ACT Upstream Transceiver

Clearing Misconceptions

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Overview

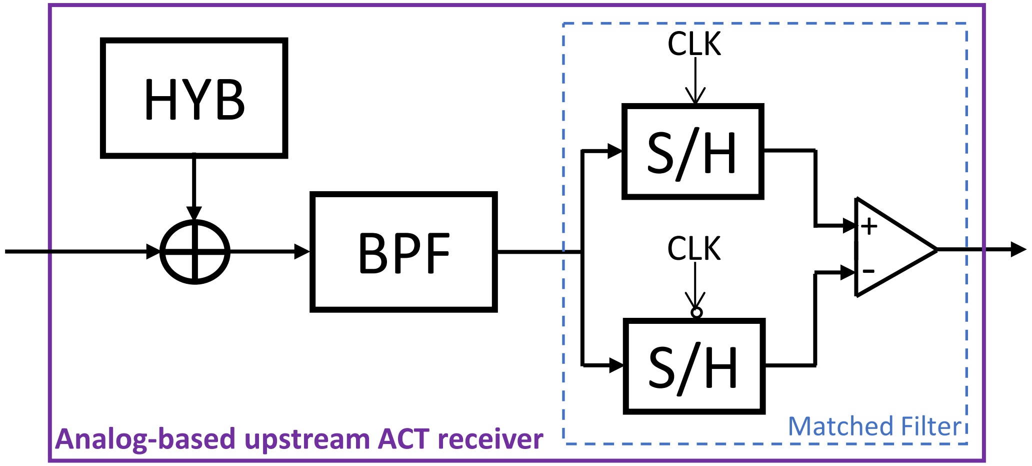
- It is previously shown that upstream receiver is trivial with
  - No need for equalizer
  - No need for echo canceller
  - No need for complex ADC or DSP blocks
  - Superior electromagnetic (EM) immunity

- Further clarification is provided here to address recent concerns about:
  1. MDI RL and its impact on echo
  2. Eye diagram
  3. Phase lock and timing recovery
  4. EM immunity

ACT Upstream Receiver

A trivial Analog-based receiver is shown to operate with no echo canceller, no equalizer, no ADC and no DSP engines achieving 6 dB of SNR margin (discounting FEC) under worst conditions:

- Pathological echo channel with in-band RL as low as 13 dB
- Extreme imbalance of transmit power
- High level of background noise
- Simple hybrid with strong residue
- IL : 28 dB at 3 GHz



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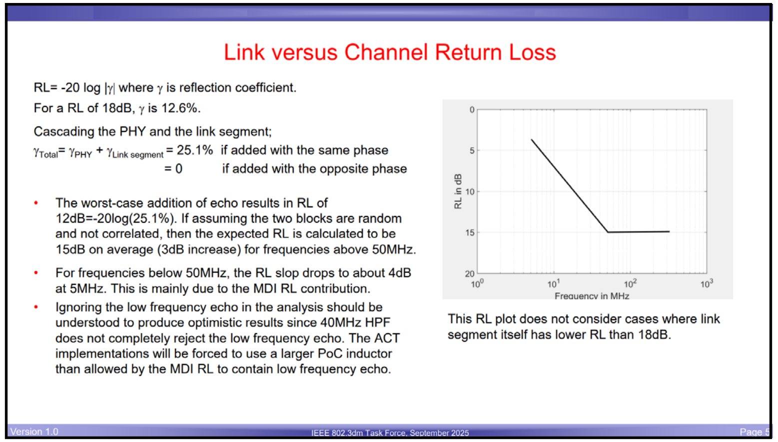
1- MDI RL and Near-end Echo

- It is asserted that the limit on MDI RL should be considered as a contributing factor to the near-end echo, adding 3 dB to overall echo power
- But MDI RL does not contribute to near-end echo as it represents the reflections of an incoming remote signal away from the local PHY


Link versus Channel Return Loss

RL= -20 log |γ| where γ is reflection coefficient.

For a RL of 18dB, γ is 12.6%.

Cascading the PHY and the link segment;

$\gamma_{Total} = \gamma_{PHY} + \gamma_{Link\ segment}$ = 25.1% if added with the same phase

= 0 if added with the opposite phase

- The worst-case addition of echo results in RL of 12dB=-20log(25.1%). If assuming the two blocks are random and not correlated, then the expected RL is calculated to be 15dB on average (3dB increase) for frequencies above 50MHz.
- For frequencies below 50MHz, the RL slop drops to about 4dB at 5MHz. This is mainly due to the MDI RL contribution.
- Ignoring the low frequency echo in the analysis should be understood to produce optimistic results since 40MHz HPF does not completely reject the low frequency echo. The ACT implementations will be forced to use a larger PoC inductor than allowed by the MDI RL to contain low frequency echo.

This RL plot does not consider cases where link segment itself has lower RL than 18dB.

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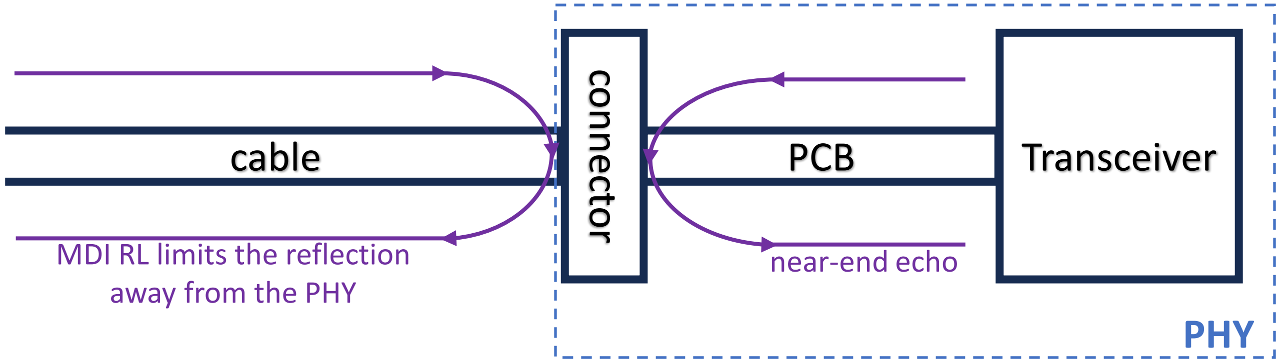
https://www.ieee802.org/3/dm/public/0925/Chini_3dm_02_09152025.pdf



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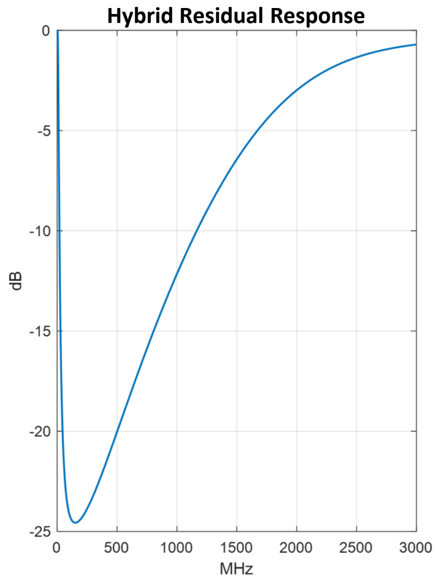
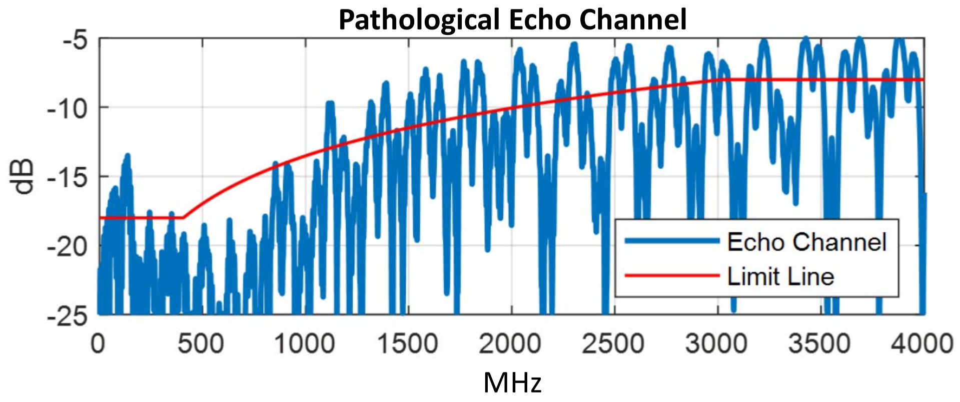
MDI RL vs Hybrid

- PHY designer has no control over the far-end reflections and MDI RL should represents a loose limit and envelope for all compliant implementations
- PCB is part of the PHY, and the near-end echo is known to, and under control of the PHY designer
- The near-end echo is captured as part of hybrid residual response
- ACT receiver operates with 6 dB margin in extreme echo conditions:
  - RL as low as 13 dB within band
  - Poor hybrid matching at low and high frequencies





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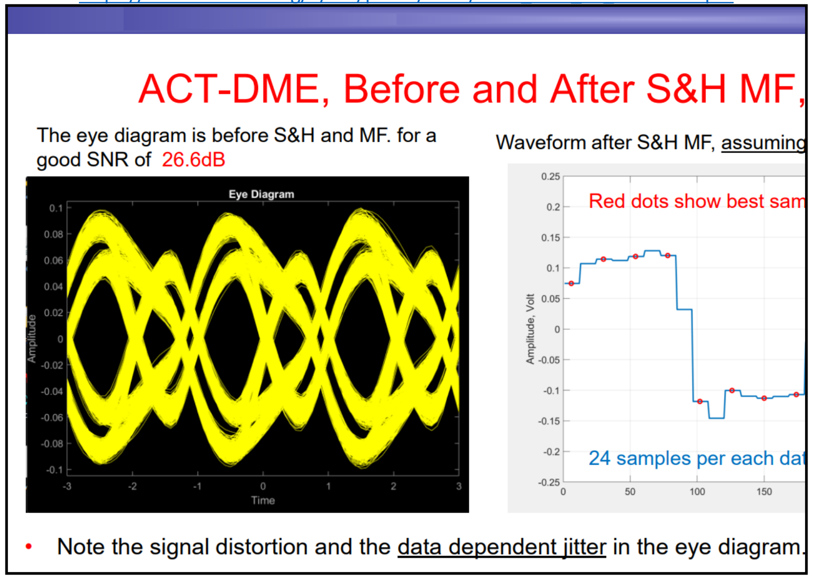
2- Eye Diagram

- It is asserted that the eye diagram in DME systems does not have proper shape at the input of matched filter
- But eye diagram is only meaningful if it is looked at the end of receive signal path where symbols are detected and sliced
- In DME system, eye diagram is only meaningful after matched filtering and **not** before that

https://www.ieee802.org/3/dm/public/0925/Chini_3dm_02_09152025.pdf



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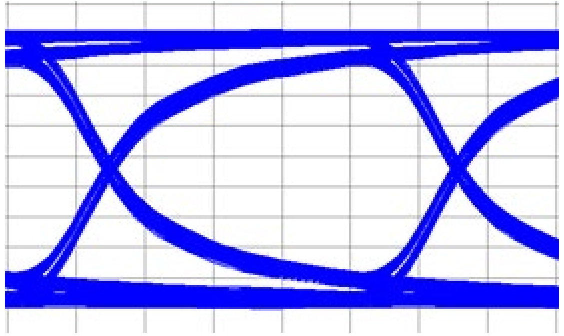
Eye Diagram for Various Modulations

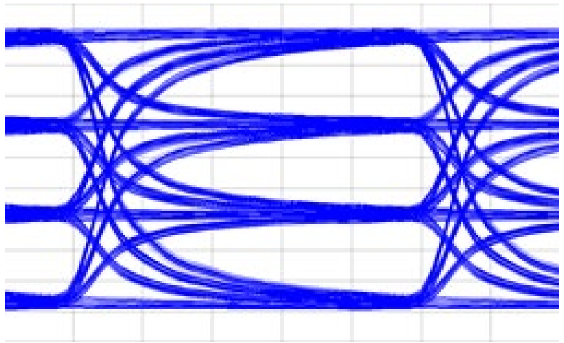
- It is wrong to expect the eye diagram in DME system to look like that of PAM2, the same way that the eye diagram in PAM4 does not look like PAM2

PAM2



- What is interpreted as "*signal distortion*" or "*data dependent jitter*" is nothing but an expected behaviour of the Manchester encoding of the signal with no detrimental impact on a well-designed DME receiver

PAM4



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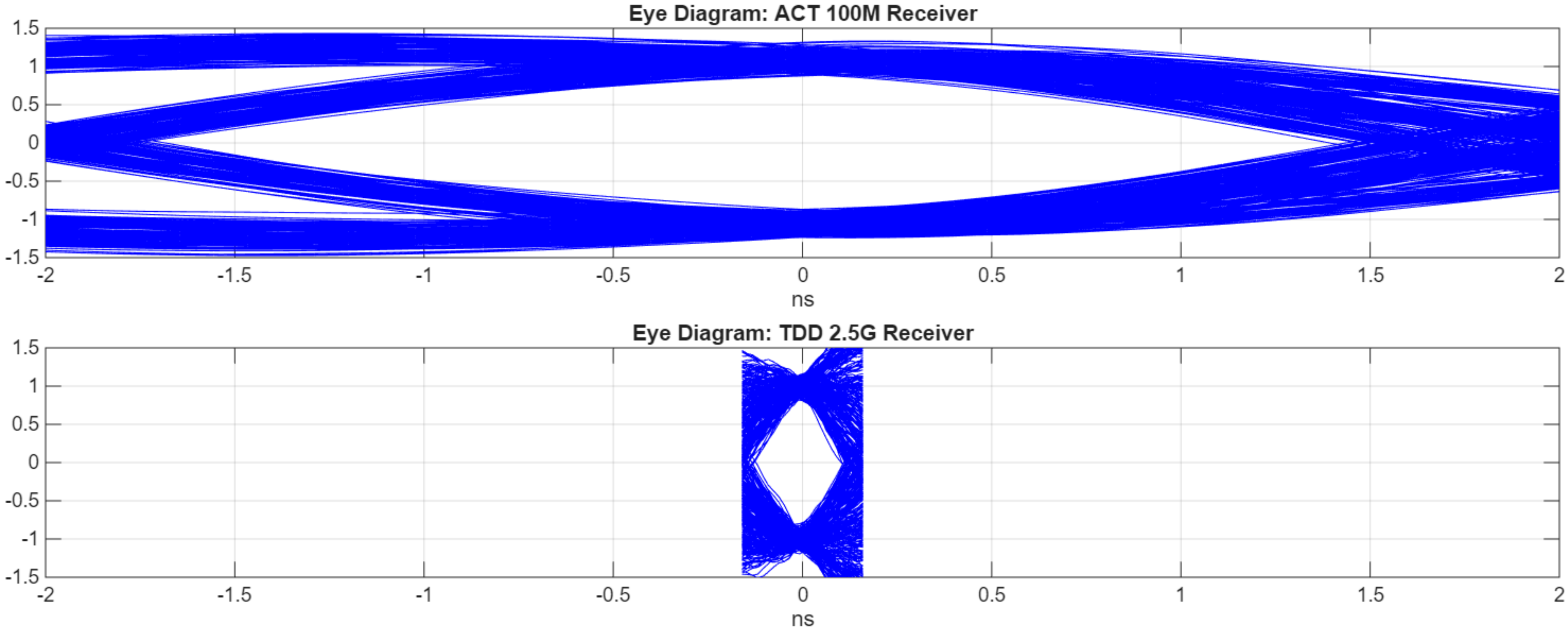
Eye Opening: ACT-TDD Comparison

- Same vertical opening indicates the same operating SNR of 23 dB for both receivers
- Same time scale for both diagrams illustrates much wider horizontal eye opening for ACT, indicating its superior resilience to phase noise and timing jitter



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3- Phase Detector in DME Systems

- A phase detector designed for PAM2 signal does not obviously work for DME signal

- A PAM2 phase detector may see a DME signal as “*distorted and jittery waveform*”

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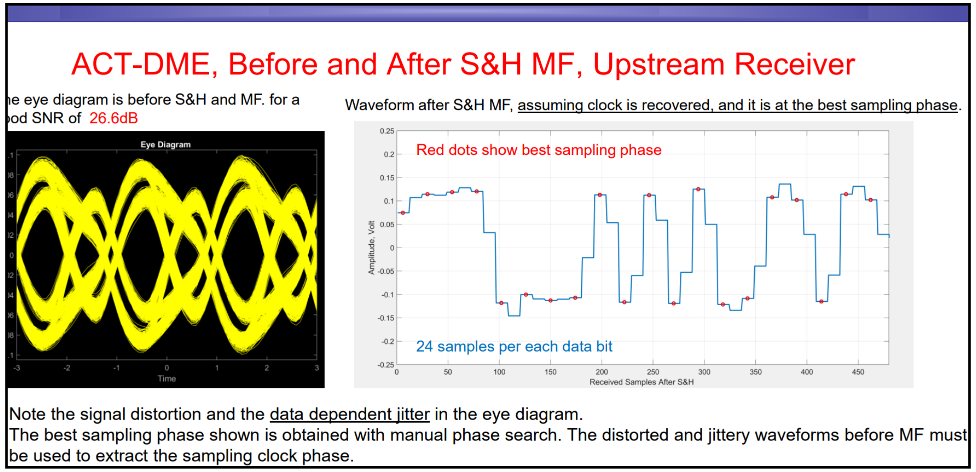

- But there is no need for “*manual*” placement of sampling phase, as phase detection, timing recovery and optimal phase tracking are very well-understood for DME systems with good number of options for each function

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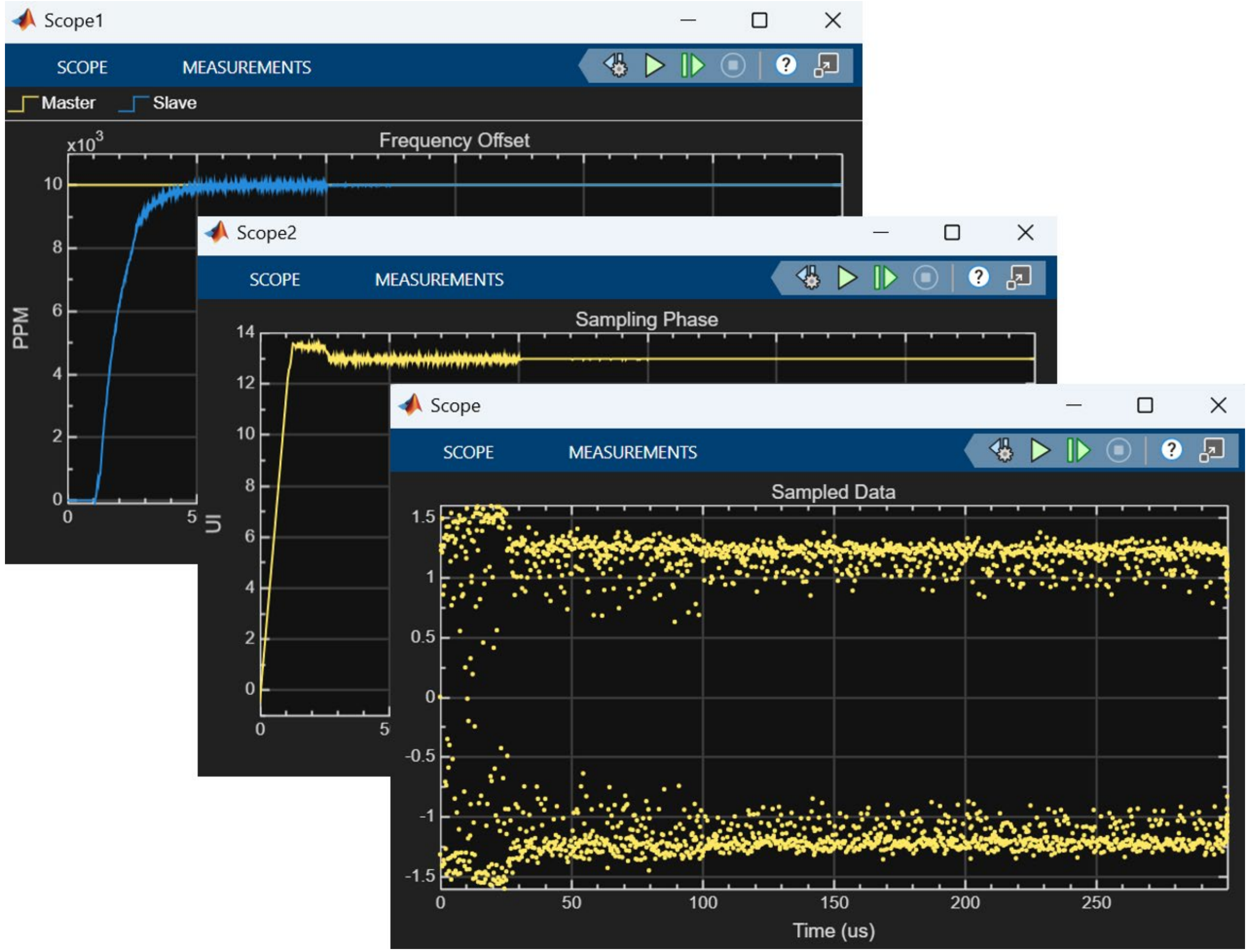
Optimal Sampling Phase

- A simple DME phase detector with traditional timing recovery loop captures 10,000 PPM (1%) of frequency offset and locks to optimal phase very quickly

- **<u>No</u>** "*equalization*" is used for phase detector



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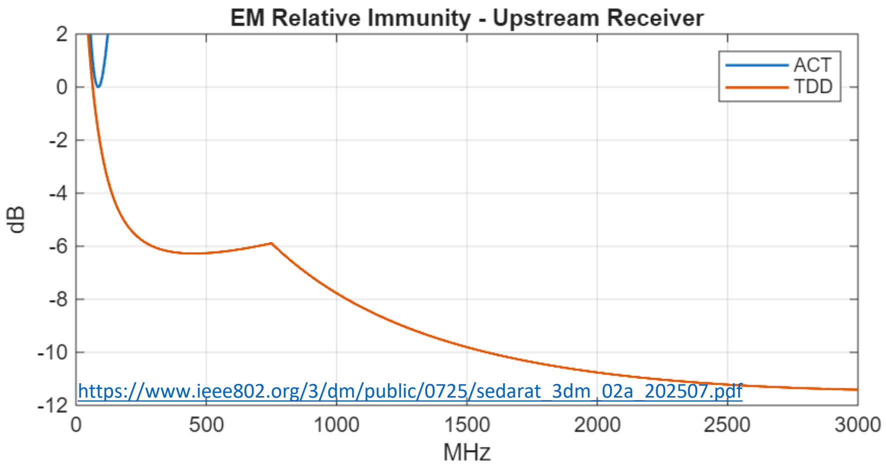
4- Electromagnetic Immunity (EMI)

- It is shown that upstream ACT receiver, operating in worst corner, is by far more immune to EM ingress than a TDD receiver, operating in its nominal point



- It is argued that downstream receiver in TDD performs better than ACT
- The Analysis needs clarification in:
  - The incomparable choice of operating points for ACT and TDD
  - Seemingly arbitrary choices of SNR for TDD and ACT
  - Double-counting of the transmit power in both SNR and eye-opening

https://www.ieee802.org/3/dm/public/0925/Chini_3dm_02_09152025.pdf

TDD versus ACT, Downstream Ingress Noise Tolerance

To compare TDD and ACT for downstream noise tolerance over Coaxial cables, it is assumed that the ACT receiver operates at 6dB margin to the required 17dB SNR and TDD operates at 10dB SNR margin (no echo effect). With 6dB margin, 50% of the eye opening is the ingress noise tolerance. With 10dB margin, 66% of eye opening is the ingress noise tolerance.

The maximum transmit levels are considered to scale the ingress tolerance.

For ACT downstream, the ingress noise tolerance is adjusted for the baud rate, SNR margin and transmit voltage difference.

	TDD -2.5G	ACT-2.5G	TDD-5G	ACT-5G
2m Coax[1]	171mVpp	97mVpp	190mVpp	124mVpp
8m Coax[1]	114mVpp	65mVpp	100mVpp	65mVpp
15m Coax[1]	64mVpp	36mVpp	50mVpp	33mVpp

2.5G ACT Adjustments versus TDD: 50% / 66% * 3G/2.81 * 560mVpp/800mVpp = 57%
5.0G ACT Adjustments versus TDD: 50% / 66% * 6G/5.62 * 800mVpp/1000mVpp= 65%

SNR margin Baud rate TX Voltage

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EMI Strategies

1. Design with extra SNR margin to tolerate EM noise
   - Effective mostly for weak to moderate EM sources
   - Becomes inefficient and/or ineffective strategy for strong EM sources

2. Adaptive EM filtering and cancellation
   - Uses advanced DSP engines to learn the EM ingress signal, and filters or cancels its effect in the receive path
   - Effective for any EM source as long as it does not overwhelm the front-end
   - Unlike traditional SERDES architectures, many current high-speed automotive PHYs take advantage of these engines

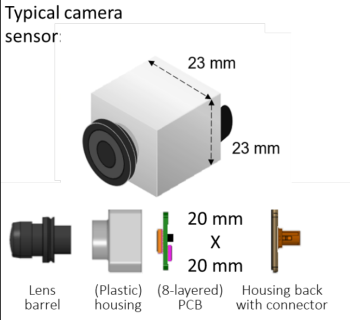
Power and Cost Sensitive Node

- One of the main objectives of 802.3dm is to specify a PHY for the camera node with lowest complexity and lowest power consumption

- The PHY in aggregator is not limited by the same stringent requirements on power efficiency and complexity

https://www.ieee802.org/3/cfi/0723_1/CFI_01_0723.pdf

Automotive cameras are very power and cost sensitive components.



(source: Daniel Hopf, Continental)

- Sensor quality degrades exponentially with increased temperature.
- Cameras have no active cooling system (too costly).
- Plastic housing is preferred (also for cost reasons). Plastic does not conduct heat as well as metal does.
- Assembly and mounting space is typically very limited. Cameras are therefore as small as possible (which impacts temperature behavior).
- Cameras are often located at positions exposed to sunlight and heat (bumper, vehicle grille, windshield).

Because power dissipation means heat:

- The power consumption of every component counts. Providing more than needed (e.g. in terms of data rate) wastes power.
- Heat dissipated from one component may quickly heat up the whole sensor.

- A reasonable EMI strategy: PHY in the aggregator to use advanced DSP technique for best EMI performance

➔ The overall EMI performance should be limited only by the PHY in camera which cannot take advantage of the advanced EMI strategies

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ACT Combines Efficiency and Immunity

- There is no disagreement on importance of EM immunity of an automotive PHY, and the difficulty in achieving it

https://www.ieee802.org/3/dm/public/0925/Chini_3dm_02_09152025.pdf

- The in-car cable is typically longer than 2m cable used in component level testing and the noise level requirement is higher than 100V/m for some OEMs.
- Comparing the shielding effectiveness of a new versus mechanically-aged coaxial cables (RG174 in particular). There can be up to 20dB change in EMC performance due to aging that affects shielding effectiveness.
- Regardless of what limit line is specified in 802.3dm, the difference remains between the EMC results measured on a new cable versus aged one with up to 20dB degradation.

- The standard specifications should not prevent a highly immune PHY

- A specification based on TDD prevents the use of DSP techniques to achieve higher EM immunity as the US receiver remains the bottleneck with its poor EM performance

Summary

ACT upstream receiver is extremely simple

- There is no need for echo canceller – even in unrealistically extreme conditions
- There is no need for equalization, neither for signal nor for phase detection
- Can easily and quickly capture large frequency offset and lock to optimal phase
- It is a superior solution that meets the required efficiency and EM immunity

Previous conclusions:

- Analog-based receiver is possible with no need for ADC or digital signal processing
- Time-domain analysis confirms high operating margin
- Very narrow bandwidth and very low clock frequency
- Very small dynamic range with trivial Analog signal path
- No baseline-wander effect
- Tolerant of simple and imperfect hybrid cancellation
- Not sensitive to MDI return loss and double-reflections

Request for Information

- To replicate some of the results presented for TDD upstream receiver, need information on
  - Equalization, particularly for CTLE
  - Noise floor
  - Baseline wander cancellation
- Information on added complexity due to repurposing a traditional SERDES for TDD duplexing in automotive applications addressing
  - Excessive phase drift during off period and excessive phase transients at on/off boundaries, particularly in the case of crystal-less
  - Extra headroom needed for transmit driver to tolerate strong echo
  - Baseline wander cancellation needed for PoC with small inductor
  - Large decoupling caps (and PoC complexities) needed to reduce supply noise due to very large fluctuations of supply current due to TDD on/off cycle


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Thank You