10 Mb/s Single Twisted Pair Ethernet

Noise Environment for PHY Proposal Evaluation

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Noise in Process Automation Applications

- In process automation applications two different types of noise are common:
  - Impulse noise, typically coming from switching events of high power loads.
  - Continuous noise, typically coming from AC lines, inverters for speed controlled motors and switch mode power supplies within the cabinet.
- Impulse noise is only happening infrequently for short time durations in the range of some microseconds, occurring in packets up to a few milliseconds (e.g. due to contact bounce effects).
  - During an impulse noise event, which typically comes infrequently, it is accepted that a data telegram is being disturbed.
  - Nevertheless the link may not drop.
- Continuous noise can happen over a longer period of time, e.g. as long as a pump or agitator is operated.
  - Using unregulated actuators the frequency range will be mains frequency in the range of 50/60 Hz resp. 100/120 Hz when taking rectification effects into account.
  - Using electronic inverters, the frequency range can go up to about 500/1000 Hz.
  - Depending on the used inverters they could also produce harmonics in the range of up to about 100 kHz or even higher on the cables to the motor (in this case shielded power cables are being used).
  - Industrial switch mode power supplies typically operate within a frequency range between 40 and 150 kHz.
  - Depending on the load conditions the amplitude and frequency of such noise may change over time.
- Doing EMC tests with e.g. 10/100 Mbit/s Ethernet ports conducted immunity and ESD are the most critical tests.

Noise in Process Automation Applications

- Good installation practice in process automation applications recommends to maximize the distance between communication lines and power lines to prevent signal disturbance.
- As a guideline for Profibus DP installations the recommendation is to keep 200 mm minimum distance between a Profibus DP communication line and an unshielded power line.
- When using a separation strip consisting of aluminium the distance may be reduced to 100 mm, when using a separation strip consisting of steel the distance may be reduced to 50 mm.
- There are two possible shielding options:
  - Hard grounding of both ends of the cable shield.
  - Hard grounding of one end of the cable shield and capacitive grounding (typ. 4.7 nF) of the other side of the cable shield.
- A third shielding option, grounding the shield only on one side and leaving the other end of the cable shield open, like done in today's fieldbus applications, seems to be impractical for high frequency communication signals.

Insertion Loss Temperature Influence

- The possible noise tolerance for impulsive or continuous disturbers depends mainly on the transmit signal amplitudes and the insertion loss of the cable.
- Current preliminary link segment definitions do not include the influence of elevated temperatures, which can occur in industrial environments.
- At elevated temperatures (e.g. 50 °C and 70 °C) the insertion loss of a link segment gets higher compared to an ambient temperature of 20 °C.
- Assuming that the skin effect is having the biggest influence on the insertion loss for the given frequency range, the insertion loss is proportional to the resistance of the cable.
- Therefore the insertion loss can be calculated depending on the temperature:

$$R_{cable} = R_{cable,20°C} \cdot \left(1 + 0.0041\,\frac{1}{K} \cdot (T_{amb} - 20\,°C)\right)$$

$$IL\,[db] = IL_{20\,°C} + 20 \cdot log\left(1 + 0.0041\frac{1}{K} \cdot (T_{amb} - 20\,°C)\right)$$

Insertion Loss for 1000 m Link Segments

- Worst-Case Model: IL [dB] = 10 * (1.23 * SQRT(f/MHz) + 0.01 * f/MHz + 0.2 / SQRT(f/MHz))
  + 10 * 0.015 * SQRT(f/MHz)

- The following table gives the typical insertion loss for different long distance (1000 m) link segment types at different temperatures and also the values for the preliminary worst-case link segment model (assuming the same temperature behavior) at a frequency of 3.75 MHz:

Link Segment Type	20 °C	50 °C	70 °C
AWG18/1	22.4 dB	23.4 dB	24.0 dB
AWG18/7	24.7 dB	25.7 dB	26.3 dB
AWG16/7	20.3 dB	21.3 dB	21.9 dB
AWG14/7	18.1 dB	19.1 dB	19.7 dB
worst-case model	25.5 dB	26.5 dB	27.1 dB

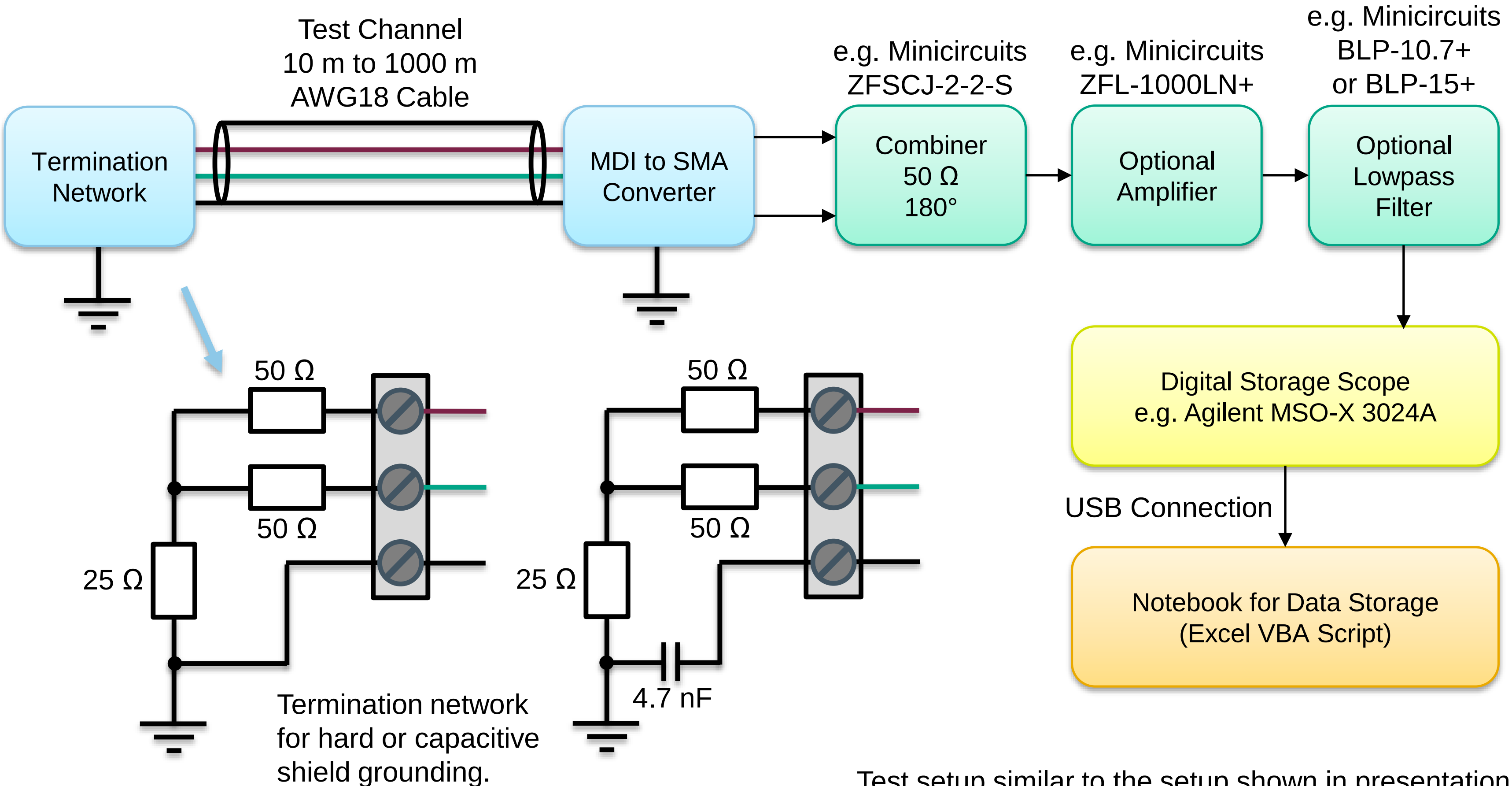
Insertion Loss for 200 m Link Segments

- Worst-Case Model: IL [dB] = 2 * (1.23 * SQRT(f/MHz) + 0.01 * f/MHz + 0.2 / SQRT(f/MHz))
  + 4 * 0.015 * SQRT(f/MHz)

- For a short distance link segment (200 m), the resulting insertion loss is much lower (only about 5.2 dB for a worst-case link segment with 4 inline connectors at 70 °C).
- Even, if the signal amplitude is reduced to 1 V_{pp} (-0.5 V, 0 V, +0.5 V) due to intrinsic safety requirements, the remaining signal amplitude at the receive side is still about 15.9 dB (6 times) higher than for a worst-case long distance 1000 m link segment.
- This will allow for a significantly higher noise immunity.

Impulsive Noise Measurement

- To be able to measure ambient noise, which is being coupled to a shielded 2-wire cable, the following test setup is being suggested:



Test setup similar to the setup shown in presentation [„Impulse Noise Measurement Test Setup“](#).

Impulsive Noise Measurement

- Related to the suggested measurement setup there are some questions:
  - What impedance is being expected between cable and ground?
  - Would 50 ohms common mode impedance to earth be better or 150 ohms as it is being used as terminating impedance in CDNs for EMC testing?
  - Does it make sense to measure both termination networks (with hard and capacitive shield coupling) or is it enough to measure with the capacitively coupled termination network only?
  - What would be a suitable cable length (typical link segment could be 10 m to 1000 m)?

- What is the requirement for the signal integrity, if impulsive noise is present?
  - In most industrial applications impulsive noise is occurring infrequently.
  - ESD is expected to be much less of an issue than in office environments (especially in hazardous areas measures must be taken to prevent ESD from happening, but also in normal process industry environments special safety measures are taken to reduce ESD events (e.g. safety shoes, clothing etc.)
  - Currently during EFT or ESD events it is accepted, that a data transmission is being corrupted and that a retransmit must be done.
  - In industrial protocols up to two retransmissions (three transmissions in total) are allowed before an alarm is being activated.
  - What will be the requirements for the BER under the occurrence of EFT or ESD noise?
  - If there is need to keep the BER at the same level under EFT or ESD noise, how long will be the noise period, which needs to be tolerated?
  - Which noise levels need to be tolerated?

Radiated Noise from RF Transmitters

Aggressor	FM Radio	VHF/UHF TV	Mobile Phone	Two-Way Radios	Amateur Radio
EIRP	100 kW	1000 kW	2 W	5 W	1500 W
Distance	300 m	500 m	0.3 m	0.3 m	10 m
Frequency	87.5 - 108 MHz	VHF 54 - 88 MHz, 174 - 216 MHz UHF 540 - 800 MHz	LTE: 746 – 793 MHz GSM: 824 – 960 MHz 850 MHz 900 MHz 1800 MHz 2100 MHz	151 MHz, 461 - 468MHz	LF to EHF: 28 - 29.7 MHz 50 - 54 MHz 144 MHz, 220 MHz, 420 - 450 MHz
Field Strength	6 V/m	11 V/m	26 V/m	40 V/m	21 V/m

- Values from presentation „Potential Broadband RFI In UHF Band".
- All these radio transmitters operate in a much higher frequency range compared to the expected signal frequency range for the 10 Mbit/s transmission.
- FM radio and VHF/UHF television transmissions are from the field strength point of view similar to the values tested during EMC testing so that this should be covered by the testing.
- In industrial applications the maintenance personnel is aware of the high field strength of mobile phones or two-way radios (placing them near to several devices will cause them to fail or to deliver wrong measurement values).
- Therefore all these noise sources should be covered by EMC testing.

Radiated Noise from RF Transmitters

- Other low power noise sources could be:
  - WLAN networks (2.4 GHz and 5 GHz) with an EIRP of 100 mW (indoor) to 1000 mW (outdoor).
  - Bluetooth (2.4 GHz) with an EIRP of 100 mW.
  - DECT (1880 to 1900 MHz) with an EIRP of 250 mW.
  - These wireless devices should not cause significant disturbances (at least if some distance is kept).

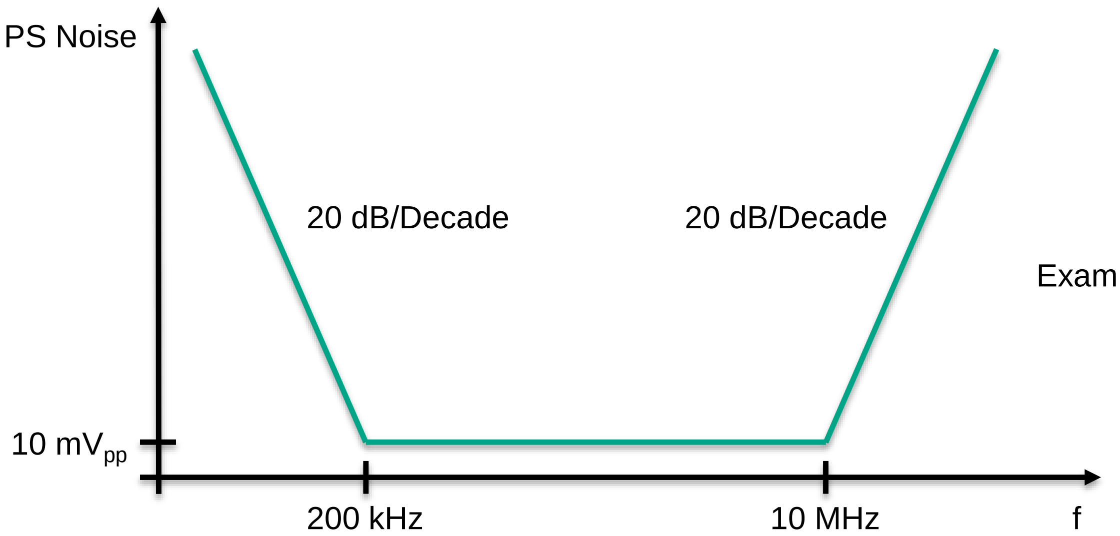
- Within the signal frequency range one significant source of noise could be the AM broadcast radio band (526.5 - 1606.5 kHz in Europe, 530 - 1720 kHz in America).
- Typical transmit power is in the range of several 100 kW (the highest power AM broadcast transmitter in Europe has a transmit power of 2000 kW).
- The bandwidth of an AM broadcast transmitter is quite narrow (9 kHz in Europe and 10 kHz in America).
- The expectation is to have a similar field strength as terrestrial television broadcast stations (but at a much lower bandwidth).

- Is there experience from other applications, e.g. DSL technologies, what influence such transmitters have on the communication?

Power Supply Noise Sources

- One significant source of noise, especially in higher complexity devices like a field switch, is noise coming from the main power supply and several auxiliary power supplies.
- The main power supply typically operates between 40 and 150 kHz, while the point of load regulators typically work with switching frequencies between 200 kHz and above 1 MHz.
- All these power supplies produce some kind of ripple and also high frequency harmonics.

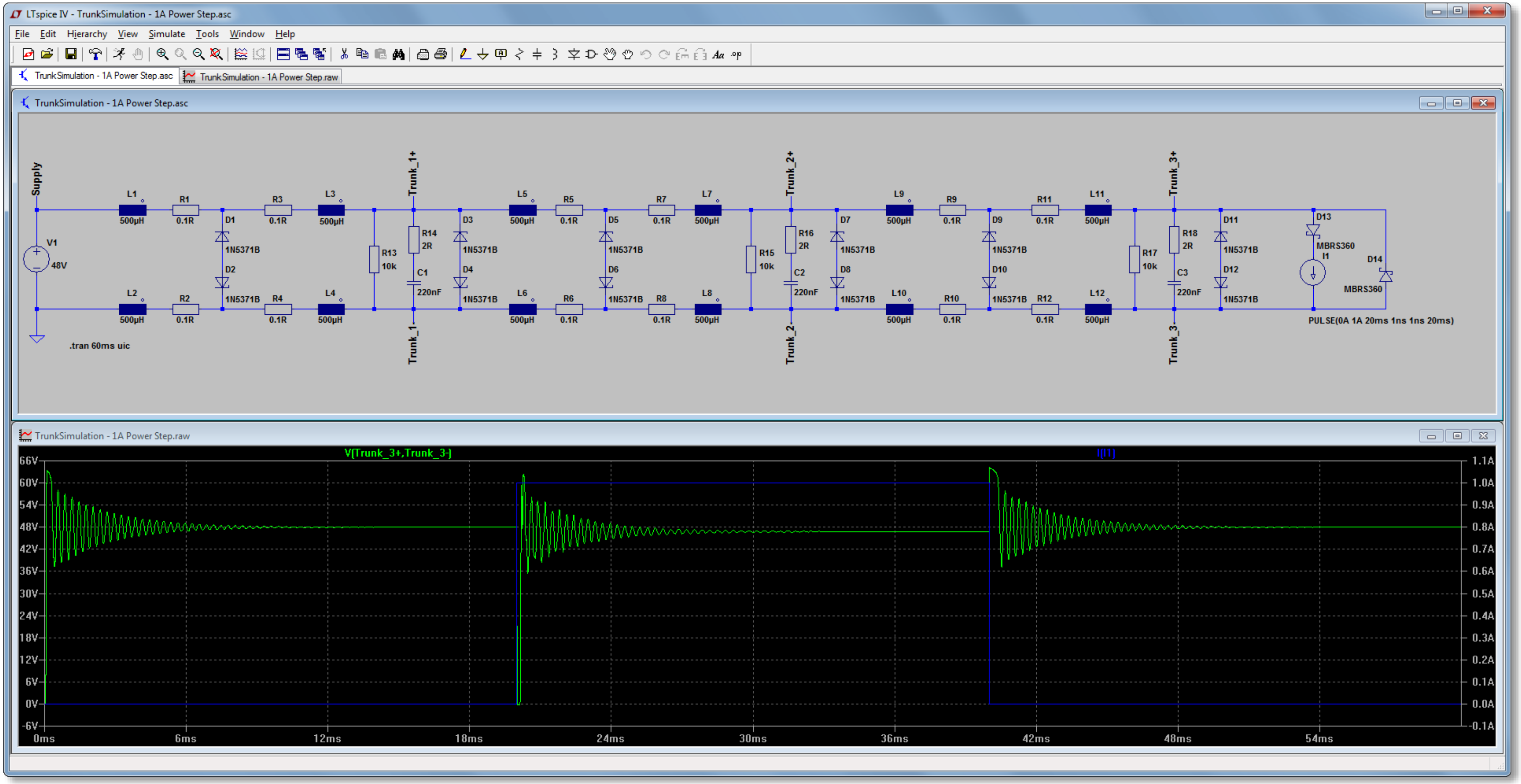
- To allow to have power and communication on the same two wires some kind of limit curve for the power supply noise needs to be defined, so that the communication on the link segment is not being disturbed by the injected power supply noise:



Example for a power supply noise limit curve.

Power Impulse Noise Sources

- In a two wire system providing communication and power over the same two wires, changes in the power consumption will lead to high impulse noise levels with a duration of several milliseconds.
- A disturbance of the communication is allowed, but no link loss.



Fieldbus Noise Immunity

- According to the current fieldbus specification a field device may not respond to a signal level below 75 mV_{pp} and must respond to a communication signal level above 150 mV_{pp}.
- Therefore noise with an amplitude above 75 mV_{pp} may disturb fieldbus communication.
  - This does typically not happen by significantly disturbing the communication signal itself, which is having a much higher signal amplitude than 75 mV_{pp}, even using long cables.
  - Mainly the communication on the bus is being influenced by disturbing the idle timers due to a noise event, which is higher than the sense level of the receiver.
  - In this case a field device has the opinion that another device is transmitting and therefore does not start its own transmission, running in communication timeouts.
- Nevertheless in most fieldbus applications the communication is working without issues and therefore it could be assumed, that the given in-band noise tolerance of at least 75 mV_{pp} is suitable for industrial fieldbus applications using today's installation and wiring practice.
- Fieldbus segments are mainly influenced by external noise source coming from power applications.
- The noise influence of nearby fieldbus segments is not significant, taking the low signal amplitude of about 1 V_{pp} and a coupling attenuation of at least 50 to 60 dB into account.
- The frequency band for fieldbus applications is roughly between 1 kHz and 100 kHz (the standard shows 7.8 kHz to 39 kHz, but most implementations have a wider frequency range).

Ethernet Noise Immunity

- The measurements provided in the "PHY Ideas" presentation show a noise immunity of about 60 mV_{pp} at the communication frequency (3.75 MHz, for other frequencies the noise immunity is higher) for a typical AWG18/1 fieldbus cable (1032 m) with an insertion loss of the link segment of 22.7 dB.

- Assuming, that a noise immunity of 75 mV_{pp} is suitable for an industrial environment, at least in a frequency range below about 100 kHz and taking the intended cable and the actual installation practice into account, it is assumed, and this still needs to be validated, that also for the 10SPE communication system, operating at a significant higher frequency range, the maximum possible cable length for an equivalent noise immunity could be estimated.

- Assuming a signal amplitude of 2 V_{pp} (+1 V, 0 V, -1 V) using a 3-PAM and taking into account, that an insertion loss of 22.7 dB @ 3.75 MHz leads to a noise immunity of approx. 60 mV_{pp}, a noise immunity of 75 mV_{pp} is assumed to be reached for a maximum insertion loss of:

$$IL\ [dB] = 22.7\ dB\ - 20\ \cdot \log\left(\frac{75\ mV_{pp}}{60\ mV_{pp}}\right) = 20.8\ dB\ @\ 3.75\ MHz$$

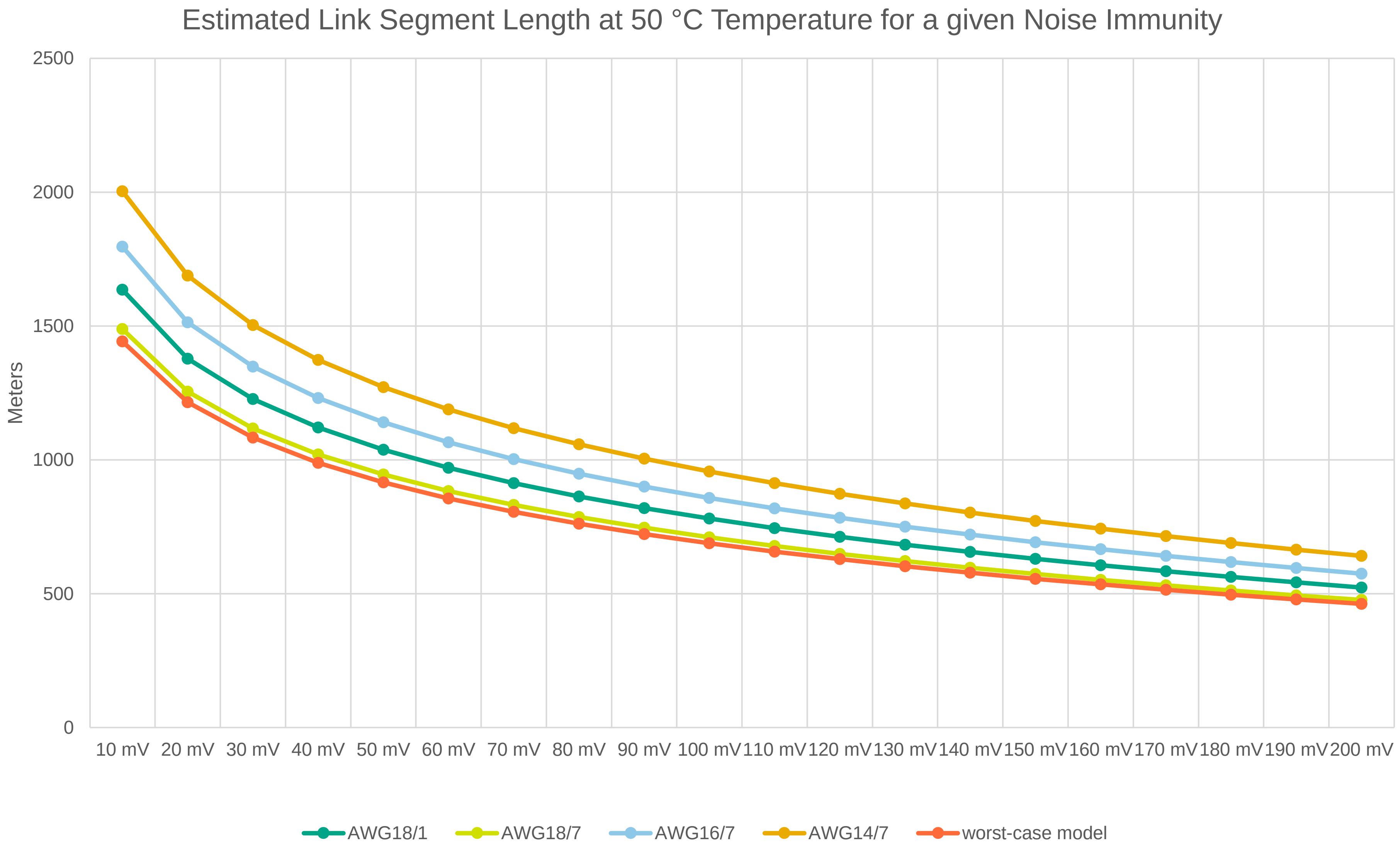
Maximum possible Link Segment Length

- Comparing the insertion loss values with the reference value of 20.8 dB, depending on the cable type for the different link segments, the following length is possible for different ambient temperatures:

Link Segment Type	20 °C	50 °C	70 °C
AWG18/1	927 m	887 m	865 m
AWG18/7	841 m	808 m	789 m
AWG16/7	1023 m	975 m	948 m
AWG14/7	1148 m	1087 m	1053 m
worst-case model	814 m	783 m	765 m

- As it can be seen from the table, depending on the wire diameter similar noise immunity as for today's fieldbus can be assumed for a cable length in the range between 800 and 1000 m.
- For the worst-case link segment model nevertheless a noise immunity of about 75 mV_{pp} can only be reached for a maximum cable length of about 800 m.
- For the powered long distance link segments the larger wire diameters will be used to reduce the power losses, in parallel also reducing the insertion loss of the cable.
- Nevertheless for a non-powered link segment typically AWG18/1 cabling will be used.

Noise Immunity vs. Cable Length



Possible Improvements

- In principle the following possibilities exist to improve the system's noise tolerance:
  - Increasing the transmit signal amplitude for the long distance link.
  - Reducing the insertion loss of the cable for the long distance link.
  - Adding of some kind of forward error correction at least for the long distance link (if necessary).

- Moderately increasing the signal amplitude on the long distance link (e. g. from 2 V_{pp} signal level to 2.4 V_{pp} signal level) helps compensating for the additional insertion loss caused by an elevated cable temperature.
- Using thicker cables on the long distance links, especially at cable length above 800 m, also helps increasing the noise immunity.
- Adding a FEC could help to improve the impulsive noise tolerance.
  - Depending on the impulse noise disturbance length, FEC could add a significant amount of latency (depending on the block code size and chosen overhead).
  - Expectation is, that implementing a FEC could lead up to approx. 4 dB coding gain (improved noise tolerance for impulsive noise) and therefore has a similar effect than using thicker cables as described above.
  - Currently it is not known, if a FEC is necessary or not (and this will have a significant impact on the PHY design).
  - Idea is to use an evaluation board (see other presentation) for doing practical tests, if a system without FEC provides acceptable noise margin or, if FEC needs to be added to pass the relevant tests.

Open Questions

- Impulsive noise measurement
  - Improvements on the suggested measurement method?
  - Who can help doing measurements in different environments?
- Radiated noise from RF transmitters
  - Is there any experience with AM broadband radio transmitter interference?
  - Even, if the output power is comparable with VHF/UHF TV broadband transmitters, the bandwidth of the transmitted signals is much smaller, is this expected to have a negative impact?
  - AM broadband transmitters have a declining relevance in Europe, how is this in America?
  - Do we need to assume an industrial plant nearby a high power AM broadband transmitter?
- Power Supply noise sources
  - Is it suitable to limit the power supply noise to 10 mV_{pp} in-band noise (200 kHz to 10 MHz) over the industrial temperature range (-40 °C to 70 °C)?
- Continuous noise immunity
  - Is it suitable to transfer the noise immunity levels of fieldbus applications to the 10 Mbit/s Ethernet application?
  - What expectations of continuous noise do we have in a frequency range between 200 kHz and 10 MHz?

Thank You