Tx Function to Rx Function Channel Considerations

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Purpose

- **Tx Function to Rx function channel considerations**

Background – 802.3bj/by/cd/ck

IEEE Standards - 25/50/100 Gb/s Operation – Shielded Cable

- 802.3bj - 100GBASE-CR4 - 2-level PAM - 25.78125 GBd per lane – Channel loss budget (35 dB@12.8906 GHz). Link segment up to at least 5 m (22.8 dB@12.8906 GHz)

- 802.3by - 25GBASE-CR and 25GBASE-CR-S - 2-level PAM - 25.78125 GBd per lane – Channel loss budgets (35 dB, 29 dB, 28.02 dB)@12.8906 GHz . Link Segments 3-5 m (22.48 dB, 16.48 dB, 15.50 dB)@12.8906 GHz reach depending on FEC

- 802.3cd - 50GBASE-CR, 100GBASE-CR2, and 200GBASE-CR4– PAM4 - 26.5625 GBd per lane – Channel loss budgets 30 dB@13.28 GHz. Link Segment up to at least 3 m reach 17.6 dB@13.28 GHz.

- 802.3ck - 100GBASE-CR1, 200GBASE-CR2, and 400GBASE-CR4 – PAM4 - 53.125 GBd per lane – Channel loss budgets 28.5 dB@26.56 GHz. Link Segment up to at least 3 m reach 19.75 dB@26.56 GHz

Background – 802.3bj/by/cd/ck

- The channel is defined between the transmitter and receiver blocks to include the transmitter and receiver differential controlled impedance printed circuit board and the cable assembly (link segment).

- Test points provide specification references for channel and cable assembly and RX and TX

- Test fixtures enable testing at test points – module compliance board (MCB); host compliance board (HCB)
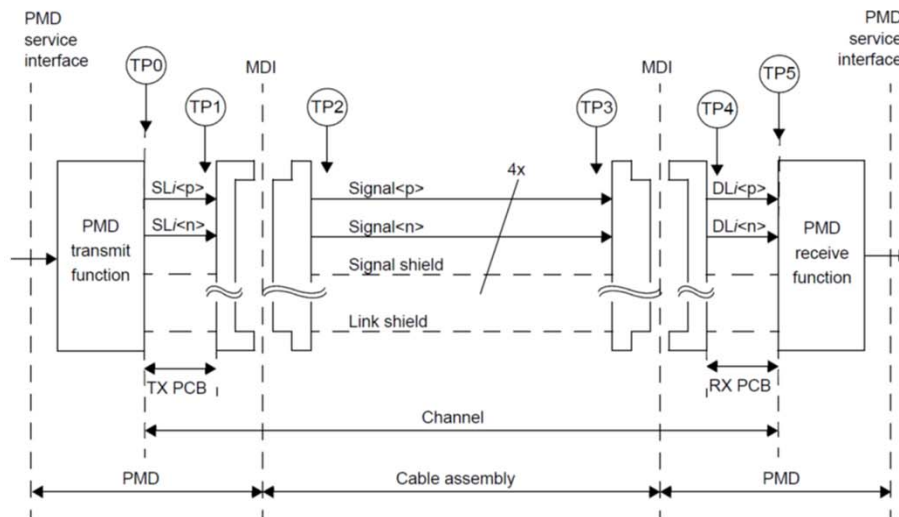
Test points	Description
TP0 to TP5	The 100GBASE-CR4 channel including the transmitter and receiver differential controlled impedance printed circuit board insertion loss and the cable assembly insertion loss.
TP1 to TP4	All cable assembly measurements are to be made between TP1 and TP4 as illustrated in Figure 92–2. The cable assembly test fixture of Figure 92–17 or its equivalent, is required for measuring the cable assembly specifications in 92.10 at TP1 and TP4.
TP0 to TP2 TP3 to TP5	A mated connector pair has been included in both the transmitter and receiver specifications defined in 92.8.3 and 92.8.4. The recommended maximum insertion loss from TP0 to TP2 or TP3 to TP5 including the test fixture is specified in 92.8.3.6.
TP2	Unless specified otherwise, all transmitter measurements defined in Table 92–6 are made at TP2 utilizing the test fixture specified in 92.11.1.
TP3	Unless specified otherwise, all receiver measurements and tests defined in 92.8.4 are made at TP3 utilizing the test fixture specified in 92.11.1.

Background – 802.3bj/by/cd/ck

- TP0 and TP5 test point parameters and channel characteristics (802.3ck Annex 162A - (informative))
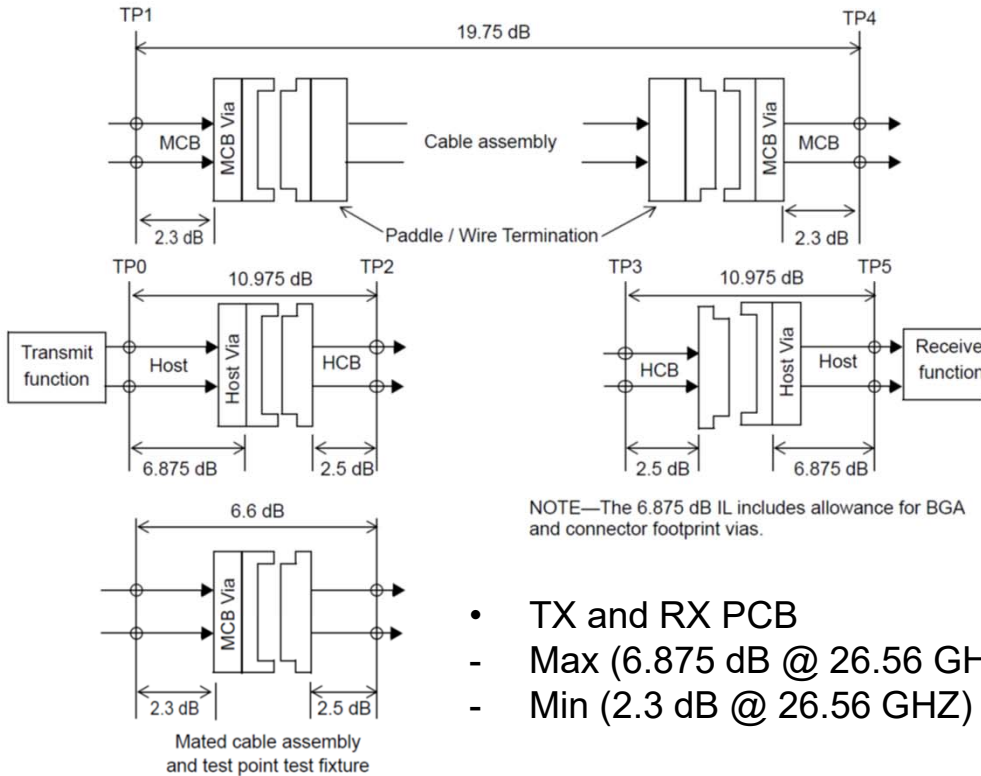- Test fixture – module compliance board (MCB); host compliance board (HCB)

Figure 162A–3—Cable assembly, host, and test fixture insertion loss at 26.56 GHz

NOTE—2.3 dB MCB PCB IL includes the RF connector (up to the RF connector reference plane). The MCB via allowance is 0.2 dB.

NOTE—The 6.875 dB IL includes allowance for BGA and connector footprint vias.

- TX and RX PCB
- Max (6.875 dB @ 26.56 GHZ)
- Min (2.3 dB @ 26.56 GHZ)

Channel IL = 28.5 dB @ 26.56 GHz = 2*(6.875+1.6)+11.55

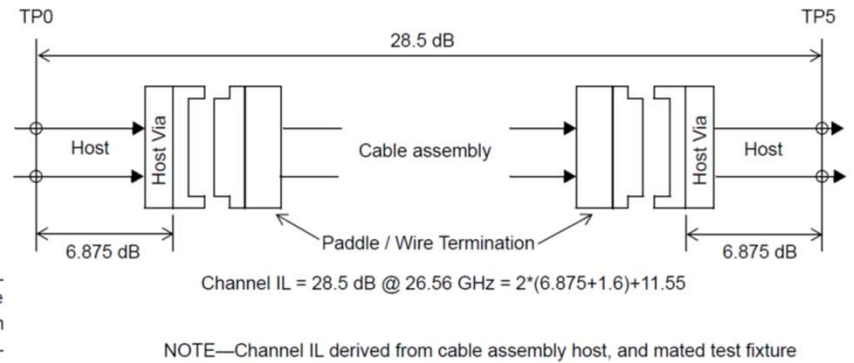NOTE—Channel IL derived from cable assembly host, and mated test fixture

Figure 162A–4—Channel insertion loss at 26.56 GHz

Table 162A–1—Insertion loss budget values at 26.56 GHz

Parameter	Value	Units
IL_{Chmax}	28.5	dB
IL_{Camax}	19.75	dB
IL_{Chmin}	19.75	dB
IL_{Camin}	11.0	dB
$IL_{MaxHost}$	10.975	dB
$IL_{MatedTF}$	6.6	dB

Tx Function to Rx function channel considerations

IEEE Std 802.3ch-2020 - Annex 149C
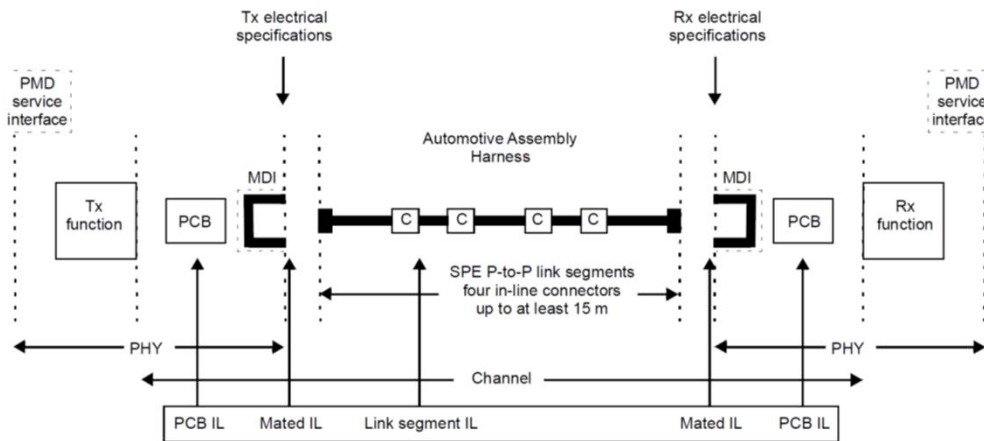
149C.2 Differential printed circuit board trace loss

The recommended maximum and minimum printed circuit board trace insertion losses are as specified in Equation (149C–1) and Equation (149C–2), respectively.

$$IL_{PCB(76.2mm)} = \left(0.0071 \times \sqrt{\frac{f}{1000}} + 0.0045 \times \frac{f}{1000}\right) \times 76.2 \ (dB) \qquad (149C–1)$$

$$IL_{PCB(25.4mm)} = \left(0.0071 \times \sqrt{\frac{f}{1000}} + 0.0045 \times \frac{f}{1000}\right) \times 25.4 \ (dB) \qquad (149C–2)$$

where

f is the frequency in MHz; $1 \leq f \leq F_{max}$

$F_{max} = 4000 \times S$ (149C–3)

See Table 149–1 for the definition of S.

149C.3 Channel insertion loss

The channel topology with the 76.2 mm PCB insertion loss is determined using Equation (149C–4), Equation (149C–5), and Equation (149C–6).

$$IL_{channel} = 2 \times IL_{PCB(76.2mm)} + 2 \times IL_{MDI} + IL_{LinkSegment} \qquad (149C–4)$$

$$IL_{MDI} = 0.1 \times \sqrt{\frac{f}{1000}} \qquad (149C–5)$$

$$IL_{LinkSegment} = 0.002 \times f + 0.68 \times f^{0.45} \qquad (149C–6)$$

where

f is the frequency in MHz; $1 \leq f \leq F_{max}$

F_{max} is defined by Equation (149C–3)

Table 149C–1—Channel insertion loss for each PHY type

PHY	Rate MBd	Bandwidth (MHz)	$IL_{PCB(76.2mm)}$ (dB)	$IL_{LinkSegment}$ (dB)	IL_{MDI} (dB)	$IL_{channel}$ (dB)
2.5GBASE-T1	1406.25	703.125	0.6948	14.3982	0.084	15.955
5GBASE-T1	2812.5	1406.25	1.1238	20.56	0.119	23.045
10GBASE-T1	5625	2812.5	1.8717	29.8688	0.168	33.948

Tx Function to Rx function channel considerations

Annex 149C - IEEE Std 802.3ch-2020

149C.4 Channel return loss

TX MDI | LINK SEGMENT | RX MDI

Figure 149C–2—Tx/Rx function channel topology

149C.4.2 Link segment return loss
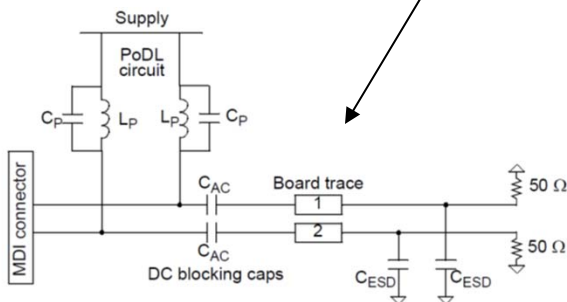
$$RL = 20\log_{10}|\Gamma|$$

$$\Gamma = \frac{Z_{in} - Z_s}{Z_{in} + Z_s}$$

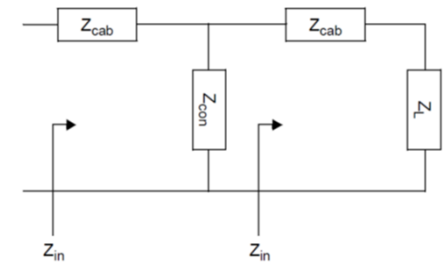Figure 149C–3—Example implementation MDI to Tx function

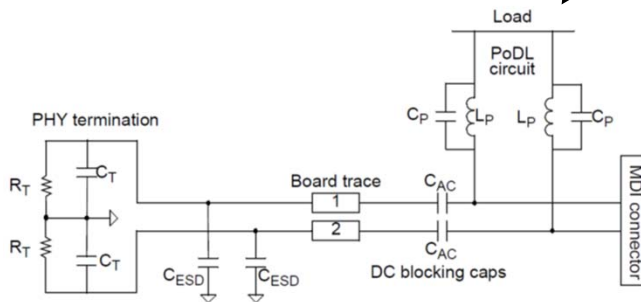Figure 149C–5—Two–port ladder network

Figure 149C–4—Example implementation Rx function to MDI
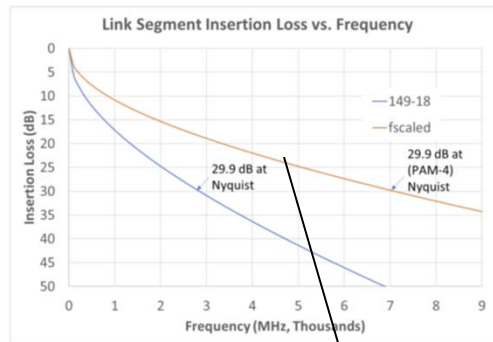
Table 149C–2—Analysis parameters and values

Element	Unit	Minimum	Nominal	Maximum
R_T	Ω	45	50	55
Z_O	Ω	45	50	55
C_T	pF	—	0.1	—
L_P	µH	—	4.7	—
C_P	pF	—	0.18	—
C_{ESD}	pF	—	0.4	—
C_{AC}	nF	—	10	—

Channel Insertion Loss – 802.3cy

Frequency Scaled link segment IL

$$IL \leq 0.002\left(\frac{f}{2.5}\right) + 0.68\left(\frac{f}{2.5}\right)^{0.45}$$

This is a starting point
Same IL at Nyquist as .3ch

Link Segment Insertion Loss vs. Frequency

— 149-18
— fscaled

29.9 dB at Nyquist

29.9 dB at (PAM-4) Nyquist

https://www.ieee802.org/3/cy/public/nov20/zimmerman_3cy_01a_1120.pdf

$$IL_{Channel} \leq 2 \cdot IL_{PCB(76.2mm)} + 2 \cdot IL_{MDI} + IL_{Linksegment} \quad \textbf{(dB)}$$

$$IL_{PCB(76.2mm)} \leq \left(0.0071\sqrt{f/2.5 \cdot 10^{\wedge}3} + 0.0045 \cdot f/2.5 \cdot 10^{\wedge}3\right) \cdot 76.2 \quad \textbf{(dB)}$$

$$IL_{Linksegment} \leq 0.002\left(\frac{f}{2.5}\right) + 0.68\left(\frac{f}{2.5}\right)^{0.45} \quad \textbf{(dB)}$$

$$IL_{MDI} \leq 0.1\sqrt{\frac{f}{10^{\wedge}3}} \quad \textbf{(dB)}$$

149C.3 Channel insertion loss

The channel topology with the 76.2 mm PCB insertion loss is determined using Equation (149C–4), Equation (149C–5), and Equation (149C–6).

$$IL_{channel} = 2 \times IL_{PCB(76.2mm)} + 2 \times IL_{MDI} + IL_{LinkSegment} \quad (149C–4)$$

$$IL_{MDI} = 0.1 \times \sqrt{\frac{f}{1000}} \quad (149C–5)$$

$$IL_{LinkSegment} = 0.002 \times f + 0.68 \times f^{0.45} \quad (149C–6)$$

where
- f is the frequency in MHz; $1 \leq f \leq F_{max}$
- F_{max} is defined by Equation (149C–3)

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The recommended maximum and minimum printed circuit board trace insertion losses are as specified in Equation (149C–1) and Equation (149C–2), respectively.

$$IL_{PCB(76.2mm)} = \left(0.0071 \times \sqrt{\frac{f}{1000}} + 0.0045 \times \frac{f}{1000}\right) \times 76.2 \quad (\text{dB}) \quad (149C–1)$$

$$IL_{PCB(25.4mm)} = \left(0.0071 \times \sqrt{\frac{f}{1000}} + 0.0045 \times \frac{f}{1000}\right) \times 25.4 \quad (\text{dB}) \quad (149C–2)$$

where
- f is the frequency in MHz; $1 \leq f \leq F_{max}$
- $F_{max} = 4000 \times S$ (149C–3)

See Table 149–1 for the definition of S.

PHY	MBd	Bandwidth (MHz)	PCBILdb/76.2mm	IL Link Segment	IL MDI	IL Channel Max
2.5GBASE-T1	1406.25	703.125	0.6948	14.3982	0.084	15.955
5GBASE-T1	2812.5	1406.25	1.1238	20.5600	0.119	23.045
10GBASE-T1	5625	2812.5	1.8717	29.8688	0.168	33.948
25GBASE-T1	14062.25	7031.25	1.8717	29.8688	0.168	33.948

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TX and RX PCB Loss

IEEE 802.3bj/by/cd

Host Tx and Rx PCB losses

- Transmitter and receiver differential printed circuit board trace loss

GHz	dB/in
1	0.1856
6.5	0.8971
7	0.9557
12.89	1.5924
14	1.702

Attenuation* (dB/in) at:	1 GHz	6.5 GHz	7 GHz	12.89 GHz	14 GHz
Meg6_LowSR – Wide	0.0951	0.4159	0.4433	0.7562	0.8127
Meg6_LowSR – Narrow	0.1466	0.5849	0.6205	1.0152	1.0847
Meg6_HighSR – Wide	0.1175	0.5960	0.6367	1.0891	1.1688
Meg6_HighSR – Narrow	0.1856	0.8971	0.9557	1.5924	1.7020
ImpFR4_LowSR – Wide	0.1202	0.6096	0.6541	1.1772	1.2734
ImpFR4_LowSR – Narrow	0.1717	0.7794	0.8323	1.4410	1.5512
ImpFR4_HighSR – Wide	0.1427	0.7904	0.8484	1.5158	1.6367
ImpFR4_HighSR – Narrow	0.2106	1.0930	1.1692	2.0283	2.1813

PROPOSED PARAMETERS; GRAPHS ON PREVIOUS SLIDE

*using Algebraic Model v2.02a -- see backup slides for values entered in Model

Proposal for Defining Material Loss
26-Jan 12

Elizabeth Kochuparambil
Joel Goergen

Cisco

http://www.ieee802.org/3/bj/public/jan12/kochuparambil_01a_0112.pdf

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802.3bj Cu specifications

http://www.ieee802.org/3/bj/public/may12/diminico_01a_0512.pdf

PHY	MBd	Bandwidth (MHz)	PCBILdb/76.2mm	PCBILdb/in
25GBASE-T1	14062.25	7031.25	1.8717	0.624

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# Dk Df Algebraic Model

Background

- Model first shown in Kochuparambil_01_1111
  - Filling a gap – allows us to talk the same "language"
  - Great for initial channel loss discussions!
- Model is made public:
  http://www.ieee802.org/3/bj/public/tools.html
- No secret sauce
  - All equations used in the model are given in reference document
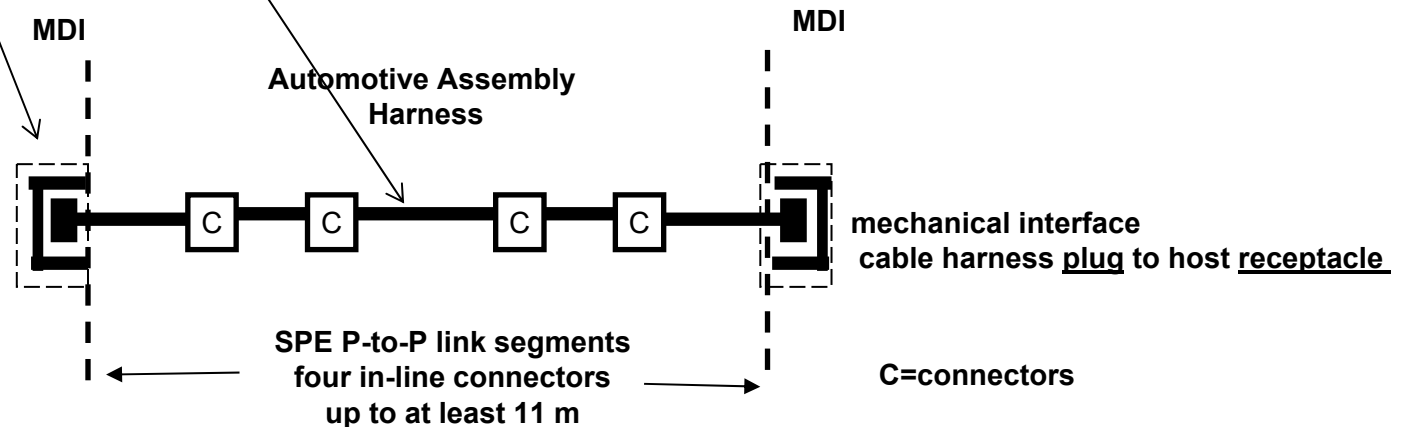 - Also in public Tools folder; link above
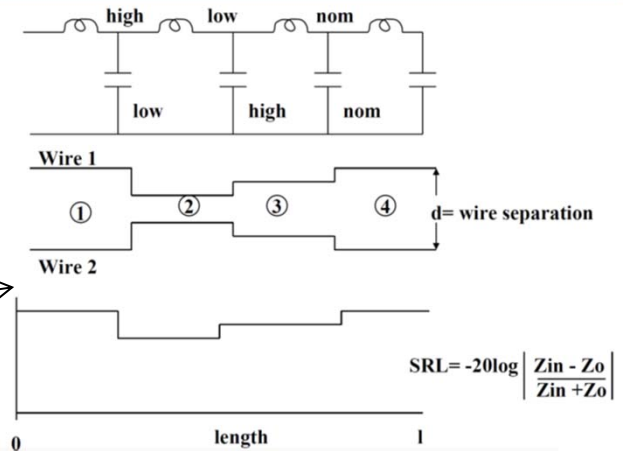
Insertion Loss Deviation

Echo Response in Time

- The echo pulse response consists of major reflections from a maximum of 6 discontinuities in the link segment
  - 2 MDI interfaces
  - No more than 4 connectors

- There are micro reflections, in between discontinuities and spread throughout the cable, due to cable inhomogeneity (nonuniform characteristic impedance)
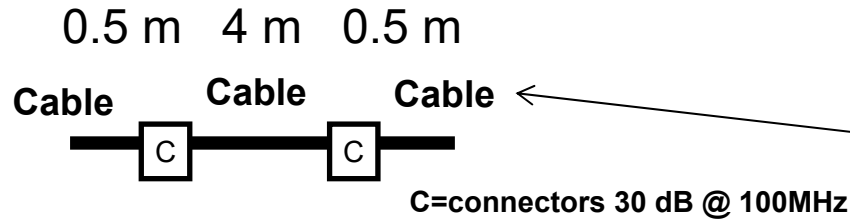
https://grouper.ieee.org/groups/802/3/cy/public/adhoc/sedarat_3cy_01_0920.pdf
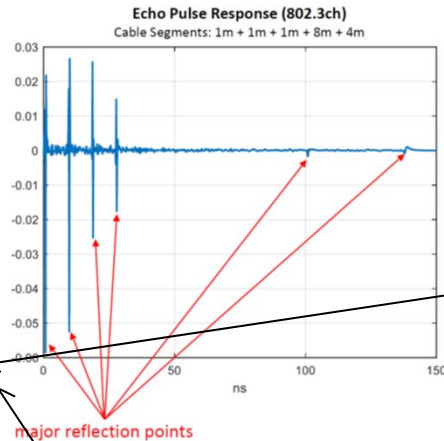
Echo Pulse Response (802.3ch)
Cable Segments: 1m + 1m + 1m + 8m + 4m

major reflection points

Structural Return Loss (SRL) - Structural Variation Associated With Impedance Variations Of A Cable

high   low   nom

low   high   nom

Wire 1

① ② ③ ④   d= wire separation

Wire 2

Z

$$SRL = -20\log\left|\frac{Zin - Zo}{Zin + Zo}\right|$$

0   length   l

MDI

MDI

Automotive Assembly Harness

mechanical interface cable harness <u>plug</u> **to host** <u>receptacle</u>

SPE P-to-P link segments four in-line connectors up to at least 11 m

C=connectors

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Insertion Loss Deviation

0.5 m   4 m   0.5 m

Cable   Cable   Cable

C=connectors 30 dB @ 100MHz

Return loss is computed by multiplication of transmission matrices for each component (cable and connectors) in the link segment. Each component is modeled by its transmission matrix. Cable structure is added as pseudorandom impedance to asymptotic cable impedance.
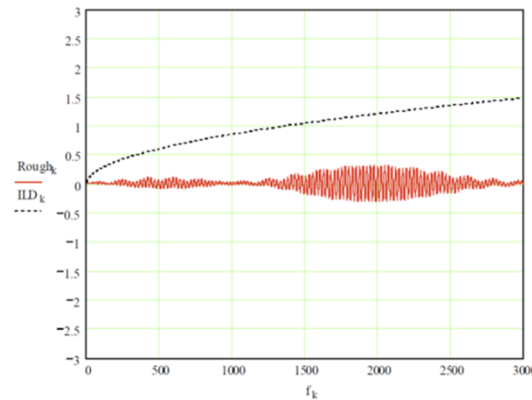
Structural Return Loss (SRL) - Structural Variation Associated With Impedance Variations Of A Cable

high   low   nom

low   high   nom

Wire 1

① ② ③ ④   d= wire separation

Wire 2

Z

ΔL

$$SRL = -20\log\left|\frac{Z_{in} - Zo}{Z_{in} + Zo}\right|$$

0   length   l

$$\begin{bmatrix} A & B \\ C & D \end{bmatrix} = \prod_k [T_k] \qquad Z_{in} = \frac{A + \dfrac{B}{100}}{C + \dfrac{D}{100}} \qquad RL = -20\log\left(\frac{Z_{in} - 100}{Z_{in} + 100}\right)$$

Cable Insertion Loss Specification Scaled to Length of Channel
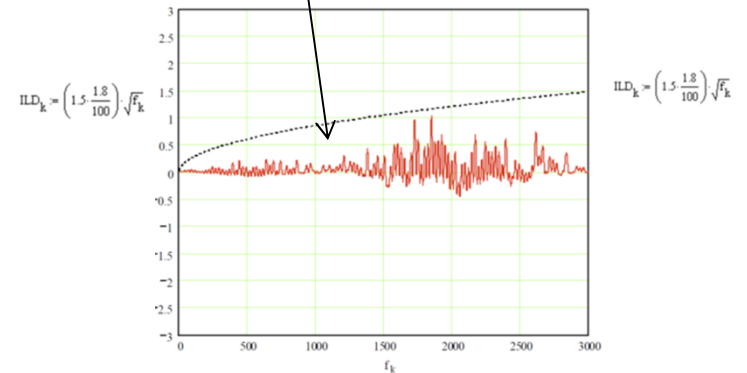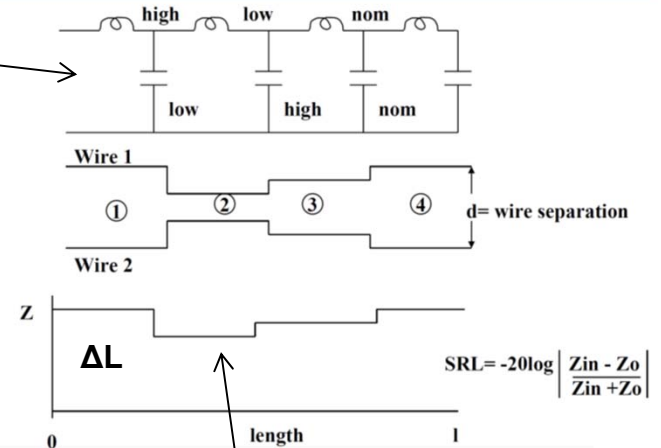
$$Atten_k := \frac{Att_k \cdot x_9}{100}$$

Insertion Loss Deviation Channel IL - Cable IL spec

$$Rough_k := 1 \cdot \left(IL_k - Atten_k\right)$$

$$ILD_k := \left(1.5 \frac{1.8}{100}\right)\sqrt{F_k}$$

$$ILD_k := \left(1.5 \frac{1.8}{100}\right)\sqrt{F_k}$$

cable without structure

cable with structure added pseudo-random Z ΔL

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93A.3 Fitted insertion loss

The fitted insertion loss as a function of frequency is given by Equation (93A–51).

$$IL_{fitted}(f) = a_0 + a_1\sqrt{f} + a_2 f + a_4 f^2 \tag{93A–51}$$

Denote the insertion loss, in dB, measured at frequency f_n as $IL(f_n)$. Given the insertion loss measured at N uniformly-spaced frequencies from start frequency f_{min} to stop frequency f_{max} with step no larger than Δf, the coefficients for the fitted insertion loss shall be calculated as follows.

Define the weighted frequency matrix F using Equation (93A–52).

$$F = \begin{bmatrix} 10^{-IL(f_1)/20} & \sqrt{f_1}10^{-IL(f_1)/20} & f_1 10^{-IL(f_1)/20} & f_1^2 10^{-IL(f_1)/20} \\ 10^{-IL(f_2)/20} & \sqrt{f_2}10^{-IL(f_2)/20} & f_2 10^{-IL(f_2)/20} & f_2^2 10^{-IL(f_2)/20} \\ \cdots & \cdots & \cdots & \cdots \\ 10^{-IL(f_N)/20} & \sqrt{f_N}10^{-IL(f_N)/20} & f_N 10^{-IL(f_N)/20} & f_N^2 10^{-IL(f_N)/20} \end{bmatrix} \tag{93A–52}$$

Define the weighted insertion loss vector L using Equation (93A–53).

$$L = \begin{bmatrix} IL(f_1)10^{-IL(f_1)/20} \\ IL(f_2)10^{-IL(f_2)/20} \\ \cdots \\ IL(f_N)10^{-IL(f_N)/20} \end{bmatrix} \tag{93A–53}$$

The fitted insertion loss coefficients are then given by Equation (93A–54).

$$\begin{bmatrix} a_0 \\ a_1 \\ a_2 \\ a_4 \end{bmatrix} = (F^T F)^{-1} F^T L \tag{93A–54}$$

The values assigned to f_{min}, f_{max}, and Δf are defined by the Physical Layer specification that invokes this method.

93A.4 Insertion loss deviation

The insertion loss deviation $ILD(f)$ is the difference between the measured insertion loss $IL(f)$ and the fitted insertion loss $IL_{fitted}(f)$ (see 93A.3) as shown in Equation (93A–55).

$$ILD(f) = IL(f) - IL_{fitted}(f) \tag{93A–55}$$

A figure of merit for a channel that is based on $ILD(f)$ is given by Equation (93A–56). In Equation (93A–56), f_n are the frequencies considered in the computation of the fitted insertion loss and $W(f_n)$ is the weight at each frequency as defined by Equation (93A–57).

$$FOM_{ILD} = \left[\frac{1}{N} \sum_n W(f_n) ILD^2(f_n) \right]^{1/2} \tag{93A–56}$$

$$W(f_n) = \text{sinc}^2(f_n/f_b)\left[\frac{1}{1+(f_n/f_t)^4} \right]\left[\frac{1}{1+(f_n/f_r)^8} \right] \tag{93A–57}$$

The variable f_b is the signaling rate. The 3 dB transmit filter bandwidth f_t is inversely proportional to the 20% to 80% rise and fall time T_t. The constant of proportionality is 0.2365 (e.g., $T_t f_t = 0.2365$; with f_t in Hertz and T_t in seconds). The variable f_r is the 3 dB reference receiver bandwidth.

The values assigned to f_b, T_t, and f_r are defined by the Physical Layer specification that invokes this method.

Summary

- ## Tx Function to Rx function channel IL proposal
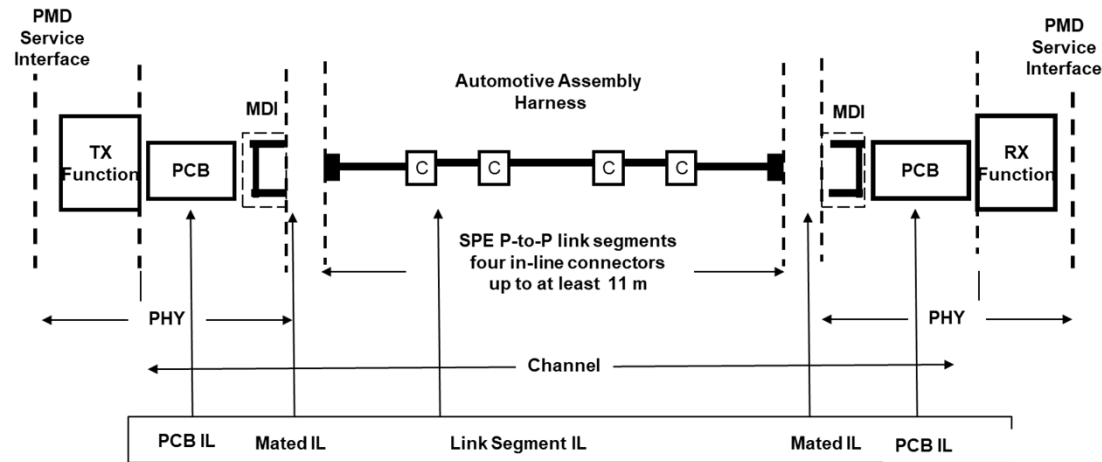
$$IL_{Channel} \leq 2 \cdot IL_{PCB(76.2mm)} + 2 \cdot IL_{MDI} + IL_{Linksegment} \quad (\text{dB})$$
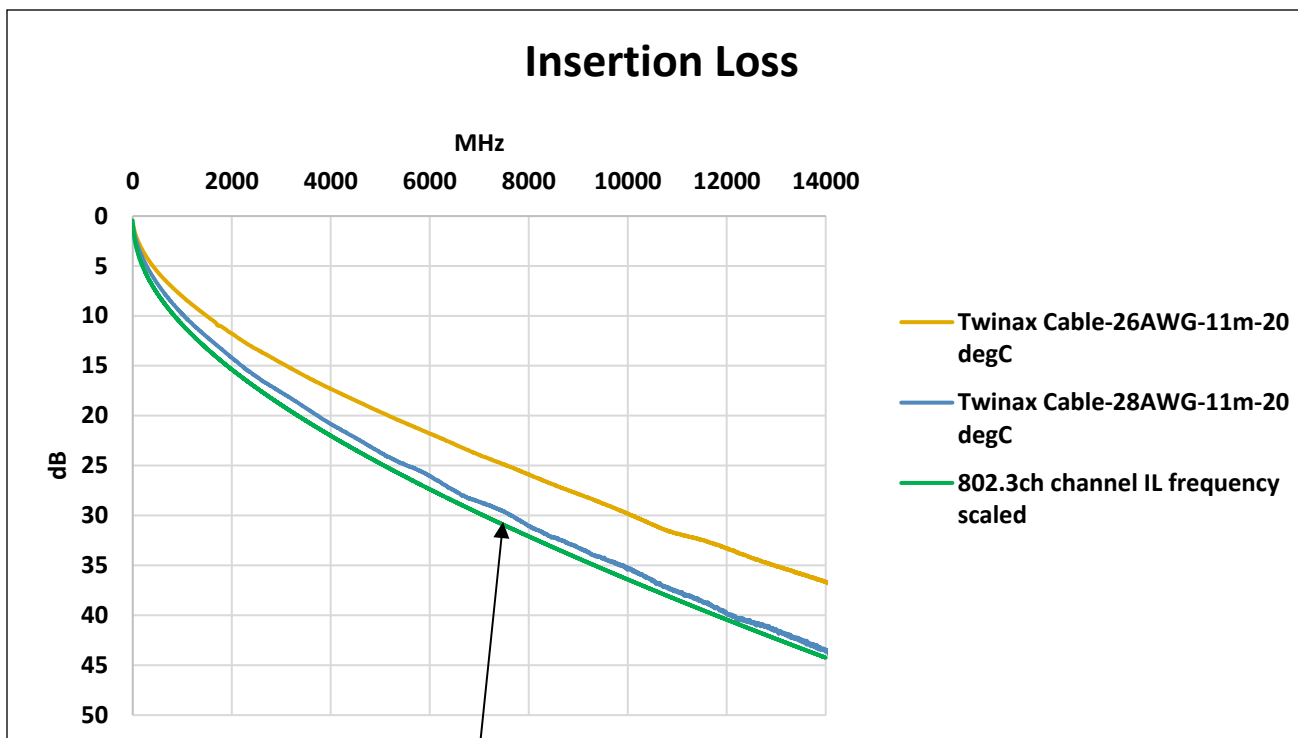
$$IL_{PCB(76.2mm)} \leq \left(0.0071 \cdot \sqrt{f/2.5 \cdot 10^{\wedge}3} + 0.0045 \cdot f/2.5 \cdot 10^{\wedge}3 \right) \cdot 76.2 \ (\text{dB})$$

$$IL_{Linksegment} \leq 0.002 \left(\frac{f}{2.5} \right) + 0.68 \left(\frac{f}{2.5} \right)^{0.45} \ (\text{dB})$$

$$IL_{MDI} \leq 0.1 \sqrt{\frac{f}{2.5 \cdot 10^{\wedge}3}} \quad (\text{dB})$$

PHY	MBd	Bandwidth (MHz)	PCBILdb/76.2mm	IL Link Segment	IL MDI	IL Channel Max
25GBASE-T1	14062.25	7031.25	1.8717	29.8688	0.168	33.948

Insertion Loss Consideration

Insertion Loss

MHz

Legend:
- Twinax Cable-26AWG-11m-20 degC
- Twinax Cable-28AWG-11m-20 degC
- 802.3ch channel IL frequency scaled
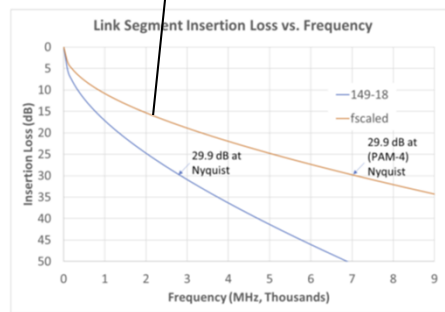
Frequency Scaled link segment IL

$$IL \leq 0.002 \left(\frac{f}{2.5}\right) + 0.68 \left(\frac{f}{2.5}\right)^{0.45}$$

This is a starting point
Same IL at Nyquist as .3ch

Link Segment Insertion Loss vs. Frequency

- 149-18
- fscaled

29.9 dB at Nyquist

29.9 dB at (PAM-4) Nyquist

IEEE 802.3cy TG

Link Segment – 802.3cy

- ## Link transmission parameters (up to at least 11 m)
  - Characteristic impedance (100 ohms)
  - Insertion loss (TBD) - TBD MHz ≤ f ≤ TBD MHz
  - Return loss (TBD)   - TBD MHz ≤ f ≤ TBD MHz
  - Coupling Attenuation (TBD) - TBD MHz ≤ f ≤ TBD MHz
  - Shielding Effectiveness (TBD) - TBD MHz ≤ f ≤ TBD MHz
  - Maximum Link Delay (TBD) - TBD MHz ≤ f ≤ TBD MHz

- ## Coupling parameters between link segments
  - Power sum alien near-end crosstalk (PSANEXT) -(TBD) - TBD MHz ≤ f ≤ TBD MHz
  - Power sum alien attenuation to crosstalk ratio far-end (PSAACR-F) - (TBD) - TBD MHz ≤ f ≤ TBD MHz

# Link Segment – SNR

- Technical feasibility – SNR
    - Link transmission parameters (up to at least 11 m)
        - Insertion loss (TBD) - TBD MHz ≤ f ≤ TBD MHz
            - Topology – length, number of inline connectors
            - Wire gauge
            - Operating temperature
    - Noise environment –
            - Electromagnetic environment (shielding considerations),
            - Alien crosstalk - Topologies

Main application spaces - Topologies

Backbone / Displays

- Contain 0, 1 or 2 in-line connections
- Are 0.2 m to 7.0 m in total length (not all combinations of the below lengths are possible)
 - Note: Segment lengths will vary by at least 10%

0.2 to 7 m

0.3 to 2.5 m   0.7 to 6 m

0.3 to 2.5 m   0.7 to 5 m   1 to 5 m
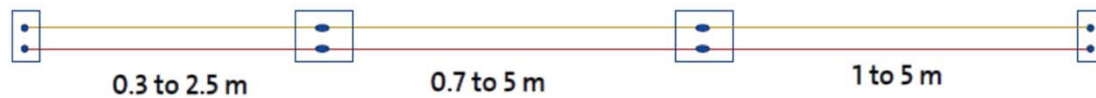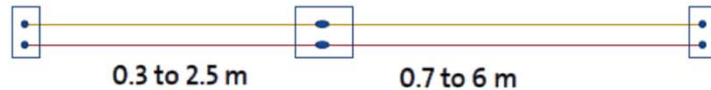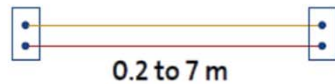
•Located in the passenger compartment
•Limited temperature range, -40C to 95C
•Unsealed connectors
•Shorter length

Source:wienckowski_3+10G_01a_0519.pdf

Cameras

- Contain 0, 1 or 2 in-line connections
- Are 0.2 m to 11.0 m in total length (not all combinations of the below lengths are possible)
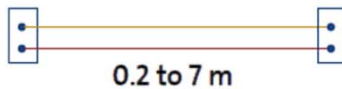 - Note: Segment lengths will vary by at least 10%

0.2 to 7 m

0.3 to 2.5 m   0.7 to 6 m

0.3 to 2.5 m   0.7 to 5 m   1 to 5 m
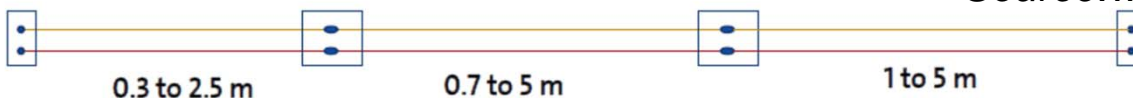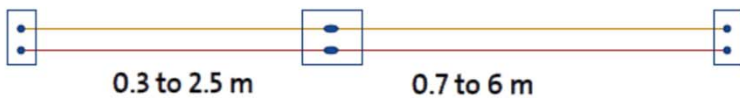
•Located at "edges" of vehicle
•Expanded temperature range, -40C to 105C
•Sealed connectors
•Longer length

Source:wienckowski_3+10G_01a_0519.pdf

Application space - Topologies

POTENTIAL NETWORKS

- Small percentage of application or requested for future flexibility

- Contain 3 or 4 in-line connections

- Are 11 m to 15.0 m in total length (not all combinations of the below lengths are possible)
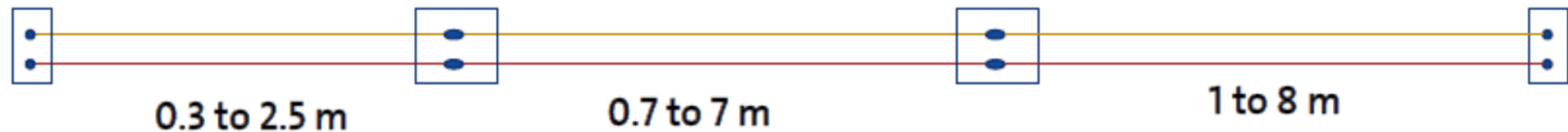 - Note: Segment lengths will vary by at least 10%

- Requested by OEMS who haven't investigated use cases

0.3 to 2.5 m   0.7 to 7 m   1 to 8 m

Source:wienckowski_3+10G_01a_0519.pdf

Application spaces – Topologies - SNR

- Backbone display

  - Link transmission parameters (up to at least 7 m)

    - Insertion loss (TBD) - TBD MHz ≤ f ≤ TBD MHz

      - 2 inline connectors
      - Wire gauge (TBD)
      - Operating temperature -40C to 95C,

  - Coupling between link segments

    - Shielded cables

      - dB Isolation (>60 dB – TBD)

- Cameras

  - Link transmission parameters (up to at least 11 m)

    - Insertion loss (TBD) - TBD MHz ≤ f ≤ TBD MHz

      - 2 inline connectors
      - Wire gauge (TBD)
      - Operating temperature -40C to 105C,

  - Coupling between link segments

    - Shielded cables

      - dB Isolation (>60 dB – TBD)