IL & RL limits for STP and Coax cable harnesses

IEEE 802.3dm

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Motivation

- It has been proposed and discussed the adoption of a single IL limit for both STP and Coax cable-links – Ragnar Johnsson
  - Title: [802.3_ISAAC] Insertion Loss Limits for 802.3dm – May 28th 2024
- A discussion thread per email was created with broad discussion on whether this is applicable or not.
- This presentation summarizes arguments and reasons to separate both types of cable links:
  - arguments from 3 perspectives: cables, connectors and PHY
  - arguments from practices already being used by currently available specifications

- Furthermore, this presentation argues to specify a channel from the Automotive harness practice perspective, not isolated data of components

Agenda

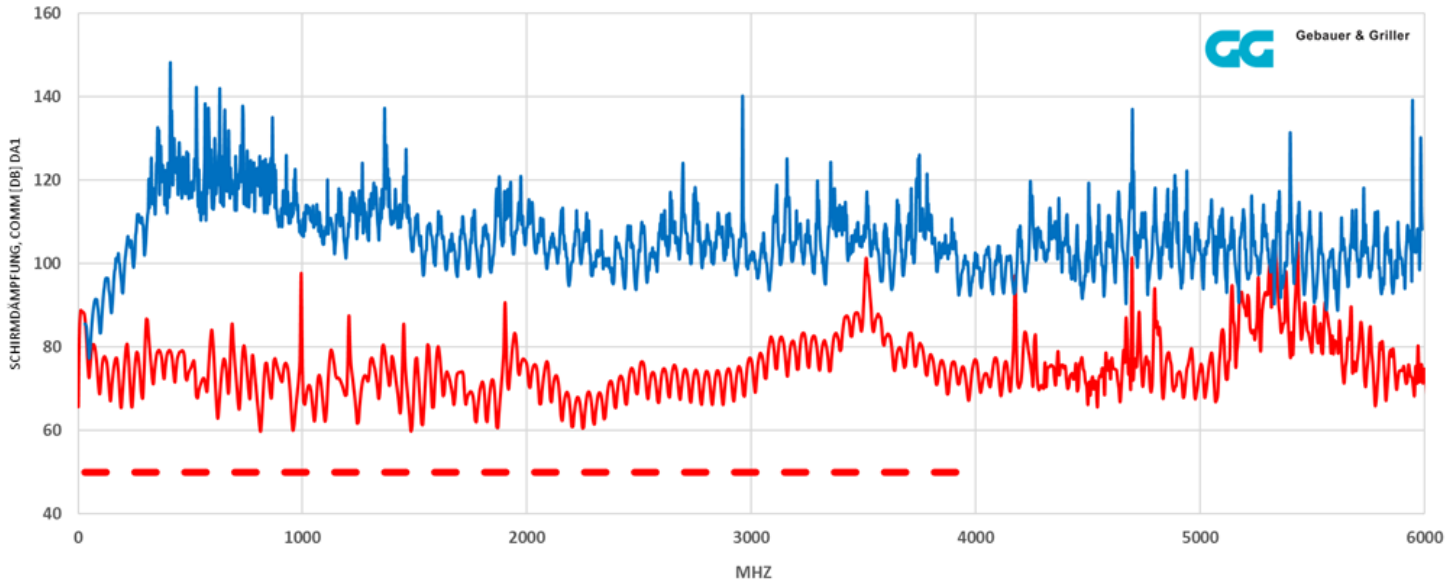
- Construction of STP and Coax cables & connectors
- From cable to harness
- System and Physical Layer perspective
- Reference data: available norms, standards, industry practices
- Summary

Construction differences of STP and Coax cables

- Insertion Loss:
  - Characteristic “suck-out” caused by and depending on twist length (STP case) – The so called “suck out” is inevitable in the STP cables and will hinder the max operational frequency of the link. Depending on link speed needs, different types of cables can be used. Hence, the creation of speed grades (SG) differentiation for the STP case will give the standard flexibility in cable choice. Obviously, the SG will depend also on PHY requirements and capabilities.
  - Coaxial Cables normally have higher transmission performance (IL in dB/m) than STP cables. This results in shorter STP links to cope with desired IL levels.
    - The conductors in the coax cable can be normally thicker than in STP – No need of twist and less mechanical stresses in the geometry of the cable.
    - Nevertheless, depending on the PHY design, higher disturbers can be observed
  - TC9 “Standard IL STP” 10m vs. “Low IL STP” 15m
    - Available STP cable products for Automotive
    - https://opensig.org/wp-content/uploads/2024/05/TC9-MultiGBASE-T1-channel-and-components-v1.1-public.pdf (page 70)

Construction differences of STP and Coax cables

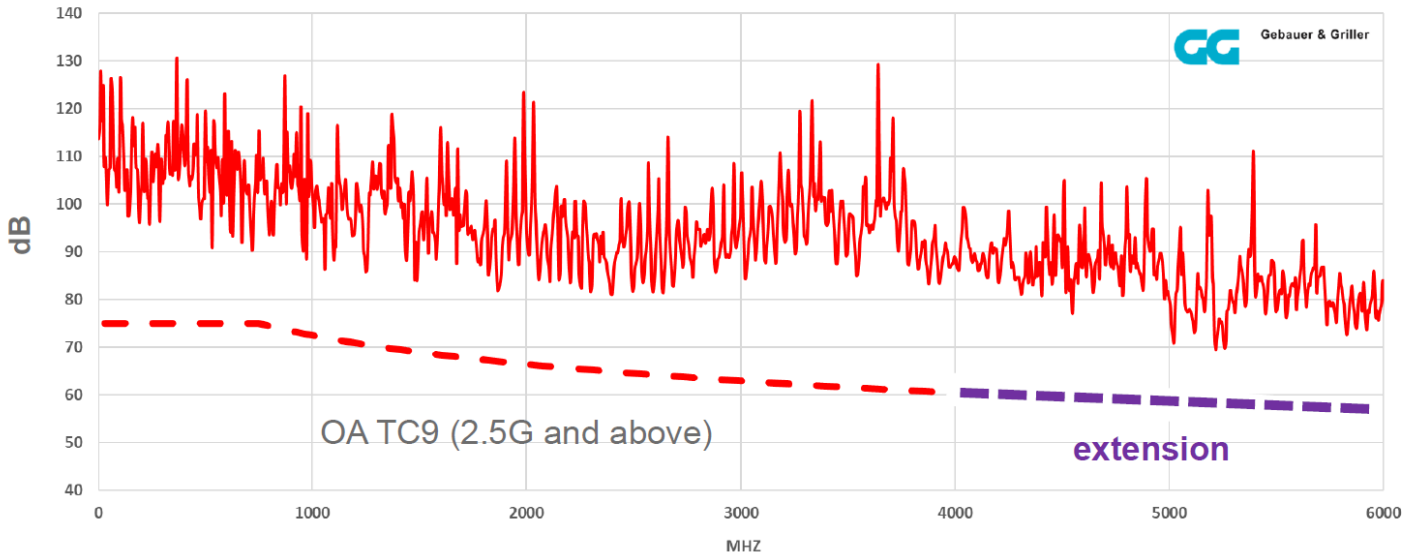
- Shielding Attenuation features
  - Normally coax shielding attenuation levels can be better than that of the STP cables (see fig.: red-STP; blue-coax cable).
  - Shielding contacting/grounding – different uses of the shield:
    - Coax shield used in signal transmission
    - In the STP case, the shielding is not directly involved in the signal transmission
    - Different connector types



Shielding attenuation measurement of a 0.14mm² STP cable. OA TC9 shielding attenuation limit.

Construction differences of STP and Coax cables

- Mode Conversion – only required in the case of STP cables.
  - Differently of coaxial cables, mode conversion (line balancing) and **coupling attenuation** must be defined for differential pairs.



Coupling attenuation measurement of a 0.14mm² STP cable. OA TC9 Coupling Attenuation Limit was extrapolated to 6GHz.

Construction differences of STP and Coax cables

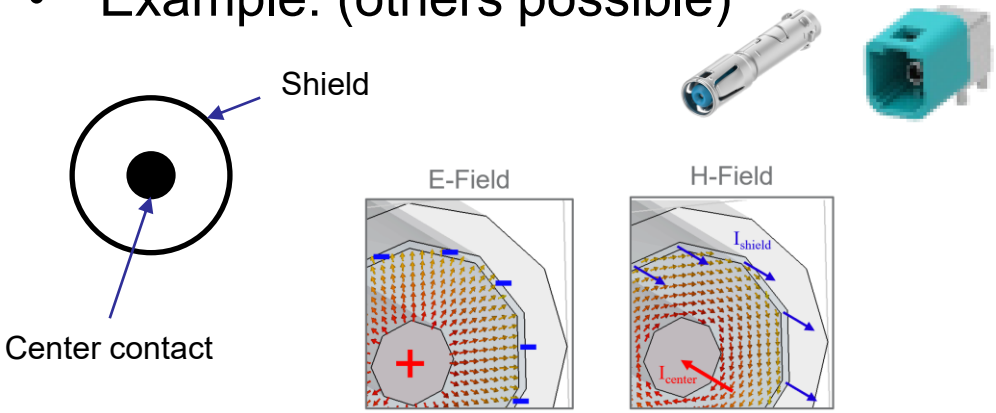
- System characterization
  - Measurements, different limitations/specification/systems for test fixtures
- Cable engineering to withstand mechanical stresses (dynamic vs. static).
  - Coax, unlike STP due to the design, is normally more resilient to mech. stresses.
    - As an example, this could have an impact on the required performance requirements for systems intended for dynamic applications (ex.: tailgate). Normally the twisted pair will be less prone to mech. stresses due to its construction geometries.
- MDI Implementation
  - Two distinct connectors with different sets of electrical characteristics

Construction of STP and Coax connectors

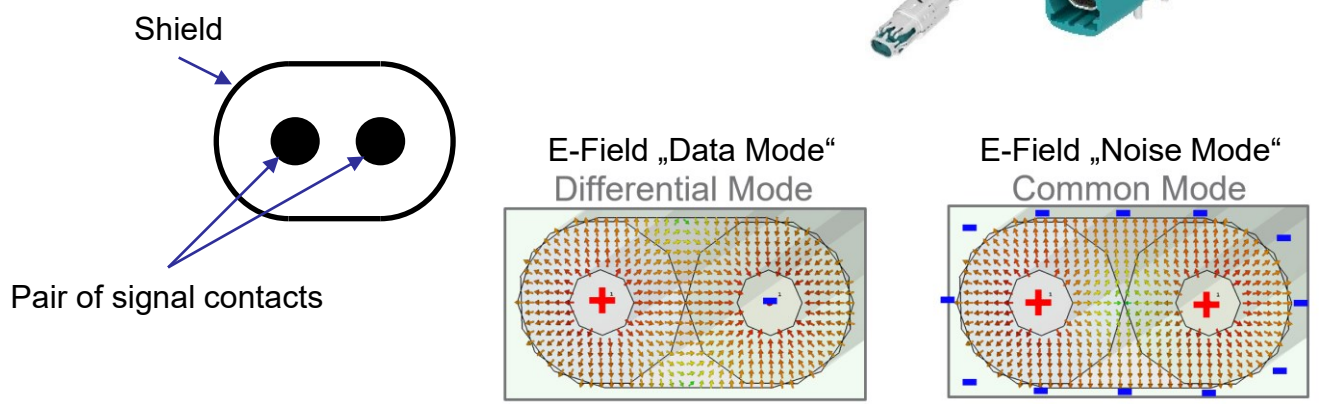
- Coax
  - 50 Ohm nom. impedance
  - Insertion Loss
  - Return Loss
  - Screening attenuation (according IEC 62153-4-7)

- STP
  - 100 Ohm nom. impedance differential mode
  - Insertion Loss
  - Return Loss
  - For multiport connectors: PSANEXT loss and PSAFEXT loss
  - Screening attenuation and coupling attenuation (according IEC 62153-4-7)

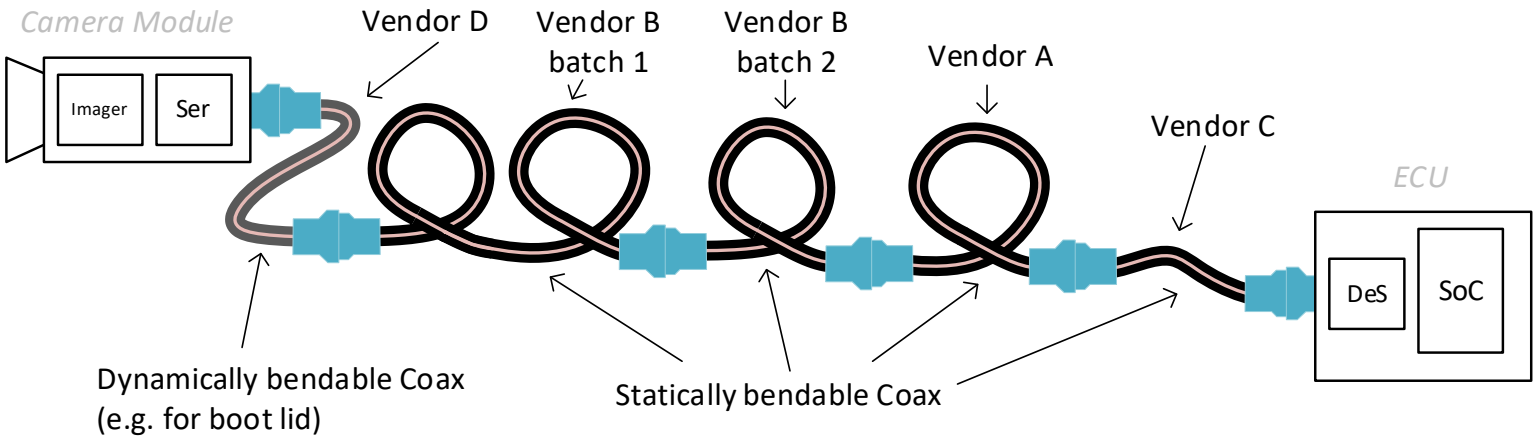
- Example: (others possible)



- Example: (others possible)



Assembling a Cable Harness



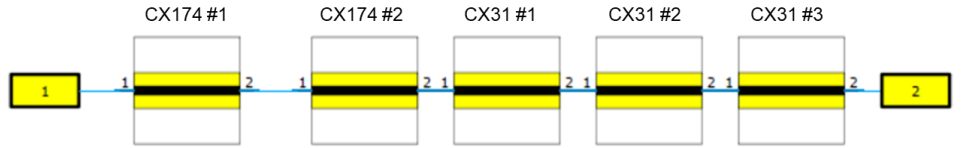
- For this type of application, OEM sources different cable harness segments in batches
  - Different (coax) cables types, different vendors with different products
- Assembler takes one from the batch of a certain cable harness segment and installs it
- Even same vendor, same cable type neighboring segments in a harness were most likely not on the same cable spool, and almost certainly not from one continuous segment on the spool

→ Assembled cable harness is a combination of harness segments with randomly selected electrical parameters (within the range of the respective data sheet)

From cable to harness

- Example for Coax – cable only, no connectors:
  Possible IL link segment performance based on cable measurements at 105°C (no ageing)

  - Cable models based on measurements @ 105°C
  - Lengths and impedance variations for simulation according to table



Connectors not included

	CX174 #1	CX174 #2	CX31 #1	CX31 #2	CX31 #3
Length variation [m]	0,3 ; 1 ; 1,5	0,36 ; 1 ; 1,5	1 ; 2 ; 4	1 ; 4	1 ; 4
Impedance variation [Ohm]	47 ; 50 ; 53	47 ; 50 ; 53	47 ; 50 ; 53	47 ; 50 ; 53	47 ; 50 ; 53

→ max. 15m

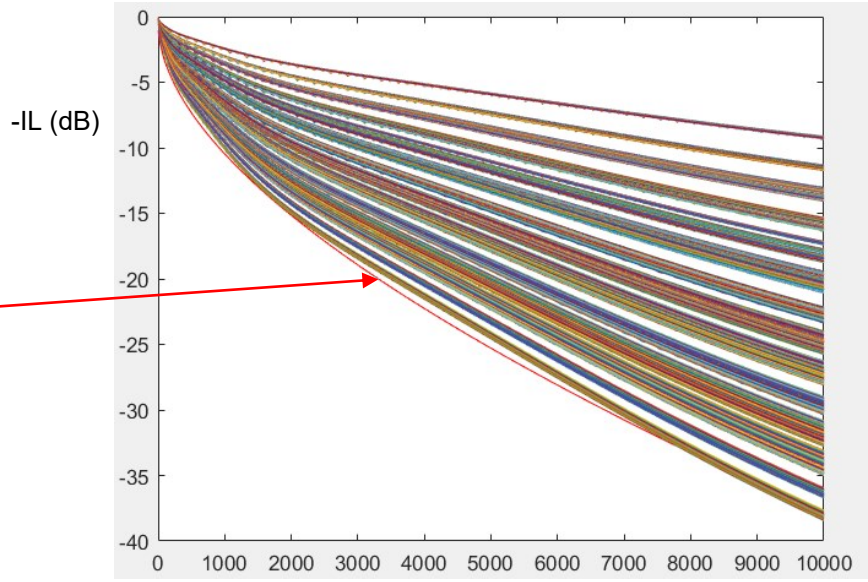
Possible IL requirement with mixed cable grades (CX174, CX31):

$$IL \leq 15\left(0.000055f + 0.023\sqrt{f} + \frac{0.032}{\sqrt{f}} + 0.02\right) - 0.05\sqrt{f}$$

f in $MHz, f \geq 10\ MHz$

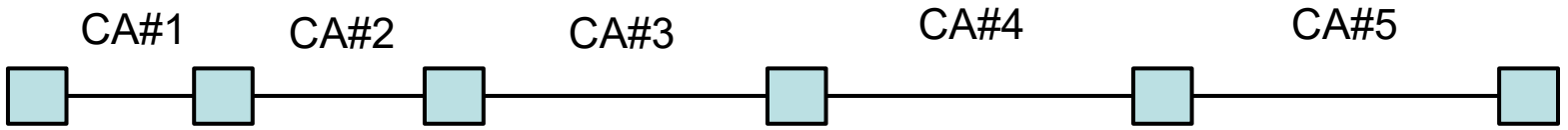
Possible Link Segment Limit

5 connectors deducted



From cable to harness

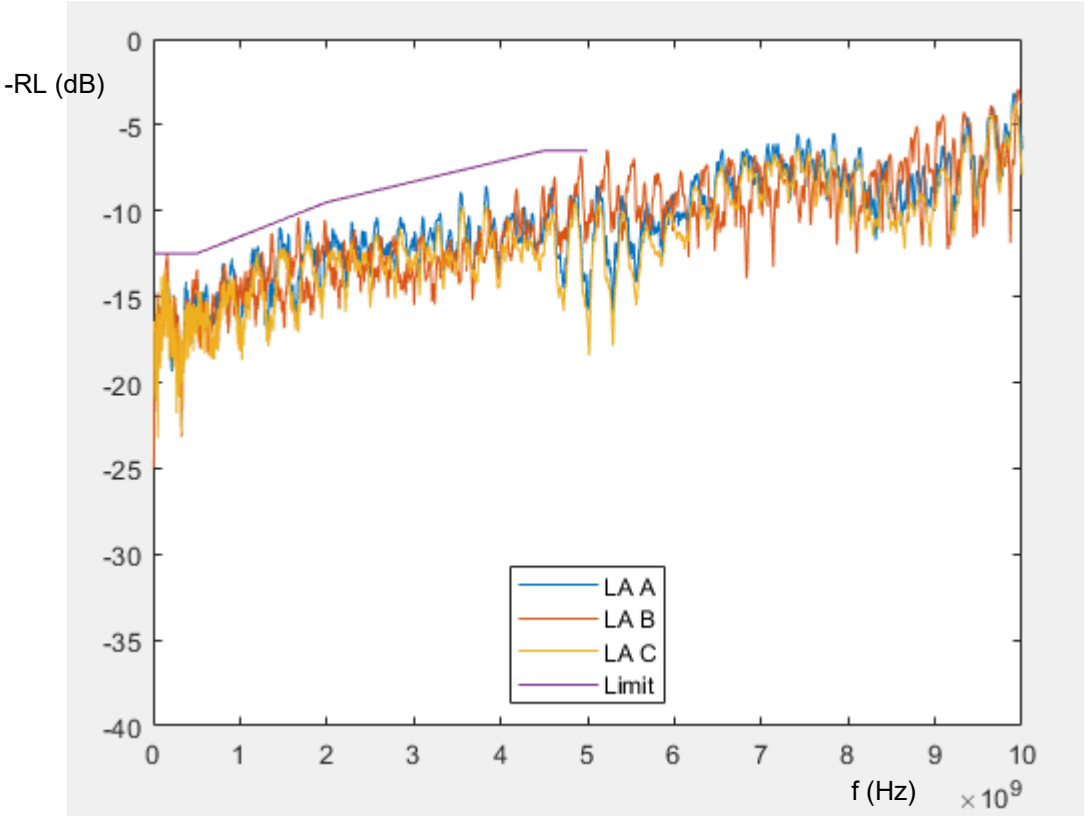
- Example for Coax – with connectors:



Topology variations, realistic connector model (no worst-case):

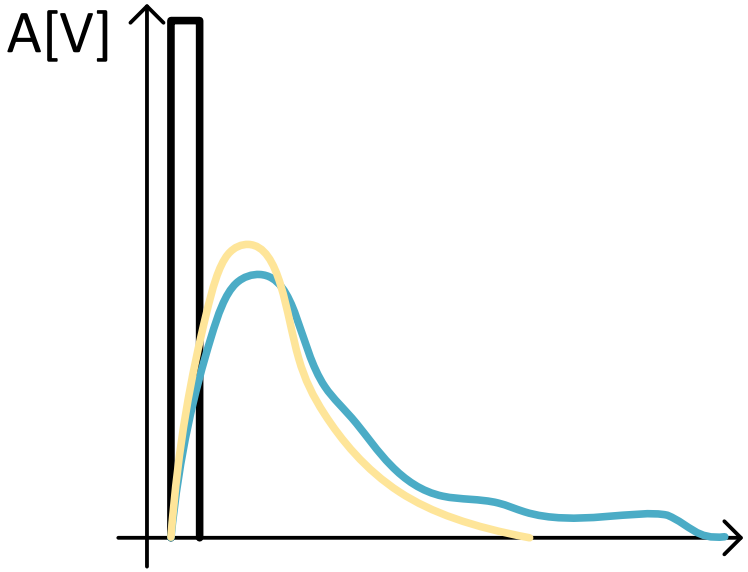
LA RL worst case (A)	CA#1	CA#2	CA#3	CA#4	CA#5
cable	CX174	CX174	CX31	CX31	CX31
length	0.3m	0.36m	1.0m	11.84m	1.5m
LA RL worst case (B)	CA#1	CA#2	CA#3	CA#4	CA#5
cable	CX31	CX31	CX31	CX31	CX174
length	0.3m	0.36m	1.0m	11.84m	1.5m
LA RL worst case (C)	CA#1	CA#2	CA#3	CA#4	CA#5
cable	CX174	CX174	CX31	CX31	CX31
length	0.3m	0.36m	6.34m	4m	4m

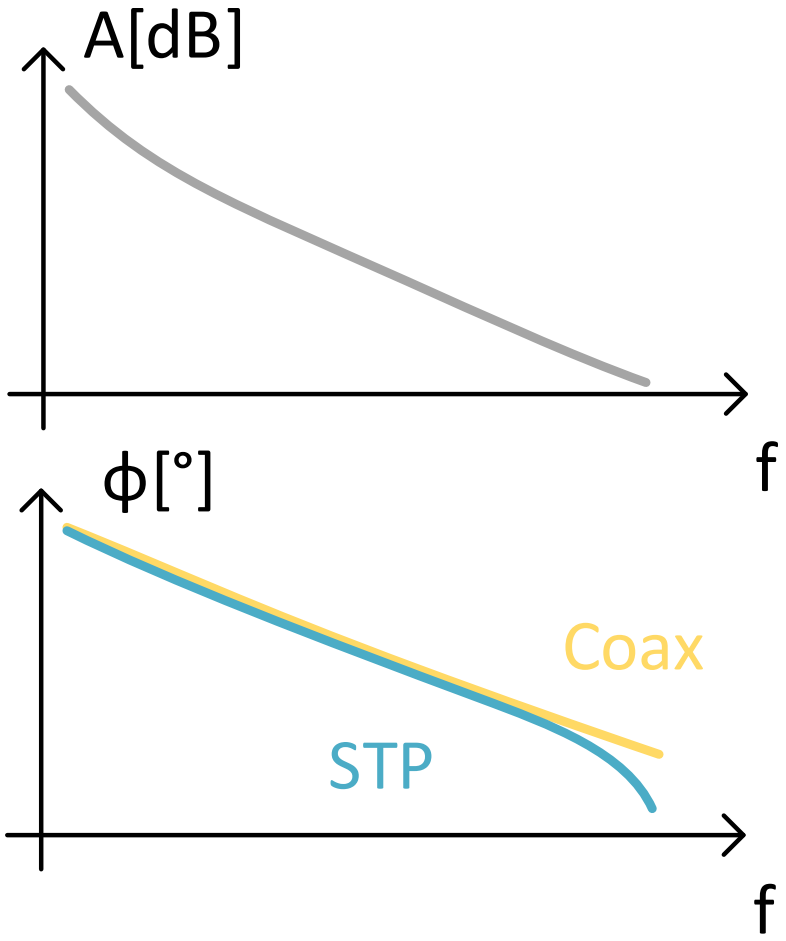
$$RL \geq \begin{pmatrix} 12.5 & 10\ MHz \leq f < 500\ MHz \\ 12.5 - 3\frac{f-500}{1500} & 500\ MHz \leq f < 2000\ MHz \\ 9.5 - 3\frac{f-2000}{2500} & 2000\ MHz \leq f < 4500\ MHz \\ 6.5 & 4500\ MHz \leq f \leq 5000\ MHz \end{pmatrix} \text{dB}$$



System and Physical Layer perspective

- Coax
  - One wire strand
  - Dielectric
  - Foil, the shield weave
- STP
  - Two wire strands
  - Each with dielectric
  - Twist two wires
  - Foil, then shield wave over non-circular geometry

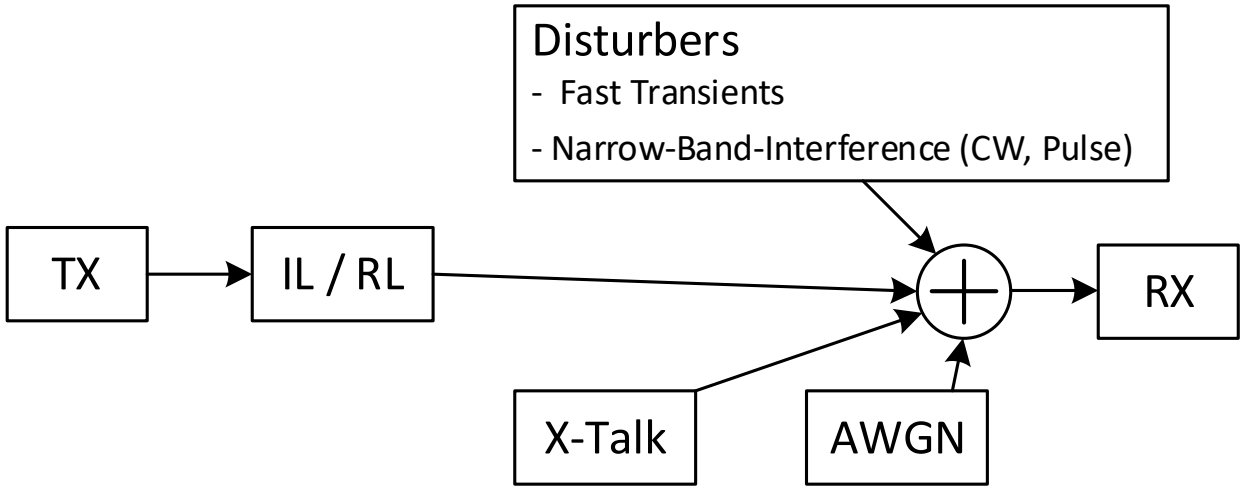




- Same Insertion Loss response/limit will have very different pulse responses on STP vs. Coax
  - Requiring different receive capabilities

System and Physical Layer perspective

- Channel / System perspective
- Beyond IL / RL, other channel parameters are also different
  - X-Talk
  - Disturber Fast Transient
  - Disturber NBI
- Comparison is for signal component
  - STP has also common mode signal, which will show higher X-Talk and disturber levels
  - Coax is single-ended system
- For most cost-efficient system, the PHY should not be over-/under-specified for one cable type (or the other)

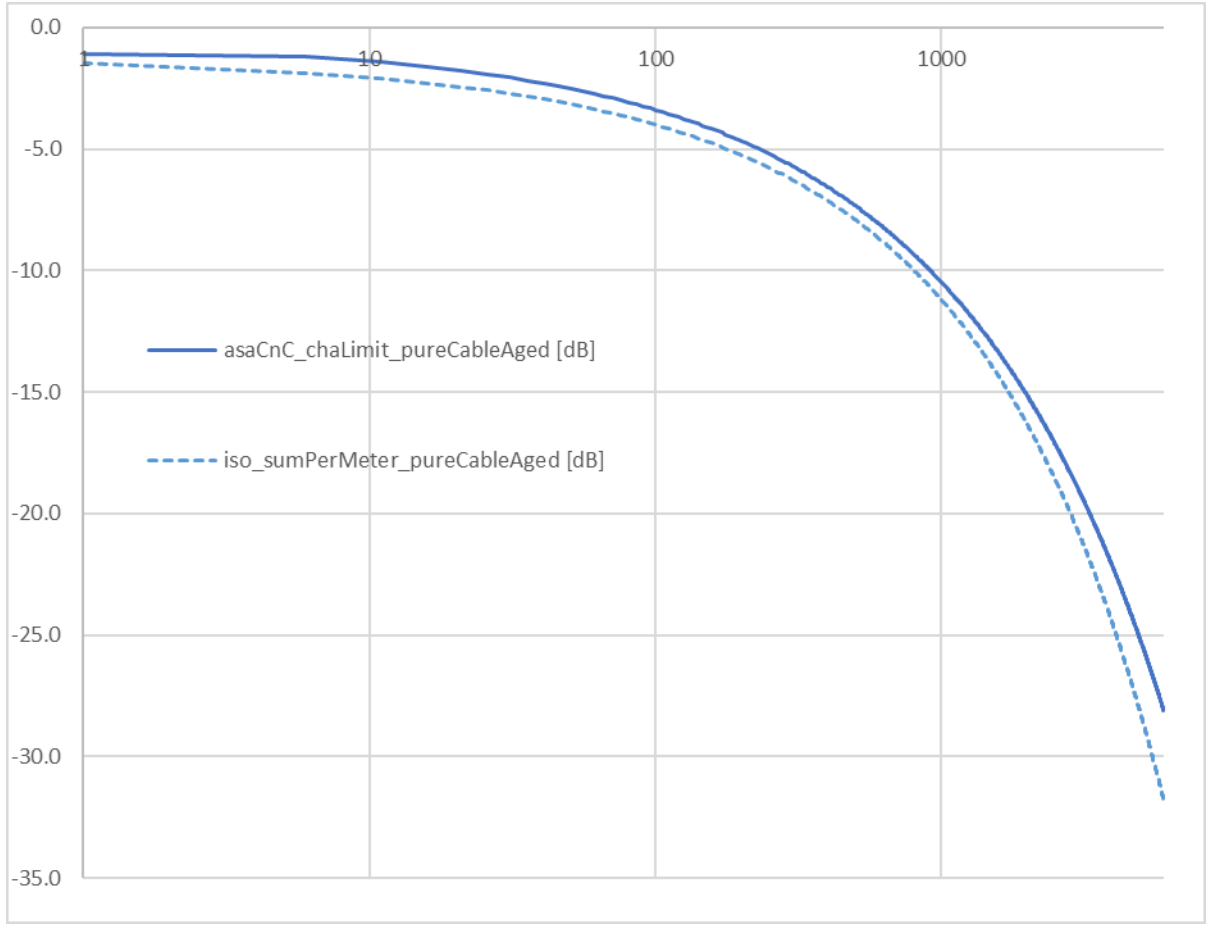


	X-Talk	**Fast Transients**	**NBI**
Coax	LF higher HF lower	Larger amp Longer tail	LF higher HF similar
STP	LF lower HF higher	Lower amp Shorter tail	LF lower HF similar

Reference data - Coax

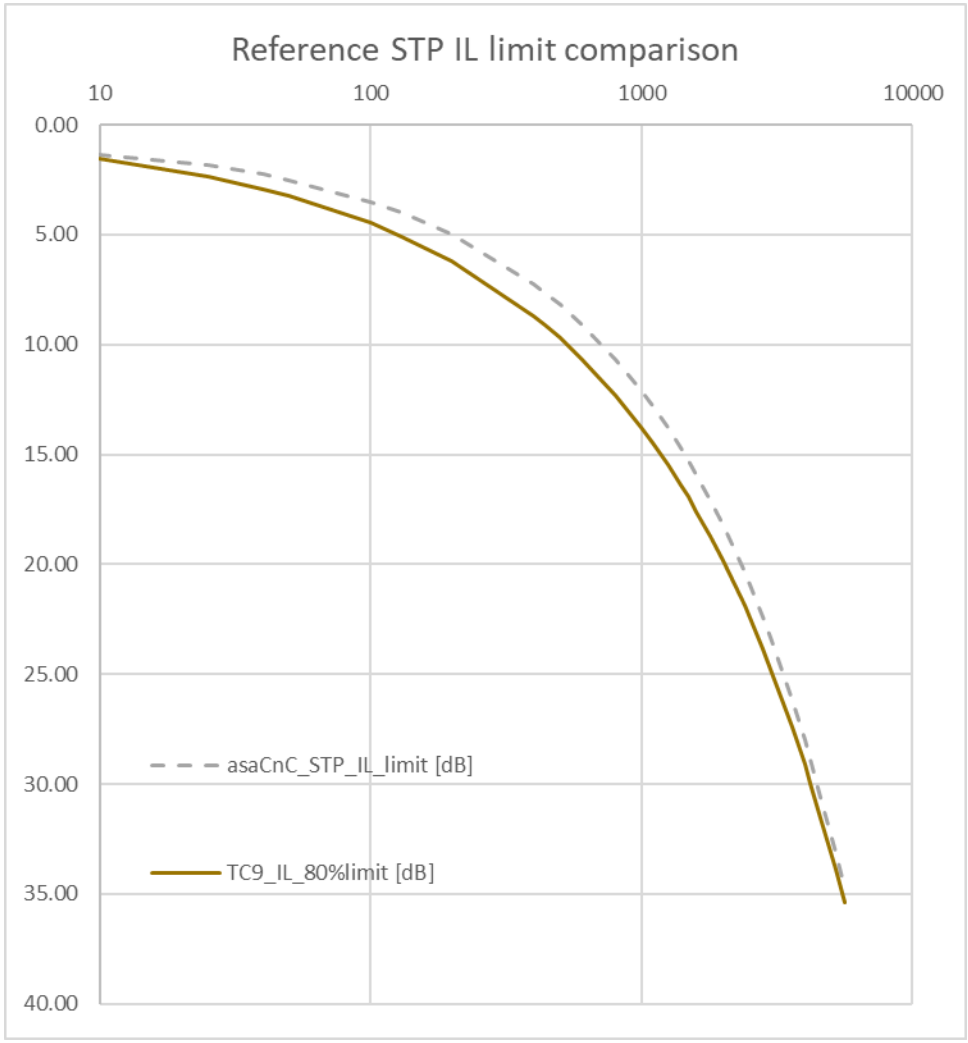
- ISO 19642-11
  - Using ISO formulas per meter for CX31 and CX174
    - Including aging applied
    - Aging budget „generous“ in ISO with 15% for both cable types
  - Mathematically combined into LA with 3m+12m (no inliners)

- ASA
  - Coax cable limit (Coax channel with inliners removed)
  - In addition, ASA allocates specific IL limits/budgets to the ECU boards



Reference data - STP

- TC9
  - https://opensig.org/wp-content/uploads/2024/05/TC9-MultiGBASE-T1-channel-and-components-v1.1-public.pdf (page 76ff)
- ASA “Channel and Components Test Specification” draft
  - In addition, ASA allocates specific IL limits/budgets to the ECU boards
- ASA targets higher signal bandwidth than referenced TC9 spec



Summary

- Coax & STP are different transmission media
  - Construction, electrical specification, impact on (Automotive) system design
- Trying to squeeze two transmission media into one limit, and then design a system around it … yields an inefficient system
- Cable harness should be the basis of “link segment limits”, not just cable data
- Propose to differentiate electrical limits between STP and Coax
- Differential pair reference data should be taken from latest work (TC9, ASA)
- Coax reference data should be taken from latest work (ASA) and available norms (ISO)

Thank You!