IEEE 802.3 GT10MSPE Study Group

100BASE-T1L Reach and Connectors

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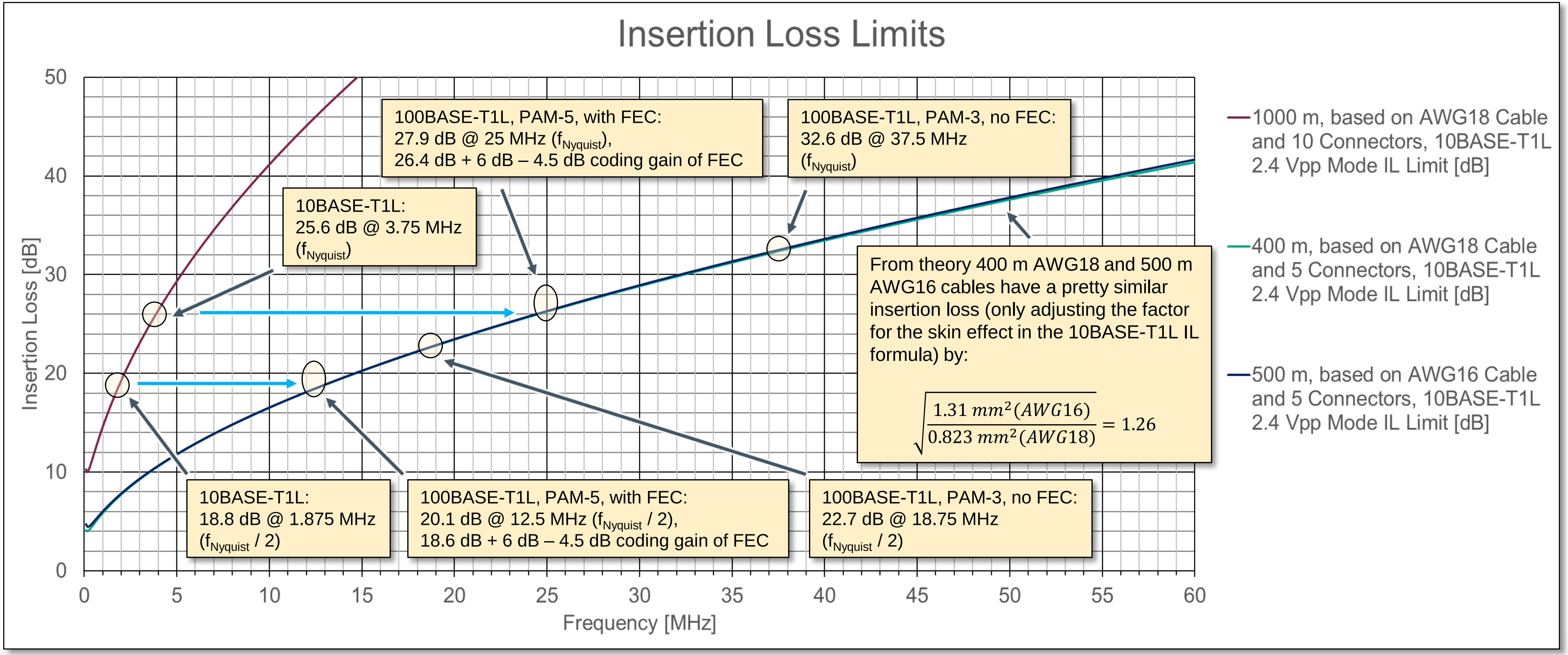
10BASE-T1L Upgrade Path to 100BASE-T1L

- Two possible ideas (potentially reducing the effort in developing a 100BASE-T1L PHY):
  - Use 10BASE-T1L PCS encoding and increase speed by a factor of 10.
  - Use 1000BASE-T PCS encoding, reduce speed per lane by a factor of 10 and multiplex the data of all four lanes into one single data stream.

	100BASE-T1L, PAM-3, based on 10BASE-T1L PCS	**100BASE-T1L, PAM-5, based on 1000BASE-T PCS**
Symbol rate	75 MBd	50 MBd
Nyquist frequency	37.5 MHz	25 MHz
FEC	No FEC	Trellis-Code
Latency	As no FEC is used, pretty low latency (< 1.5 µs, likely much less) seems to be possible.	State of the art 1000BASE-T PHYs have a latency of about 300 ns. At a 10 times lower rate, a latency between 3 µs and 5 µs seems to be possible. If a lower latency is necessary, a special operating mode would be required disabling the FEC.
SNR	Same SNR requirement as for 10BASE-T1L.	6 dB additional SNR margin required (partly compensated by 4-5 dB coding gain of Trellis-Code).
Noise environment	As higher signal frequencies are used, crosstalk at the connectors is expected to be more critical.	Lower signal frequencies are expected to provide a better overall system performance, as crosstalk is increasing at higher frequencies.
Disparity	Strictly controlled.	Not strictly controlled (uncritical for unpowered intrinsically safe link segments, but might be critical for powered intrinsically safe link segments, **needs decision, as it has a large impact**).

Insertion Loss Limits

- Also a question about which cable diameter (AWG18 or AWG16) is being used:



400 or 500 m?

- The reachable cable length significantly depends on the diameter of the cable being used.
- Using **500 m AWG16** cable leads to a pretty similar insertion loss as a **400 m AWG18** cable, taking the larger wire diameter and thus reduced attenuation caused by the skin effect into account.

- Ethernet-APL currently specifies the following power profile for a trunk:
  - 46 – 50 VDC output voltage at Power Switch
  - 1.25 A maximum supply current
  - 28.8 V minimum input voltage of Field Switch

- For a typical AWG16 cable, the loop resistance is 13.6 Ω for 500 m (at 20 °C).
- Running the 1.25 A over a 500 m AWG16 cable, the resulting voltage is 46 V - 13.6 Ω × 1.25 A = 29 V, just close to the 28.8 V minimum supply voltage, so e.g. calculating with a typical 1 A supply current, this fits well also at higher temperatures, where the cable resistance is higher.

- To keep the DC losses over the trunk cable low enough, for reaching 500 m, large diameter cables, like AWG16 will need to be used anyhow, as otherwise not enough power could be provided to the field switches.

400 or 500 m?

- Therefore it is suggested to use a **500 m length objective** to reflect, that it is expected and possible to run a 100BASE-T1L link up to this length and also adjust the link segment latency spec accordingly, but also assume a larger cable diameter and thus lower insertion loss per unit length when doing the insertion loss modelling of the link segment.

- This would result in approx.
  - 500 m reach using an AWG16 cable (this allows to meet the Ethernet-APL Phase 2 length requirement of 500 m).
  - 400 m reach using an AWG18 cable.
  - 200 m reach using an AWG24 cable (this would also support auxiliary powered devices for the 200 m spurs).

- Using a similar insertion loss limit as for a 400 m AWG18 cable allows to make the PHY development more reasonable (as it is not at the edge), but supporting up to 500 m link length, when using an AWG16 cable is important for a broad market acceptance within process industries.

- Would also need some input from cable experts related to e.g. structural return loss at higher frequencies for the larger cable diameters (one potential reason to increase the number of PAM levels to reduce the upper signal frequency).

Technical Feasibility

- Looking at the suggested insertion loss limits a 500 m AWG16 cable provides pretty much the same **insertion loss** at 12.5 MHz (**half Nyquist frequency** for a PAM-5 modulated 100BASE-T1L) than a 1000 m AWG18 cable at 1.875 MHz (half Nyquist frequency for 10BASE-T1L), in both cases **about 19 dB**.
- Due to the PAM-5 coding 6 dB additional margin are required, which can be partly compensated for by the Trellis-Code coding gain of 4 to 5 dB, thus a similar noise margin would be required, but at higher frequencies.
- At **Nyquist frequency** (25 MHz for 100BASE-T1L, PAM-5 vs. 3.75 MHz for 10BASE-T1L) the **insertion loss** is **about 26 dB** in both cases, but for a PAM-5 each level is 6 dB smaller compared to PAM-3. Thus for the ADC/DSP about **1 additional bit in the data path** would be required for the PAM-5 (e.g. needing a 9 bit ADC).
- Also the **noise environment** must at least provide the same margin as for 10BASE-T1L (but at higher frequencies, thus **crosstalk and noise environment get more important and need input from experts**).
- Most of the noise ingress in a 10BASE-T1L segment happens through the unshielded connectors.
- Thus providing better shielding or larger spacing between the connectors will significantly help.
- Just increasing the speed by factor of 10 of a 10BASE-T1L link would be another option, but would require the ADC and PHY running at a higher speed, thus consuming more energy and due to the higher signal frequencies making crosstalk more critical (especially in comparison to the higher insertion loss).

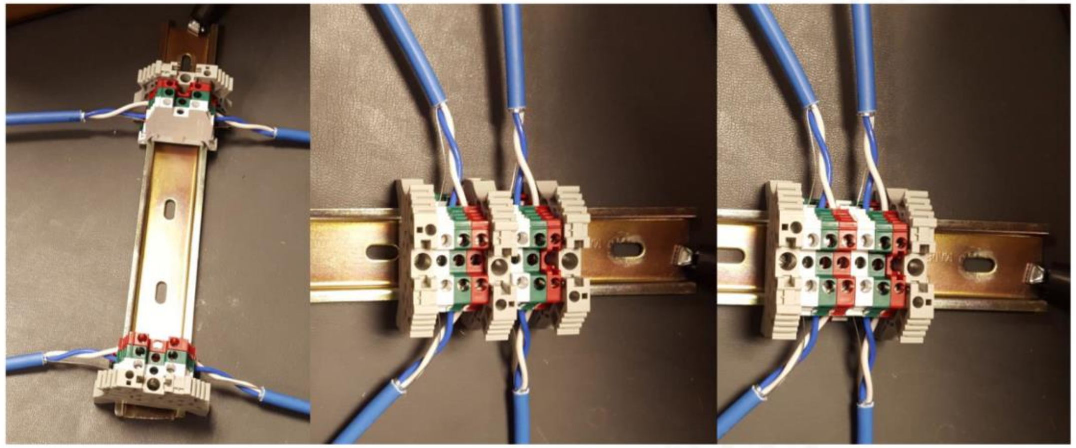
Connector Crosstalk Measurements

Excerpt from connector measurements presentation shown during Ethernet-APL meeting by Cameron Jones, image courtesy of Rockwell Automation:

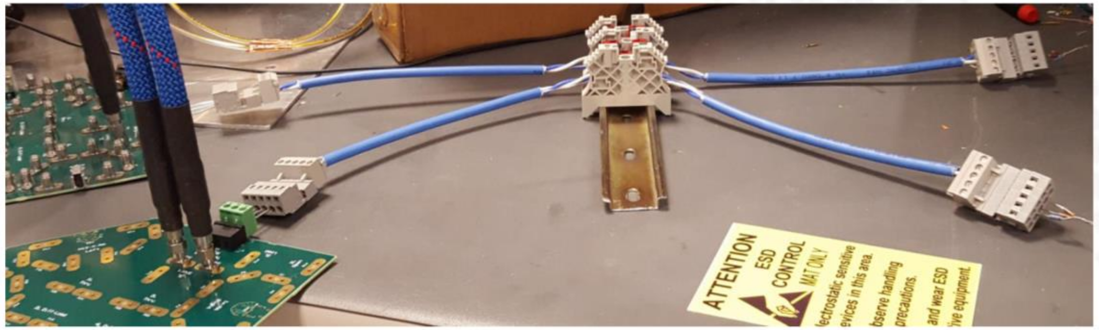
Fixture

The fixture consists of a set of three symmetrical terminal block assemblies, with resistor line terminators for simulated channel termination. A cable length of 0.2m Was used on each segment to allow termination separation and connection to the test fixtures (Pictures to the right show initial investigations on spacing)

The terminations applied a standard T termination with 50 ohm common mode termination to the shield and 100 ohm differential signal termination



Measurement with Wide Spacing *Measurement with Fixed Spacer* *Measurement with Minimal Installation*

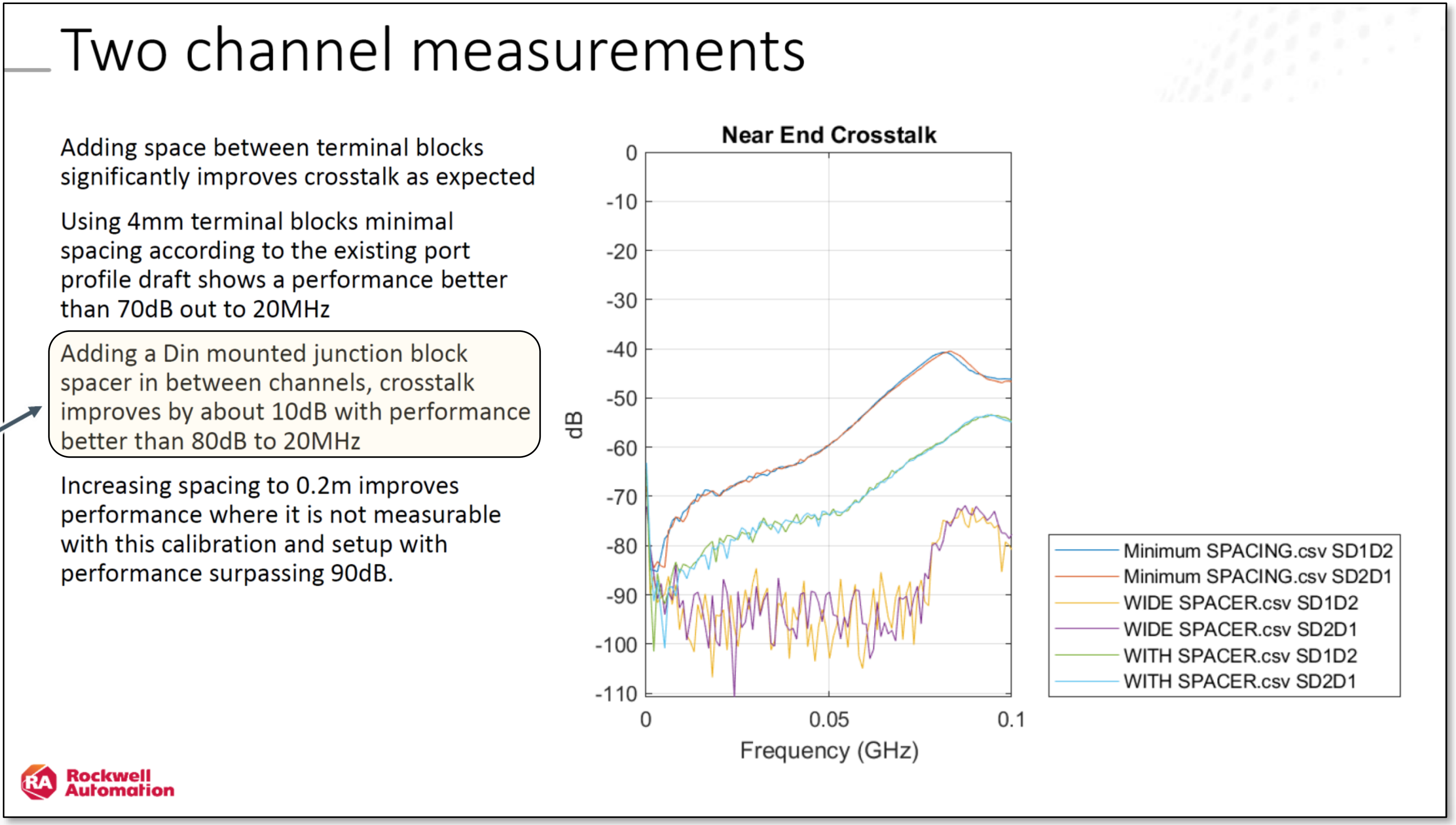


Full Measurement Fixture

Rockwell Automation

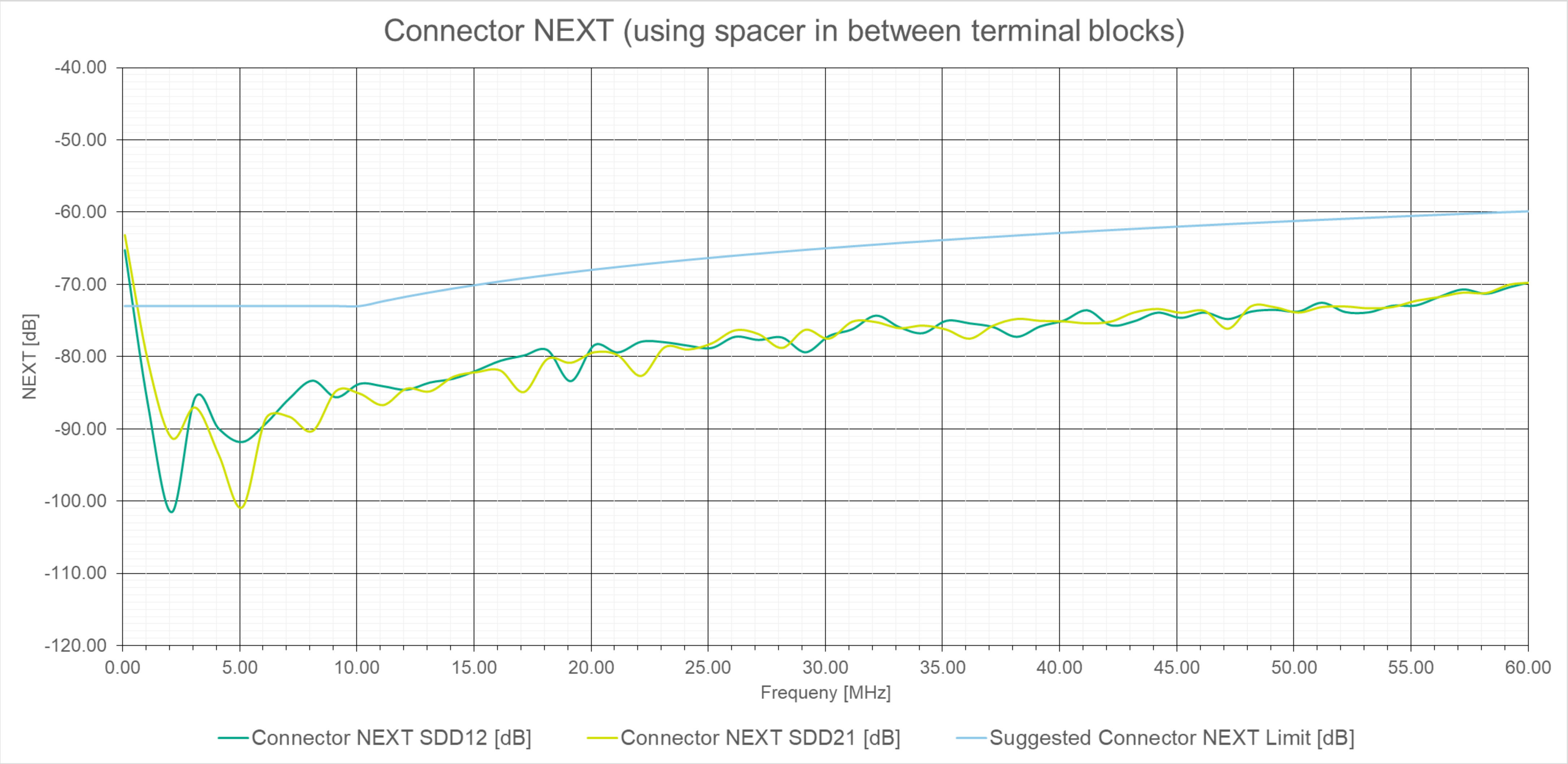
Connector Crosstalk Measurements

Excerpt from connector measurements presentation shown during Ethernet-APL meeting by Cameron Jones, image courtesy of Rockwell Automation:

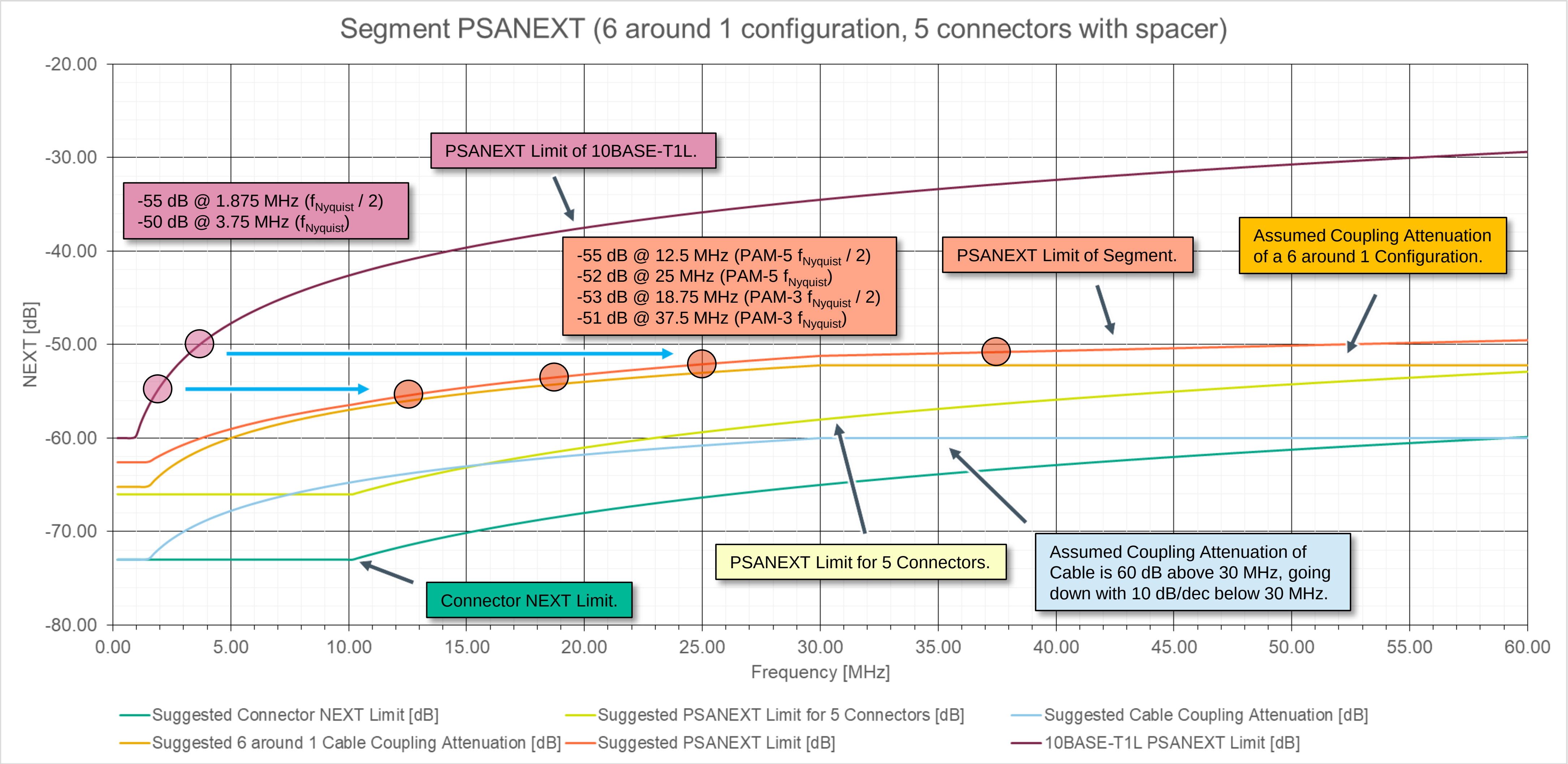


Even, if the screw terminals (certified for Ex e applications) will still be needed, adding a simple plastic spacer already provides about 10 dB better performance, using a grounded metal spacer is expected to improve the crosstalk even further.

Connector Crosstalk



Segment Crosstalk



Crosstalk

- The measurements on the previous slides show, that the connector crosstalk performance can be significantly improved by adding some defined space in between the terminal blocks.
- Comparing the crosstalk between two adjacent segments without a spacer, the crosstalk at **20 MHz** reaches a similar level as the crosstalk between two adjacent segments using a spacer in between the terminal blocks at **60 MHz** (approx. 70 dB for the used terminals, but we should account for some margin, so estimating a NEXT limit for the connectors of about 60 dB @ 60 MHz).
- Allowing only a minimum number of terminals/connectors of 5 instead of 10 provides an additional margin of about 3 dB compared to 10BASE-T1L for the connector NEXT.

- 10BASE-T1L uses a noise model, where all connectors are concentrated on one side of the link segment and having a PHY not using power back-off for short link segments.
- Thus PSANEXT and PSAFEXT limits for 10BASE-T1L are both pretty similar.
- Allowing the transmitter in the PHY to reduce the transmit power at shorter link segments would significantly reduce the far end crosstalk, providing additional margin.

Summary

- Allowing 500 m for an AWG16 cable provides a similar insertion loss as a 400 m AWG18 cable, but supporting 500 m provides a larger market acceptance.
- Assuming a PAM-5 modulation at 50 MBd, this provides a similar insertion loss as for 10BASE-T1L, but needs 6 dB higher margin, which will need to be partly compensated by the FEC.
- As the crosstalk for the connectors is higher at higher communication frequencies, additional measures, like larger spacing or adding a shielding plate in between two segments is required.
- E.g. adding a 5 – 6 mm plastic spacer in between two terminal blocks provides an improved crosstalk of about 10 dB using the shown terminals.
- From an application perspective these measures lead to additional efforts, but compared to the overall installation cost and size constraints, are expected to have no major impact and could be accepted where screw/spring type terminals must be used due to hazardous area requirements or environmental conditions.
- Reducing the number of intermediate connectors/terminals from 10 to at least 5 (the more the better, but less than 5 becomes critical), will provide additional margin.

Summary

- The 10BASE-T1L eval board has shown a noise margin of about 9 dB compared to the alien crosstalk model for 10BASE-T1L, see https://www.ieee802.org/3/cg/public/Mar2018/Graber_3cg_05_0318.pdf.
- With the shown PSANEXT values in this presentation, using a PAM-3 would lead to about 6 dB less margin at half Nyquist frequency compared to 10BASE-T1L, which likely needs an additional improvement in the noise environment, which seems to be possible, but might need additional shielding and not just adding some kind of spacer in between the segments.
- With the shown PSANEXT values, using a PAM-5 with assumed 4.5 dB coding gain for the FEC would lead to about 1.5 dB less margin at half Nyquist frequency compared to 10BASE-T1L, which still seems to be acceptable.
- Goal of the presentation is to provide some ideas about technical feasibility and not to decide for a possible implementation, as this needs significantly more analysis and has to take part in the task force then.
- **Suggested is to use 500 m maximum link segment length (assuming an AWG16 cable) and at least 5 intermediate connectors within the objectives.**

Thank you!