Link Segment Baseline Proposal Industrial Applications IEEE 802.3 10 Mb/s Single Twisted Pair Ethernet Task Force

Vancouver, BC

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Contributors

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Purpose

- **Scope**
  - **Link Segment baseline proposal for Industrial Applications**

- **Rationale**
  - **Link segment baseline to address objectives and to generate first draft**

- **Link Segment**
  - **Developed in conjunction with the Industrial networking industries**

IEEE 802.3cg: Adopted Objectives

Objectives (2)

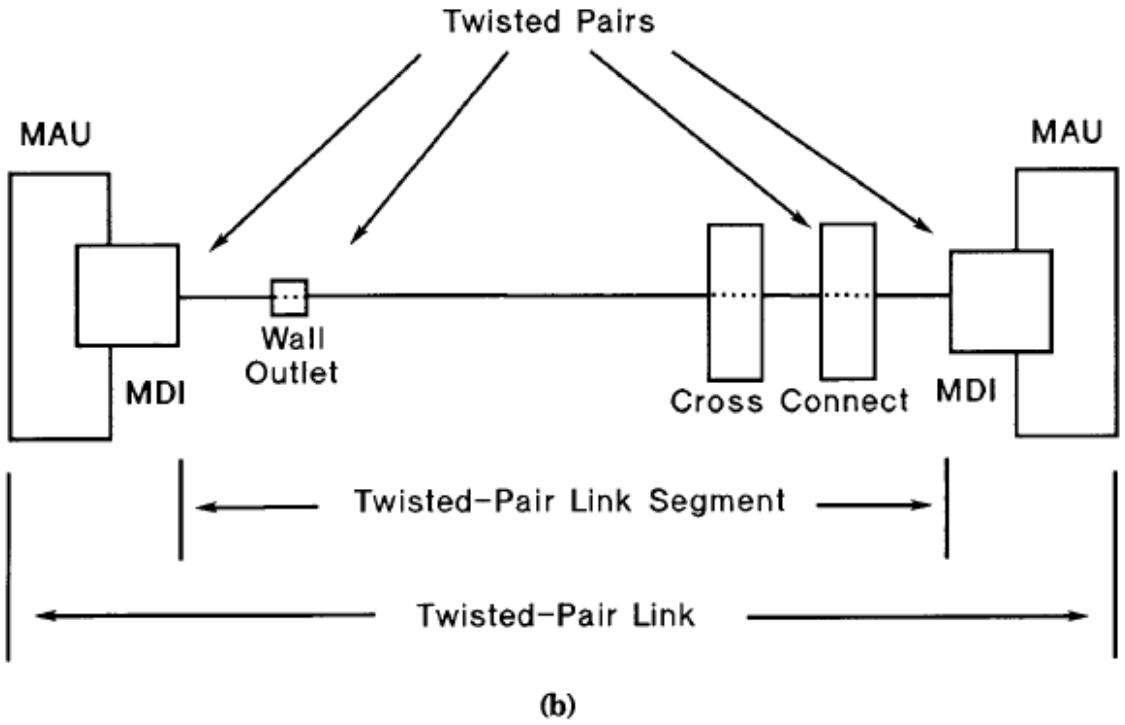
11. Define the performance characteristics of a link segment and a PHY to support operation over this link segment with single twisted pair supporting up to four inline connectors using balanced cabling for up to at least 15 m reach
12. Define the performance characteristics of a link segment and a PHY to support point-to-point operation over this link segment with single twisted pair supporting up to 10 inline connectors using balanced cabling for up to at least 1 km reach
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 100ms
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 15m, and 10^{-9} on link segments up to at least 1km
15. Specify one or more optional power distribution techniques for use over the 10 Mb/s single balanced twisted-pair link segments, in conjunction with 10 Mb/s single balanced twisted-pair PHYs, in the automotive and industrial environments

Source: http://www.ieee802.org/3/10SPE/objectives_10SPE_111016.pdf

Link Segment

1.4.242 link segment: The point-to-point full-duplex medium connection between two and only two Medium Dependent Interfaces (MDIs).

- **Example 10BASE-T**



(b)

Figure 14–2—Twisted-pair link

Link Segment Insertion Loss Specifications

- **Cable insertion loss – 20 deg C**

AWG	Diameter(in)	Diameter(mm)	dB/m at 4 MHz solid	dB/m at 4 MHz stranded	dB/m at 20 MHz solid	dB/m at 20 MHz stranded
14	0.064085	1.627754	0.013389	0.016067	0.029505	0.035407
15	0.057069	1.449551	0.015035	0.018042	0.033133	0.039759
16	0.050821	1.290858	0.016883	0.020260	0.037206	0.044647
17	0.045257	1.149538	0.018959	0.022751	0.041780	0.050136
18	0.040303	1.023689	0.021290	0.025548	0.046916	0.056299
19	0.035890	0.911618	0.023907	0.028688	0.052684	0.063221
20	0.031961	0.811816	0.026846	0.032215	0.059161	0.070993
21	0.028462	0.722941	0.030146	0.036175	0.066434	0.079720
22	0.025346	0.643795	0.033852	0.040623	0.074601	0.089521
23	0.022571	0.573314	0.038014	0.045617	0.083772	0.100526
24	0.020100	0.510549	0.042687	0.051225	0.094071	0.112885
25	0.017900	0.454655	0.047935	0.057522	0.105635	0.126762
26	0.015940	0.404881	0.053828	0.064594	0.118622	0.142346
27	0.014195	0.360555	0.060446	0.072535	0.133204	0.159845
28	0.012641	0.321083	0.067876	0.081452	0.149580	0.179496
29	0.011257	0.285931	0.076221	0.091465	0.167969	0.201563
30	0.010025	0.254628	0.085591	0.102710	0.188619	0.226342
31	0.008927	0.226752	0.096114	0.115336	0.211807	0.254168
32	0.007950	0.201928	0.107929	0.129515	0.237845	0.285414

*Reference IL =1.82*SQRT(f)+0.0091*f+0.25/SQRT(f)*

**commercially available specified to 500 MHz*
***~12% increase/decrese per gauge*
****20% increase for stranded*

Link Segment Cable IL (100m) = (0.56)(1.2)*(1.82*SQRT(f)+0.0091*f+0.25/SQRT(f)*

guage size correction 20% Increase for stranded

Contribution on Channel Insertion Loss

Insertion loss

as presented in Rational for 1000m and Proposal for Objectives

J. Gottron L.Winkel 5 October 2016

1.2 Insertion loss

The insertion loss for the pair of a channel shall not exceed the limits computed, to one decimal place, using the formula of Table 2.

Table 2 – Formulae for insertion loss limits for a 1000 m channel

Frequency MHz	Maximum insertion loss
$1 < f \leq 20$	$10 * \left(1{,}23\sqrt{f} + 0{,}01f + 0{,}2/\sqrt{f}\right) + 10 \times 0{,}015\sqrt{f}$

Note: to be deleted before publication. ILD is marginal for this frequencies.

Cable IL (100 m) = 10(1.23*SQRT(f)+0.01*f+0.2/SQRT(f))*

*Connector IL (10 connectors) = 10*0.015 *SQRT(f)*

Connector values even lower as presented by Chris Diminico in San Antonio

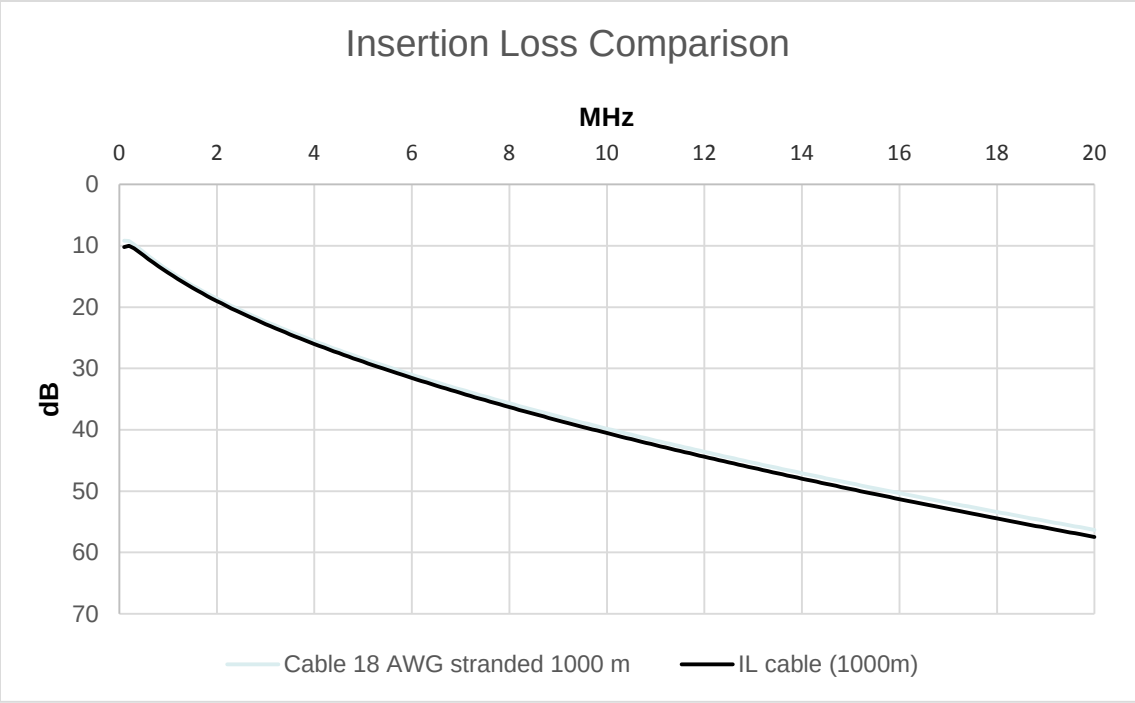
Source: http://www.ieee802.org/3/10SPE/public/adhoc/Fritsche_Schicketanz_121416_10SPE_01a_ad%20hoc.pdf

Cable insertion loss comparison

- *Cable IL (100 m) = (1.223*SQRT(f)+0.006*f+0.168/SQRT(f)*
- *Cable IL (1000 m) = 10*(1.223*SQRT(f)+0.006*f+0.168/SQRT(f))*

•*Source: http://www.ieee802.org/3/10SPE/public/adhoc/Fritsche_Schicketanz_121416_10SPE_01a_ad%20hoc.pdf*

  – *Cable IL (1000 m) = 10*(1.23*SQRT(f)+0.01*f+0.2/SQRT(f))*



Category Cabling IL

	Frequency (MHz)	Insertion loss (dB)
Category 3	$1 \le f \le 16$	$0.10\sqrt{f}$
Category 5e	$1 \le f \le 100$	$0.04\sqrt{f}$
Category 6	$1 \le f \le 250$	$0.02\sqrt{f}$
Category 6A	$1 \le f \le 500$	$0.02\sqrt{f}$

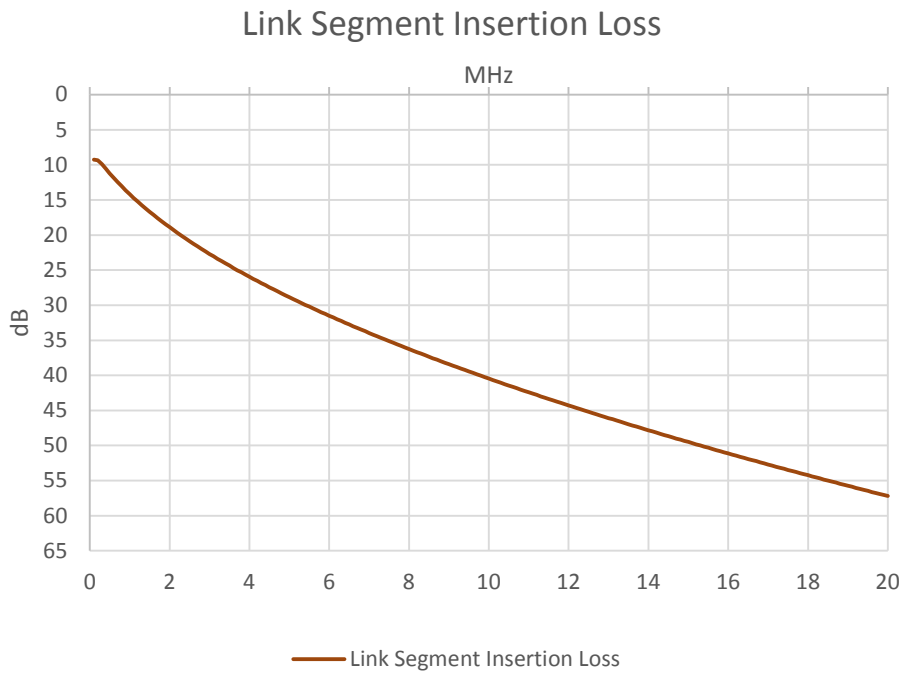
Connector measurements IL < 0.02 dB
100 KHz ≤ f ≤ 20 MHz

Link Segment Insertion Loss Proposal

- The link segment shall meet the values determined using Equation (xx) dB

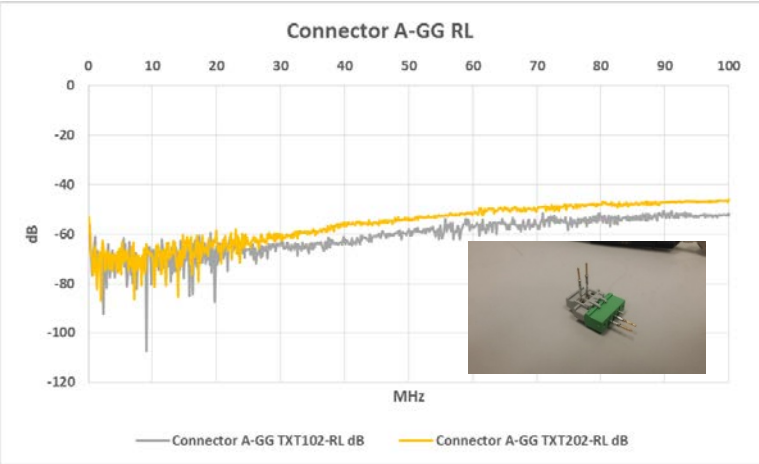
Insertion Loss (f) ≤ 10(1.23*SQRT(f)+0.01*f+0.2/SQRT(f))+10*(0.02*sqrt(f)) (dB)*

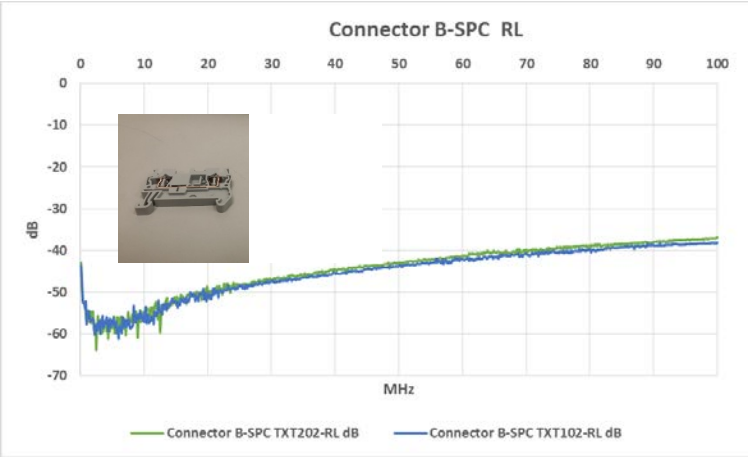
where
f is the frequency in MHz; [.1 MHz to 20 MHz]

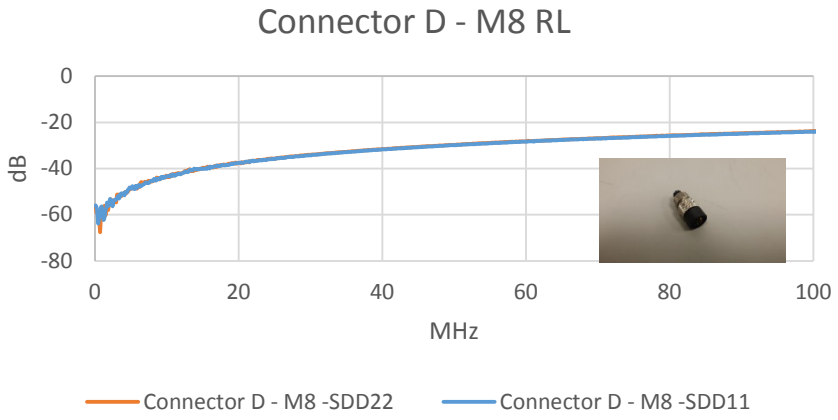


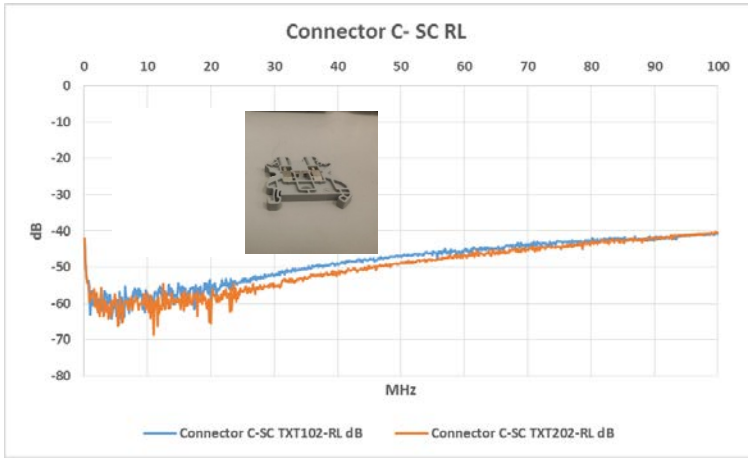
25.95 dB @ 4 MHz

Connector Return Loss Measurements





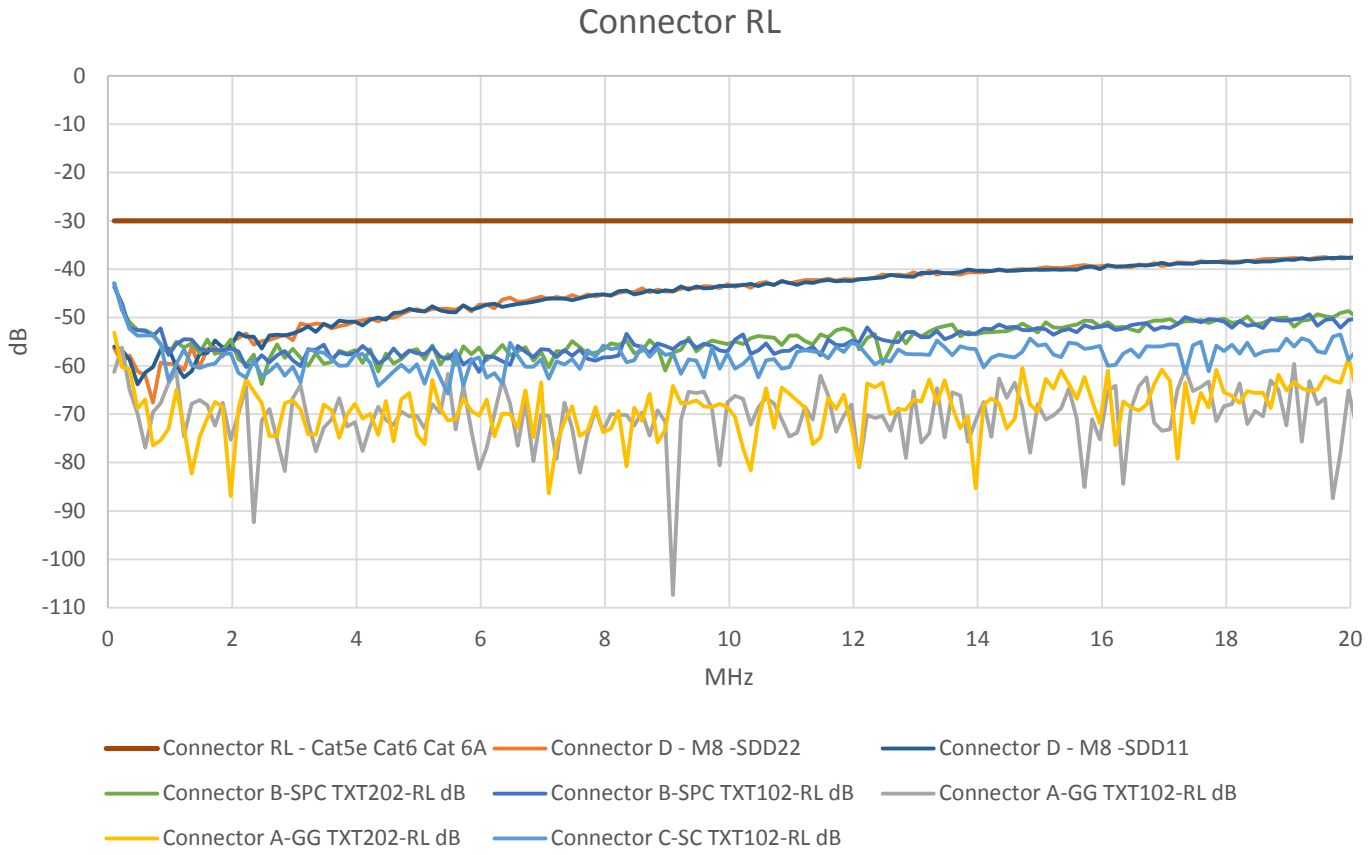




Background:
http://www.ieee802.org/3/10SPE/public/Sept2016_Interim/diminico_01_0916.pdf
http://www.ieee802.org/3/10SPE/public/Nov2016/diminico_01b_1116.pdf

IL < 0.02 dB
100 KHz ≤ f ≤ 20 MHz

Connector Return Loss Measurements



IL < 0.02 dB
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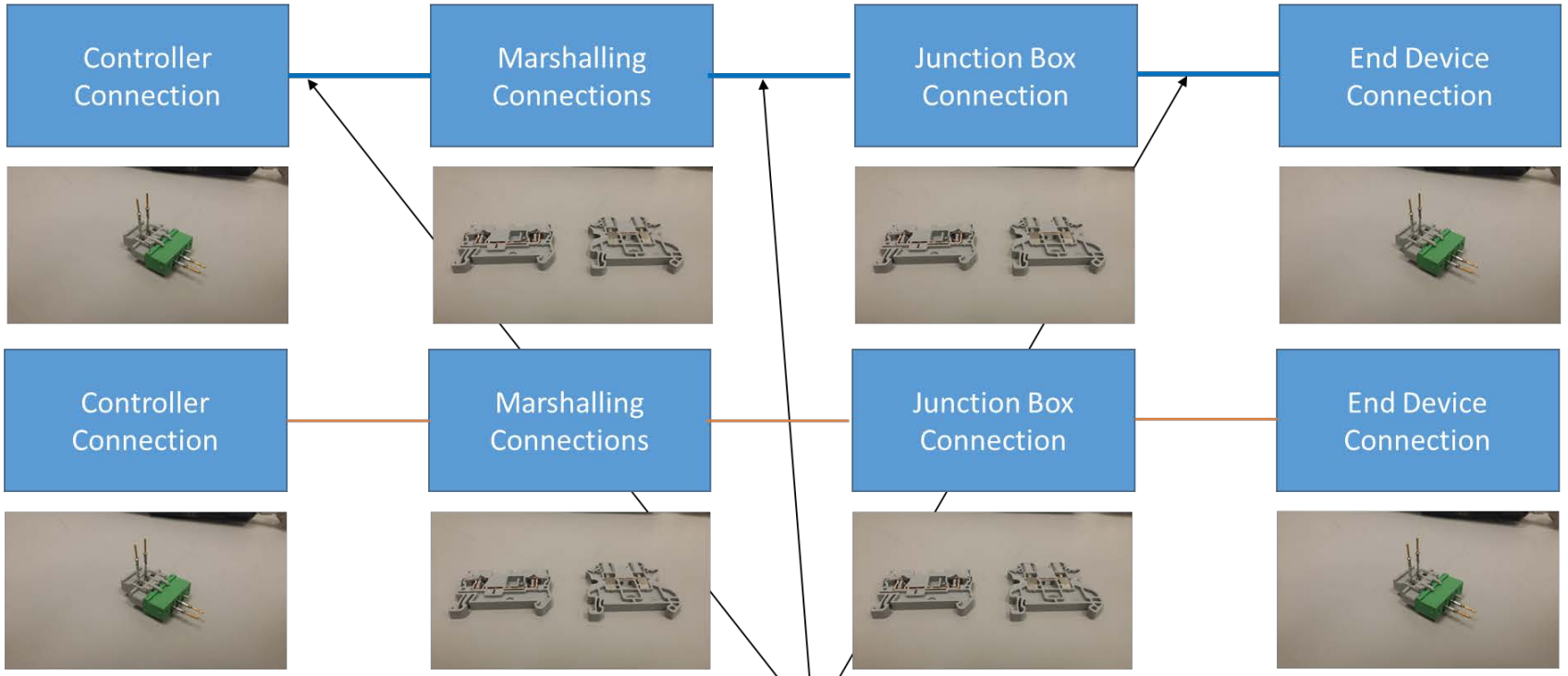
http://www.ieee802.org/3/10SPE/public/Nov2016/diminico_01b_1116.pdf

Link Segment Measurements

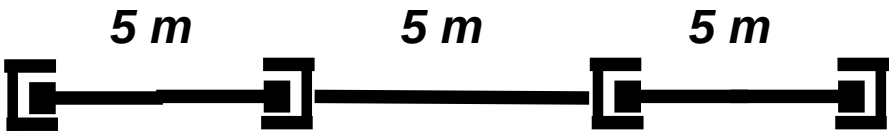
MEASURED CONFIGURATION

CHANNEL 1 (Blue Pair)



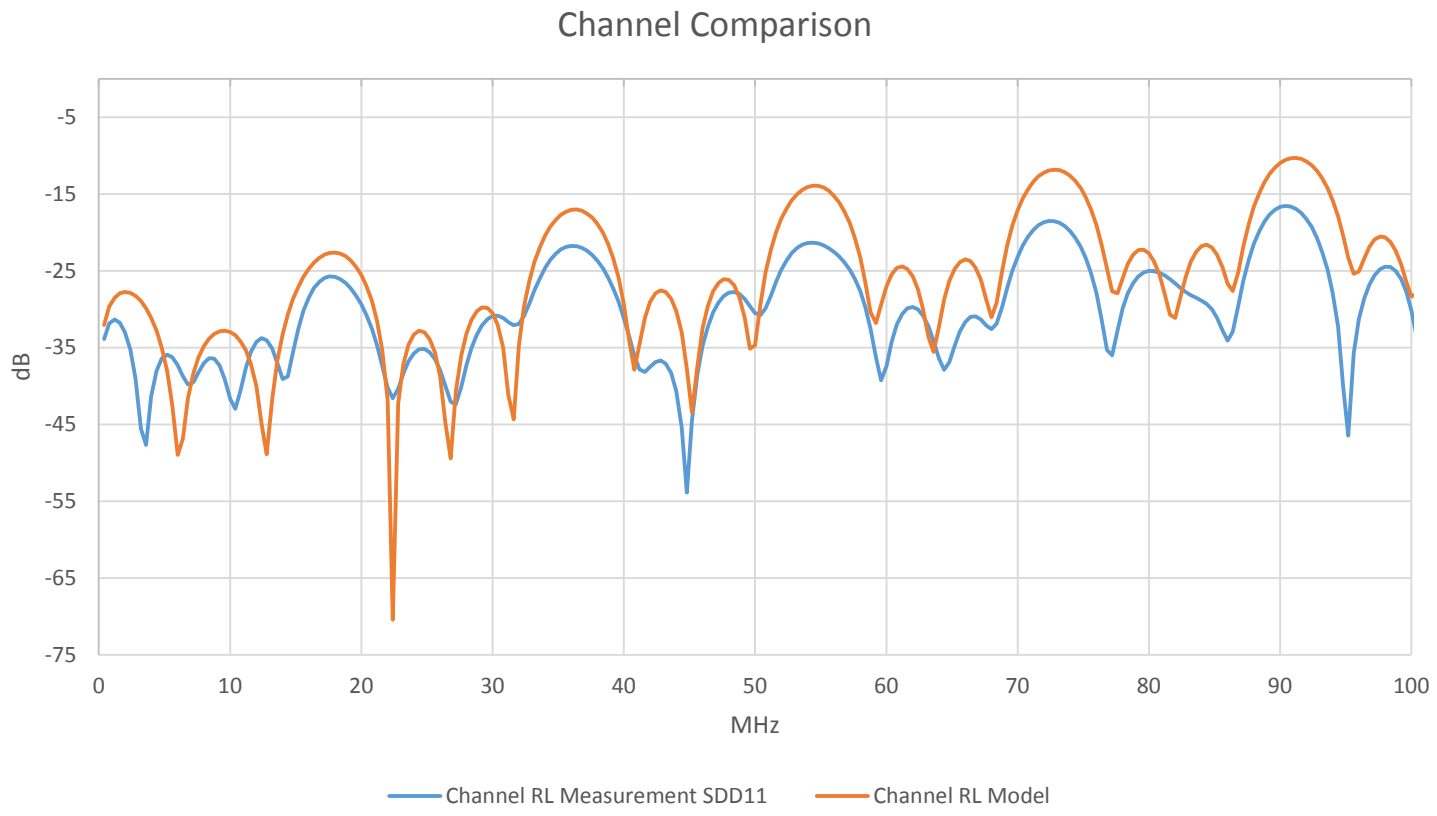
CHANNEL 2 (Orange Pair)

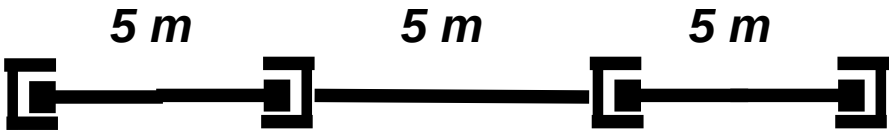
5 meter lengths of 23+ AWG twisted pair harvested from Category 8 cable, 3 places



Link Segment RL Model

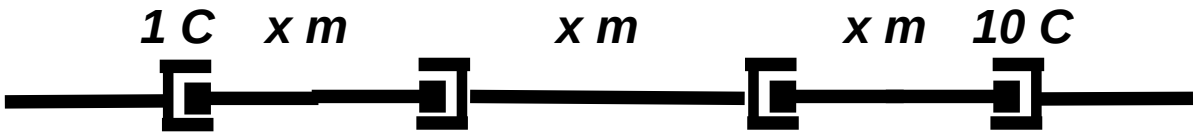
- Cascade ABCD matrices of connectors and cables





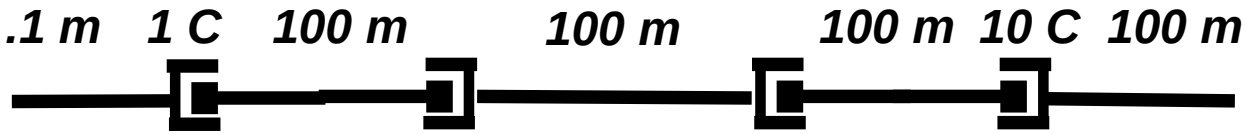
Link Segment RL Model

- 10 connectors separated by 10, 20,30,100 meters
- All cables 100 ohms



X=10, 20,30,100 meters
10 connectors, 11 cable lengths

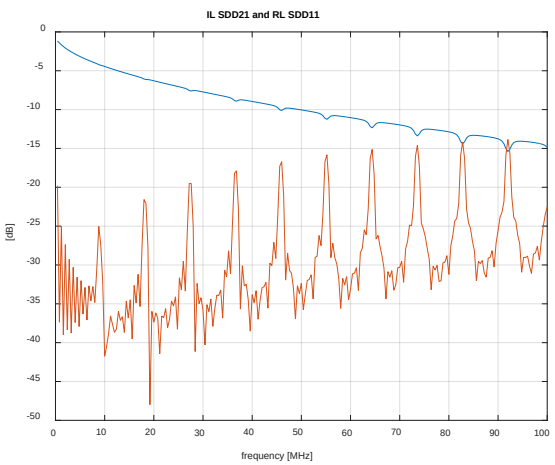
- 10 connectors separated by 100 meters
- All cables 100 ohms



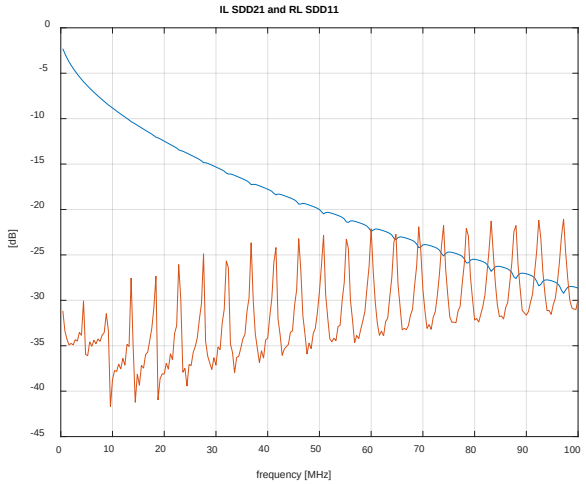
Link Segment RL Model

- 10 connectors separated by 10, 20,30,100 meters

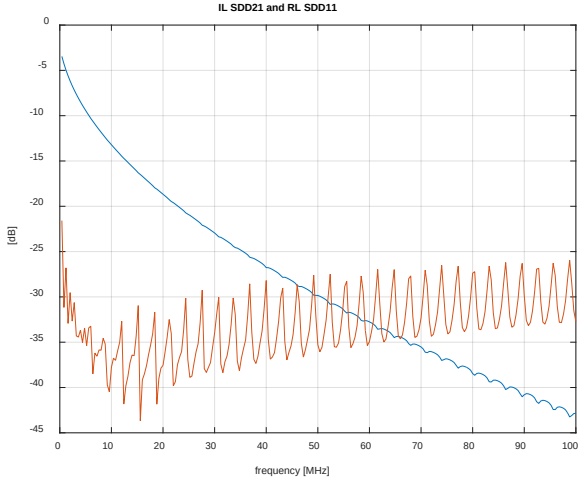
10 meters



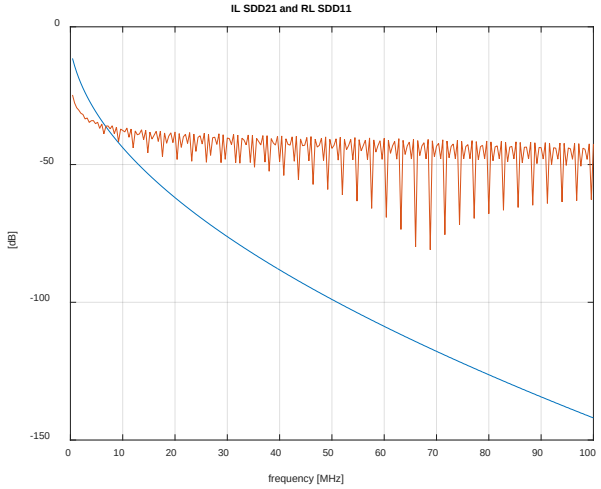
20 meters



30 meters

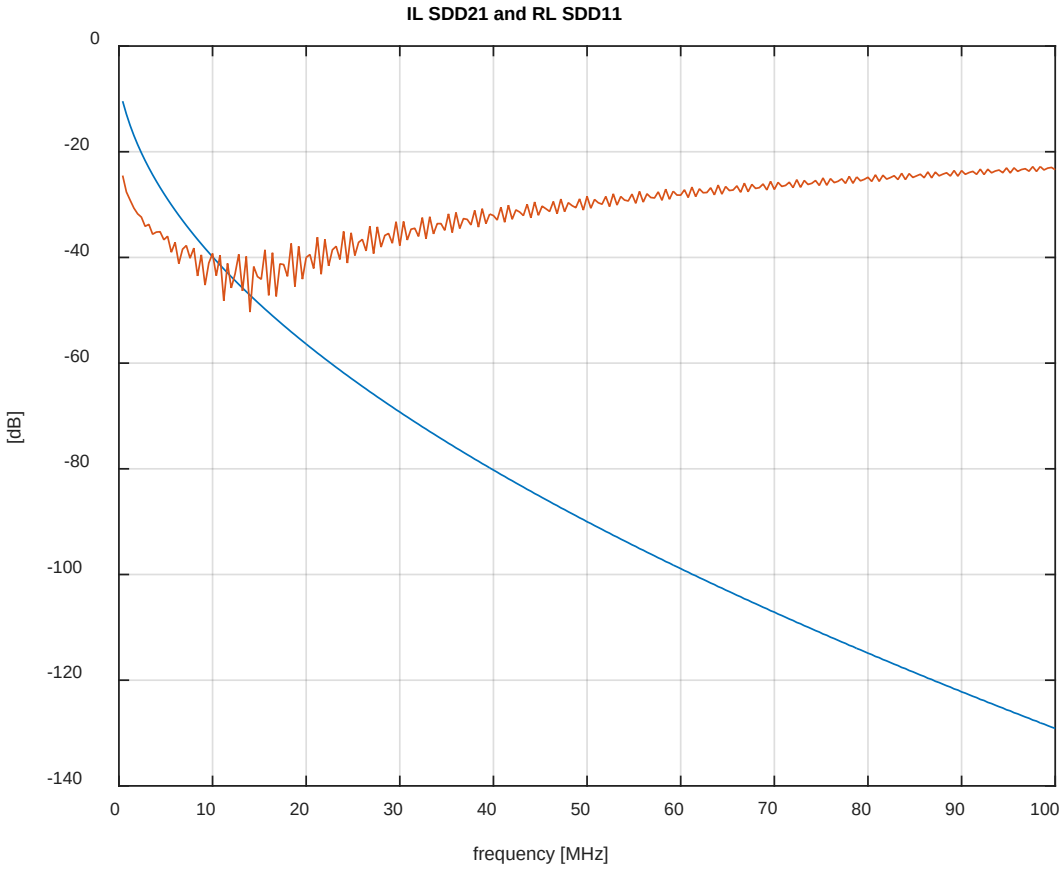


100 meters



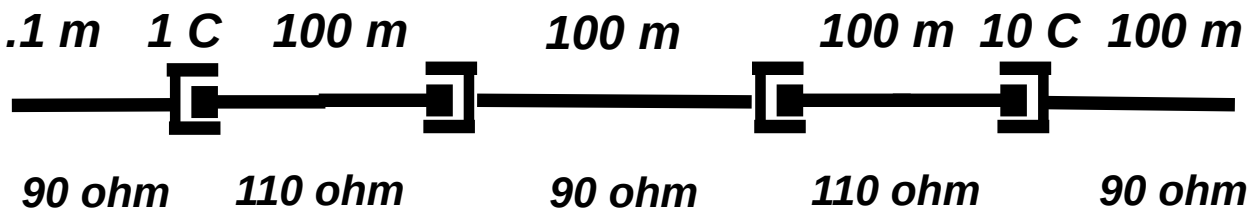
Link Segment RL Model

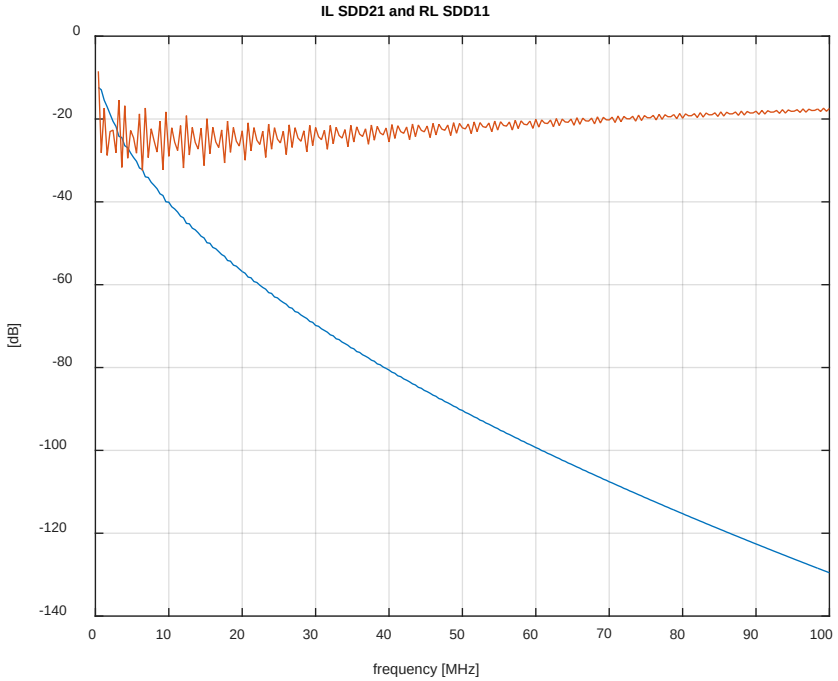
- 10 connectors separated by 100 meters
- .1 m cable at input



Link Segment RL Model

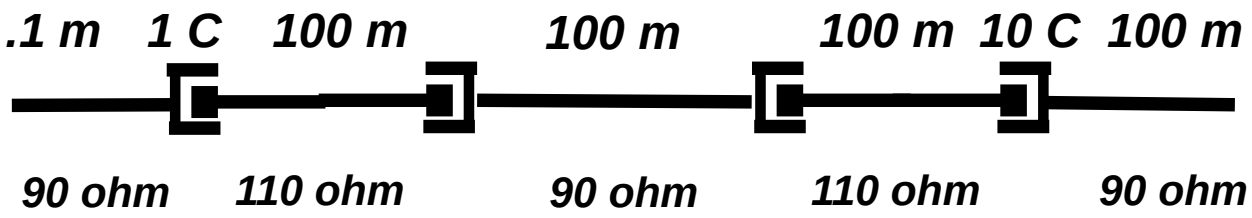
- 10 connectors separated by 100 meters
- Cables +/- 10%

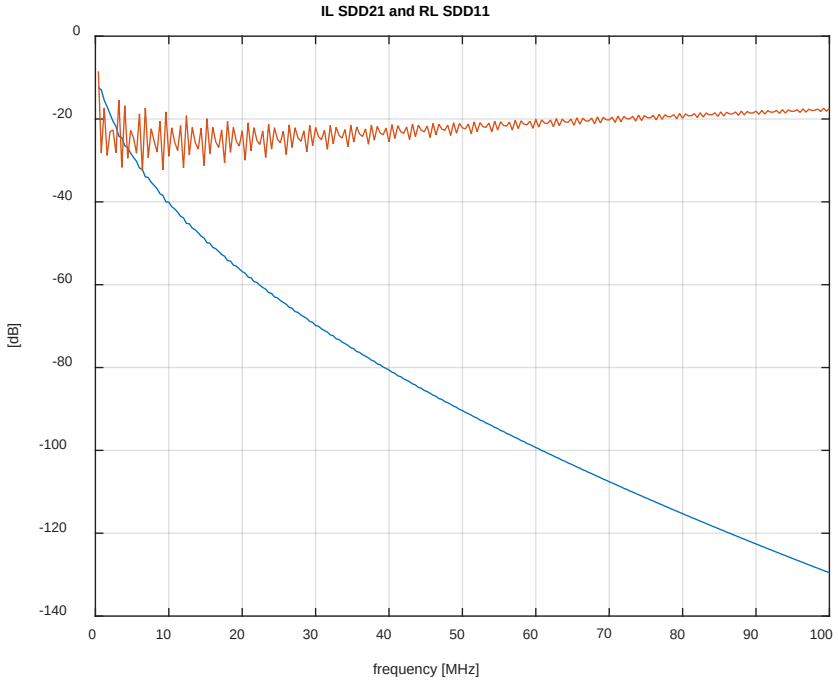




Link Segment RL Model

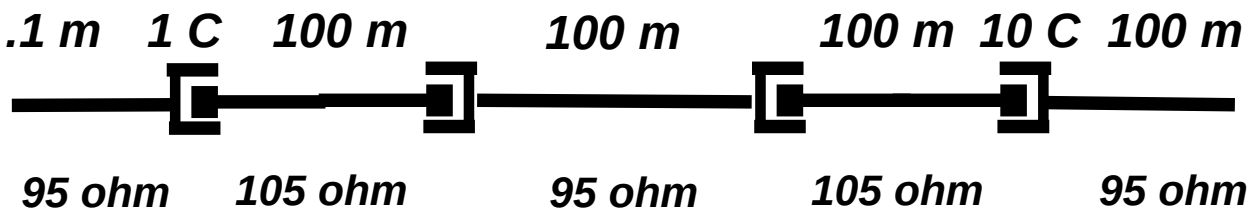
- 10 connectors separated by 100 meters
- Cables +/- 10%

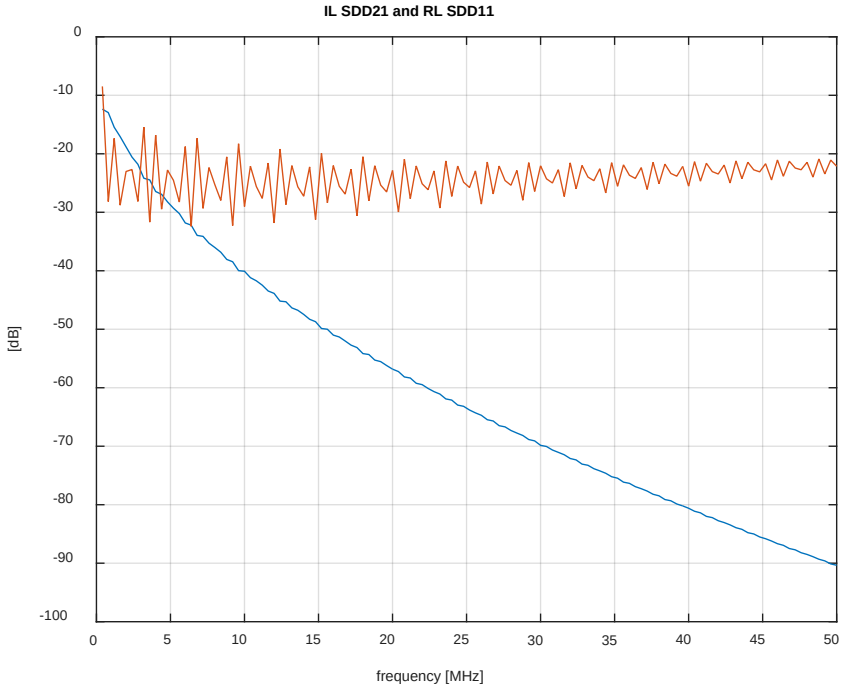




Link Segment RL Model

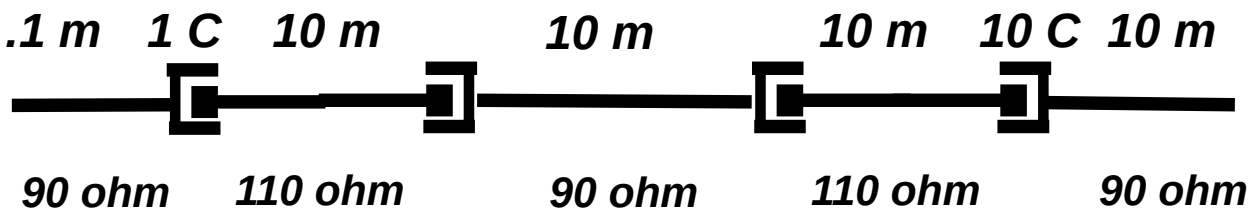
- 10 connectors separated by 100 meters
- Cables +/- 5%

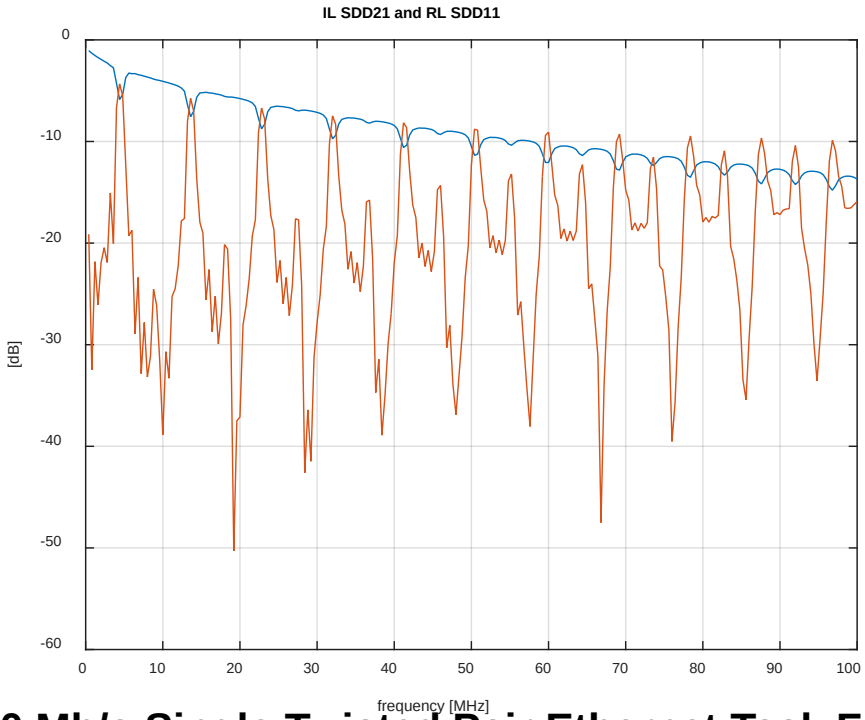




Link Segment RL Model

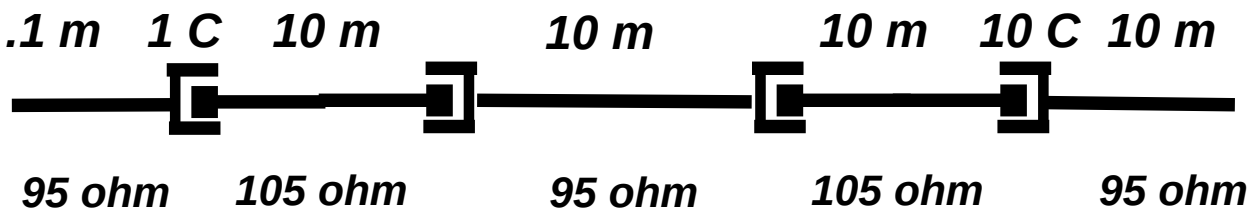
- 10 connectors separated by 10 meters
- Cables +/- 10%

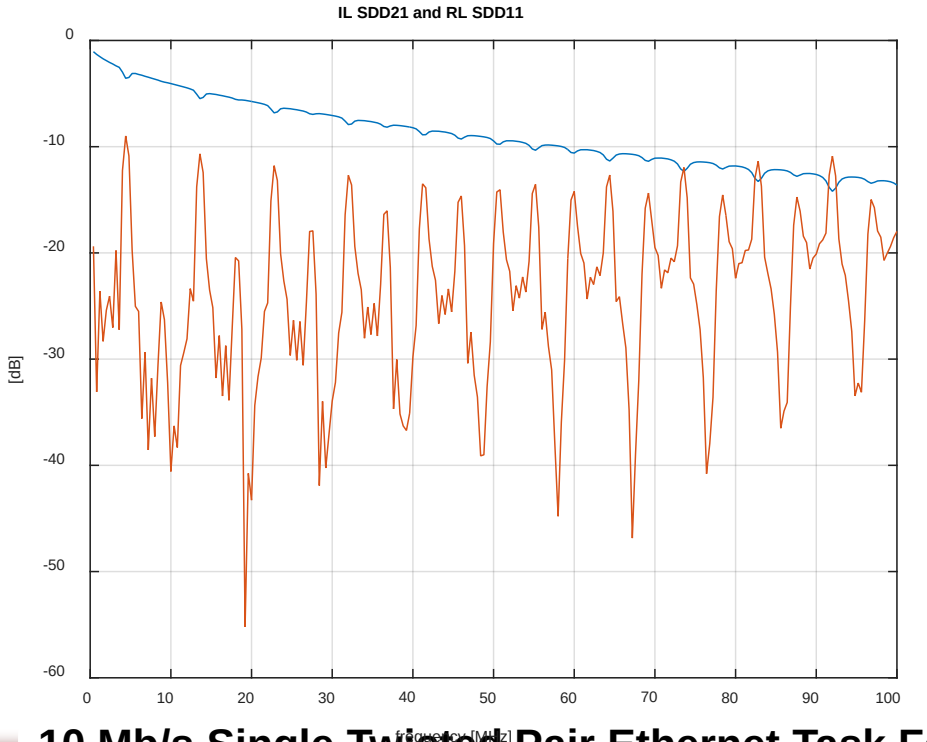




Link Segment RL Model

- 10 connectors separated by 10 meters
- Cables +/- 5%





Contribution on Channel RL

Return loss

1.1 Return loss

The return loss for the pair of a channel shall not exceed the limits computed, to one decimal place, using the formula of Table 1.

Table 1– Formula for return loss limits of a channel

Frequency MHz	Minimum return loss dB
$1 \le f \le 20$	19,0

The number of connection allowed is related to the link length:

- 10 connectons up to 1000m
- 8 connectons up to 750m
- 6 connectons up to 500m
- 4 connectons up to 200m

Note: This low value for return loss is to take care of cables with low impedance

•*Source: http://www.ieee802.org/3/10SPE/public/adhoc/Fritsche_Schicketanz_121416_10SPE_01a_ad%20hoc.pdf*

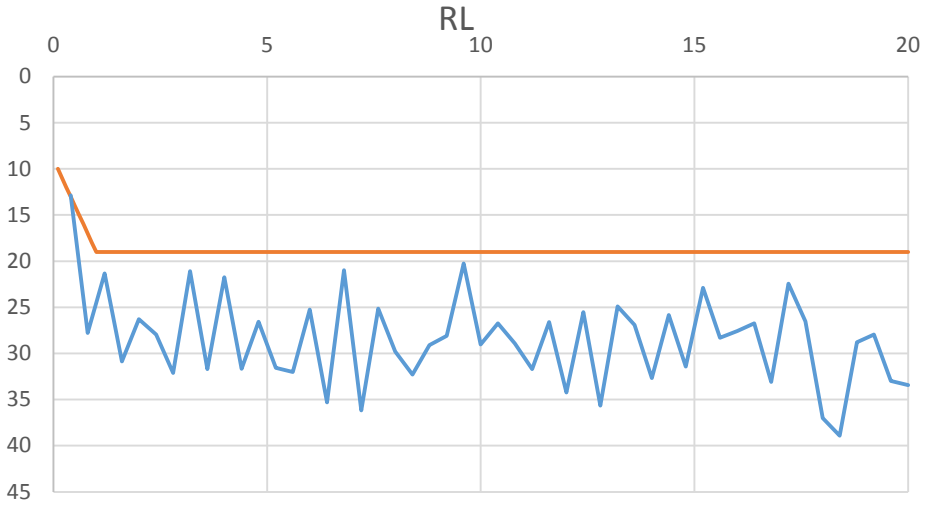
Category Cabling Channel RL

	Frequency (MHz)	Return loss (dB)
Category 3	$1 \le f \le 16$	n/s
Category 5e	$1 \le f < 20$ $20 \le f \le 100$	17 $17 - 10\log(f/20)$
Category 6	$1 \le f < 10$ $10 \le f < 40$ $40 \le f \le 250$	19 $24-5\log(f)$ $32-10\log(f)$
Category 6A	$1 \le f < 10$ $10 \le f < 40$ $40 \le f < 398.1$ $398.1 \le f \le 500$	19 $24-5\log(f)$ $32-10\log(f)$ 6

Link Segment Return Loss Proposal

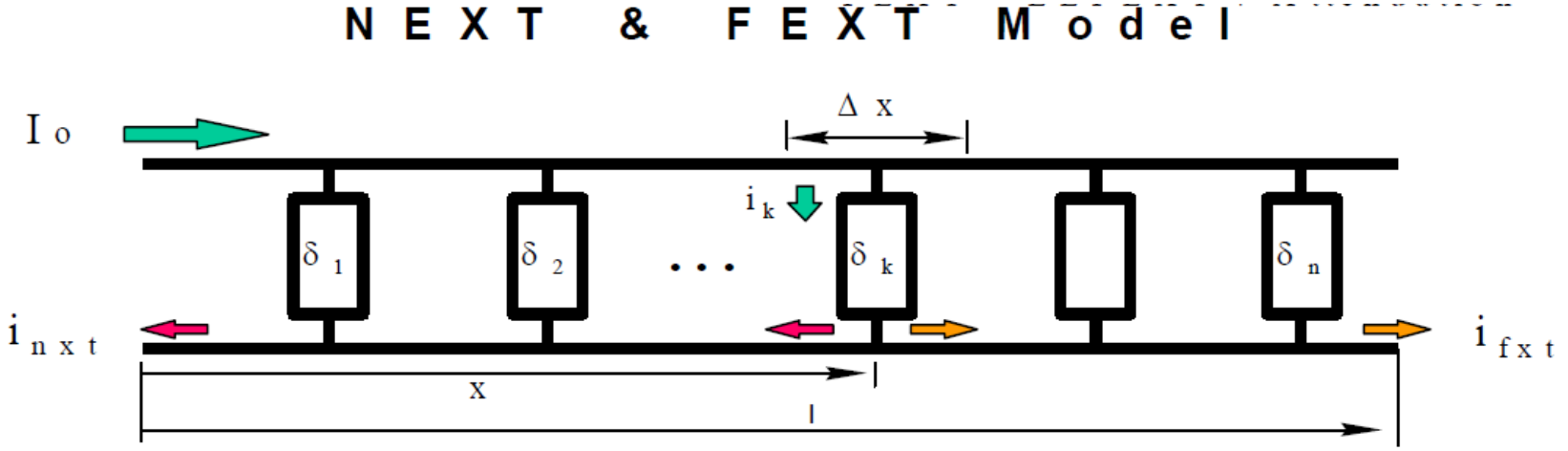
- The link segment shall meet the value in Equation (xx) at all frequencies from .1 MHz to 20 MHz. The reference impedance for the return loss specification is 100 ohms.

Return Loss (f) ≥ 9+f*10 dB [.1 MHz to 1 MHz]
19 dB [1MHz to 20 MHz]



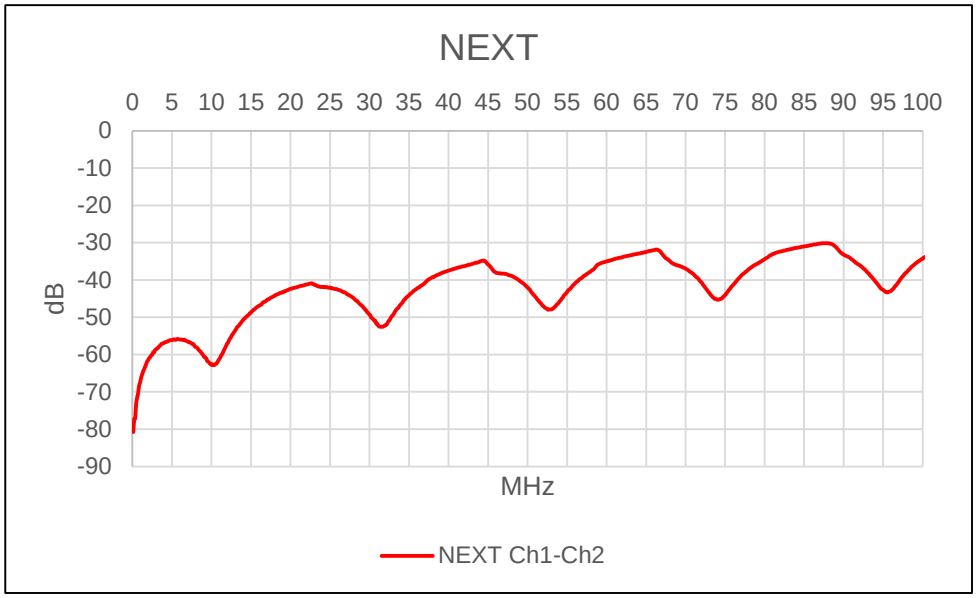
- Includes randomly distributed cable structural impedance

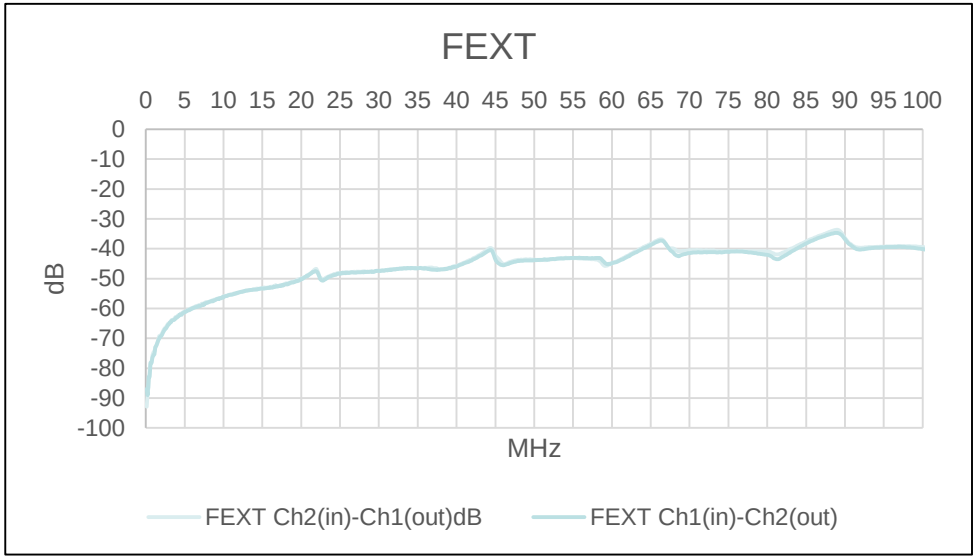
Link Segment Alien Crosstalk Proposal



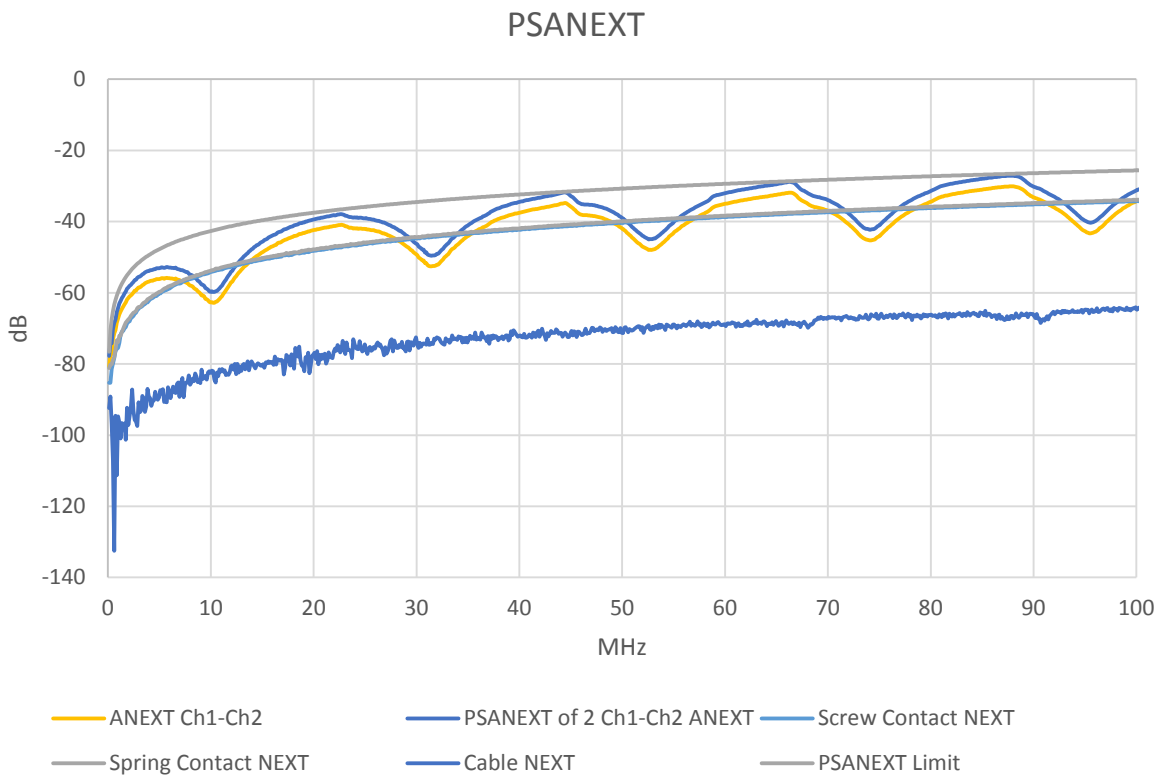
- For ANEXT, the current starts at the near end of the disturbing pair is coupled into the disturbed pair and travels back to the near end of the disturbed pair. The total distance traveled is (2x). The coupling current (inxt) experiences an attenuation and phase delay of ($e^{-2\lambda x}$) relative to the input signal.
- For AFEXT, the current starts at the near end of the disturbing pair couples into the disturbed pair and travels to the far end of the disturbed pair. The coupling occurs along the length of cable segments and at the connectors. The coupling current (ifxt) experiences an attenuation and phase delay of ($e^{-\lambda l}$) relative to the input signal where l is the length of the link segment.
  - The magnitude of AFEXT depends on link segment length, connector coupling and number, and the cable coupling.
  - Relative to connector, minimal cable coupling.

Alien Crosstalk Link Segment Measurements





Link Segment Alien Crosstalk Proposal (ANEXT)

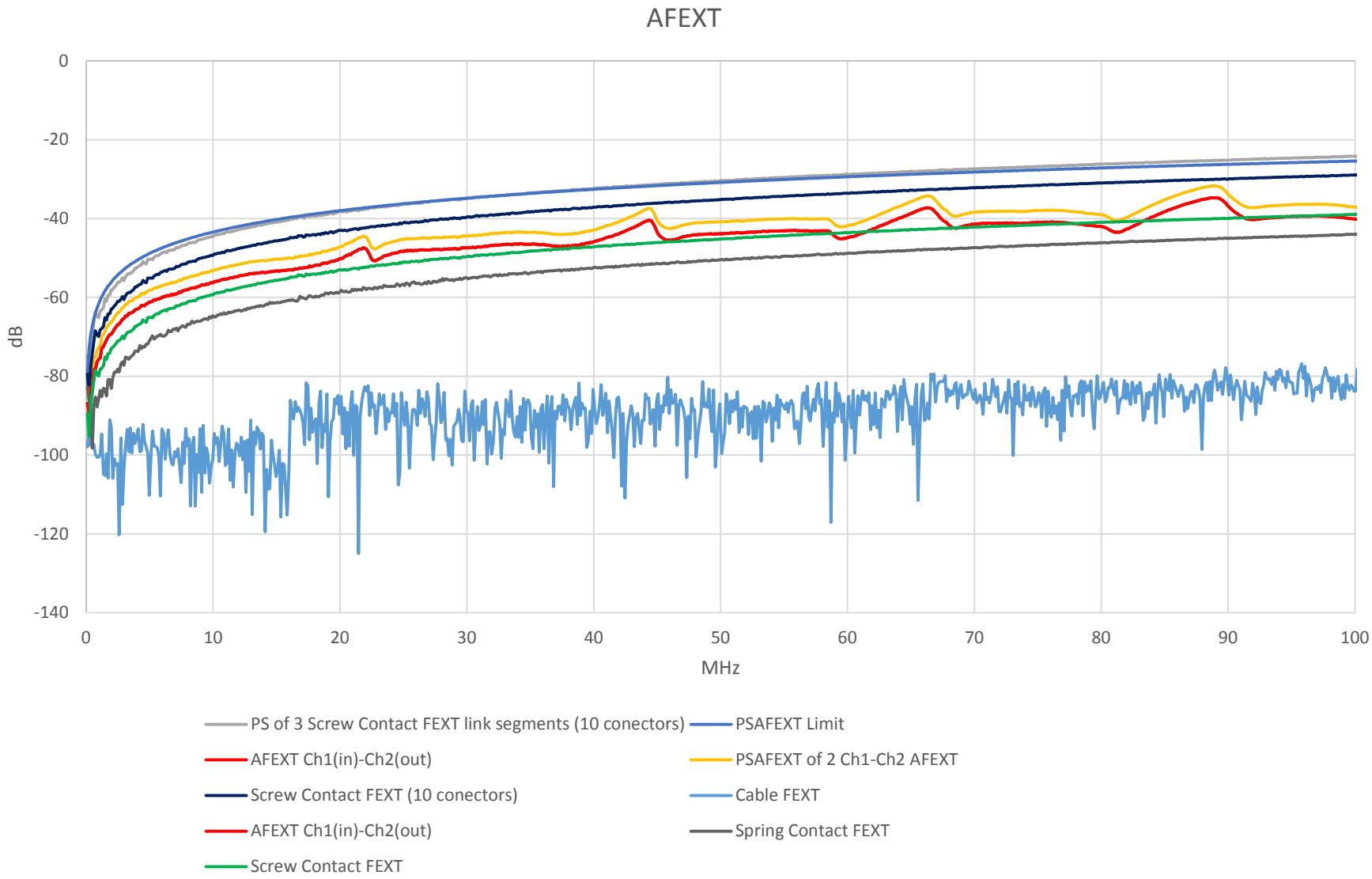


The alien NEXT coupled into a link segment is specified as the power sum of the individual alien NEXT disturbers. The link segment shall meet the values determined using Equation (xx) dB

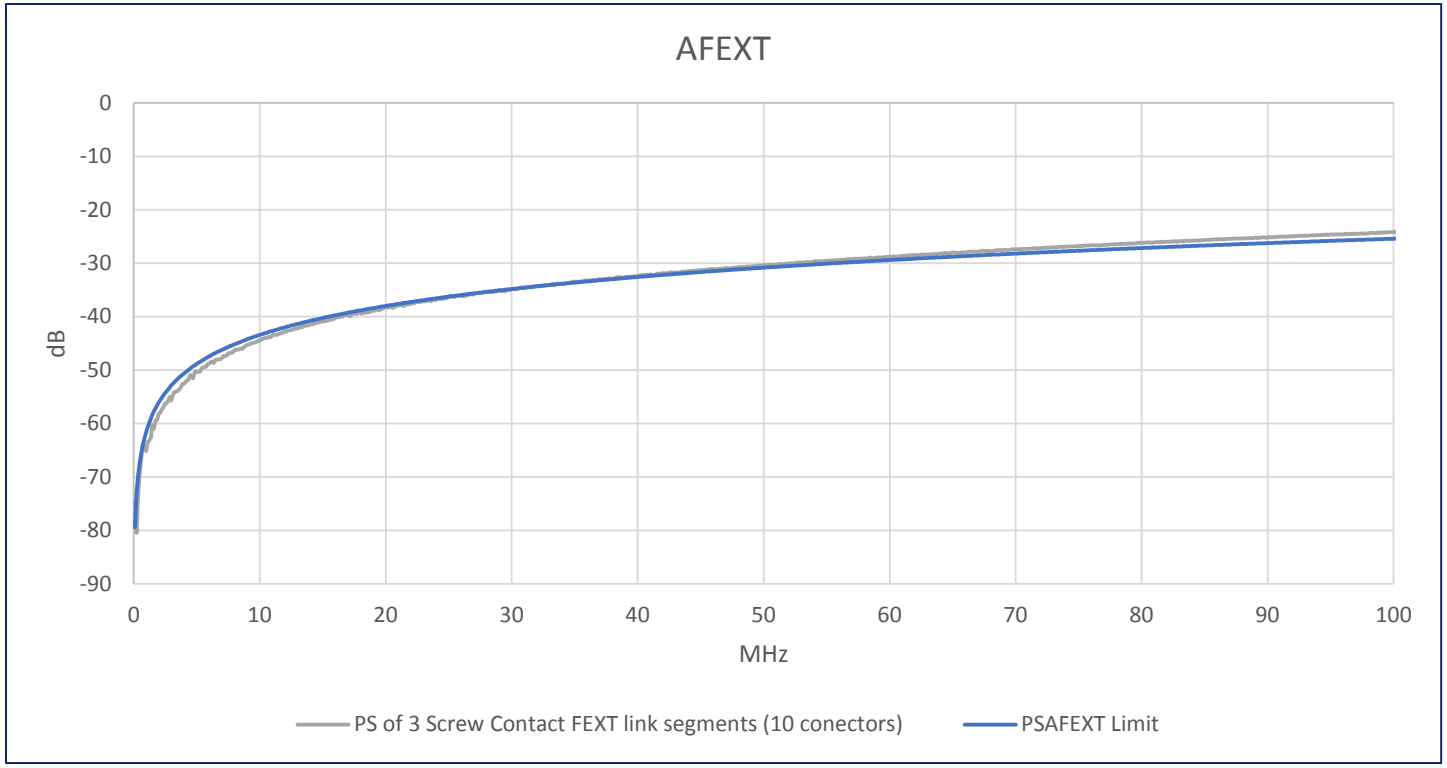
*ANEXT(f) ≥ =37.5-17*log(fMhz/20) (dB) (Note: >1 dB margin from measurement)*

where
f is the frequency in MHz; [.1 MHz to 20 MHz]

Link Segment Alien Crosstalk Proposal (AFEXT)



Link Segment Alien Crosstalk Proposal (AFEXT)



The alien FEXT coupled into a link segment is specified as the power sum of the individual alien FEXT disturbers. The link segment shall meet the values determined using Equation (xx) dB

*AFEXT(f) ≥ =38-18*log(fMhz/20) (dB)*

where
f is the frequency in MHz; [.1 MHz to 20 MHz]

Cable DC Resistance - ANSI/TIA-568-C.2-2009

- 6.4.1 DC resistance
  DC resistance shall be measured in accordance with ASTM D4566 for all horizontal cable pairs. For all categories of horizontal cable, the resistance of any conductor shall not exceed 9.38 Ω per 100 m (328 ft) at or corrected to a temperature of 20 °C.

  •.4 % increase per degree C (DC correction-ASTM Test Method B 193-(.393%))
  DC loop=

Temp degC	Conductor	DC Loop	%increase
20.00	9.38	18.76	
30.00	9.76	19.51	4
40.00	10.13	20.26	8
50.00	10.51	21.01	12
60.00	10.88	21.76	16
65.00	11.07	22.14	18

Connector DC Resistance - ANSI/TIA-568-C.2-2009

6.8.1 DC resistance

DC resistance shall be measured in accordance with ASTM D4566 at 20 ℃ ± 3 ℃ for all connecting hardware cable pairs.

> NOTE – DC resistance is a separate measurement from contact resistance as specified in Annex A. Whereas DC resistance is measured to determine the connector's ability of transmit direct current and low frequency signals, contact resistance is measured to determine the reliability and stability of individual electrical connections.

Category 3 connecting hardware DC resistance between the input and the output connections of the connecting hardware (not including the cable stub, if any) used to terminate 100 Ω twisted-pair cabling shall not exceed 0.3 Ω.

Category 5e, 6, and 6A connecting hardware DC resistance between the input and the output connections of the connecting hardware (not including the cable stub, if any) used to terminate 100 Ω twisted-pair cabling shall not exceed 0.2 Ω.

Channel DC Loop Resistance (100 m)

Channel (4 connectors):

•DC Resistance

	90 meters	90 meters	4 connectors	100 meter channel
degC	conductor	loop	2x(4x.3 ohm per connector)	with 10m ScTP patch (2.8 ohm)
20.00	8.44	16.88	2.40	22.08
30.00	8.78	17.56	2.40	22.76
40.00	9.12	18.23	2.40	23.43
50.00	9.46	18.91	2.40	24.11
60.00	9.79	19.59	2.40	24.79
65.00	9.96	19.92	2.40	25.12

100 ohm ScTP patch cords and cross-connect:

•TIA/EIA/IS-729- DC resistance - For 26 AWG conductors, the resistance of the conductors shall not exceed 14 ohm per 100 meters (328 ft) at or corrected to a temperature of 20 C. (DC correction-ASTM Test Method B 193-(.393%))

Max DC Loop = ~25 ohm

802.3cg Link Segment - copper cable DCR

AWG	Diameter(in)	Diameter(mm)	Diameter(m)	area (m^2)	Resistance (m)
14	0.064085	1.627754	0.001627754	2.08098E-06	0.0092
15	0.057069	1.449551	0.001449551	1.65028E-06	0.0116
16	0.050821	1.290858	0.001290858	1.30872E-06	0.0147
17	0.045257	1.149538	0.001149538	1.03785E-06	0.0185
18	0.040303	1.023689	0.001023689	8.2305E-07	0.0233
19	0.035890	0.911618	0.000911618	6.52703E-07	0.0294
20	0.031961	0.811816	0.000811816	5.17614E-07	0.0371
21	0.028462	0.722941	0.000722941	4.10483E-07	0.0468
22	0.025346	0.643795	0.000643795	3.25526E-07	0.0590
23	0.022571	0.573314	0.000573314	2.58152E-07	0.0744
24	0.020100	0.510549	0.000510549	2.04722E-07	0.0938
25	0.017900	0.454655	0.000454655	1.62351E-07	0.1183
26	0.015940	0.404881	0.000404881	1.28749E-07	0.1492
27	0.014195	0.360555	0.000360555	1.02102E-07	0.1881
28	0.012641	0.321083	0.000321083	8.09698E-08	0.2372
29	0.011257	0.285931	0.000285931	6.42115E-08	0.30
30	0.010025	0.254628	0.000254628	5.09217E-08	0.38
31	0.008927	0.226752	0.000226752	4.03824E-08	0.48
32	0.007950	0.201928	0.000201928	3.20245E-08	0.60

Reference conductor resistivity = 1.92*10^-8 Ω m

802.3cg Link Segment - copper cable DCR

AWG	Diameter(in)	Diameter(mm)	dB/m at 4 MHz solid	dB/m at 4 MHz stranded	Cable @ 4 MHz stranded @ IL limit (dB)	Cable (m) @ IL limit	10*connectors (dB)	Channel Il (dB)
14	0.064085	1.627754	0.013389	0.016067	25.54	1589	0.4	25.94
15	0.057069	1.449551	0.015035	0.018042	25.54	1415	0.4	25.94
16	0.050821	1.290858	0.016883	0.020260	25.54	1261	0.4	25.94
17	0.045257	1.149538	0.018959	0.022751	25.54	1123	0.4	25.94
18	0.040303	1.023689	0.021290	0.025548	25.55	1000	0.4	25.95
19	0.035890	0.911618	0.023907	0.028688	25.55	891	0.4	25.95
20	0.031961	0.811816	0.026846	0.032215	25.55	793	0.4	25.95
21	0.028462	0.722941	0.030146	0.036175	25.55	706	0.4	25.95
22	0.025346	0.643795	0.033852	0.040623	25.54	629	0.4	25.94
23	0.022571	0.573314	0.038014	0.045617	25.54	560	0.4	25.94
24	0.020100	0.510549	0.042687	0.051225	25.54	499	0.4	25.94
25	0.017900	0.454655	0.047935	0.057522	25.54	444	0.4	25.94
26	0.015940	0.404881	0.053828	0.064594	25.54	395	0.4	25.94
27	0.014195	0.360555	0.060446	0.072535	25.54	352	0.4	25.94
28	0.012641	0.321083	0.067876	0.081452	25.54	314	0.4	25.94
29	0.011257	0.285931	0.076221	0.091465	25.54	279	0.4	25.94
30	0.010025	0.254628	0.085591	0.102710	25.54	249	0.4	25.94
31	0.008927	0.226752	0.096114	0.115336	25.54	221	0.4	25.94
32	0.007950	0.201928	0.107929	0.129515	25.54	197	0.4	25.94

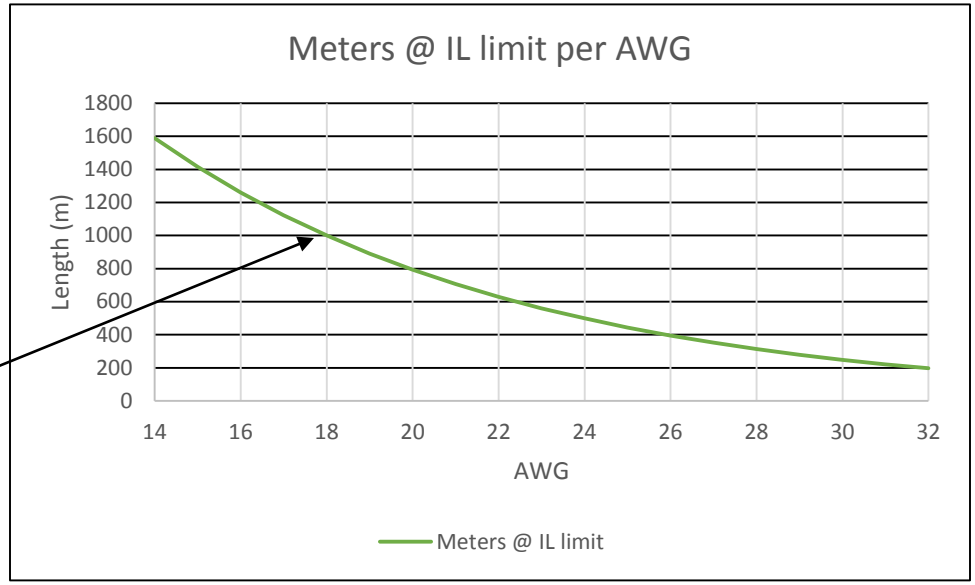
Link segment IL - 25.95 dB @ 4 MHz

802.3cg Link Segment - DCR

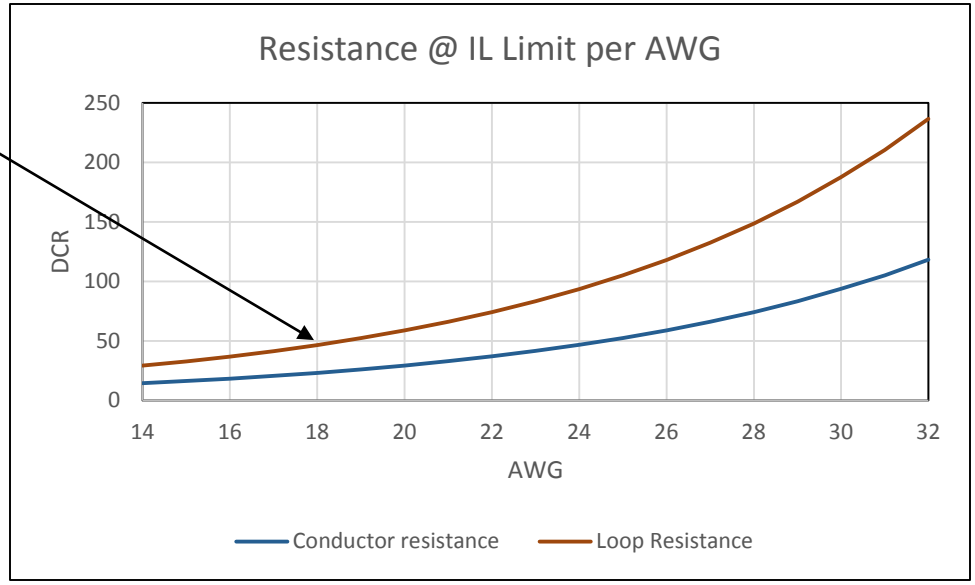
AWG	Diameter(in)	Diameter(mm)	Diameter(m)	area (m^2)	Resistance per meter (ohm)	Length @ IL limit (m)	Conductor resistance @ IL limit (ohm)	Loop resistance @ IL limit (ohm)	10 connector DCR	Link segment resistance @ IL limit (ohm)
14	0.064085	1.627754	0.001627754	2.08098E-06	0.0092	1589	14.67	29.33	4.00	33.33
15	0.057069	1.449551	0.001449551	1.65028E-06	0.0116	1415	16.47	32.94	4.00	36.94
16	0.050821	1.290858	0.001290858	1.30872E-06	0.0147	1261	18.50	37.00	4.00	41.00
17	0.045257	1.149538	0.001149538	1.03785E-06	0.0185	1123	20.78	41.55	4.00	45.55
18	0.040303	1.023689	0.001023689	8.2305E-07	0.0233	1000	23.33	46.66	4.00	50.66
19	0.035890	0.911618	0.000911618	6.52703E-07	0.0294	891	26.20	52.40	4.00	56.40
20	0.031961	0.811816	0.000811816	5.17614E-07	0.0371	793	29.42	58.84	4.00	62.84
21	0.028462	0.722941	0.000722941	4.10483E-07	0.0468	706	33.04	66.07	4.00	70.07
22	0.025346	0.643795	0.000643795	3.25526E-07	0.0590	629	37.10	74.19	4.00	78.19
23	0.022571	0.573314	0.000573314	2.58152E-07	0.0744	560	41.66	83.31	4.00	87.31
24	0.020100	0.510549	0.000510549	2.04722E-07	0.0938	499	46.78	93.55	4.00	97.55
25	0.017900	0.454655	0.000454655	1.62351E-07	0.1183	444	52.53	105.05	4.00	109.05
26	0.015940	0.404881	0.000404881	1.28749E-07	0.1492	395	58.98	117.96	4.00	121.96
27	0.014195	0.360555	0.000360555	1.02102E-07	0.1881	352	66.23	132.46	4.00	136.46
28	0.012641	0.321083	0.000321083	8.09698E-08	0.2372	314	74.37	148.74	4.00	152.74
29	0.011257	0.285931	0.000285931	6.42115E-08	0.30	279	83.51	167.02	4.00	171.02
30	0.010025	0.254628	0.000254628	5.09217E-08	0.38	249	93.78	187.55	4.00	191.55
31	0.008927	0.226752	0.000226752	4.03824E-08	0.48	221	105.30	210.60	4.00	214.60
32	0.007950	0.201928	0.000201928	3.20245E-08	0.60	197	118.24	236.49	4.00	240.49

- Use Table xx as 802.3cg link segment DCR characteristics.

802.3cg Link Segment - copper cable DCR



1 km 18 AWG
DCR = 46.66 Ω



802.3cg Link Segment – Connector DCR

- shall not exceed 0.2 Ω.

802.3cg Link Segment – DCR

- Link segment DCR (Ω) = Link segment loop resistance (Ω) + Connector resistance*10 (Ω) (TBD)

Summary

- **Link Segment baseline proposal for Industrial Applications**
- **Link segment baseline to address objectives and to generate first draft**
- **Link Segment developed in conjunction with the Industrial networking industries**