IEEE 802.3dg Task Force

100BASE-T1L Long Reach Link Segment Ideas

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100BASE-T1L Long Reach Link Segment

- 100BASE-T1L long reach link segment in this presentation means the 500 m link segment, not the 100 m high noise, low latency environment (e.g. for motor control applications).

- Important question: **Which cable/connectors to use?**

- From https://www.ieee802.org/3/GT10MSPE/public/graber_GT10MSPE_01_11082021.pdf the suggestion is to take 500 m AWG16 (alternatively 400 m AWG18, which is from the insertion loss equivalent to 500 m AWG16) and 5 inline connectors into account.

- **How does this fit to the installed fieldbus base or upcoming Ethernet-APL 10 Mbit/s base?**

- Current fieldbus or upcoming Ethernet-APL installations use AWG18 cable for the spurs and AWG18 or AWG16 cables for the trunk, mainly chosen according to the length and thus voltage drop across the cables (smaller plants with short trunks typically use AWG18, larger plants typically use AWG16 trunk cables to keep the voltage drop across the cable low, see example calculations on next slide).

100BASE-T1L Long Reach Link Segment

- AWG18 cable has a loop resistance of 44 Ω/km, AWG16 cable has a loop resistance of 28 Ω/km.

- Fieldbus applications are powered with 28 - 30 V, a field barrier needs a minimum of 16 V to function, a typical power supply delivers 500 mA.
- Adding 10 % margin (increased cable temperature) for the resistance and 2 V margin for the minimum supply voltage, this leads to:
- AWG18: ((28 V – 18 V) / 500 mA) / (44 Ω/km * 1.1) = 413 m
  AWG16: ((28 V – 18 V) / 500 mA) / (28 Ω/km * 1.1) = 649 m
- Based on these numbers a typical fieldbus segment with 500 mA current consumption can use an AWG18 cable up to about 400 m and needs an AWG16 trunk cable for more than 400 m.

- Ethernet-APL power switches provide 46 - 50 V and have power profiles supporting 1.25 A and 2 A maximum current, a field switch has a minimum supply voltage of 28.8 V.
- Just taking a 1 A typical current consumption (for larger currents only shorter trunks are possible or even AWG14 cables are required).
- Adding 10 % margin (increased cable temperature) for the resistance and 2 V margin for the minimum supply voltage, this leads to:
- AWG18: ((46 V – 30.8 V) / 1 A) / (44 Ω/km * 1.1) = 314 m
  AWG16: ((46 V – 30.8 V) / 1 A) / (28 Ω/km * 1.1) = 493 m
- Based on these numbers a typical Ethernet-APL segment with 1 A current consumption can use AWG18 cable until about 300 m trunk length; an AWG16 cable can be used for up to about 500 m.

- **The numbers shown above fit pretty well to the suggested 400 m AWG18/500 m AWG16 and the expectation is to cover most of the existing fieldbus or upcoming 10 Mbit/s Ethernet-APL installations by this choice.**

100BASE-T1L Long Reach Link Segment

- Currently in by far most applications (personally I would say > 95 %) the following connectors/terminals are used in process automation for fieldbus (Profibus PA, Foundation Fieldbus) or Ethernet-APL:

Trunk Ex eb [2)]	**Trunk non-Ex or Ex ec [3)]**	**Spur Ex i**	**Spur non-Ex**
Certified screw type terminals [1)]	Screw type terminals	Screw type terminals	Screw type terminals
Certified spring type terminals [1)]	Spring type terminals	Spring type terminals	Spring type terminals
Certified screw type connectors [1)]	Screw type connectors	Screw type connectors	Screw type connectors
Certified spring type connectors [1)]	Spring type connectors	Spring type connectors	Spring type connectors
M8/M12 have too small internal distances.	M12 connectors	M8/M12 connectors	M8/M12 connectors

- Terminals are typically used as in-line connectors, while pluggable connectors are often used at the device ports/MDI.
- [1)] Needs a certification for Ex eb (acc. to IEC 60079-7) from a notified body.
- [2)] Ex eb is the used type of protection for high power trunks going into Zone 1 (specific measures like redundant contacts are required, limiting the amount of available connector types and manufacturers).
- [3)] Ex ec is the used type of protection for high power trunks going into Zone 2 (only good industrial quality required).

100BASE-T1L Long Reach Link Segment Insertion Loss

- Proposed insertion loss limit curve for the link segment (500 m AWG16 cable, 5 inline connectors/terminals):

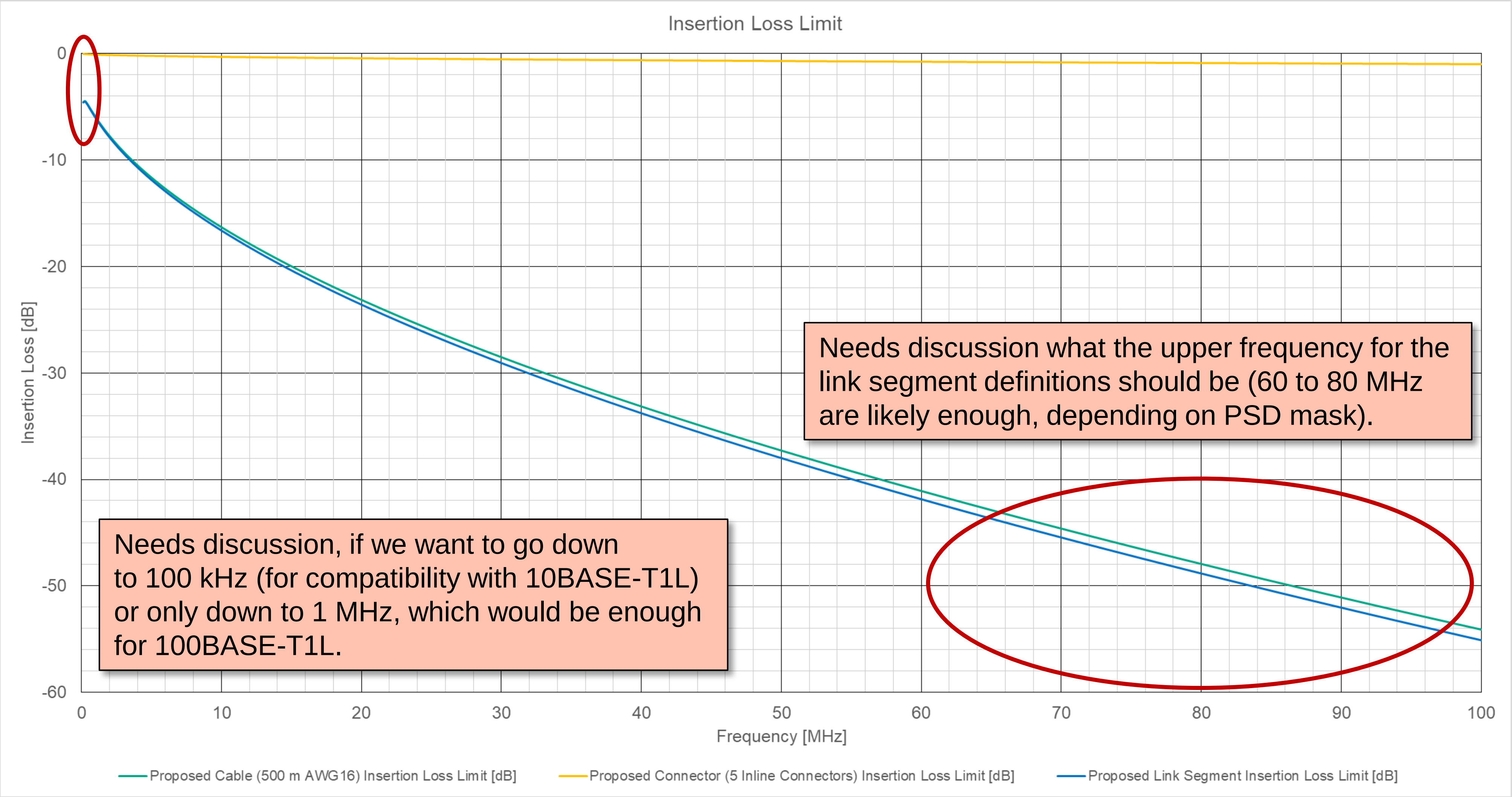
$$IL[dB] = 5 \cdot \left(0.98 \cdot \sqrt{f} + 0.01 \cdot f + \frac{0.2}{\sqrt{f}} \right) + 5 \cdot 0.02 \cdot \sqrt{f}, 0.1\ MHz \leq f \leq 100\ MHz, with\ f\ in\ MHz$$

- A factor of 0.98 instead of 1.23 for the 10BASE-T1L link segment is being used in the term for the skin effect, reflecting the larger wire diameter of an AWG16 instead of an AWG18 cable:

$$1.23 \cdot \sqrt{\frac{0.823\ mm^2 (AWG16)}{1.31\ mm^2 (AWG18)}} = 0.98$$

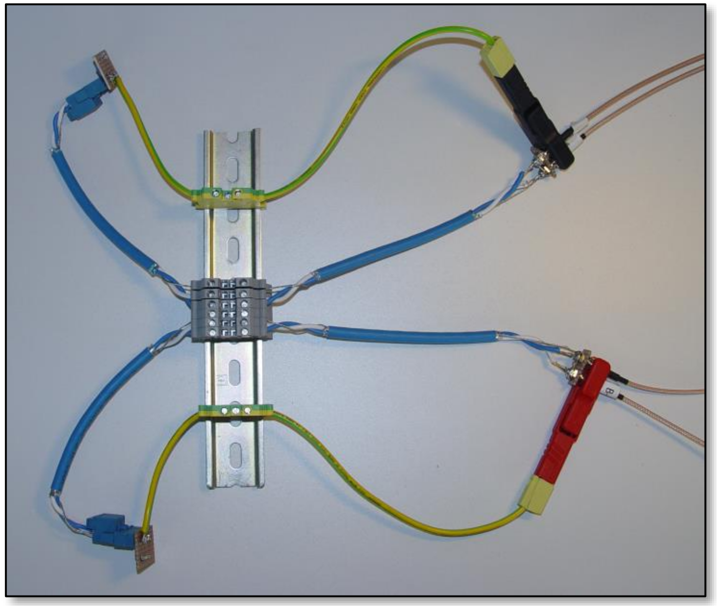
- The insertion loss term for each inline connector/terminal is proposed to be identical to the 10BASE-T1L link segment, but with an extended frequency range to 60 … 100 MHz.
- The lower 100 kHz limit is kept to allow backwards compatibility to 10BASE-T1L.
- Needs discussion, if we want to keep the 100 kHz or if the lower frequency limit should be increased to 1 MHz, as the 100 kHz limit would only be required for 10BASE-T1L backwards compatibility.
- Also the upper frequency limit might be reduced, depending on how the PSD mask limits the higher frequencies in the transmit signal (likely 60 to 80 MHz could be sufficient, e.g. comparable to the 600 MHz for 1000BASE-T1).

100BASE-T1L Long Reach Link Segment Insertion Loss

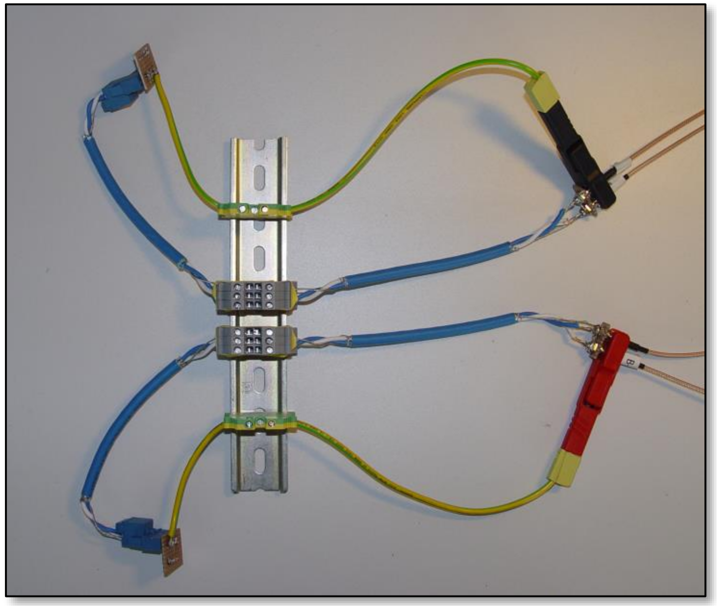


Connector/Terminal Measurements

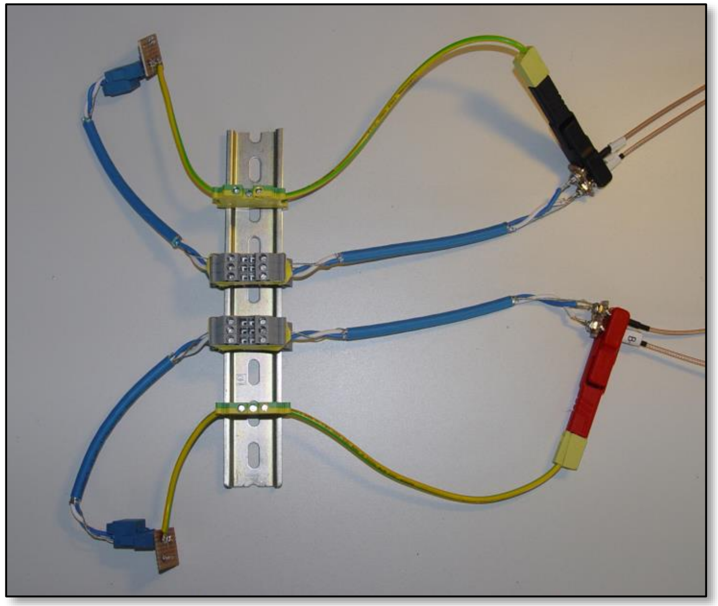
- The following pictures show the inline screw terminals (Phoenix Contact UT 2,5) being measured.
- The terminals have been assembled on a DIN rail and the return loss and crosstalk have been measured. After each measurement the distance between the terminals of the two adjacent link segments has been increased by 5 mm (from 0 mm to 5 mm, 10 mm, 15 mm, and 20 mm).
- The termination network has 100 ohm differential impedance and 50 ohm common mode impedance to earth.



0 mm distance



10 mm distance



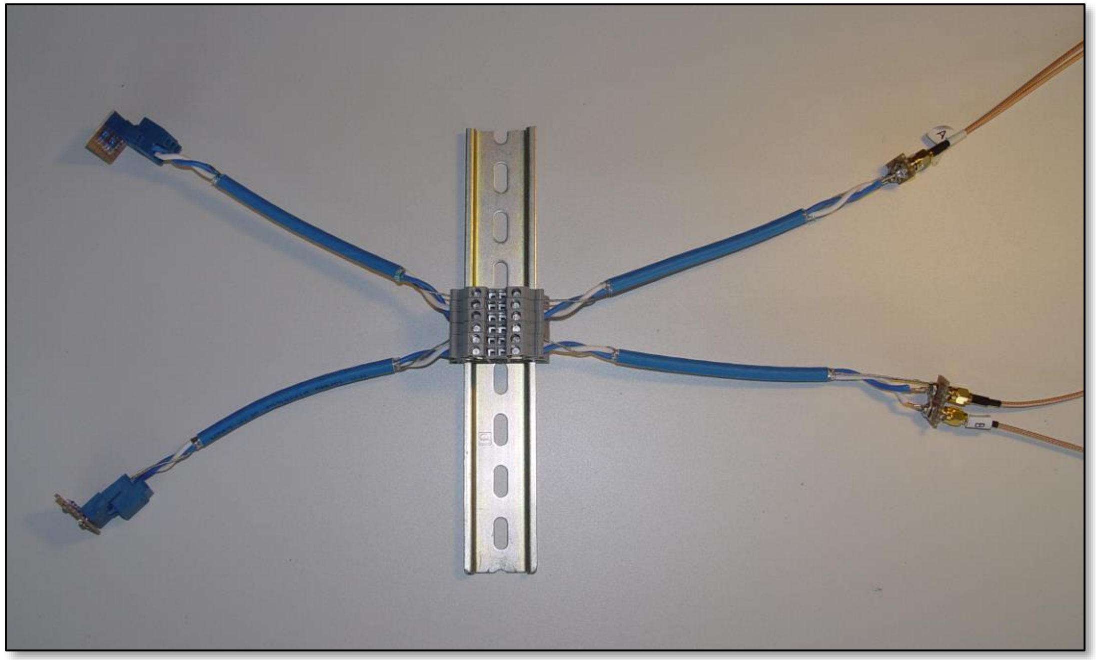
20 mm distance

Connector/Terminal Measurements

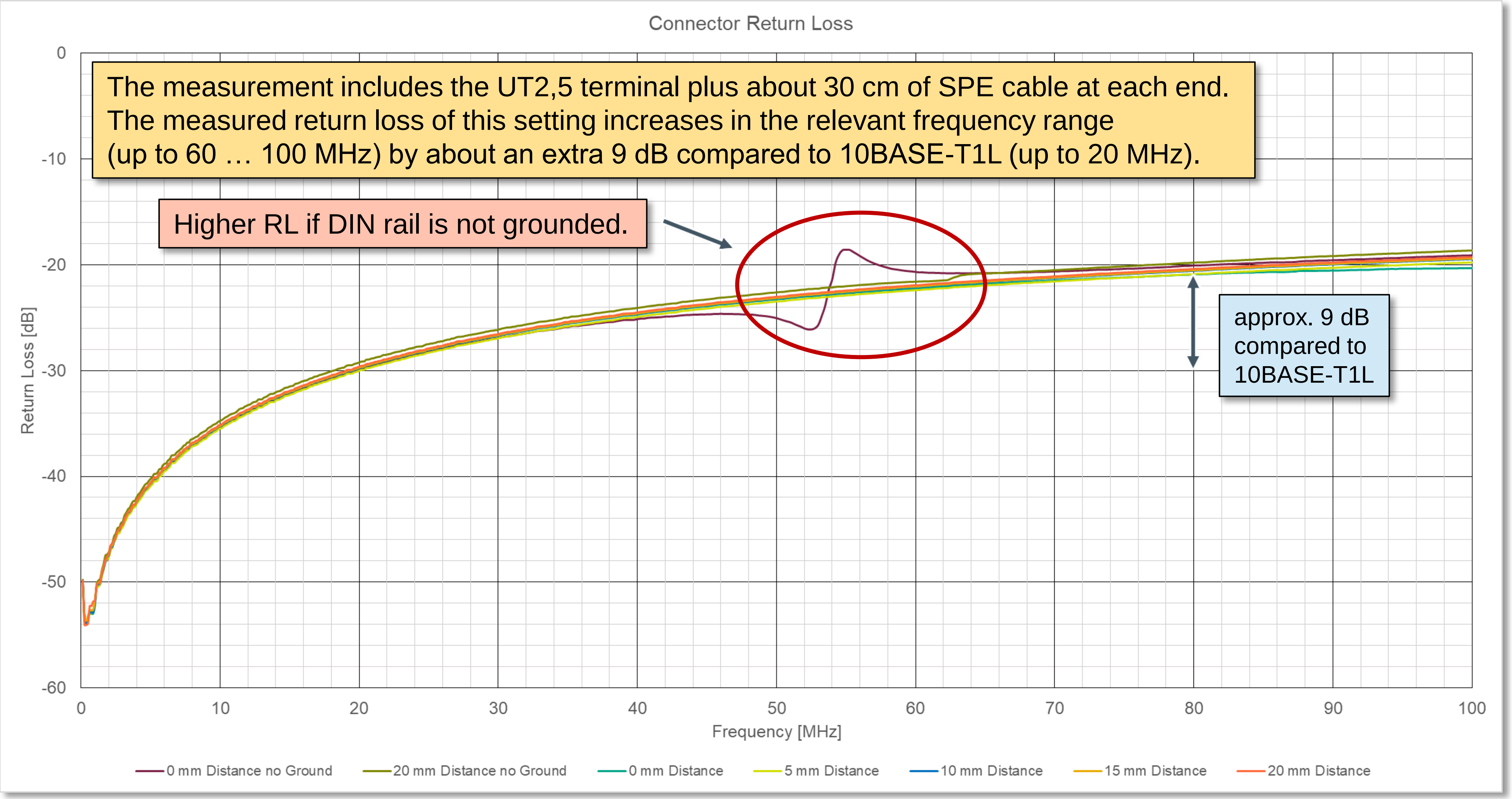
- For the crosstalk measurements the DIN rail has been grounded (as this is typically also the case within the application).
- Not grounding the DIN rail during the measurements led to increased reflections and crosstalk in the frequency range of about 50 MHz caused by an unbalance to ground (mainly caused by the (+, -, S) connector pinout, see following graphs).
- See backup slides at the end of the presentation comparing a (+, -, S) to a (+, S, -) connector pinout.

- A (+, -, S) connector pinout has been chosen, to reduce crosstalk when using 10BASE-T1L in high density Ethernet-APL installations.
- A (+, -, S) connector pinout also reduces the return loss at the connector, as the distance between the wires of the differential pair is smaller.
- For 100BASE-T1L a better symmetry to ground (+, S, -) might be more important, even if this requires an additional increase in distance and provides a worse return loss.
- Following measurements are done with (+, -, S) pinout.

- Additional measurements from terminal/connector manufacturers are very important.



Connector/Terminal Return Loss



100BASE-T1L Long Reach Link Segment Return Loss

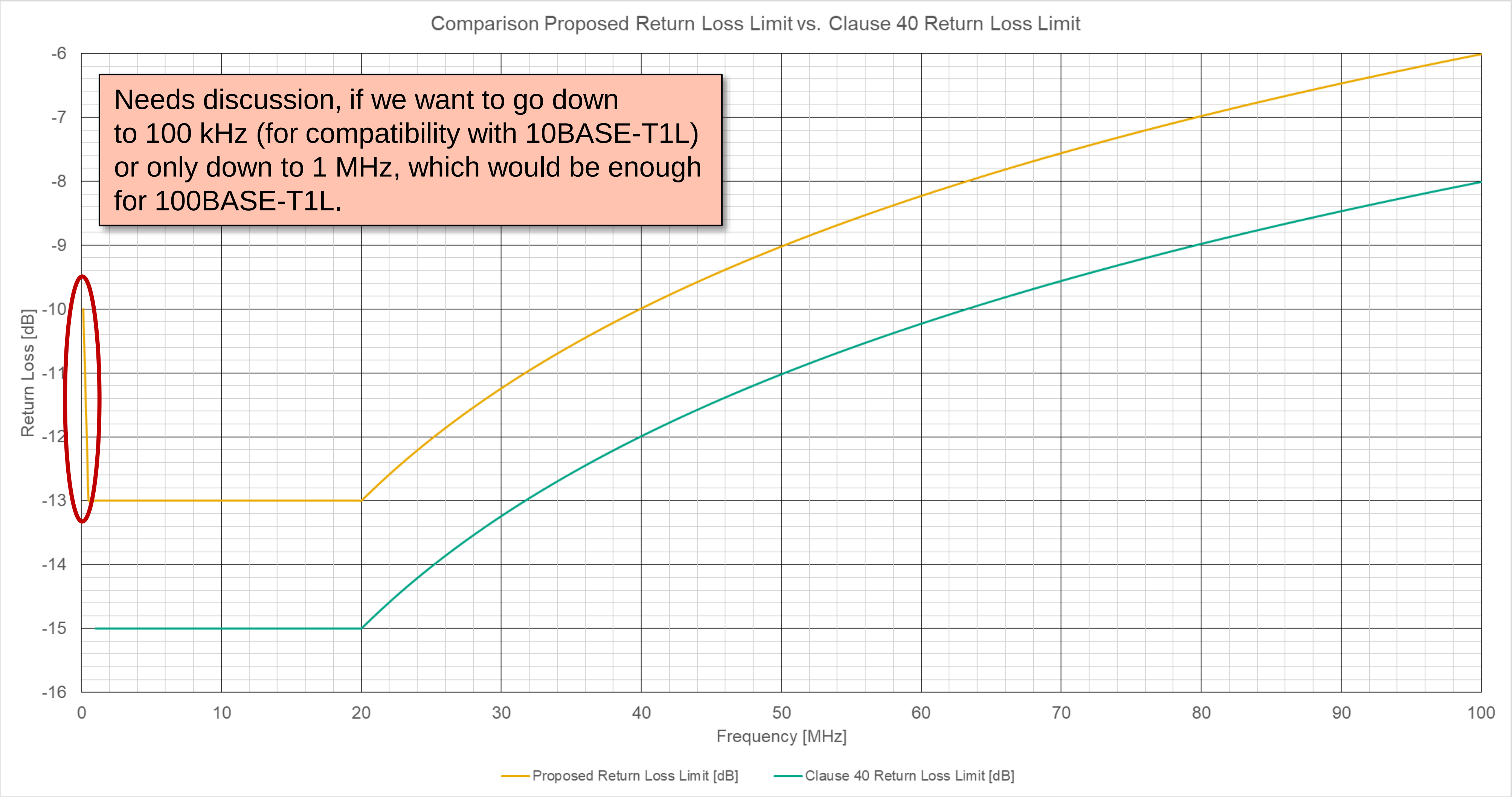
- The idea is to keep the return loss limit in the lower frequency range (below 20 MHz) identical with 10BASE-T1L, and adapt the return loss at higher frequencies to allow for a higher return loss, which is pretty likely needed by the used connectors (just as an initial starting point).
- Definitely requires additional measurements from connector/terminal manufacturers and also an agreement by the group on how the link segment will look in detail (what is the distance between the connectors, where are the positions, how are they grouped, what pinout is used)).

- Looking into the Clause 40 RL definition and using 13 dB (10BASE-T1L) instead of 15 dB (Clause 40) as a base for the RL below 20 MHz leads to (in case of going down to 100 kHz):

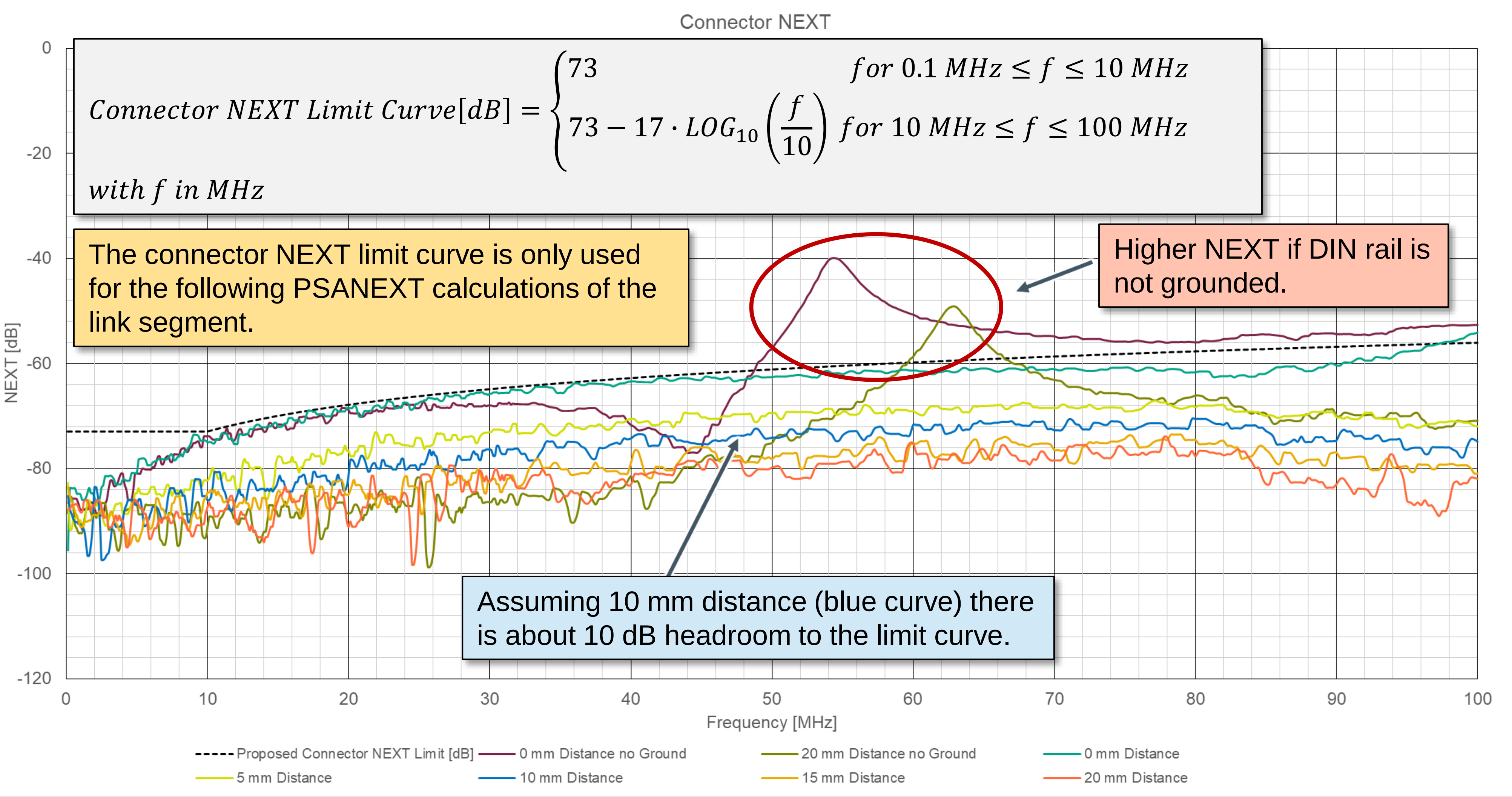
$$RL[dB] = \begin{cases} 9 + 8 \cdot f & for\ 0.1\ MHz \leq f < 0.5\ MHz \\ 13 & for\ 0.5\ MHz \leq f < 20\ MHz \\ 13 - 10 \cdot LOG_{10}\left(\frac{f}{20}\right) & for\ 20\ MHz \leq f \leq 100\ MHz \end{cases}$$

$$with\ f\ in\ MHz$$

100BASE-T1L Long Reach Link Segment Return Loss



Connector/Terminal NEXT Measurements



$$\text{Connector NEXT Limit Curve}[dB] = \begin{cases} 73 & \text{for } 0.1\,MHz \le f \le 10\,MHz \\ 73 - 17 \cdot LOG_{10}\left(\frac{f}{10}\right) & \text{for } 10\,MHz \le f \le 100\,MHz \end{cases}$$

with f in MHz

100BASE-T1L Long Reach Link Segment PSANEXT

- IEC 61156-11 specifies as crosstalk for the cable up to 600 MHz (see https://www.ieee802.org/3/dg/public/May_2022/fischer_3dg_01_08172022.pdf, page 9):

$$NEXT\ [dB] = 70\ - 10\ \cdot log_{10}\left(\frac{f}{100}\right) for\ f\ in\ MHz, 0.1\ MHz \le f \le 600\ MHz, with\ f\ in\ MHz$$

- As 100BASE-T1L potentially runs at 10 times lower speed, the suggestion is to use as NEXT for the cable:

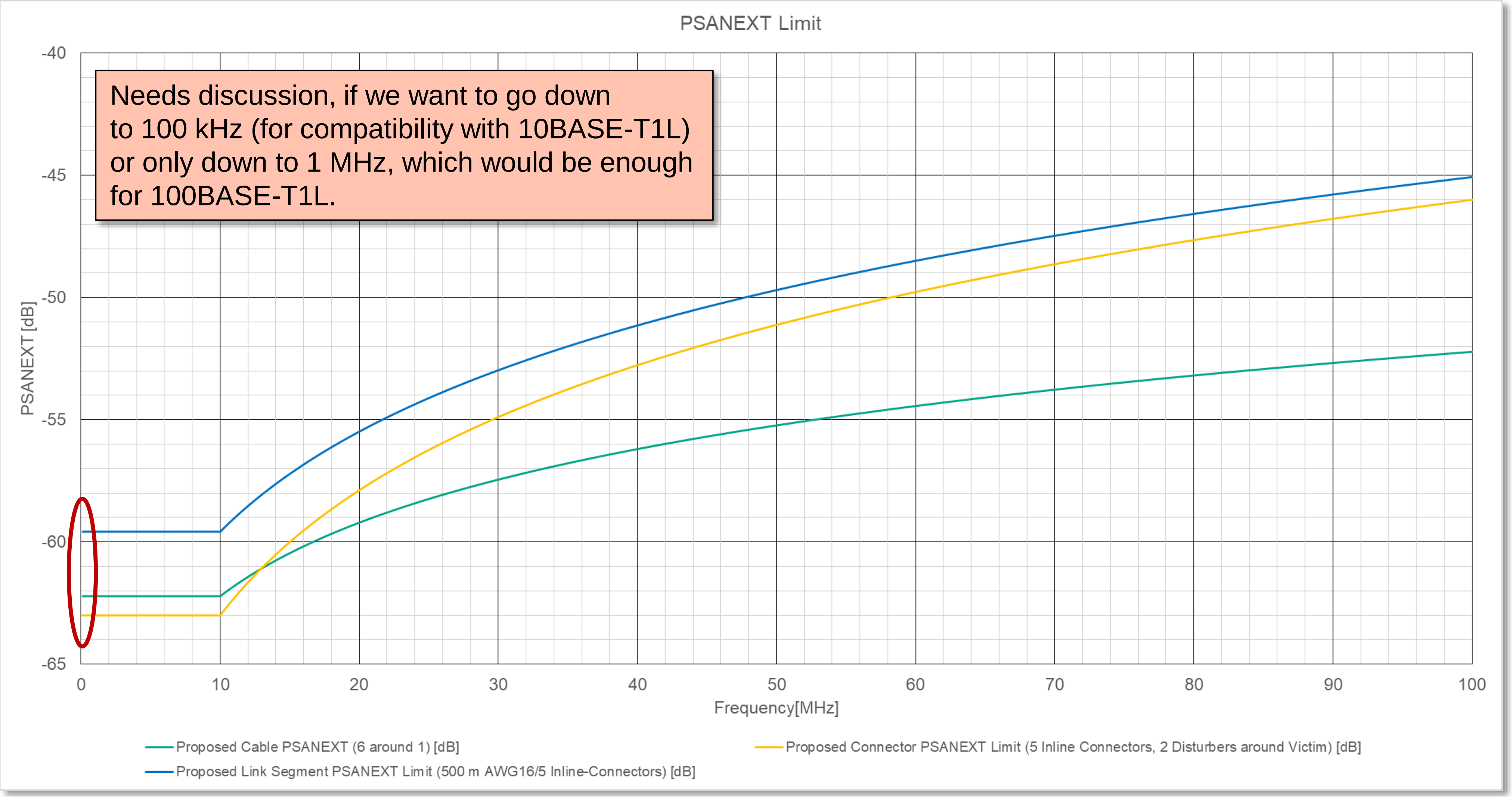
$$NEXT\ [dB] = \begin{cases} 70 & for\ 0.1\ MHz \le f \le 10\ MHz \\ 70\ - 10\ \cdot log_{10}\left(\frac{f}{10}\right) & for\ 10\ MHz \le f \le 100\ MHz \end{cases}$$

- Assuming a 6-around-1 disturber model, and up to 5 inline terminals/connectors, with 2 disturbers (left and right), this would result in:

$$PSANEXT\ [dB] = 10 \cdot log_{10}\left(6 \cdot 10^{-\frac{70\ - 10\ \cdot log_{10}\left(\frac{f}{10}\right)}{10}} + 5 \cdot 2 \cdot 10^{-\frac{73\ - 17\ \cdot log_{10}\left(\frac{f}{10}\right)}{10}}\right)$$

$$PSANEXT\ [dB] \approx 60 - 15 \cdot log_{10}\left(\frac{f}{10}\right)\ with\ a\ suggested\ plateau\ at\ 60\ dB\ below\ 10\ MHz$$

100BASE-T1L Long Reach Link Segment PSANEXT



Discussion

- Based on previous discussions, backwards compatibility of the link segment to 10BASE-T1L seems to be a major goal (including downshift, see https://www.ieee802.org/3/dg/public/May_2022/jones_3dg_01_08172022.pdf).
- In this case for the frequency range between 0.1 and 20 MHz insertion loss, return loss, PSANEXT, PSAFEXT and maximum latency need to be identical or better for the new link segment compared to the 10BASE-T1L link segment.
- For 100BASE-T1L a lower limit of 1 MHz would be ok, so the question is, if we want to stop at 1 MHz or go down to 100 kHz.

- The proposed insertion loss limit has been adapted for an AWG16 cable instead of an AWG18 cable as standard cable for 100BASE-T1L to have an additional margin in signal attenuation and to allow reaching the 500 m under the assumption of a similar noise environment as for 10BASE-T1L (with AWG18 cable 400 m are expected to work under the same conditions).
- The idea behind the return loss limit is to keep it identical with 10BASE-T1L in the lower frequency range, but adapt it, similar to Clause 40 for higher frequencies.
- The definitions for the long reach (500 m) link segment might/will be different from the definitions for the low latency, high noise (100 m) link segment, which is out of scope of this presentation.

- Above assumptions for the cables and connectors/terminals need additional measurements and validation from cable and connector manufacturers (especially as there are many different connector/terminal types, and there might be worse ones).
- Are there additional requirements/comments and who can provide additional contributions?

Discussion

- For the crosstalk only some ideas for the PSANEXT are shown, where it is as worst-case assumed, that the connectors are concentrated at one position (which only partly reflects the typical use case, where the inline-connectors/terminals are concentrated close to both ends of the link segment).
- Based on further connector and link segment measurements an adaption of the limit curve is likely.
- The shown limit curve already requires a significant improvement in the shielding of the used connectors or an increase in separation distances between adjacent segments.

- Within this presentation there is no suggestion for the PSAFEXT (as in 10BASE-T1L), which initially, not having more data, could be chosen to be in a similar/same range as the PSANEXT limit (assuming the connectors are concentrated at the other side of the link segment and most of the crosstalk is created at the connectors and not the cable). For a 10BASE-T1L link segment PSANEXT and PSAFEXT are e.g. pretty similar.

- Typically other SPE standards provide PSAACR-F instead of PSAFEXT values.
- Would it be better to specify PSAFEXT (as for 10BASE-T1L) or to specify PSAACR-F?
- Who can help bringing a proposal for the PSANEXT/PSAACR-F for 100BASE-T1L forward?

Discussion

- The observed ground unbalance effects might become an issue, especially as a low impedance grounding of the DIN rail cannot be guaranteed in all cases; possibly a change of the pinout can help, but increases crosstalk and required separation.
- As these effects seem to be mainly present above 50 MHz, the main energy of the signal should be in a lower frequency range, the PSD mask should be chosen to limit overtones of the transmit signal as good as possible, which could also help to use a lower upper limit for the link segment definitions.
- While for many applications well shielded connectors can be used, the number of choices in process automation is limited, as the terminals/connectors must be certified according to IEC 60079-7 (Ex eb) for high power Ethernet-APL trunks and (at least to me) only unshielded screw and spring type terminal connectors are known (there exist e.g. Ex de connectors for high power connections, but they are large in size even less suitable for high speed data transmissions).
- Have the ground unbalance effects also been observed by connector manufacturers, especially those producing Ex eb connectors/terminals (which is the required connector/terminal type for an Ethernet-APL trunk)?
- Otherwise, alternatives like small junction boxes, with a PCB inside and soldered terminals could be used, to have a more defined system setup.
- This leads to higher system cost/lower density but could be a valid option, if no other solution is found, but still needs further technical analysis.

Discussion

- Just simply looking at a PAM-3 with 4B3T coding (running 10 times faster than 10BASE-T1L), the insertion loss at $f_{Nyquist}$ / 2 (18.75 MHz) would be about 23 dB vs. 19 dB (which would need an FEC with 4 dB coding gain to compensate for, but would also increase latency and might be more critical for continuous tonal noise, as e.g. caused by PWM modulated signals).
- Important would be to get relevant noise information from process and other industries early (especially, how long the impulsive noise duration can be, as this has a high influence on the reachable latency/efficiency of the FEC).

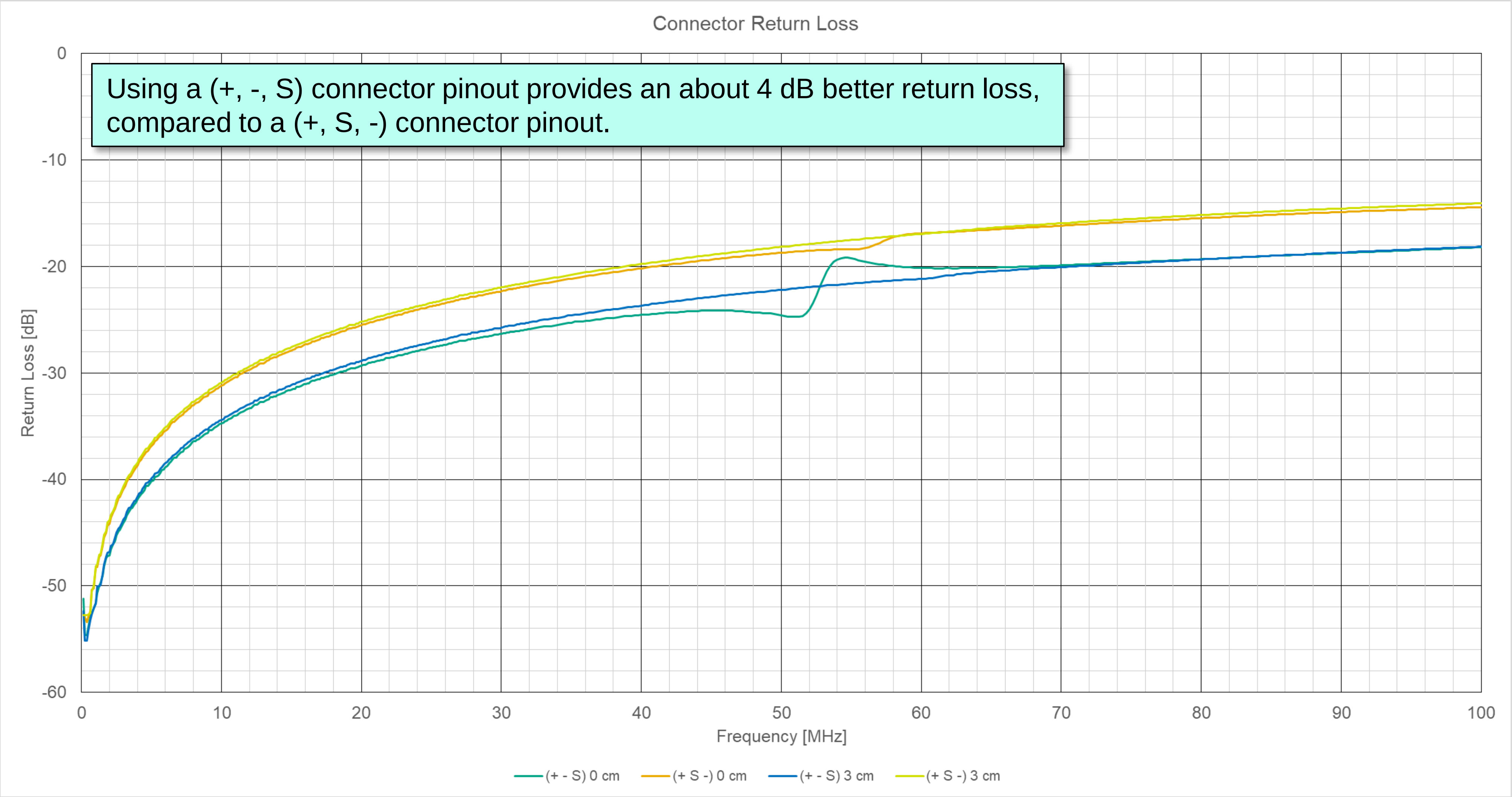
- Using a more efficient line coding instead of the 4B3T coding could bring up to about 1.5 dB lower attenuation.
- Further discussions/contributions are needed on how to limit the lower frequency boundaries of the transmitted signal, as this has a significant influence on PoDL powering, droop specifications and how large the power coupling inductors will get in size.
- This is important especially for the potentially larger power deliveries (higher speeds only make sense, if more power for the application is available) and if the 100 Mbit/s should be used on intrinsically safe links, where the maximum voltage is limited.

- Assuming a Nyquist frequency of below e.g. 40 MHz (and limiting the overtones), the return loss according to the suggested limit would be about 3 dB worse than for 10BASE-T1L.
- The proposed PSANEXT limit curve at $f_{Nyquist}$ / 2 shows about 56 dB, which is similar to the 55 dB for 10BASE-T1L.

- **Feedback from PHY and cable/connector experts is very welcome, especially about potential critical topics, not foreseen so far; also additional measurements are important, the more different measurements, the better ☺.**

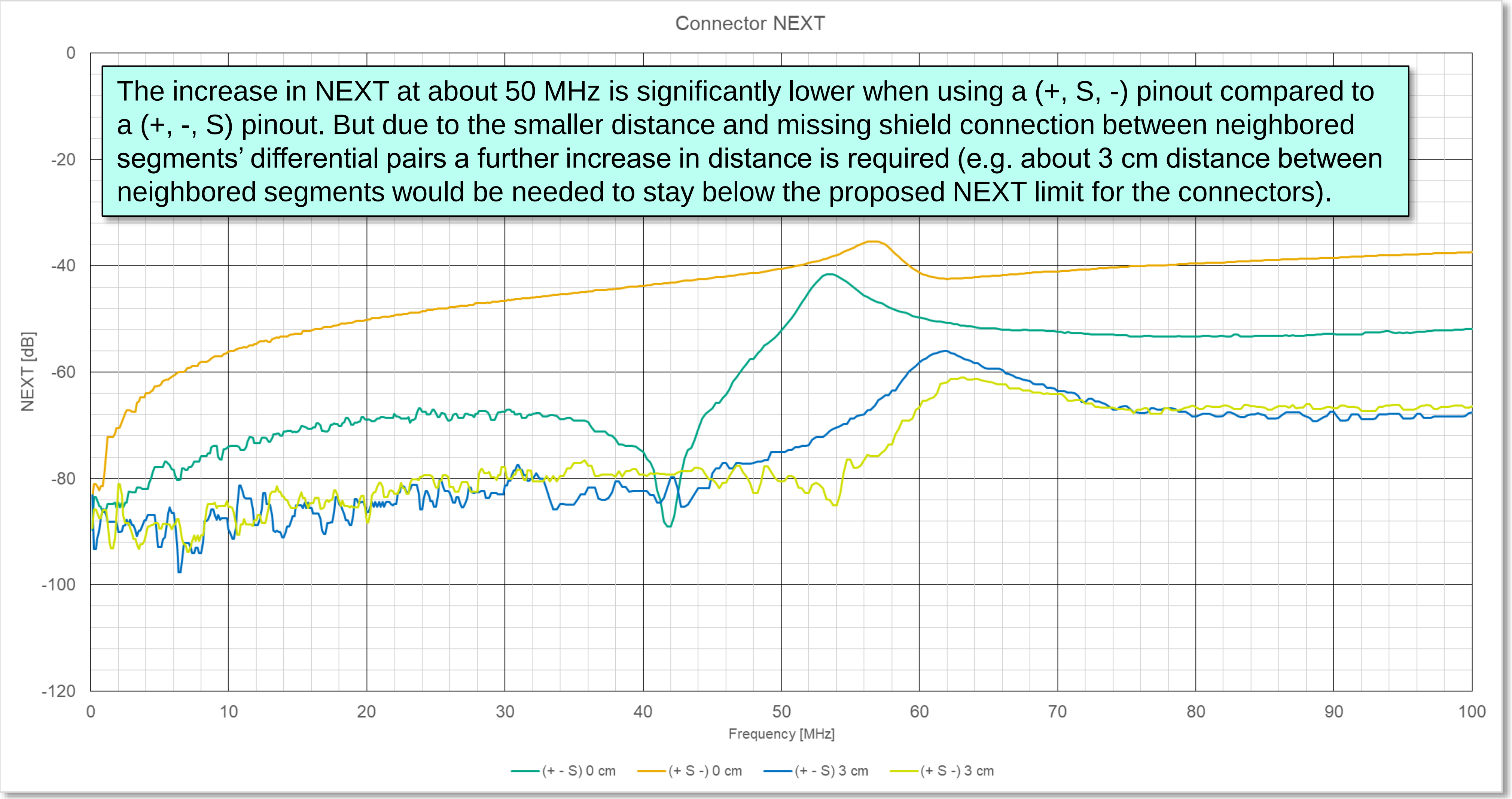
Backup Slides

Connector Pinout (+, -, S) vs. (+, S, -) – Return Loss

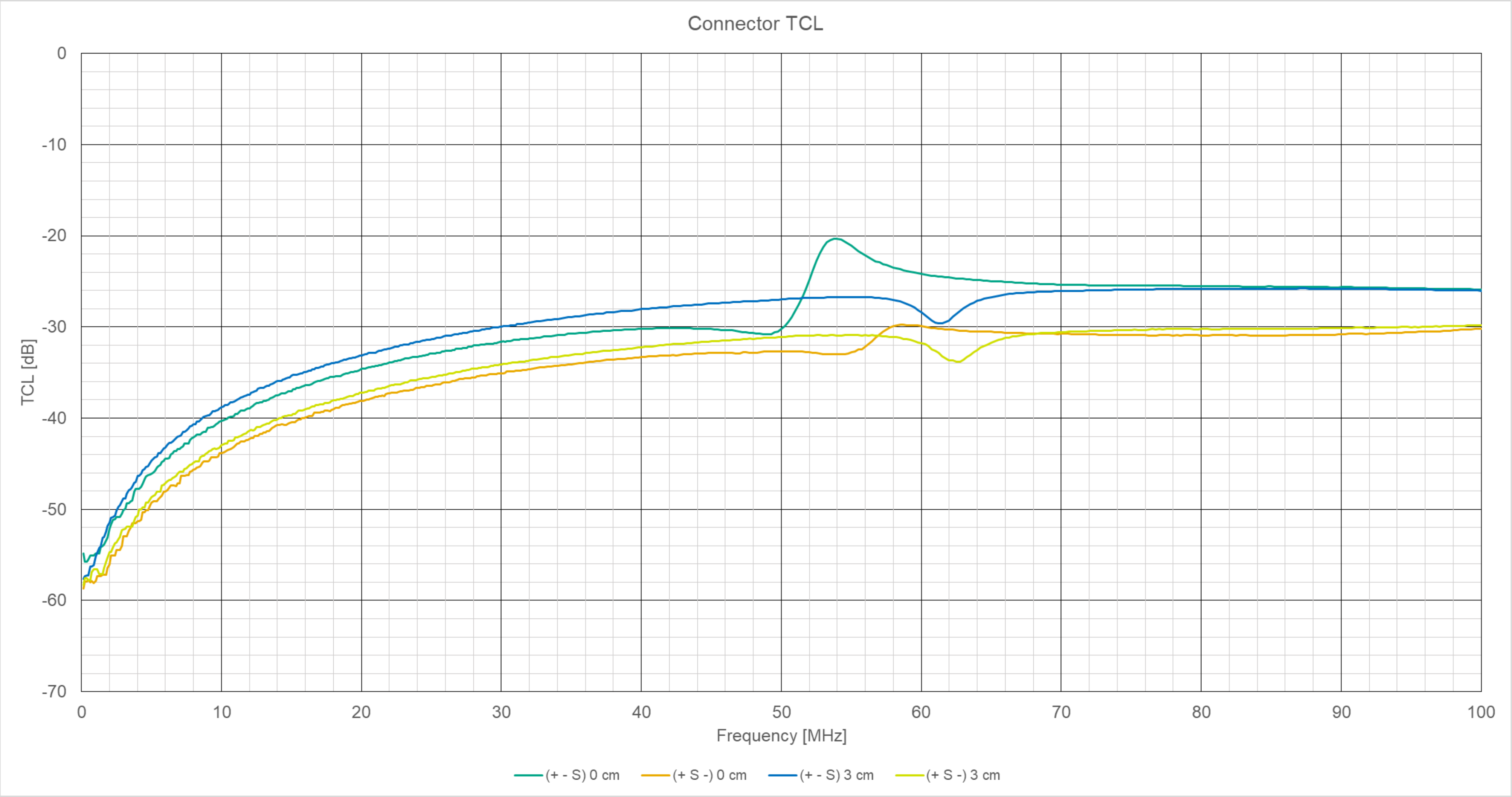


Connector Pinout (+, -, S) vs. (+, S, -) – NEXT

The increase in NEXT at about 50 MHz is significantly lower when using a (+, S, -) pinout compared to a (+, -, S) pinout. But due to the smaller distance and missing shield connection between neighbored segments’ differential pairs a further increase in distance is required (e.g. about 3 cm distance between neighbored segments would be needed to stay below the proposed NEXT limit for the connectors).



Connector Pinout (+, -, S) vs. (+, S, -) – TCL



Thank you!