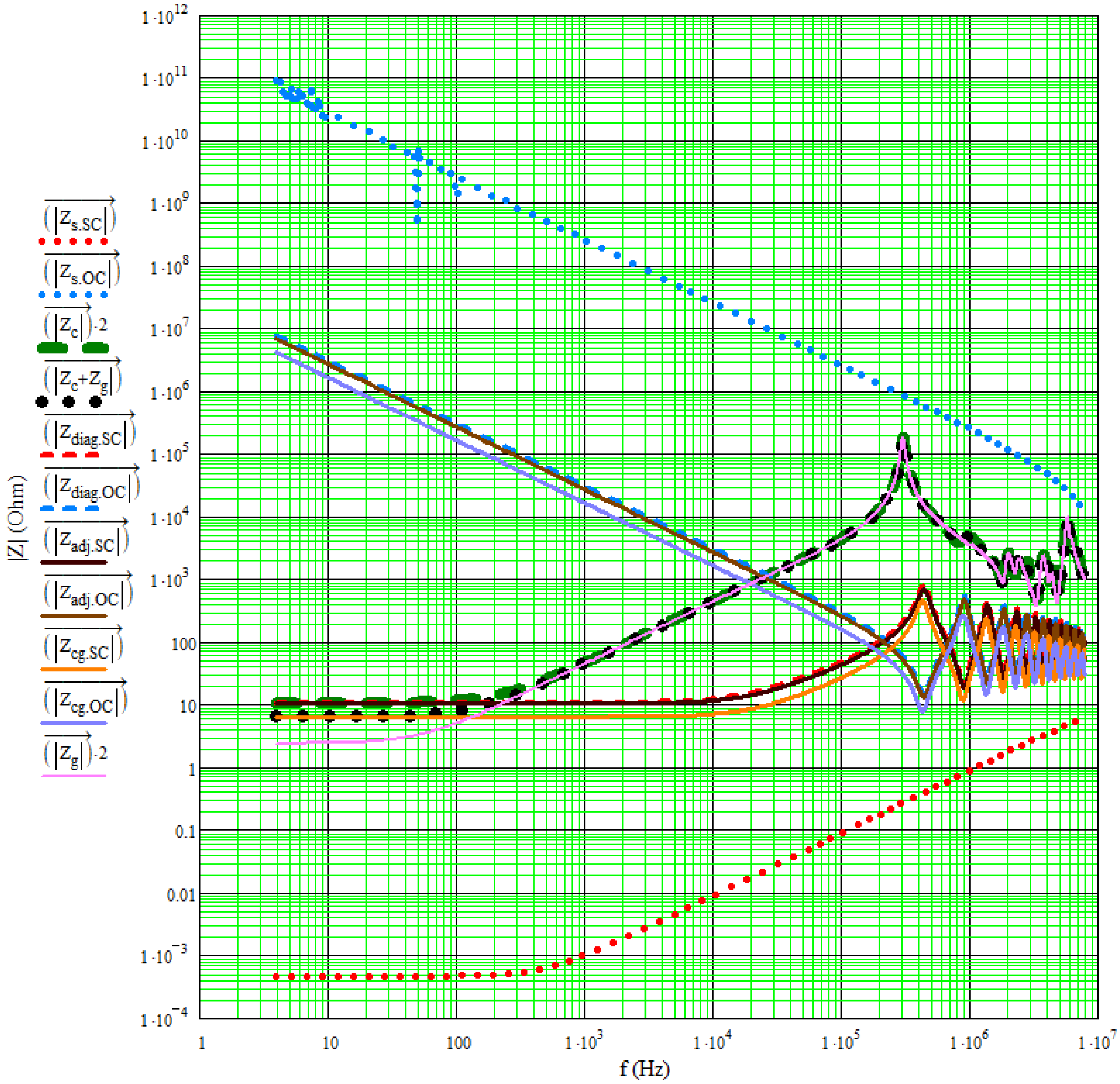


Figure 47. Source (Zs), calibrated wire (Zc, Zg) and 2cTL (Zdiag, Zadj, Zcg) |Z| (y-axis) over frequency (x-axis) for the stranded wires cable. The |Zs| curves are well distanced from the cables |Z|, ensuring a better measurement and calibration.

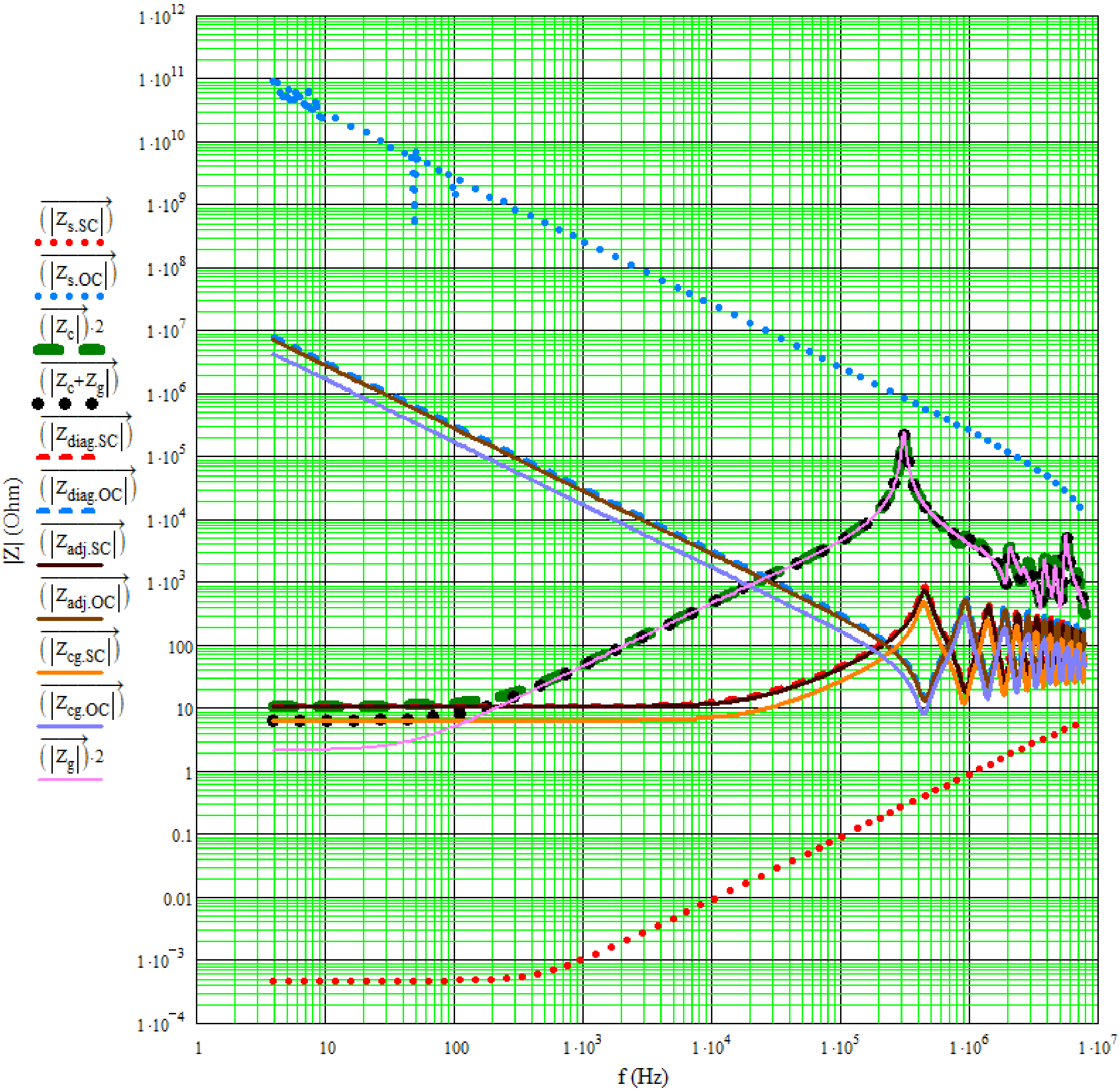


Figure 48. Source (Zs), calibrated wire (Zc, Zg) and 2cTL (Zdiag, Zadj, Zcg) |Z| (y-axis) over frequency (x-axis) for the solid wires cable. The |Zs| curves are well distanced from the cables |Z|, ensuring a better measurement calibration.

The LCR was set at its highest output setting in all measurements, in order to maximise accuracy. As no other external devices were used, the specifications (e.g. accuracy) of the Z-measurements are as stated in the manufacturer's manual.

1.1.3. Results

General

The electrical properties of the cable describe all of its conductors individually as well as all of the possible 2cTLs of the MTL. As seen in a cross section, there are 2 types of conductors: main conductors and shield and there are 3 possible 3cTLs that can be formed: diagonal-conductor (diag), adjacent-conductor (adj) and between any of the conductors and the shield (cg). Even though the diag 2cTL is of main importance for the transmission of the intended signal, its properties depend on the full MTL model. For example, a C is formed between the two diagonal conductors but this C is only one of the components of the capacitance matrix that is formed, the equivalent C of which, is the effective equivalent C of the diag 2cTL. It is noted that as inductance is mildly frequency dependent all inductances were defined at 100 kHz, at which, all wire and SC measurements were at an almost purely inductive f region.

Properties

The properties acquired were: resistance (r), self inductance (L_{self}), inductive coupling coefficient (k), and capacitance (C). As the distance between conductors differs for different 2cTLs, k and C have different values per each of the 3 aforementioned TLs. The values of the distributed properties of the MTL are stated on Tables 1,2 and 3. The values actually measured are the same for k and the resistance R_0 which is equal to the characteristic impedance Z_0 at f = ꝏ but multiplied by a factor of 100 for the rest of the properties, as a nominal length of 100 m was assumed. Conductance was beyond the measuring capabilities of the LCR, thus lower than 1/(10 GΩ) for the 100m cables for all wires and TLs measurements at DC.

The TL properties r_{TL}, L_{TL} and C_{TL} shown in Table 1, describe the respective effective equivalent transmission line properties. For example, even though the C of a TL is in reality a capacitance matrix, the equivalent C of that matrix is also a distributed property which is the C that effectively describes that TL). In Table 1, the values that describe the TL that is selected for signal transmission (diag) are in bold font. The wire properties r and L_{self} shown in Table 2, describe the two types of conductors in the cable (main conductors and shield conductor). The k and C matrix component properties shown in Table 3, describe the individual components that form the k and C matrices in the perspective of a cross section of the cable. For example, k_{diag} is the coefficient that describes the inductive coupling between two diagonal conductors. Finally, c type describes the main conductor type being a stranded or solid wire, which is the main difference between the two cable types.

TABLE 1 TRANSMISSION LINE PROPERTIES

2cTL	c type	r_{TL} (Ω/m)	L_{TL} (H/m)	C_{TL} (F/m)	R_0 (= Z_0 at f = ꝏ)
adj	*Stranded*	$1.05 \cdot 10^{-1}$	$6.00 \cdot 10^{-7}$	$5.82 \cdot 10^{-11}$	$8.76 \cdot 10^{1}$
	Solid	$1.07 \cdot 10^{-1}$	$5.93 \cdot 10^{-7}$	$5.69 \cdot 10^{-11}$	$8.81 \cdot 10^{1}$
diag	***Stranded***	$\mathbf{1.06 \cdot 10^{-1}}$	$\mathbf{6.63 \cdot 10^{-7}}$	$\mathbf{5.24 \cdot 10^{-11}}$	$\mathbf{9.78 \cdot 10^{1}}$
	Solid	$\mathbf{1.06 \cdot 10^{-1}}$	$\mathbf{6.58 \cdot 10^{-7}}$	$\mathbf{5.05 \cdot 10^{-11}}$	$\mathbf{9.97 \cdot 10^{1}}$
cg	*Stranded*	$6.43 \cdot 10^{-2}$	$3.75 \cdot 10^{-7}$	$9.50 \cdot 10^{-11}$	$5.49 \cdot 10^{1}$
	Solid	$6.39 \cdot 10^{-2}$	$3.76 \cdot 10^{-7}$	$9.20 \cdot 10^{-11}$	$5.51 \cdot 10^{1}$

TABLE 2 WIRE PROPERTIES

Wire	c type	r (Ω/m)	L_{self} (Ω/m)
c	*Stranded*	$5.28 \cdot 10^{-2}$	$3.46 \cdot 10^{-5}$
	Solid	$5.33 \cdot 10^{-2}$	$3.59 \cdot 10^{-5}$
g	*Stranded*	$1.20 \cdot 10^{-2}$	$3.43 \cdot 10^{-5}$
	Solid	$1.06 \cdot 10^{-2}$	$3.55 \cdot 10^{-5}$

TABLE 3 MATRIX COMPONENT PROPERTIES

Matrix Component	c type	Value (SI unit/m)
k_{adj}	*Stranded*	$9.91 \cdot 10^{-1}$
	Solid	$9.92 \cdot 10^{-1}$
k_{diag}	*Stranded*	$9.90 \cdot 10^{-1}$
	Solid	$9.91 \cdot 10^{-1}$
k_{cg}	*Stranded*	$9.95 \cdot 10^{-1}$
	Solid	$9.95 \cdot 10^{-1}$
C_{adj}	*Stranded*	$1.65 \cdot 10^{-11}$
	Solid	$1.69 \cdot 10^{-11}$
C_{diag}	*Stranded*	$3.36 \cdot 10^{-12}$
	Solid	$2.31 \cdot 10^{-12}$
C_{cg}	*Stranded*	$6.50 \cdot 10^{-11}$
	Solid	$6.526 \cdot 10^{-11}$

1.1.4. Discussion

General

Comparing between the two cables types, from Table 1, it can be seen that almost all properties are of the same order of magnitude and in most, almost equal. Even though the solid wires cable would provide slightly faster transmission (having slightly lower C and L), it was observed that they were very brittle and would break, if bent at a right angle for more than one or two times.

Influence of connection points and termination

On a SC or OC measurement, at point of resonance, the $|Z|$ is expected to be nearly equal to R_0, as the Imaginary part of Z is 0. Theoretically at the resonance points $|Z_{SC}|$ intersects $|Z_{OC}|$ and approximately $|Z_{SC}|=|Z_{OC}|=R_0$. Consistent increasingly strong divergence from R_0 at high frequencies, as seen above 6 MHz on Figures 4 and 5, means that the input Z (Z_{in}) of the TL is gradually taking the character of the input connector/connection instead of the cable measured. This translates to the fact that measurements beyond that f are not a pure measurement of the TL itself. Calibrating for the character of the input connector/connection at these frequencies is practically impossible as a connection or the connection leads will never be exactly the same. For example, comparing any measurement to the calibration measurements, contact resistances and small deviations of the physical positioning of the source leads have such a huge impact on the Z_{in}, that the cable properties affect Z_{in} negligibly. However, obtaining the properties at lower frequencies, enables the prediction of the Z response at any f. For example, at frequencies considerably far from the first resonance (as is the case here of 500 MHz as compared to the first TL resonances at a f lower that 500 kHz) it will approximately be $|Z_{SC}| = |Z_{OC}| = R_0$.

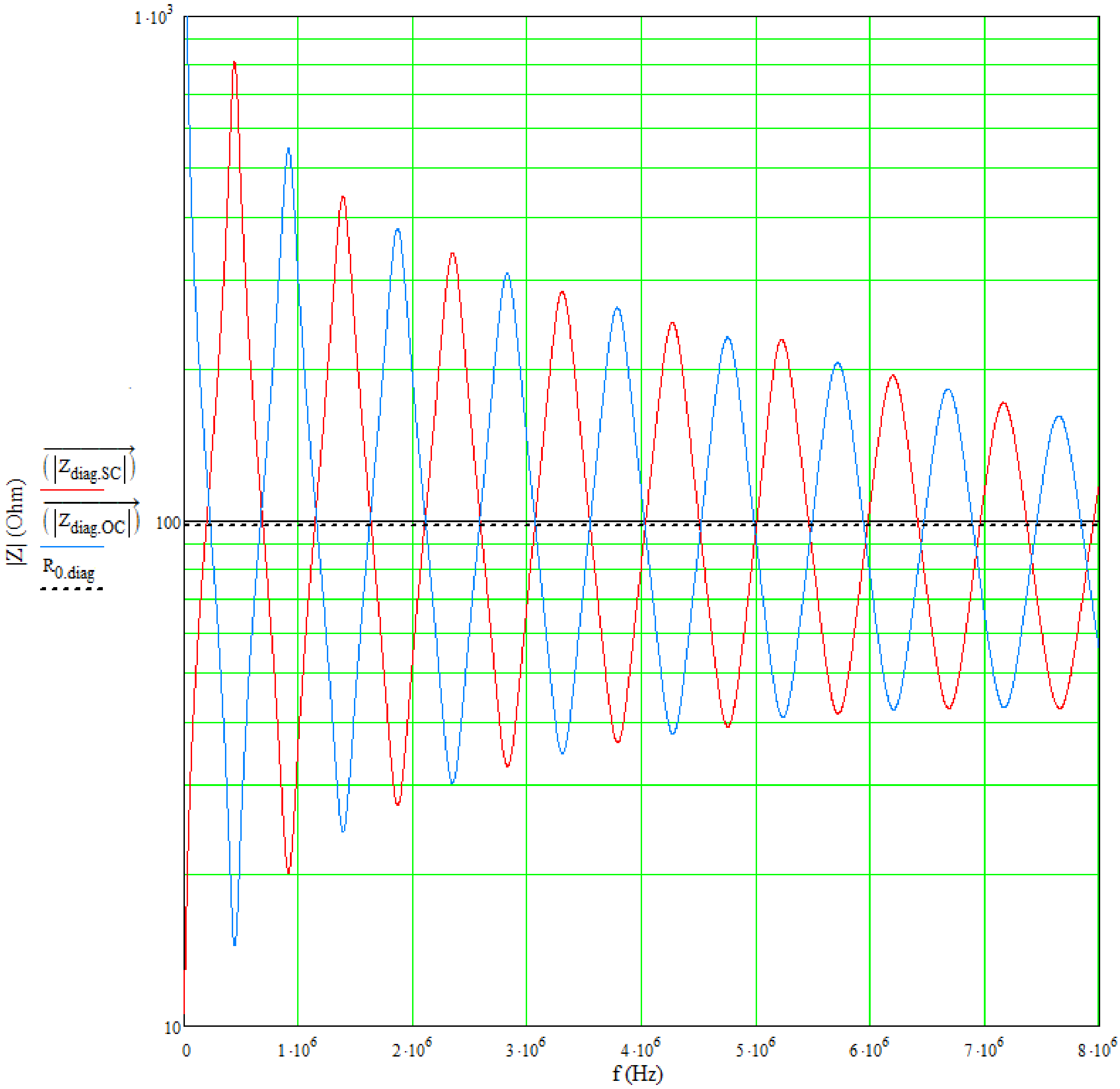


Figure 49. Calibrated |Z| (y-axis) over frequency (x-axis) for the solid wires cable diag 2cTL.

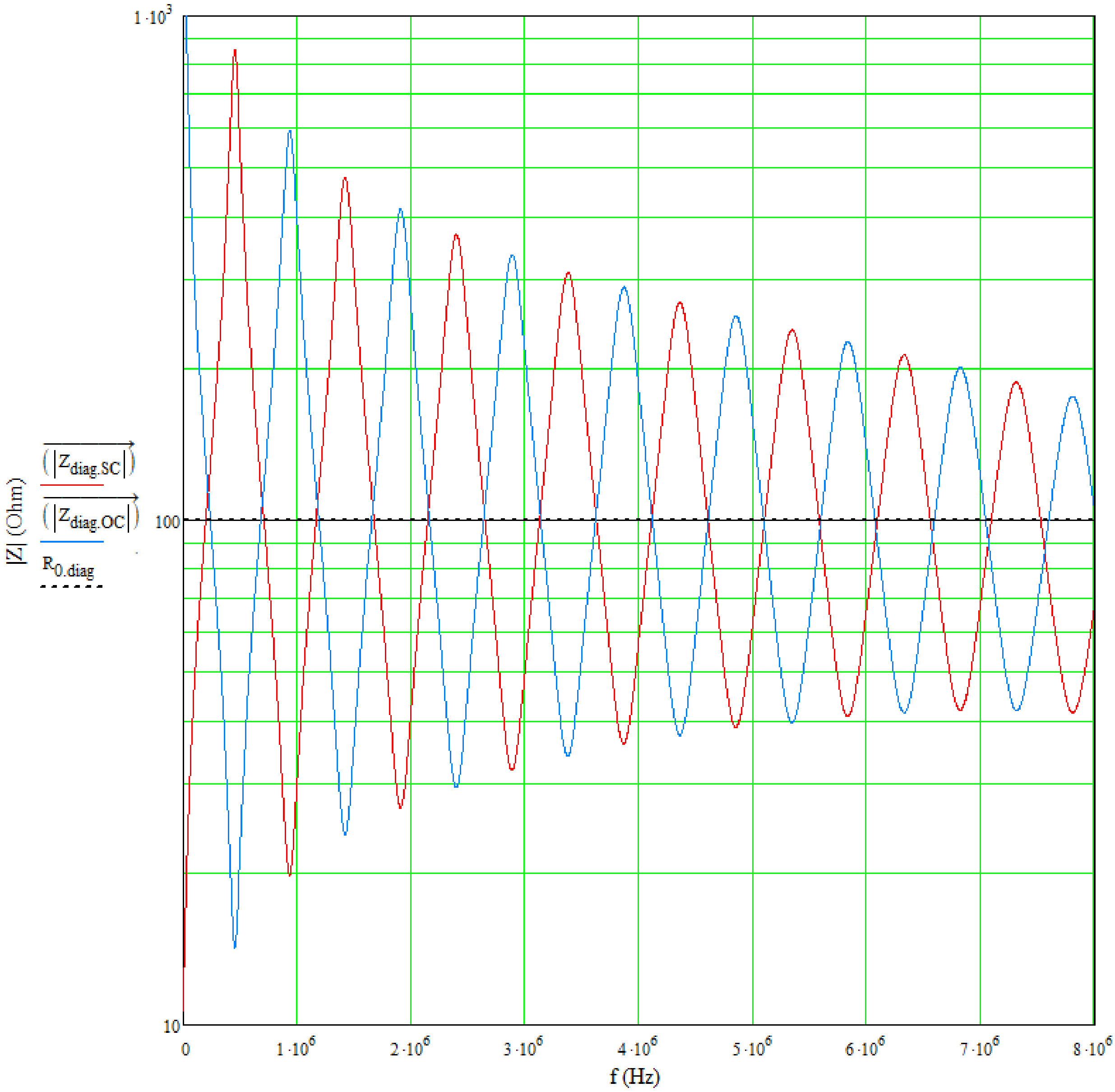


Figure 50. Calibrated |Z| (y-axis) over frequency (x-axis) for the solid wires cable diag 2cTL.

2. Impact of connections

2.1 Without connections

The Insertion Loss and Return Loss will be first tested with different cable lengths. For this experiment cable of 1m, 2m, 3m, 5m, 10m and 20m will be used.

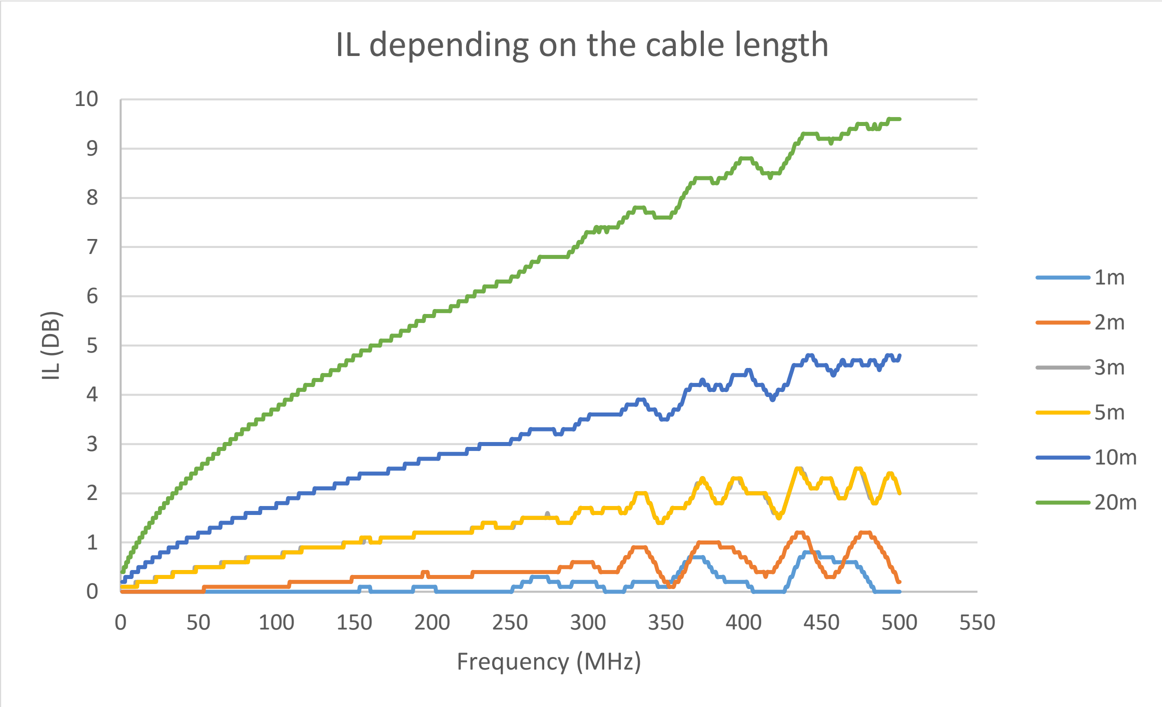


Figure 51

IL increases with as the length of a cable increases. Insertion Loss also increases when the frequency increases.

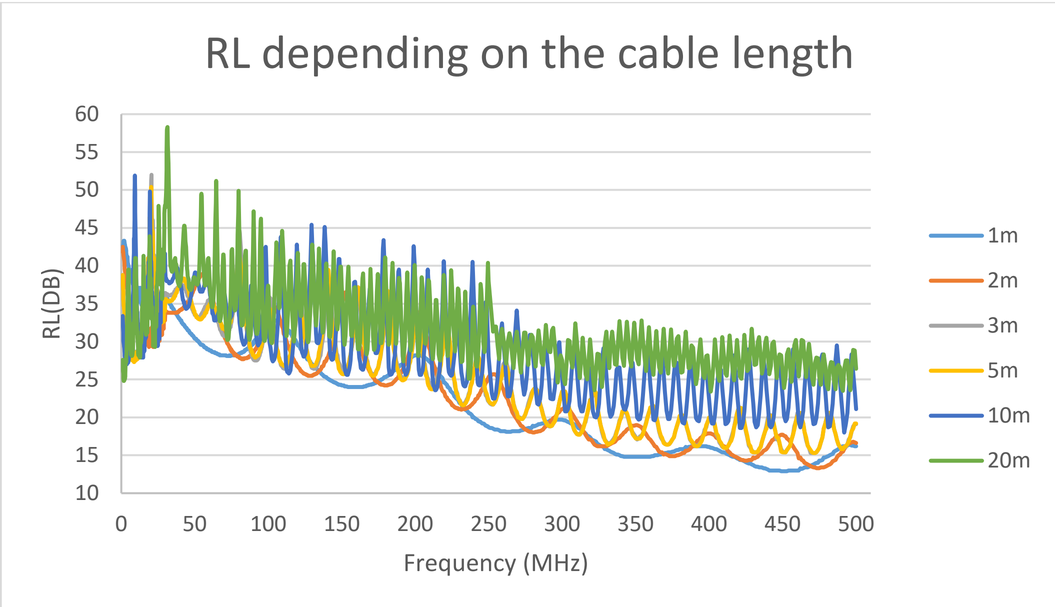


Figure 52

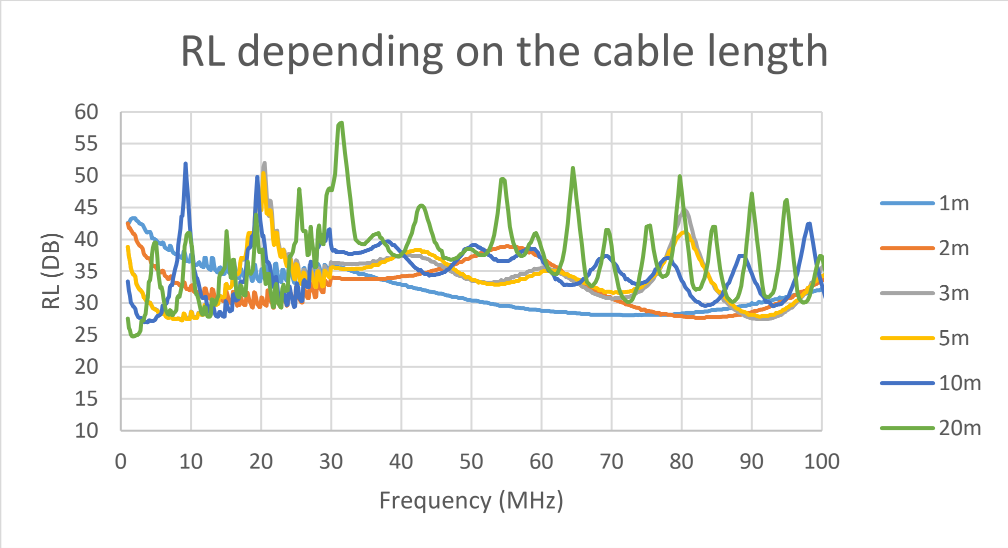


Figure 53

Return Loss is higher on the longer cables. As the frequency increases, the return loss decreases. Above the frequency of 30 MHz, RL fluctuate less when the frequency increases.

2.2. Impact of a junction

Figure 54: Junction

Junction are used to connect two Profinet cables. To see what effect a junction will have in both IL and RL, we will compare the Return Loss and Insertion Loss between 5m cable and cable made by connecting 2 and 3m.

Insertion Loss

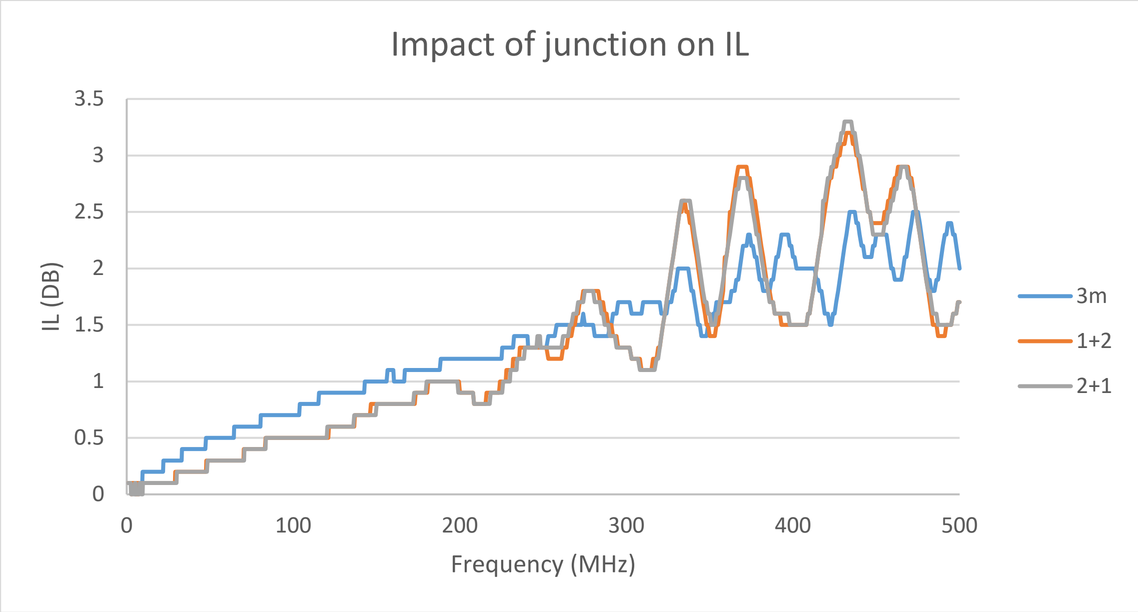


Figure 55: Impact of junction on IL on 3m cable

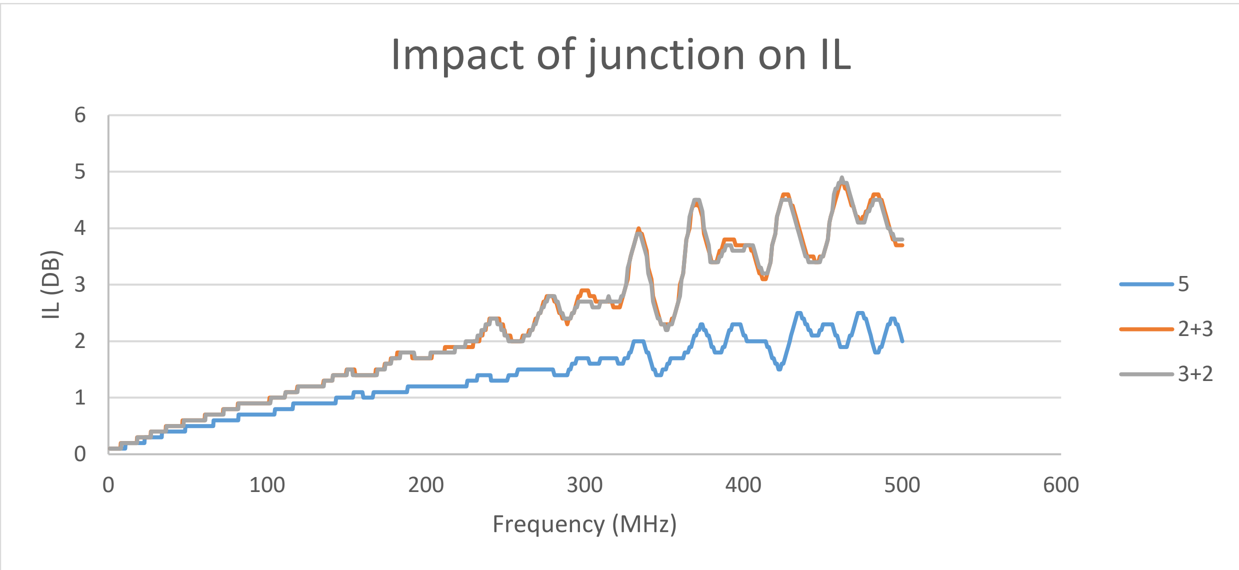


Figure 56: Impact of junction on IL on 5m cable

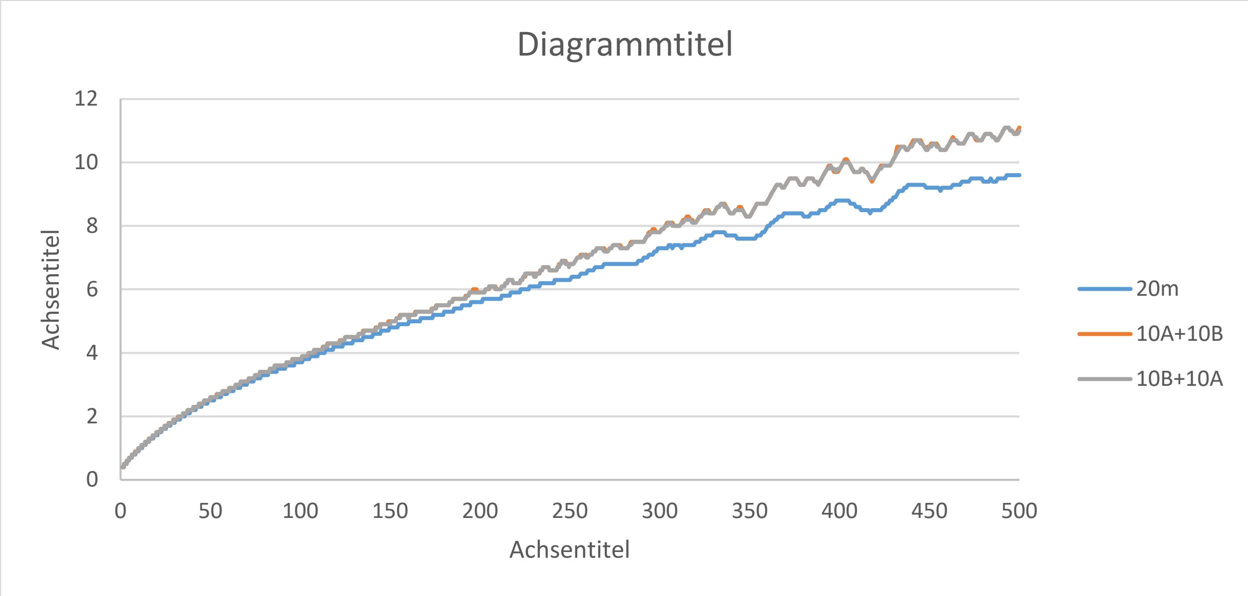


Figure 57: Impact of junction on IL on 20m cable

As the frequency increases, the insertion loss also increases. The cable without the connectors has the least amount of IL. Lower Insertion loss means better performance of the cable. The position of longer cable on the main side or remote side doesn't has similar amount of Insertion loss.

On 3m cable the frequency increases, the insertion loss also increases. But unlike other experiment the single cable has more Insertion loss than two cable connected with junction.

Return Loss

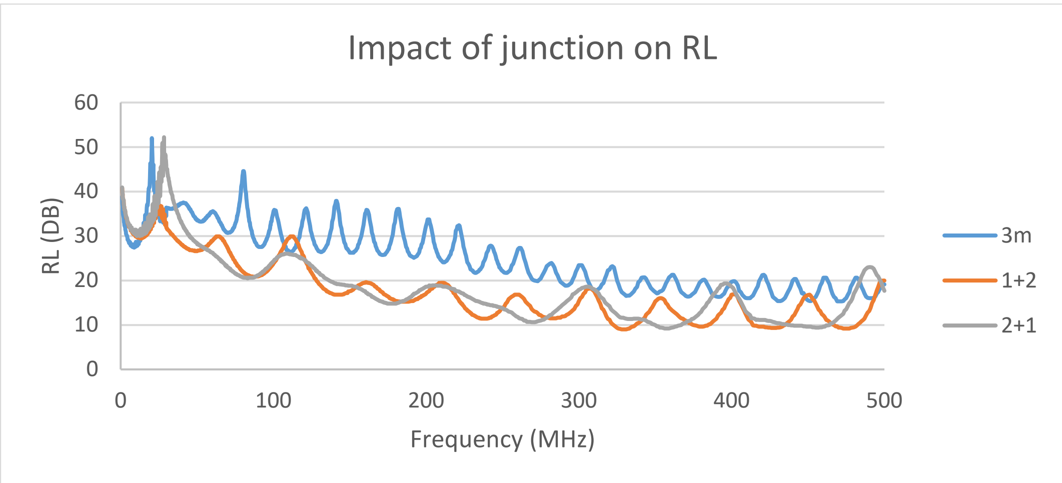


Figure 58: Impact of junction on RL on 3m Cable

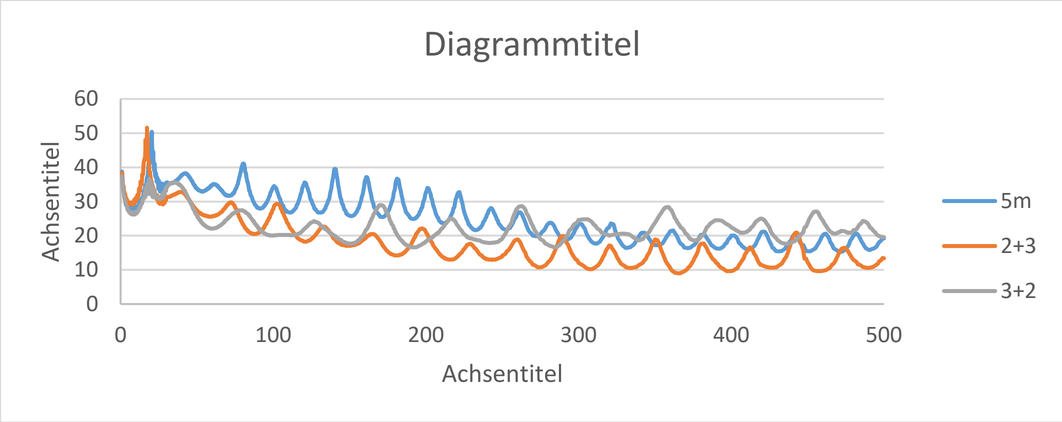


Figure 59 :Impact of junction on RL on 5m Cable

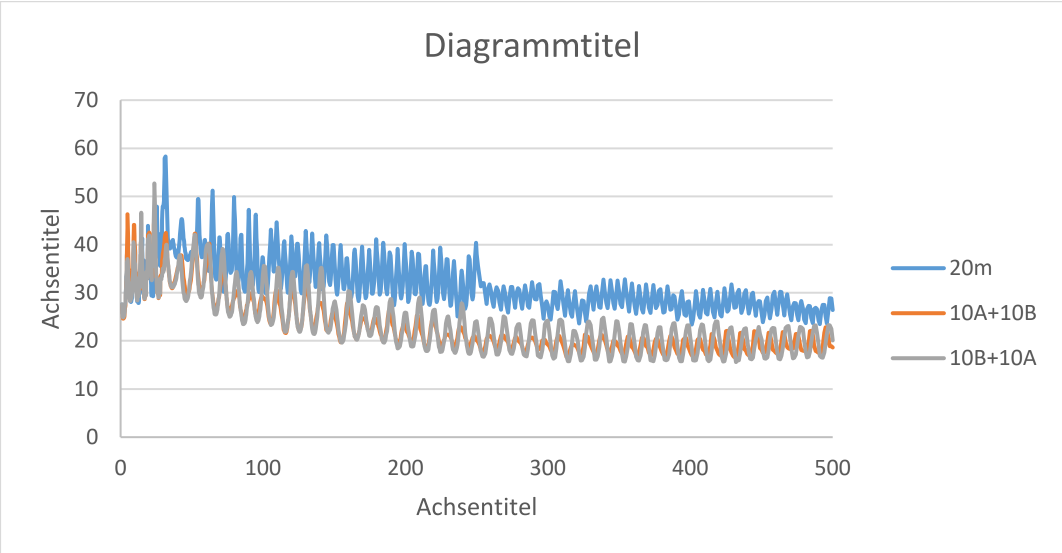


Figure 60: Impact of junction on RL on 20m Cable

Junction causes for lower return loss comparing with a single cable of same length. As the frequency increases, the RL decreases.

2.3. Impact of a splitter

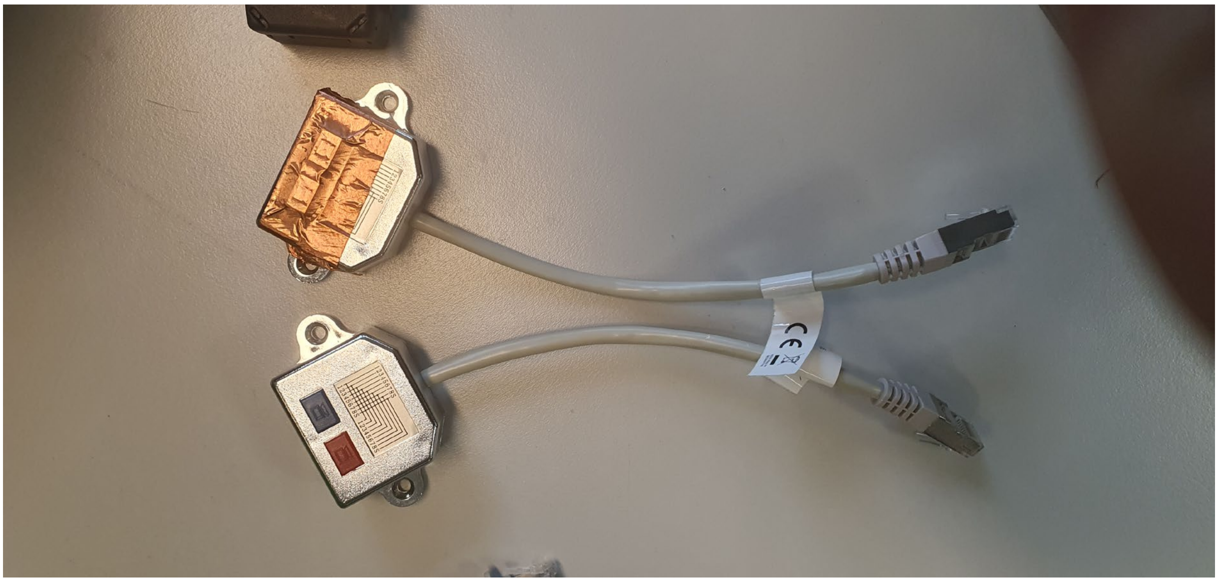


Figure 61: Splitters

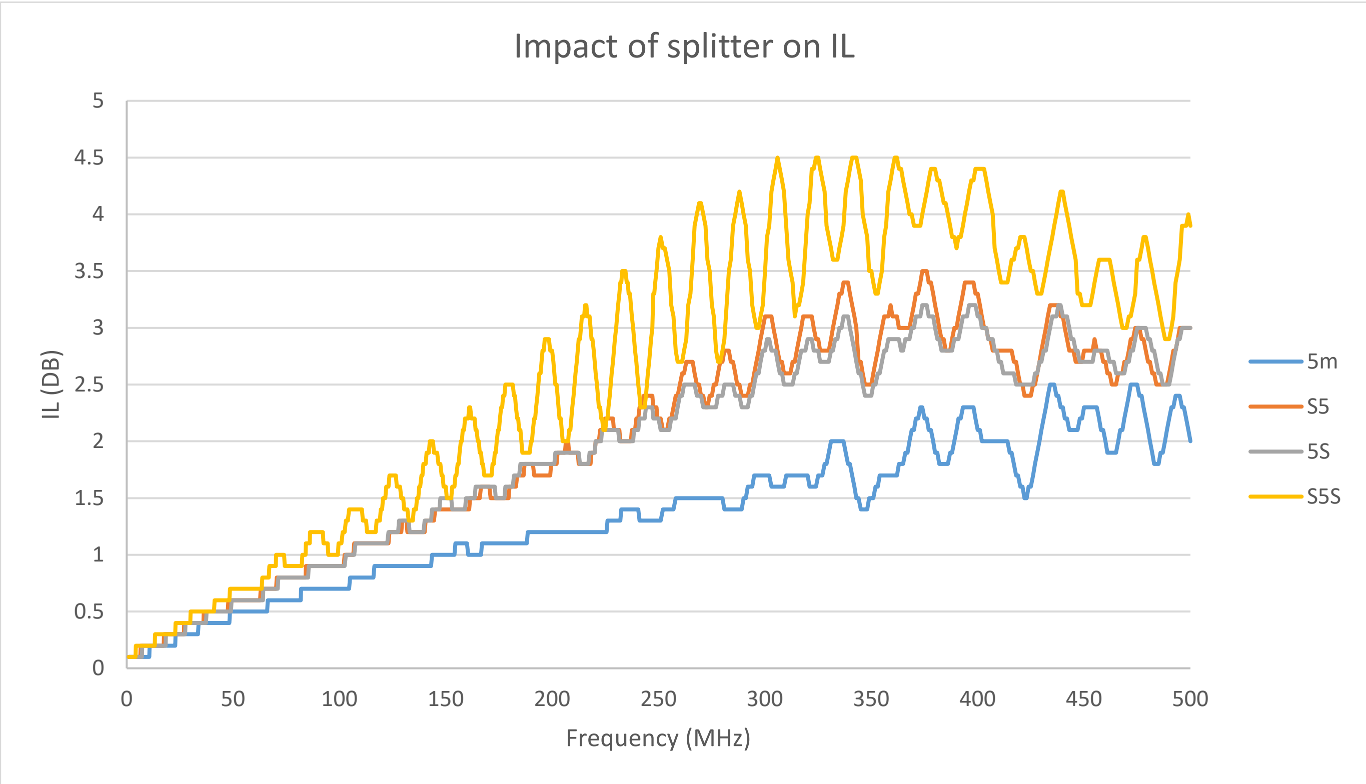


Figure 62: Impact of splitter on IL

Splitter causes for increased Insertion Loss and Insertion Loss is higher with higher number of splitters. Splitter being on the main side or end side has no different effect on IL. Multiple number of splitters causes for increased insertion loss.

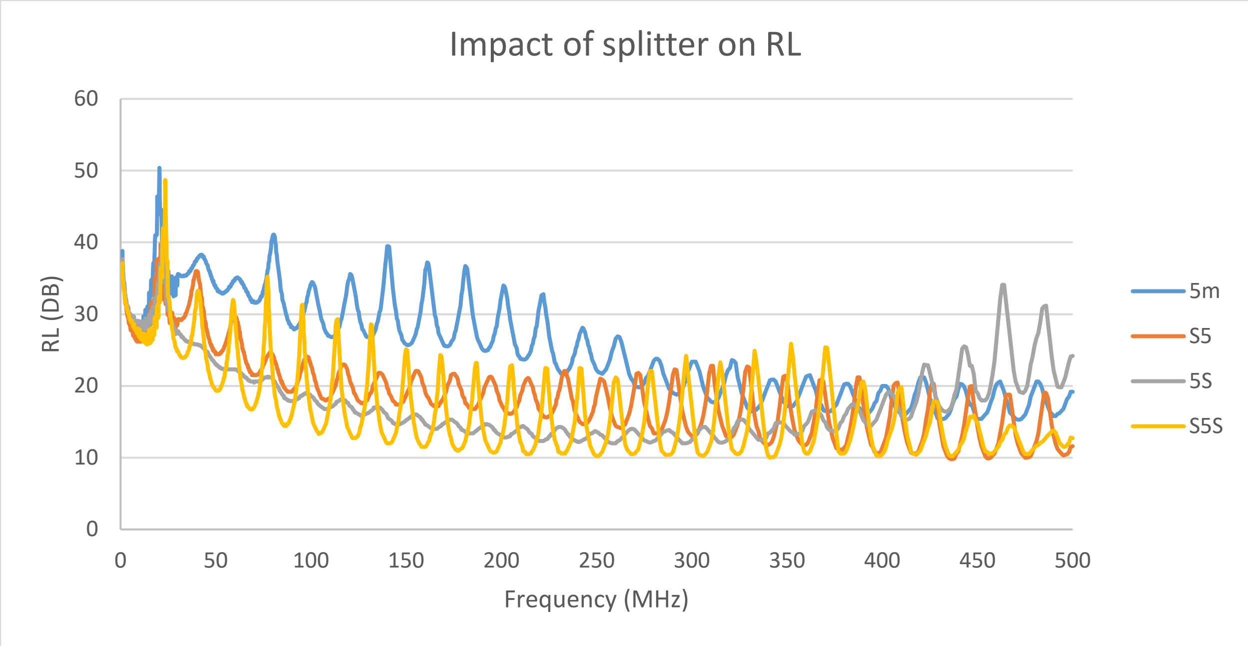


Figure 63: Impact of splitter on RL on 5m cable

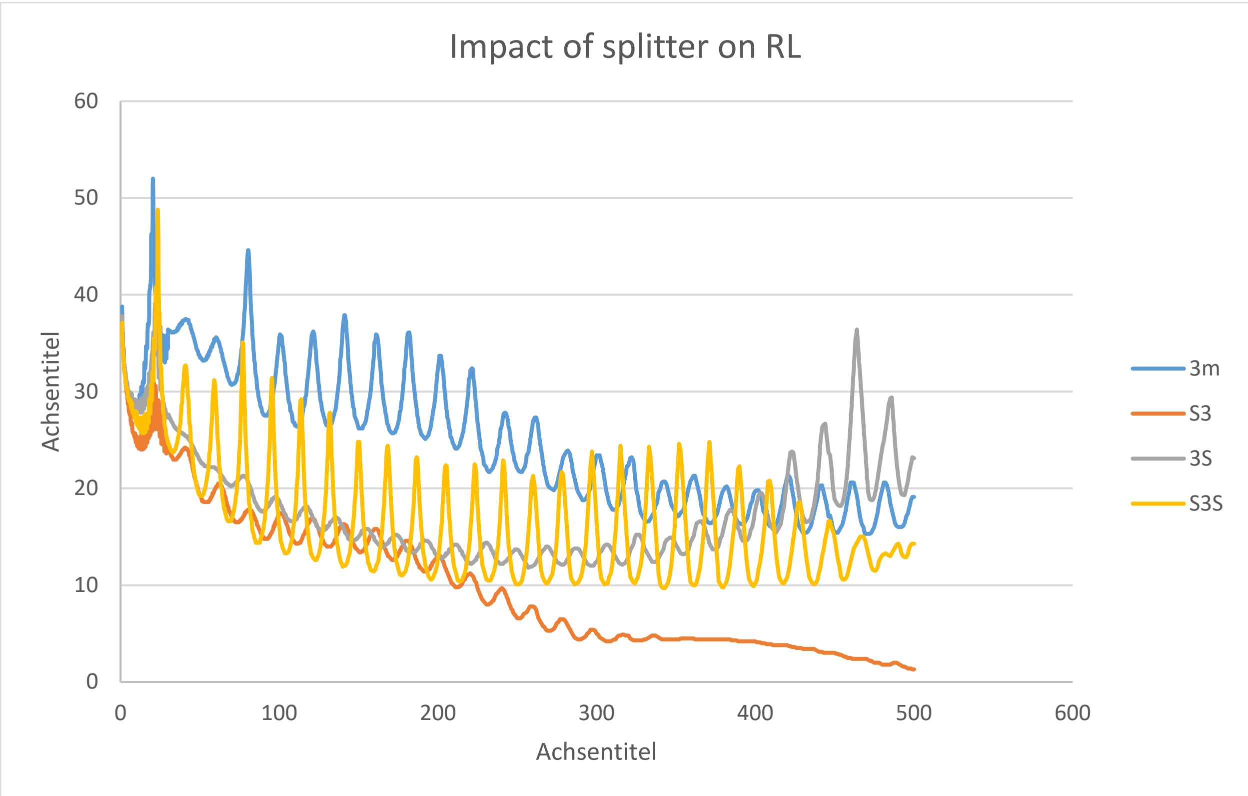


Figure 64: Impact of splitter on RL on 3m cable

Splitter being on the main side or end side has different effect on RL. When the splitter is on the remote side, RL starts to increase above the frequency of 300 MHz. As you can see on the plot this effect is clearer on the experiment with 3m cable.

2.4. Impact of a splitter with extension

Figure 65: Expeiment with splitter with extension

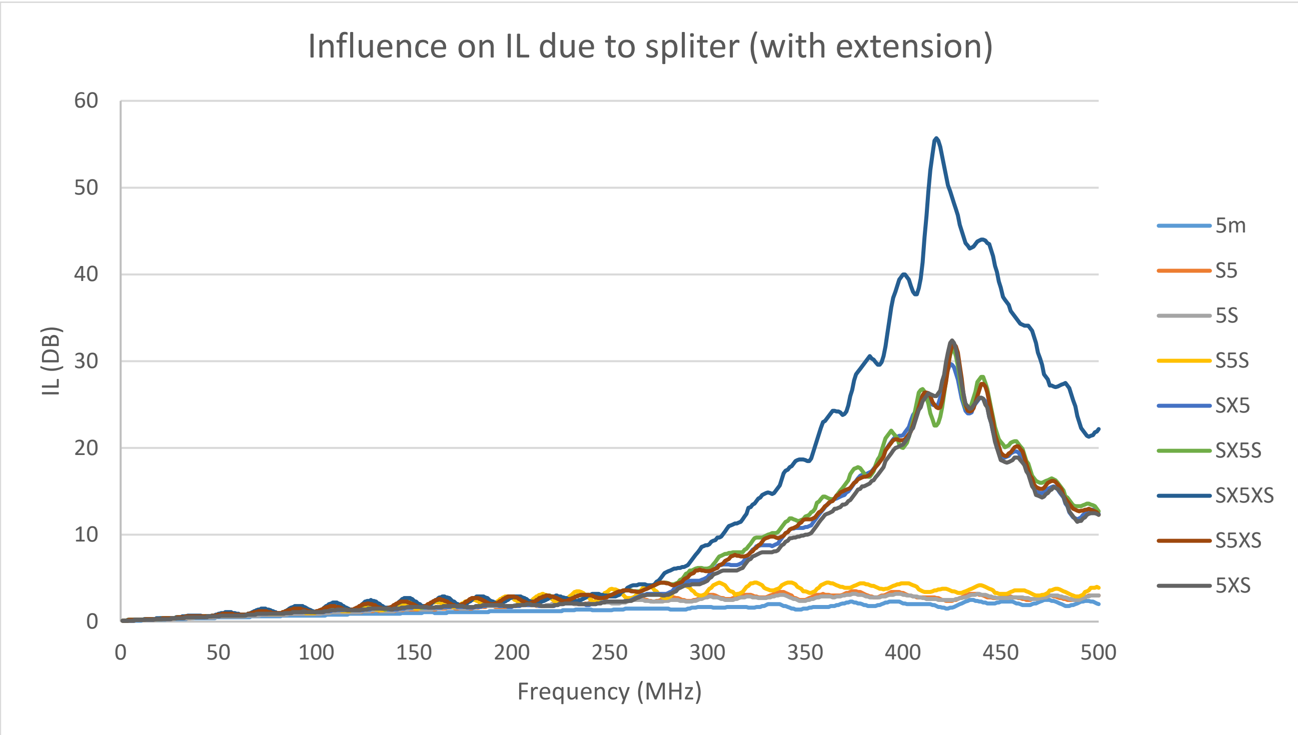


Figure 66: Influence on IL due to spliter (with extension)

Here also we can see that the Insertion loss increases with the increasing frequency.

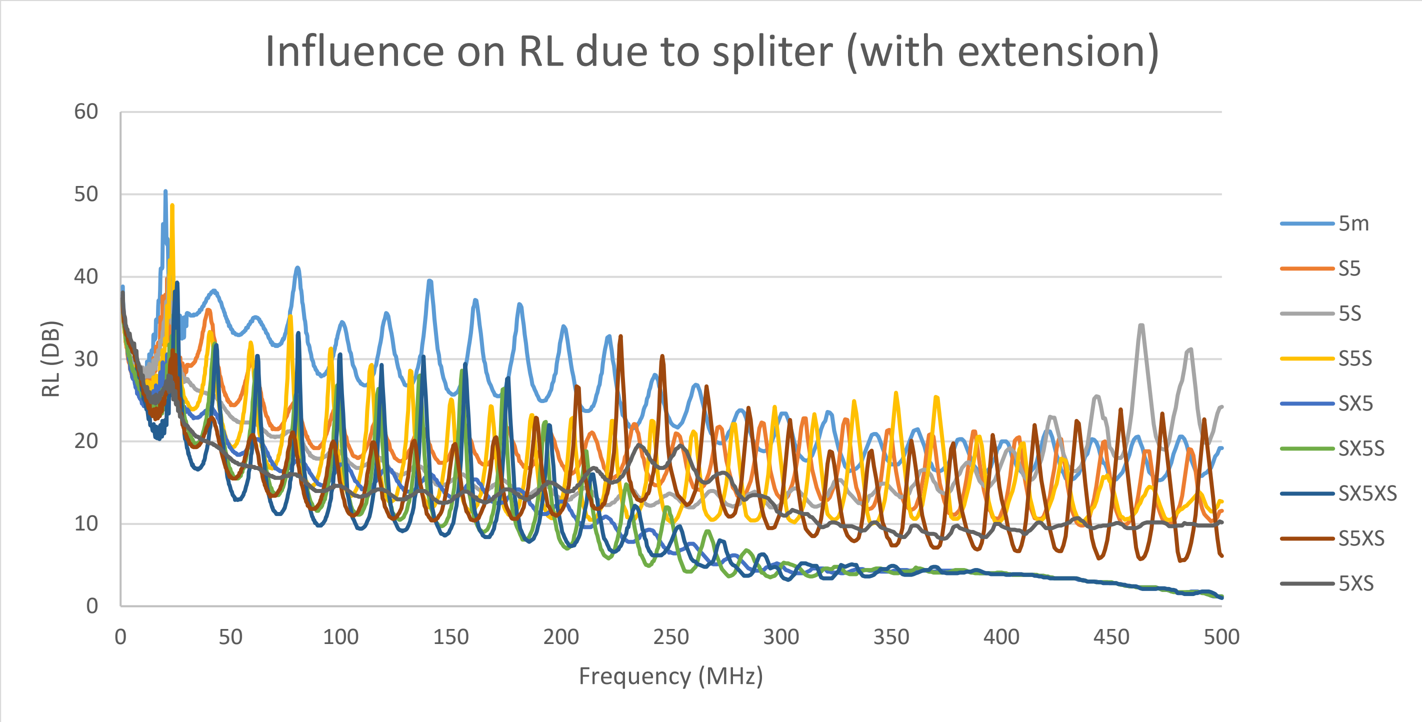


Figure 67: Influence on RL due to spliter (with extension)

2.5. Impact of ferrite

The goal of this experiment is to see if a ferrite causes impact on Profinet cable. Three models of ferrite are placed on one or both end of the cable. F1, F2 and F3 are each label given for the ferrites. For example, F1F2 3 F2F1 means that ferrite 1 and ferrite 2 are place on both end of the cable.


注 意 ： 易 碎
MAGNET INDUSTRY LTD.
www.ferrite.com.tw
Cat 8.1 / Class I
TESTPRO
Cat 8.1 / Class I
TESTPRO

Figure 68: Experiment with 2 ferrites on each side

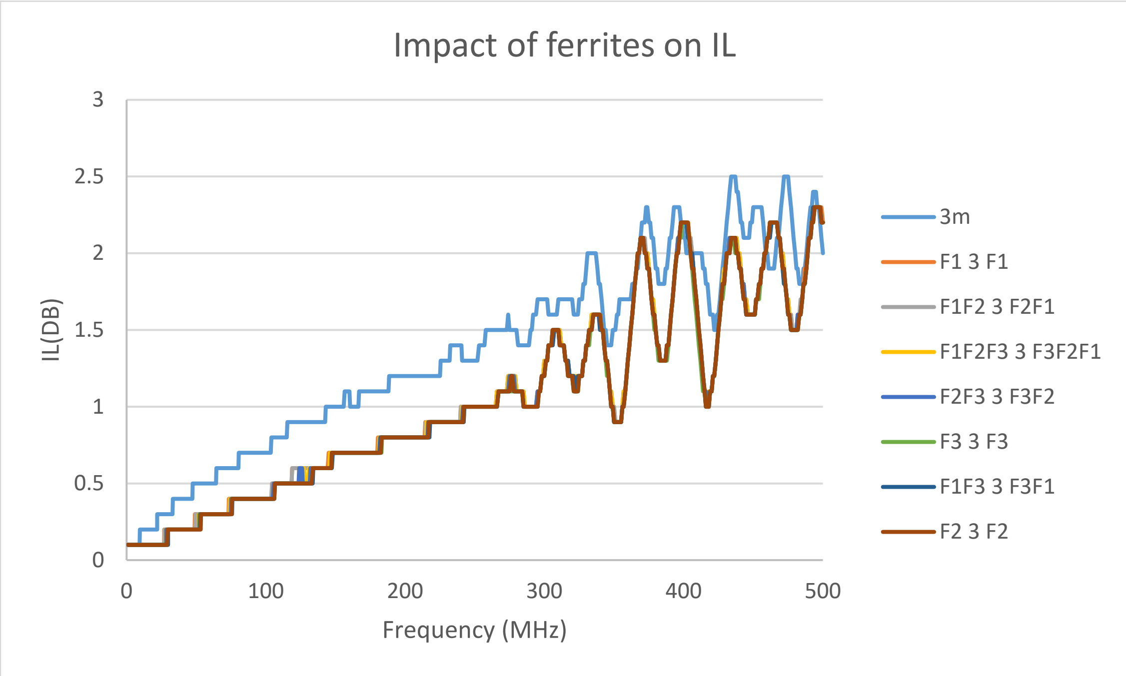


Figure 69: Impact of ferriet on IL

We can see that a ferrite cause for lower Insertion loss than a cable without ferrites. The model of the used ferrite or the number of ferrites has no impact on the insertion loss.

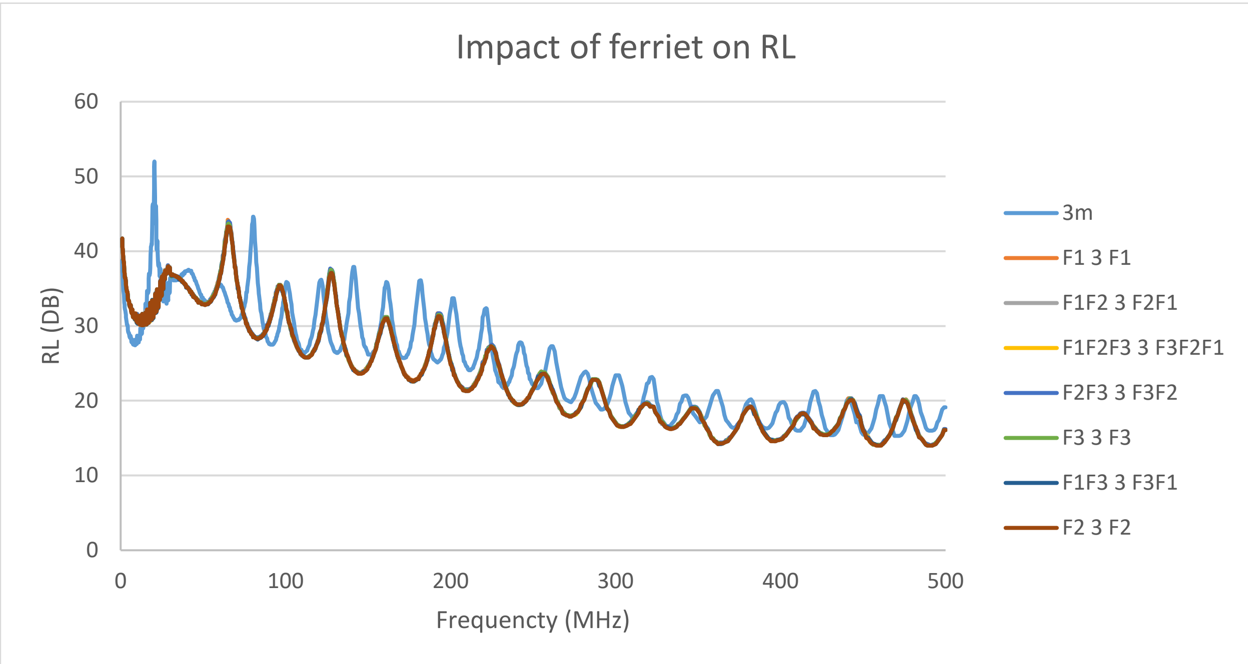


Figure 70: Impact of ferriet on RL

RL decrease when there is ferrite around the cable. But different model of ferrite and different numbers of ferrite has same impact on RL.

3. Interference on PN cables

3.1. Setup

The first part of the measurements, measurements were mainly made using the RF Clamp. Here, an inductive coupling was created to inject the interference. Differential probes were used. The first differential probe (M1) is located at the beginning of the test cable, the last measurement probe is located at the end of the test cable.

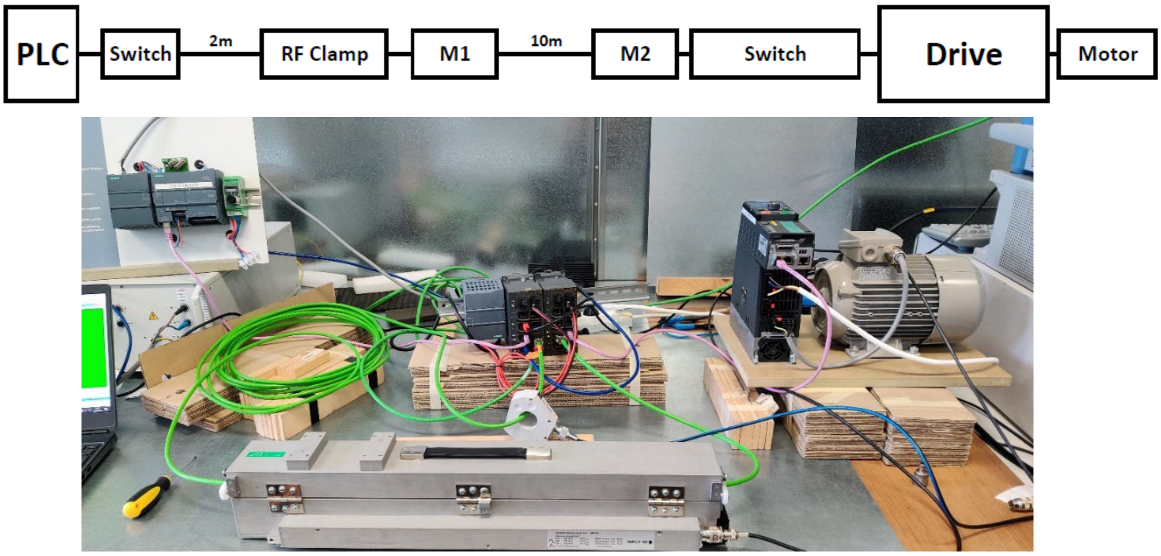


Figure 72. Setup

3.2. Analyses

The first step was to determine at which disturbances (frequency and amplitude) Profinet communication is no longer possible. The test method went as follows:

1. Start at low frequency
2. Increase amplitude until communication is no longer possible.
3. Record highest amplitude just before failure
4. Increase frequency
5. Return to step 2

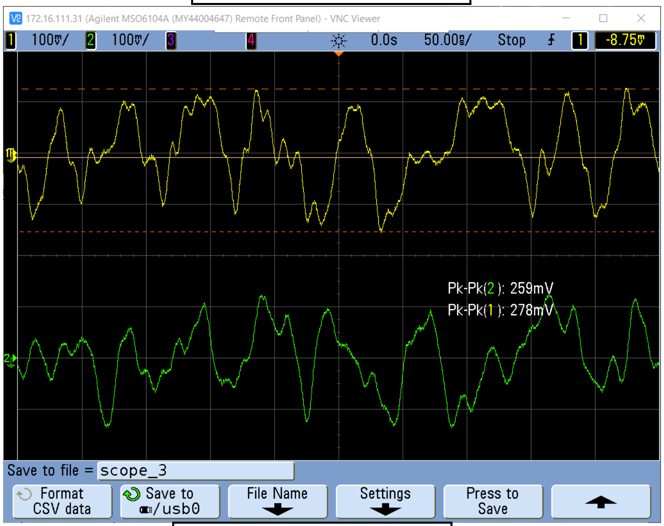
The following table was measured:

Frequency (MHz)	Level (dBµV)	Figure
0	0	scope-2
45	100	scope-3

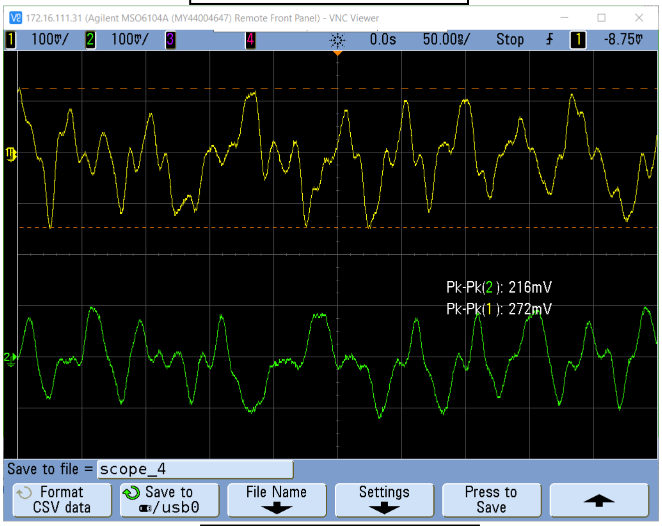
60	95	scope-4
70	106	scope-5
80	102	scope-6
90	107	scope-7
100	90	scope-8
105	100	scope-9
99,2	92,3	scope-10

Some observations:
-The red values indicate that the communication did not stop and that we are colliding at the maximum power of the amplifier.
-When the Profinet communication went down there was sometimes still normal Ethernet communication visible on the scope. However, when the amplitude was increased even more no normal Ethernet traffic was possible anymore.
-When the coupling is done directly the communication went out much faster. Direct coupling is best avoided to test realistic scenarios because in practice we want to deal with EMC failures and thus there is no direct coupling.

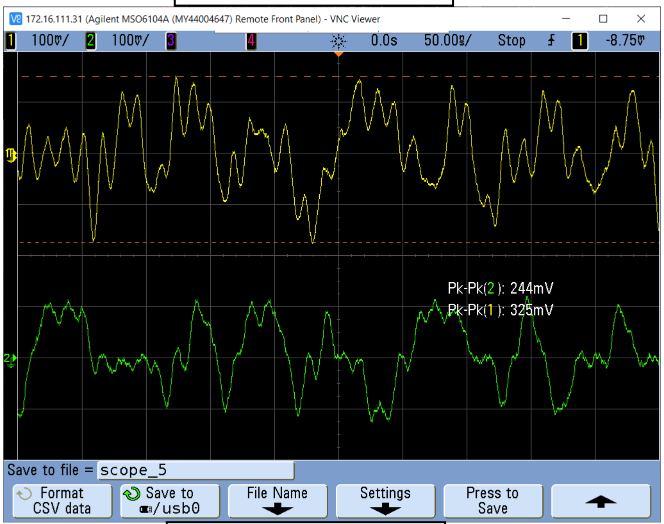
45MHz – 100 dBµV



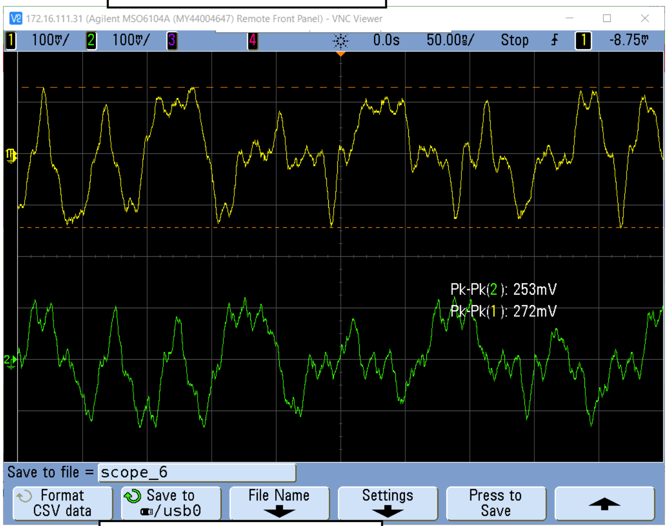
60MHz – 95 dBµV



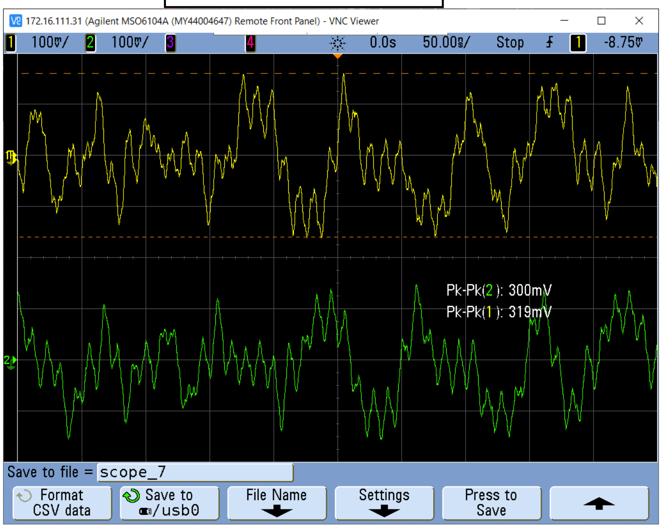
70MHz – 106 dBµV



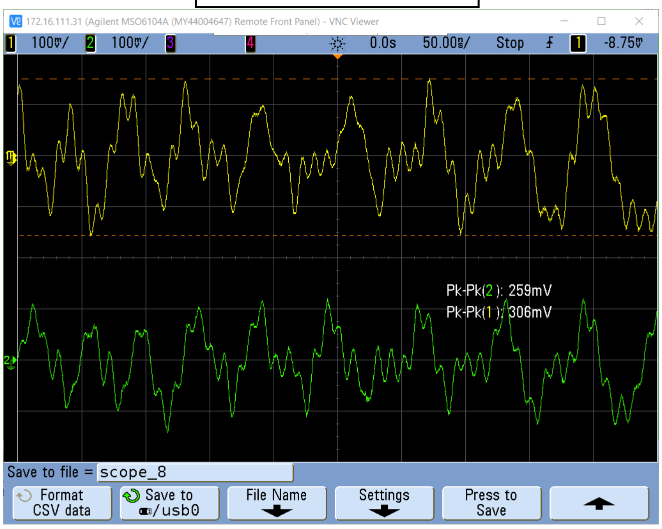
80MHz – 102 dBµV



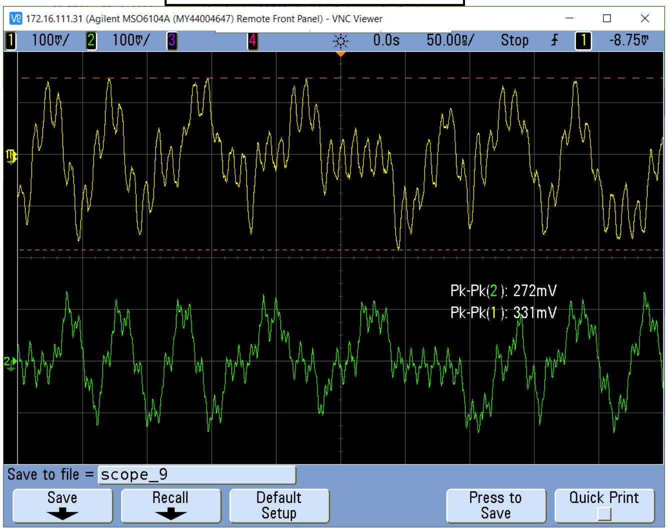
90MHz – 107 dBµV



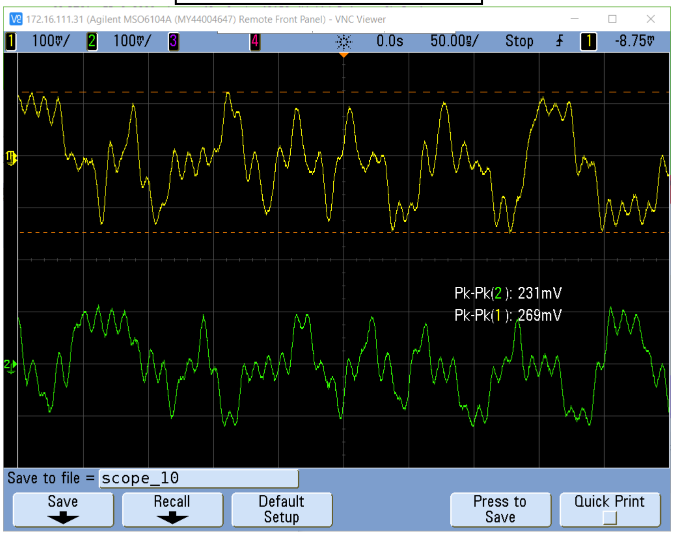
100MHz – 90 dBµV



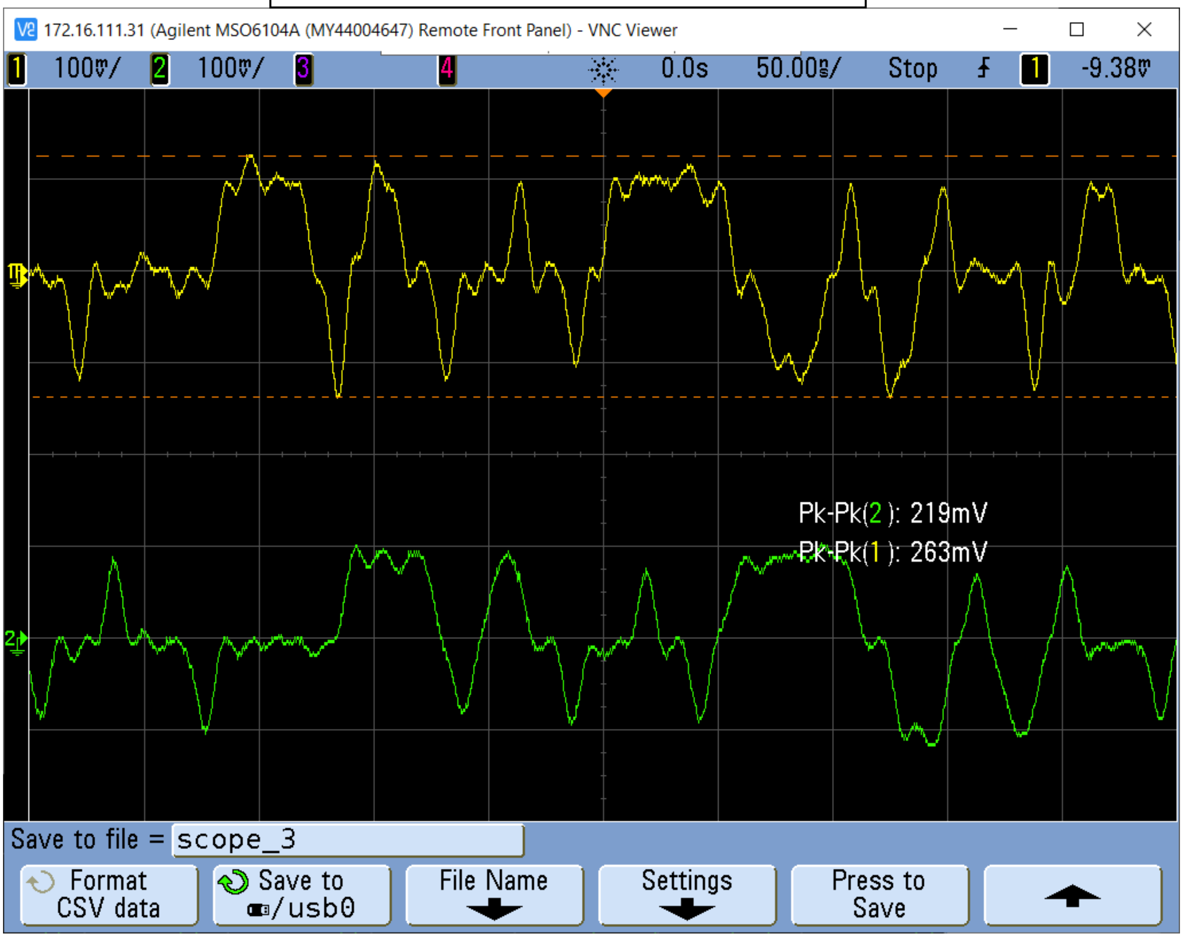
105MHz – 100 dBµV



99.2MHz – 92.3 dBµV



Normal communication without disturbance



To easily see if Profinet communication is still present, a visual indication was set up in Wireshark using port mirroring on switch 1. This was set to a flashy green color using Color rules. Also when an error occurs it was visually represented by a red color. A filter was also applied to see only the communication between the PLC and the Drive (eth.addr == 28:63:36:8a:d2:56) || (eth.addr == 00:1f:f8:e2:b2:1f).

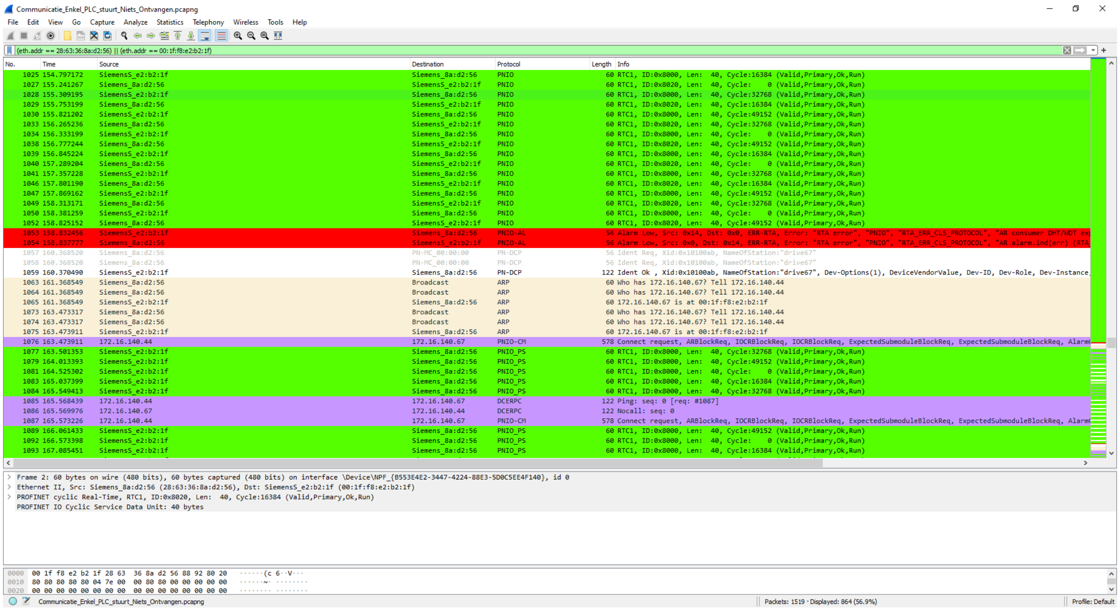


Figure 73. Wireshark view

When we were close to the maximum amplitude, it was noticed that sometimes the communication went through and sometimes not. This can be seen in the following screenshot. It can also be noted that in addition to Profinet communication, ordinary Ethernet traffic can also be seen such as ARP broadcast.

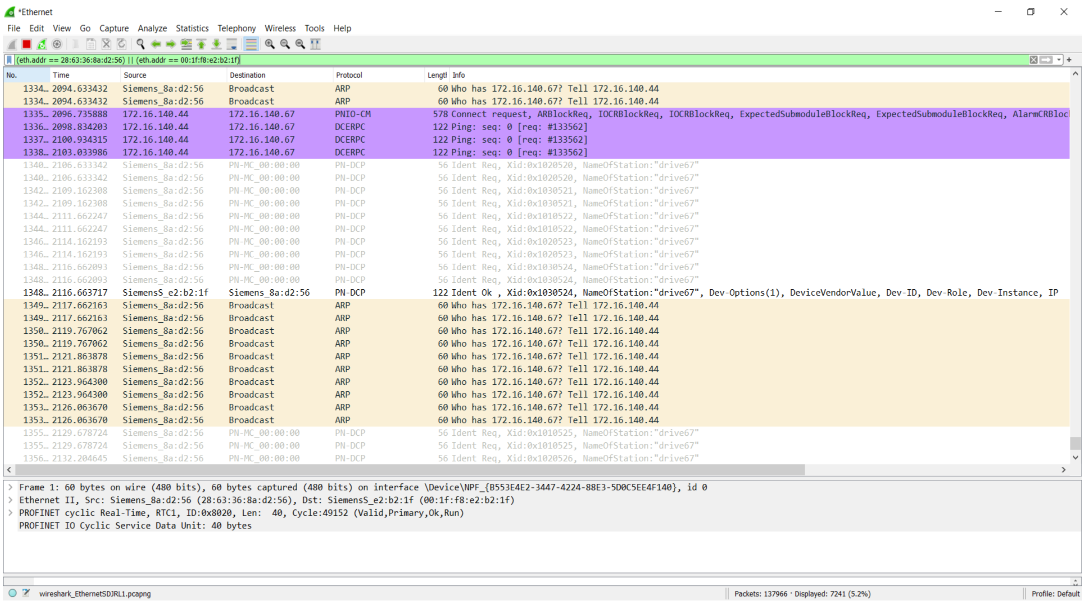


Figure 74. Wireshark view

4. Injection of shield currents

In this section, we want to examine how shield currents affect communications. The setup was simplified to eliminate many external influences. The shield current was measured by a current clamp.

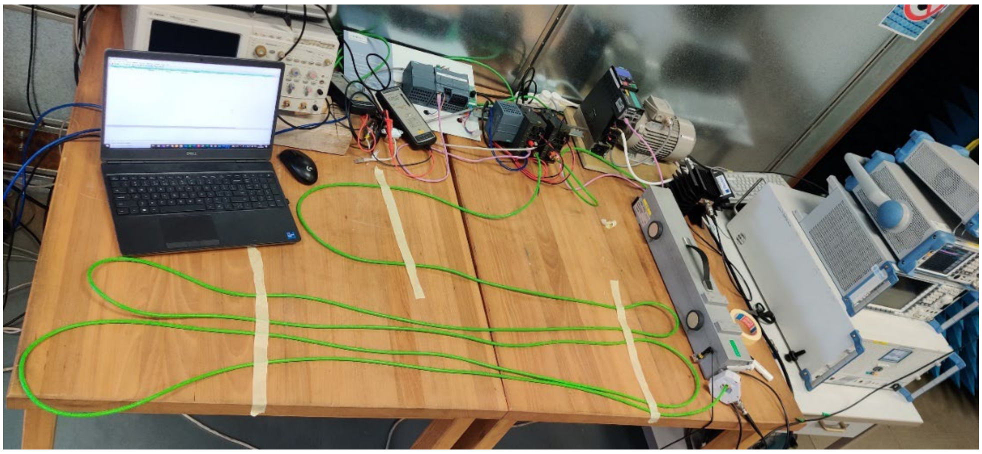
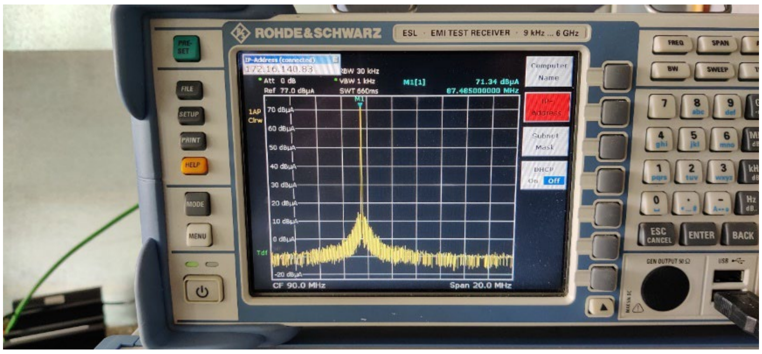


Figure 75. Setup

First, it was noted when the clamp is pushed the shield current + power + reflected power changes. This mainly had an effect on the non-EUT side of the Clamp. The amplitude of the shield current was looked at using the spectrum analyzer and at different points on the cable. It was noted that the interference frequency always had the largest amplitude. Based on this amplitude, we can determine the size of the shield current.



The main finding was that the magnitude of shield current depends on position on cable. When measured, peaks and dips were clearly noticed. The location of these peaks and dips depend on the frequency of the injected disturbance. To set up a realistic scenario, a new setup was used. A heavy motor setup was used where the shield current can be tapped. The shield current was tapped and placed on the shield of the Profinet. This was used to see if the communication stops when there are realistically large currents across the shield currents.

However even with this setup, the Profinet communication could go undisturbed. To visualize this, the shield current was measured as well as 1 pair of the Profinet communications. The following figure shows a graph of the measurements where the orange curve represents the Profinet communication and the blue graph the shield current.

When measuring the communication and shield current, the effect of the shield current was barely observed. As can be noticed in the figure below the current has little to no effect on the measured values. The shield currents reached peak to peak values of 3.5 A. An explanation for this could be that the frequency of the shield current (2MHz) has little effect on the signal.

Different scenarios were tested, the grounding was temporarily interrupted to get larger shield currents (1A -> 3.5A). Different lengths of cables were also tested (19m, 10m,...). The result stays similar, no impact due to shield currents.

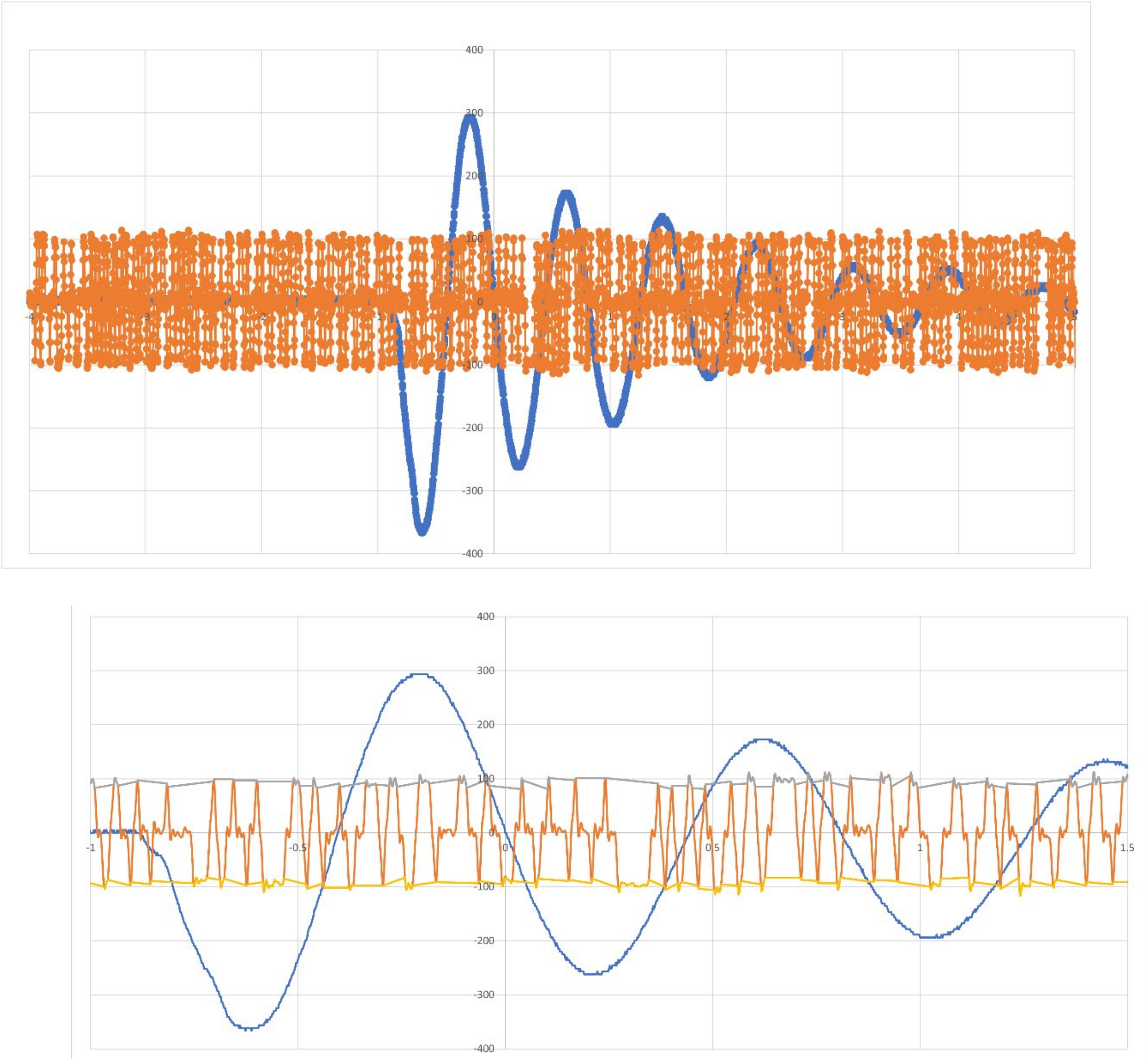


Figure 76. Shield current (blue) and PN communication (orange)

Appendix B: Best practices part 1

This report describes a number of best practices experienced while using / experimenting on large setups and in industry.

Line depth

Each switch that is placed between a device and its controller introduces a delay in the data transfer. The number of switches between a controller and a device is called the "line depth". The designer must take account of the line depth in the proposed topology. A line topology will exhibit a significant line depth because of the integrated switches in the devices. A large line depth will introduce delay and jitter which must be considered when planning the topology. Figure 1 shows an example with a line depth of 9.

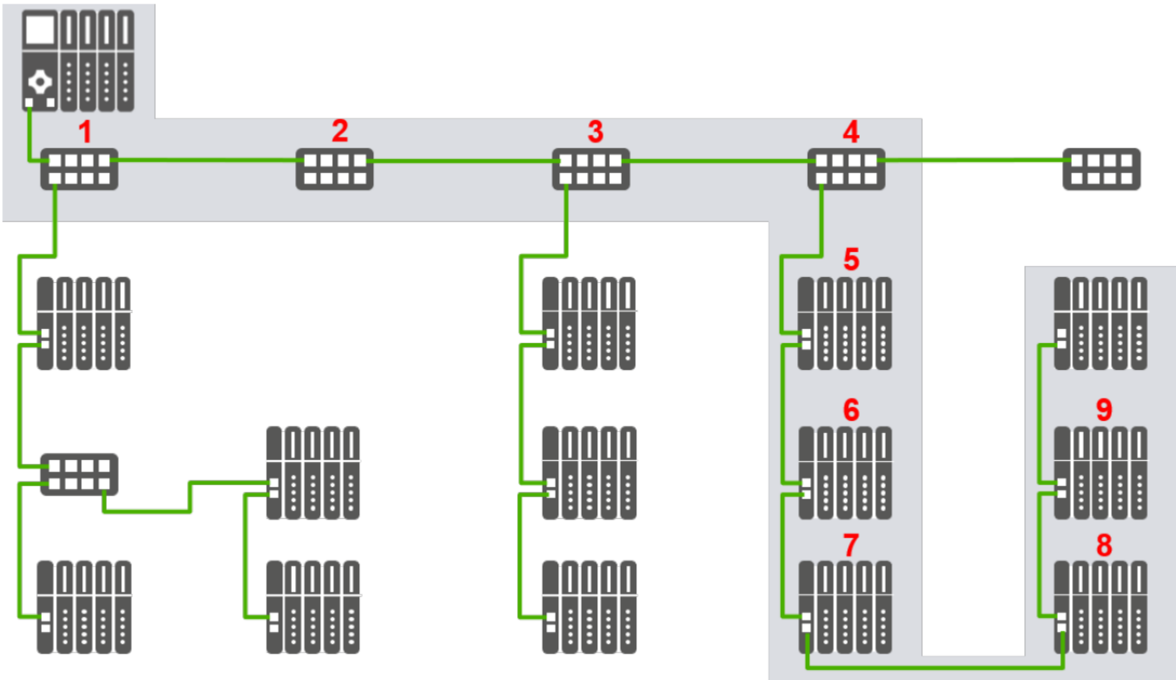


Figure 77: Line depth example[6]

The influence of the line depth depends on the data rate of the links between the devices, on the packet length and on the use of Cut Trough or Store-and-Forward switches. Industry standard 100BASE-TX, for PN design fairly new 1000BASE-T and SPE variant 10BASE-T1L will be considered.

An overview of the duration of a typical PROFINET frame (84 bytes) and a maximum size (standard) frame (1542 bytes) can be found in Table 1 for different data rates. The frame duration will have a large influence on the end-to-end delay in a network in combination with the line depth. This is especially true for store-and-forward switches since the switch has to wait until the entire frame arrived before it can start transmitting it on the egress port.

[6] PROFINET Design Guideline (https://www.profibus.com/download/profinet-installation-guidelines)

Table 12: Duration of a PROFINET frame and a maximum length Ethernet frame on different data rates

	Typical PROFINET frame (84 bytes)	**Longest (standard) frame (1542 bytes)**
10 Mbps	67,2 µs	1233,6 µs
100 Mbps	6,72 µs	123,36 µs
1000 Mbps	0,672 µs	12,336 µs

100BASE-TX

The maximum line depths for Store-and-Forward switches at 100 Mbps are listed for several PROFINET update times in Figure 2.

Update rate	1 ms	2 ms	4 ms	8 ms
Maximum line depth	7	14	28	58

Figure 78: Maximum line depths with "Store and Forward" switches on 100 Mbps[7]

The maximum line depths for Cut Through switches at 100 Mbps are listed for several PROFINET update times in Figure 3.

Update rate	1 ms	2 ms	4 ms	8 ms
Maximum line depth	64	100	100	100

Figure 79: Maximum line depth with "Cut Through" switches on 100 Mbps[7]

When non-PROFINET (longer packets) traffic is introduced on the network, the influence of the line depth becomes very apparent. Figure 4 shows the difference in end-to-end delay between 3 switches with only PN traffic, 3 switches with other traffic (35% of bandwidth for BE (Best Effort) traffic) and 6 switches with other traffic (35% BE traffic).

[7] PROFINET Design Guideline (https://www.profibus.com/download/profinet-installation-guidelines)

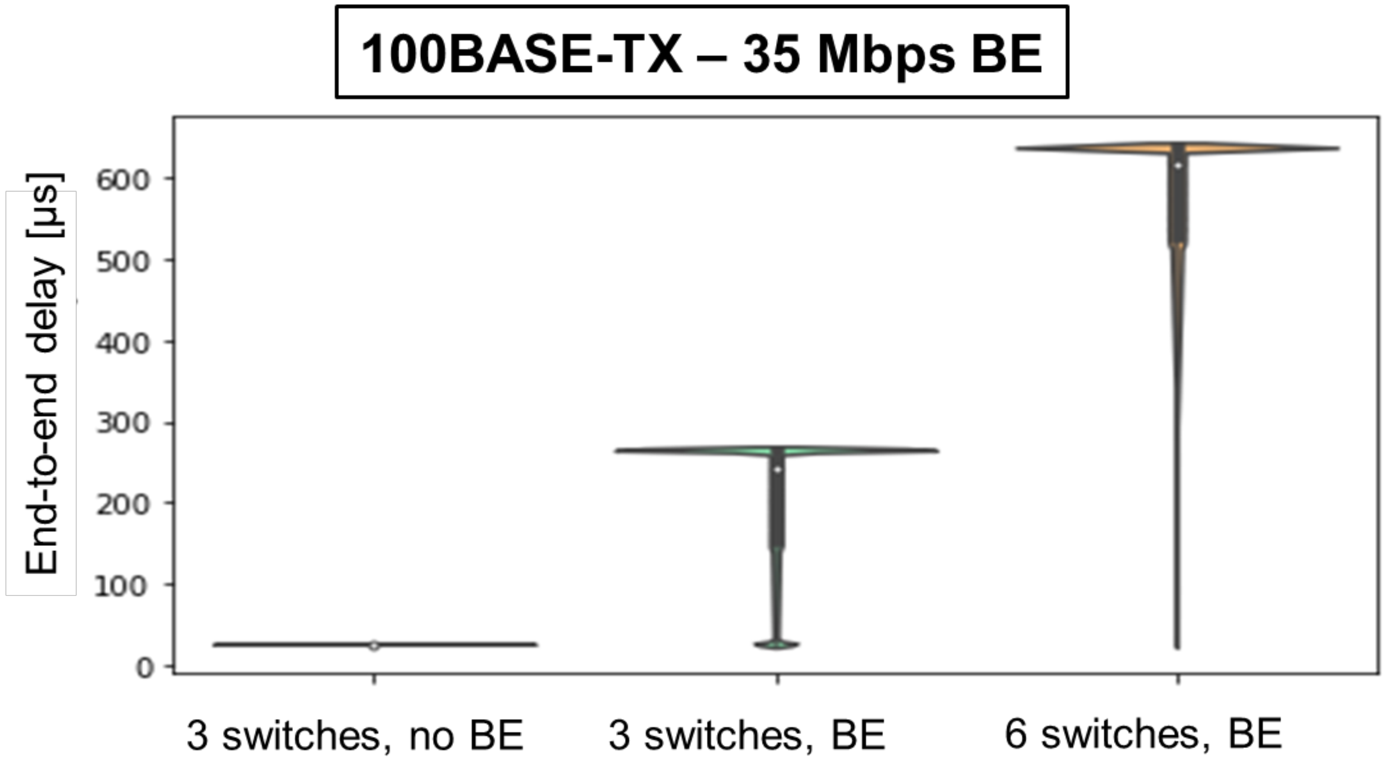


Figure 80: End-to-end delay on 100BASE-TX (35 Mbps BE)

1000BASE-T

By increasing the data rate to 1000 Mbps, the influence of the line depth is still apparent, but overall the delay is a lot smaller. Figure 5 shows the difference in end-to-end delay between 3 switches with only PN traffic, 3 switches with other traffic (35% BE traffic) and 6 switches with other traffic (35% BE traffic).

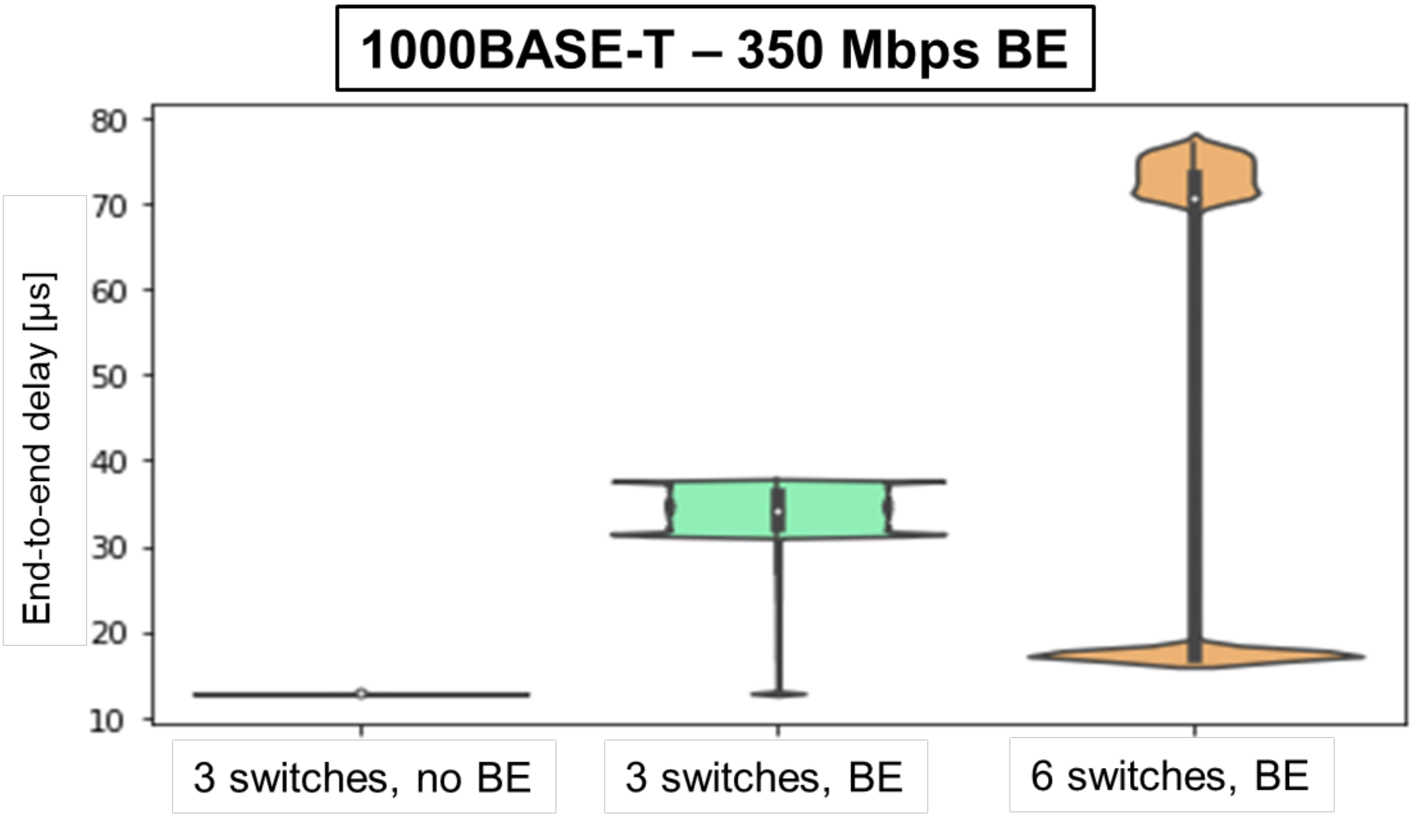


Figure 81: End-to-end delay on 1000BASE-T (350 Mbps BE)

It is recommended that in to be designed new networks, 1000 Mbps (TSN) switches are used as backbone. This will reduce the overall end-to-end delay and thus increase the allowed line depth, and will lower the possibility of (future) bandwidth problems.

10BASE-T1L

When lowering the data rate to 10 Mbps as in SPE 10BASE-T1L (and APL), the limitations on line depth are severe: the frames are 10 times longer in comparison with a data rate of 100 Mbps.

In case of APL (Advance Physical Layer based on 10BASE-T1L), the line depth is calculated similarly when using only APL field switches (Figure 6), only the last link to the end devices is 10 Mbps.

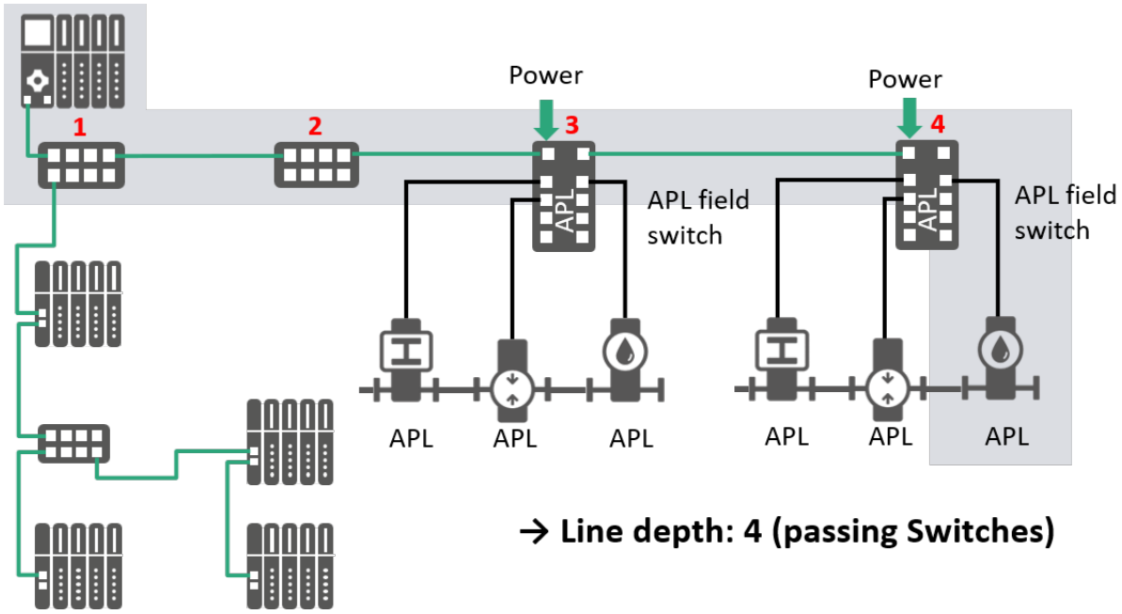


Figure 82: Line depth with APL Field-switches connected to 100 Mbit/s network[8]

This changes when APL field switches are added to the network (Figure 7). At the time of writing, the PROFINET Design Guideline only allows one APL field switch connected to a trunk. The limitation to one field switch per trunk is a preliminary value due to PROFINET as conformance testing is ongoing. This limitation is not related to Ethernet-APL and assumed to be changed in future.

[8] PROFINET Design Guideline (https://www.profibus.com/download/profinet-installation-guidelines)

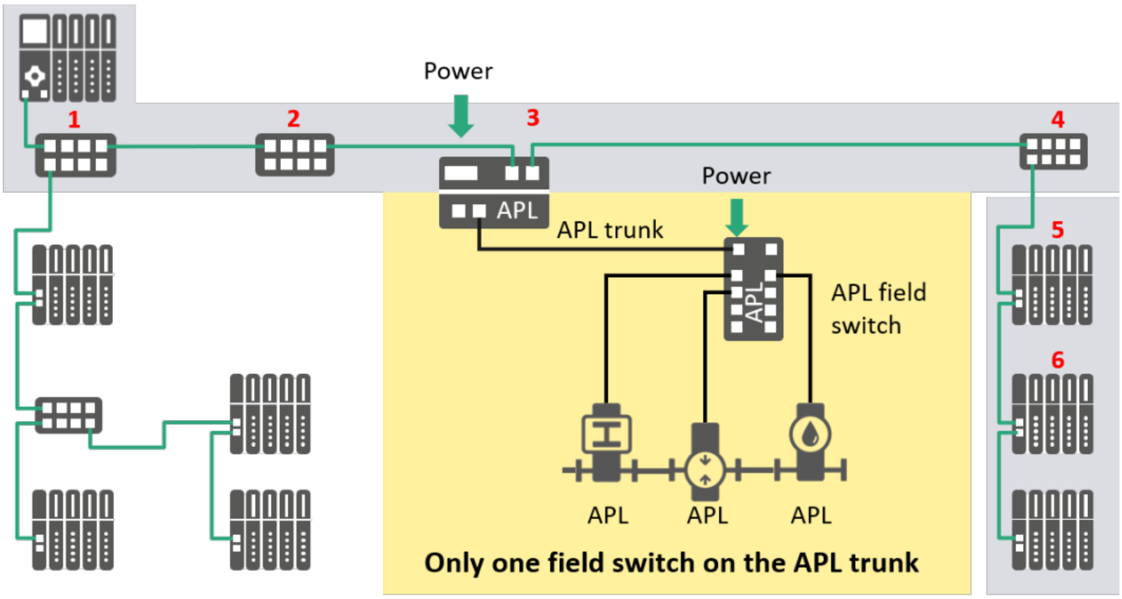


Figure 83: Line depth with APL trunk[8]

Integrating legacy devices

Example of a brownfield system including large PROFIBUS DP networks

Components of the brownfield system

- One main PLC with multiple DP masters
- Multiple DP slaves per master

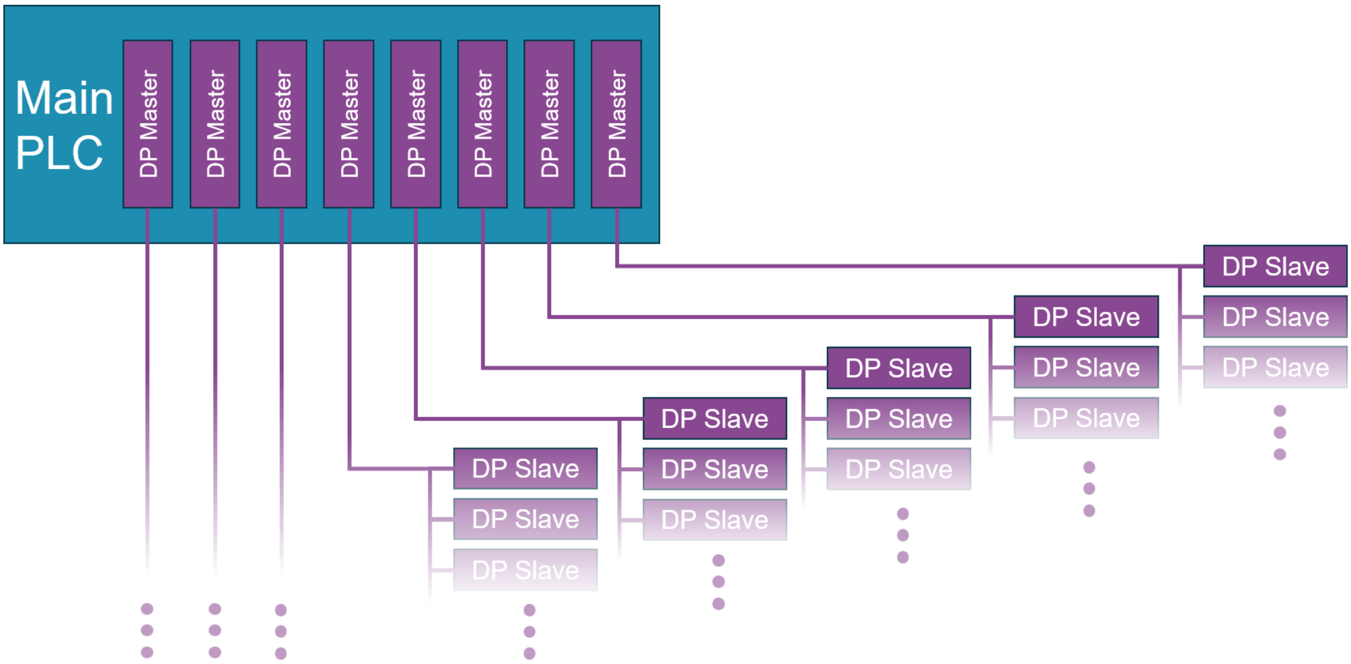


Figure 84: Brownfield system with PROFIBUS DP

The main PLC (GE) needs to be replaced by a new one which doesn't support PROFIBUS DP, the DP slaves will over the years be gradually replaced by PROFINET IO devices.

- How is the network structure designed and tested?
- How much extra delay is added? (The overall cycle time is close to the maximum allowed.)
- Which possibilities exist for communication between the new main PLC and the DP slaves?
    - IE/PB LINK per DP network
    - PN/PB Proxy per DP slave
    - PLC as I-device with multiple DP master modules
    - …

IE/PB LINK per DP network

The DP masters in the main PLC can be replaced by PROFINET/PROFIBUS gateways (e.g. Siemens IE/PB LINK).

This solution has two big disadvantages. The tested IE/PB LINK (Siemens) has no GSDML file, and thus cannot be integrated in other programming tools. For each DP slave a PROFINET frame is sent in both directions between the PLC and the IE/PB LINK after which the DP slave is located. If the PROFIBUS DP bus cycle time is already (very) high (e.g. > 20 ms), the update time between the PLC and the IE/PB LINK adds another delay to this. A solution would be to set the update time to 1 ms, minimizing the extra delay, but for a large number of devices the required bandwidth is too high. E.g. 80 devices with minimum frame size (40 bytes payload) already requires 56,32 Mbps at 1 ms update time (see chapter V for more information about network load calculation).

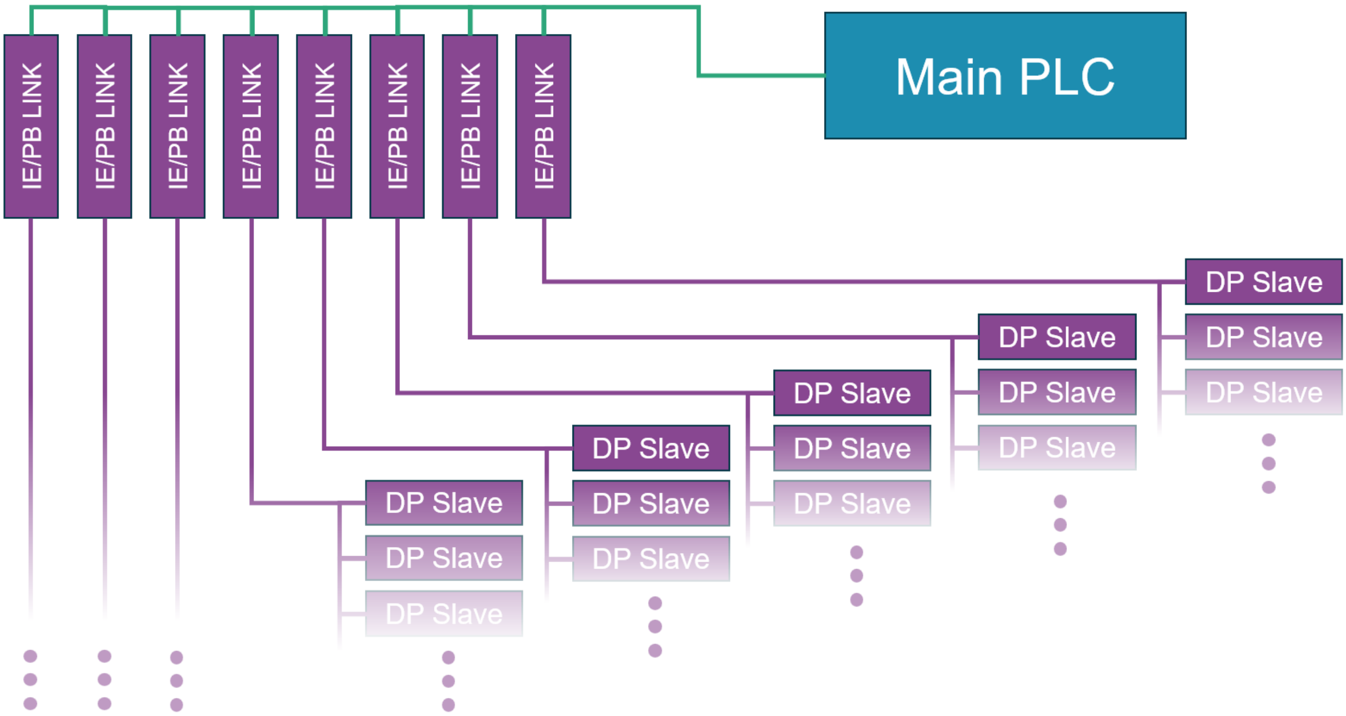


Figure 85: IE/PB LINK per DP network

```
2339… 2023-08-24 12:47:49,667545 Siemens_b5:95:51     [cpu1516-131.x1]     PNIO_PS     60 RTC1, ID:0x801a, Len:  40, Cycle:42560 (Valid,Primary,Ok,Run)
2339… 2023-08-24 12:47:49,667545 Siemens_b5:95:51     [cpu1516-131.x1]     PNIO_PS     60 RTC1, ID:0x801d, Len:  40, Cycle:42560 (Valid,Primary,Ok,Run)
2339… 2023-08-24 12:47:49,668533 [cpu1516-131.x1]     Siemens_b5:95:51     PNIO_PS     60 RTC1, ID:0x8003, Len:  40, Cycle:54208 (Valid,Primary,Ok,Run)
2339… 2023-08-24 12:47:49,668533 [cpu1516-131.x1]     Siemens_b5:95:51     PNIO_PS     60 RTC1, ID:0x8005, Len:  40, Cycle:54208 (Valid,Primary,Ok,Run)
2339… 2023-08-24 12:47:49,668533 Siemens_b5:95:51     [cpu1516-131.x1]     PNIO_PS     60 RTC1, ID:0x801c, Len:  40, Cycle:42592 (Valid,Primary,Ok,Run)
2339… 2023-08-24 12:47:49,668533 Siemens_b5:95:51     [cpu1516-131.x1]     PNIO_PS     60 RTC1, ID:0x801e, Len:  40, Cycle:42592 (Valid,Primary,Ok,Run)
2339… 2023-08-24 12:47:49,668533 Siemens_b5:95:51     [cpu1516-131.x1]     PNIO_PS     60 RTC1, ID:0x801b, Len:  40, Cycle:42592 (Valid,Primary,Ok,Run)
2340… 2023-08-24 12:47:49,669569 [cpu1516-131.x1]     Siemens_b5:95:51     PNIO_PS     60 RTC1, ID:0x8004, Len:  40, Cycle:54240 (Valid,Primary,Ok,Run)
2340… 2023-08-24 12:47:49,669569 [cpu1516-131.x1]     Siemens_b5:95:51     PNIO_PS     60 RTC1, ID:0x8001, Len:  40, Cycle:54240 (Valid,Primary,Ok,Run)
2340… 2023-08-24 12:47:49,669569 [cpu1516-131.x1]     Siemens_b5:95:51     PNIO_PS     60 RTC1, ID:0x8002, Len:  40, Cycle:54240 (Valid,Primary,Ok,Run)
```

Figure 86:Communication between the main PLC and one IE/PB LINK (each ID is another DP slave)

A compact PN/PB Proxy per DP slave

There are PROFINET / PROFIBUS Proxy connectors available in a small form factor (e.g. Figure 11). These can be connected directly on the DP slaves, creating small standalone PROFIBUS DP networks with one master and one slave. This will result in a short bus cycle time on DP-side, which in combination with an update time of e.g. 8 ms, still provides a good overall reaction time while not requiring an excessive amount of bandwidth at the Ethernet side.

This solution requires a “full” PROFINET backbone network from the beginning, but since this is also needed over time for the migration to PROFINET IO devices, the backbone will still be useable in the future.

Each PN/PB Proxy needs to be configured manually and a GSDML needs to be created and imported in the network configuration software. If there are a lot of DP slaves, this may be time consuming and rather complicated (also for long time maintenance).

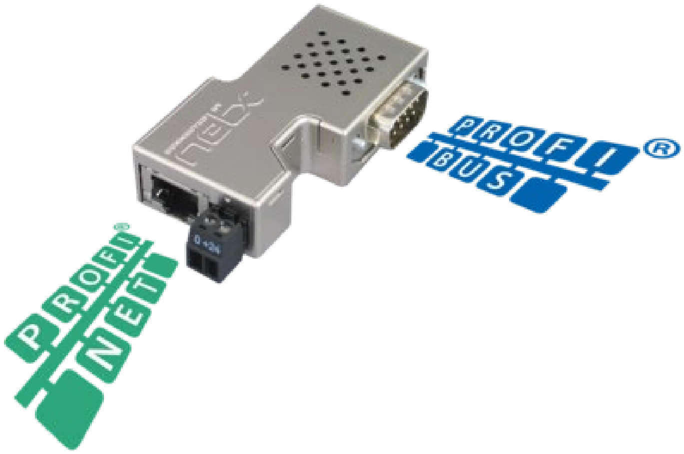


Figure 87: Hilscher NL 51N-DPL

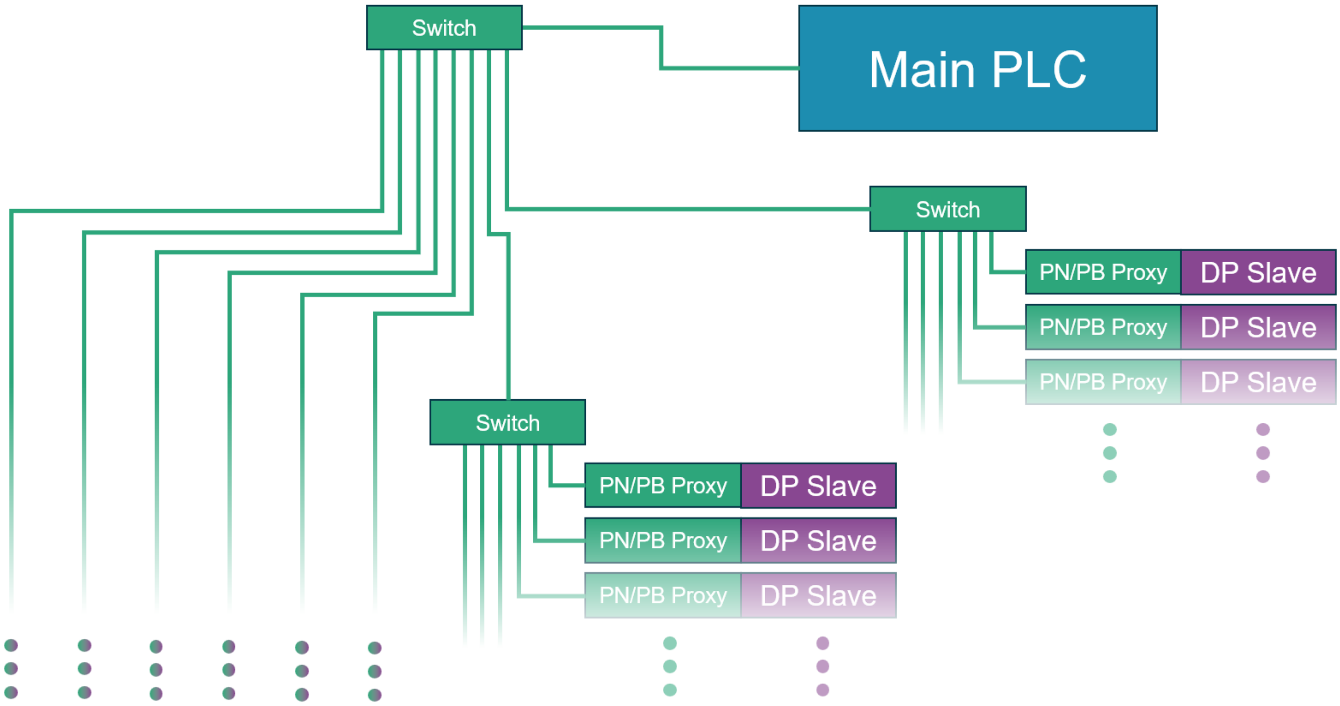


Figure 88: PN/PB Proxy per DP slave

Interface PLC as I-device with multiple DP master modules

One PLC equipped with a rather large number of DP-cards os configured as I-device and servers as “interface PLC”. A GSDML file can be generated for the main PLC, allowing the use of e.g. GE PLC controllers. The interface PLC and its programming tools can be used for commissioning and fault finding in the DP networks. The existing DP networks can be connected directly to the DP masters of the PLC. The IO data is exchanged through transfer areas between the I-device and the main PLC which can be updated over PROFINET every 1 ms (or slower). The cycle times of the DP networks remain the same.

There are two options when replacing DP slave with PROFINET IO devices in this solution:

- The new IO device can still communicate with the I-device, which will exchange the data with the main PLC through the transfer areas. Replacing a DP slave with an PN IO device requires only changes in the I-device. This option is easy to gradually replace DP-devices by PN-devices over time.
- The new IO device can communicate directly with the main PLC, removing its data from the I-device transfer areas. Replacing a DP slave with an IO device requires changes in both the I-device and the main PLC.

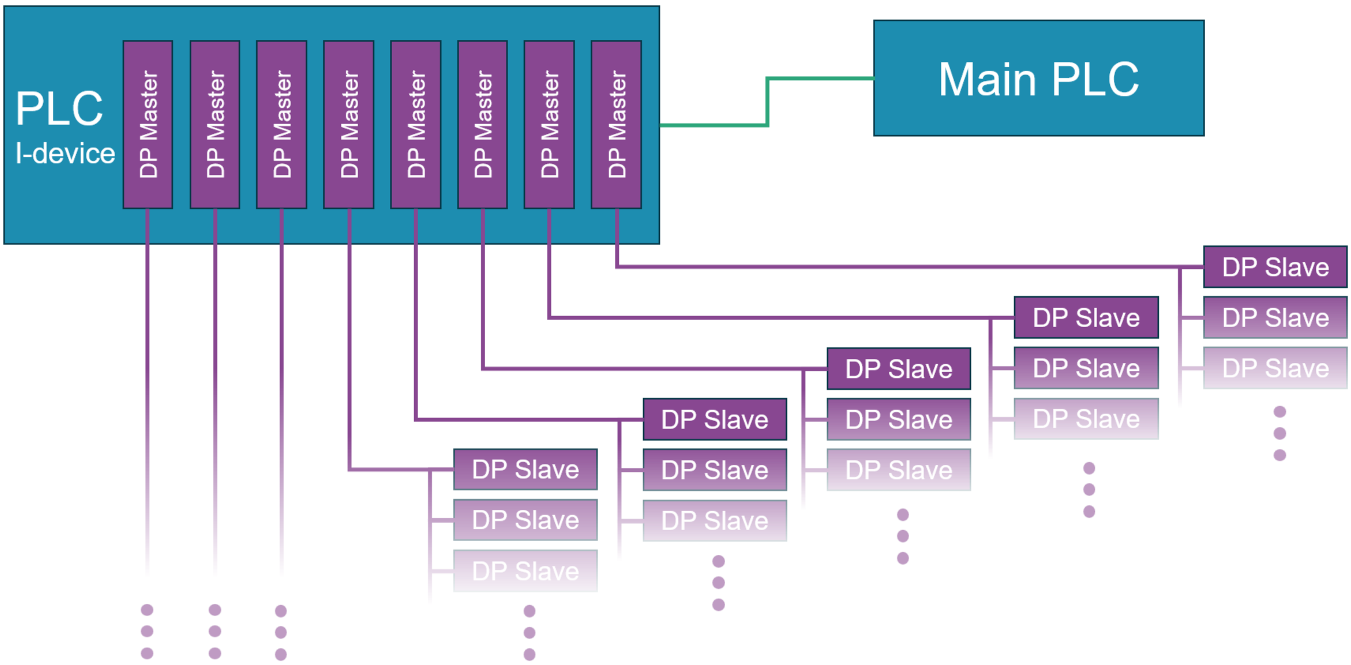


Figure 89: Interface PLC as I-device with multiple DP master modules

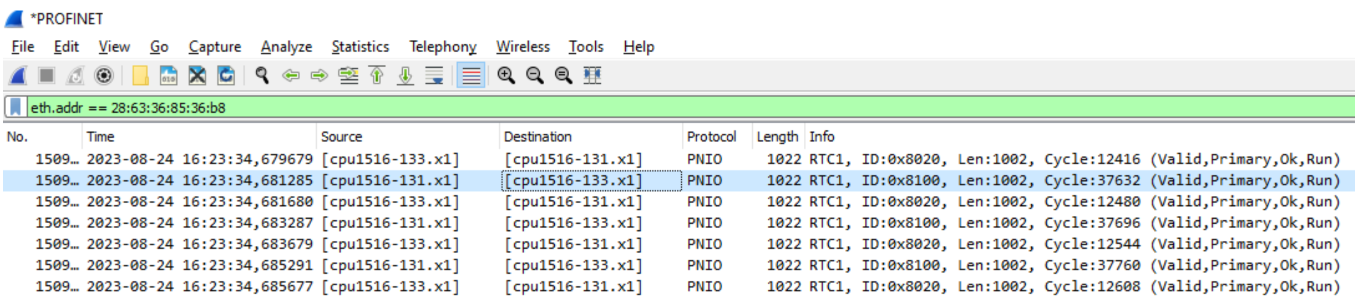


Figure 90: Communication between the main PLC and the I-device

Comparison between an IE/PB LINK and an interface PLC as I-device

Some measurements were carried out in the lab to compare the timing when using an IE/PB LINK or an I-device. The results can be found in Table 2 (yellow is the changed parameter between configurations), an example of the oscilloscope measurement can be found in Figure 15.

Table 13: Comparison between an IE/PB LINK and an interface PLC as I-device

	IE/PB LINK Config 1	IE/PB LINK Config 2	I-device Config 2	IE/PB LINK Config 3	IE/PB LINK Config 4	IE/PB LINK Config 5
PROFIBUS data rate	1,5 Mbps	1,5 Mbps	1,5 Mbps	93 kbps	93 kbps	93 kbps
PROFIBUS cycle time	0,8 ms	0,8 ms	0,8 ms	12 ms	12 ms	12 ms
PROFINET update time	2 ms	2 ms	2 ms	2 ms	8 ms	16 ms
CPU cycle time	1 ms	20 ms	20 ms	20 ms	20 ms	20 ms
Minimum time (DI-DO) Marker “a”	8 ms	27 ms	28 ms	35 ms	49 ms	50 ms
Maximum time (DI-DO) Marker “b”	13 ms	50 ms	48 ms	77 ms	78 ms	95 ms
Jitter (DO)	4,7 ms	22 ms	20 ms	42 ms	29 ms	45 ms

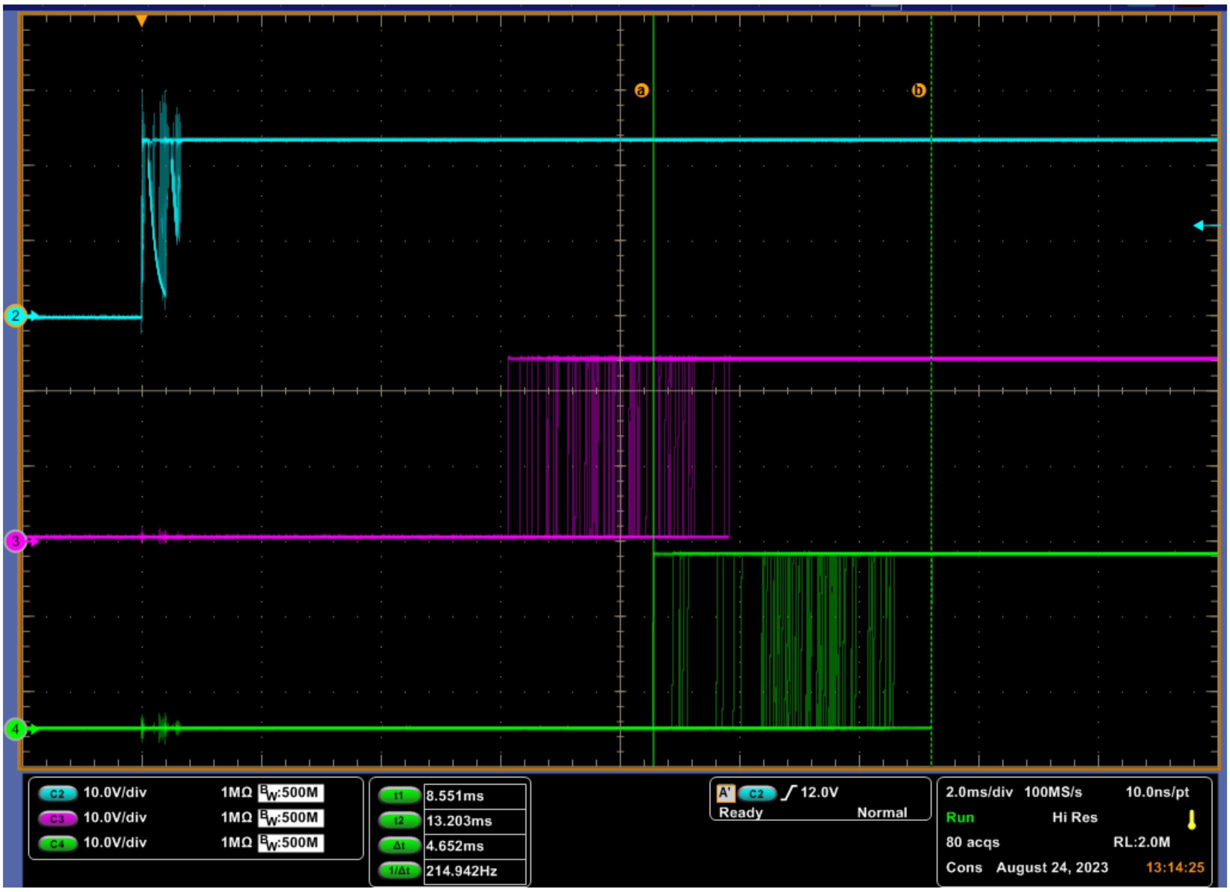


Figure 91: Oscilloscope measurement for IE/PB LINK Config 1

Inserting 100 and 1000 Mbps TAPs in industrial Ethernet

Larger networks, especially in installations with a high cost during unplanned standstill; benefit from the use of permanent diagnostic tools and devices. Besides extensive staff training and performing baseline measurements in new installations, the diagnostic tools need to be present. As they are very expensive, it is interesting to install Test Access Points (TAPs) throughout the installation, and insert whenever needed the expensive diagnostic tools behind the TAPs without interrupting the live networks.

This section covers 100 and 1000 Mbps TAPs and their properties.

Physical layers

100BASE-TX

This physical layer uses two wire pairs, each wire pair transmits in one direction. The frames can be directly decoded when measuring on a wire pair.

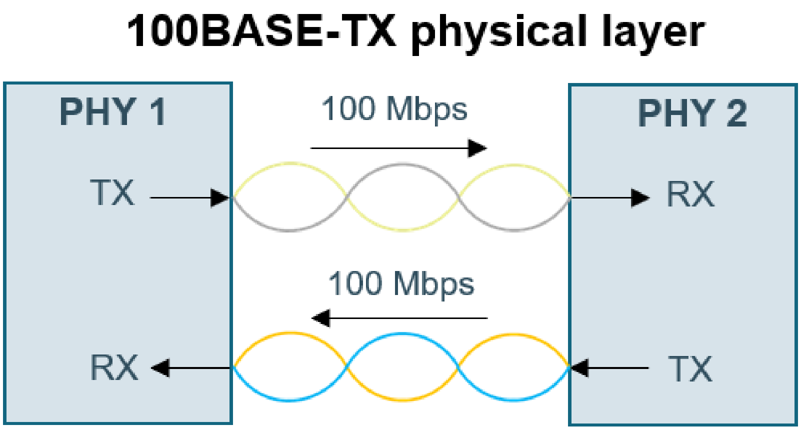


Figure 92: Schematic representation of 100BASE-TX communication

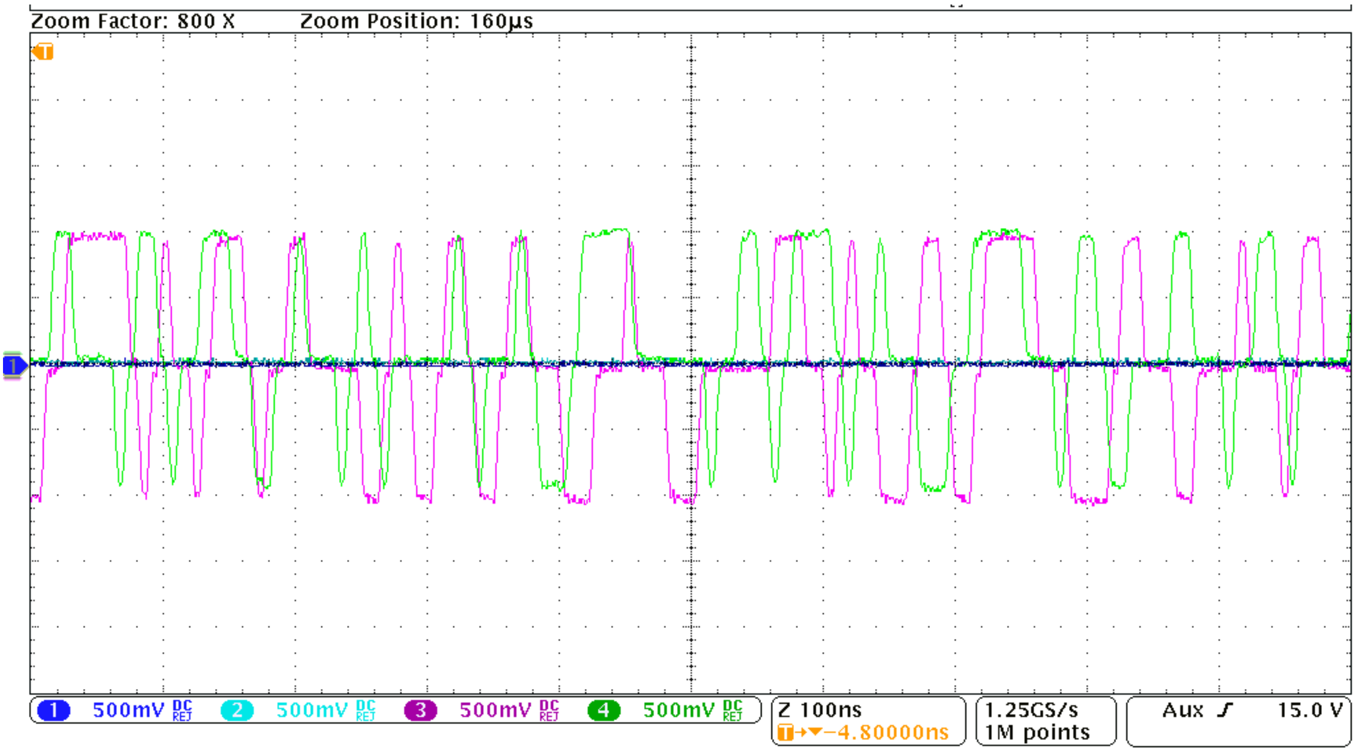


Figure 93: 100BASE-TX signals in a very short connection (no attenuation)

1000BASE-T

This physical layer uses four wire pairs, two transmitters send simultaneously over one wire pair. This means that the voltage signals are superimposed on the wire and it is impossible to distinguish the transmitter signals, so direct decoding with an oscilloscope is not possible.

This is the same principle as Single Pair Ethernet, so it comes with the same challenges when it comes to decoding.

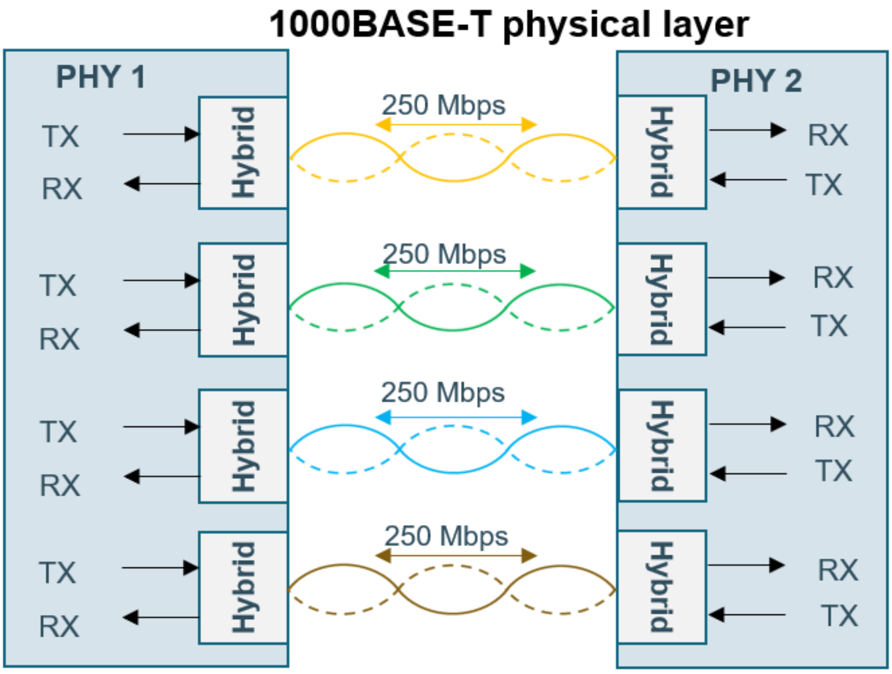


Figure 94: Schematic representation of 1000BASE-T communication

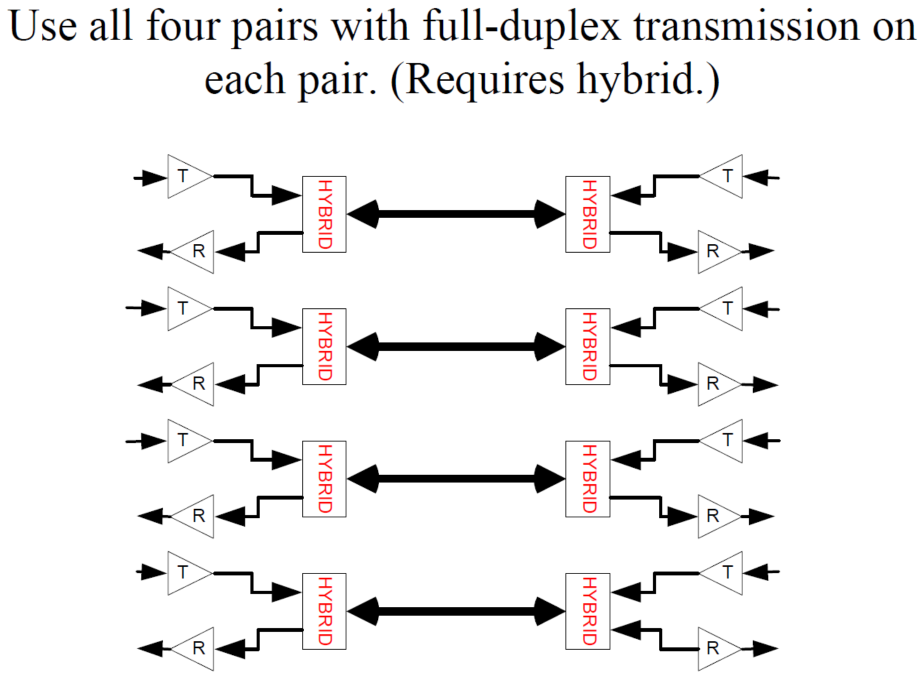


Figure 95: Use of hybrids[9]

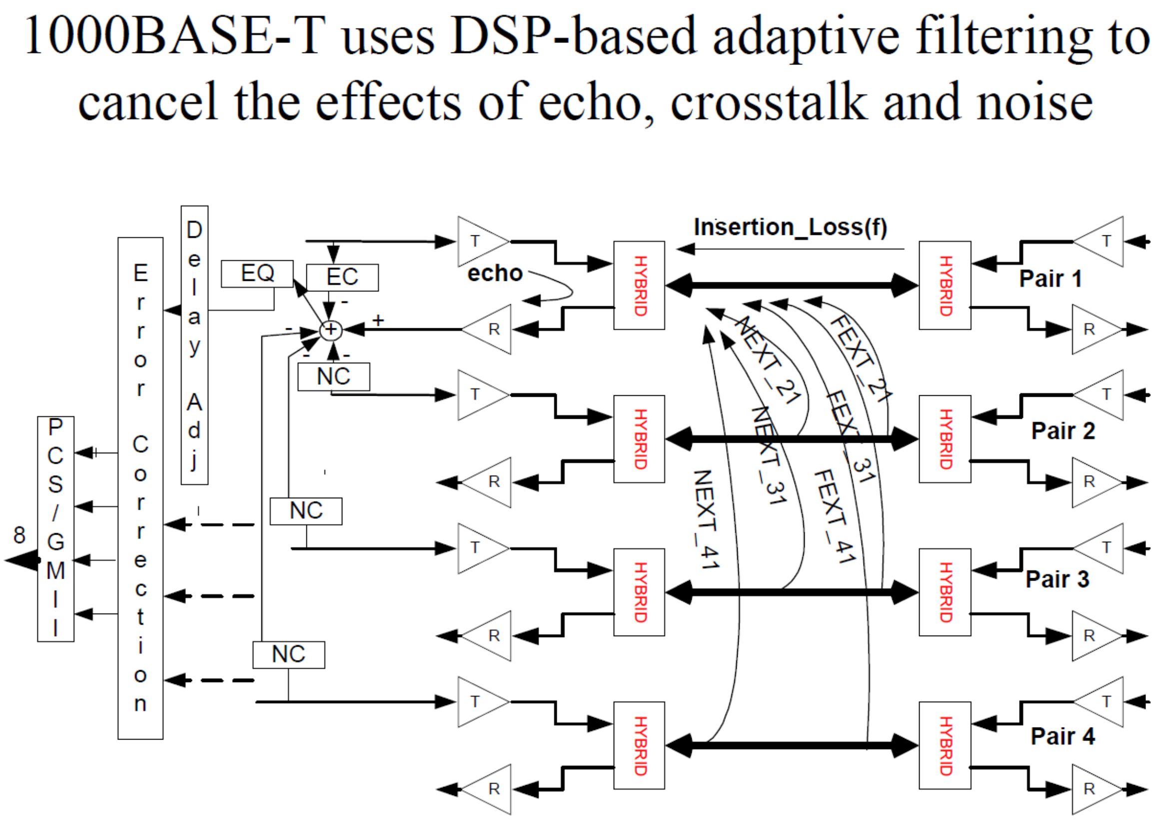


Figure 96: DSP-based adaptive filtering[10]

[9] "How 1000BASE-T Works", Geoff Thompson, IEEE802.3 Plenary, 13 Nov 97, Montreal PQ CANADA
[10] "How 1000BASE-T Works", Geoff Thompson, IEEE802.3 Plenary, 13 Nov 97, Montreal PQ CANADA

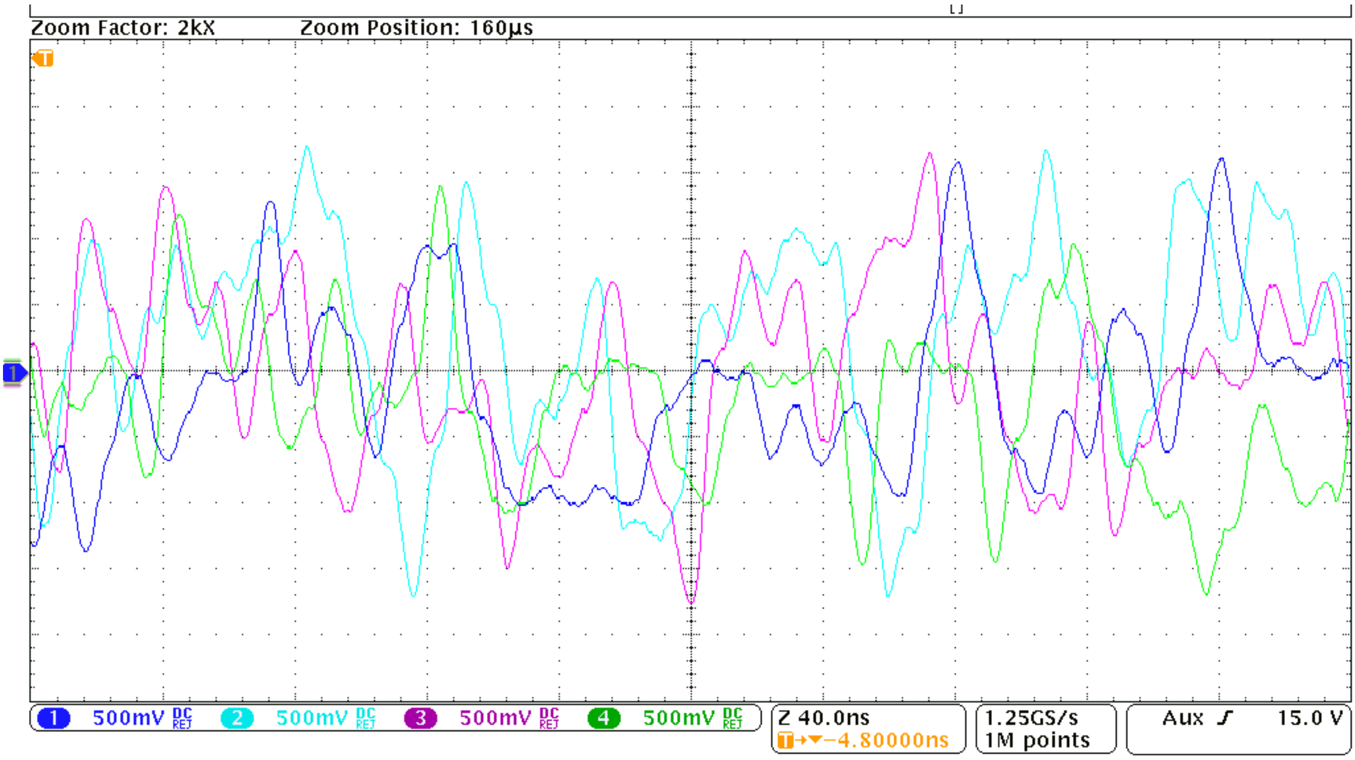


Figure 97: 1000BASE-T signals

TAPs

Principles

A TAP makes a real-time "copy" of Ethernet voltage signals and puts the signals on the "monitor" ports.

The ideal TAP should have no latency (in-line nor line-to-tap), provide no extra risk for the installation (e.g. no failover time in case of a power supply interruption) and lose no data even at 100% netload (not possible with mirror ports on switches).

Keep in mind that connecting a TAP using shielded cables can reroute shield currents.

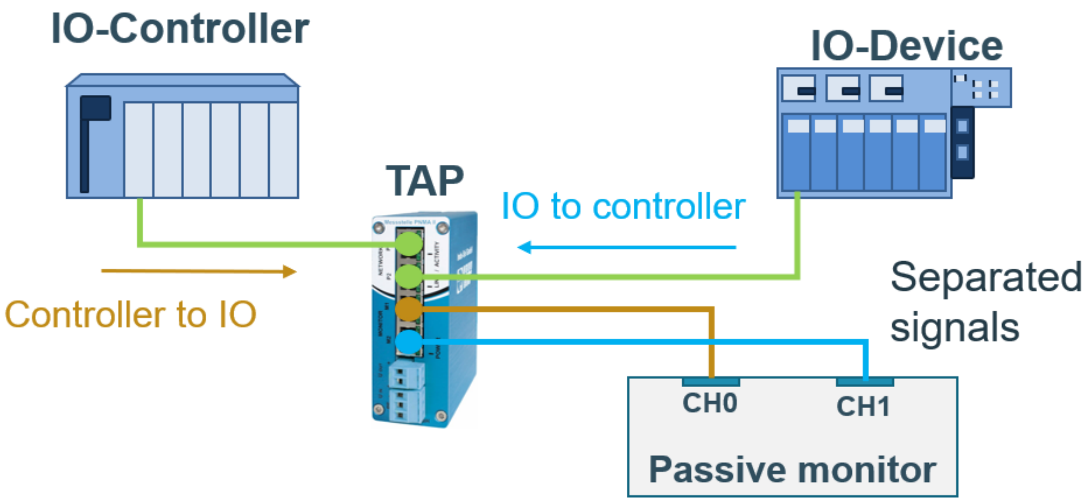


Figure 98: Connecting a TAP with passive monitor

100BASE-TX

TAPs for 100BASE-TX are passive devices, the signal from both transmitters can simply be duplicated. This means that there is no latency introduced and power supply interruption does not result in a link failure.

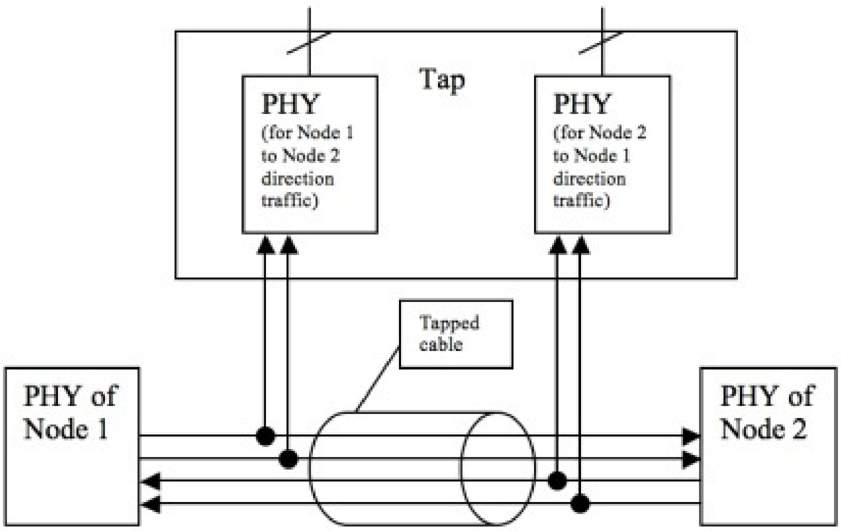


Figure 99: Schematic representation of a 100BASE-TX TAP

1000BASE-T

TAPs for 1000BASE-T are active devices, the signal from both transmitter sides can not be distinguished. That's why an extra pair of PHY chips is used in these TAPs which will negotiate with the neighbour ports. The communication is then duplicated from the SGMII (Serial Gigabit Media-Independent Interface) and converted again to 1000BASE-T signals using another extra pair of PHY chips. Because the signal is converted inside the TAP, latency is introduced inside the monitored link.

The active TAPs typically use physical relays to switch the communication path to the extra PHY chips when the power is connected (Figure 24). This means that the monitored link may still be active when the TAP is not powered, but switching the relays always causes a short link failure.

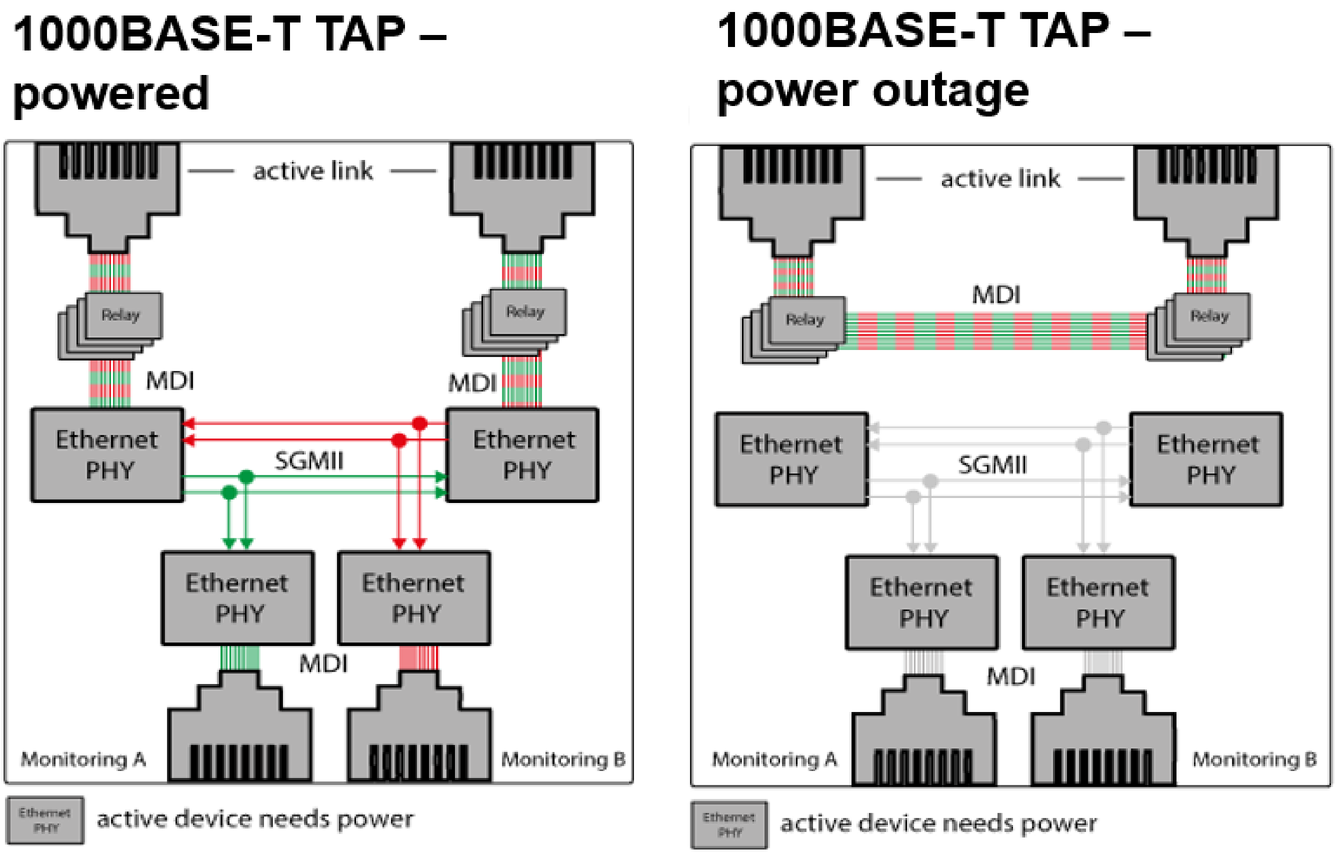


Figure 100: Schematic representation of a 1000BASE-T TAP in powered and unpowered state

Examples

Table 14: Examples of TAPs

	Link speed (Mbps)	**Latency**	**Network interrupted in case of power supply failure?**
Indu-Sol PNMA II	100	None	No
SCALANCE TAP104	100	None	No
PROFITAP C1R-1G	100 / 1000	1000 Mbps: 425 ns 100 Mbps: 700 ns	Yes (use redundant power supply)

		In-line jitter: 32 ns	

Planning tools

In the planning phase of new, large networks, it is advised to use planning tools to make sure that these new networks are sufficient for current and future communications, both for OT and IT. There is advanced software available for planning, e.g. of UC memebers Indu-Sol PROnetplan V2 and Siemens SINETPLAN, but free basic tools can also be used, e.g. the PI Network Load Calculation Tool.

This chapter briefly describes the above mentioned tools.

Indu-Sol PROnetplan V2

PROnetplan V2 allows the pre-planning of convergent industrial networks based on Industrial Ethernet and PROFINET. PROnetplan V2 focuses in particular on bandwidth planning. As a result, it can be ensured right from the network planning stage that all future applications used in the network can communicate smoothly.

Parameters taken into account and displayed by PROnetplan V2 are:

- Type of application (PROFINET, TCP/IP application)
- Number of devices / payload
- Server (communication sink)
- Data throughput / backplane capacity / required number of ports of the switches used
- Bandwidth / network load for each connection
- Update times of the cyclic devices (e.g. PROFINET)
- Required number of ports
- Available line depth
- Uni- / bidirectional communication, broadcast

Figure 25 shows an entire network (example taken from use case II. AMG WWA Mill Maintenance Hall of D5c), Figure 26 shows a detail of the network. The calculated load is indicated as a percentage in each communication link in both directions.

Figure 27, Figure 28, Figure 29 show the details of an IO device, a controller and a connection respectively.

Applications (e.g. PROFINET, camera, …) can be added to the devices and for each application the server can be defined (e.g. IO controller, IT server, …). Depending on the kind of application several parameters can be set (e.g. update rate, throughput, payload, …). The software will use these applications to calculate the required bandwidth on each link between the device(s) and the server(s).

For each of the links or connections the transmission medium (copper cable, optic fiber or WLAN) and connection speed can be chosen.

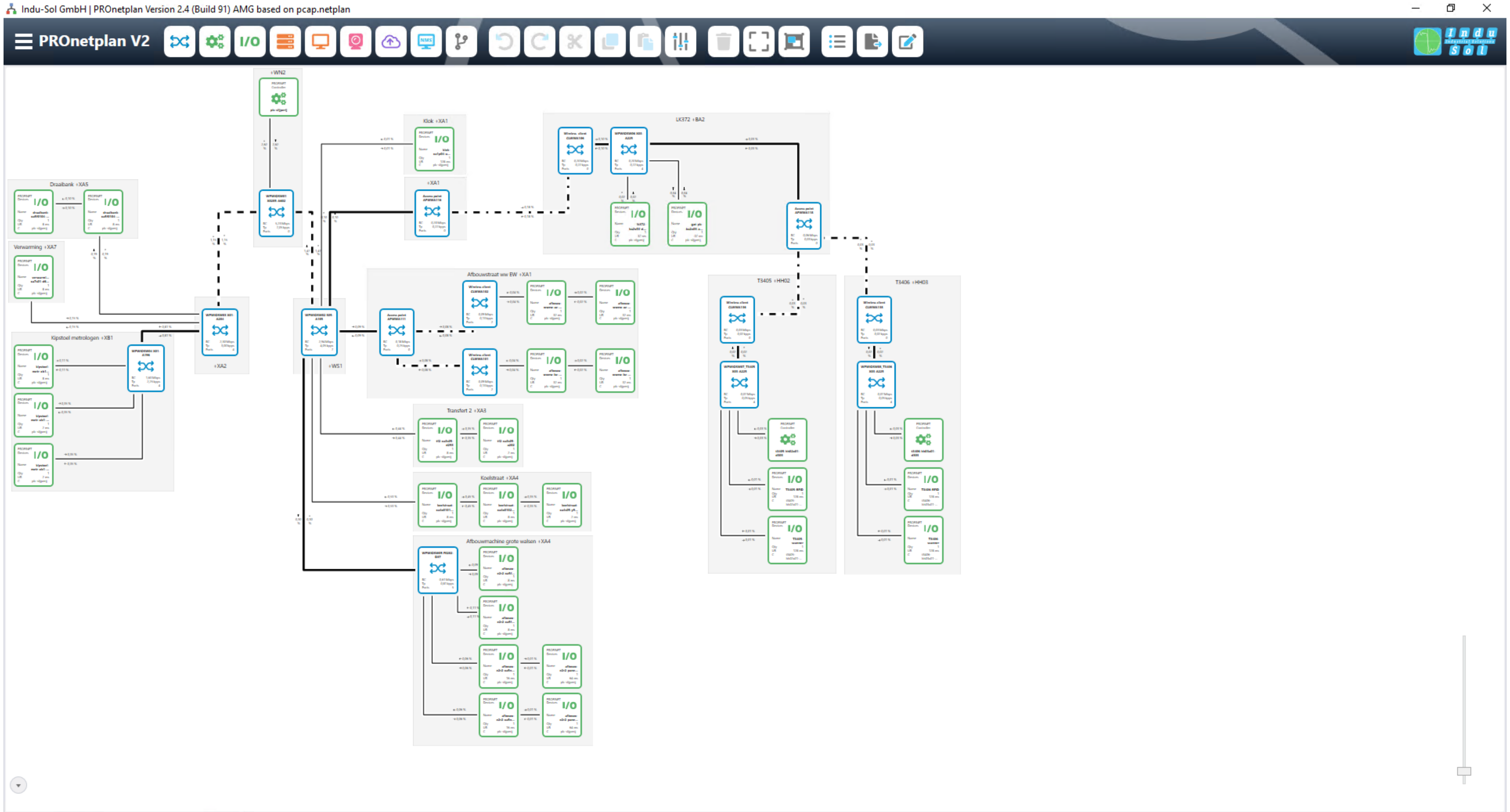


Figure 101: Overview of an entire network

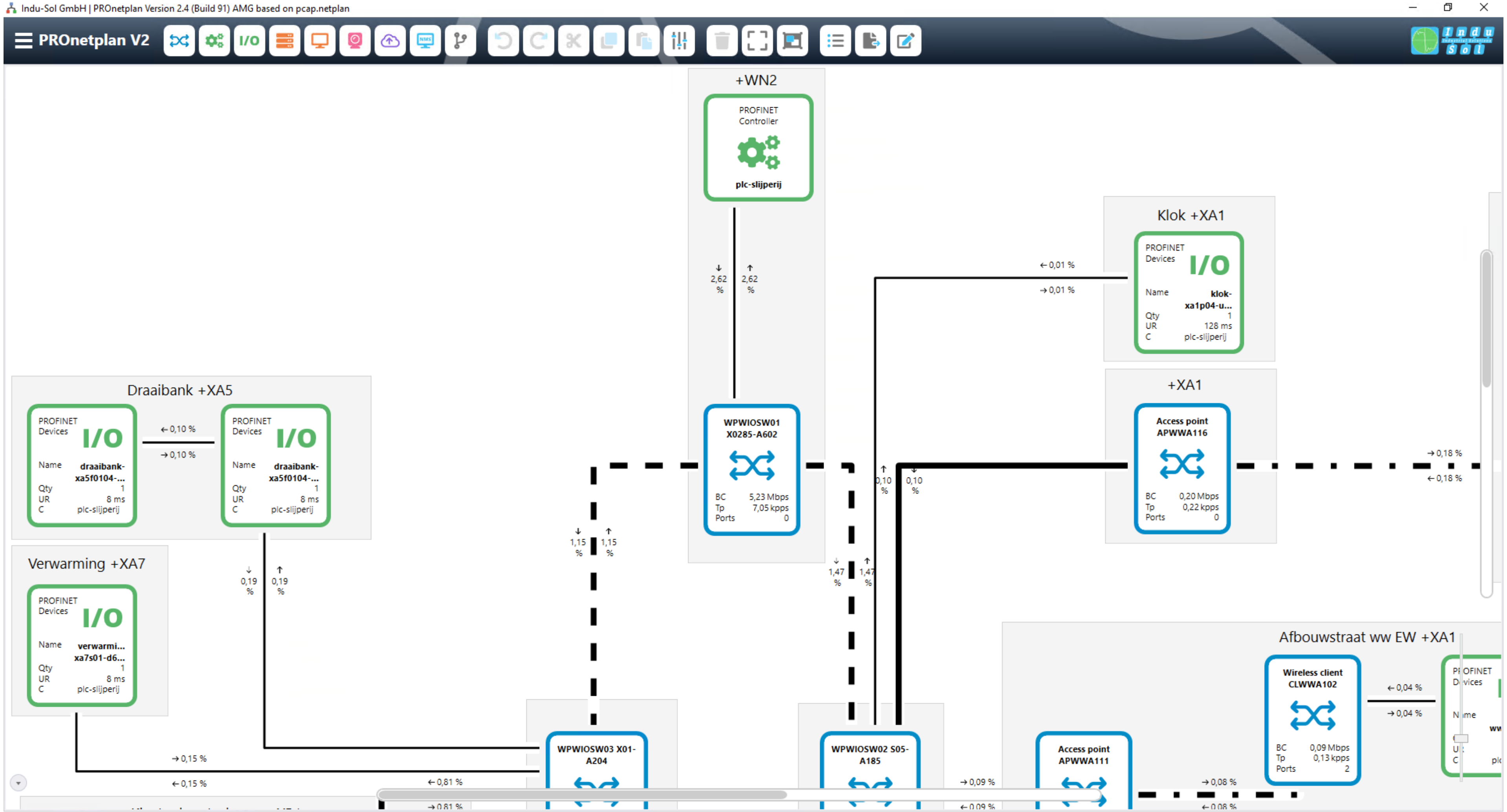


Figure 102: Detail of a network

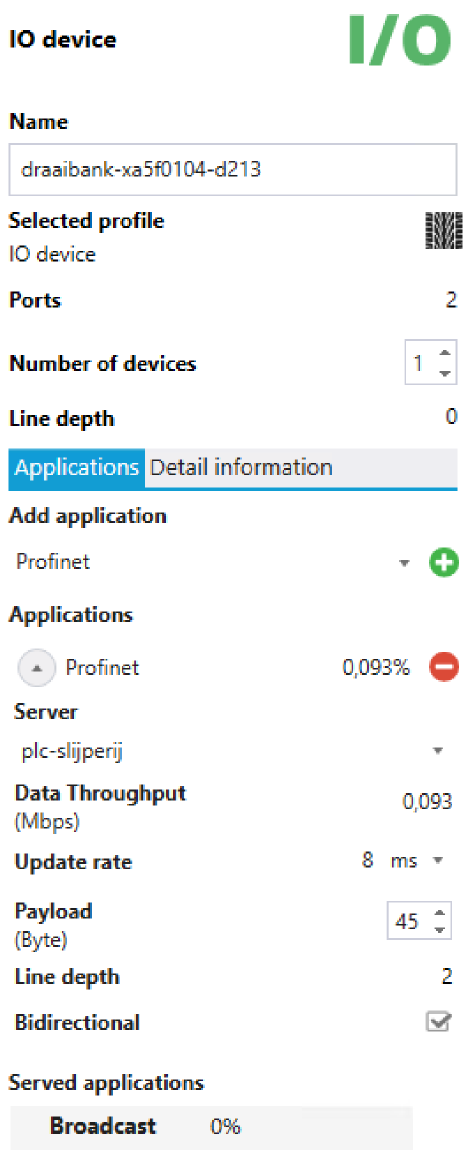


Figure 103: Details of an IO device

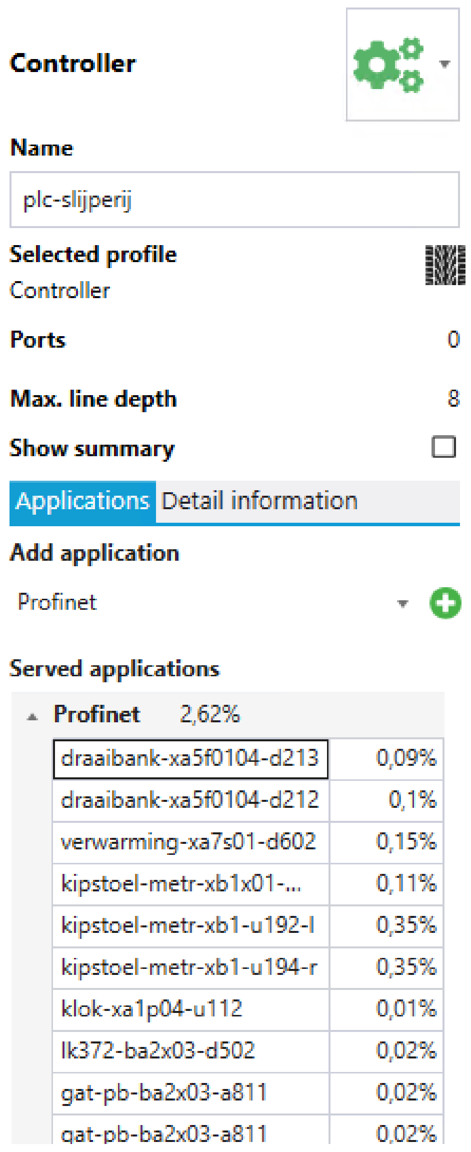


Figure 104: Details of a controller

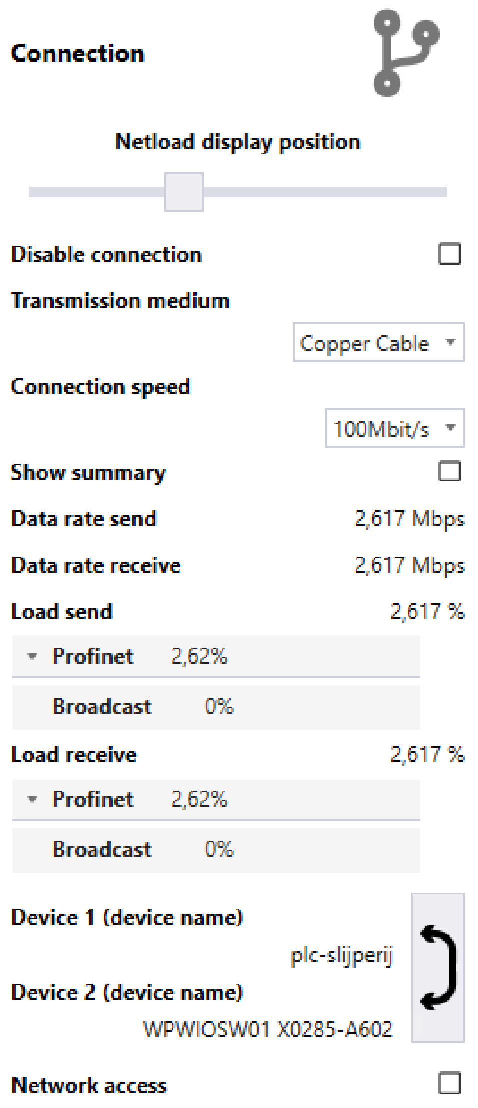


Figure 105: Details of a connection

Siemens SINETPLAN

SINETPLAN supports in planning and designing PROFINET networks.

It calculates the data traffic in the network and points out critical segments in which the traffic load is too high.

To do so, the tool simulates:

- Real-time data traffic between IO controllers and IO devices (real-time communication).
- Data traffic between regular Ethernet devices, such as TCP/IP data or UDP data (non-real-time communication).

As a result, you will have an overview of the utilization of the planned network prior to installation and commissioning.

If SINETPLAN displays critical network segments, you can easily revise your plans and start the simulation once again.

That way you optimize the planned network and prevent problems from occurring during commissioning or in production.

Figure 30 shows an overview of the network with the calculation results. Figure 31 shows an overview of all devices in the network. Figure 32 shows the configured dataflows, in this case imported via pcap-file. The dataflows can be configured manually or imported via pcap-file. A TIA Portal project can also be imported, this will import the devices from the project, but it will also create dataflows based on the configuration in the project.

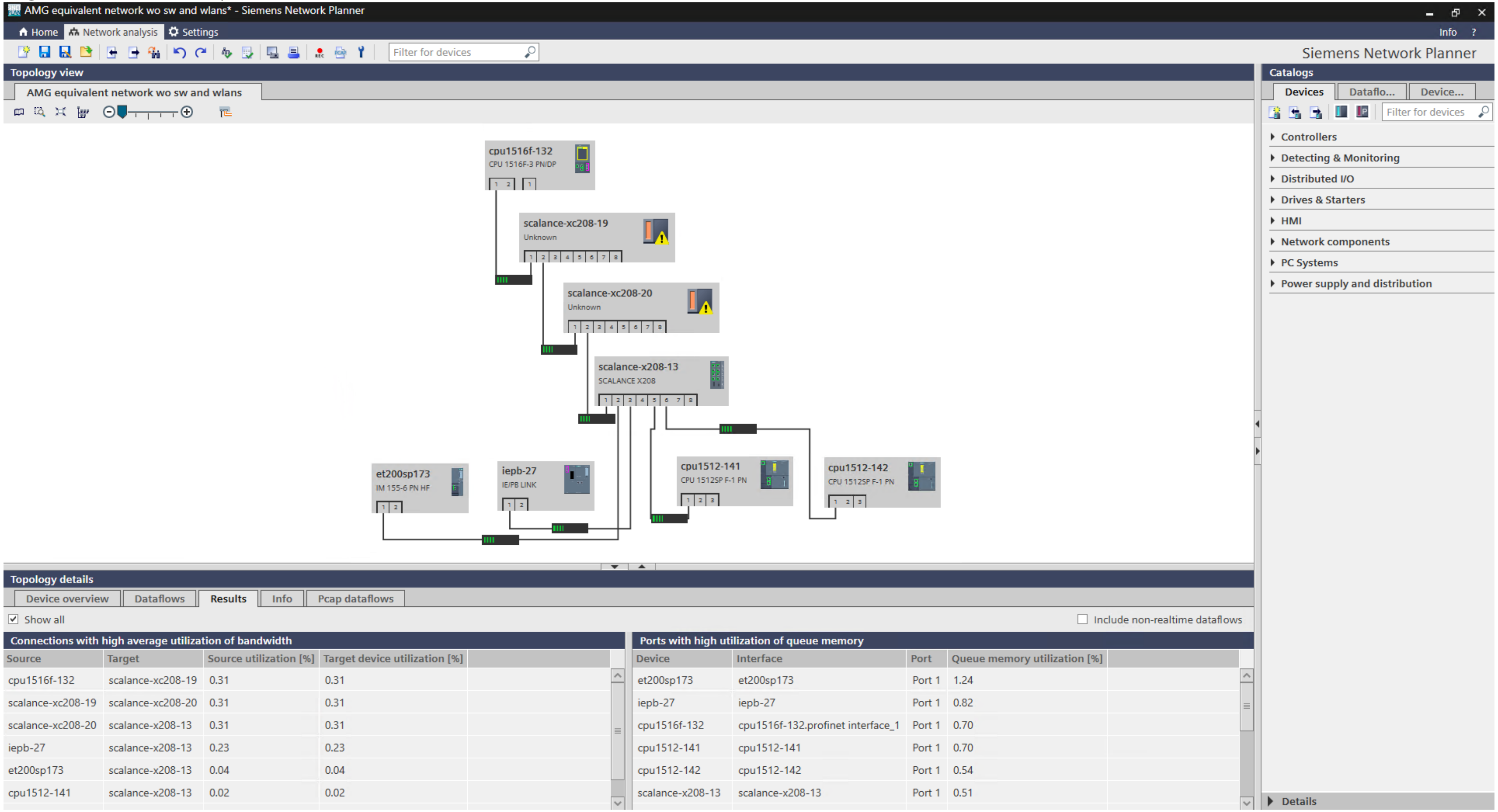


Figure 106: Overview of the network with the calculation results

Topology details

Device overview | Dataflows | Results | Info | Pcap dataflows

#		Name	Interface name	IP address	SW revision
	*	*	*	*	*
1		cpu1516f-132	cpu1516f-132.profinet interface_1	192.168.0.132	V2.0
2		cpu1512-141	cpu1512-141	192.168.0.141	V2.0
3		cpu1512-142	cpu1512-142	192.168.0.142	V2.6
4		scalance-xc208-19	scalance-xc208-19	192.168.0.19	V4.0
5		scalance-xc208-20	scalance-xc208-20	192.168.0.20	V4.0
6		scalance-x208-13	scalance-x208-13	192.168.0.13	V5.1
7		et200sp173	et200sp173	192.168.0.173	V4.2
8		iepb-27	iepb-27	192.168.0.27	V3.0

Figure 107: Device overview

Topology details

Device overview | Dataflows | Results | Info | Pcap dataflows

#	☑	Name	Source device	Target device	Real-time class	Max packet size [B]	Burst [B]	Average rate [B/s]
	*	*	*	*	*	*	*	*
1	☑	PCAP import PN-RTC1 1	cpu1516f-132	et200sp173	PROFINET IO RT Class 1	76	76	5500
2	☑	PCAP import PN-RTC1 2	cpu1516f-132	iepb-27	PROFINET IO RT Class 1	76	76	29334
3	☑	PCAP import PN-RTC1 3	et200sp173	cpu1516f-132	PROFINET IO RT Class 1	76	76	5500
4	☑	PCAP import PN-RTC1 4	iepb-27	cpu1516f-132	PROFINET IO RT Class 1	76	76	29334
5	☑	PCAP import PN-RTC1 5	cpu1512-142	cpu1516f-132	PROFINET IO RT Class 1	240	240	1969
6	☑	PCAP import PN-RTC1 6	cpu1512-141	cpu1516f-132	PROFINET IO RT Class 1	244	244	2000
7	☑	PCAP import PN-RTC1 7	cpu1516f-132	cpu1512-141	PROFINET IO RT Class 1	244	244	2000
8	☑	PCAP import PN-RTC1 8	cpu1516f-132	cpu1512-142	PROFINET IO RT Class 1	240	240	1969

Figure 108: Dataflows

PI Network Load Calculation Tool

The PI Network Calculation Tool is available for download at:

https://www.profibus.com/download/profinet-installation-guidelines

The tool itself is an Excel spreadsheet with 4 sheets:

- Calculation: main page where the user can input the required information to calculate the network load
- Description: describes the required parameters for the calculation
- User manual: info about the interface and operation of the Calculation Tool
- Program flowchart: explanation about the calculation itself

The entire spreadsheet is protected against unwanted changes, but it can be unprotected to see how the Calculation sheet works. There are also some hidden columns and rows which contain extra values and formulas needed for the calculation.

Figure 33 shows an example of a calculation using the tool. Figure 34 shows the program flowchart of one part of the network calculation tool. This flowchart is used for one device group and one transmission direction, it is used in the same way for other device groups and the other transmission directions.

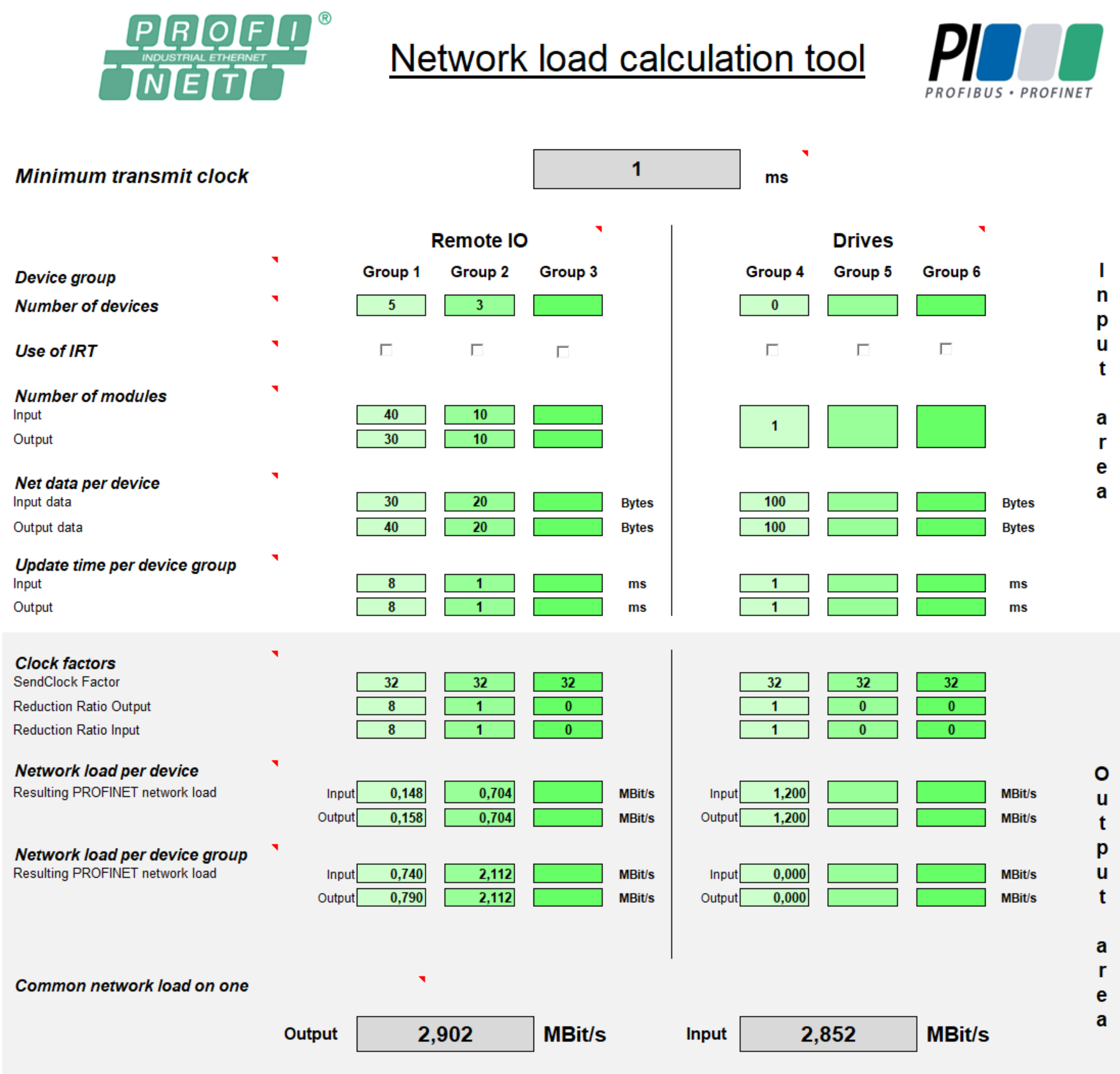


Figure 109: PI Network Load Calculation Tool

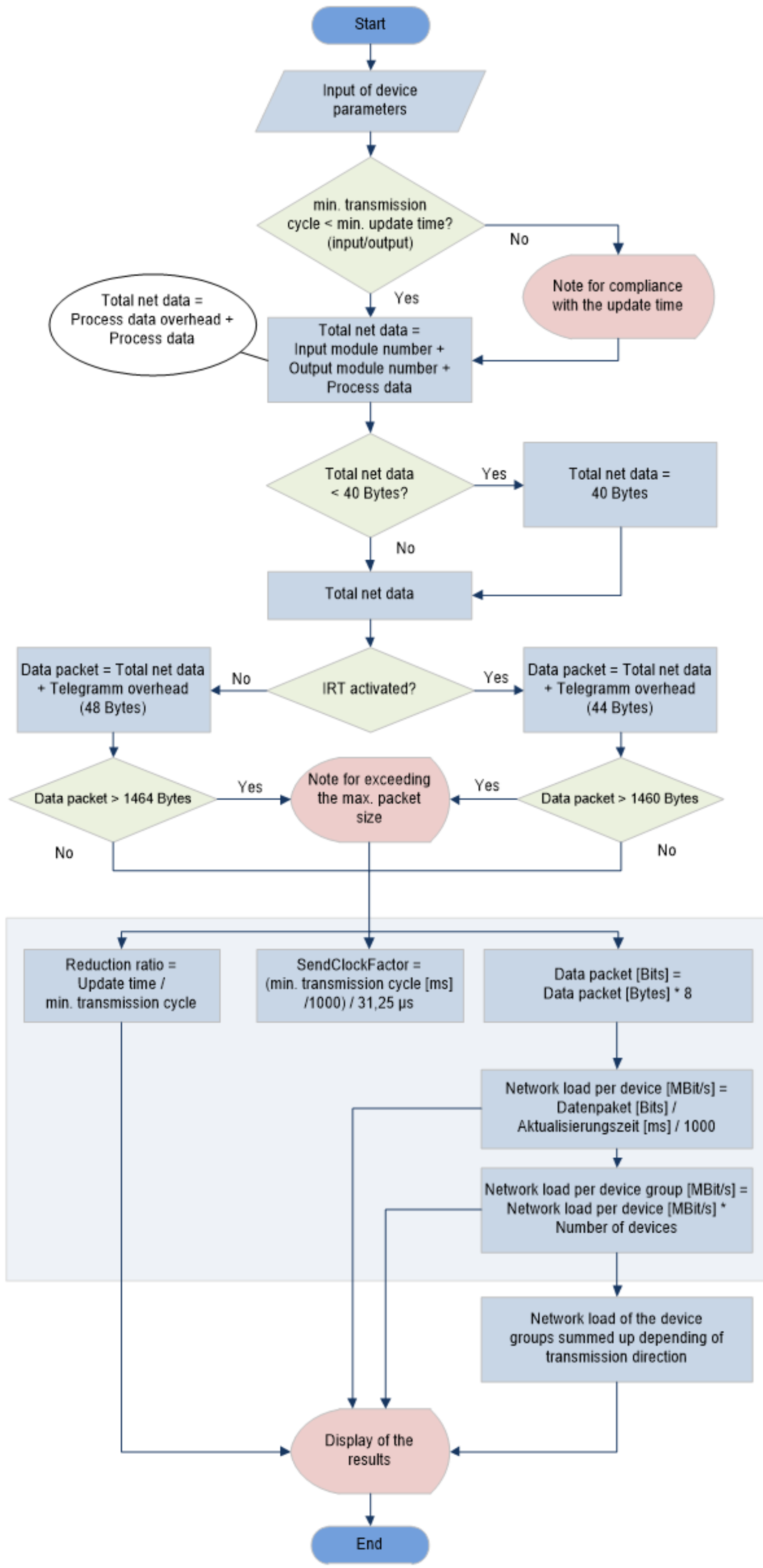


Figure 110: Program flowchart of one part of the network calculation tool

Single Pair Ethernet over brownfield cabling

Cabling requirements for 100BASE-T1 and 1000BASE-T1

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

Cabling requirements for 10BASE-T1L

- 200 m (1 Vptp) or 1000 m (2.4 Vptp)
- Shielded
- 20 MHz bandwidth required
- Cabling requirements fit Fieldbus type A cable (e.g. PROFIBUS PA, Foundation Fieldbus) !
- 100 Ω characteristic impedance

The cabling requirements state that brownfield cabling (Fieldbus type A) may be used for 10BASE-T1L. KU Leuven did some testing on a PROFIBUS PA cable (Siemens 6XV1830-5FH10) of 100 meters (Figure 35). Auto-negotiation during startup phase succeeded, and in preliminary tests trying to disturb the communication with UGent’s EMC amplifier and clamp (described in other reports), it proved to be very robust.

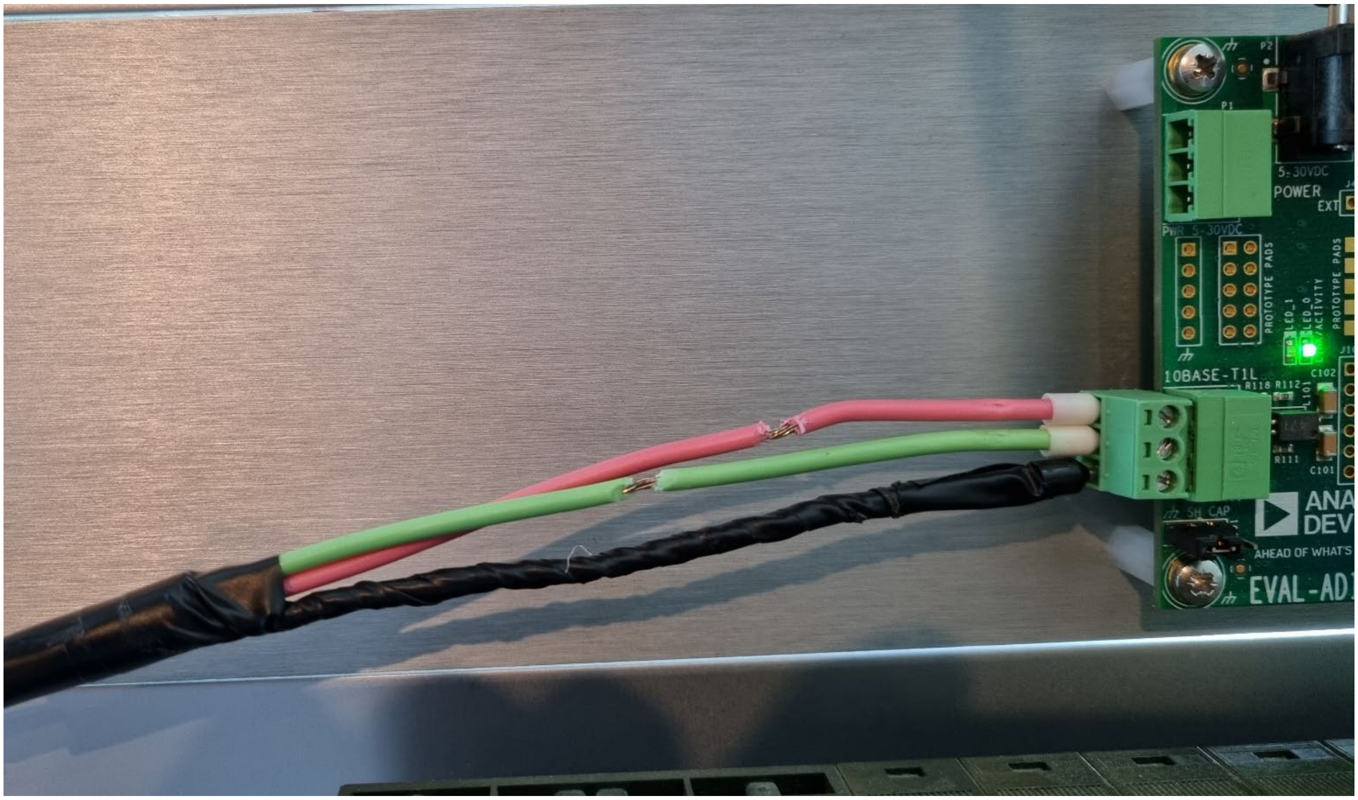
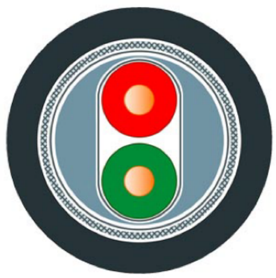


Figure 111: PROFIBUS PA cable connected to an Analog Devices 10BASE-T1L media converter

SIEMENS

Data sheet **6XV1830-5FH10**

product description	Bus cable (2-core), sold by the meter, unassembled PB FC Process Cable GP/ Ethernet-APL cable GP, bus cable for IEC 61158-2 (PB) and IEC TS 60079-47 (2-WISE) sheath color black for Ex applications 2-core shielded, sold by the meter delivery unit max. 1000 m minimum order quantity 20 m.



suitability for use	Use in fieldbus systems according to IEC 61158-2 (e.g. PROFIBUS PA) and IEC TS 60079-47 (2-WISE) / for APL (cable type A), suitable for non-Ex applications
cable designation	02YSY (ST) CY 1x2x1,0/2,55-100 SW OE FR
electrical data	
attenuation factor per length	
• at 38.4 kHz / maximum	0.003 dB/m
return loss	
• at 3 MHz	19 dB
impedance	
• rated value	100 Ω
• at 31.25 kHz	100 Ω
• at 3 MHz ... 20 MHz	100 Ω
relative symmetrical tolerance	
• of the characteristic impedance at 31.25 kHz	20 %
• of the characteristic impedance at 3 MHz ... 20 MHz	15 %
loop resistance per length / maximum	44 mΩ/m
shield resistance per length / maximum	6.5 Ω/km
capacity per length / at 1 kHz	92 pF/m
inductance per length	0.65 µH/m
operating voltage	
• RMS value	80 V
mechanical data	
number of electrical cores	2
design of the shield	Overlapped aluminum-clad foil, sheathed in a braided screen of tin-plated copper wires
type of electrical connection / FastConnect	Yes
outer diameter	
• of inner conductor	1.05 mm
• of the wire insulation	2.55 mm
• of the inner sheath of the cable	5.4 mm
• of cable sheath	8 mm
symmetrical tolerance of the outer diameter / of cable sheath	0.4 mm
material	
• of the wire insulation	polyethylene (PE)
• of the inner sheath of the cable	PVC
• of cable sheath	PVC
color	
• of the insulation of data wires	red/green
• of cable sheath	Black

6XV18305FH10
Page 1/2

9/13/2023

Subject to change without notice

Figure 112: Datasheet Siemens 6XV1830-5FH10 (1)

bending radius	
• with single bend / minimum permissible	40 mm
• with multiple bends / minimum permissible	80 mm
tensile load / maximum	150 N
weight per length	103 kg/km
ambient conditions	
ambient temperature	
• during operation	-40 ... +80 °C
• during storage	-40 ... +80 °C
• during transport	-40 ... +80 °C
• during installation	-20 ... +80 °C
• note	Electrical properties measured at 20 °C, tests according to DIN 47250 part 4 respectively DIN VDE 0472
ambient condition / for operation	Transfer rate of cable: 31.25 Kbit/s
fire behavior	flame resistant according to IEC 60332-3-24 (Category C)
class of burning behaviour / according to EN 13501-6	Eca
chemical resistance	
• to mineral oil	conditional resistance
• to grease	Conditional resistance
• to water	conditional resistance
radiological resistance / to UV radiation	resistant
product features, product functions, product components / general	
product feature	
• halogen-free	No
• silicon-free	Yes
standards, specifications, approvals	
UL/ETL listing / 300 V Rating	Yes; c(UL)us, CMG / CL3 / Sun Res
UL/ETL style / 600 V Rating	Yes
certificate of suitability	
• EAC approval	Yes
• CE marking	Yes
• RoHS conformity	Yes
product conformity	
• IEC TS 60079-47 (2-WISE) / for APL (cable type A)	Yes
Marine classification association	
• American Bureau of Shipping Europe Ltd. (ABS)	No
• French marine classification society (BV)	No
• Det Norske Veritas (DNV)	No
• Germanische Lloyd (GL)	No
• Lloyds Register of Shipping (LRS)	No
• Nippon Kaiji Kyokai (NK)	No
• Polski Rejestr Statkow (PRS)	No
reference code	
• according to IEC 81346-2	WG
• according to IEC 81346-2:2019	WGB
further information / internet links	
internet link	
• to web page: selection aid TIA Selection Tool	http://www.siemens.com/tia-selection-tool
• to website: Industrial communication	http://www.siemens.com/simatic-net
• to website: Industry Mall	https://mall.industry.siemens.com
• to website: Information and Download Center	http://www.siemens.com/industry/infocenter
• to website: Selection guide for cables and connectors	https://sie.ag/2QdlxcP
• to website: Image database	http://automation.siemens.com/bilddb
• to website: CAx-Download-Manager	http://www.siemens.com/cax
• to website: Industry Online Support	https://support.industry.siemens.com

last modified: 7/7/2022

Figure 113: Datasheet Siemens 6XV1830-5FH10 (2)

During the negotiation phase the signals have different properties in comparison to the normal communication. Figure 38 shows the negotiation phase for a 10BASE-T1L link. The lowest frequency during negotiation is at 312,5 kHz. Some (long) brownfields cables with high insertion losses around 500 kHz may limit the T1L length because of the auto-negotiation.

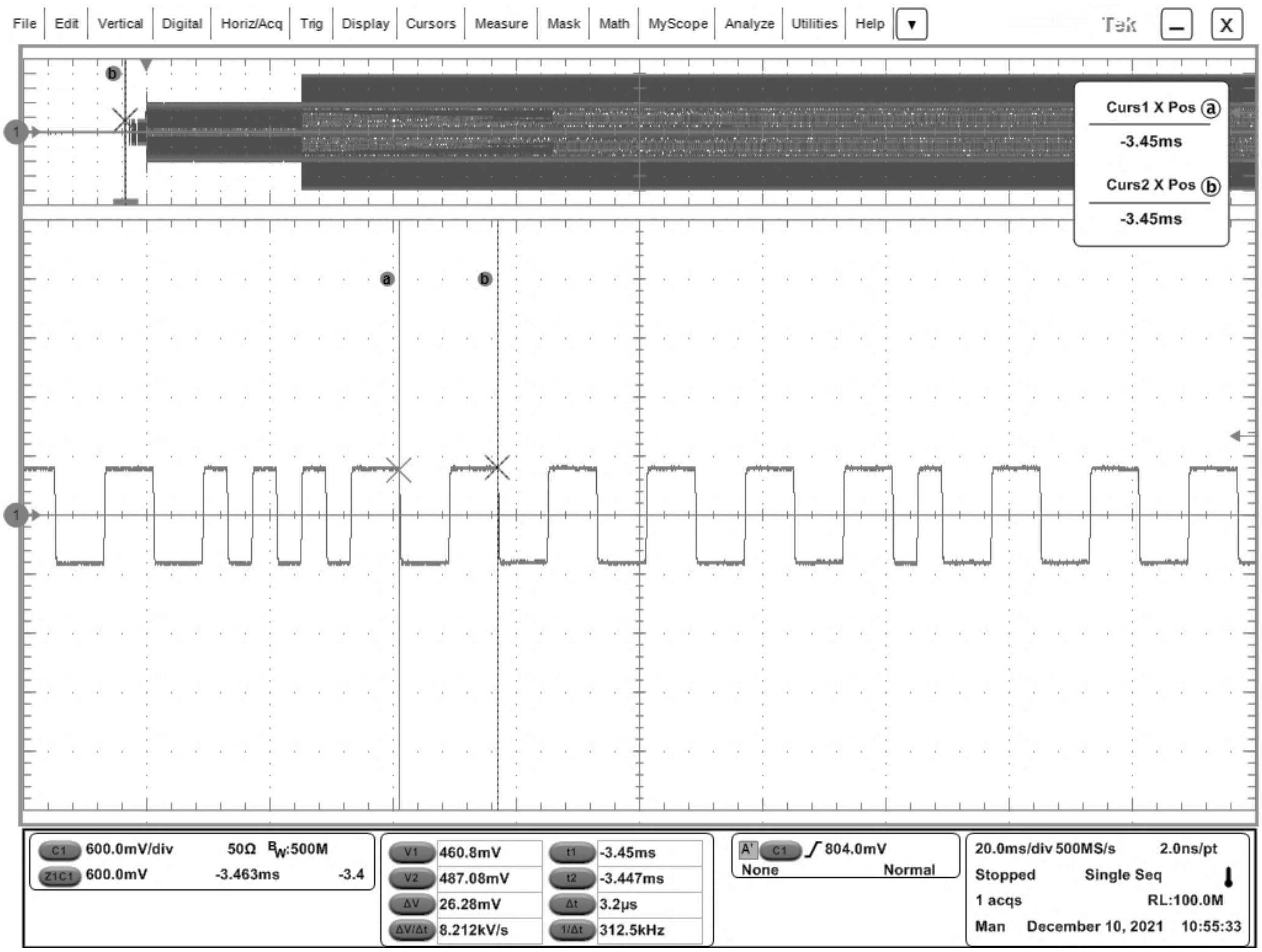


Figure 114: 10BASE-T1L negotiation

Texas Instruments provides some measurements on brownfield fieldbus cables in [11].

Figure 39 shows measurements on a Siemens 6XV1830-5EH10 cable: black is the reference, blue is 200 m, green is 1000 m and red is 1200 m. The cable complies up to 1000 m, there is a small violation for 1200 m. It functions up to 1000 m with auto-negotiation and even up to 2000 m in forced mode for negotiation.

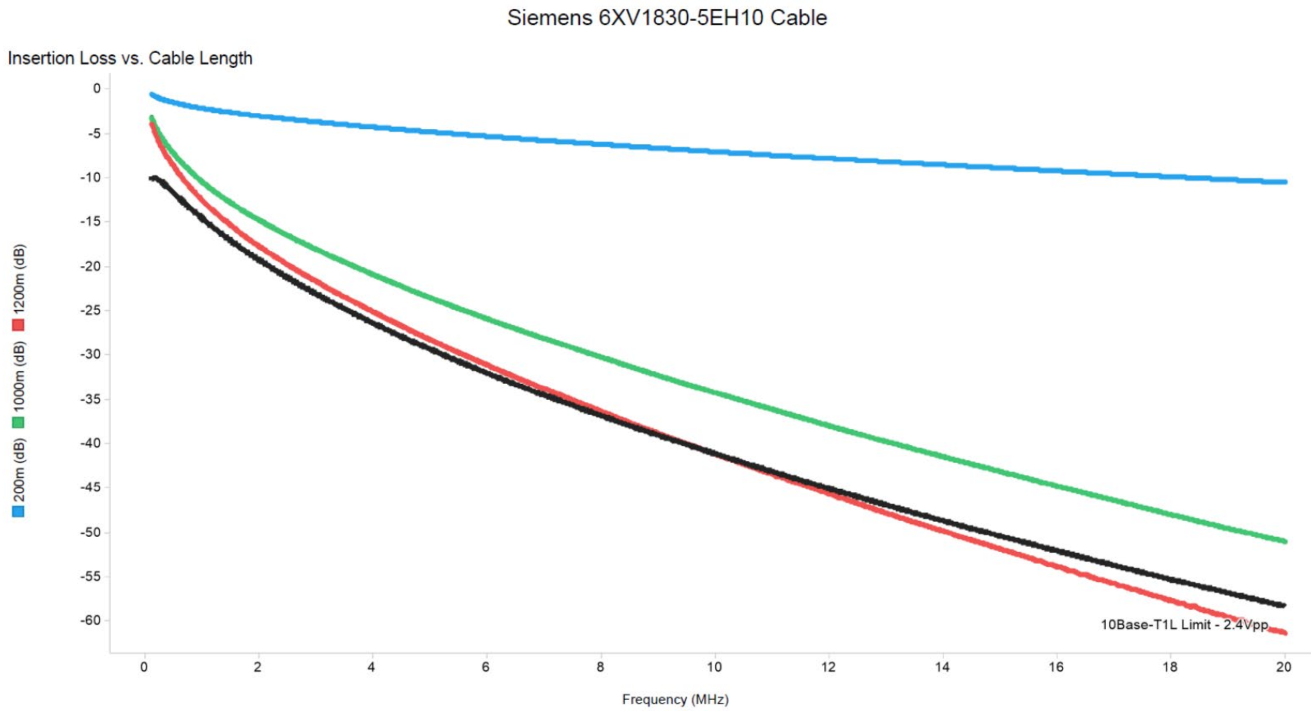


Figure 115: Texas Instruments measurement on Siemens 6XV1830-5EH10 cable

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

Figure 40 shows measurements on a Belden 3076F cable: black is the reference, blue is 600 m and green is 800 m. The cable complies up to 400 m. It functions up to 260 m with auto-negotiation and up to 600 m in forced mode for negotiation.

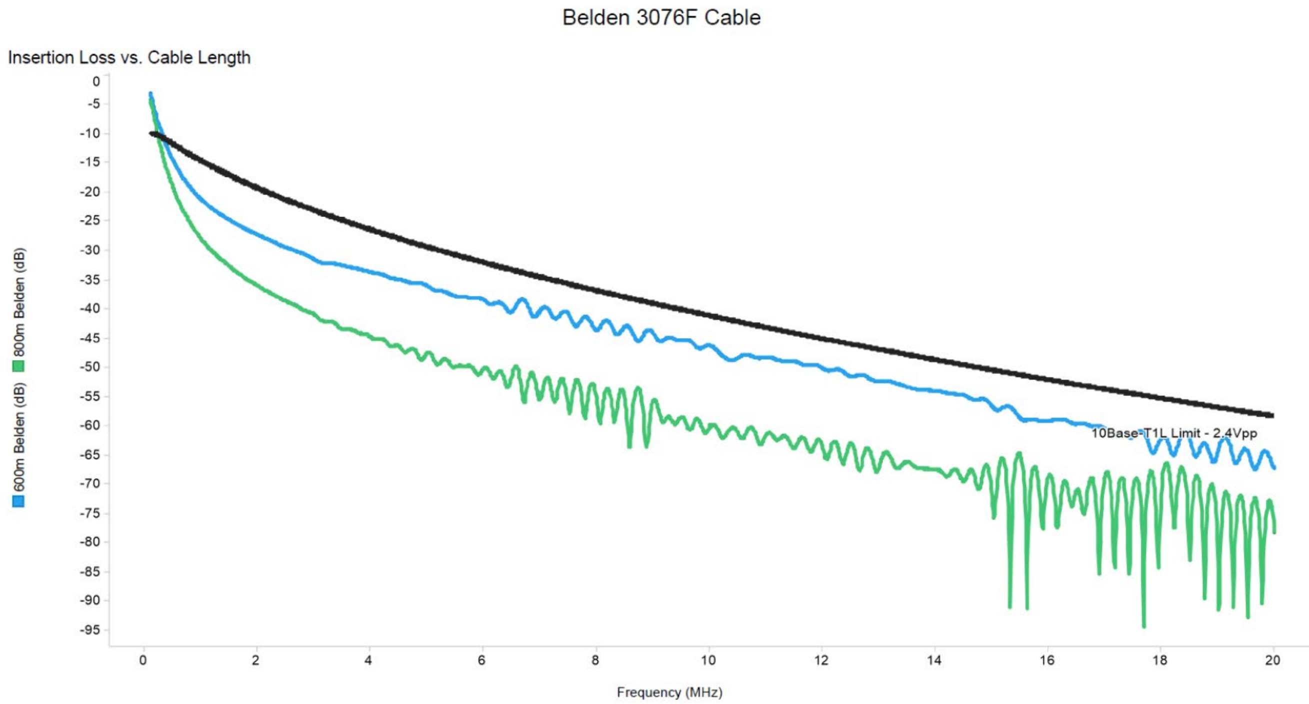


Figure 116: Texas Instruments measurement on Belden 3076F cable

In conclusion, brownfield cables may be used for 10BASE-T1L, but it is advised to use a cable tester to determine the insertion losses[12] for a given cable length. A workaround might be to use forced mode.

[12] E.g. AEM TestPro CV100

Appendix C: Best Practices 2

Introduction

In this introduction, some of the key conclusions and/or best practises will be listed for each use case. A more in depth report can be found in each of the next chapters.

TSN Brownfield PROFINET Evaluation

At 100 Mbps in a line of 7 switches, implementing preemption in isolation provides a significant reduction in end-to-end delay and jitter compared to “legacy” PN under converged network conditions with an OT + IT netload of 35%. This reduction in end-to-end delay and jitter provides for a faster and more deterministic industrial network. Comparing the reduction in end-to-end delay and jitter to the PN cycle time of 1 ms, we can state that deterministic PN RT communication is achieved for a brownfield PN over TSN network under converged OT/IT conditions with high netload.

At 1000 Mbps in a line of 7 switches, implementing preemption in isolation provides a reduction in end-to-end delay and jitter compared to “legacy” PN under converged network conditions with an OT + IT netload of 70%. This reduction is less spectacular when compared to the reduction at 100 Mbps, since the 1000 Mbps link speed already provides low end-to-end delay and jitter even without preemption. With or without preemption, at 1000 Mbps converged OT/IT networks with high BE (IT) throughput can be set up, upholding robust brownfield PROFINET communication at high OT netload scenarios.

AMG WWA Mill Maintenance Hall Analysis

- Make sure that wired Ethernet links are never longer than the maximum permitted distance (e.g. 100 m is the maximum for 100BASE-TX), it may work at longer distances but there might occur occasional errors like e.g. frame gaps. 10BASE-T1L SPE is the (near) future alternative.
- When using Wi-Fi, make sure that there is no overlap with other (IT or OT) channels.
- When using Wi-Fi, try to maintain line of sight as much as possible, especially over long distances and/or environments with a lot metal constructions and/or equipment.

EMC AMG SDG

- Terminate the PROFIBUS cable in accordance with the guidelines.
- Check whether the terminal station is (properly) actively terminated, if necessary use a dedicated *active* termination.
- When the PROFIBUS network cycle time allows it, test a lower bit rate to see if this solves the issue (lower bit rates are more robust).
- Use capacitors or filters to suppress interference pulses.
- Use good mesh (!) bonding over the entire network

- In case of ignition transformers and spark plugs, use a spark plug with two dedicated electrodes instead of one that uses the ground and installation as the return path.

EMC Prolink-engineering (Renson)

- Check the spectral content of the common mode current on the PROFINET cable.
- If the emission is broadband, zoom with 200 Hz BW to identify the switching frequency.
- If the emission is narrowband, identify the fundamental frequency by measuring the distance between harmonics.
- Depending on this identify the possible sources.
- Visually check every cable and motor connection and every switchbox in between.

Historically grown converged OT/IT networks at Barry Callebaut

- Use redundancy where possible, especially in the backbone of the network, so in case one of the components fails, only a part of the network fails.
- Pay attention to the network design: separate OT and IT traffic as much as possible, unless there is a solution in place that prioritizes the OT traffic (e.g. TSN).

ArcelorMittal Gent – Steel Shop

- Choosing the right diagnostic and/or management tools depends heavily on the structure of the network. In case of faults, it depends on the faults which diagnostic tool(s) is (are) most appropriate. (Refer to WP6, workshops)
- Having a decision tree for fault finding, makes it easier and faster to find a specific fault, it also helps in contacting the right people for fixing the fault (e.g. is it a job for maintenance technicians or network specialists?).

TSN Brownfield PROFINET Evaluation

PROcess Field Net or PROFINET (PN) is an open industrial Ethernet standard compatible with standard Ethernet. It is described in IEC 61158 and IEC 61784. PN has a Real Time (RT) and an Isochronous Real Time (IRT) variant. The real time behaviour of PN RT is achieved using IEEE 802.1p Quality of Service (QoS). In large networks (or even small networks with high line depth), this results in considerable jitter in the presence of even little IT traffic.

Time-Sensitive Networking (TSN) defines a set of standards that build on standard IEEE 802.3 Ethernet. TSN aims to enable deterministic message exchange in Ethernet networks, it impacts OSI layer 2. Specific for industry applications, TSN allows the integration of Operational Technology (OT) and Information Technology (IT) communication on a single converged network. In this paper, OT traffic is referred to as Real-Time (RT) traffic, IT traffic is referred to as Best-Effort (BE) traffic. TSN is based on a common notion of time using synchronization paired with mechanisms for scheduling, determinism, low latency, and robustness. It consists of several sub-standards which can be classified in 4 groups: timing and synchronization, high reliability, bounded low latency and resource management.

IEC/IEEE 60802 defines a TSN profile for industrial automation. The basis of a TSN network is 802.1AS time synchronization. Additional relevant standards for industrial automation are 802.1Qbv Enhancements for Scheduled Traffic, 802.1Qbu Frame Preemption, 802.3br Interspersing Express Traffic, 802.1Qci Per-Stream Filtering and Policing and 802.1CB Frame Replication and Elimination.

Analysis of a large 100BASE-TX network

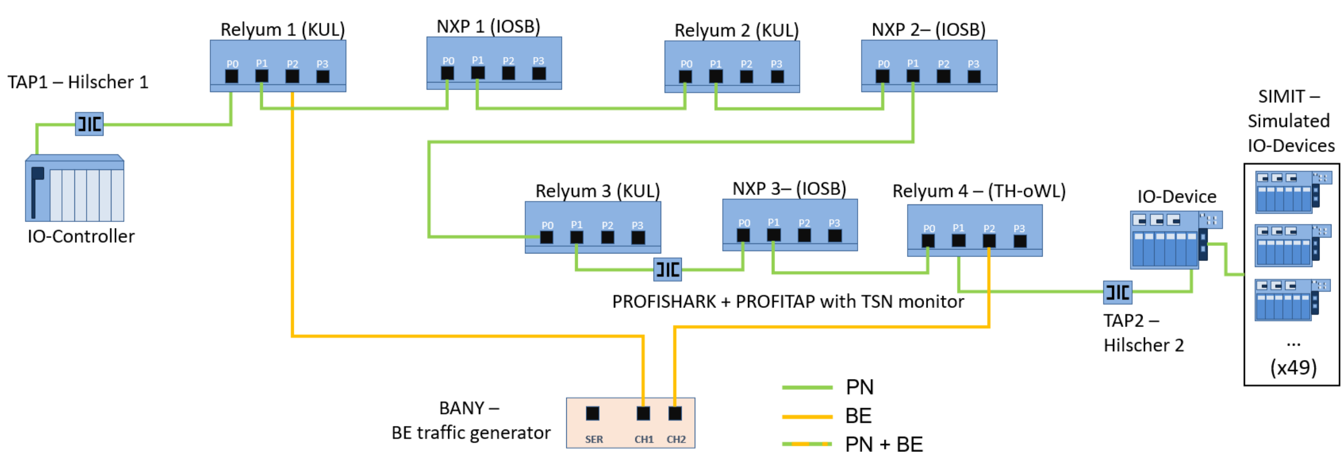
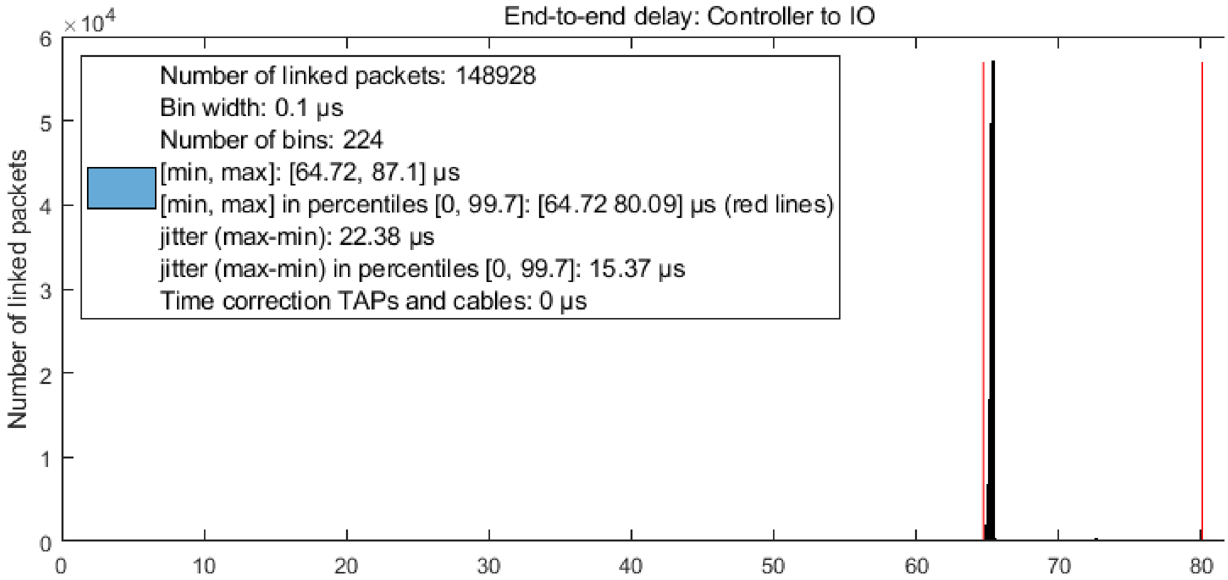


Figure 117: Measurement setup for analysis of a large 100BASE-TX network

Without preemption, without BE traffic



Time [µs]

Figure 118: Relyum and NXP, 100BASE-TX, without preemption, without BE traffic

Without preemption, with BE traffic (35 Mbps)

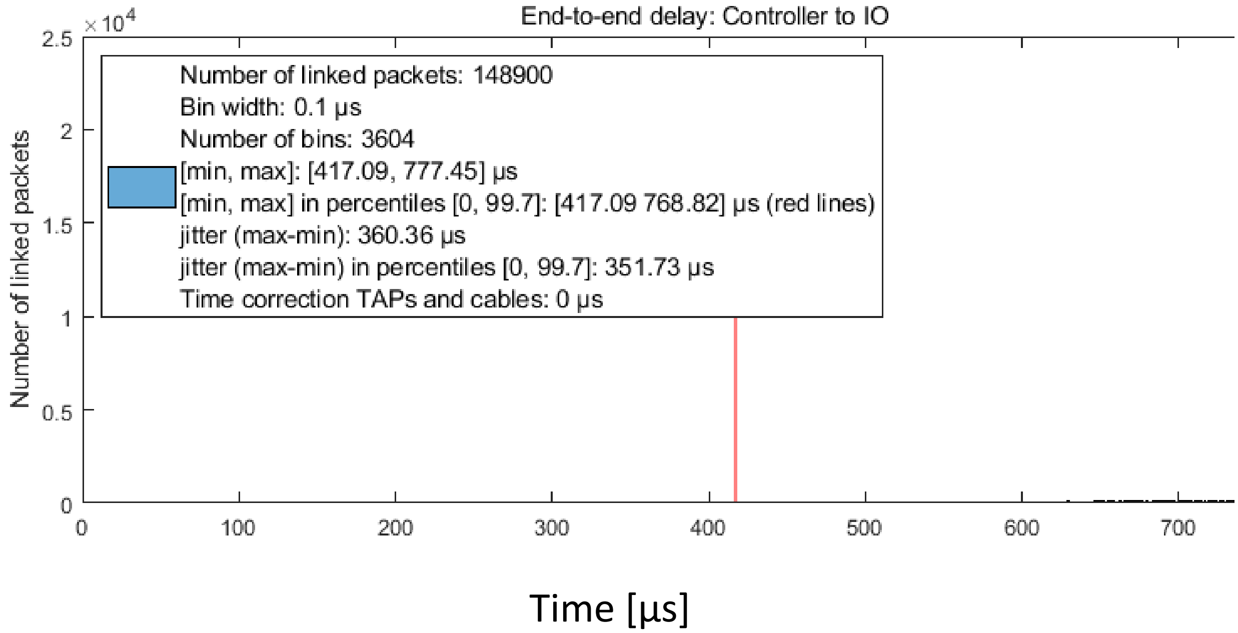


Figure 119: Relyum and NXP, 100BASE-TX, without preemption, with BE traffic

With preemption, without BE traffic

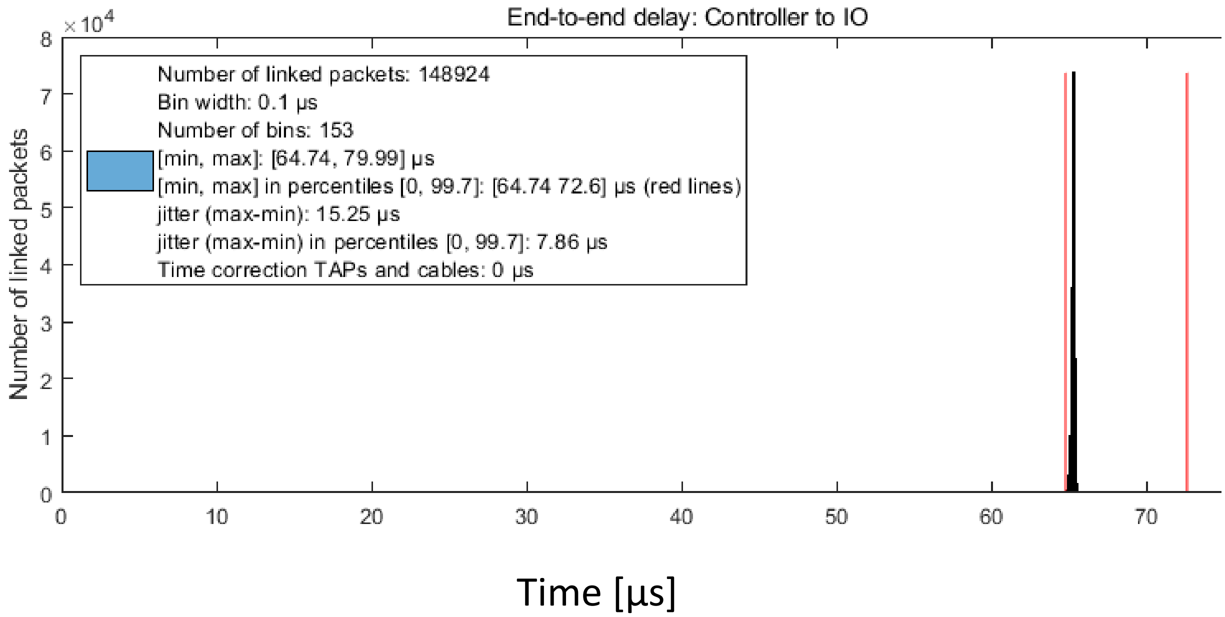


Figure 120: Relyum and NXP, 100BASE-TX, with preemption, without BE traffic

With preemption, with BE traffic (35 Mbps)

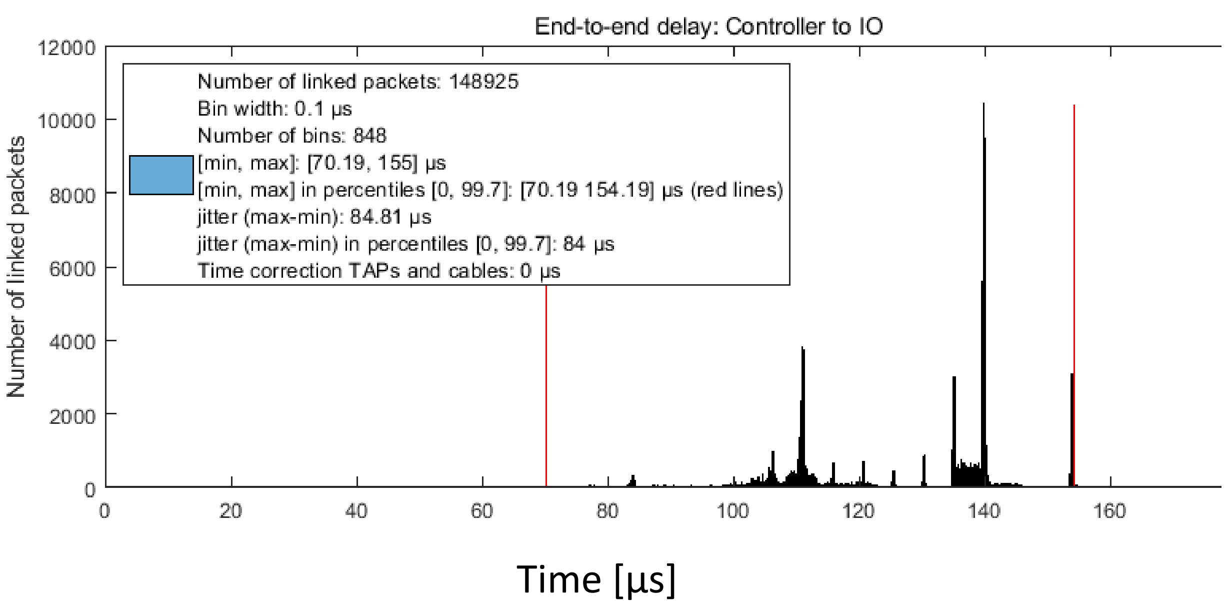


Figure 121: Relyum and NXP, 100BASE-TX, with preemption, with BE traffic

Analysis of a large 1000BASE-T network

Relyum and NXP

This is the same network as the large 100BASE-TX setup.

Preemption was not activated during these measurements.

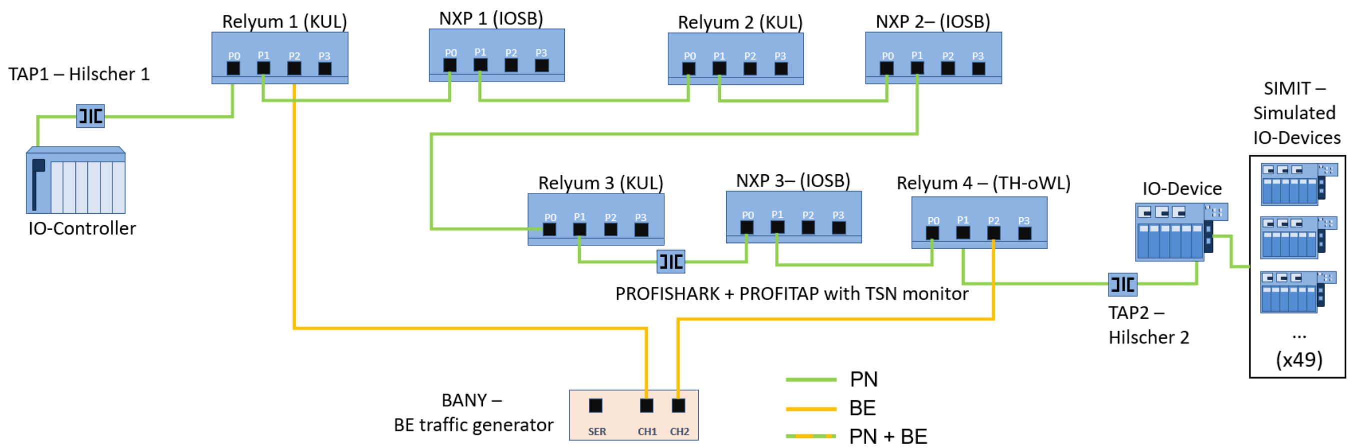


Figure 122: Measurement setup for analysis of a large 1000BASE-T network (Relyum and NXP)

Without preemption, without BE traffic

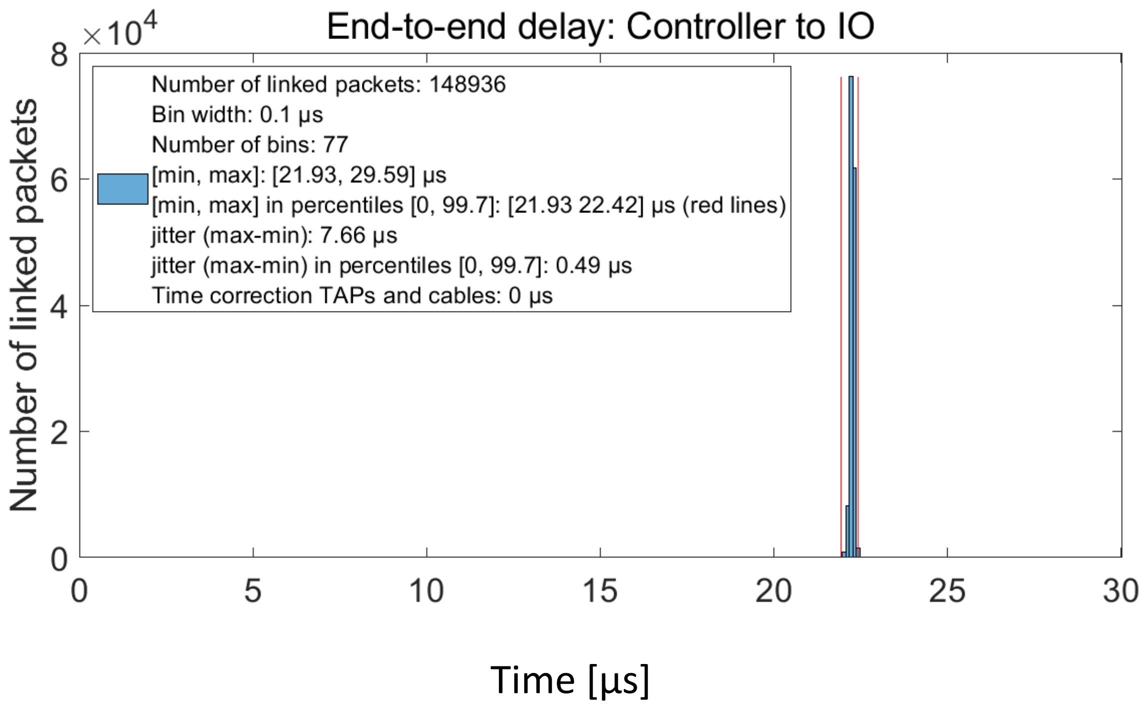


Figure 123: Relyum and NXP, 1000BASE-T, without preemption, without BE traffic

Without preemption, with BE traffic (700 Mbps)

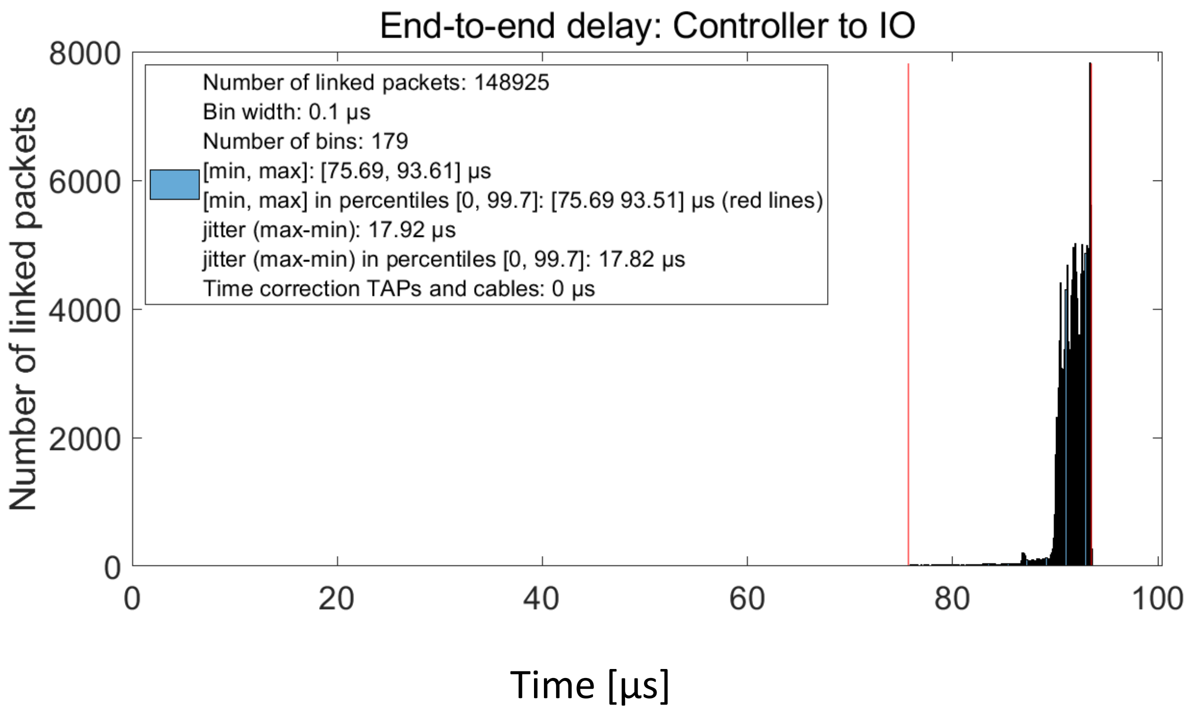


Figure 124: Relyum and NXP, 1000BASE-T, without preemption, with BE traffic

Phoenix Contact and NXP

These measurements were done with and without preemption.

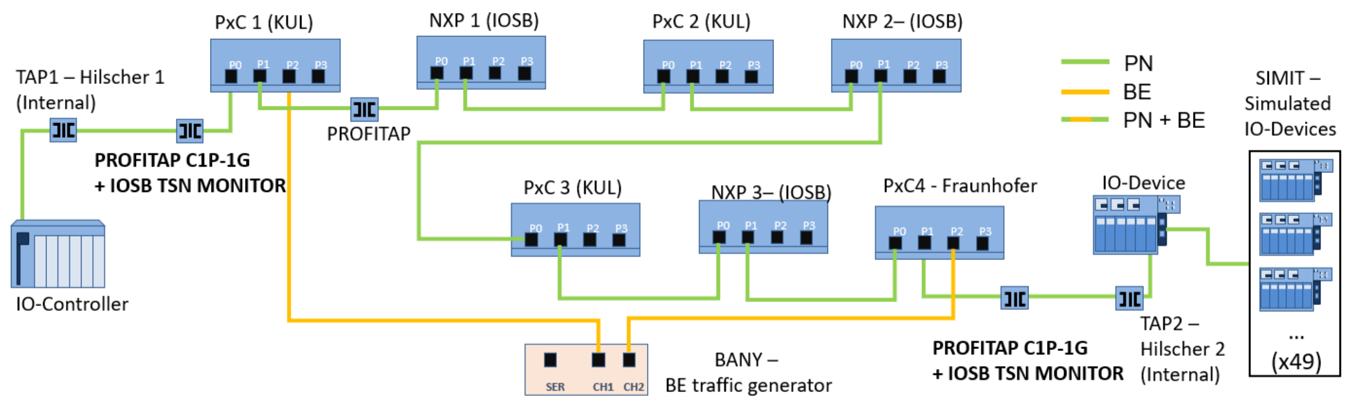


Figure 125: Measurement setup for analysis of a large 1000BASE-T network (Phoenix Contact and NXP)

Without preemption, without BE traffic

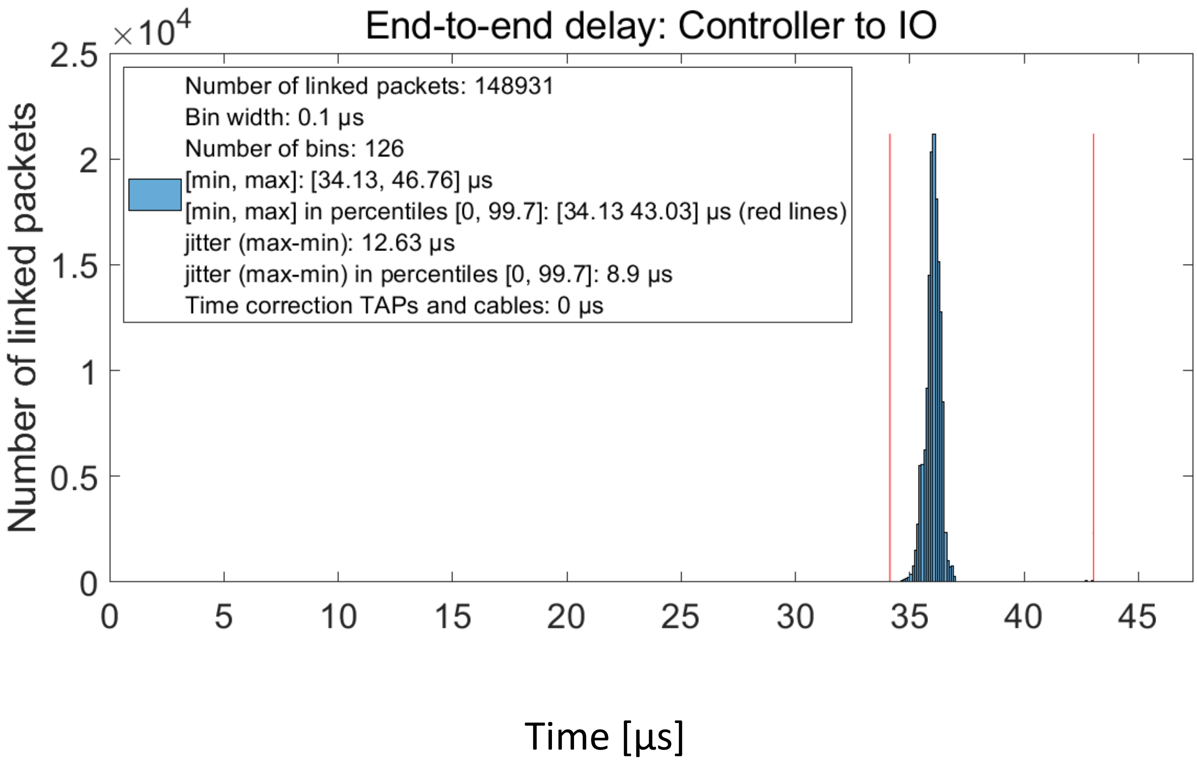


Figure 126: Phoenix Contact and NXP, 1000BASE-T, without preemption, without BE traffic

Without preemption, with BE traffic (700 Mbps)

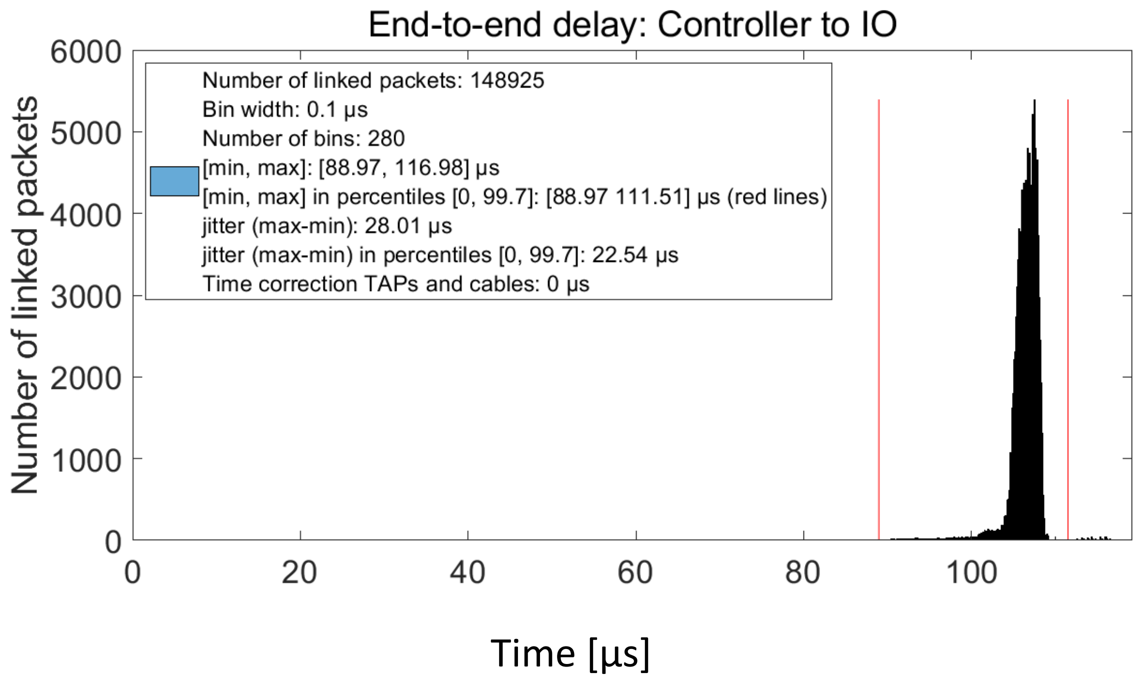


Figure 127: Phoenix Contact and NXP, 1000BASE-T, without preemption, with BE traffic

With preemption, without BE traffic

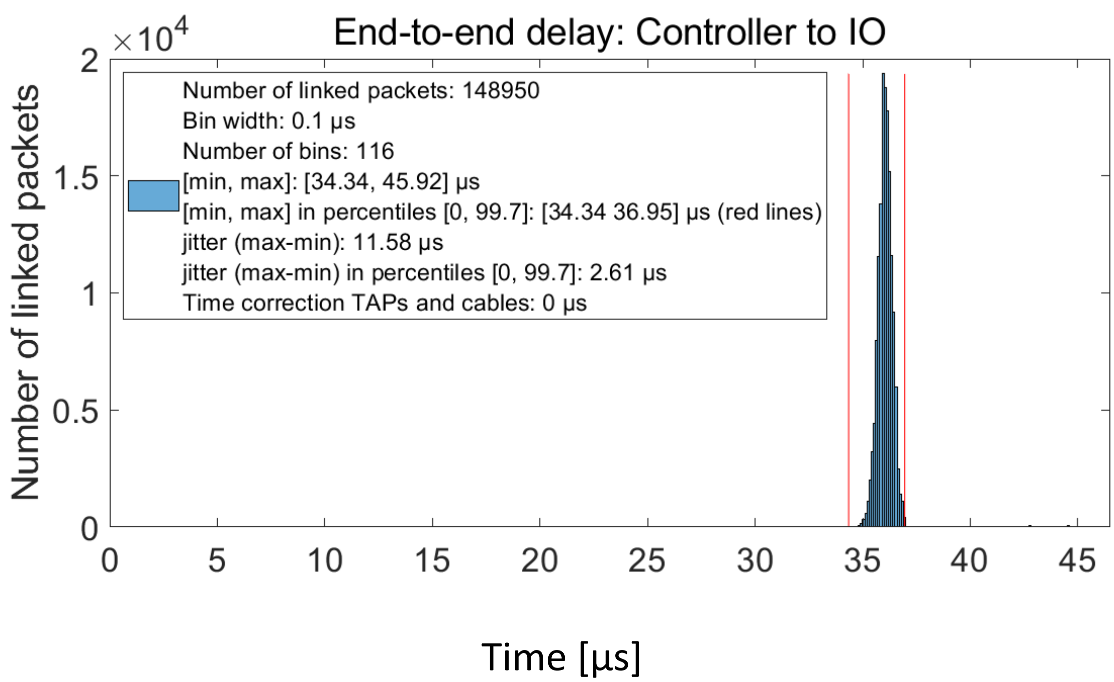


Figure 128: Phoenix Contact and NXP, 1000BASE-T, with preemption, without BE traffic

With preemption, with BE traffic (700 Mbps)

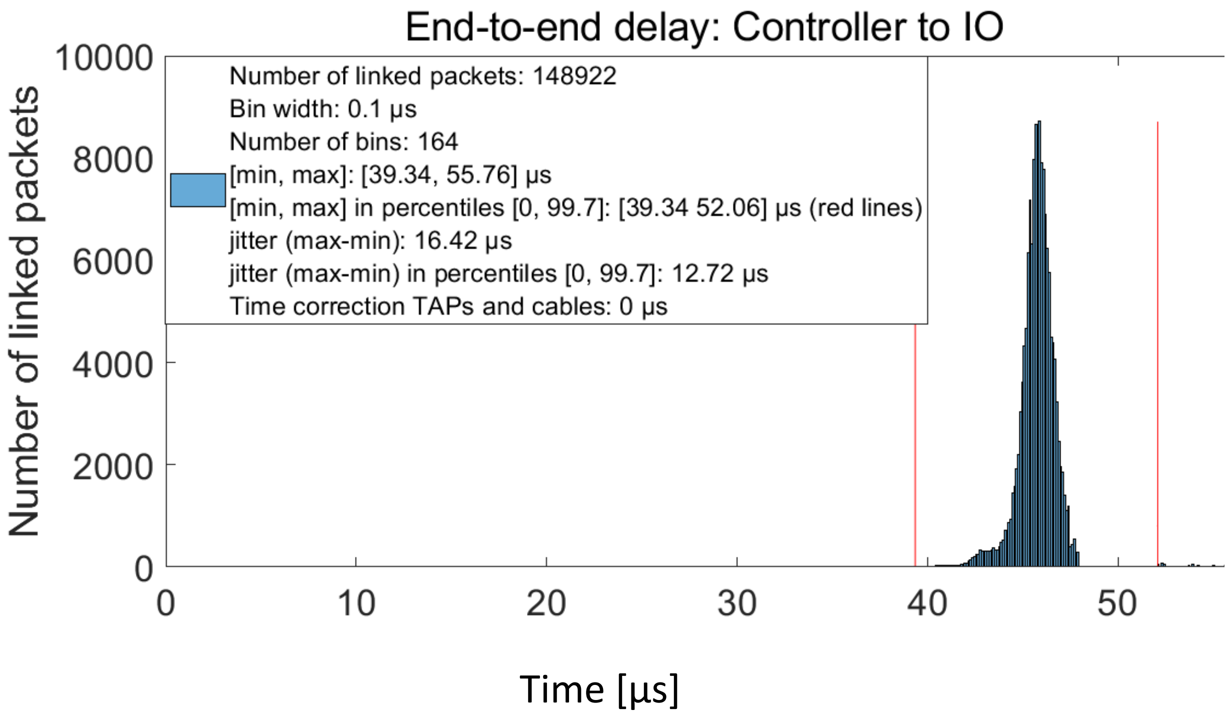


Figure 129: Phoenix Contact and NXP, 1000BASE-T, with preemption, with BE traffic

AMG WWA Mill Maintenance Hall Analysis

The IO controller has a large network with several "branches", 2 of which have occasional (A) or very rare (B) problems.

This use case is still ongoing, waiting for the positions of the crane during faults.

Wired network problem – Lathe (draaibank)

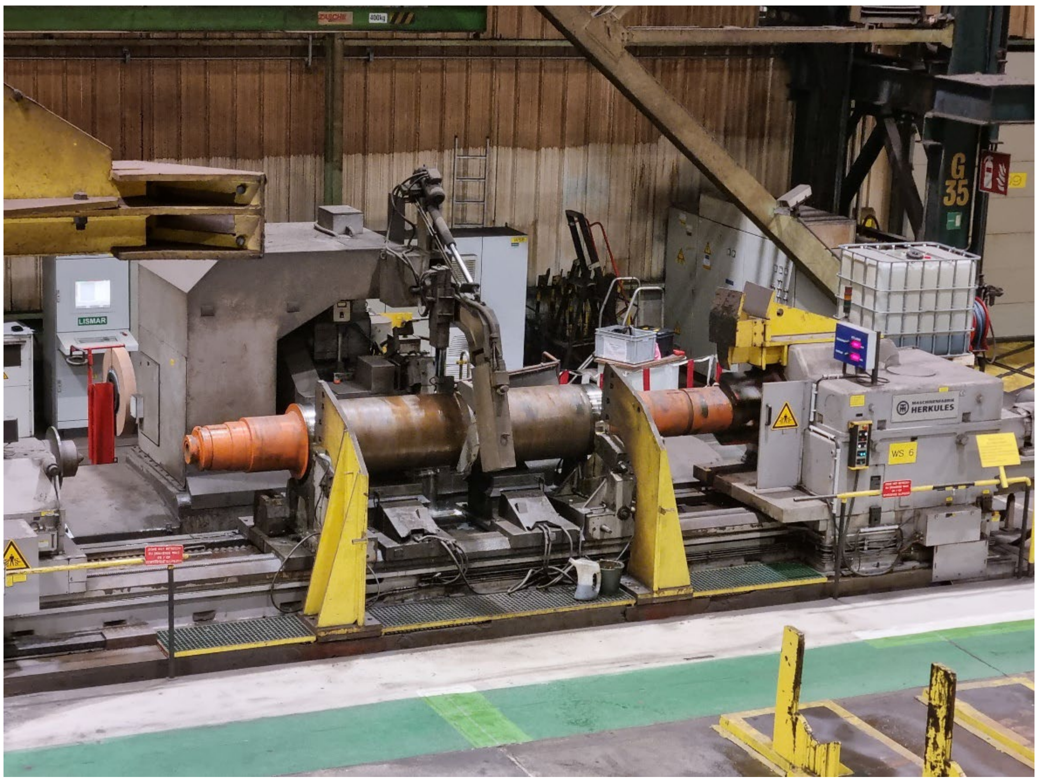


Figure 130: One of the lathes in the mill maintenance hall

Frame gaps occur between the IO controller and the two IO devices.

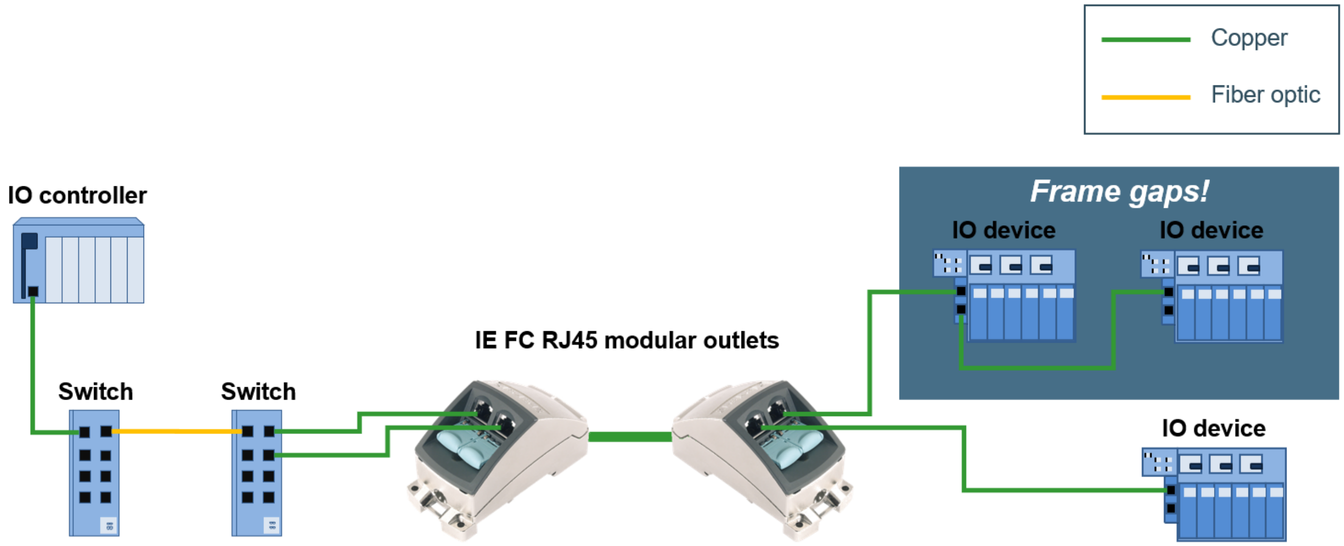


Figure 131: Overview of the network at one of the lathes

Wireless/wired network problem – LK372 (overhead traveling crane)

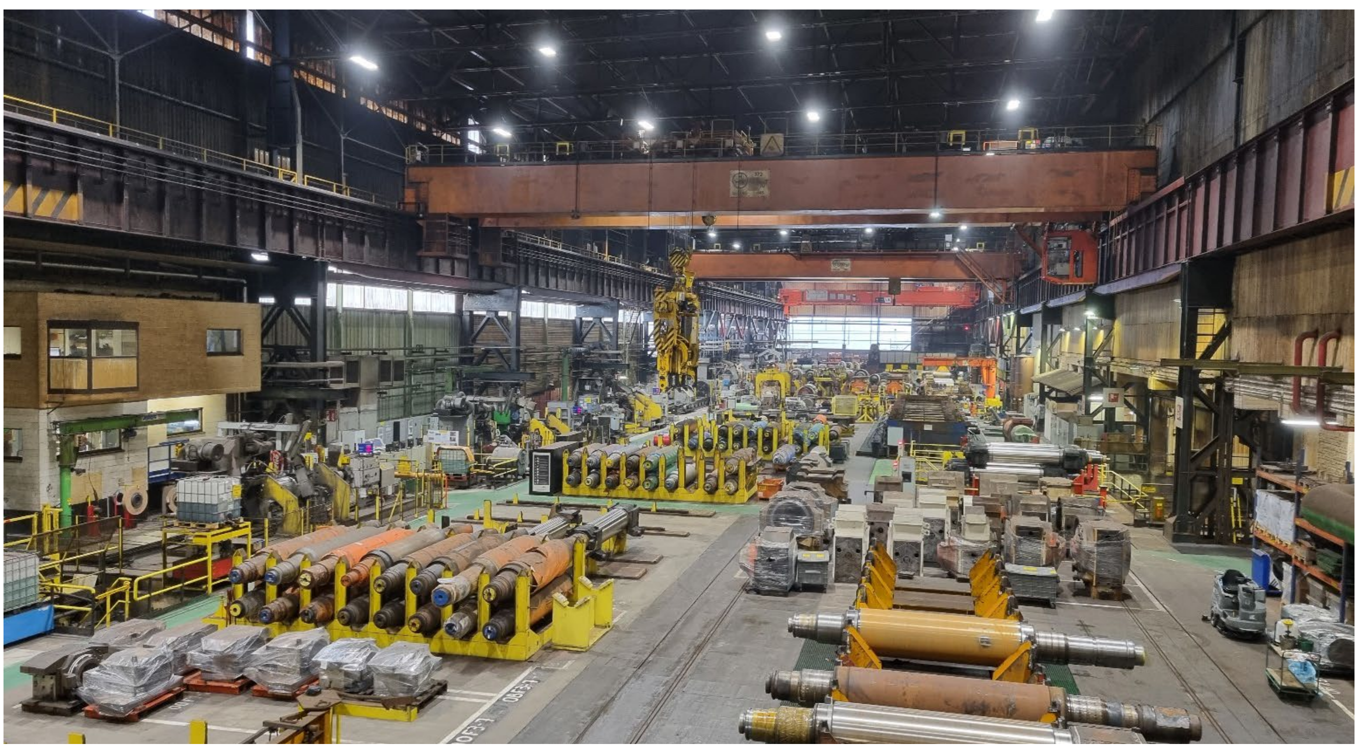


Figure 132: Overview of the mill maintenance hall with LK372 (closest crane at the top of the picture)

The IO-controller loses communication with the I-devices.

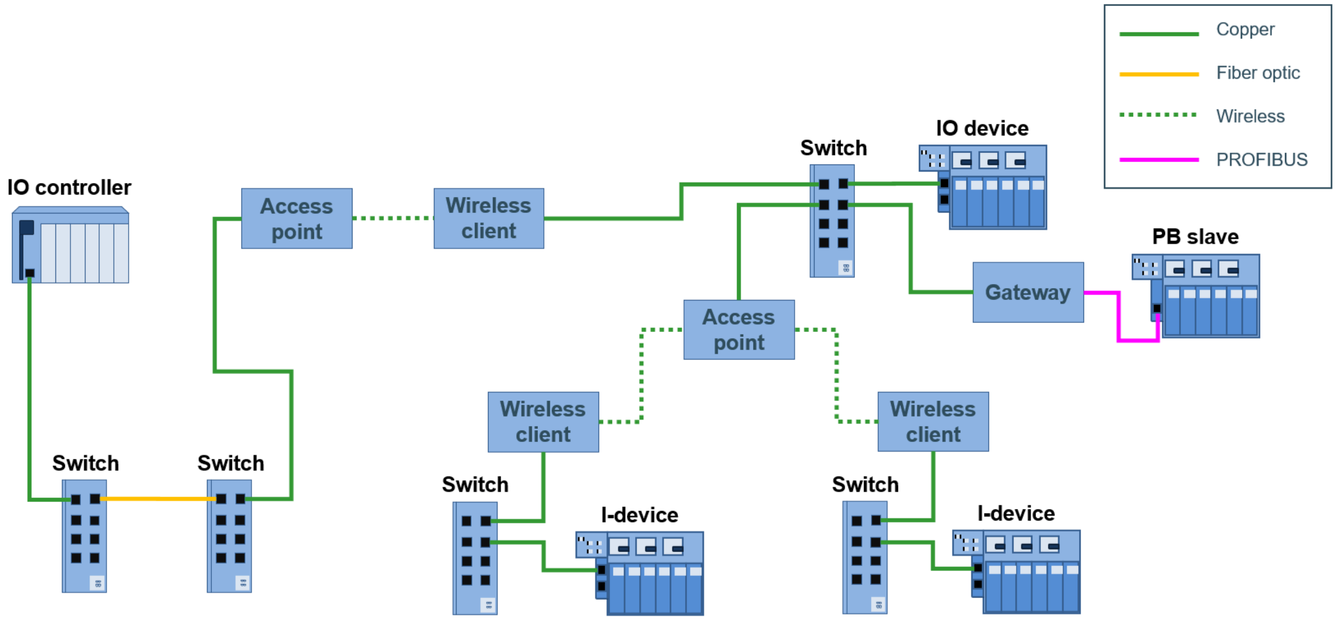


Figure 133: Overview of the network at LK372

Analysis

See the detailed analysis in the attached PowerPoint document.

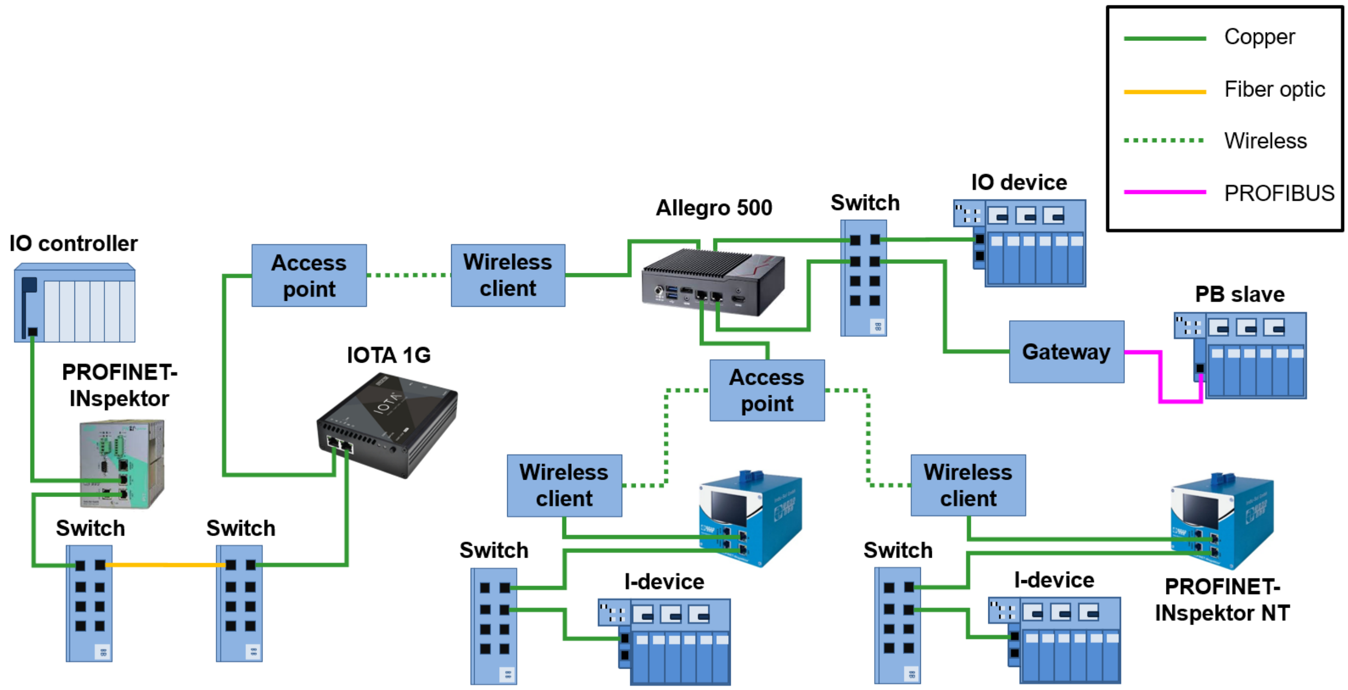


Figure 134: Overview of the measurement setup

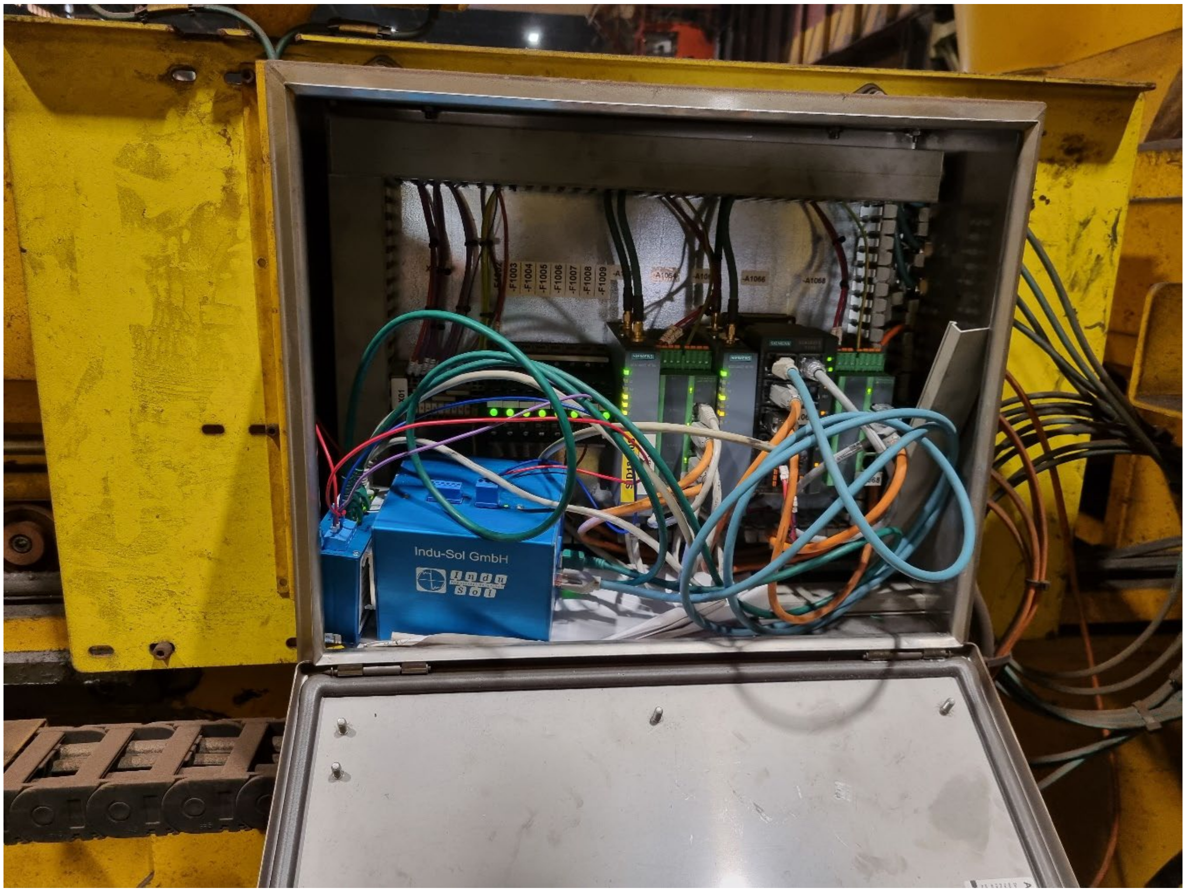


Figure 135: Measurement setup on one of the crane hooks with an Indu-Sol PROFINET-Inspektor NT

EMC

AMG SDG

The PROFIBUS DP networks in AMG production line SDG4 regularly experience error messages via the permanent diagnosis by ComBricks. EMI problems are suspected, possibly combined with network issues. This represents an interesting CINI4.0 use case for diagnostics, EMI, network planning, etc.

This use case is still ongoing, waiting for possible dates to do some more measurements.

Summary, including a list of possible measures

Visual inspecton

General observations

- No litz wires in the electrical installation, only PE cables, but litz wires on the gas installation.
- It is unclear whether the connections of the PE cables to the building's earthing provide good contact everywhere (high-frequency, low-impedance, bare metal).
- DIN rails in the electrical cabinet are mounted on painted metal parts, no litz to base plate.
- PROFIBUS cables enter the electrical cabinet without removing the shield.

Figure 136: Litz wires on the gas installation (1)

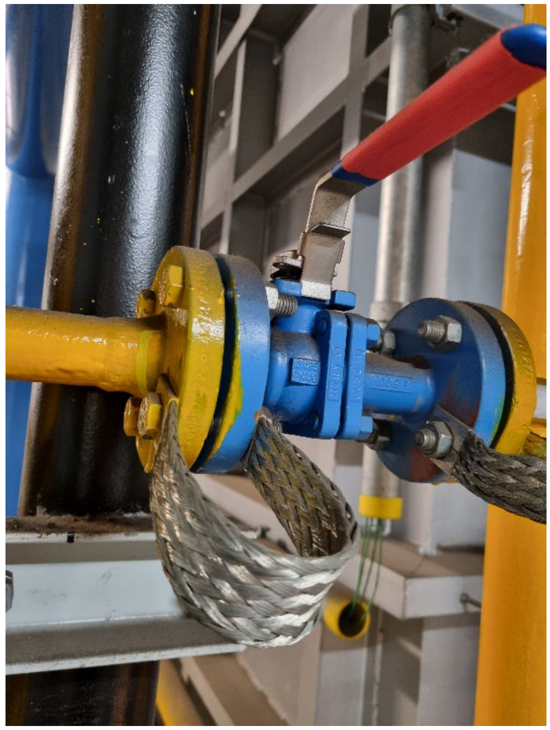


Figure 137: Litz wires on the gas installation (2)

Figure 138: PE connection to the building's earthing

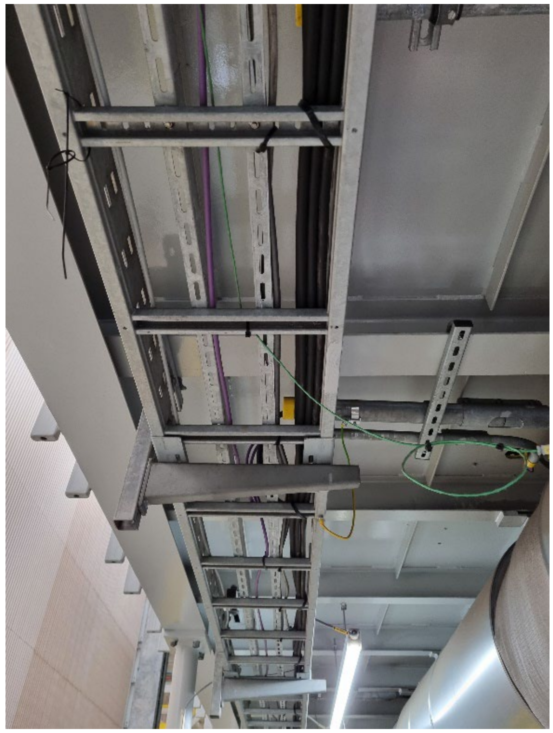


Figure 139: Cable tray

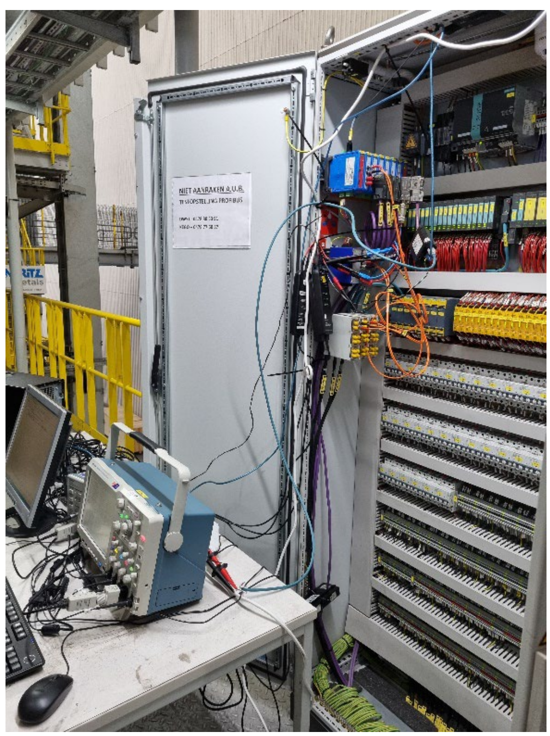


Figure 140: Cabinet with measurement setup

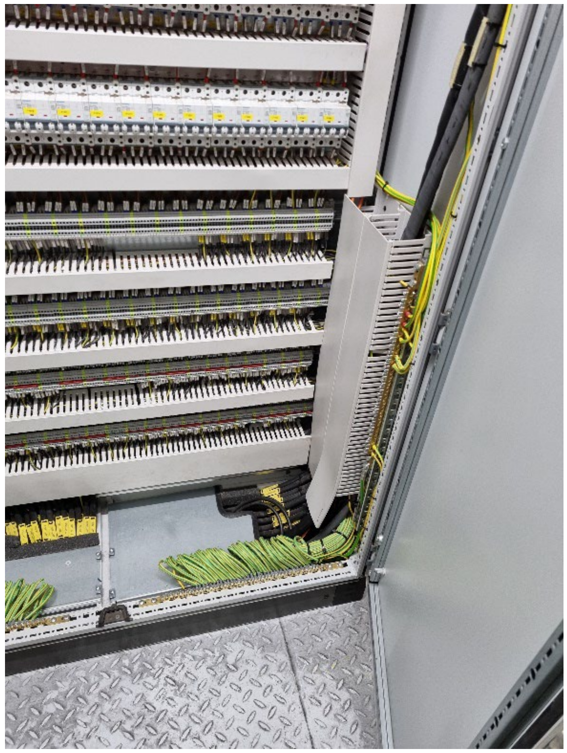


Figure 141: Detail of the cabinet

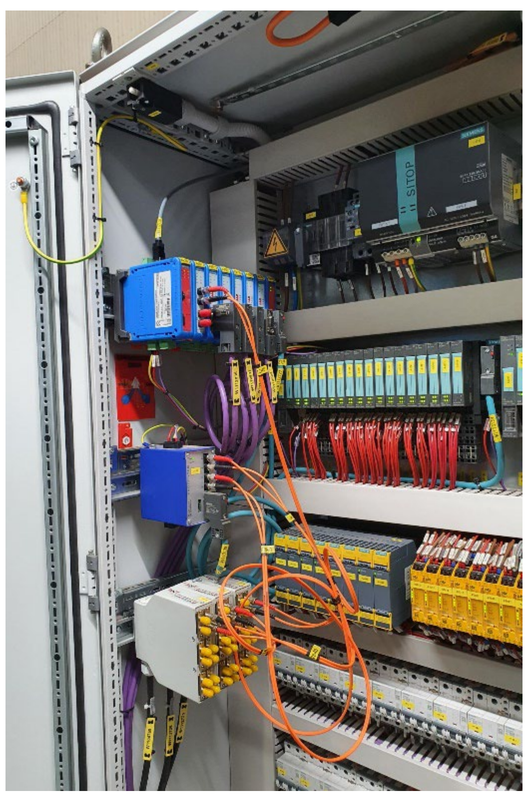


Figure 142: PROFIBUS devices (ComBricks) inside the cabinet

Figure 143: Detail of the PROFIBUS devices (ComBricks) inside the cabinet

Specific observations Dungs

- No EMC cable glands, so not mounted when entering the cabinet, nor at the actual connector.
- Shield connected to PE via pigtail.
- PROFIBUS cable has been dismantled over a length that is far too great and is no longer manually twisted, is located near separate 230 V_{AC} cores (during the last measurements it was observed that there are also pulses from the igniters on the 230 V_{AC}, see 12) Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO)).

Figure 144: Dungs cabinet

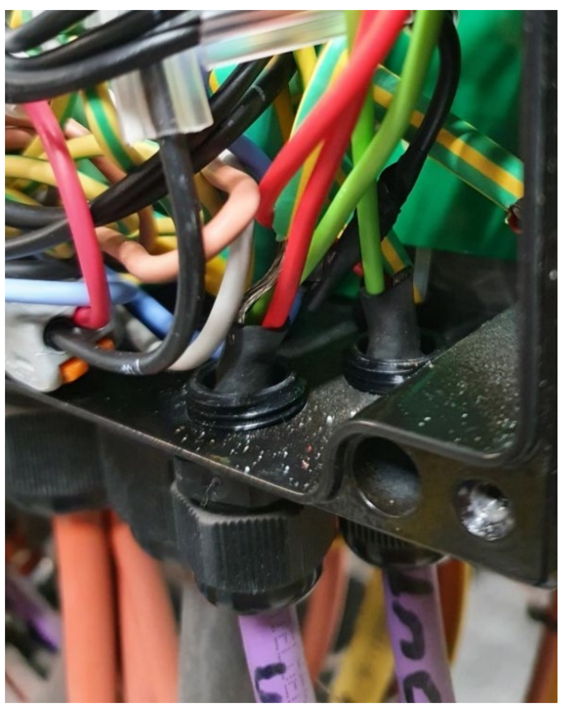


Figure 145: PROFIBUS cables entering the Dungs cabinet

Figure 146: Detail of the PROFIBUS cable (1)

Figure 147: Detail of the PROFIBUS cable (2)

Ignition of the burners

Large interference pulses on the signal between A and shield and the signal between B and shield. These are caused by the ignition of the burners, see 12) Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO).

The differential signal experiences a (usually) small interference, in most cases not enough to cause an error, but depending on the size and location of the interference this could disrupt a telegram, the most delicate moment is probably the rising or falling edge of a bit or the beginning of a telegram (leaving RS485 rest level).

Additional observation measurements: clear disturbances are visible on the differential signal on a number of measurements (see 12) Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO)) and in some places also quite large reflections of the flanks (see 11) Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor and wire on spark plug). These disturbances are sufficiently large at A-B to take the drivers out of the rest level during the rest level, or to disrupt bits.

In the 1st series of measurements, the current peaks in the PROFIBUS shield are slightly larger over the entire measurement, but not noticeably larger during the ignition pulses that are visible on the voltage signals.

During the last measurement session, a large peak in the shield current is visible, and coupling to the differential signal AB; see page 192 and following. In the 2nd series of measurements, a higher sample rate was used in the oscilloscope, and there was also subsequent processing with TekScope software.

(The ptp values are automatically measured over the entire acquisition as peak-to-peak value (box with automatic measurements on the scope images)).

Suggested remedies for 1 and 2:

→ Work on the cause: (try to) eliminate the source of the fault by connecting the ignition transformer with two wires.

a) In new installations a different type of spark plug.
b) With litz wire from spark plug directly back to the brown cable in box (which is connected to the PE): tried with a temporary connection, no effect.
c) (After offline processing of last measurements, pulse signals at 230 Vac) Disconnect brown cable from earth and connect directly to the outside of the spark plug via wire, see *12) Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO)*

→ Indirect remedies: better finishing of the PROFIBUS cable in the Dungs cabinet, better bonding over the entire network, testing a lower bit rate (500 kbps), suppressing the interference pulses with capacitors or filters.

(Meanwhile tested: 1 nF capacitors do not help).

500 kbps may be possible (see cycle time in the measurements @ 1.5 Mbps), the individual bits will be 3x wider (may not help if the interference pulse differentially couples to the rest levels, as was seen later when processing the measurement results) .

Transmission speed: 1.5 Mbps
Number of Masters: 1
Number of slaves: 38
Cycle time: Min: 8.25 ms, Avg: 12.31 ms, Max: 17.19 ms

50 Hz sinus

Large 50 Hz sine wave on the signal between A and shield and the signal between B and shield.

The amplitude of the 50 Hz was measured manually at three locations using the rest levels in the PROFIBUS signal. The tables below show the difference in rest levels for 3 locations (= measure of amplitude of the sinus).

Source: 2) Zero measurement with loose capacitor no burner pulses (segment A2825)			
ComBricks (A2825)	Max. rest level (V)	Min. rest level (V)	Difference in rest level (V)
CH2 (B)	4,123	1,660	2,463
CH3 (A)	3,213	0,836	2,277

Source: 7) Ignitions on another segment (A2823)			
ComBricks (A2823)	Max. rest level (V)	Min. rest level (V)	Difference in rest level (V)
CH2 (B)	4,863	1,014	3,849
CH3 (A)	4,083	0,095	3,987

Source: 13) Measurement at station 61 (last slave of a segment)			
Station 61 (A2823)	Max. rest level (V)	Min. rest level (V)	Difference in rest level (V)
CH2 (B)	4,791	-2,053	6,844
CH3 (A)	5,859	-1,103	6,962

The amplitude of the 50 Hz sine wave therefore differs greatly per measurement location.

The amplitude has been eliminated in the differential signal, but could influence the electronics at the time of interference pulses.

→ Remedies: better bonding, check whether the terminal station is (properly) actively closed, if necessary extend the cable and actively close it in the main cabinet.

Small current peaks during standstill without burner ignition pulses

Small current peaks (4 kHz) on the PROFIBUS shield (45 mApk-pk).

Presumably caused by the Siemens drives of SAS rollers (see 2) Zero measurement with loose capacitor no burner pulses (segment A2825)).

In the stored measurements this seems too small to cause errors.

Litz between mounting ignition transformer and spark plug

Litz connected in this way has no visible influence (see 11) Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor and wire on spark plug).

See above, 1) b) remedy c).

Capacitor

The loose capacitor affects the flanks, the gaps are distorted but not better (see various measurements).

The Würth Elektronik DB9 has no visible influence on the scope, not measured in operation with the ComBricks (see various measurements).

Suggest next measurements

Issues with past measurements:

- ProfiTrace: limit file size of the loggings with “File recording” (not limited during previous measurements, which caused ProfiTrace to freeze).
    - Limit for normal message recording: 1 000 000 telegrams
    - Limits for file recording:
        - File size limit: 2047 Mbyte
        - Max. messages per file is 100 000 000
        - Max. files is 10 000.
- Frequency of the current/voltage peaks was unexpectedly high → use higher sample rate and probes with higher bandwidth.
    - 100 instead of 50 MHz probe 500/50:1, or since they are low voltages, 500 or 1000 MHz low voltage probes.

    - There is not really a solution for shield current: the 15 MHz revolver is needed to fit around the PB cable. 100 MHz current probes can only be placed around individual wires (or around a PN cable without insulation).
- The above matters can be adjusted after better final assembly of the Dungs and/or receipt of the Würth filter.

Zero measurement with loose capacitor no burner pulses (segment A2825)

Connection diagram and signals (for this and subsequent measurements unless otherwise stated)

- CH 1 (yellow): PB B-A
- CH 2 (blue): PB B-SHIELD
- CH 3 (purple): PB A-SHIELD
- CH 4 (green): Current in PB shield

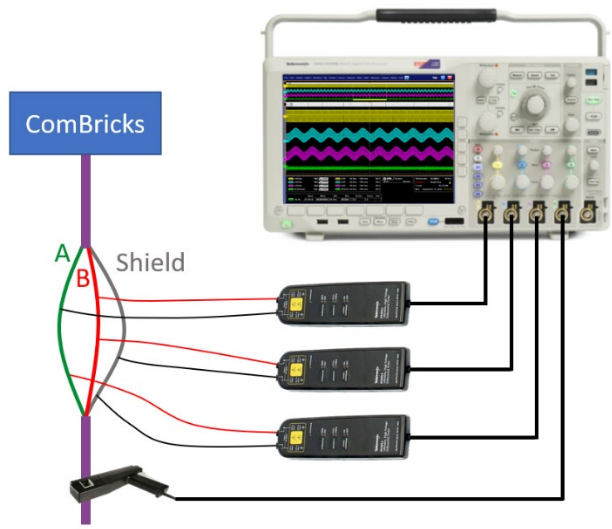


Figure 148: Connection diagram

Figure 149: Zero measurement with loose capacitor no burner pulses (segment A2825) (1)

Strong 50 Hz sine wave on the signal between A and shield and the signal between B and shield.

ComBricks (A2825)	Max. rest level (V)	Min. Rest level (V)	Difference in rest level (V)
CH2 (B)	4,123	1,660	2,463
CH3 (A)	3,213	0,836	2,277

Figure 150: Zero measurement with loose capacitor no burner pulses (segment A2825) (2)

Differential signal is good, as is the rest level, only small reflections after an edge.

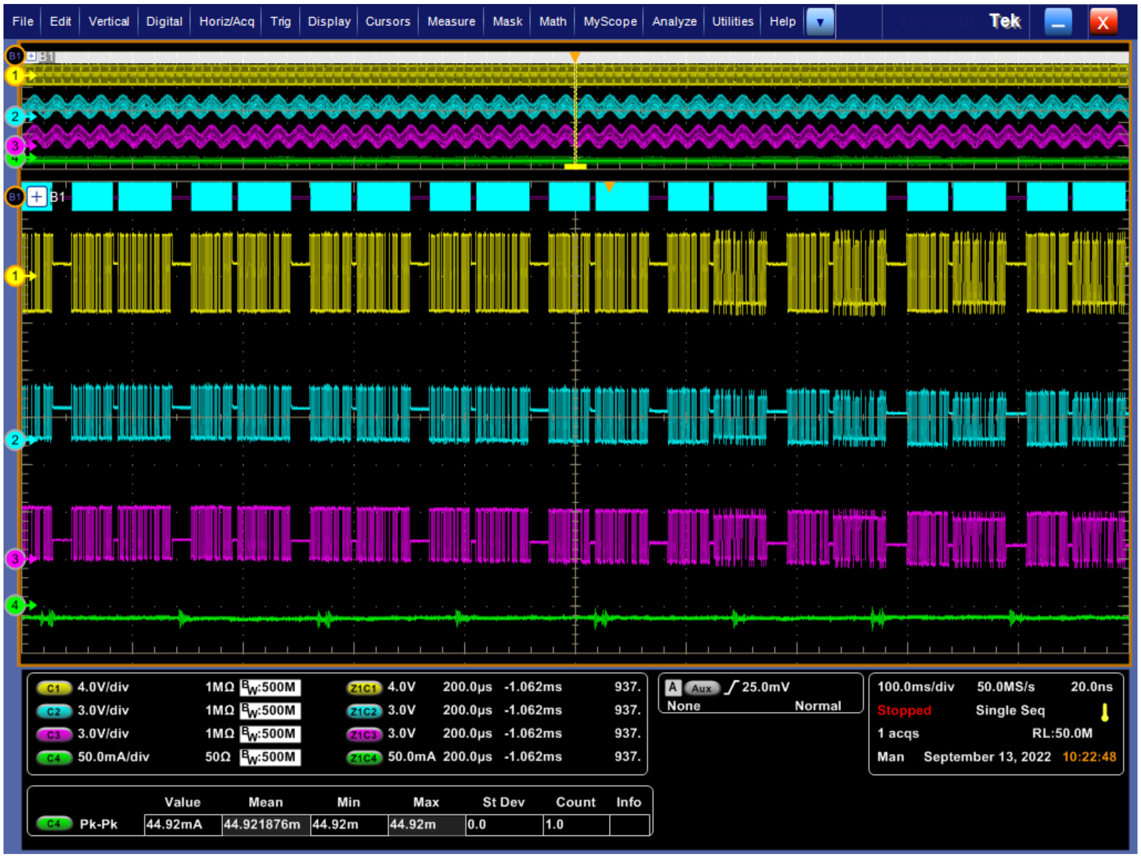


Figure 151: Zero measurement with loose capacitor no burner pulses (segment A2825) (3)

Small current peaks (4 kHz) on the PROFIBUS shield (45 mA_{pk-pk}). Presumably caused by the Siemens drives of SAS roles. Frequency of these current peaks: 1-3 MHz.

Looking back/zoomed in with TekScope software:

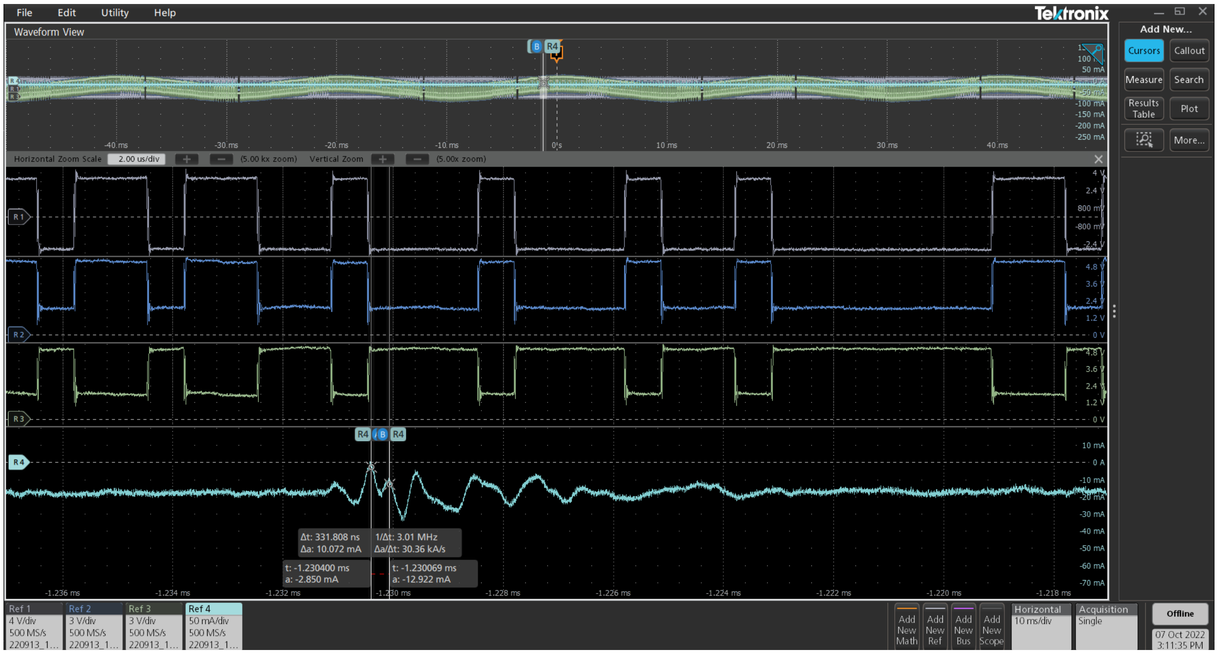


Figure 152: Zero measurement with loose capacitor no burner pulses (segment A2825) (4)

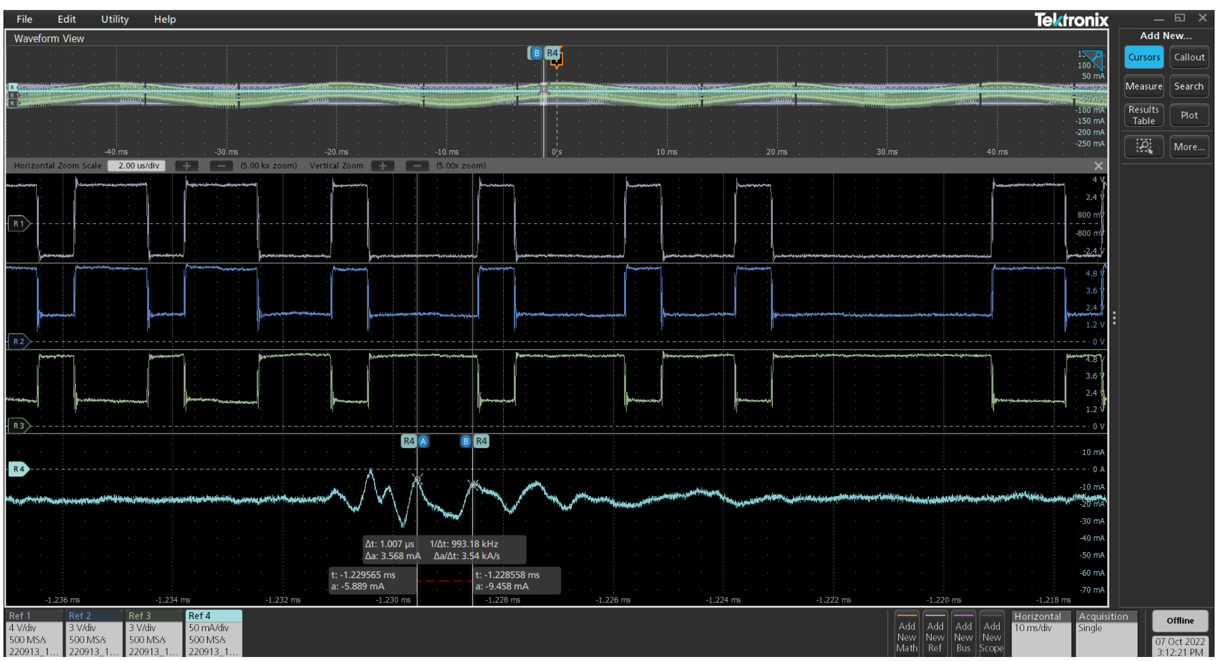


Figure 153: Zero measurement with loose capacitor no burner pulses (segment A2825) (5)

Ignitions with separate capacitor (segment A2825)

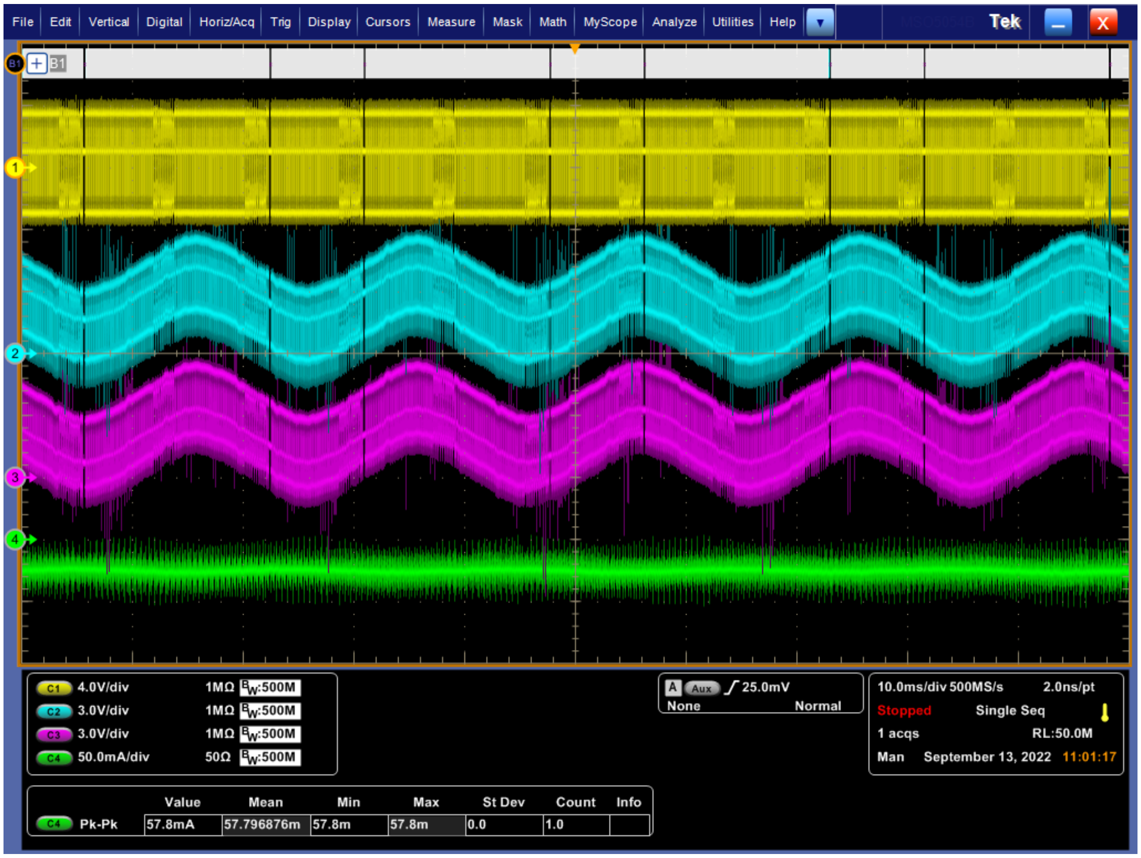


Figure 154: Ignitions with separate capacitor (segment A2825) (1)

Major interference with the signal between A and shield and the signal between B and shield, caused by the ignition of the burners.

Figure 155: Ignitions with separate capacitor (segment A2825) (2)

Differential signal (yellow) is experiencing a minor interference, **in this case** not enough to cause an error but depending on the size and location of the interference this could disrupt a telegram. (Under point 12), major disturbances can be seen on the differential signal in the last measurements during subsequent processing.)

Figure 156: Ignitions with separate capacitor (segment A2825) (3)

Current peaks slightly larger over the entire measurement, but not especially during the ignitions that are visible on the voltage signals.

Frequency of these current peaks: 40 ns peak to peak, 25 MHz.

Figure 157: Ignitions with separate capacitor (segment A2825) (4)

The edges on the telegrams of the ComBricks are strongly distorted (measured on ComBricks), the overshoot on the edges has changed level due to the capacitor (see below).

1) Ignition without capacitor (segment A2825)

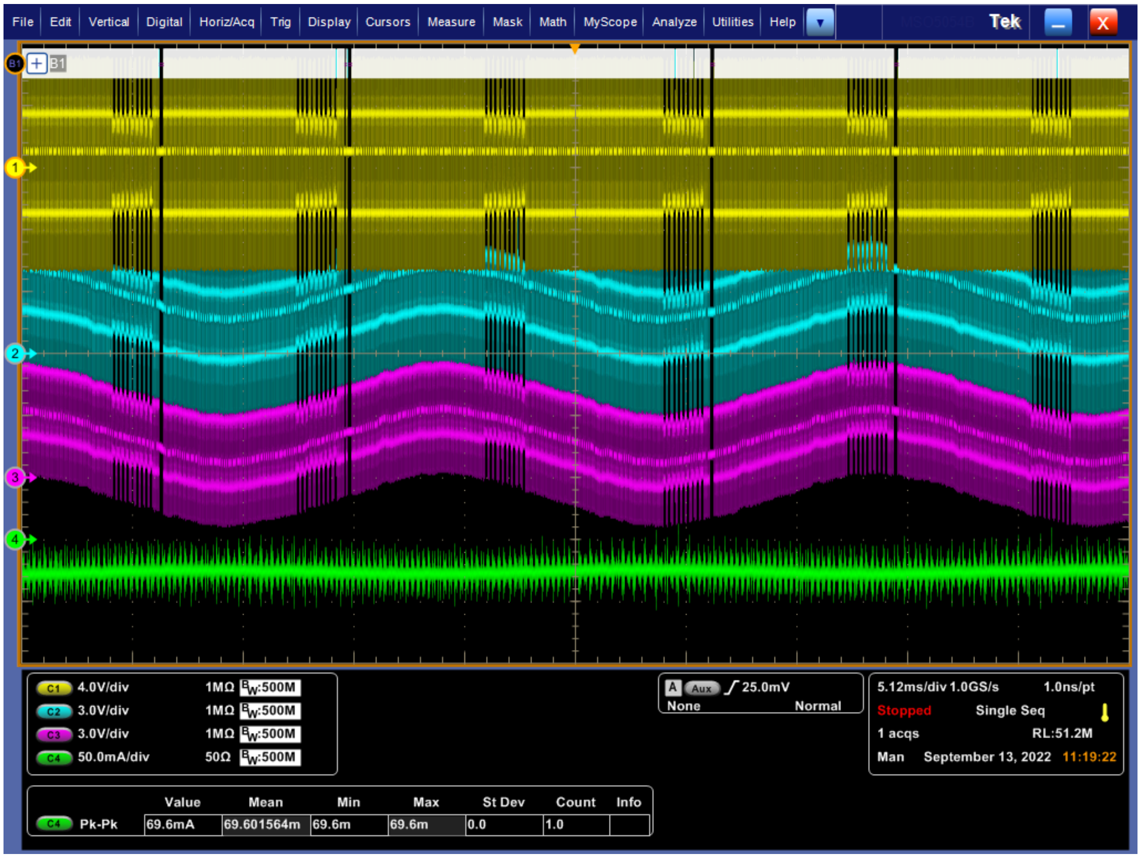


Figure 158: Ignition without capacitor (segment A2825) (1)

Removing the capacitor causes the overshoot after an edge to increase, making the signals appear larger than they are.

Figure 159: Ignition without capacitor (segment A2825) (2)

When zooming in on the edges in telegrams on the ComBricks side, it is clearly visible that the overshoot after an edge has returned to a normal level now that the capacitor has been removed.

Ignitions with Würth Elektronik DB9 with capacitor (segment A2825)

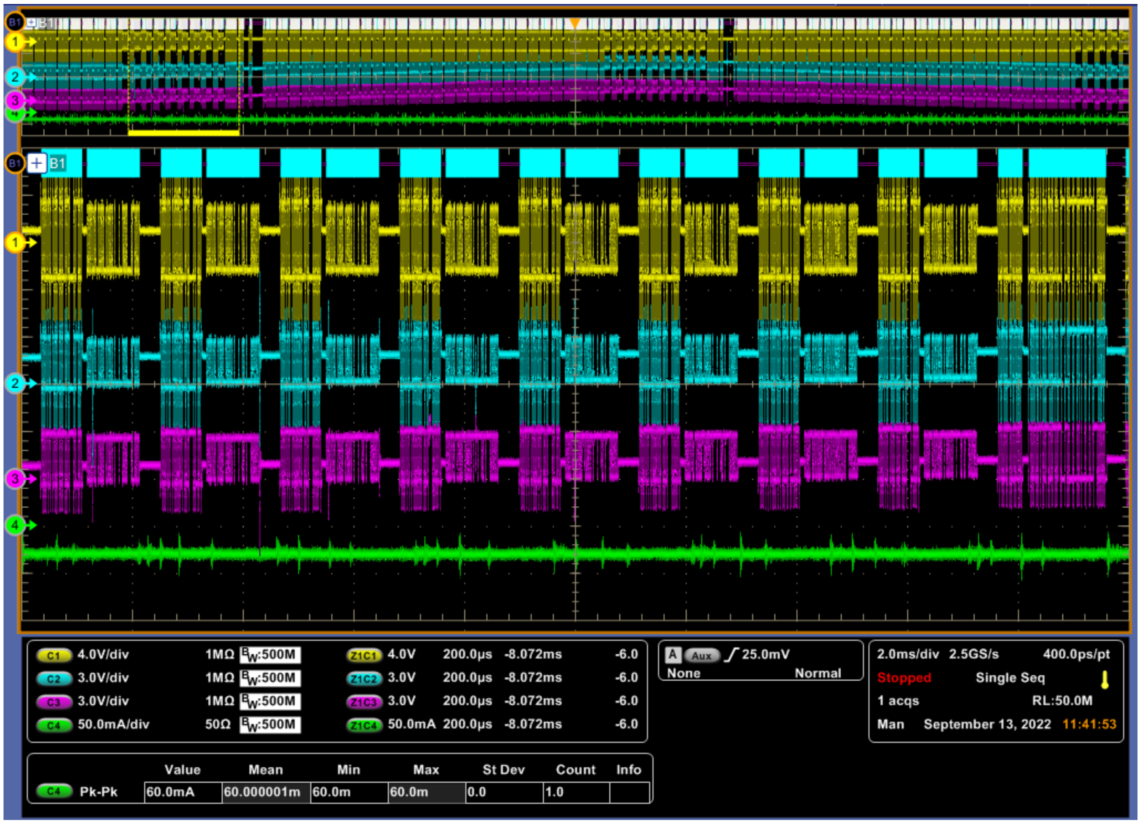


Figure 160: Ignitions with Würth Elektronik DB9 with capacitor (segment A2825) (1)

Figure 161: Ignitions with Würth Elektronik DB9 with capacitor (segment A2825) (2)

The Würth Elektronik DB9 with capacitor has no visible influence.

Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825)

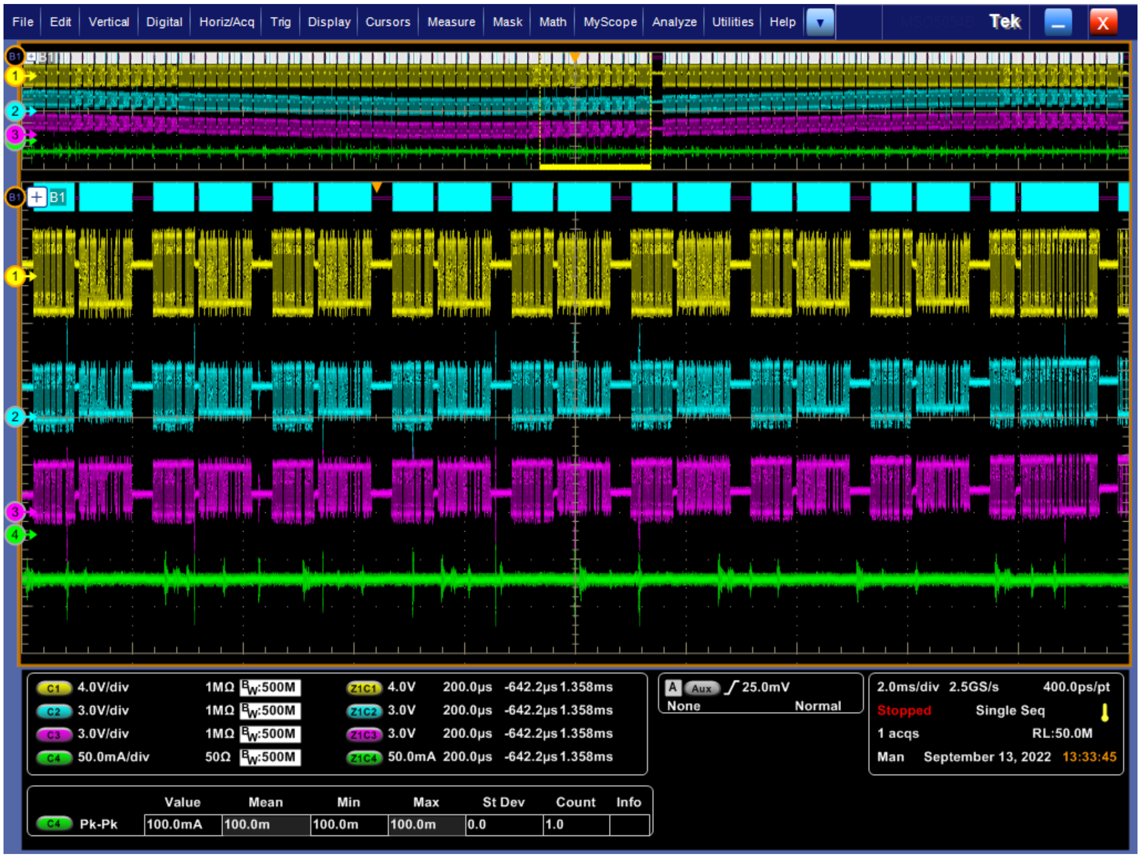


Figure 162: Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825) (1)

Figure 163: Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825) (2)

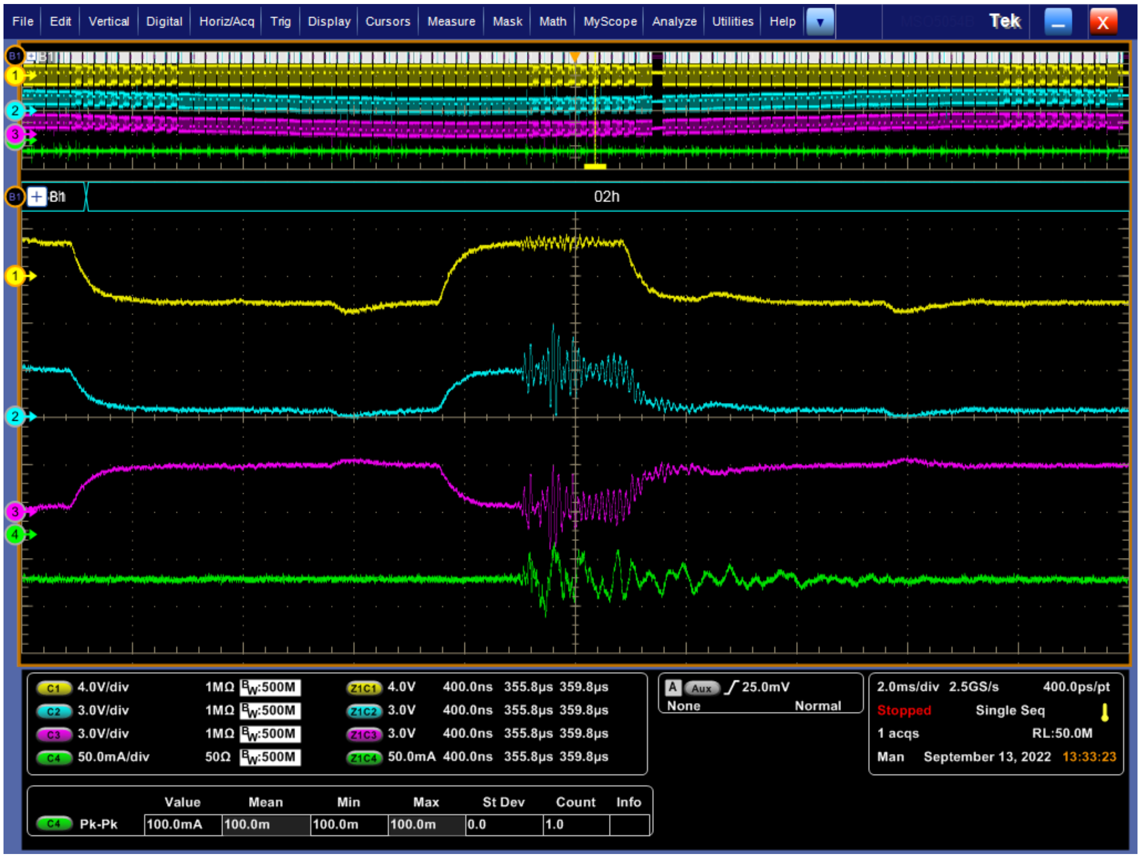


Figure 164: Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825) (3)

The ignitions on another segment cause similar disturbances to the voltage signal.

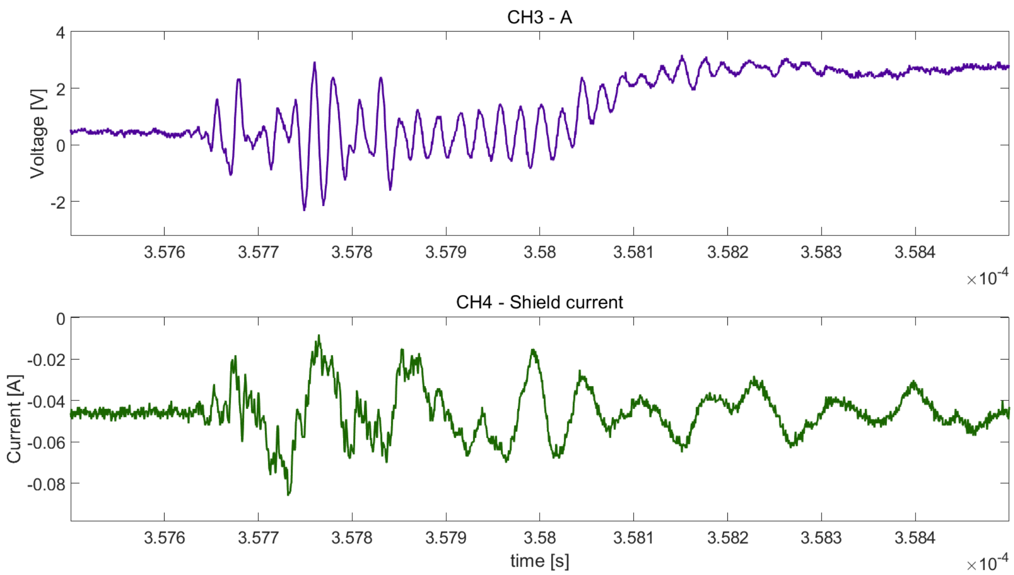


Figure 165: Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825) (detail of the measurement)

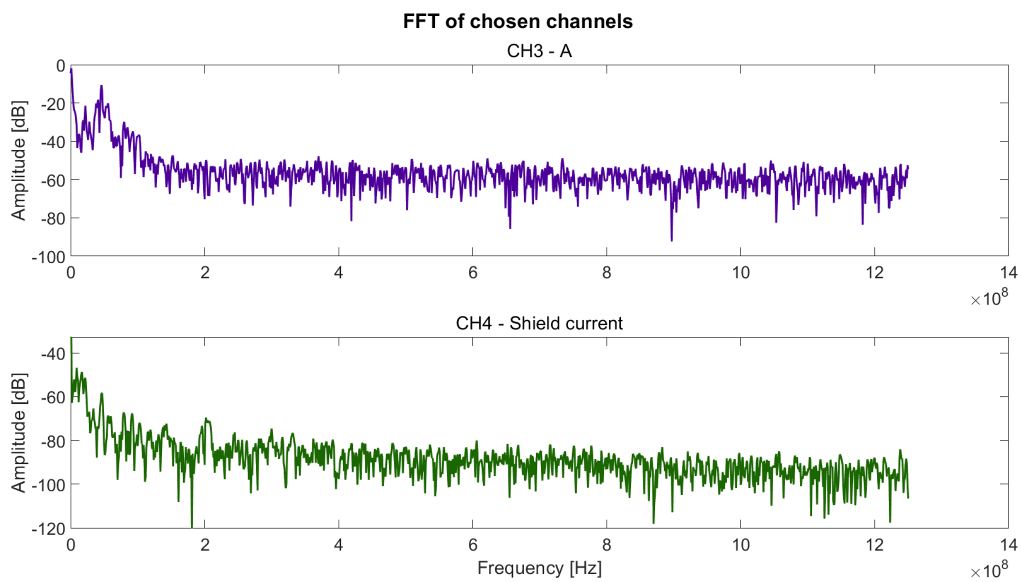


Figure 166: Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825) (FFT)

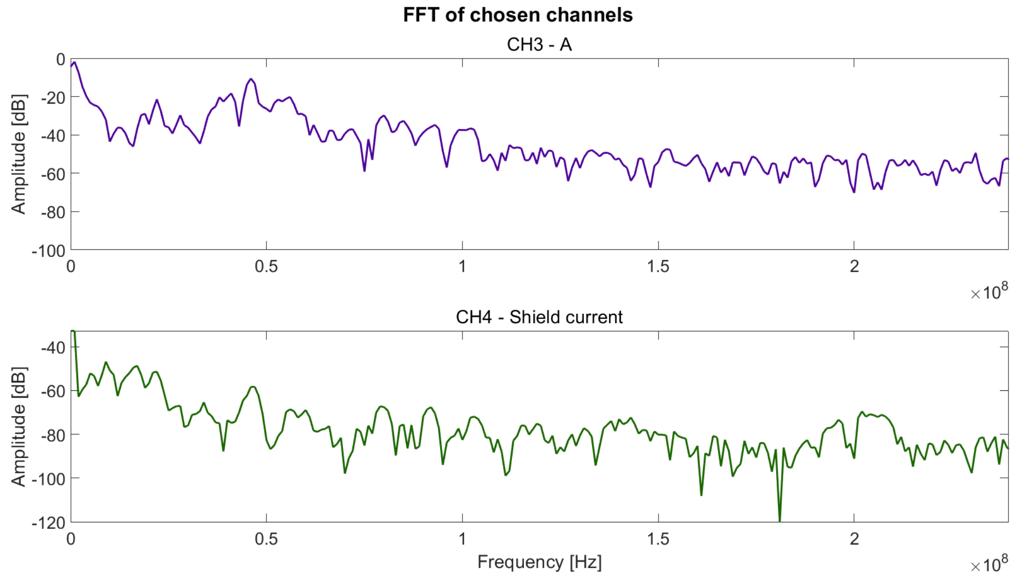


Figure 167: Ignitions on another segment (A2823) with Würth Elektronik DB9 with capacitor (measurement on segment A2825) (detail of the FFT)

Even at this high sample rate, there are not really many points to achieve a high spectral resolution; the bandwidth of the current probe is 15 MHz, that of the voltage probes is 50 MHz.
The easiest way to estimate the fundamental frequency is the distance between the peaks in the time domain.

Ignitions on another segment (A2823)

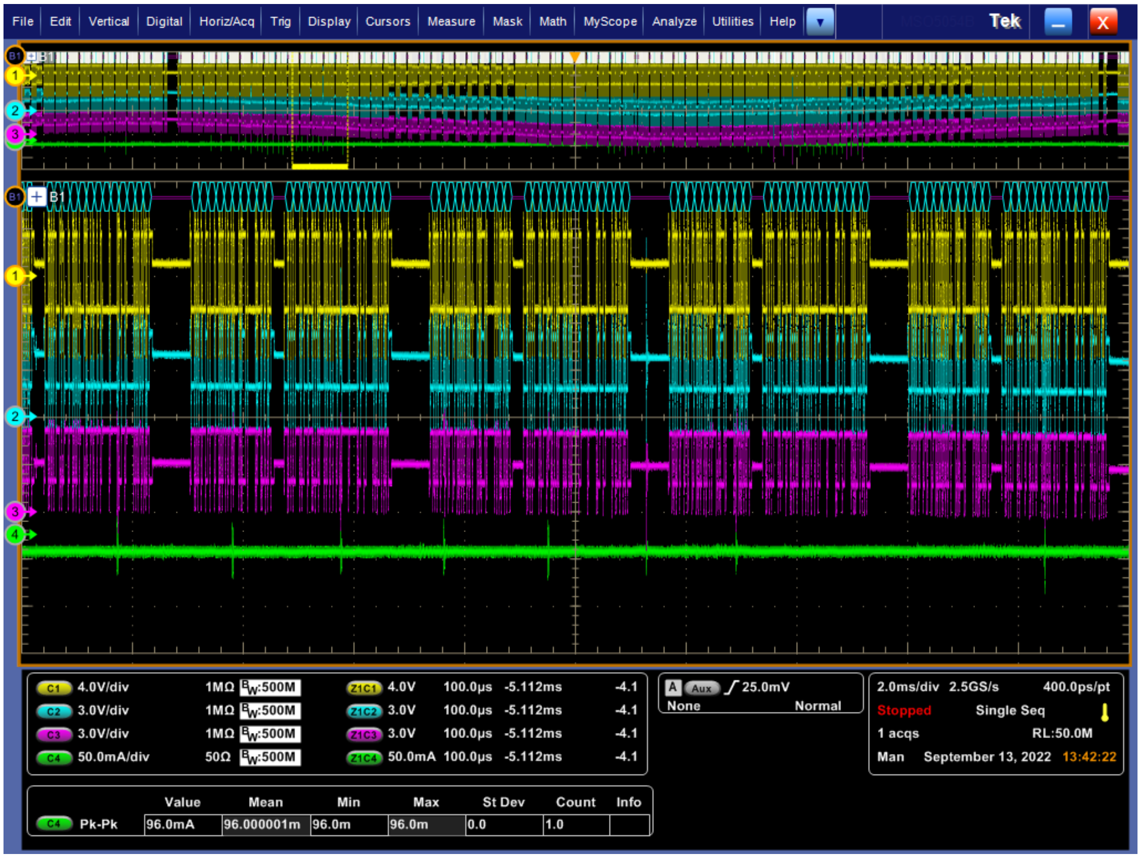


Figure 168: Ignitions on another segment (A2823) (1)

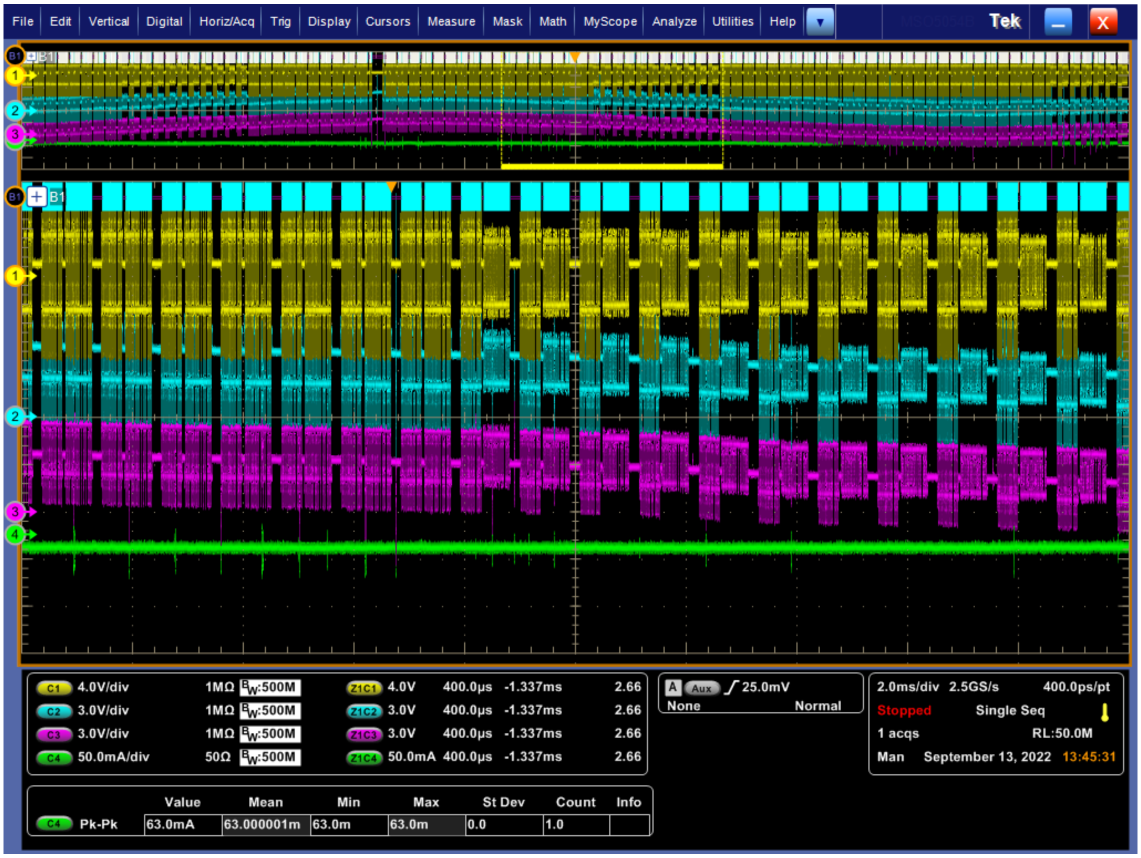


Figure 169: Ignitions on another segment (A2823) (2)

Here too, major interference can be seen on the signal between A and shield and the signal between B and shield, caused by the ignition of the burners.
This again has a small influence on the differential signal.

ComBricks (A2823)	Max. rest level (V)	Min. Rest level (V)	Difference in rest level (V)
CH2 (B)	4,863	1,014	3,849
CH3 (A)	4,083	0,095	3,987

Ignitions only on other segment (A2823)

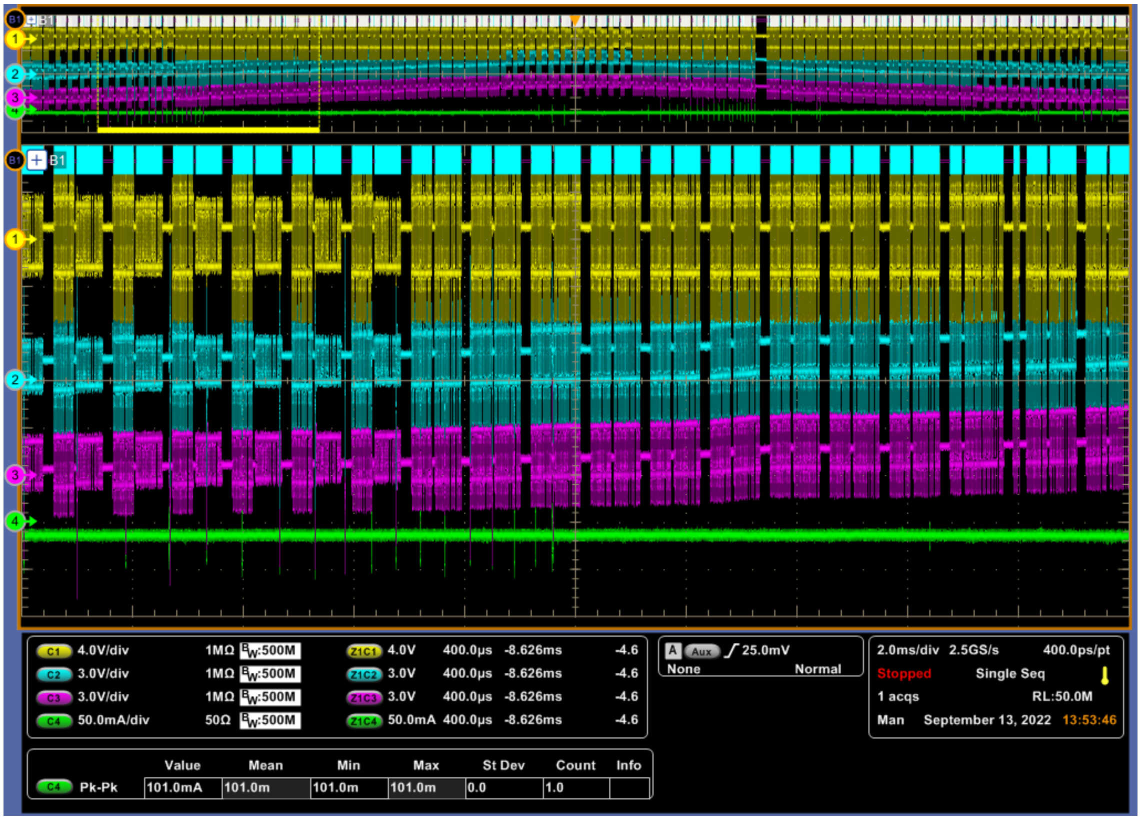


Figure 170: Ignitions only on other segment (A2823) (1)

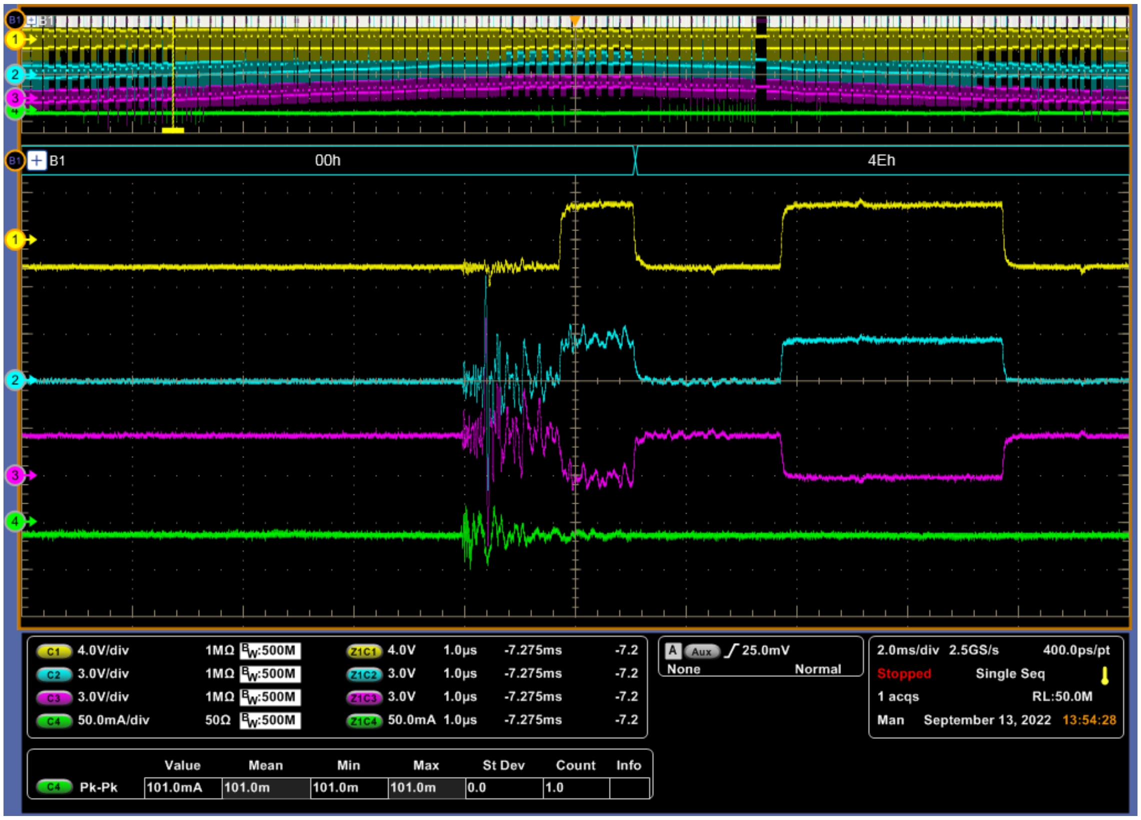


Figure 171: Ignitions only on other segment (A2823) (2)

Same as with 8 Ignition on other segment (A2823). Also in this measurement there is little influence on the differential signal AB.

Zero measurement on another segment (A2823) with Würth Elektronik DB9 with capacitor

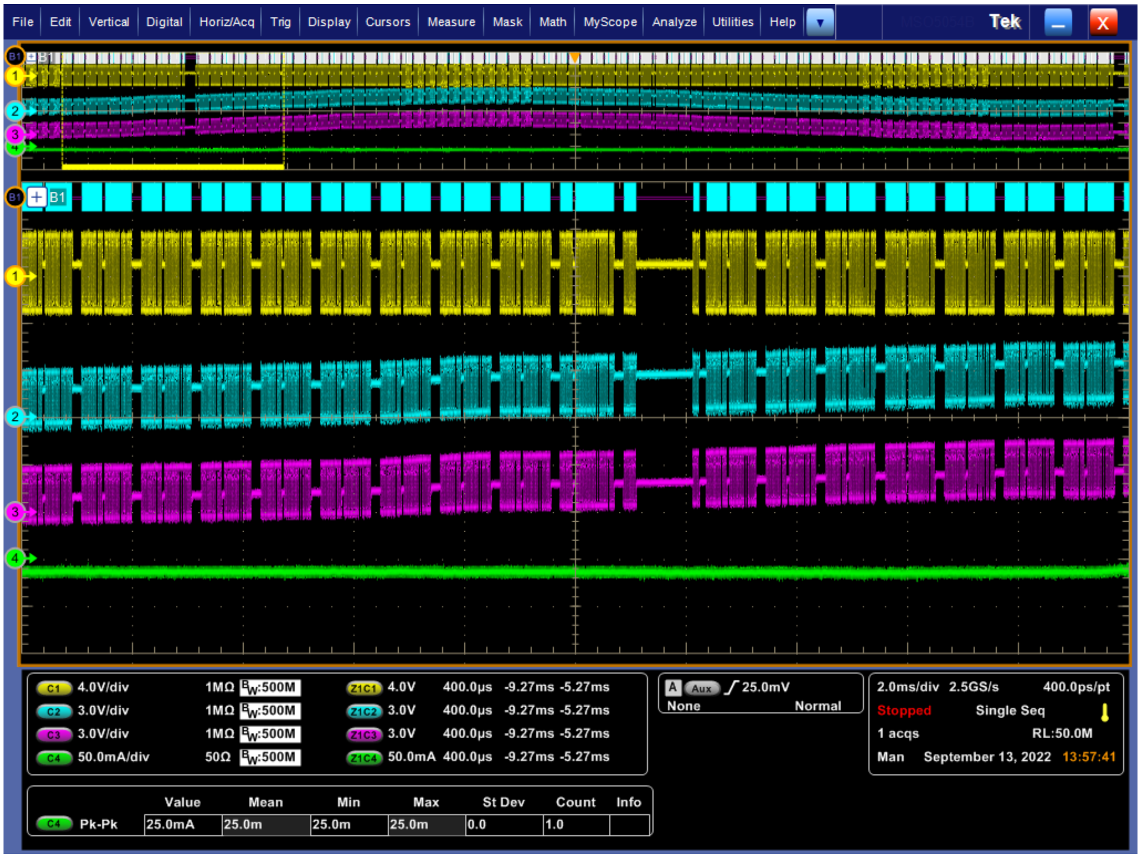


Figure 172: Zero measurement on another segment (A2823) with Würth Elektronik DB9 with capacitor

The Würth Elektronik DB9 with capacitor has no visible influence.

Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor

Figure 173: Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor

Same as 12) Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO).

Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor and wire on spark plug

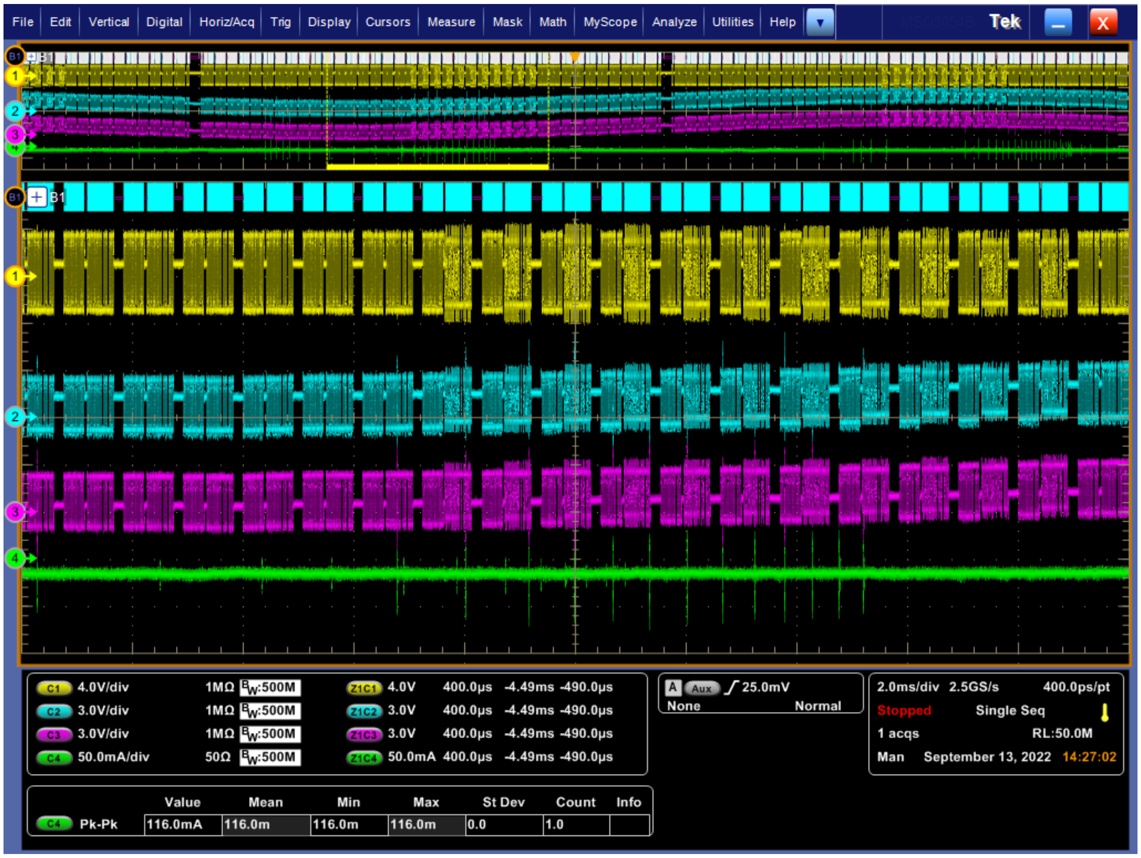


Figure 174: Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor and wire on spark plug (1)

Figure 175: Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor and wire on spark plug (2)

Applying the litz in this way has no effect.

Distance measurement reflections:

≈ 220 ns → distance about 50 m round trip, 25 m distance.

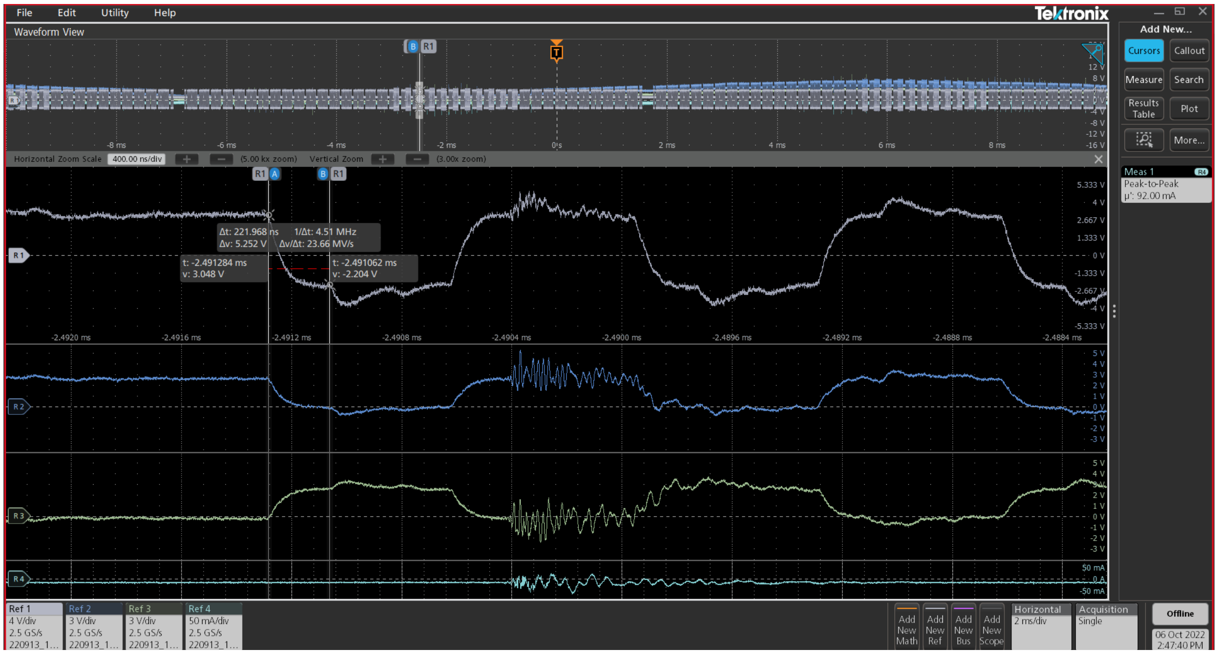


Figure 176: Ignitions only on other segment (A2823) with Würth Elektronik DB9 with capacitor and wire on spark plug (3)

Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO)

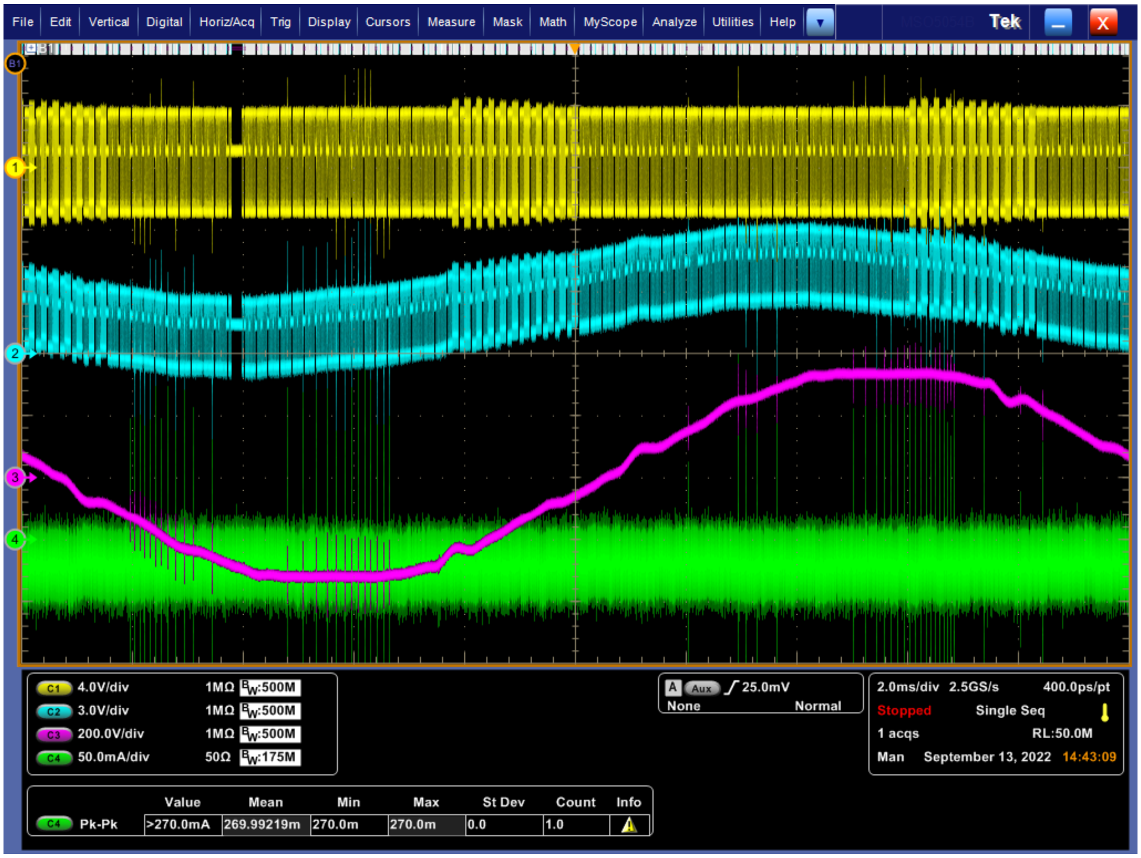


Figure 177: Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO) (1)

Ignition pulses visible on the “Primary supply voltage” of the ignition transformer (!).

Zoom in afterwards with TekScope software:

- R1: Differential PROFIBUS signal (B-A)
- R2: Signal between B and shield
- R3: “Primary supply voltage” of the ignition transformer
- R4: Current through the PROFIBUS shield

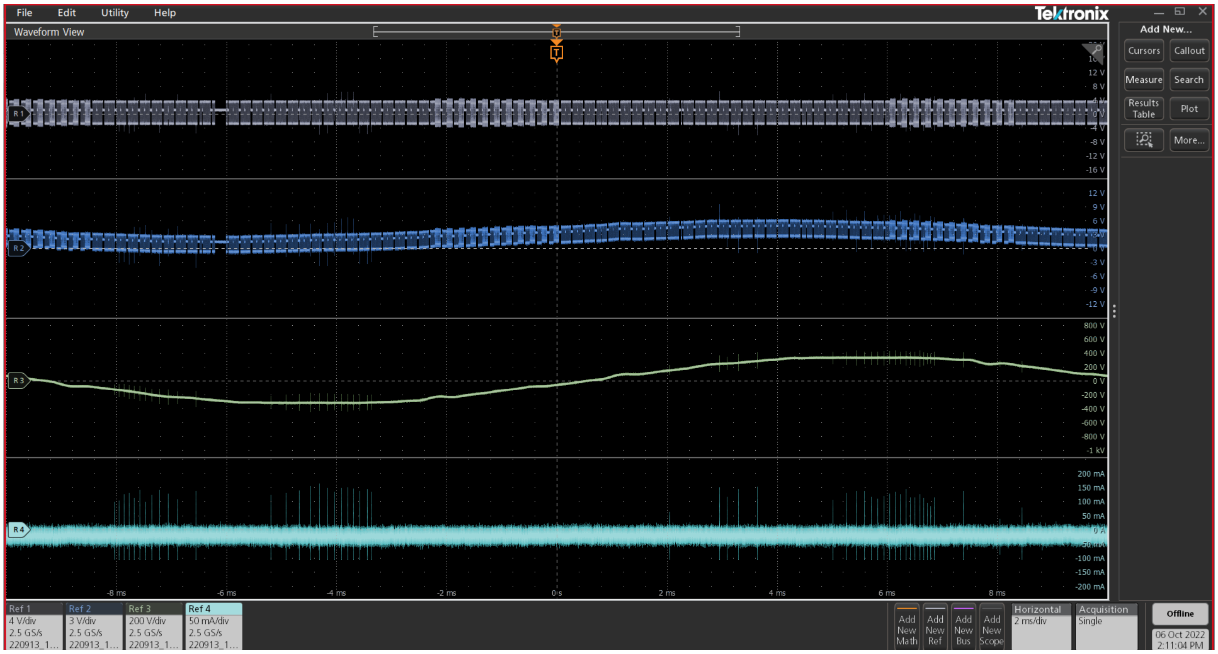


Figure 178: Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO) (2)

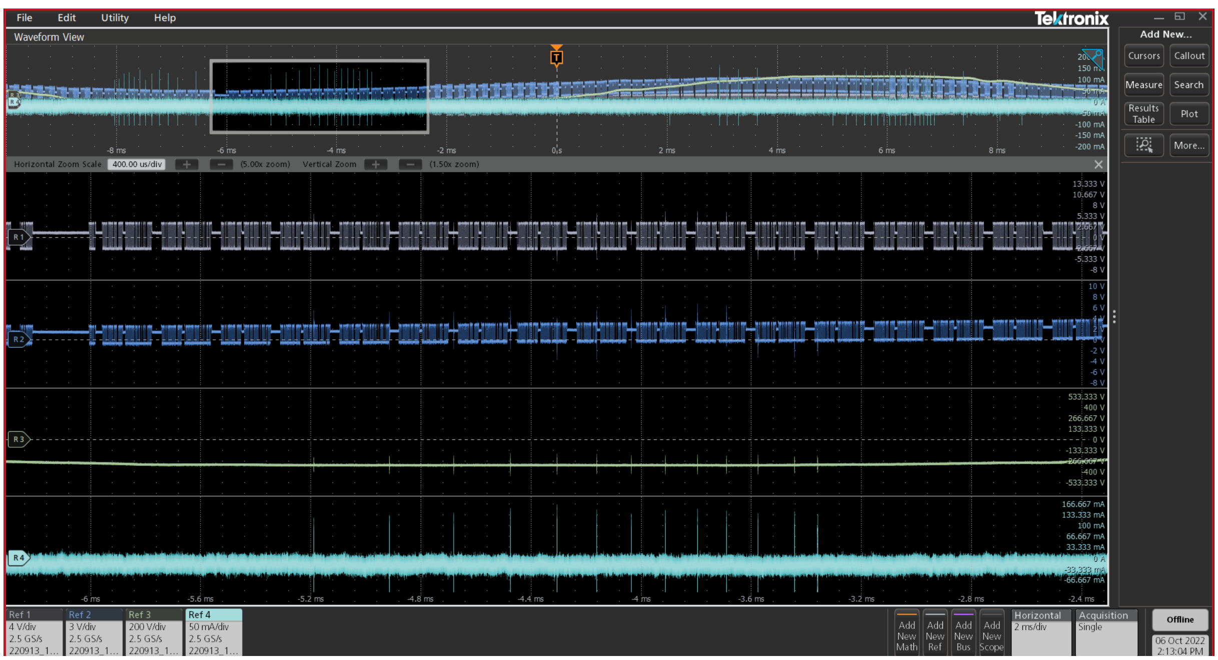


Figure 179: Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO) (3)

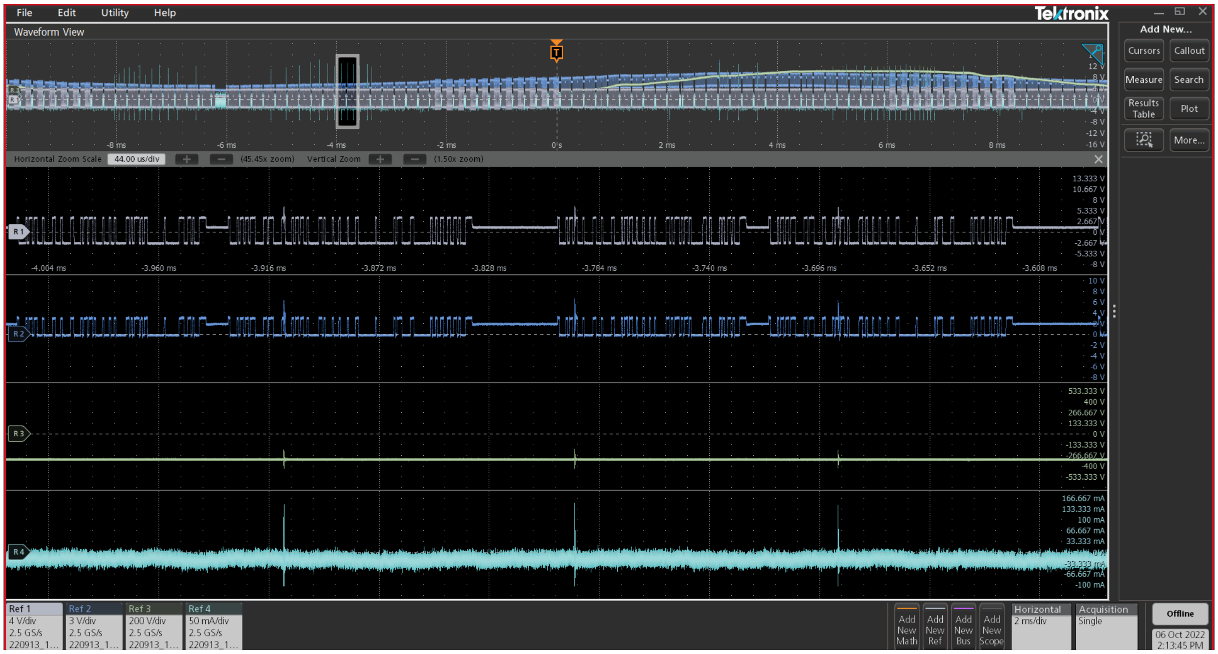


Figure 180: Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO) (4)

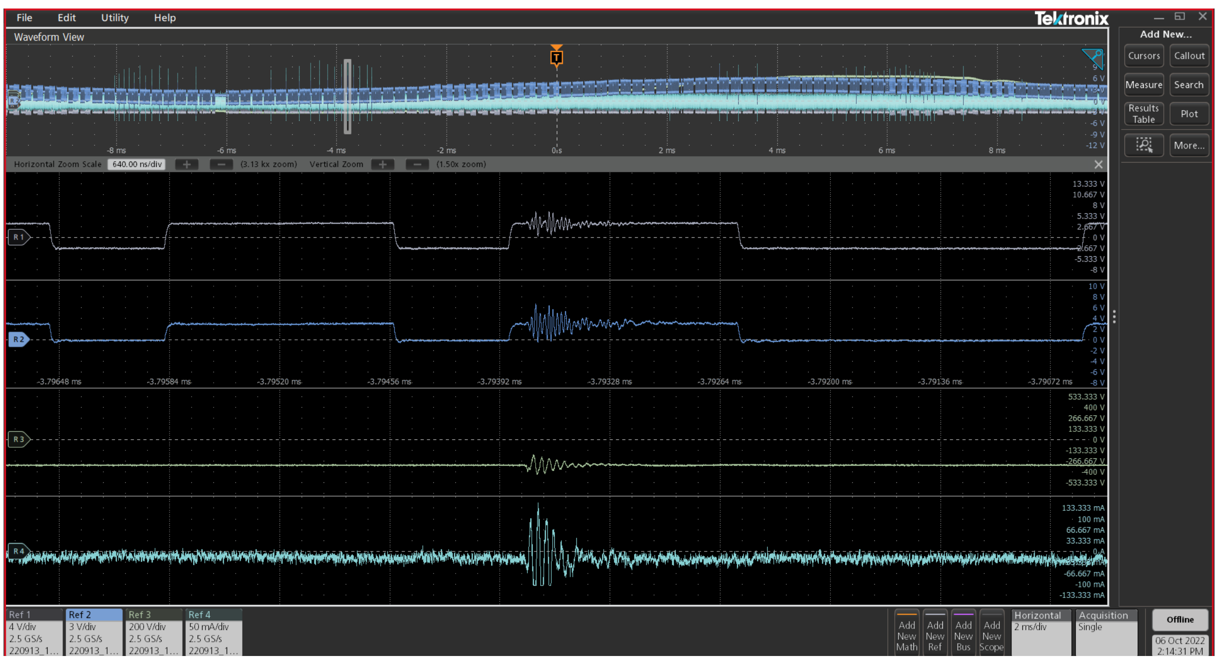


Figure 181: Measurement of “Primary supply voltage” of the ignition transformer (DIZ 110 SEO) (5)

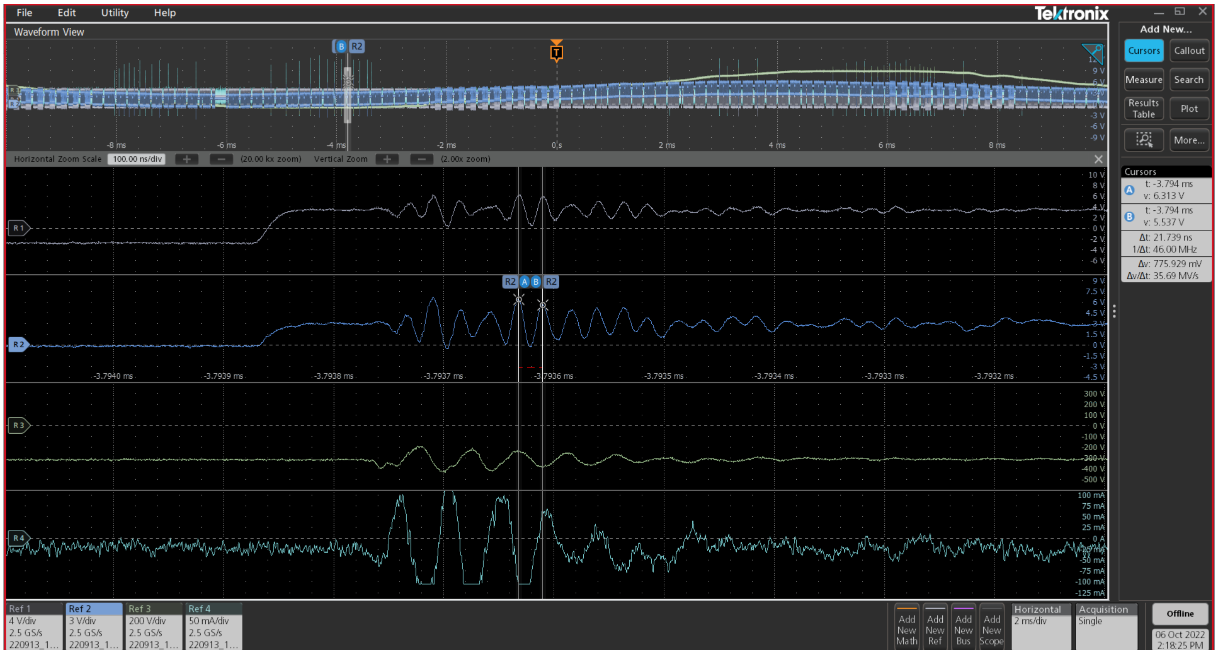


Figure 182: Measurement of "Primary supply voltage" of the ignition transformer (DIZ 110 SEO) (6)

Current peaks in the PROFIBUS shield and the voltage peaks on the "Primary supply voltage" of the ignition transformer have the same frequency (≈ 23 MHz).

The voltage peaks on the differential PROFIBUS signal and between the B signal and the shield have double the frequency (≈ 46 MHz).

Here the influence of the disturbances on the differential signal is clear and sufficient to disrupt messages - especially if this occurs during the rest level - or to bring the drivers out of the rest level without a valid message following.

Recommendation for additional measurements:

- Measuring with voltage probes with higher bandwidths (500-1000 MHz), now measured with 50 MHz voltage probes.
- Same for the current: currently measured with a 15 MHz current probe with a large opening to click over the cable. The 100 MHz current probes cannot pass over the shield of the PB cable, but we could measure the "Primary supply voltage" if the currents are low enough.
- Higher voltages this time with a 100 MHz insulating voltage probe ("Primary supply voltage" Dungs).

The question remains whether it is a direct reaction of the ignition circuit to the supply voltage, or whether it is caused by the 7 kV pulses (neutral - PE - ground problem).

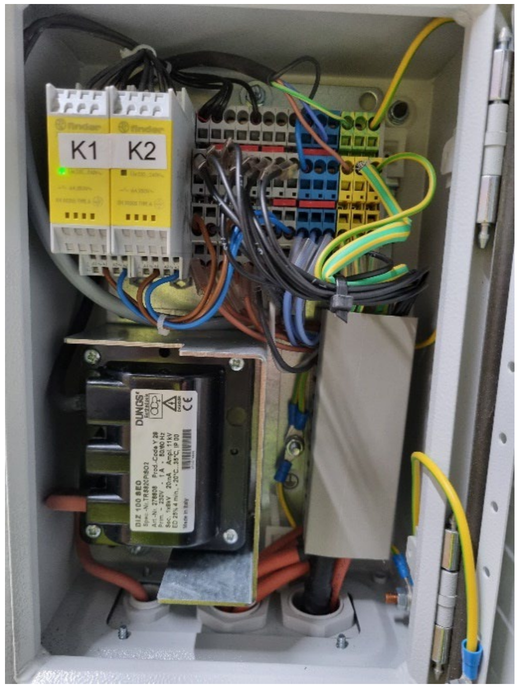


Figure 183: Current wiring (1)

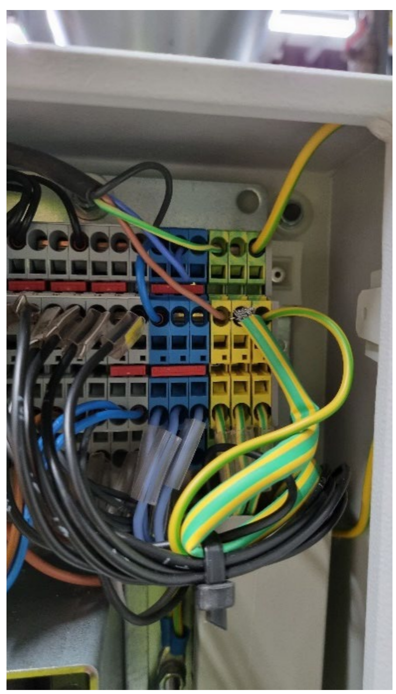


Figure 184: Current wiring (2)

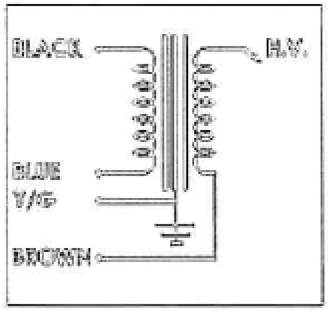
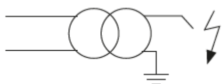
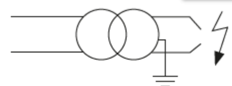


Figure 185: Connections of ignition transformer

DEZ 1xx



DEZ 2xx



DEZ Versions	DEZ 100	DEZ 101	DEZ 100 SEO	DEZ 101 SEO	DEZ 200
High-voltage outputs	1	1	1	1	2
Mains voltage [VAC]	230/240	120	230	120	230/240
Frequency [Hz]	50/60	50/60	50/60	50/60	50/60
Current consumption [A]	0.3	0.5	0.3	0.5	0.14
Power consumption [VA]	69	55	69	60	32
Secondary voltage [kV] +/- 10 %	1 x 15	1 x 15	1 x 15	1 x 15	2 x 10
Secondary frequency [kHz]	10	13	10	16	10
Short-circuit current [mA]	30	30	30	30	20
Duty cycle 3 min.	33 %	33 %	33 %	33 %	100 %
Protection type	IP 54	IP 54	IP 54	IP 54	IP 54
Ambient temperature ta [°C]	-20…60 °C	-20…60 °C	-20…60 °C	-20…60 °C	-20…60 °C
Weight [kg]	0.32	0.32	0.32	0.32	0.32
Article no.	252 113	255 018	257 126	257 127	252 114

Figure 186: Datasheet ignition transformer

It is advisable to ask the manufacturer whether we can lay a wire from the bottom of the spark plug (well connected, bare metal) to the brown wire (other terminal of the transformer), and whether this last wire can be separated from the earth. to leave. This would create a high frequency low impedance return path directly to the transformer, without going around the ground system.

This would perhaps allow less RF current to flow in the return paths via the shields of the PB cables, and therefore result in less interference in the differential AB PROFIBUS DP signal.

(Since ignition signals in one segment also generate interference in another segment, bonding of all brown cables of the Dungs should also be considered.)

Measurement at station 61 (last slave of a segment)

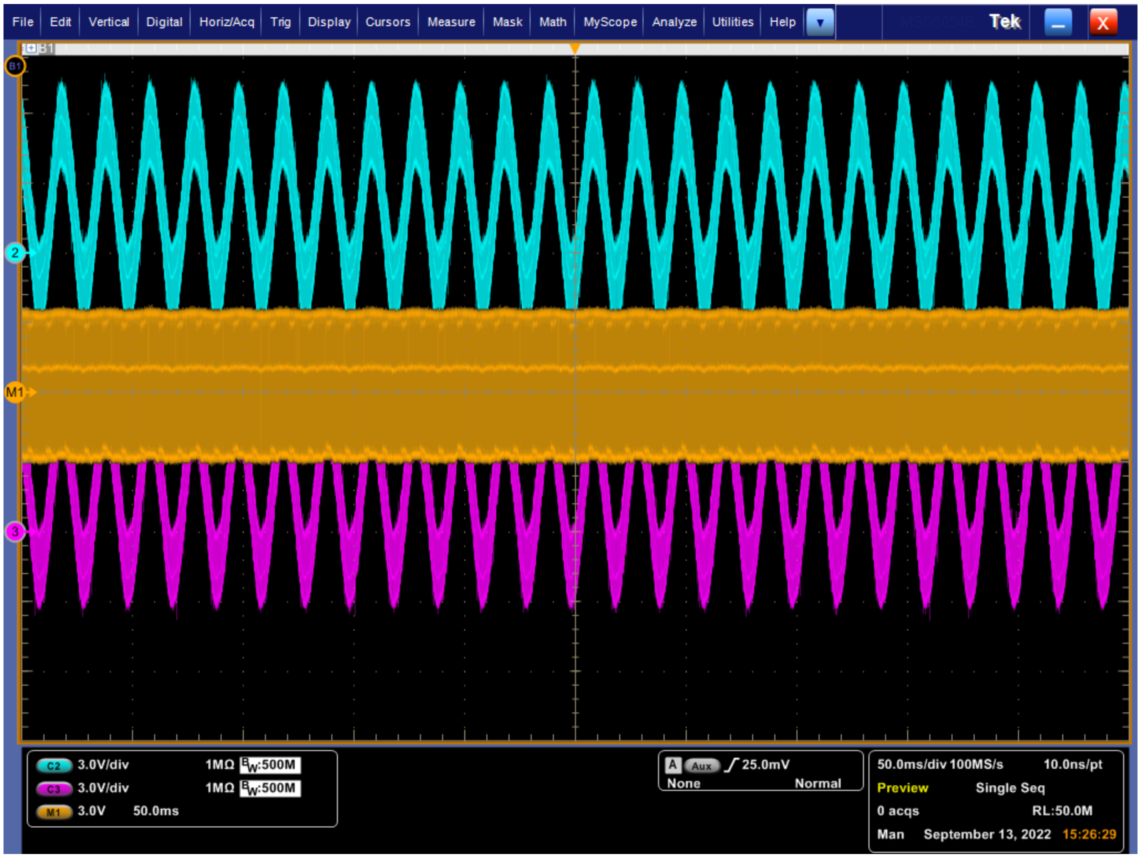


Figure 187: Measurement at station 61 (last slave of a segment) (1)

Figure 188: Measurement at station 61 (last slave of a segment) (2)

Station 61 (A2823)	Max. rest level (V)	Min. rest level (V)	Difference in rest level (V)
CH2 (B)	4,791	-2,053	6,844
CH3 (A)	5,859	-1,103	6,962

Figure 189: Measurement at station 61 (last slave of a segment) (3)

Differential rest level is good, the absolute values of A and B depend on the moment during the 50 Hz sinus.

PE, ground and active shutdown must be checked.

Triggers from 2022-04-13

a) Save on trigger 17h56

98	13-Apr-2022 16:56:09.011		SD2	2->55	SRD HIGH	Data Exchange	Req	1	00
99	13-Apr-2022 16:56:09.011	Repeat	SD2	2->55	SRD HIGH	Data Exchange	Req	1	00
100	13-Apr-2022 16:56:09.011		SD2	2<-55	DL	Data Exchange	Res	4	00 00 07 00

Figure 190: Save on trigger 17h56 in ProfiTrace

Repeat is not visible in decoded scope image.

Rest level trigger between “2→71” and “71→2”.

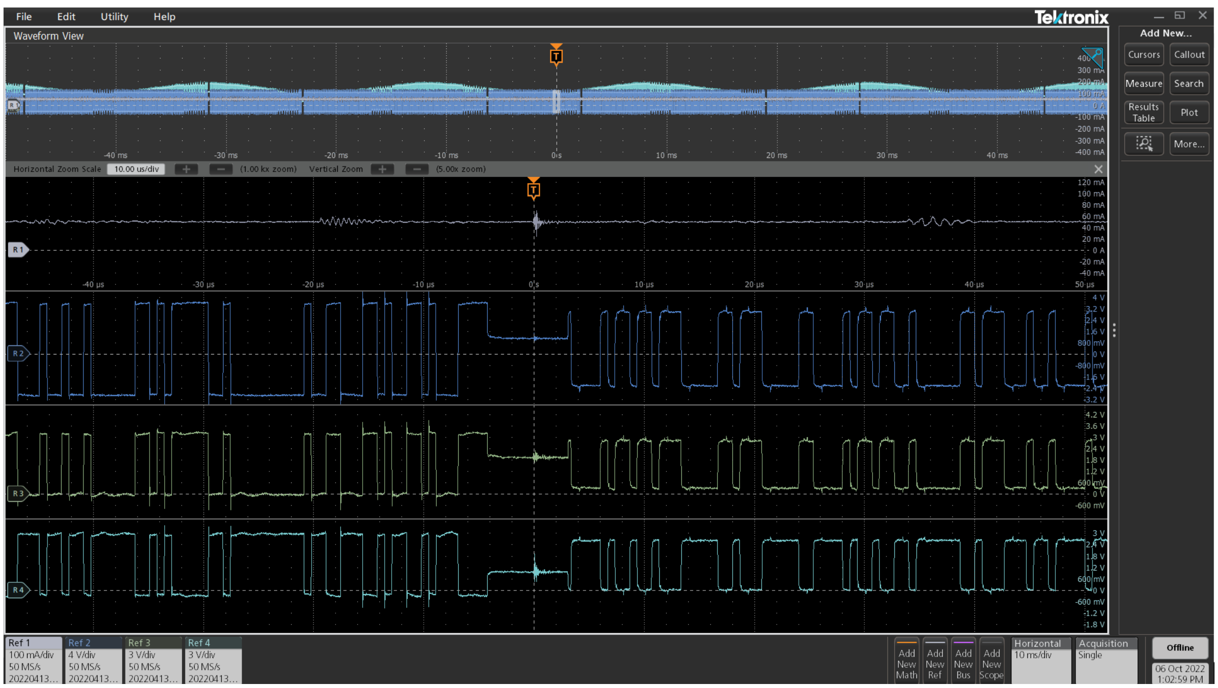


Figure 191: Save on trigger 17h56 on oscilloscope (1)

Ignition pulse couples in (too large) to differential AB signal.

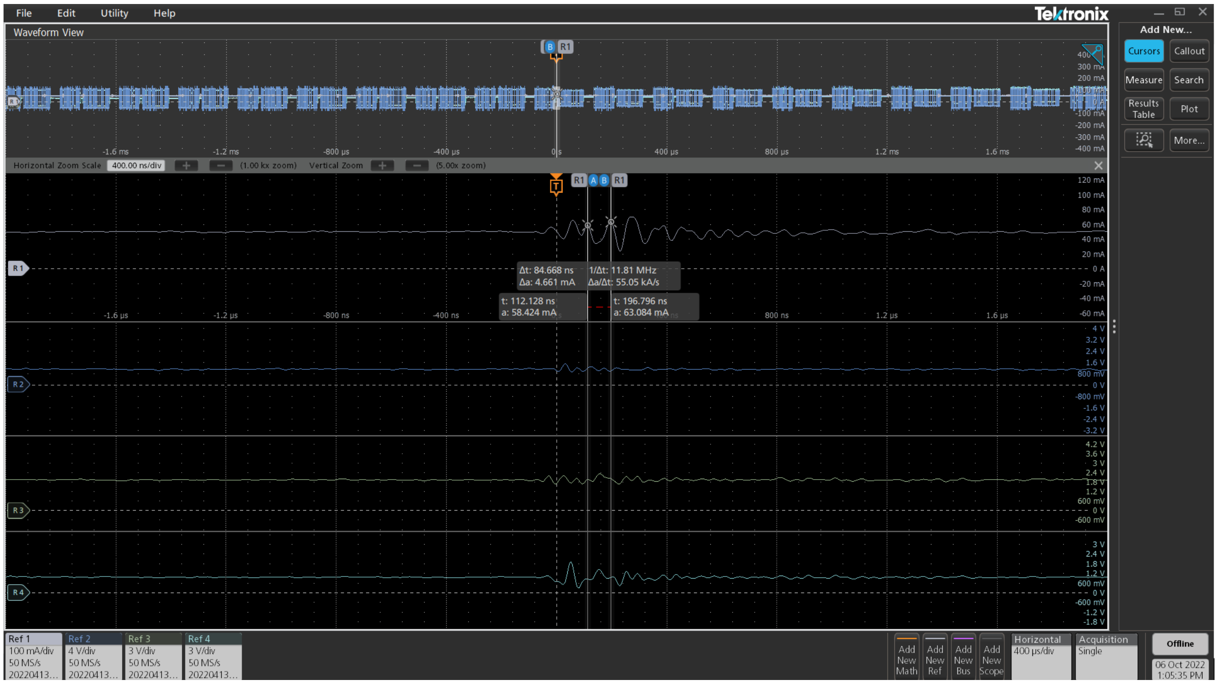


Figure 192: Save on trigger 17h56 on oscilloscope (2)

Drive pulse.

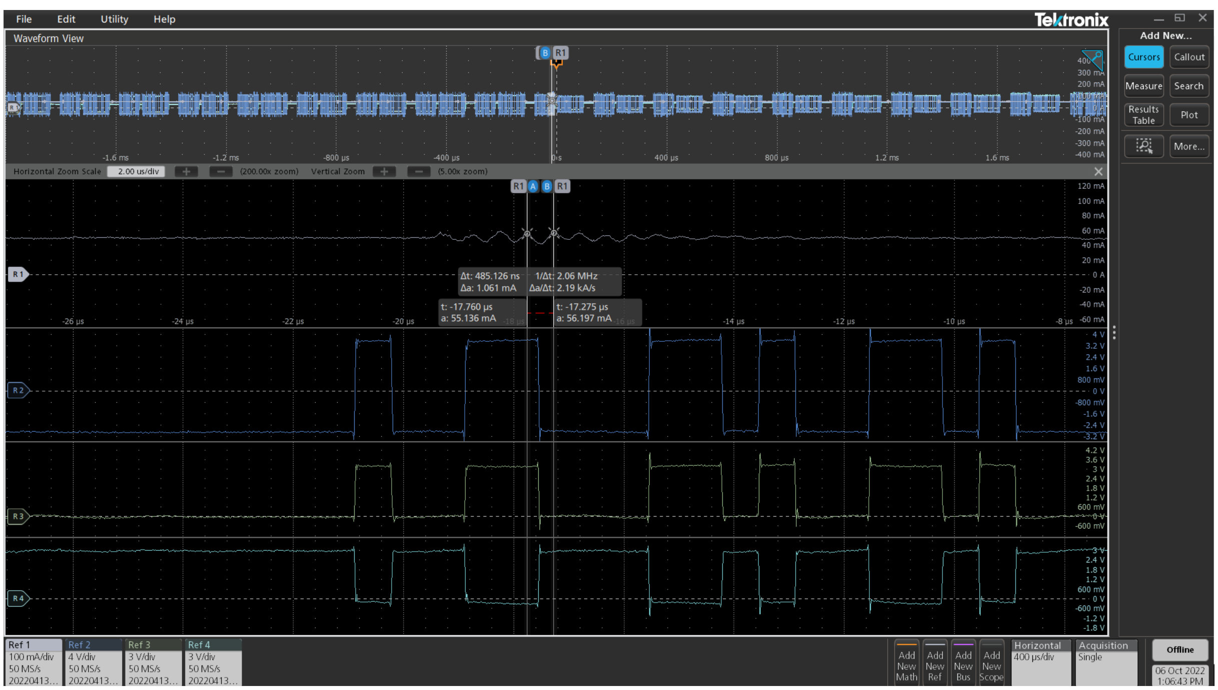


Figure 193: Save on trigger 17h56 on oscilloscope (3)

b) Save on trigger 18h20

99	13-Apr-2022 17:20:17.011		SD2	2->51	SRD HIGH	Data Exchange	Req	1	00
100	13-Apr-2022 17:20:17.011	Repeat	SD2	2->51	SRD HIGH	Data Exchange	Req	1	00
101	13-Apr-2022 17:20:17.011		SD2	2<-51	DL	Data Exchange	Res	4	00 00 07 00

Figure 194: Save on trigger 18h20 in ProfiTrace

Repeat is not visible in decoded scope image.

Trigger:

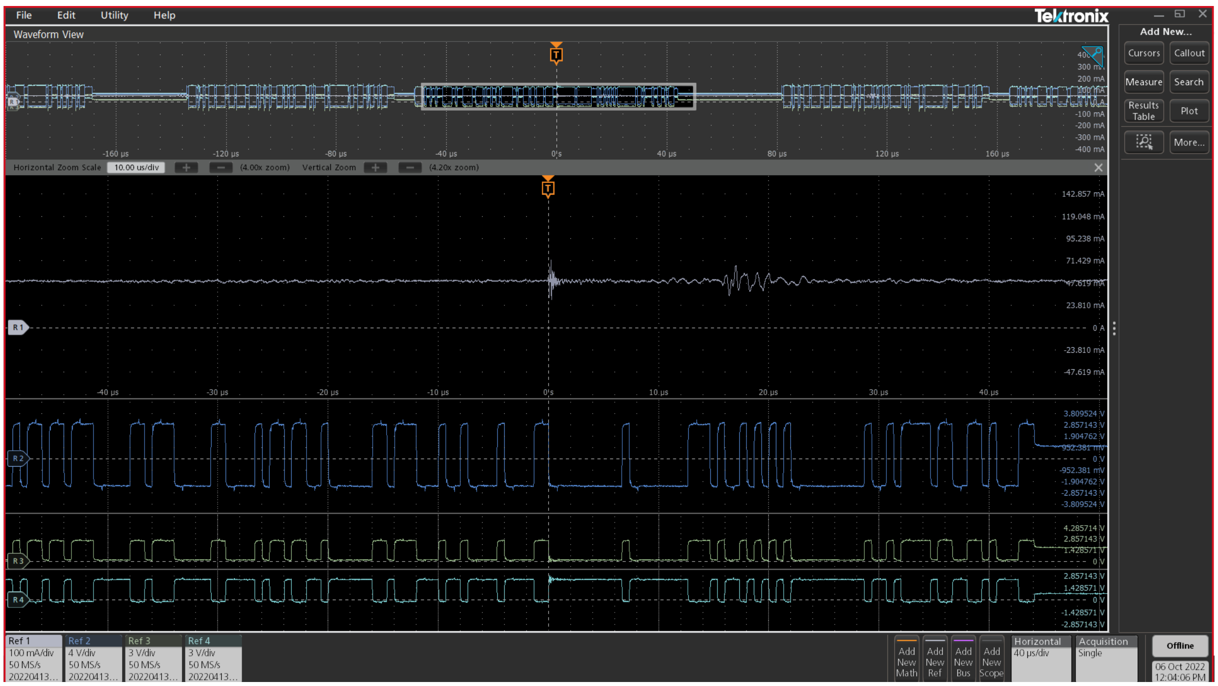


Figure 195: Save on trigger 18h20 on oscilloscope (1)

Ignition pulse:

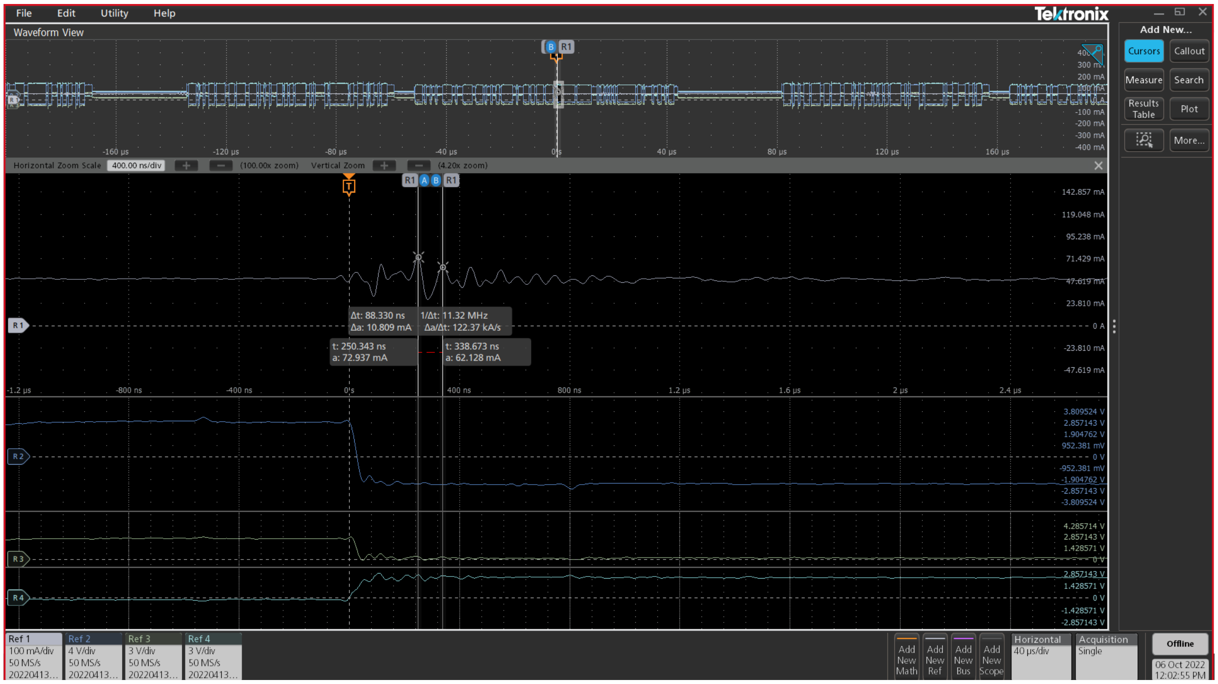


Figure 196: Save on trigger 18h20 on oscilloscope (2)

Drive pulse:

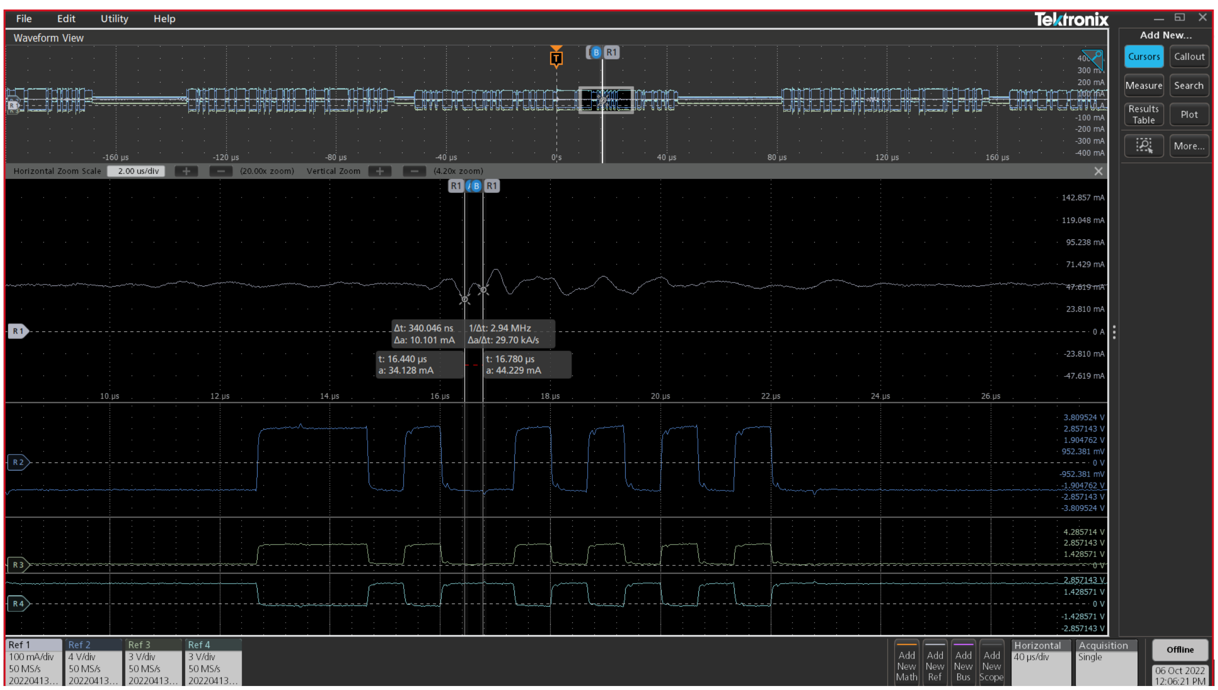


Figure 197: Save on trigger 18h20 on oscilloscope (3)

Prolink-engineering (Renson)

Prolink experienced a communication problem on a newly installed PROFINET network in Renson.

Diagnosis: The system is fully build with awareness of EMC. At first sight the system shows no EMC problems. When measuring with a current probe, the common mode current over the cable increases up to 100 dBµA (100 mA). It is known that problems start occurring around 30 mA.

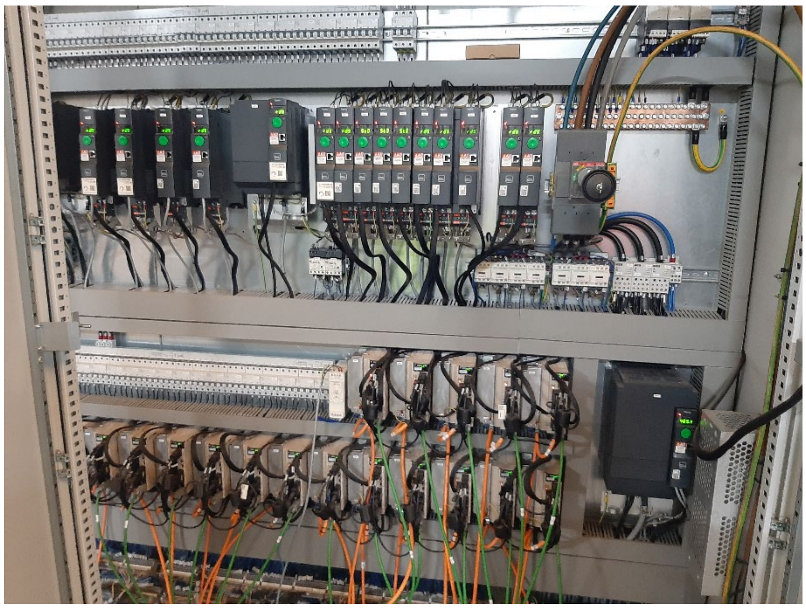


Figure 198. Impression of the installation

The increase of emission around 700 kHz indicates a grounding problem on a long motor cable. The difference motor cables were checked at the motor and in one motor the shielding was indeed not connected. By improving this connection, the problem was solved. The measurements before and after the modification can be seen in fig. 83.

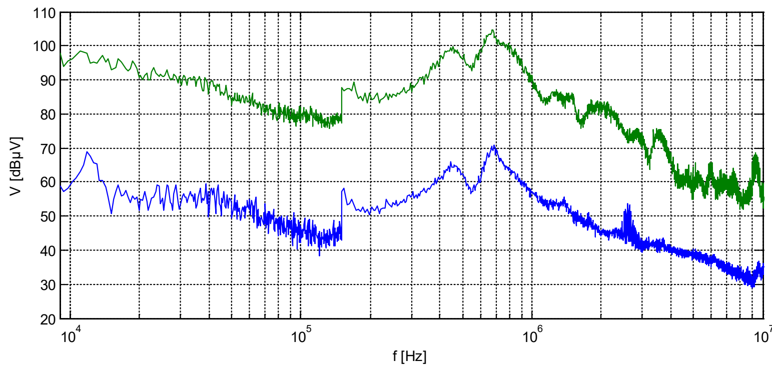


Figure 199. Measurement before (green) and after the modifications (blue)

Historically grown converged OT/IT networks at Barry Callebaut

The goal of this use case, which is also an MSc thesis project, consists of two parts: to identify the source of the current issues, and to suggest improvements for the to be designed new network.

Barry Callebaut (Halle site) has occasionally faced problems in their industrial networks, both in the past and today. The Barry Callebaut production site in Halle has grown enormously over the years, resulting in the addition of more and more buildings. Whenever a new building was constructed, the essential machines, (OT) switches, PLCs, etc. were installed to meet the requirements of the new production lines. Each building therefore contains one or more OT switches. Of all these switches, one switch is connected to an IT switch, creating an OT star topology with the IT network (see Figure 83).

Each IT switch (per building) is in turn connected to the core IT switch and this core IT switch is ultimately connected to the firewall and server infrastructure (see Figure 82).

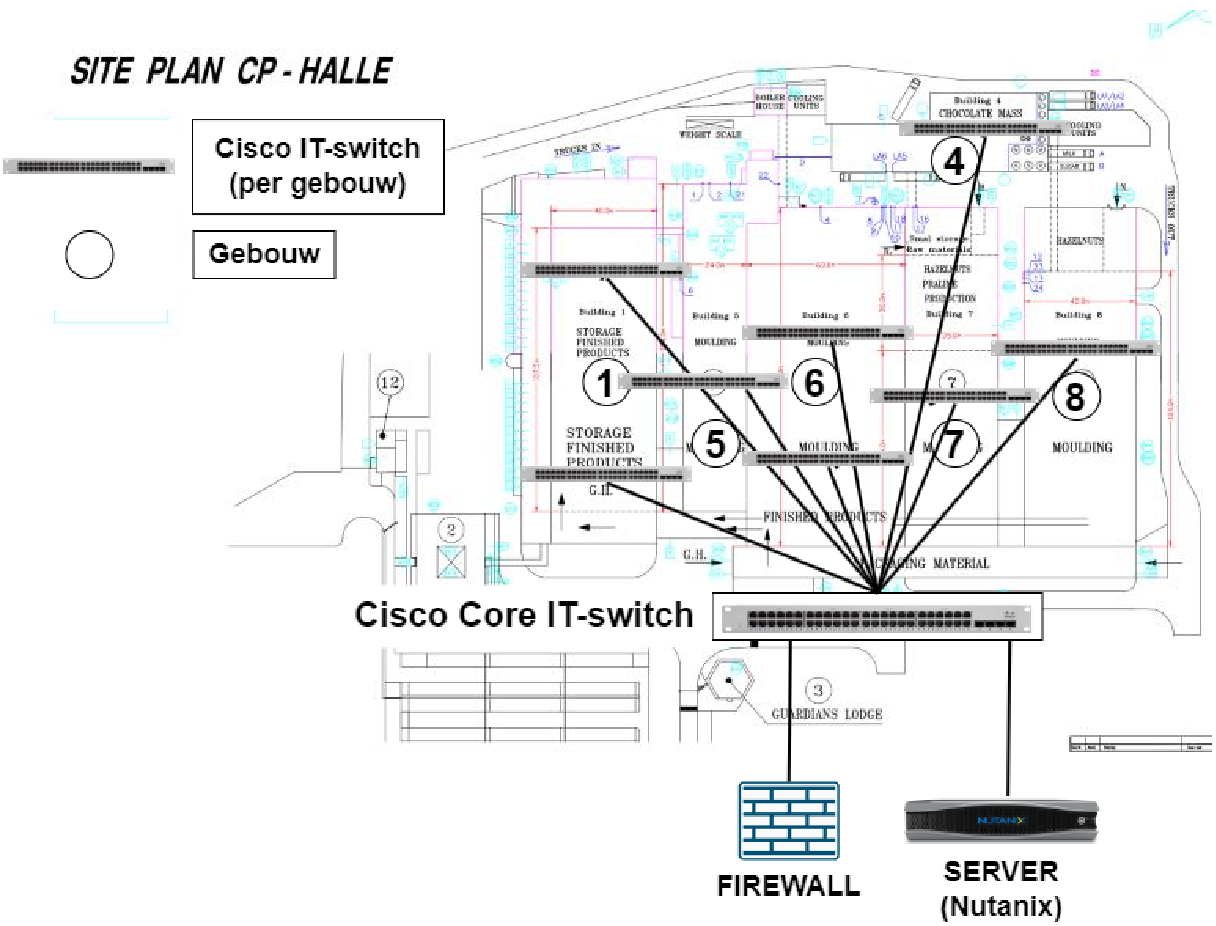


Figure 200: The current network at Barry Callebaut Halle

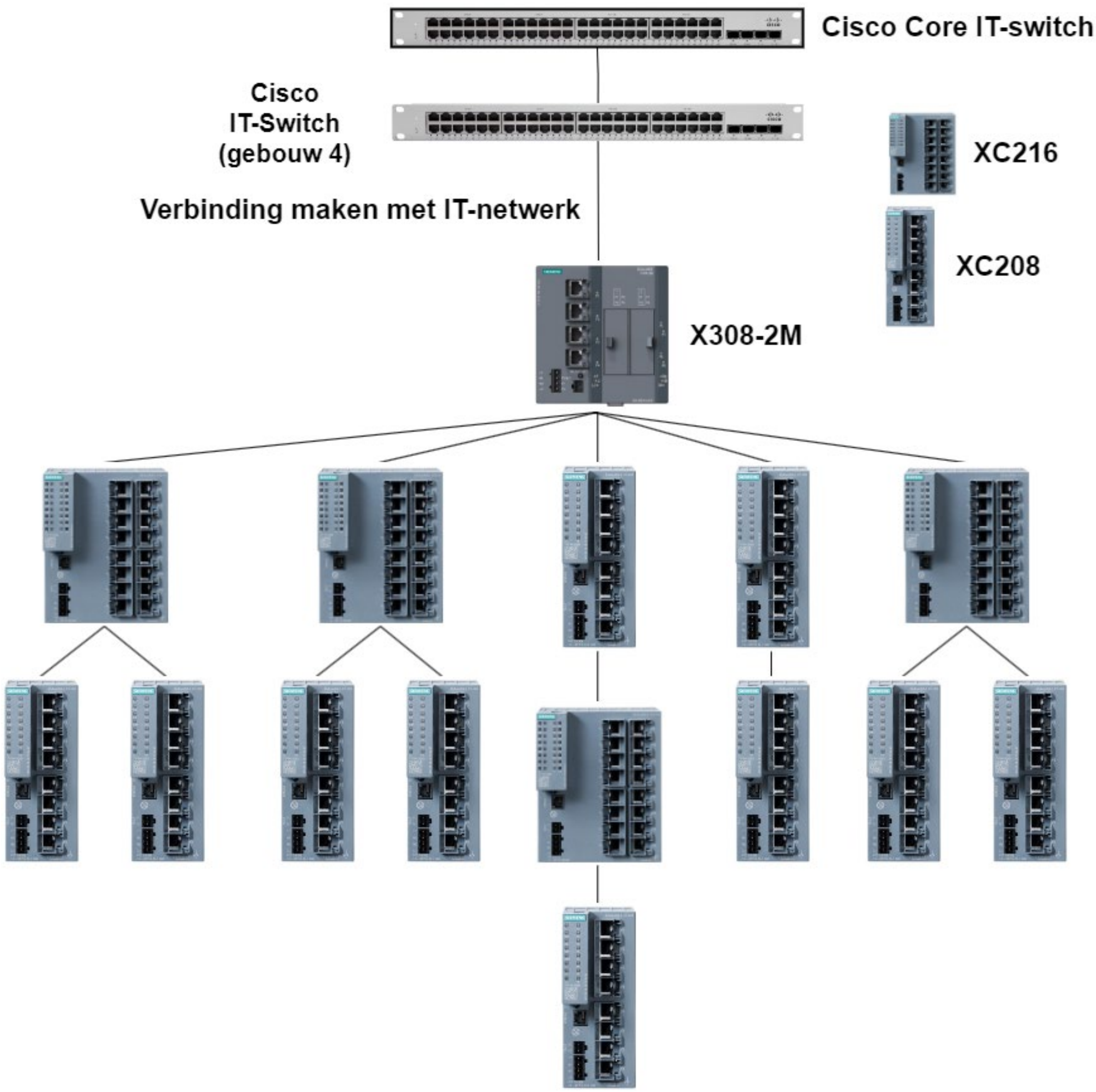


Figure 201: Star topology of the IT switch with the OT switches in building 4 at Barry Callebaut Halle

This means that a lot of data communication runs over the same cables, for both IT and OT traffic. As a result, lower priority data (refer to IEEE 802.1Q) can be interfered with by higher priority data being sent simultaneously over the same cables. This may result in data loss or unwanted delay. Within this topology there are several critical points and any errors can lead to loss of communication, and production losses.

During maintenance, three ProfiTAPs were installed in the cabinet where the PLCs responsible for the various lines in building 4 are located. Two 100 Mbps TAPs and one 1 Gbps TAP (refer to D2a) were installed (see Figure 84).

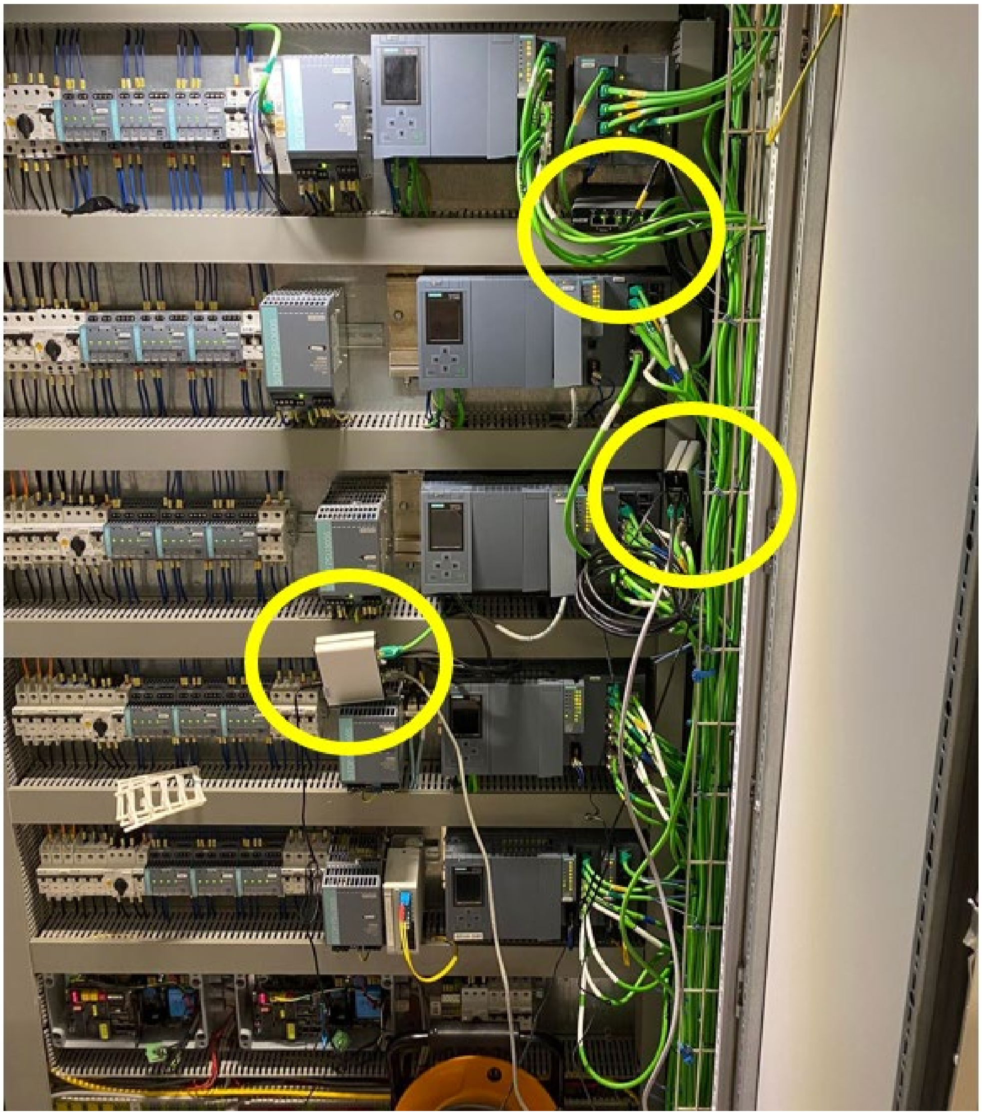


Figure 202: Cabinet with PLCs in building 4

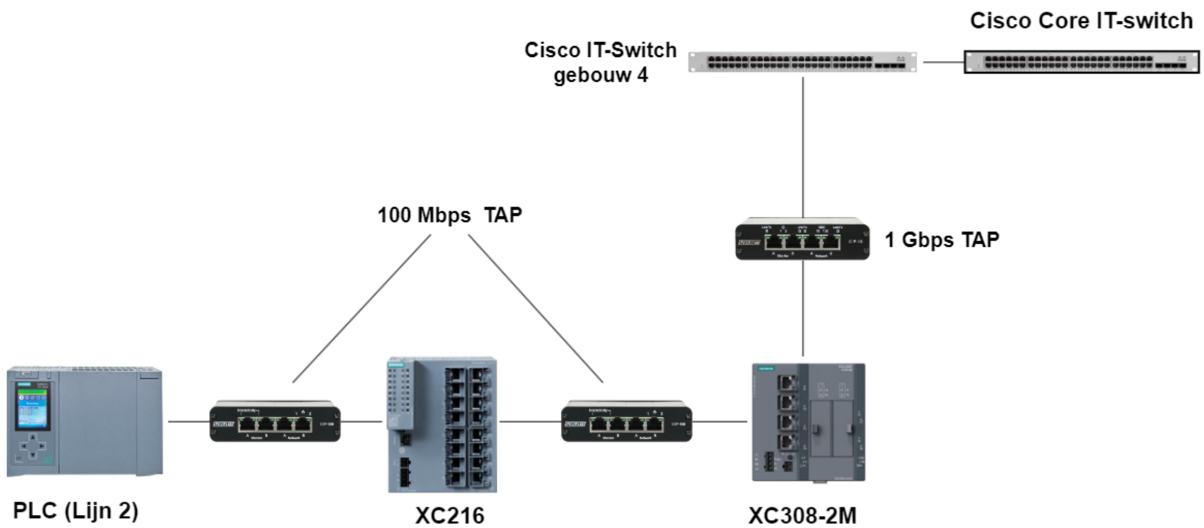


Figure 203: Schematic simplified overview of the placement of the TAPs

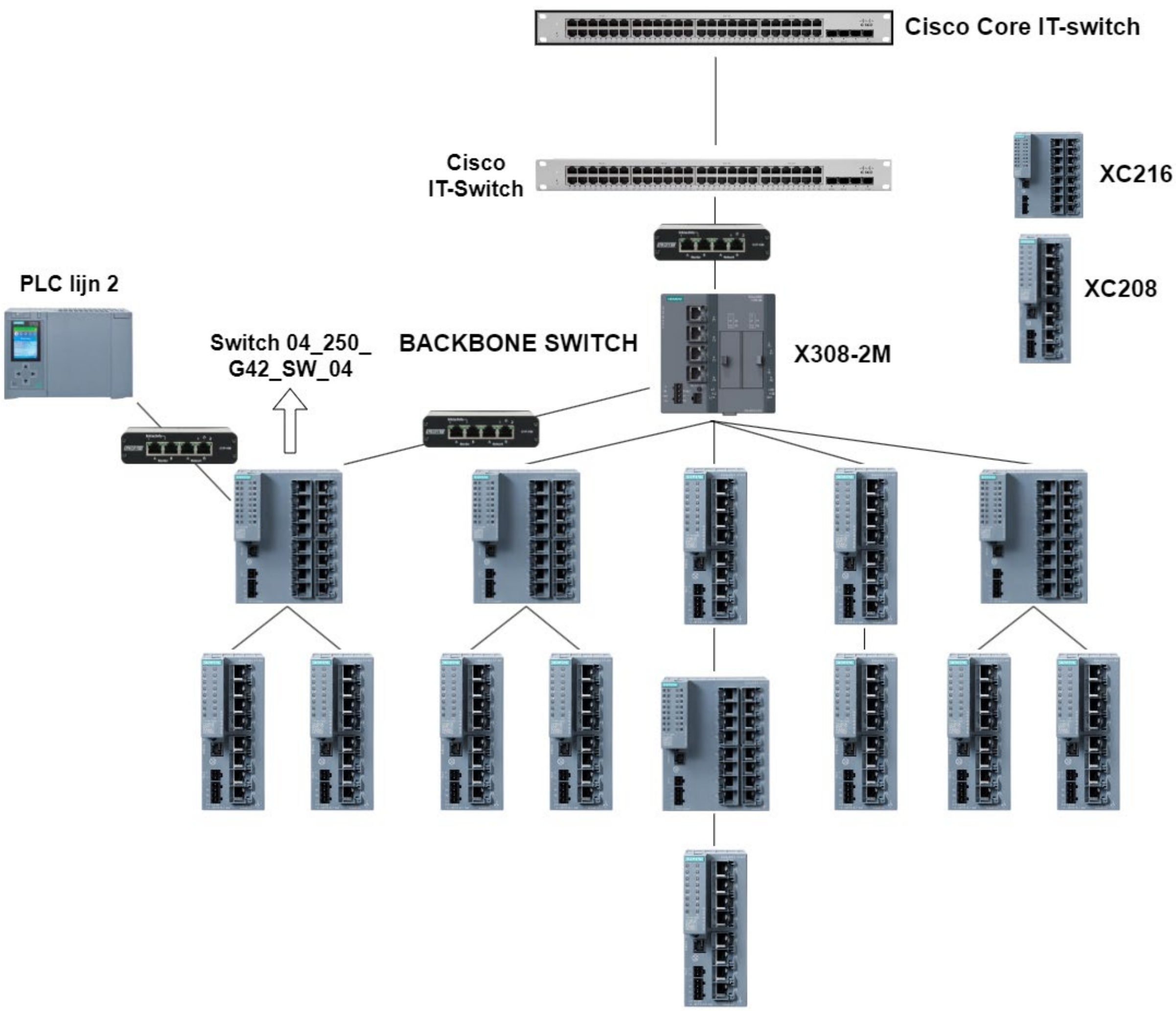


Figure 204: Location of the TAPs in building 4

More details can be found in the MSc thesis project of Klaas Barbé; conclusions in the introductory section of this report.

ArcelorMittal Gent – Steel Shop

The goal of this use case, which is also an MSc thesis project, consists of two parts: to support choice for one or more network diagnostic and management tools for Ethernet/PROFINET based industrial networks, and to design a decision tree for fault finding (having both maintenance technicians and network specialists in mind).

Part of the work is done in the factory itself (standstills for insertion of equipment, continuous measurements for some periods in some networks). Another part of the work is done offline in the lab.

The test network uses a multitude of different networking technologies and/or structures:

- Wireless
- Fiber optic
- PRP redundancy
- HSR redundancy
- MRP redundancy
- IE/PB Link
- Shared device
- Line depth

Figure 87 shows the backbone of the test network, the different networking technologies and/or structures are all connected to the “X208-11” switch. See the detailed overview in the attached PowerPoint document.

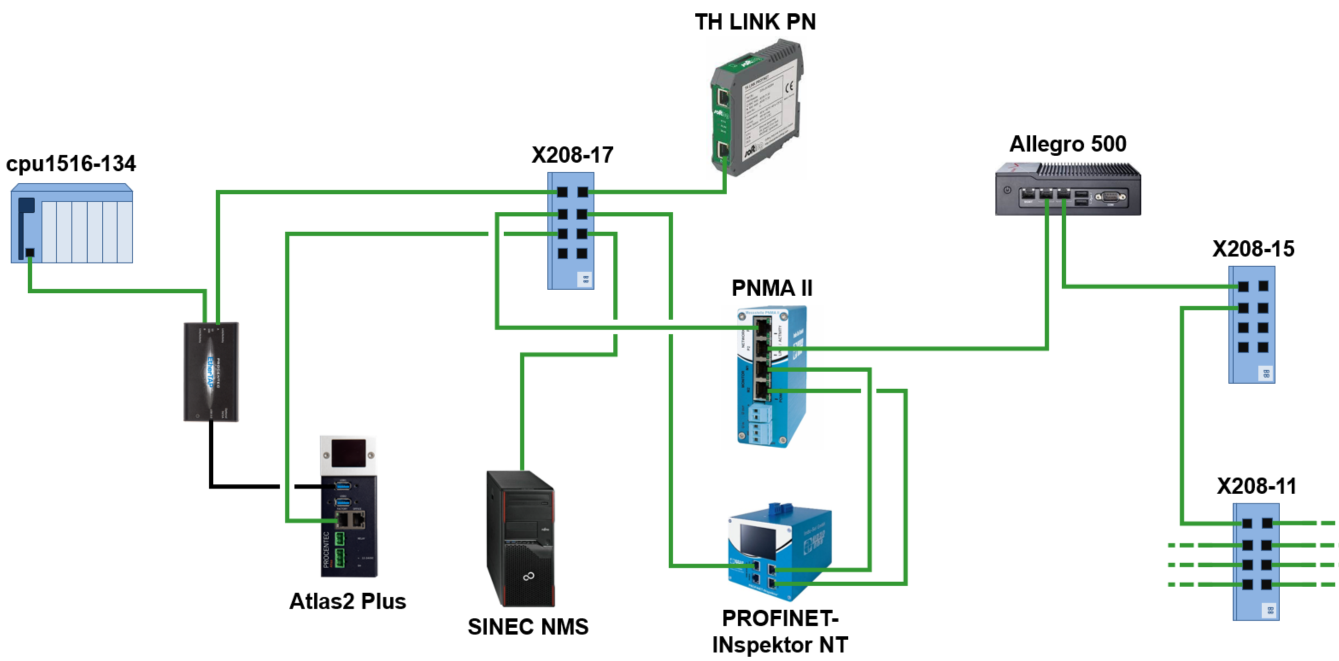


Figure 205: Backbone of the test network