IEEE 802.3da – Noise Environment Definition

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Outline

- Work required to achieve consensus on the 10BASE-T1M channel model
  - Mixing segment specifications
    - Adopted baseline text https://www.ieee802.org/3/da/public/062922/diminico_SPMD_02_06292022.pdf ✓
  - PHY TX model
    - Presented in https://www.ieee802.org/3/da/public/050422/beruto_3da_20220502_tx_model.pdf ✓
  - PHY RX model
    - In progress
- The PHY RX model is the missing piece of the puzzle
  - The end goal is to provide a criterion to discern “good” and “bad” channels
    - That is, under what minimum conditions a PHY can operate maintaining a BER < 10^{-10}
- The RX model definition requires more steps
  - Define the noise environment
  - Define the minimal signal processing required in the PHY
  - Define a metric for minimum PHY performance
  - Derive measurable, observable parameters for validation
    - Chart the course for test specifications

Agenda

- Presentation on noise environment definition (this presentation)
  - Relevant specifications
  - Challenges & potential solutions
    - Comparison with Clause 147 (802.3cg) PHY applications
- Receiver model architecture
  - Model basics (filtering, slicing, decoding, …)
  - Definition of a metric for the receiver performance vs noise environment
  - Simulation results
- Integration of the receiver model into the consensus model
  - Putting things together (mixing-segment characteristics, TX model, RX model)
- Use the consensus model to derive specifications to adopt

Noise environment definition

Overview

Overview

- What do we mean by noise environment?
  - Noise has many flavors (depending on the source) and can be modeled in several ways, e.g.
    - White [random, uniform, e.g., Johnson Noise]
    - Gaussian [sum of independent random sources, e.g., Jitter]
    - Impulse [non-stationary, short duration, high peaks, e.g., switching a motor on/off]
    - Tone [stationary CW at specific frequencies, e.g., RF generators]
  - Different applications/environments are typically dominated by different combinations of noise sources
    - The characterization of these sources defines the noise environment
- Why do we care?
  - The kind and amount of noise we have to deal with is critical for the PHY receiver design and may affect the system architecture significantly
  - Noise environments are regulated, and products are tested for conformance
    - E.g., IEC61000-4-4 (EFTs), IEC61000-4-6 / CISPR25 (RF immunity)

Applications

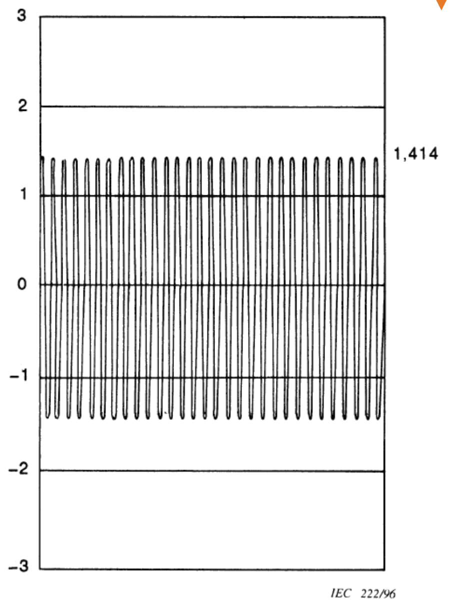
- What application should we consider for 802.3da?
  - Objective #8: support operation in the noise environments for building, industrial, and transportation applications
- These environments are mainly dominated by impulse and RF noise
- IEC61000-4-4 specifies “Electrical fast transient (EFT) / burst immunity test”
  - That is, immunity to impulse noise
- IEC61000-4-6 specifies “Immunity to conducted disturbances, induced by radio-frequency fields”
  - That is, immunity from RF aggressors
- Automotive specifications are mainly derived from CISPR25
  - Different test methods, but the noise definition is largely compatible with IEC61000
  - The major difference is with EME (Electro-Magnetic Emissions)
    - Not in scope for this presentation

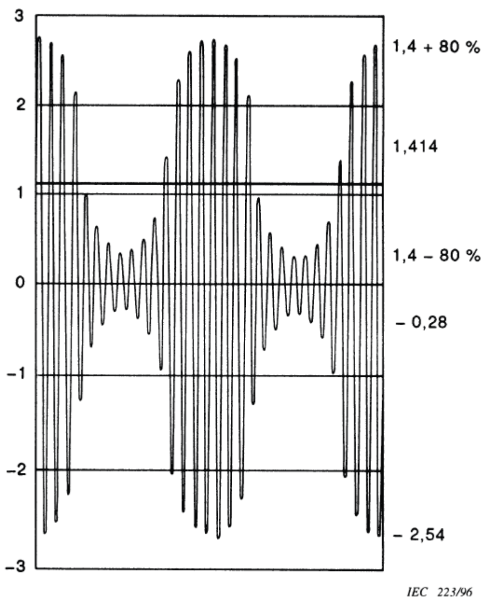
Noise environment definition

Immunity to RF disturbances

Conducted Immunity (CI)

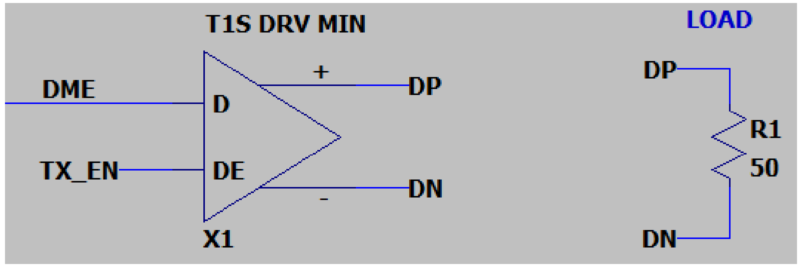
- IEC61000-4-6 models the RF noise in industrial environments as follows
  - Continuous Wave (CW) simulating “intentional” RF transmitters in the frequency range from 150 KHz to 80 MHz.
    - Some OEM requires testing above 80 MHz as well
    - Automotive typically defines the range between 1 MHz and 1 GHz
  - The CW is coupled (CM) to the channel using clamps or CDNs (preferred)
  - The amplitude of the CW is calibrated to be a specific value measured at the MDI
    - during the test, the amplitude is 80% modulated by a 1 kHz sine wave
  - The base (unmodulated) amplitude is selected among three classes, according to the application
    - Class 1 → 1 V_{rms} (Low EM radiation environment)
    - Class 2 → 3 V_{rms} (Moderate EM, typical commercial env)
    - Class 3 → 10 V_{rms} (Severe EM, typical **industrial** env)
  - The CW sweeps the frequency range in 1% steps and a minimum of 0.5 s of dwell time (typ. 2 s)

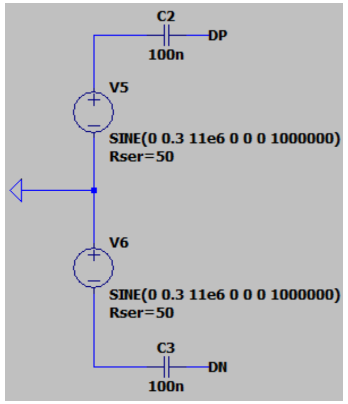


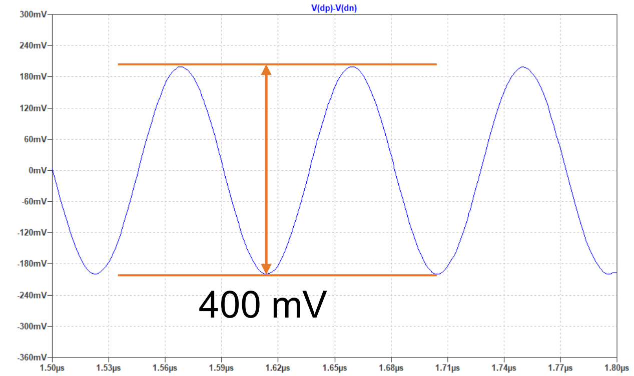


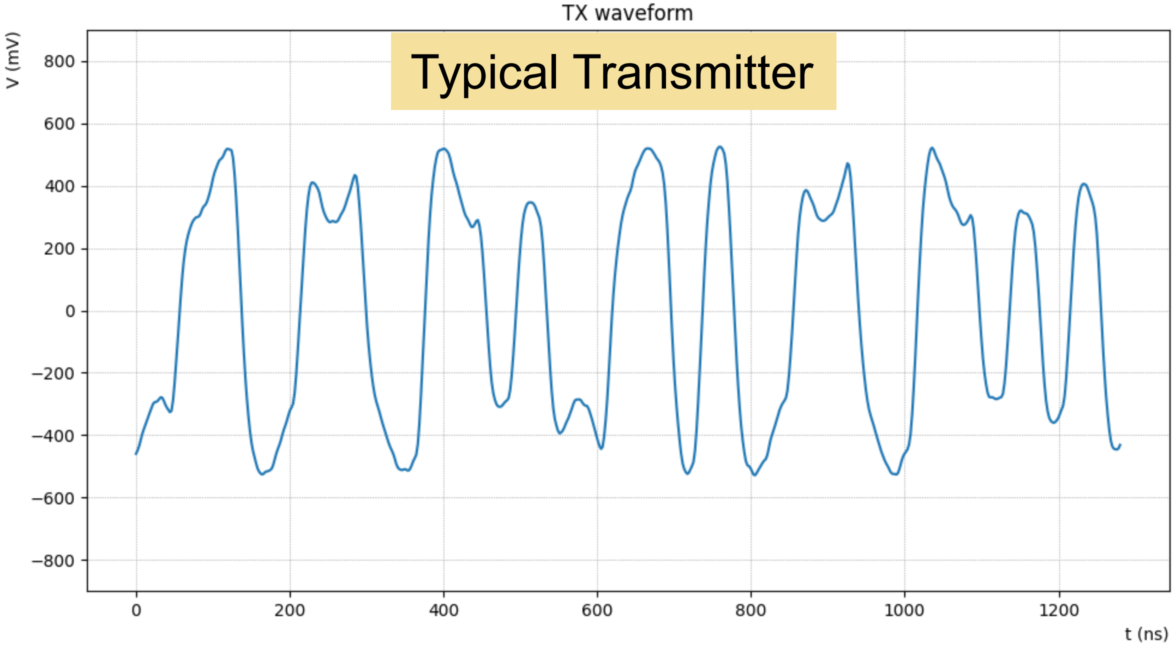
CI effect on a 10BASE-T1S/M link (1)

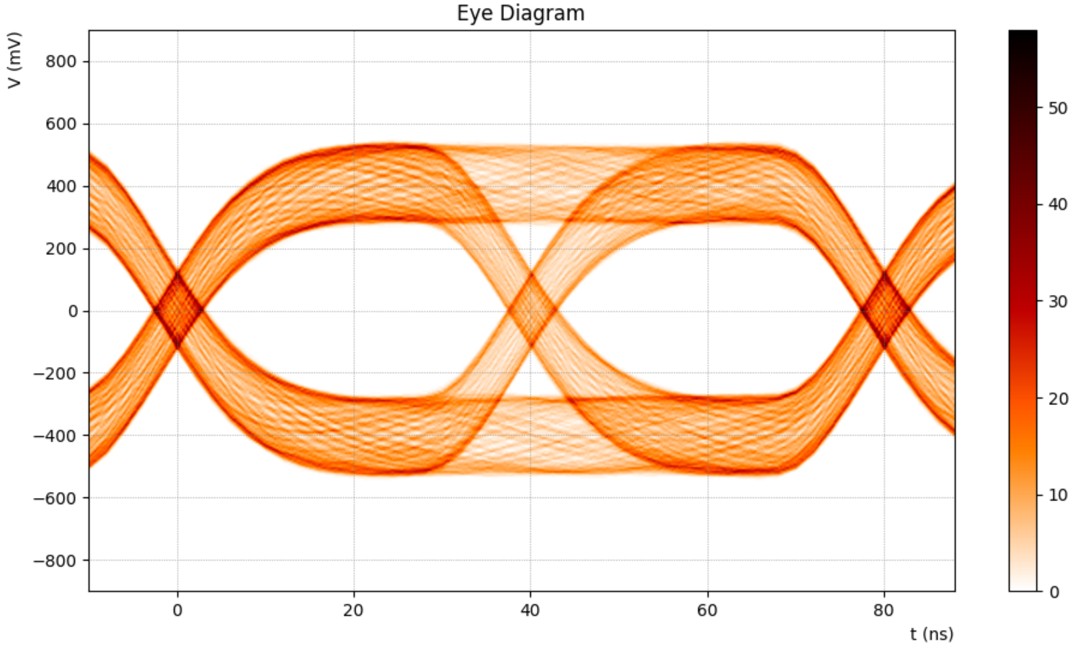
- Doing the math:
  - 10 V_{rms} calibrated at the MDI + 80% modulation → 51 $V_{p\text{-}p}$ (max, CM)
  - Considering 43 dB of MC loss (TCTL) → 360 $mV_{p\text{-}p}$ (max, DM)
  - Taking some margin for tolerances/non-idealities → 400 $mV_{p\text{-}p}$ (max, DM)
- Let's have a look at the eye diagrams
  - DISCLAIMER: the presenter is NOT suggesting using eye diagrams as a metric for deriving the receiver performance. But it is a quick & handy way to have a visual feeling.
  - Using the simulations presented already for the TX model https://www.ieee802.org/3/da/public/050422/beruto_3da_20220502_tx_model.pdf
  - Adding a CW of 400 $mV_{p\text{-}p}$ at 11 MHz (in-band)
    - Direct AC coupling

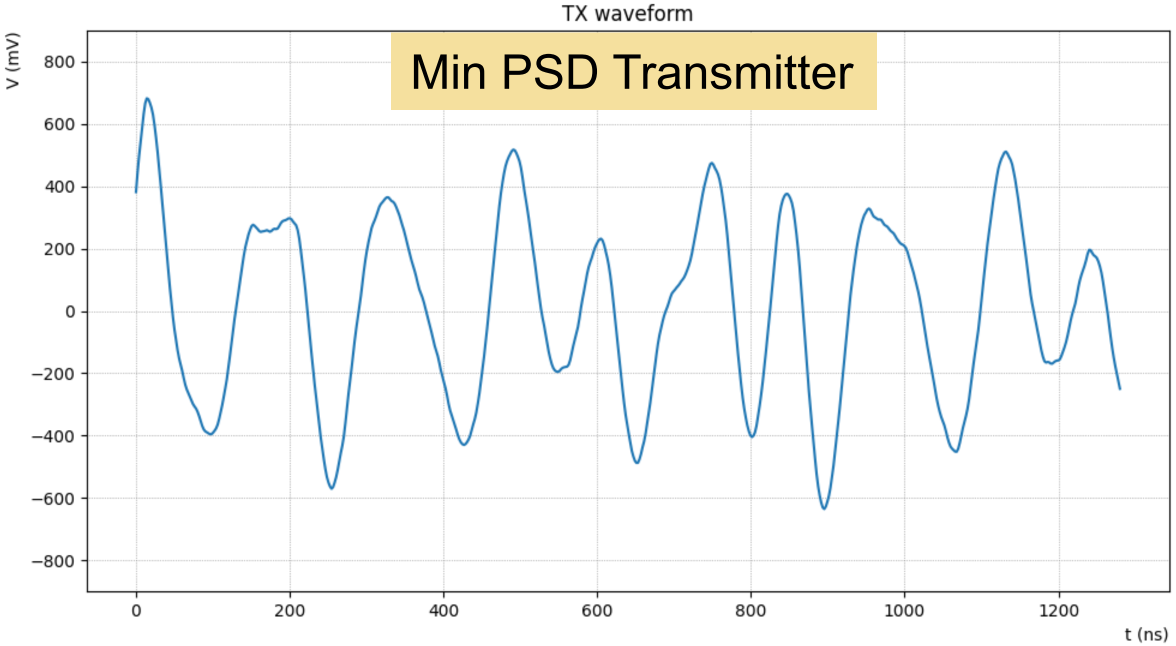


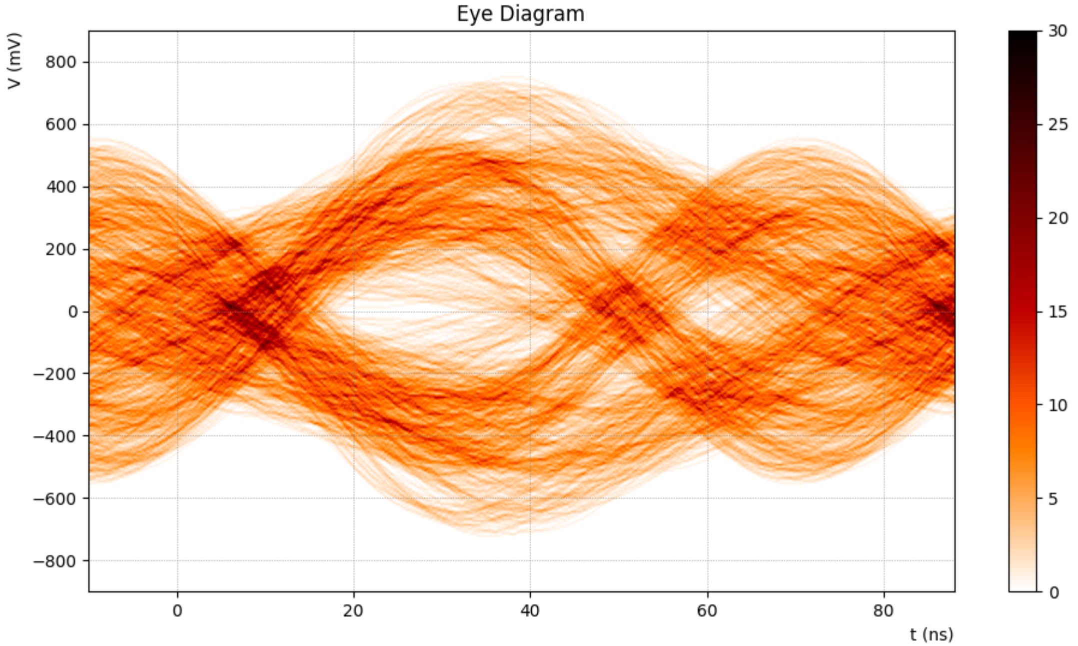












Eye diagrams w/ CW noise

Challenges

- The effect of the noise sums up with the channel IL/RL characteristics and the defined TX PSD
  - The receiver should meet the target BER in these conditions
  - We need a metric to express the receiver’s performance
- But the BER is not the only problem on a mixing segment
  - Carrier detection could be a problem: if the PHY detects a carrier out of the CW noise, the station will not transmit anymore (CRS makes the MAC defer any transmission).
    - When performing the CI test, this means forever.
  - The solution is to implement carrier detection not based (solely) on energy, but also correlating with the DME and 4B/5B properties. In other words, we can design a matched filter to distinguish noise/CW from a real carrier. BUT …
  - During a collision event, stations that are “listening” (i.e., they are not creating the collision) are still required to detect a carrier (see Clause 147.3.5 – b)
    - This can’t be easily solved with a matched filter

Isn’t this a problem for 10BASE-T1S as well?

- Systems based on 10BASE-T1S PHYs and **U**TP cables can meet Class 3 CI
  - Engineered networks using the PLCA RS (for all nodes) are collision-free
    - Therefore, the carrier can be recovered reliably using the aforesaid matched-filter technique
    - Existing 10BASE-T1S PHY implementations do this already
- Clause 147 does not define the application-specific noise environments described in this presentation
  - The minimum noise environment defined in Clause 147.5.5.2 (Alien noise cross-talk) is -101 dBm/Hz @40 MHz BW (Gaussian)
  - This is roughly equivalent to -101 – 10 log(40e6) = -25 dBm = 0.013 V_{rms}
  - Considering a BER of 10^{-10}, that brings us to 0.013 * 6.7 * 2 = 170 mV_{p-p} of CW
  - This is way lower than the requirements for CI in IEC61000-4-6
    - → Not a problem!

What about 10BASE-T1M?

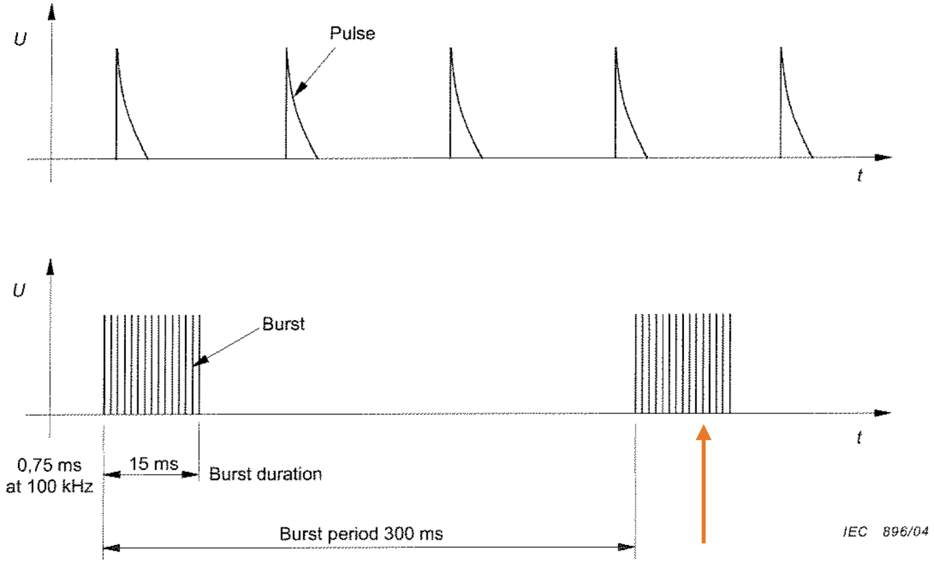
- Using static PLCA is still a valid option but…
- In 802.3da we introduced the concept of D-PLCA to allow the automatic/dynamic assignment of PLCA IDs (engineered → plug & play networks).
  - D-PLCA is **not** collision-free, at least not at startup or when nodes join the network
  - D-PLCA "evolves" on successful transmissions, not on collisions
    - i.e., D-PLCA is consistent because it converges to a situation where each node gets a unique PLCA ID without relying on collisions → no changes to D-PLCA are needed
  - Nevertheless, when not using (D-)PLCA, and during D-PLCA "learning", we are still required to detect "receive-mode collisions" (asserting CRS) as per Clause 147.3.5.
- Follow-up presentation on this topic!
  - Anticipation: can we relax Clause 147.3.5 requirements?
    - What's the purpose of detecting receive-mode collisions (RMC)?
    - What's the impact on the network if a PHY fails to detect a carrier during an RMC event?
    - If it was only a matter of performance, would this be acceptable for short reach / low number of nodes?

Noise environment definition

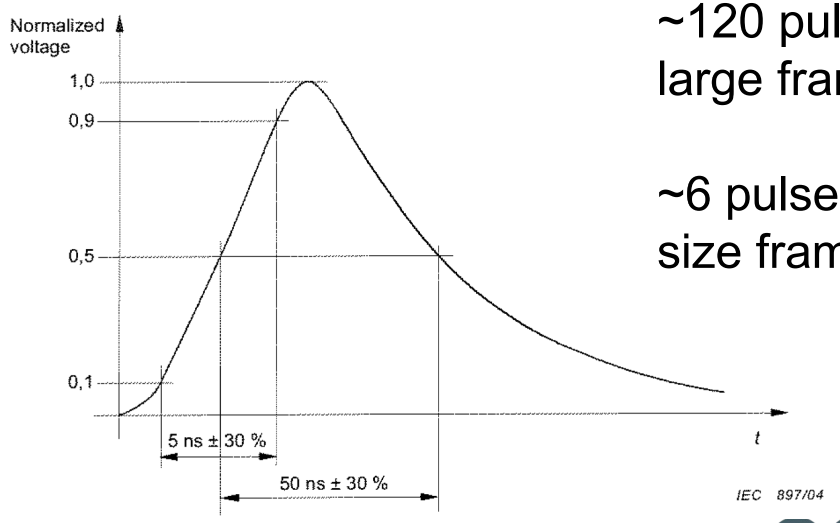
Electrical Fast Transients (EFT)

EFT (Electrical Fast Transients)

- IEC61000-4-4 models the impulse noise in industrial environments as follows
  - Calibrated pulses of up to 2kV (CM)
  - Duration: 50 ns (50% to 50%)
  - Rise time: 5 ns
  - Burst rate: 100 kHz (10 µs)
  - Burst duration: 15 ms
  - Burst repetition: 300 ms



- Pulses are calibrated on a 50 Ω load at different peak levels (classes)
  - 250 V (also typical for automotive)
  - 500 V
  - 1 kV
  - 2 kV



~120 pulses in a large frame (1.2 ms)

~6 pulses in a min size frame (57.6 µs)

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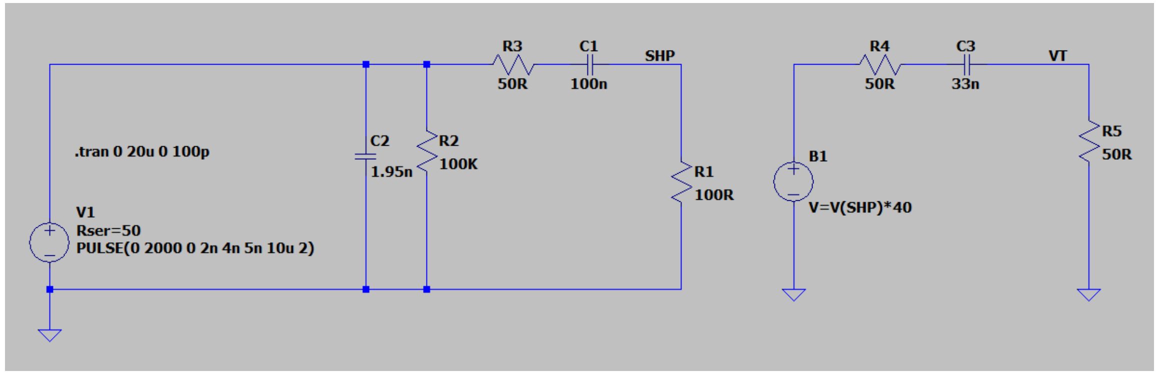
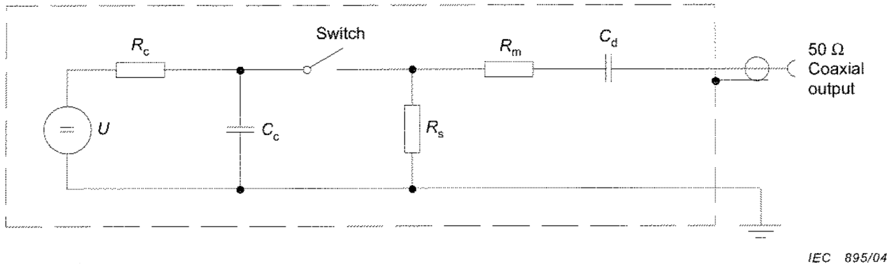
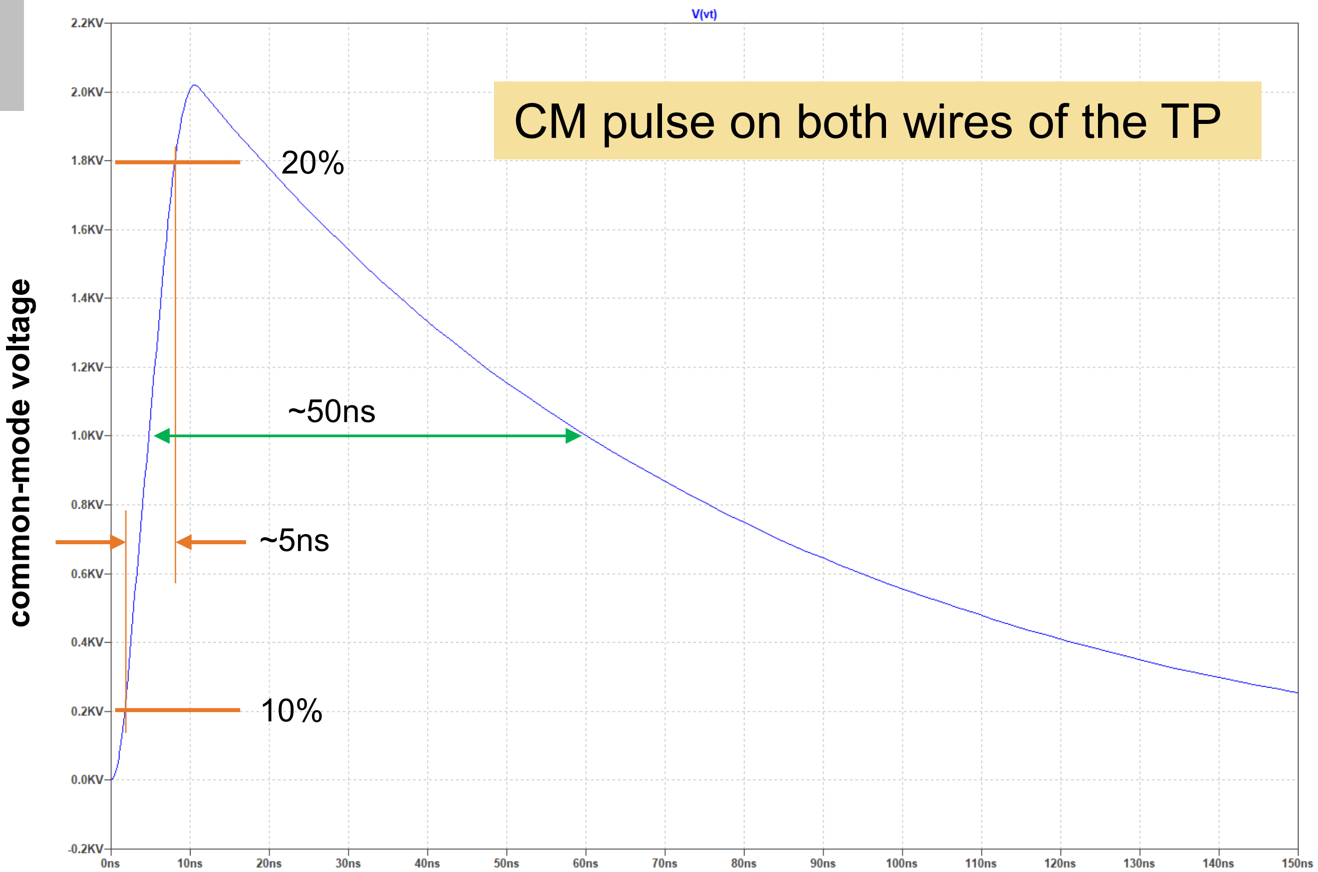
EFT effect on a 10BASE-T1S/M link (1)

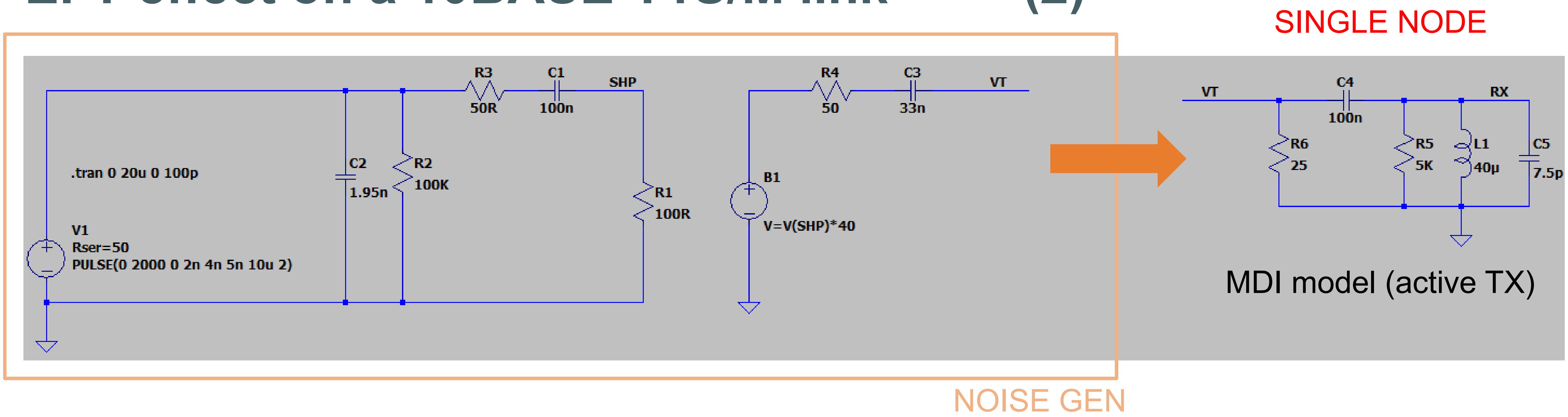




- Model of the impulse noise generator, following IEC61000-4-4 requirements
- Calibrated on a 50 Ω load
- Coupled via a 33 nF capacitor
- 2 kV peak pulse (highest class)

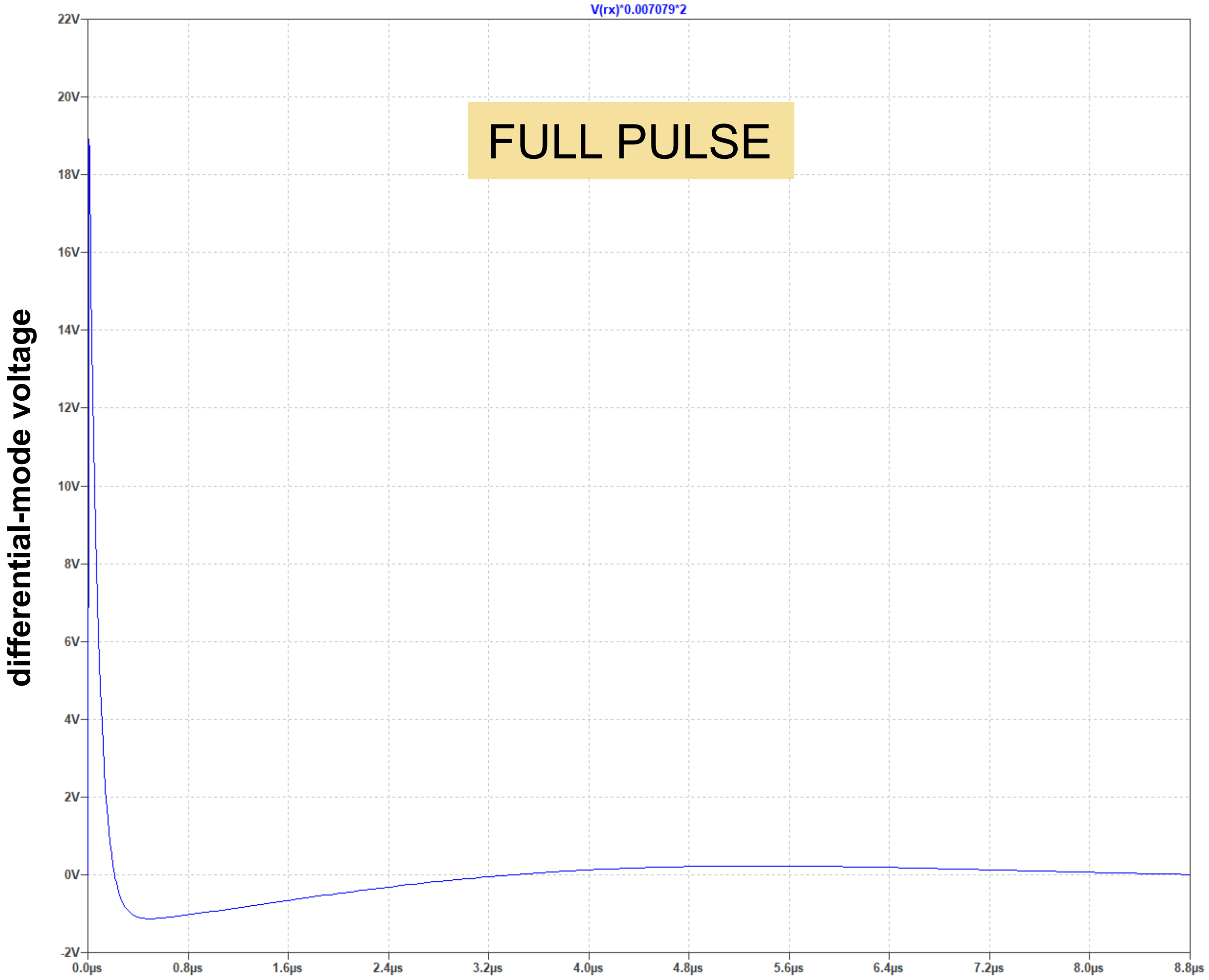


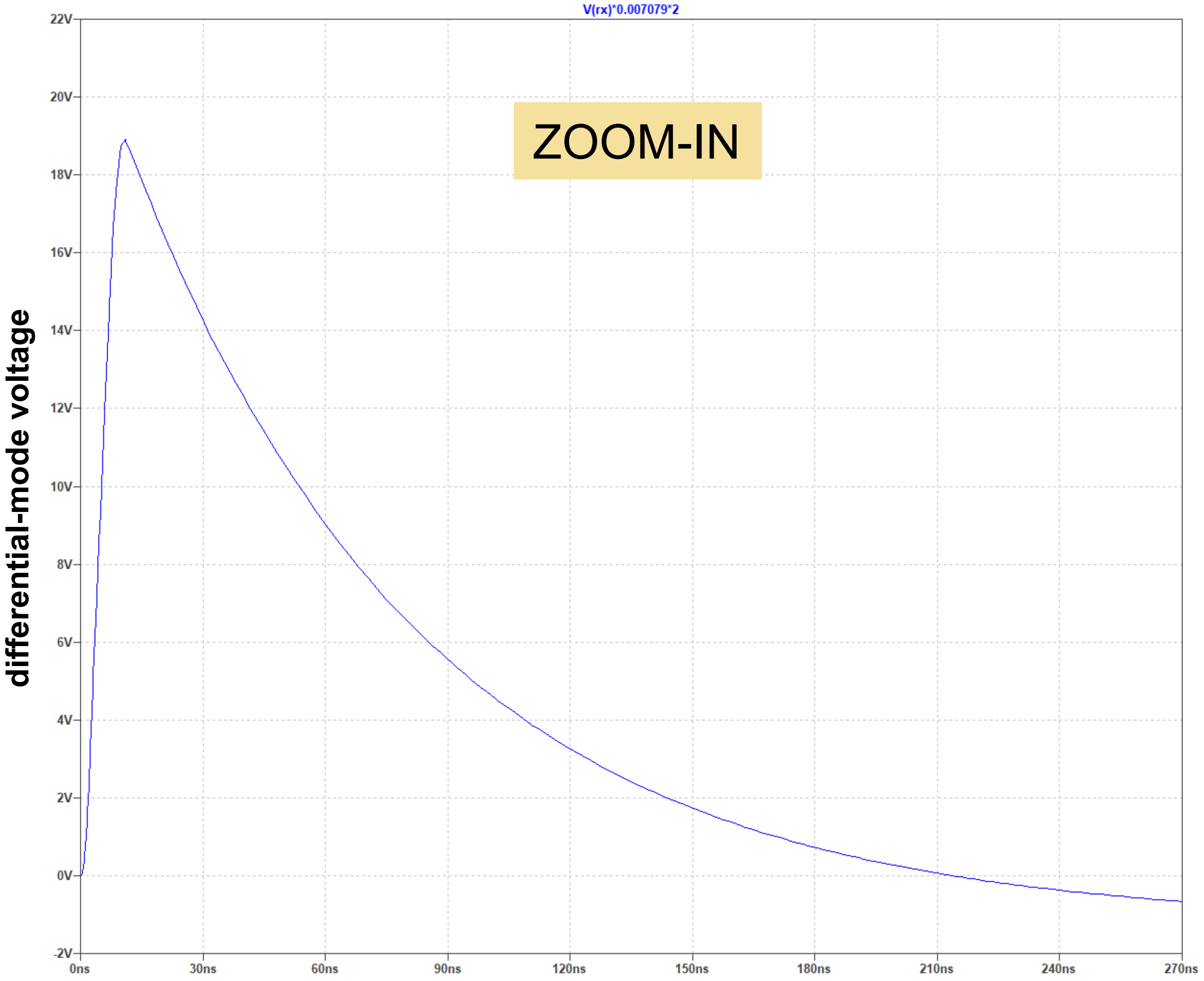
EFT effect on a 10BASE-T1S/M link (2)



- Considering a mode conversion loss of 43 dB
  - i.e., Transverse Conversion Transfer Loss (TCTL)
    - DM voltage generated by injected CM voltage at the **opposite end** of the segment (or vice-versa)
    - Not to be confused with TCL which is the CM voltage reflected back at the injection point
  - For simplicity, flat on all frequencies → DM pulse is the CM pulse lowered by 43 dB
    - In reality, MC degrades at higher frequencies, but we assume an LPF in the receiver to compensate
    - This is just an estimation!

EFT effect on a 10BASE-T1S/M link (3)





- Differential mode noise is way higher than the nominal TX amplitude (1 V_{p-p})

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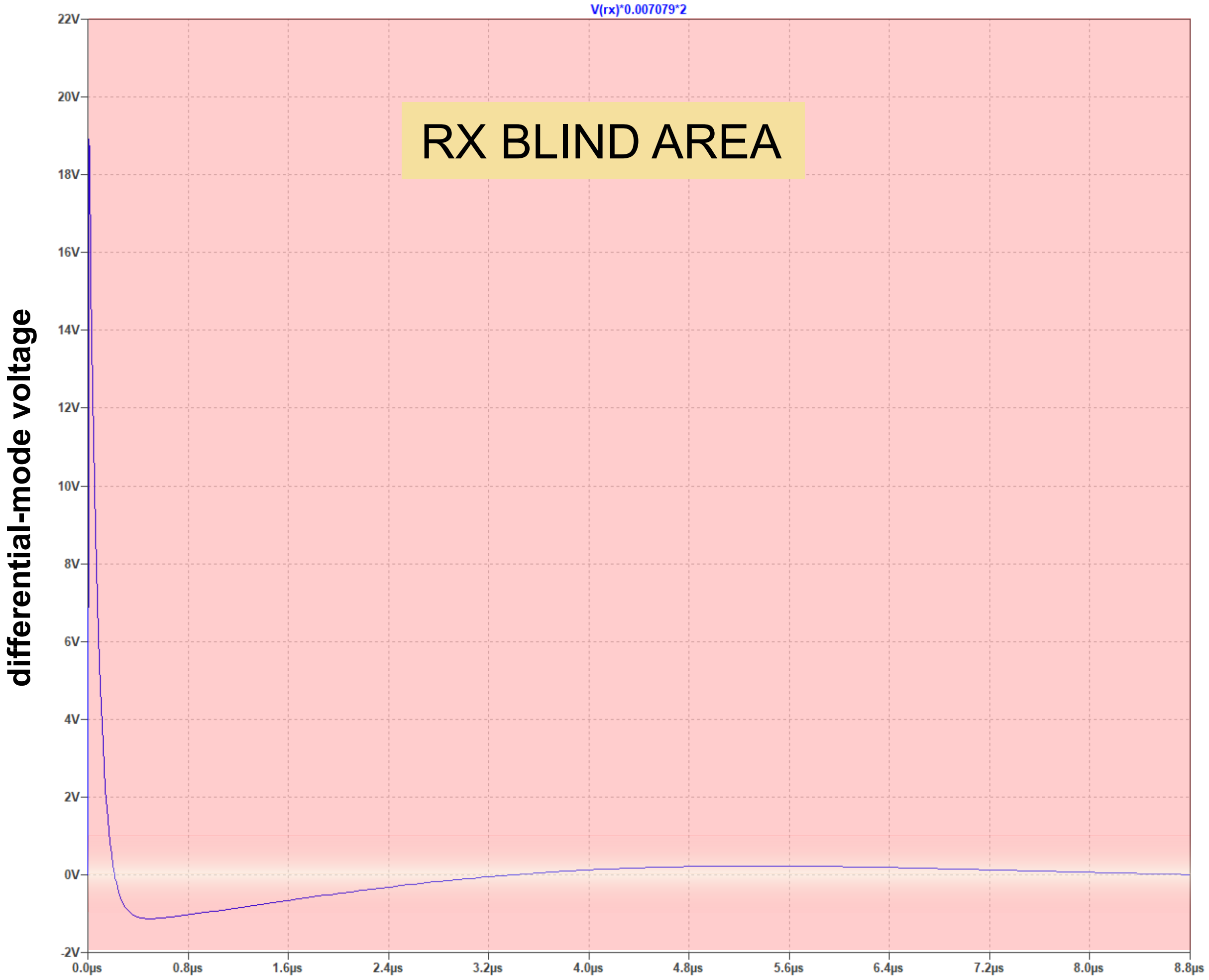
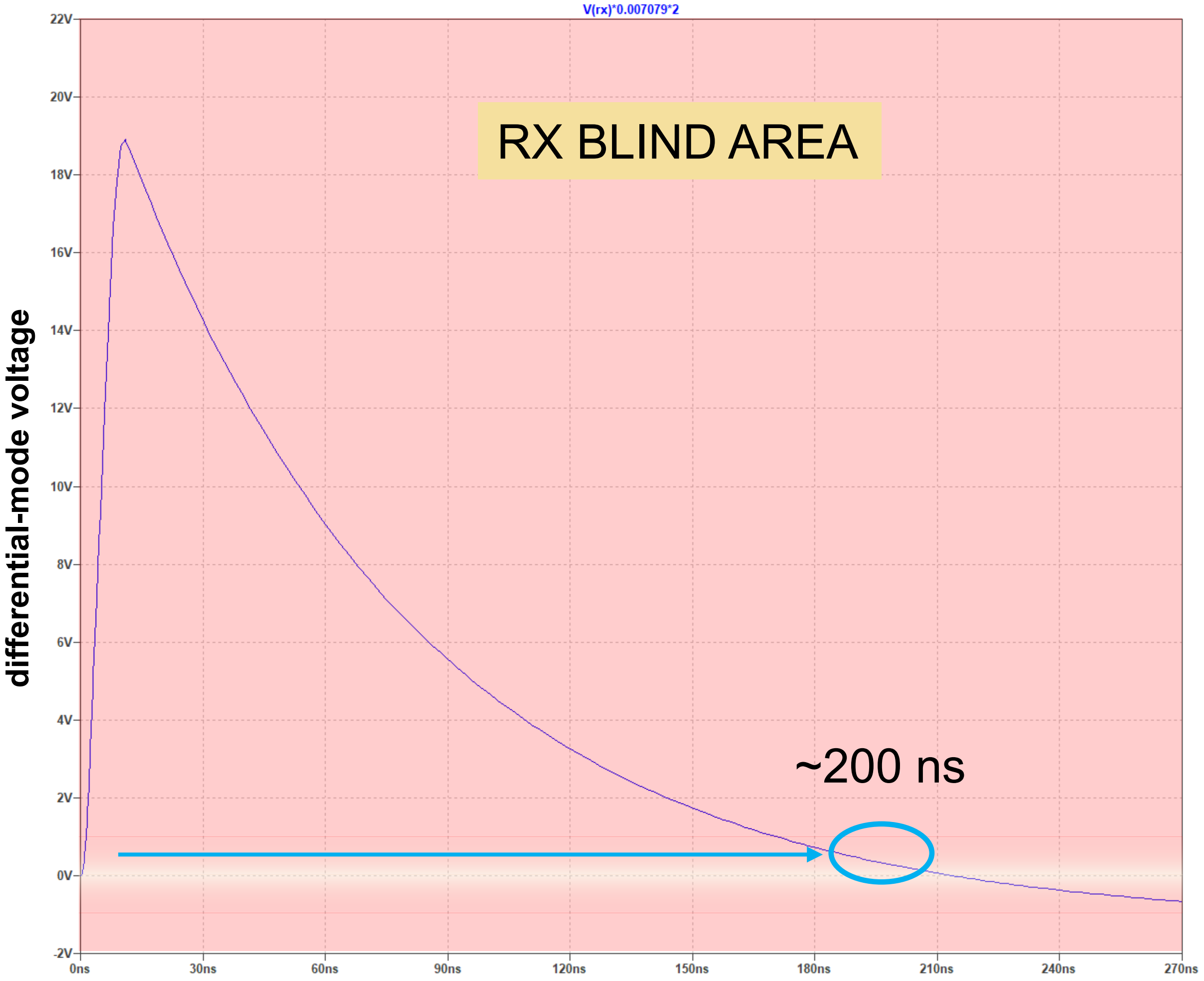
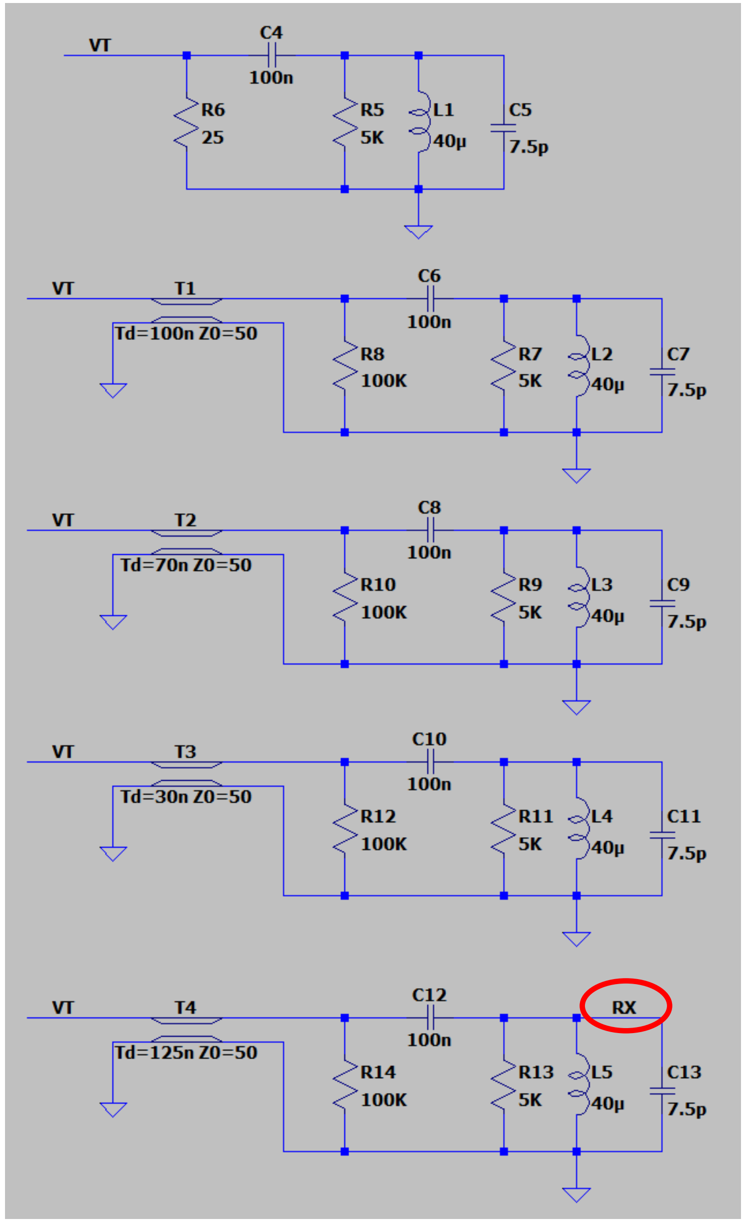
EFT effect on a 10BASE-T1S/M link (3)





- The receiver is blinded for a few DME bit-times (~3 BT)

EFT effect on a 10BASE-T1S/M link (4)



- The FEC proposal (https://www.ieee802.org/3/da/public/0721/huszak_zimmerman_fec_3da_07142021.pdf) could help
  - It can correct exactly one 5B code-group

    BUT…
- In real-life, EFT pulses are never that smooth!
- Let's see what happens, for example, using more nodes
  - 5 nodes are located at different distances (Td)
  - One node is transmitting (top one)
  - The other nodes are just receiving (High-Z state)
  - Far from being the "worst-case" topology

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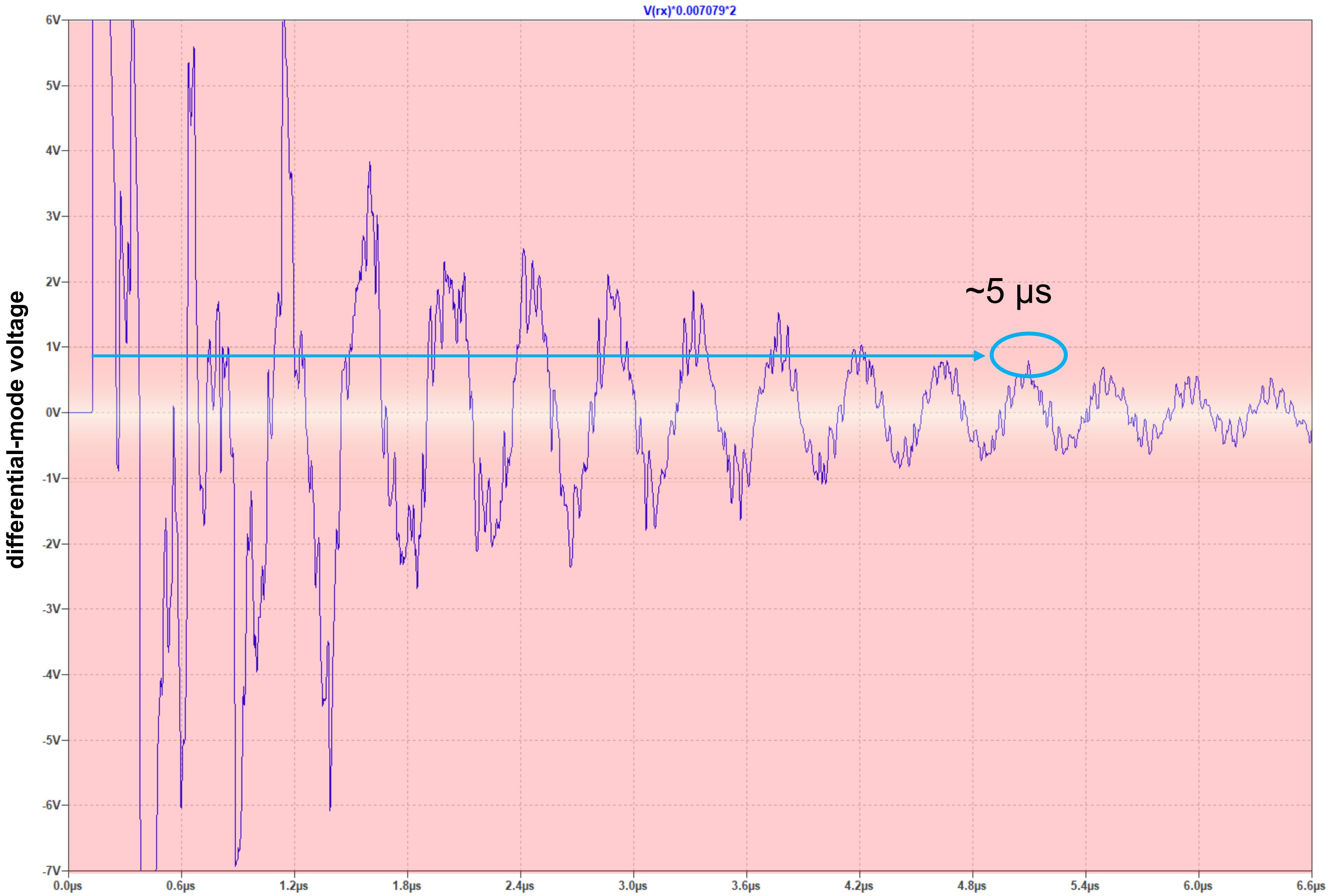
EFT effect on a 10BASE-T1S/M link (5)



- The CM pulse trigger reflections at the MDI which may span over a large time interval
- This is not a result of the Clause 147 mixing-segment / MDI definition!
- See also https://www.ieee802.org/3/cg/public/Mar2017/Graber_3cg_01a_0317.pdf
- https://www.ieee802.org/3/NGEBASET/public/entnoise/Shirani_NGEABT_03_0315.pdf

How to deal with EFT then?

- Clause 147 PHYs can meet at least EFTs at 250 V peak as defined in IEC61000-4-4
- According to my experience, Clause 147 PHYs just cannot guarantee a BER of 10^{-10} in the higher EFT classes
- However, the EFT test is a system-level test, including the higher layer protocols
  - It is allowed, for example, to have re-transmissions to meet the BER requirements
    - The bursts are limited in time (15 ms) and repeat infrequently (300 ms)
    - Most applications can tolerate this
- My conclusion: it’s probably not worth it trying to solve this problem in the PHY’s receiver
  - Note that EFTs can (likely) be detected as collisions, making the MAC back-off and re-transmit the packet

Conclusions

Conclusions

- According to 802.3da objectives, we shall support operation in the noise environments for building, industrial, and transportation applications
  - Propose to follow IEC61000-4-4 and IEC61000-4-6 to define the noise environment for 10BASE-T1M
    - Propose to extend the frequency range of CI testing to cover automotive requirements too
    - Propose NOT to deal with highest-class EFTs in the receiver, rather rely on upper layers
    - Propose to define multiple receiver performance classes (as in IEC61000-4-6) for reducing power/relative costs for non-industrial and non-automotive applications
- The challenges for meeting the receiver's performance have been presented
  - Propose to define a minimum receiver model to compare with
  - Propose to define a receiver performance metric (follow-up presentation)
  - Propose to integrate the receiver model into the consensus model and use it for deriving the minimum receiver performance based on the defined metric and channel/TX models
  - Address the problem of "receive-mode" collisions (follow-up presentation)

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