IEEE 802.3 SPEP2P SG

Higher Speed Upgrade Path for Process Automation (Ethernet-APL)

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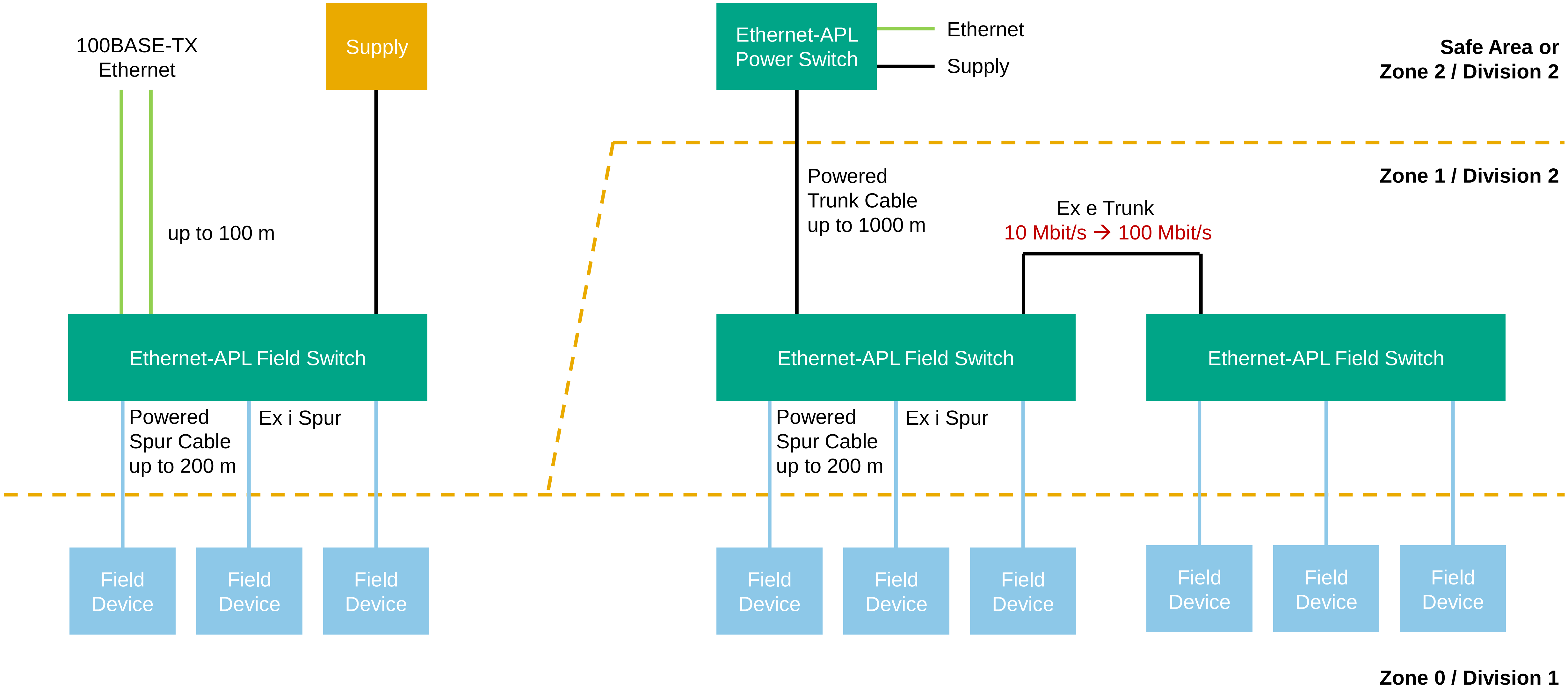
Current Situation in Process Industries

- Ethernet-APL is the agreed technology for the migration of the process industry to Ethernet in the field.
- Ethernet-APL defined (back in 2017) two phases:
  - **Phase 1: 10 MBit/s** communication, using 10BASE-T1L with additive power, technology launch during “Achema Pulse” online Event on July 15th/16th 2021, having near term market availability, **up to 1000 m trunk, up to 200 m spur** length.
  - **Phase 2: 100 MBit/s** communication for future projects having higher bandwidth requirements, **up to 500 m trunk, up to 200 m spur** length.
- Currently allows for up to 1000 m trunk reach and up to 200 m spur reach @ 10 Mbit/s full-duplex communication.
- Currently provides power up to 57.5 W on trunk and 500 mW to 1 W on spurs (depending on the power profile).
- Next revision is expected to provide up to 92 W on trunk power ports and may support 1 W to 2 W on spur power ports.
- Also suitable for intrinsically safe communication on powered spurs and unpowered trunks.
- As there are many Ethernet-APL 10 MBit/s field devices connected to a single Ethernet-APL trunk, especially for the trunk communication a higher communication speed of 100 Mbit/s is desirable in the future, while it can be expected that most of the devices will continue to run at 10 Mbit/s.
- **For a high market acceptance the goal should be to get as close as technically feasible to the topology limits and installation practices, that are currently introduced into the market for the 10 MBit/s (10BASE-T1L based) version to allow an easy future migration and interoperability path.**

Ethernet-APL Phase 1 (10 MBit/s) Topologies



Upgrade Path for 10BASE-T1L and Ethernet-APL

- For Ethernet-APL the target for a trunk segment length at 100 MBit/s is 500 m.
- Nevertheless for an easy upgrade path for existing 10BASE-T1L link segments it is suggested to **target the already existing link segment defined in 10BASE-T1L for the 1.0 V_{pp} mode** (supporting approx. 590 m), with an increased upper frequency limit.
- This would allow an easy path from existing 10BASE-T1L installations (most of them expected to run in the mandatory 1.0 V_{pp} operating mode) to higher speeds.
- Support the use of IEC 61156-13 and IEC 61156-14 cables (see later), with the option to reuse existing Fieldbus Type A cables acc. to IEC 61158-2, MAU types 1 and 3.
- Allow usage of screw terminal/spring terminal connectors, if technically feasible (important for broad market acceptance in process automation, see next slide).
- Support intrinsic safety using the 2-WISE (IEC TS 60079-47) intrinsic safety concept:
  - For unpowered trunks
  - For unpowered spurs
  - For powered spurs, if technically feasible

Ethernet-APL Products (mostly using Screw Terminals)

Source: The APL Project

Cables and Link Segment

Cables and Link Segment

- 10BASE-T1L re-uses IEC61158-2 Fieldbus Type A, MAU type 1 and 3 cables.
- It is suggested to target the same cables for the 100 MBit/s system, if technical feasible.
- Upcoming cable standards IEC 61156-13 and IEC 61156-14 will provide specifications for AWG18 cables supporting the 10BASE-T1L link segment for frequencies up to 20 MHz (the IL curves are expected to be identical to the 802.3cg 2.4 V_{pp} operating mode link segment for a 1000 m cable, RL limits are expected to be better than the definitions in 802.3cg, characteristic impedance is specified to be ±15 % @ 20 MHz instead of ±20 % over the full frequency range used for the RL definitions in IEEE802.3cg).
- APL defines cable categories for requalification of existing cables, see next page.
- Further slides show IL and RL measurements for a 1032 m (the cable used for testing the 10BASE-T1L early evaluation boards) and a 240 m (consisting of 2 x 120 m) long cable suitable for fieldbus and 10BASE-T1L applications for up to 100 MHz.
- For maximum compatibility, reusing the existing 10BASE-T1L link segment definitions for the 1.0 V_{pp} operating mode and extension to a higher frequency range up to 60 MHz is suggested.

Cables and Link Segment

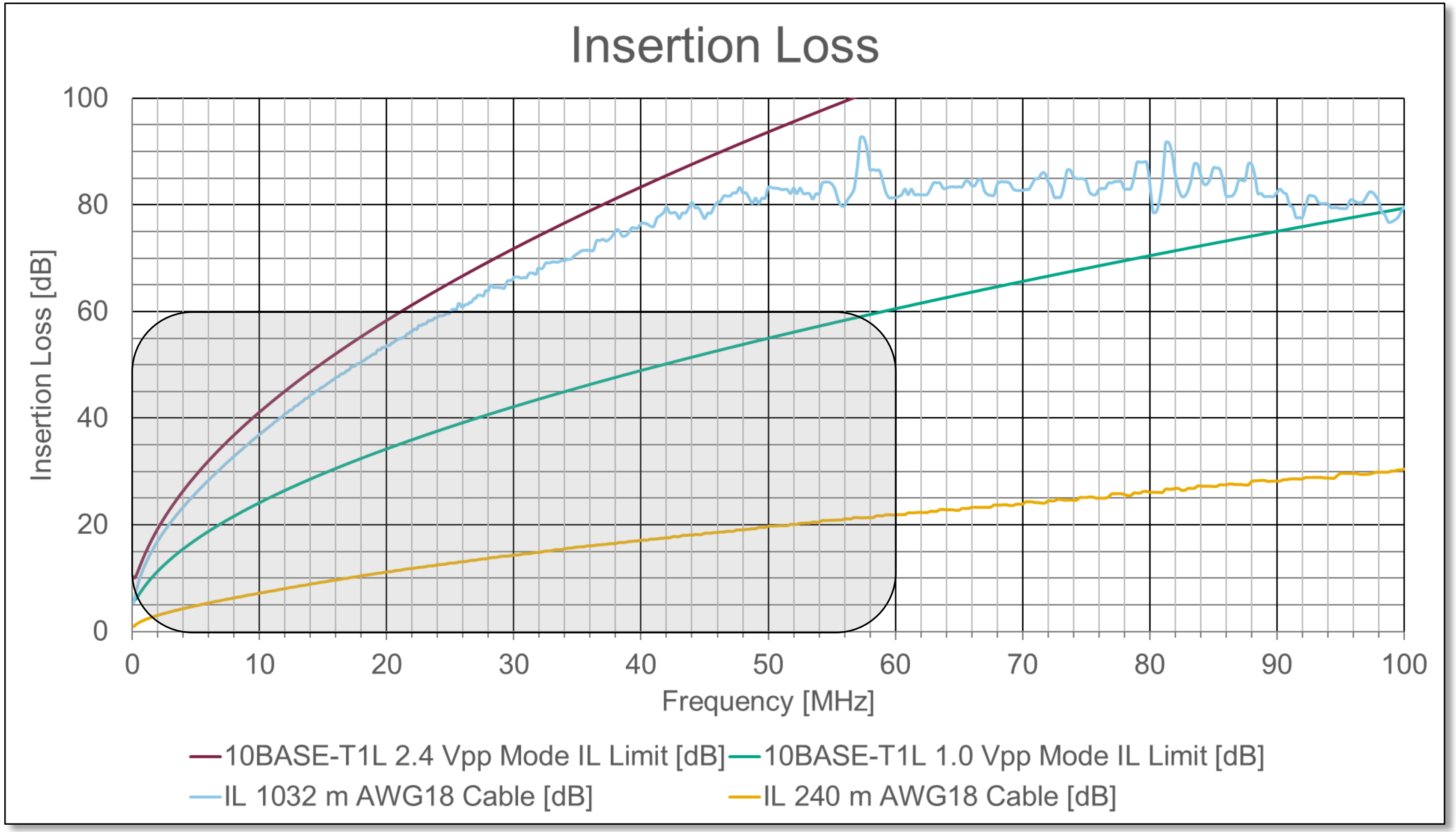
- The Ethernet-APL Installation Guideline (see https://www.ethernet-apl.org/library) in Table 4-3 provides the limits for suitable Ethernet-APL cables.
- There are four different categories defined, depending on the attenuation of the used cable.
- RL and other parameters are identical for all Ethernet-APL cable categories.
- The RL is only specified for the cable, not the full segment.
- Therefore the expectation is, that for short link segments a 6 dB worse RL might be expected.

Table 4-3: Maximum allowed cable lengths and cable parameters according APL cable category

Parameter	APL cable category			
	I	II	III	IV
Maximum trunk cable length in m	250	500	750	1000
Maximum spur cable length in m	50	100	150	200
Coupling attenuation in dB	≥ 60 (*f* is frequency in MHz; 0.1 ≤ *f* ≤ 20)			
Cable return loss in dB	≥ 15 + 8 x *f* (*f* is frequency in MHz; 0.1 ≤ *f* ≤ 0.5)			
	≥ 19 (*f* is frequency in MHz; 0.5 ≤ *f* ≤ 20)			
Trunk cable insertion loss in dB	≤ 10 × (1.23 × √*f* + 0,01 × *f* + 0.2/√*f*) (*f* is frequency in MHz; 0.1 ≤ *f* ≤ 20)			
Spur cable insertion loss in dB	≤ 2 × (1.23 × √*f* + 0,01 × *f* + 0.2/√*f*) (*f* is frequency in MHz; 0.1 ≤ *f* ≤ 20)			
Cross talk in dB, (PSANEXT/PSAFEXT wire pair to wire pair) for multi core cables	≥ 60 (f is frequency in MHz; 0.1 ≤ f ≤ 20)			

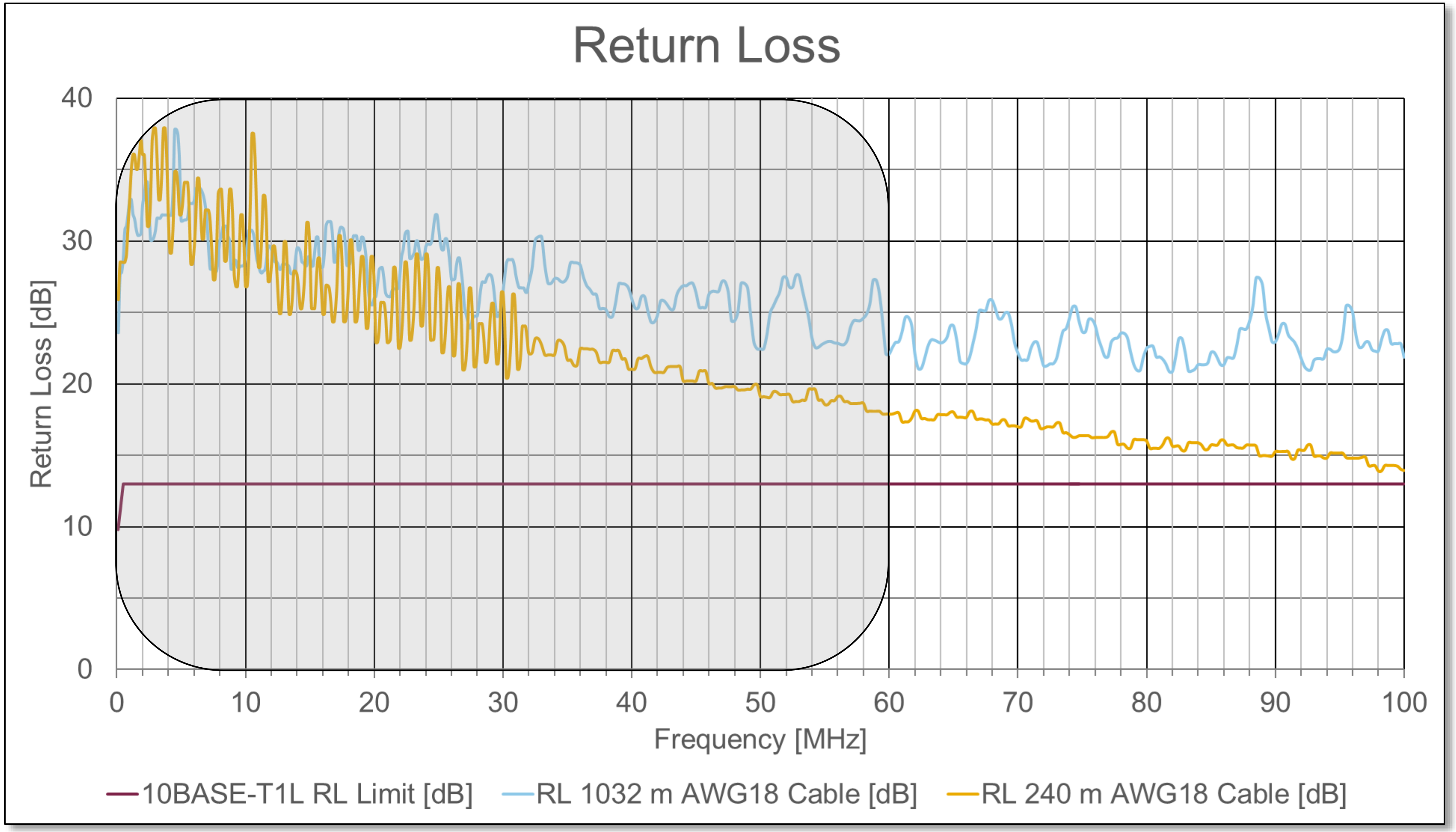
NOTE 1 The values in Table 4-3 apply for single pair and multi pair cables.
NOTE 2 Insertion loss and return loss shall be measured with a reference cable length of 500 m.
NOTE 3 The AC link segment requirements may also be verified using TIA SP1-1000 and ISO/IEC T1-A-1000 channel definitions, which might exclude IEC 61158 type A fieldbus cables from being compliant to these definitions.
NOTE 4 Depending on the APL cable category the maximum cable length is limited. This allows the use of higher insertion loss cables, which therefore can only support a lower maximum APL segment length while still fulfilling all requirements of this table.
NOTE 5 The cable return loss limit curve is 6 dB above the IEEE802.3cg limit curve taking multiple additive signal reflections occurring at short cable lengths into account.
NOTE 6 For powered APL segments, additionally the voltage drop over the cable has to be taken into account to determine the maximum supported cable length.

Insertion Loss of Fieldbus Type A Cables up to 100 MHz



- Measuring Fieldbus Type A cables suitable for 10BASE-T1L; also at higher frequencies the cables behave pretty well, above 30 MHz it seems that some small structural return loss is visible in the measurements.

Return Loss of Fieldbus Type A Cables up to 100 MHz



Below 32 MHz the frequency resolution of the VNA is 125 kHz, above 250 kHz.

- Measuring Fieldbus Type A cables suitable for 10BASE-T1L; also at higher frequencies the cables behave pretty well up to 30 - 40 MHz (6 dB reserve, so that the RL stays even at shorter link segments above the limit).

Suggested Target IL and RL Limits

Suggested Insertion Loss Limit:

$$Insertion\ Loss(f) \leq 5.9 \times \left(1.23 \times \sqrt{f} + 0.01 \times f + \frac{0.2}{\sqrt{f}}\right) dB\ with\ f\ in\ MHz;\ for\ 1\ MHz\ \leq f \leq 60\ MHz$$

- A link segment supporting both, 10BASE-T1L and the new 100 MBit/s standard, might use the same IL limits, but the limit curve has to already start at 100 kHz and then has to go up to 60 MHz.

- **Suggested Return Loss Limit:**

$$Return\ Loss(f) \geq 13\ dB\ for\ 1\ MHz\ \leq f \leq 60\ MHz$$

- A link segment supporting both, 10BASE-T1L and the new 100 MBit/s standard, might use the same RL limits, but the limit curve has to already start at 100 kHz (having a roll-off between 100 kHz and 500 kHz as defined for 10BASE-T1L) and then has to go up to 60 MHz.
- As the RL curves have just been measured for two different cables, especially related to the RL it might be necessary, to further reduce the RL limits for higher frequencies (e.g. in the 40 to 60 MHz range to e.g. 10 dB) to support more cables and a broader application space.

Power and Intrinsic Safety

Power related important Improvements

- Support hot-plugging of field switches on a powered trunk.
- Support powered redundant ring topologies on the trunk.
- Support loads needing fast current changes.

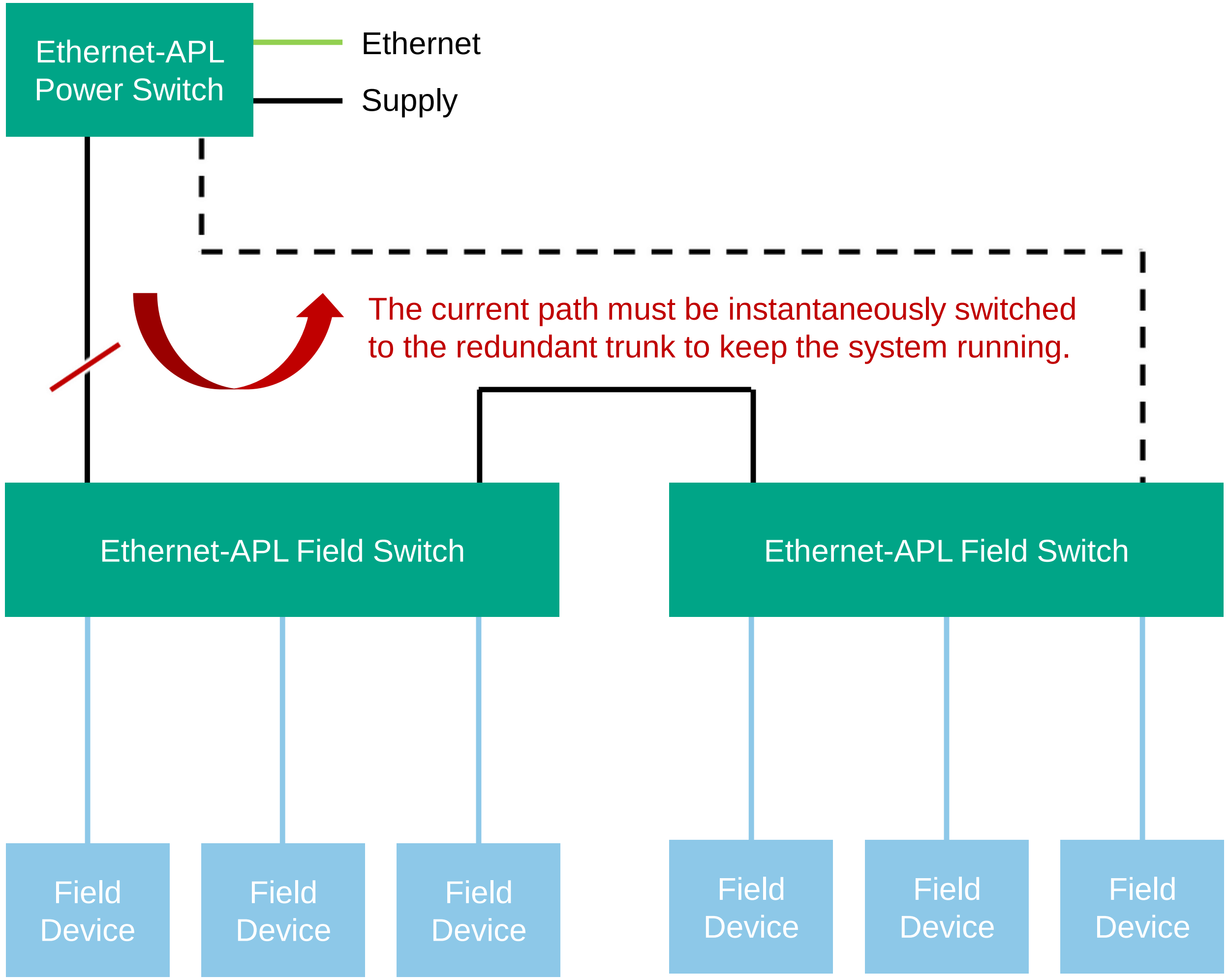
- Currently for Ethernet-APL it requires **significant efforts to keep the power consumption** of field devices and field switches **within the allowed current slew rates** so that the communication on the trunk is not disturbed or even interrupted (other than for PoE using PoDL all changes in the current consumption will be differentially visible on the link segment and can disturb the communication).

- Using PoDL power, the three requirements above can lead to a **significant differential mode disturbance** on the trunk segment, potentially dropping a running 10BASE-T1L link and doing a retraining.

- Therefore **powered redundant ring topologies** are currently technically challenging/impractical, but will be required in the future, especially when **increasing the communication speed and** thus **the number of** possible connected **field devices**.

Power related important Improvements

- For Ethernet-APL relevant disturbances are in the range of up to 2 A immediate change in current load (exceeding the PoDL di/dt slew rate limits), caused by e.g. disconnecting all but the first field switch in a daisy-chain topology or performing a redundancy switch-over in a ring topology at full segment load.
- The minimum requirement from an application perspective would be that after such a disturbance within a few milliseconds (target should be below 1-10 ms) the communication has to be back to normal operation.
- Best case would be that the communication is such robust against relevant power supply disturbances, that the BER could be kept even under such conditions.
- Likely measures need to be taken to allow the use of a higher pass filter with a relatively high cut-off frequency at the receiver side (using a PAM modulation with limited lower frequency content or even a passband modulation).

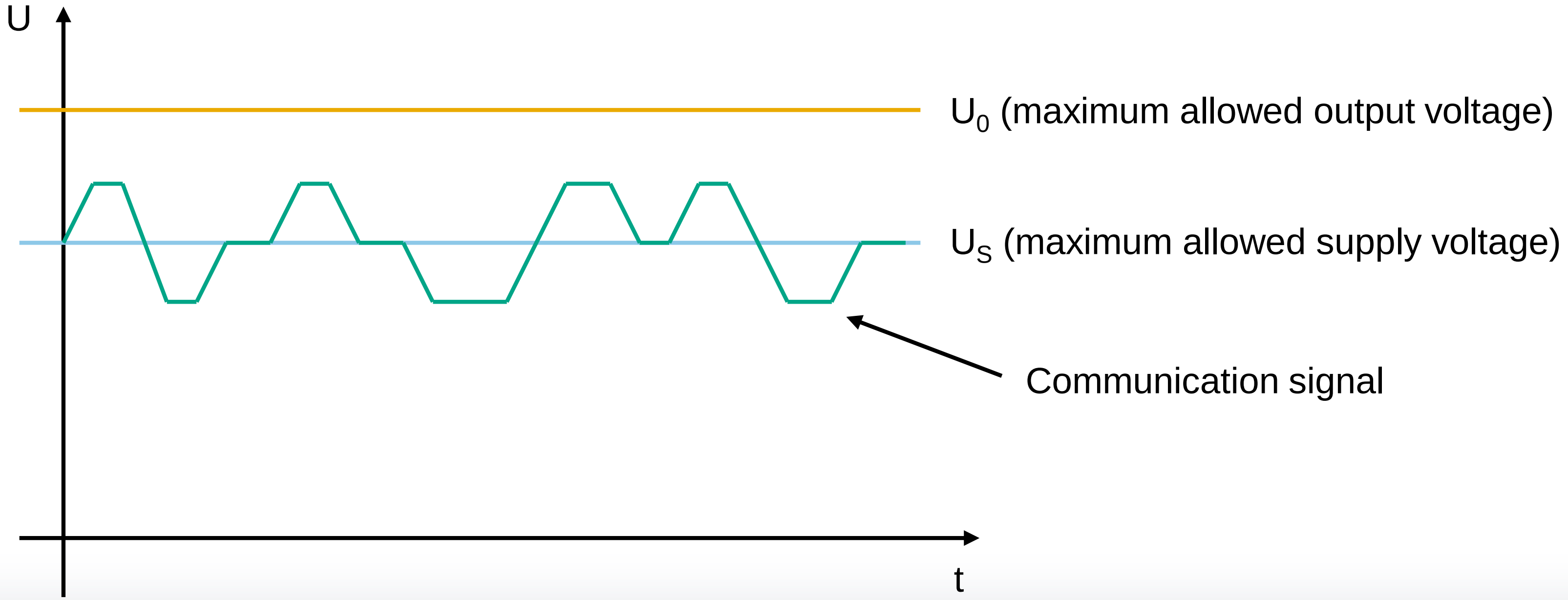


Intrinsic Safety

- Ethernet-APL currently supports power profiles for up to 500 mW (Ex ia) and up to 1 W (Ex ic).
- Future, more complex, enhancements may be expected to go up to 1 W (Ex ia) and 2 W (Ex ib).
- This is already pretty close to the limits of the ignition energies of a hydrogen gas atmosphere, so that no significant improvement is expected in the future, without e.g. going to pulsed power implementations, which theoretically could provide higher energies at a significantly higher complexity, but might interfere with the communication.
- Current Ethernet-APL prototype devices are running at 500 mW intrinsically safe power using an integrated 10BASE-T1L PHY with a power consumption of about 40 mW.
- Future devices with 250 mW to 300 mW power consumption seem to be technically feasible, if microcontrollers with adequately low power consumption will come up.
- Going from 10 MBit/s to 100 MBit/s, these numbers will significantly increase, as not only the PHY will require a higher power consumption, but also the microcontroller platform behind and the application itself.
- Therefore it will be one of the key questions, if a 1 W (or 2 W) power budget is enough to power intrinsically safe devices or if these devices require auxiliary power anyhow in the future.
- Likely answering this question will have one of the highest impacts on the planned PHY.

Intrinsic Safety

- For 10BASE-T1L a 4B3T line code has been chosen to limit the baseline wander at the price of a higher needed bandwidth.
- For intrinsically safe powered spurs this has a significant benefit, as the DC voltage and thus the available power could be increased.
- On the other side, it increased the required symbol rate assuming a PAM-3 signal from the theoretical minimum of about 6.31 MSymbols/s to 7.5 MSymbols/s (18.8 % increase), which might not be affordable when targeting maximum reach at 100 MBit/s.



Intrinsic Safety

- To fulfil the requirements for powered intrinsically safe spurs, for 10BASE-T1L the 1.0 V_{pp} operating mode with a limited transmit voltage has been introduced, limiting the reach within this mode to about 60 % of the reach in the 2.4 V_{pp} operating mode.
- If only unpowered intrinsically safe spurs would need to be supported, also on the spur side the same transmit amplitude as for the trunk could be used, as in such a case, the overlaid communication signal of both PHYs together (plus possible reflections) could use the full range up to the allowed maximum output voltage (depending on how precise the clamping circuit would work).
- Thus even a higher transmit voltage (not as much as in DSL systems, but e.g. going up to 4 V_{pp}) could be used having the possibility to use a modulation scheme with e.g. higher PAM levels and thus being able to reduce the needed bandwidth, being able to increase the reach and allowing simple low speed connectors and existing cables.
- If powered intrinsically safe spur applications are required, it might be necessary to add a different modulation scheme and/or signal amplitude for supporting these applications.

Other Topics

Auto-Negotiation

- Providing a possible upgrade path to 10BASE-T1L in the process automation world, Auto-Negotiation between 10BASE-T1L and the upcoming standard is required.
- Clause 98 Auto-Negotiation provides two different speeds:
  - 16.666 MSymbols/s DME coded (16.666 MHz Nyquist) optimized for short reach, high speed AN.
  - 625 kSymbols/s DME coded (625 kHz Nyquist) optimized for long reach, low speed AN.
- There are three different scenarios:
  - Having a combined 10BASE-T1L and 100 MBit/s long reach system, best and easy way to achieve Auto-Negotiation is to use low speed AN, as the power coupling network and link segment both support low speed AN.
  - For ports only supporting the new 100 MBit/s PHY, there are space and cost savings, if the power coupling network is only designed for that speed. In such a case there is no clear preference going for low speed or high speed AN. For low speed AN, due to a significant BLW, the AN receiver gets more complex and will likely need correlation for page delimiter detection and BLW correction. For high speed AN the IL at Nyquist might already go up to 30 dB, which again would require correlation for delimiter detection and adaptive equalization within the AN receiver.
  - Negotiating with the existing short reach PHYs only supports high speed AN, thus there will be need for correlation and equalization within the AN receiver circuit, if the same speed should be used for long reach AN applications.
- Anyhow, if high speed AN is expected to be used for long reach applications, the timing parameters will need to be adapted due to the additional latencies across the cable.
- If both AN speeds have to be supported, the AN speed toggling algorithm introduced in 802.3cg could be used.

Modulation

- Most critical requirements related to the modulation are the following topics:
  - Reduce the needed bandwidth compared to 100BASE-T1 to allow topologies and installation practices as similar as possible compared to 10BASE-T1L at a minimum reach of about 500 m.
  - Handle disturbances coming from PoDL supply circuits in daisy-chain and redundant ring topologies.
  - Tolerate a comparable amount of external noise at the receiver in harsh EMC environments in relation to 10BASE-T1L.
- This might end up in a PAM modulation with the need for an adequate FEC and also an adequate clock recovery circuit, being able to handle the differential mode power supply disturbances.
- Alternatively using a passband modulation to allow cutting of the low frequency disturbances coming from the power supply might be an option.
- When looking for a PAM modulation, likely a coded PAM-5 modulation (e.g. using a single lane of a GigE 1000BASE-T PHY or something similar running at a lower rate) might be a good choice, as a PAM-3 modulation as used for 10BASE-T1L would lead to higher than necessary bandwidth needs, especially for long reach applications.

Latency and FEC

- Most telegrams in process and factory automation applications will use pretty short 64 byte packets.
- At 100 Mbit/s speed 64 byte packets (72 byte including preamble and SFD) are transmitted within 5.76 µs.
- A typical low latency 100BASE-TX PHY e.g. adds up to 1 µs latency.
- In a low latency store-and-forward topology this results in less than 10 µs delay per switch node (less for cut-through switching).
- Such low latencies are likely not required in process automation, but are typically required in e.g. factory automation applications.
- Adding an FEC might add further latency, but will likely be required to compensate at least for a part of the higher insertion loss and/or use of a more efficient coding (e.g. PAM-5 instead of PAM-3 coding).
- A discussion is required, how much latency is acceptable for the different use cases and if for some low latency applications an operating mode with disabled FEC would be required (at the price of a reduced reach or noise immunity).

Suggested Objectives

Suggested Objectives 1/2

1. Preserve the IEEE 802.3/Ethernet frame format at the MAC client service interface.
2. Preserve minimum and maximum frame size of the current IEEE 802.3 standard.
3. Support a speed of 100 Mb/s at the MAC/PLS service interface.
4. Do not preclude meeting FCC and CISPR EMC requirements.
5. Support for optional single-pair Auto-Negotiation.
6. Support optional Energy Efficient Ethernet.
7. Support 100 Mb/s single-pair Ethernet operation in automotive environments (e.g. EMC, temperature).
8. Support 100 Mb/s single-pair Ethernet operation in industrial environments (e.g. EMC, temperature).
9. Do not preclude the ability to survive automotive and industrial fault conditions (e.g. shorts, over voltage, EMC, ISO16750).
10. Do not preclude working within an Intrinsically Safe device and system as defined in IEC 60079 for powered/unpowered link segments.

Suggested Objectives 2/2

11. Define performance characteristics for a link segment with a single balanced pair of conductors supporting up to 10 inline connectors for up to at least 500 m/590 m reach.
12. Define a PHY supporting point-to-point full-duplex operation over the 500 m/590 m link segment.
13. Support fast-startup operation using predetermined configurations which enables the time from power_on** = FALSE to a state capable of transmitting and receiving valid data to be less than 100 ms.
14. Maintain a bit error ratio (BER) at the MAC/PLS service interface of less than or equal to 10^{-10} on link segments up to at least 500 m/590 m).
15. Specify one or more optional power distribution techniques for use in conjunction with 100 Mb/s single-pair Ethernet PHYs over one or more of the defined single-pair segments.
16. Specify the required robustness levels and test criteria against disturbances coming from the optional power distribution technique, including powered daisy-chain and ring redundancy network topologies.
17. Optional objective for PHY latency and FEC.

Thank you!