TCI/Mixing Segment Specs

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With Contributions by Michael Paul / ADI

A Very Big Thank you

For lots of work to draw on, many insights through conversation (and argument), patience, and contributions to the thoughts here.

Not only the contributors over the past many months, but especially to:

Piergiorgio Beruto, David Brandt, Chris DiMinico, Chad Jones, Michael Paul, Jason Potterf, and Stephan Schreiner

Thoughts and work from each of you are in this presentation

Introduction:

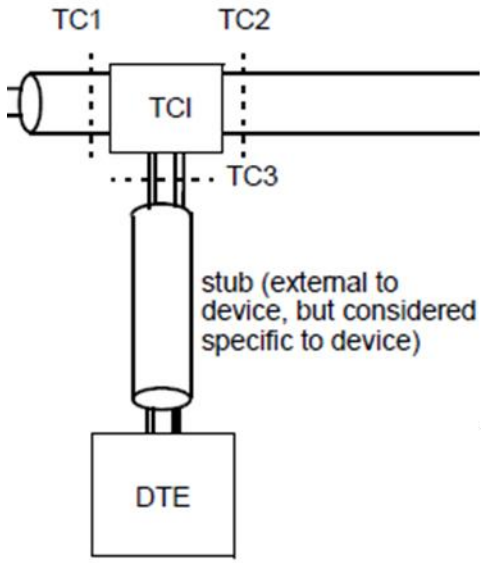
THE GOAL

Mixing Segment Specification & TCI: (168.7 & 168.8)

- THE GOAL: Mixing segment is (attempted) to be specified independent of node loading, numbers, and installation
- Standard to specify only what is necessary about:
  - The mixing segment (cabling without attached devices (PMA, DTE, etc)
  - The interface between the mixing segment and the device (TCI)
    - Note that we sometimes think of this as a device in itself... But in the standard it isn't
  - The stuff in the device – the DTE – including any PMA/PMD or PI as it relates to the TCI (interface to the cabling).

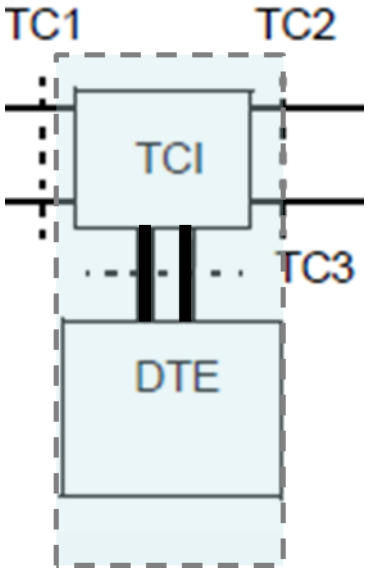
There are 2 topologies in play

T-BRIDGES WITH DETACHABLE CONNECTIONS TO DTE (E.G., STUBS)



- Couples mixing segment characteristics to presence & loading of DTE
  - Can use compensation in connector to mitigate, not eliminate
- Physically/electrically changes characteristics if DTE is attached/detached DTE

IN-AND-OUT WITH EMBEDDED CONNECTION TO PMA



- Mixing segment cannot be complete without DTE attached
  - Can use continuous wire, thru-connectors or dummy loads
  - TCI is only present if there is a PMA or PI present
- Physically/electrically changes mixing segment on adding DTE (PMA/PMD or PI)

Simulations, Proof Points, and Work to do

- 802.3da has seen numerous simulations of configurations that “can work” with statements that they represent worst-case
  - 802.3da has also seen simulations that show positional dependence of whether a configuration works
- TCI addition was intended to provide framework for figuring out what specs are necessary
  - We need to identify, clarify, and fill in the necessary specs
  - Unlikely to be all electrical characteristics of a particular implementation
- If we don’t do that, the TCI itself doesn’t matter – might as well leave it out.

The remainder of this presentation attempts to break the “spec impasse”

Outline of How we Get There

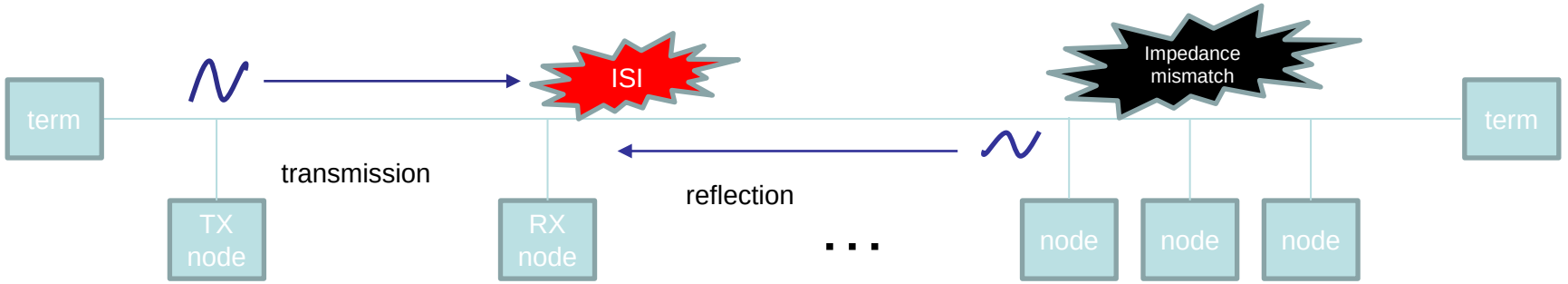
- Set TC1 and TC2 as the interface planes for node compliance testing.
- Specify TC1 and TC2 interface limits.
  - Pass RL and IL limits with DTE or dummy load attached.
- Remove TC3 as an interface plane.
  - Specs at TC3 are different than at TC1 and TC2
  - TC3 will not be accessible in all Nodes
    - These nodes will need to be qualified by measuring at TC1 and TC2 alone
- Other bodies may specify TC3 if needed for application-specific specs (e.g., ODVA)
  - Define exact cnode/lcomp match so that separate DTE and t-connectors will mate and compensate properly
- Prove that TC1 and TC2 interface compliance is sufficient for proving that assembled system will work.
  - This is the focus of this presentation
- Update Clause 168

Review:

WHERE WE ARE

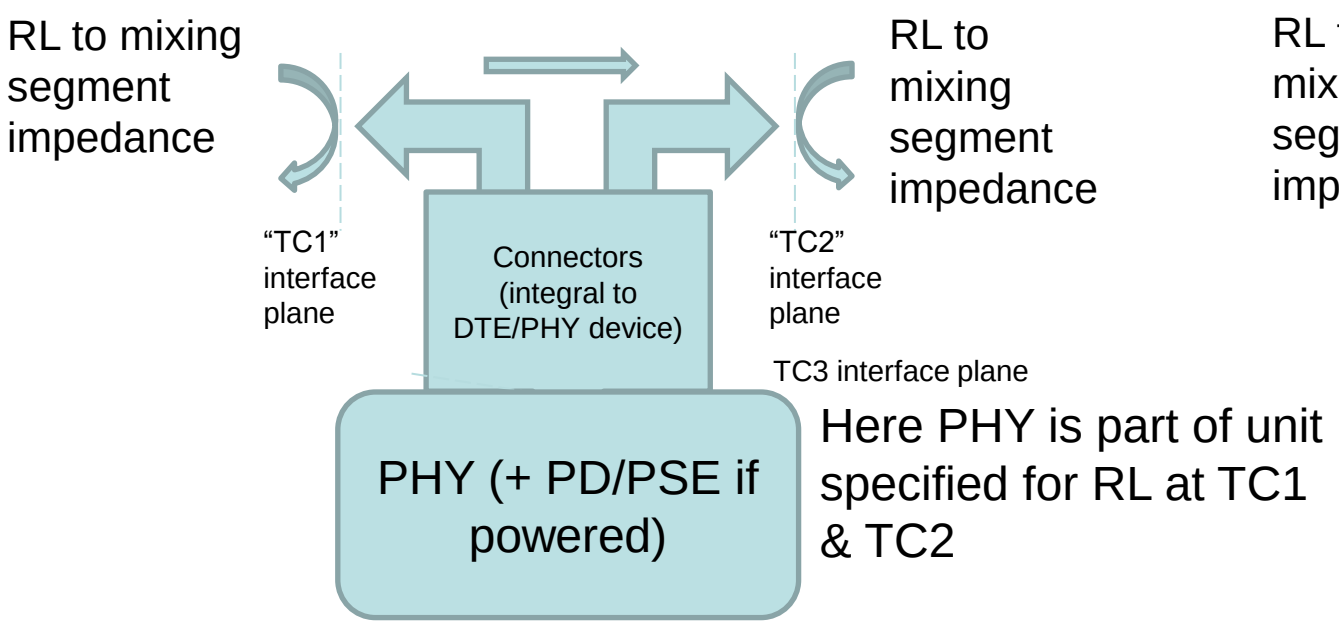
Clumped configuration w/victim close to clump is worst case for reflections off the MDI

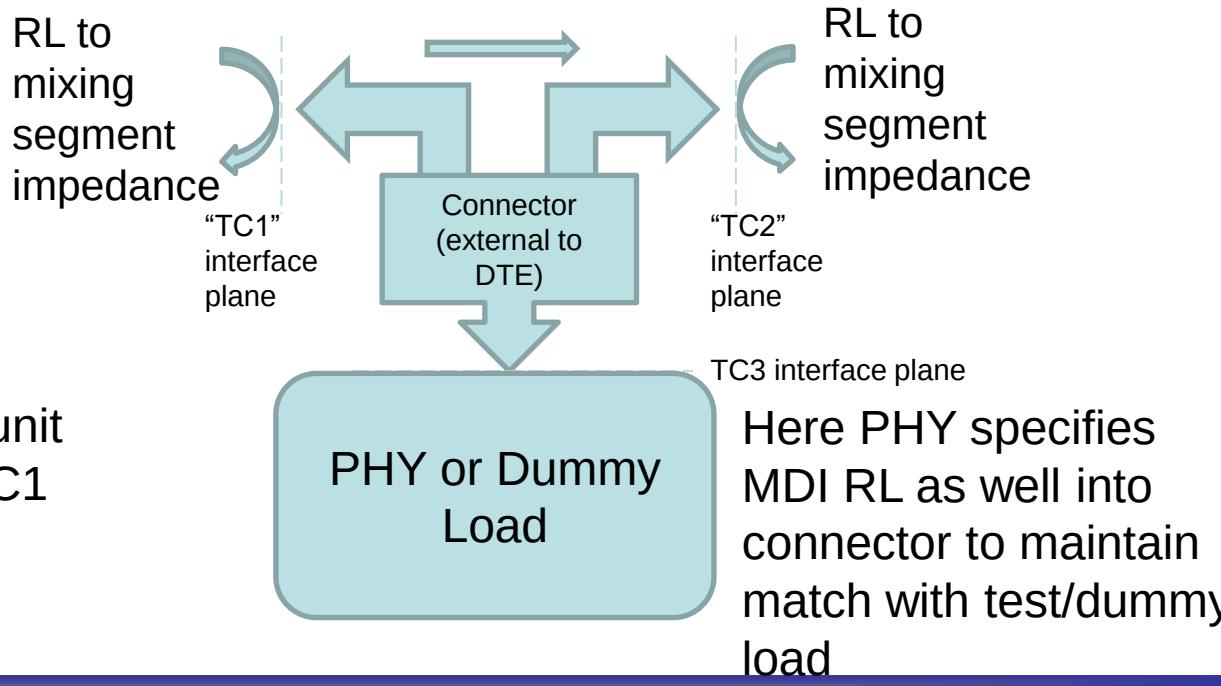
- Any configuration with reflecting nodes closer to transmitter requires a double-reflection (2xTC RL) which attenuates reflection significantly
- Any configuration with nodes further spread down the line (not in a clump) attenuates, delays, and removes coherency from reflections
- Configuration which maximizes attenuation from transmitter & minimizes attenuation from clump (while allowing sufficient delay to shift 1/2 baud) maximizes ISI
  - Worst case is receiver node ½ baud round trip (40ns, ~8m RT = 4m away) from reflection pt
  - Nodes spaced closely (within about 0.2 m) total span approximately reflect as one unit, adding in voltage
  - Nodes beyond 0.4m reflect more as power sum



Reflections at a Node – the TCI

- Connection divides mixing segment into left & right
  - Two cases – connector integral to device, connector external to DTE
- In either case, reflected energy at TC1 or TC2 determines ISI

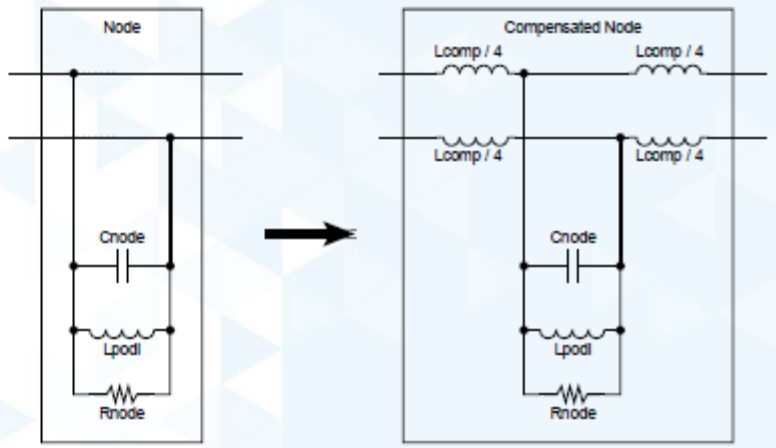




Solution – inductive compensation

Compensated Node

- For Node compensation
  - Treat the node like another Lump in the TX line
  - Add inductors to compensate Cnode
  - Lcomp = Zo^2 * Cnode



New Node Model

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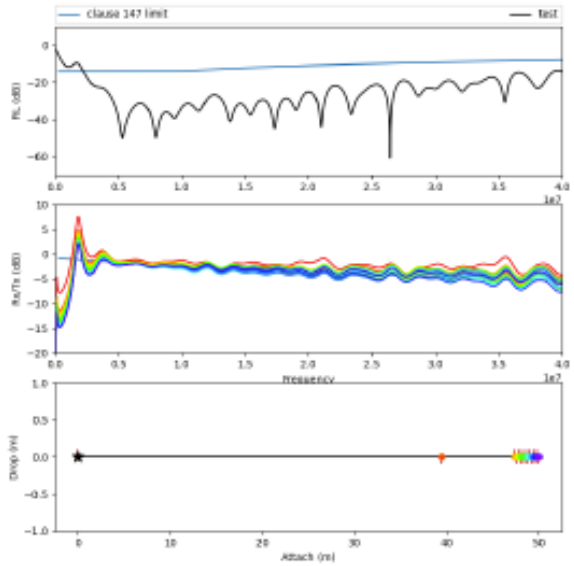
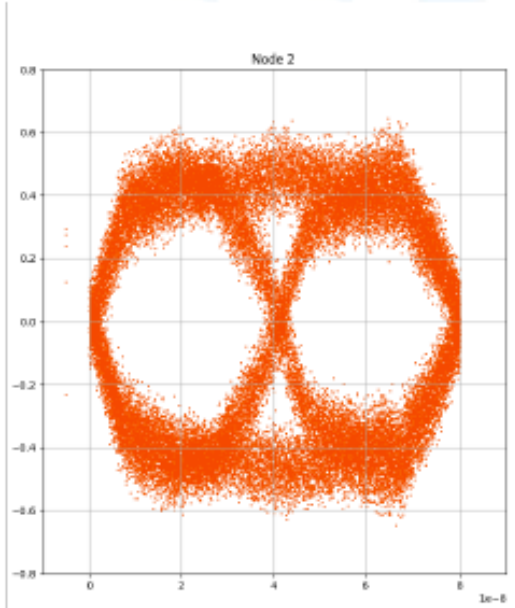
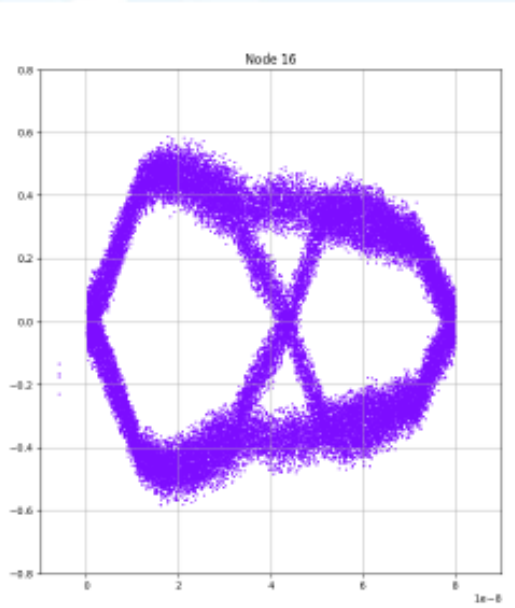
See presentations at https://www.ieee802.org/3/da/public/102021/index.html

Solution cleans up reflections

36pF, Node 2 8m from Clump Compensated (Cnode +20%, Lcomp -5%)







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Return Loss of Compensated vs. Uncompensated Nodes

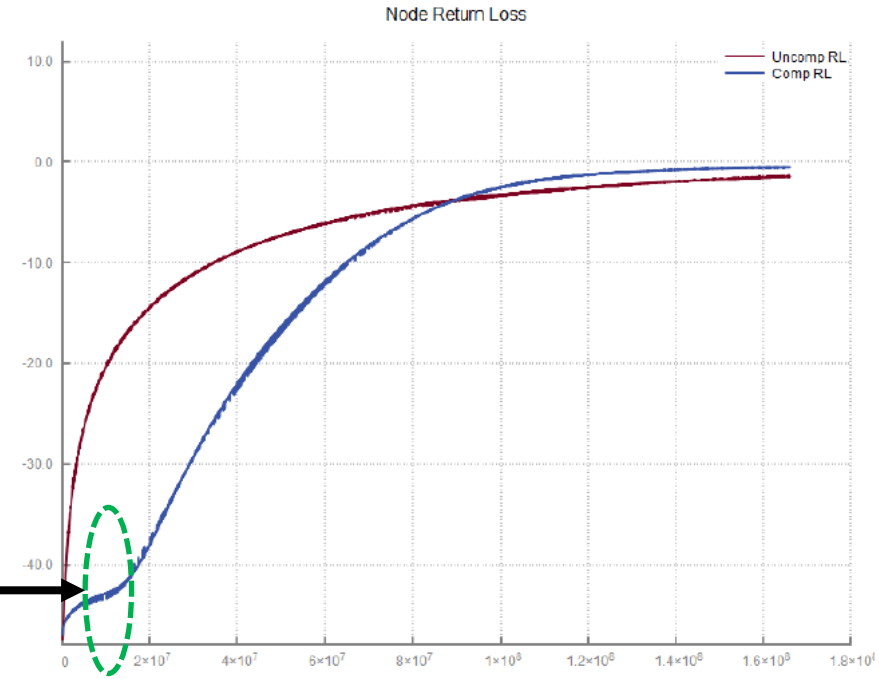
Comp / Uncomp RL

0.5m cables

100Ω Terminations

Term / tx / cable / DUT / cable / dummy / term

characterize_tee.json

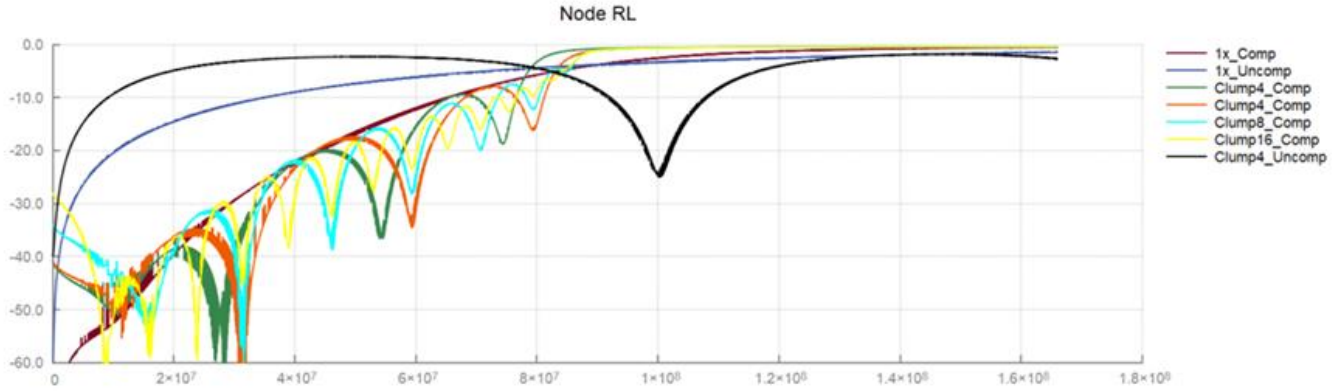


~45 dB in frequency range of interest

Thanks to Michael Paul/ADI

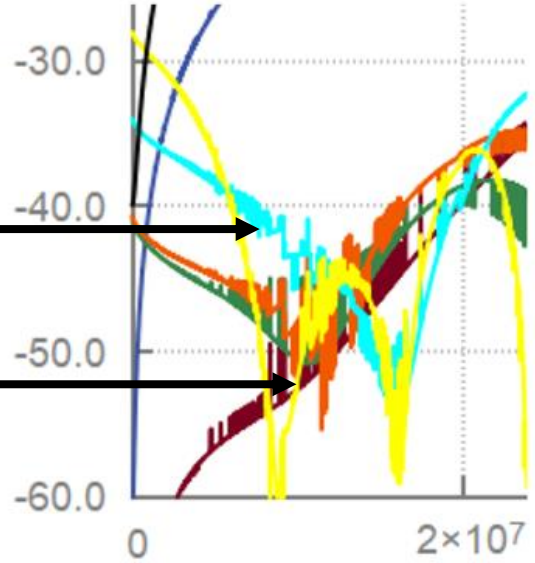
Nodes in Clumps – growth of reflections

Clumps space (unrealistically) close at 1mm…
(note, nodes interact)



8 nodes ~40dB

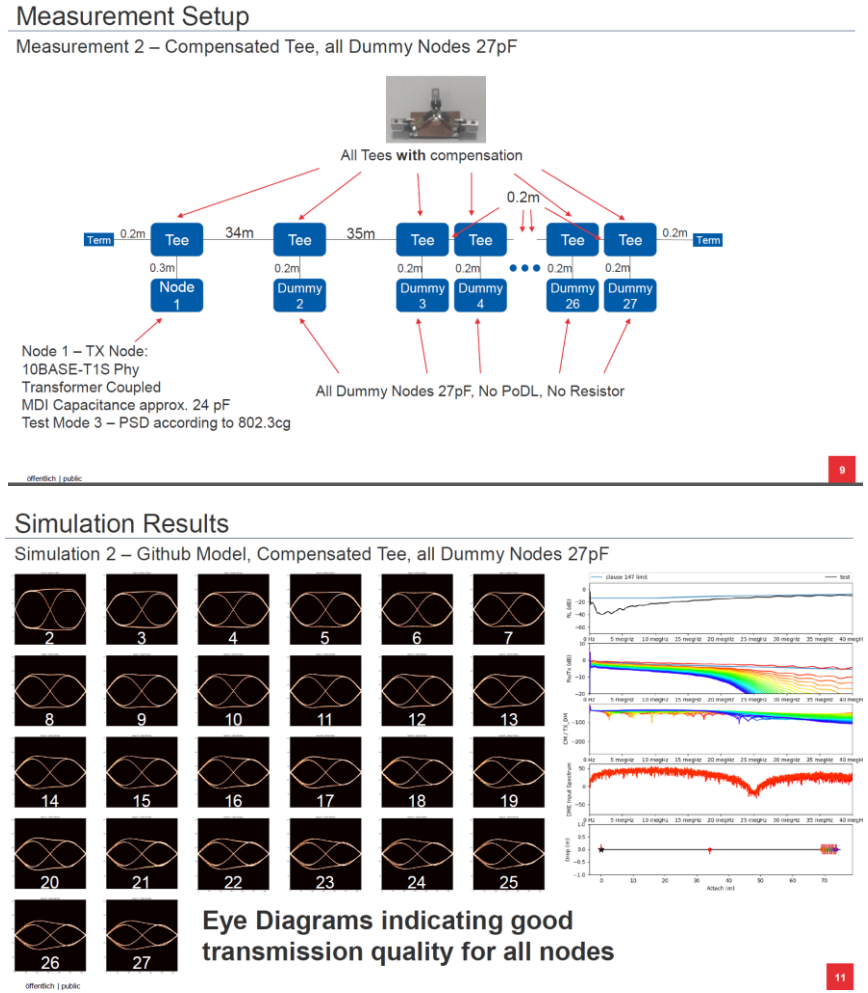
Single node ~54dB



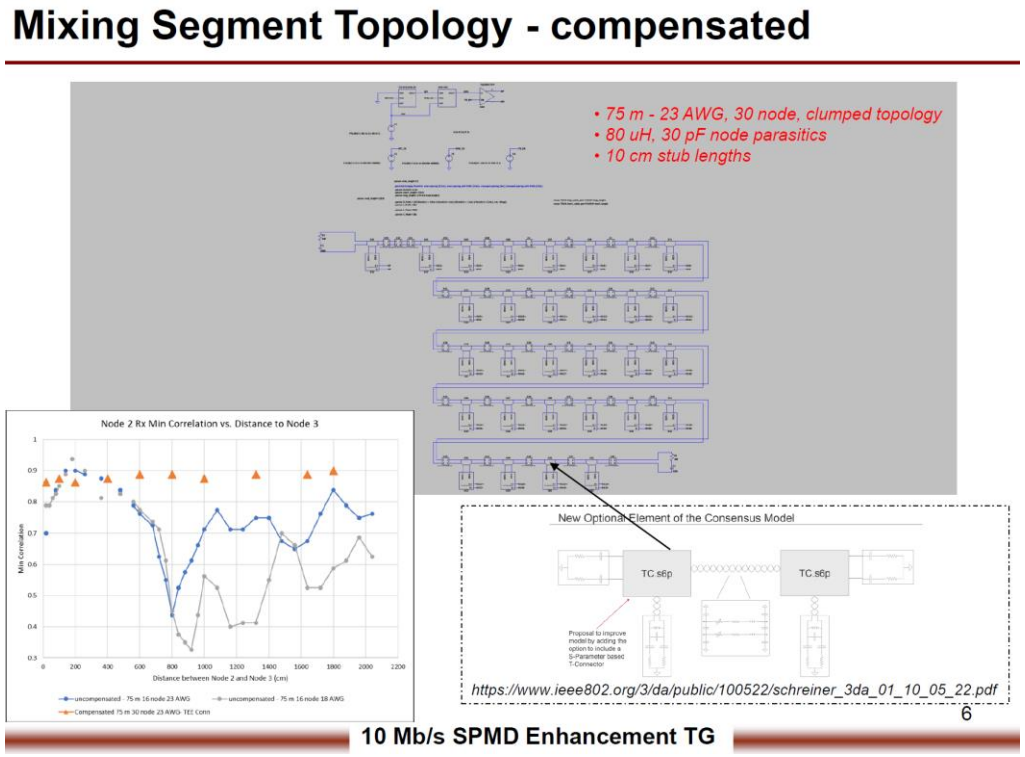
Thanks to Michael Paul/ADI

Other Contibutors (Schreiner, Diminico) are Consistent

https://www.ieee802.org/3/da/public/0723/schreiner_3da_12_July_23.pdf



https://www.ieee802.org/3/da/public/1123/diminico_SPMD_01_1123.pdf



NOTE – 20 cm clump node spacing, loss, and stubs makes these not worst-case, reflections add ~ 10log10(N_nodes-2), but still consistent

What really matters: Receiver Basics

- Receiver bandwidth – do we care about > 20 MHz
  - NOT MUCH
- Correlation/Matched filter receiver will weigh the ISI as the PSD of the pulse shape
  - Out of band reflections should be attenuated out just like out-of-band noise
- Effect of ISI will be frequency weighted by the shape of the (Mancheter) PSD from 0 to 20 MHz
  - NOT the PSD Mask, but the Biphase PSD
  - Highest around 10 MHz, zero at DC and 20 MHz

Interplay of 2 parameters

INSERTION LOSS

- Two major components
  - Signal attenuation along path and
  - Destructive interference caused by reflections at mismatch points (ILD)
- End-to-end IL limits worst-case path loss
  - Control this by IL spec
  - Controls SNR due to external noise
- Destructive interference is node-location-dependent and related to return loss at TC1 & TC2
  - Control this by RL spec (to keep IL smoother)

RETURN LOSS

- Two major components
  - Mismatch of cabling segments/terminations and
  - Mismatch of nodes to cabling
- Both control SNR due to ISI/reflections
- End-to-end RL limits cabling segment & termination mismatch
- TCI RL controls reflection ISI
  - Usually the limiting factor
  - Needs to take into account stubs & mismatch of cabling on opposite side of TCI (e.g., TC2 cabling if measuring TC1 RL)

More on Topologies

- Maximum node spacing only matters as it effects end-to-end insertion loss and delay (for PLCA & CSMA/CD)
- Physical delay span of “clumps” determines how many nodes add as voltage & how many as power
  - Implementation of T-connectors with inline inductors can effectively make nodes look like they are separated
  - Nodes further apart than about 1/20 baud start to decorrelate their reflections, fully decorrelated at ½ baud round trip

Reflections & Number of Clumped Nodes

- PSD-weighted reflection energy must be low enough to enable 1e-10 BER detection in noise
  - Because we don't specify a MINIMUM cable loss/unit length, this is entirely controlled by the RL, IL can't be considered in the specification
- In the limit where all reflecting nodes are at the same location, they add as voltage, i.e., 20log10(*N_nodes*-2) dB ; e.g., 23 dB for 16 node segments
  - *N_nodes* is the # of nodes on the mixing segment, -2 is because 1 is TX, 1 is RX
  - This is a "loose bound" – it is never achieved – real nodes are separated
- When all reflecting nodes are decorrelated, they add as power, i.e., 10log10(*N_nodes*); but this starts to be optimistic when nodes are within 0.4m
- Practically, pairs of nodes may add in-phase, and groups as power:

  6dB + 10log10(*N_nodes*/2 - 1)
- This means practical worst-case is 14 dB growth for 16 nodes, 18dB for 32 nodes, 21dB for 64…
- Loss between the nodes can improve this by reducing it by 2**ILnode* dB per node where *ILnode* is the loss from TC1 to TC2, but this comes at a cost of noise immunity or mixing segment length.

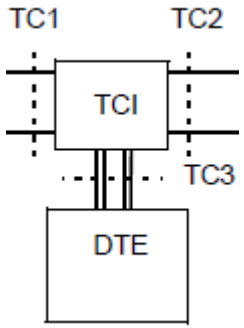
SPECIFICATIONS

Mixing Segment Specification & TCI (168.7)

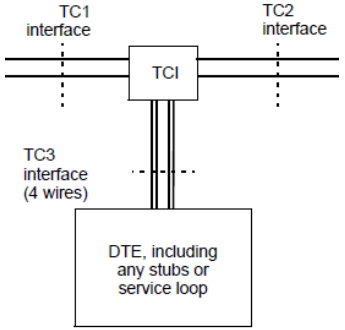
- Pictured and described as a 4-wire interface

  “each TCI has two interfaces on the mixing segment, one interface facing in the direction of left edge termination of the mixing segment (TC1), and one facing in the direction of the right edge termination of the mixing segment (TC2), and a four-wire interface facing the PMA (and any associated stub or service loop) (TC3) (see Figure 168–18).” (P71 L8-11)

From Figure 168-17:



From Figure 168-18:



- But, simulations and return loss specification use a 2 wire interface

168.7.2 Return Loss spec (at TC3), reference impedance is 50 Ω … meaning TC3 is specified as a 2-wire interface looking into the parallel impedance of the two terminations.

RECOMMEND Change figures and text to 2-wire once we resolve how to specify the mixing segment

Approach to Insertion Loss

- Specify PMA transmit levels and noise levels at TC1 & TC2
  - Takes TC1/2 to TC3 loss out of the SNR equations
  - Can recommend a maximum TC1/2 to TC3 loss for T-bridge/stub topologies if necessary
  - Need changes to Figure 168-13 (test fixture) and PMA electrical specs to reflect specification is at TC1 & TC2 each with 100 ohms in parallel.
- Specify insertion loss end-to-end (maximum transmission path)
  - T-bridges: with any known TCI's in place, and representative loads if necessary.
  - IN-and-OUT- without representative loads, thru-connectors or wire
- Includes 2 parts – Mixing segment (cabling) IL & Maximum TCI IL
  - Adjust Mixing segment IL equation for TCIs (either type) still to be added
  - Also allows configures room for innovation to increase node count
- Remember - Node reflections will be controlled by RL specification

Mixing Segment Insertion Loss (168.7.1)

- Magnitude determines signal loss & noise resistance (receiver SNR), and allowance for ILD (ripple) determines tolerance for node placement, compensation, and segment mismatch
  - IF the TC1/TC2 return loss is high (low reflections), ILD from TCI placement will also be low
- Current state:
  - Mixing segment insertion loss specified without any DTE's attached... But may be met with dummy loads attached. (P72 L6)
    - This was intended to separate the mixing segment qualification from the node installation and the TCI locations (allowing thru-connectors, e.g., barrels)
    - Need to fill in equation 168-3 – THIS IS KEY WORK, AND SHOULD BE SPECIFIED BASED ON NOISE TOLERANCE
- NOTE– comment 8 changed this to: "with DTEs or representative dummy loads attached"
  - This is what we want, because we will specify TCI (TC1 & TC2) loaded return loss to be low, hence eliminating ILD

Approach to Return Loss

Most ISI & ILD is controlled by TCI Return loss at looking into TC1 or TC2 from the mixing segment (each has the same specification) controls the reflections onto the mixing segment

- Edge terminator return loss controls segment-to-segment mismatch or in-place TCI compensation mismatch
  - As with insertion loss, adjust specification for any devices not in place
- TC3 return loss
  - Looking in from the cable is already specified by the TC1/TC2 return loss
  - Looking out from PMA, if PMA electricals are specified at TC1 & TC2, TC3 doesn't matter
- May very well not need TC3 as a specified interface, only a reference point for PMA attachment, and to explain the signal flow.
- Specify TC1 and TC2 return loss (looking in from cable) with the other port (TC2 or TC1) terminated as if on the line
  - Specified with PMA or dummy load – this is what matters
  - Beyond that, there are many questions

How high must TC1 (TC2) RL be?

- Detection requires ~13 dB SINR
  - Worst case (voltage sum), 16 nodes implies 36 dB RL minimum
  - Practical case (mix of voltage & power) implies 27 dB RL minimum
    - But these leave no margin for noise
  - Adding 6 dB reduces ISI loss to SNR to 1 dB
  - Recommend at least 34 dB minimum RL specification, no more than 42dB
- Compensated Node simulations give ~45 dB at 7-12 MHz
  - Question to be resolved: What can we achieve with realistic component tolerances?

Other TC1/TC2 Return Loss Questions

1. ***If PMA can be detached (and the dummy load forgotten or removed) does the node still need to meet TC1/TC2 RL specifications without a PMA or load? (installation-error tolerance)***

   ANSWER: Not clear we need to define this, if the DTE can be detached, any stub or service loop to TC3 must also be detached…but we also need to make it clear that the specification is to be met in the installed condition.

2. ***What impedance do we terminate 'the other' TC in (e.g., TC2 for TC1's spec)***

   ANSWER: For a high RL, 100 Ohms is good enough. RL of 40 dB gives impedance mismatch < 2% relative to 100 ohms – hence no need to drop TC2/1

Mixing Segment Return Loss (168.7.2)

- There are two specifications looking into the Mixing Segment at TC3 and at the edge terminations
  - Both are without any DTEs attached …(P72L21 & P72L28)
  - Edge Termination is RL using a reference impedance is 100 Ω, meaning TC3s are in a high impedance state, or TCIs are unterminated at TC3.
    - Consistent with a 2-wire connection and the edge terminator
    - Measurement doesn't work for the mixing segement without a DTE or through-connection from TC1 to TC2
  - RL at TC3 looking into the mixing segement has a reference impedance of 50 Ω.
    - Consistent with a TC3 as a 2-wire interface into the parallel impedance of the two 100 ohm edge terminators.
- Needs resolution, most consistent if TC3 is a 2-wire interface.
- Consistency with comment 8 would change this to: "with DTEs or representative dummy loads attached" fixing the problem with the edge-termination RL measurement
- There is an RL specification at TC3, but it appears that return loss at TC3 into the mixing segment (168.7.2, 1st paragraph) is NOT needed, TCI RL at TC1 and TC2 (168.8.2.2) should control reflections from nodes.

Example (Mixing Segment) Insertion Loss Text

The mixing segment insertion loss, without any DTEs attached, shall meet the values determined using Equation (168–3) between edge termination attachment points. The reference impedance is 100 Ω. If the mixing segment includes TCI connectors which are specified to use a dummy load, this requirement may be met with the dummy load attached. Equation (168-3) is specified for a case of a number (N_{DTE}) DTE, or DTE-equivalent loaded TCIs yet to be placed. When measured with some or all DTEs in place, N_{DTE} is decreased to the nominal number of DTEs that may be added to the mixing segment at a future time.

$$IL(f) \leq \frac{l}{100} \times \left(a\sqrt{f} + b \times f + \frac{c}{\sqrt{f}} \right) + N_{DTE} \times d$$

- NOTE (not part of example text) – *l* is the nominal loss-length of the mixing segment in meters, *a*, *b*, and *c* are constants for the loss of 100m of cabling, and *d* is the maximum loss allocated for a single loaded TCI from TC1 to TC2

Suggestion for 168.7.2 Mixing Segment RL

- Reflections looking into TC3 only attenuate PHY transmit energy, don't propagate onto the mixing segment, don't need specification at TC3

168.7.2 Return loss

The mixing segment at each point TC3, without any DTEs attached, shall meet the return loss values determined using Equation (168–4). The reference impedance is 50 Ω. If the mixing segment includes TCI connectors which are specified to use a dummy load, this requirement may be met with the dummy load attached.

$$RL(f) \geq TBD \text{ dB}, \quad 0.3 \text{ MHz} \leq f \leq 40 \text{ MHz} \qquad (168\text{–}4)$$

The mixing segment edge terminations, without any DTEs attached, shall meet the return loss values determined using Equation (168–5). The reference impedance is 100 Ω. If the mixing segment includes TCI connectors which are specified to use a dummy load, this requirement may be met with the dummy load attached.

$$RL(f) \geq TBD \text{ dB}, \quad 0.3 \text{ MHz} \leq f \leq 40 \text{ MHz} \qquad (168\text{–}5)$$

Suggestion for 168.7.2 Mixing Segment RL

- Existing specification handles cable segment mismatch

The mixing segment edge terminations, without any DTEs attached, shall meet the return loss values determined using Equation (168–5). The reference impedance is 100 Ω. If the mixing segment includes TCI connectors which are specified to use a dummy load, this requirement may be met with the dummy load attached.

$$RL(f) \geq TBD \text{ dB}, \quad 0.3 \text{ MHz} \leq f \leq 40 \text{ MHz} \qquad (168\text{–}5)$$

- ***Question:*** ***Will we also need a mixing segment characteristic impedance measured at each TC1 & TC2 looking into the cable?***
  - ***This could also be dealt with by an RL spec at TC1 & TC2 looking into the cabling(rather than the existing one at TC3), ensuring the cabling is matched at each node?***
- ***Suggest we do not need RL looking into the cabling at each TC1/TC2, as cabling mismatches should be evident in the edge-terminator RL.***

Suggestion for 168.8.1.1 TCI IL

- Maximum insertion loss from TC1 to TC2 needs to be specified
  - Only needed to be specified with a PMA or PMA dummy load attached
  - The value of "*d*" in the prior equation goes in the remaining TBD below.

168.8.1.1 TCI Insertion Loss

~~Without a PMA or PMA loading present, the differential insertion loss of the TCI between TC1 and TC2 shall be less than TBD dB *(ed note - small number)* from 0.3 to 40 MHz, in each direction, measured into 100 Ω.. This specification does not apply if the DTE cannot be electrically disconnected from the TCI.~~

~~With the PMA (or PMA load specified for the TCI) present at TC3,~~ the differential insertion loss of the TCI between TC1 and TC2 shall be less than TBD dB *(ed note - allows for compensation and phy loading –may be an equation)* from 0.3 to 40 MHz, in each direction, measured into 100 Ω.

Suggestion to Fix: (TCI return loss)

- 168.8.1.2, 2nd paragraph, P74 L36: (change as shown)

  With a PMA or PMA load present at the TCI attachment, the return loss of the TCI at TC1 and TC2 shall be greater than Equation (168–7) with the other trunk interface (i.e., TC2 or TC1, respectively) terminated in 100 Ω.

  NOTE – this specification replaces the MDI return loss and is measured at the TCI.

- Will we also need a mixing segment characteristic impedance for the trunk cable measured at each TC1 & TC2 that matches this?
- Consider whether we need the first paragraph (P74 L28-35) (do we need the fault tolerance?) – ***Recommend we delete this, retaining the loaded IL spec from TC1 to TC2:***

  Without a PMA or PMA loading present, the differential insertion loss of the TCI between TC1 and TC2 shall be less than TBD dB *(ed note - small number)* from 0.3 to 40 MHz, in each direction, measured into 100 Ω. This specification does not apply if the DTE cannot be electrically disconnected from the TCI.

- Regardless, swap the order of the 2 paragraphs – the second is mandatory, the first is optional
- Key work is to determine acceptable values for the RL validating component tolerances make it feasible

Overall Clarification for TCI specifications

- All TCI specifications are intended to be met in the operational condition. That is, with PMA attached, or, if the PMA can be detached, they may be met with a ‘dummy load’.

Therefore, add the following to 168.8.1 TCI electrical specification:

All TCI electrical specifications are intended to apply in the mixing segment’s operational condition. Therefore, the electrical specifications in 168.8.1 and subsections are to apply with a PMA or a specified PMA load connected to the TCI. Additionally, PMA loads specified for the TCI are to be connected if the DTE is electrically disconnected from the TCI.

THANK YOU!