DME Receiver Performance and EMC Comparison for ACT versus TDD

Sept 15, 2025

Ahmad Chini, Mehmet Tazebay
Broadcom

Forewords

- There has been several proposals for implementation of the ACT upstream transceiver. Notably, the latest presentation provided an architecture that includes a form of an analog Matched Filter implementation[1]. That implementation is further analyzed for its promise and challenges to operate successfully as an upstream transceiver for image sensor applications.
- While the application of DME for burst communication in half duplex mode is well known for many years, the use of DME as upstream transceiver in a full duplex operation for a crystal-less camera application brings some other challenges which need to be considered and analyzed.
- Some comments have been made in comparison of ACT and TDD EMC performance in the upstream[2]. This presentation attempts to extend the comparison to include both directions of the link and various cable lengths & speeds.
- Component level versus in-car EMC variation as well as short versus long term performance are also discussed.

1. https://www.ieee802.org/3/dm/public/0725/sedarat_3dm_01_202507.pdf
2. https://www.ieee802.org/3/dm/public/0725/sedarat_3dm_02a_202507.pdf

Major PHY parameters that affect ACT camera receiver

- There are three major parameters that affect the ACT receiver design and performance.

  1. Channel Return Loss (RL) in the lower frequencies
  2. Down stream transmit level
  3. Upstream transmit level

Each of these parameters have an impact in the overall performance of the link and therefore can not be arbitrarily set.

- This interdependency is a direct effect of full duplex PMA signaling and it is more pronounced for ACT than FDD as there is more frequency overlap in upstream versus downstream signaling.
- The channel RL could vary widely depending on the impedance mismatch between cable segments in the link, the number of in-line connectors and MDI return loss[1].
- The effect of MDI RL on the overall channel RL is discussed next.

1. https://www.ieee802.org/3/dm/public/adhoc/082125/mueller_3dm_01a_08_21_25.pdf

Link Return Loss versus Channel Return Loss

- IEEE 802.3dm specifies the MDI RL and Link segment Return loss limits separately.
- To analyze the performance of a link that is subject to echo noise, it is important to obtain the channel return loss first.

- The channel RL is determined by three blocks with RL limit line specified at the MDI. Although at lower frequencies the link segment insertion loss is small, the effect of echo from the remote side is ignored to simplify the analysis.
- The combined effect of attaching the PHY to the link segment at MDI is considered.
- For a frequency range not exceeding 300MHz, the MDI RL has a specification of 18dB above 50MHz and the link segment specification for ACT is also 18dB. The combined effect varies depending on the echo from each of the PHY and the link segment and if they are additive or subtractive.

Link versus Channel Return Loss

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

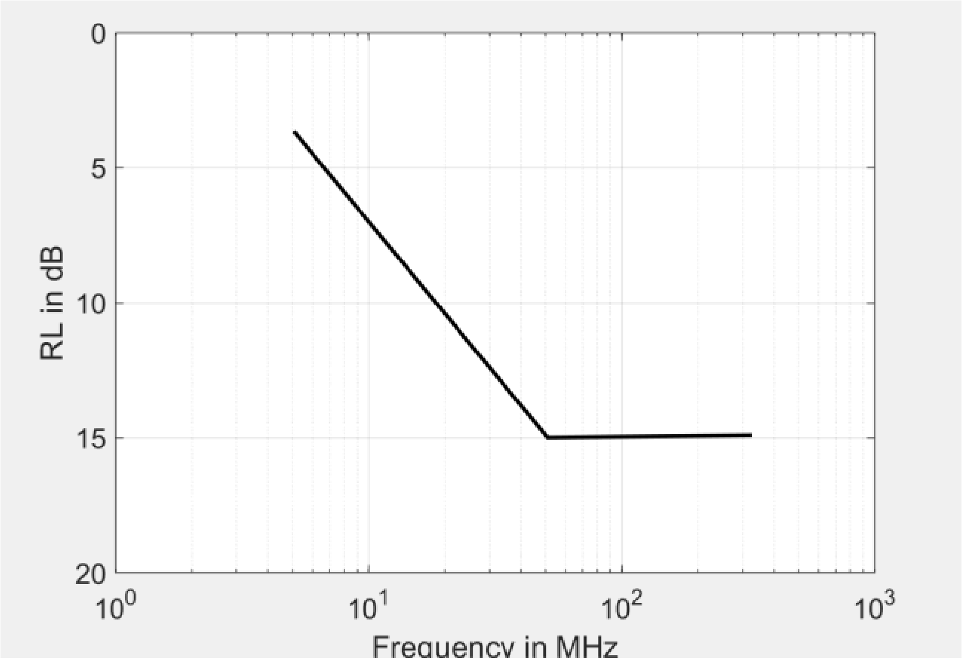
For a RL of 18dB, γ is 12.6%.

Cascading the PHY and the link segment;

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

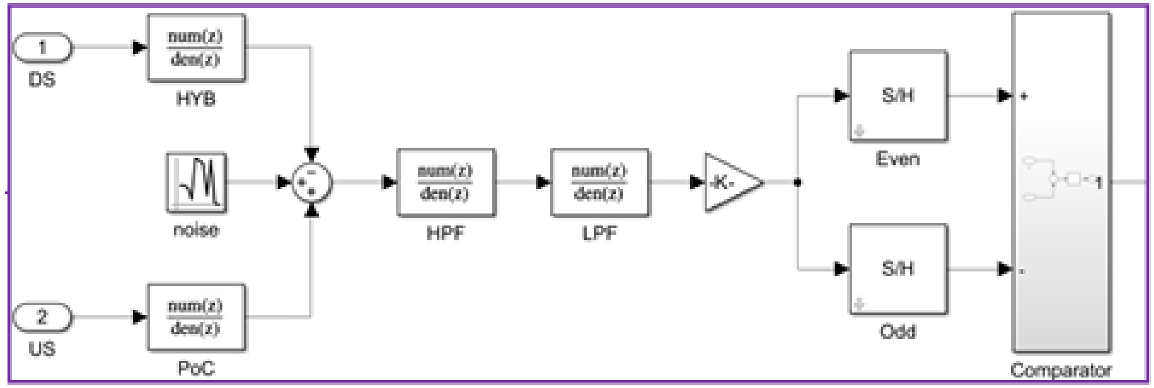
= 0 if added with the opposite phase

- 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.

ACT-DME Simulation Setup



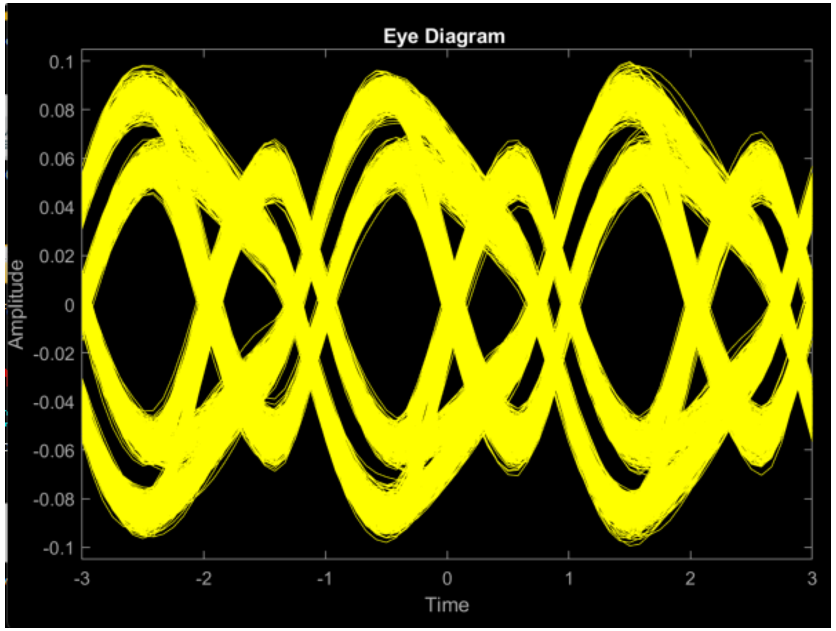
Suggested DME receiver with analog matched filter Implementation[1]

1. https://www.ieee802.org/3/dm/public/0725/sedarat_3dm_01_202507.pdf

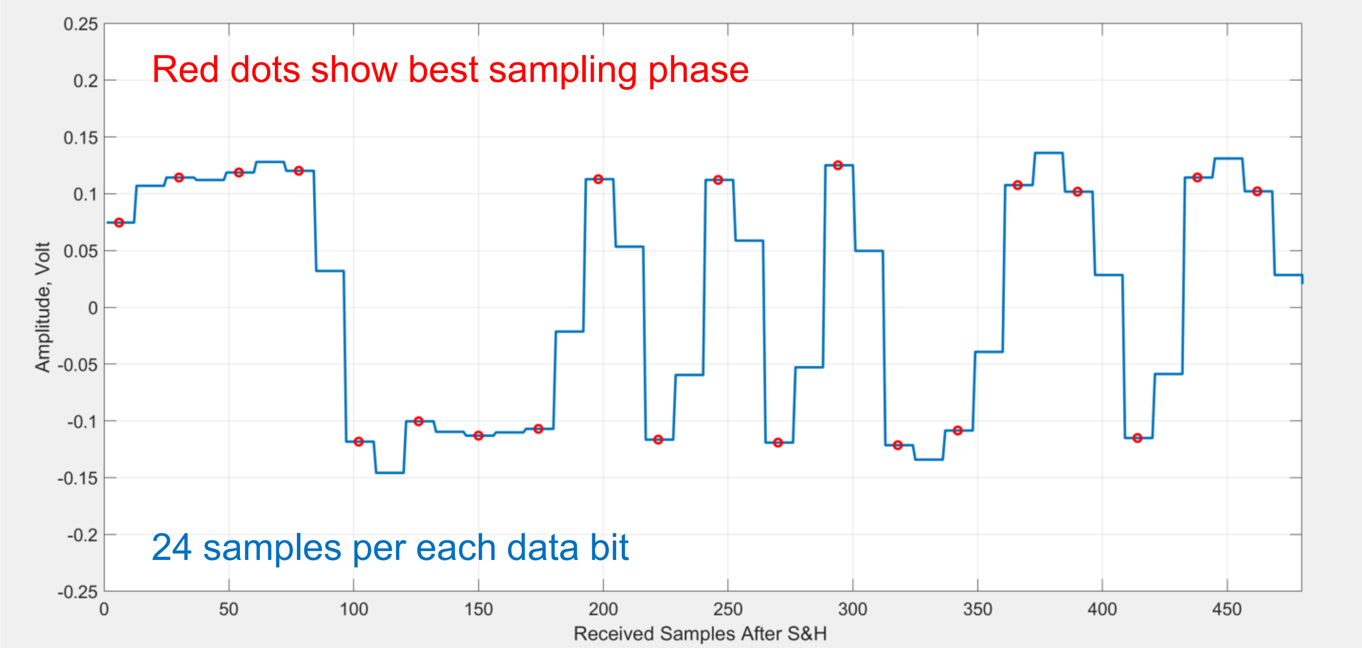
- Given the uncertainty in channel RL values, the DME analysis is performed for a relatively good SNR with no judgment on practically achievable Return Loss.
- The only noise simulated is the echo from the downstream transmitter.
- PoC high pass corner of 6MHz is assumed to match MDI RL.
- A link segment of 10.2m Coaxial cable (RTK031) with 4-inline connectors is considered.
- A transmit level of -6dBm is assumed for ACT-DME (223mVpp for Coax).
- HPF is 40MHz 1st order, LPF is 100MHz 2nd order[1].
- Simulated with 24x over sampling with respect to the data bit duration.

ACT-DME, Before and After S&H MF, Upstream Receiver

The eye diagram is before S&H and MF. for a good SNR of 26.6dB



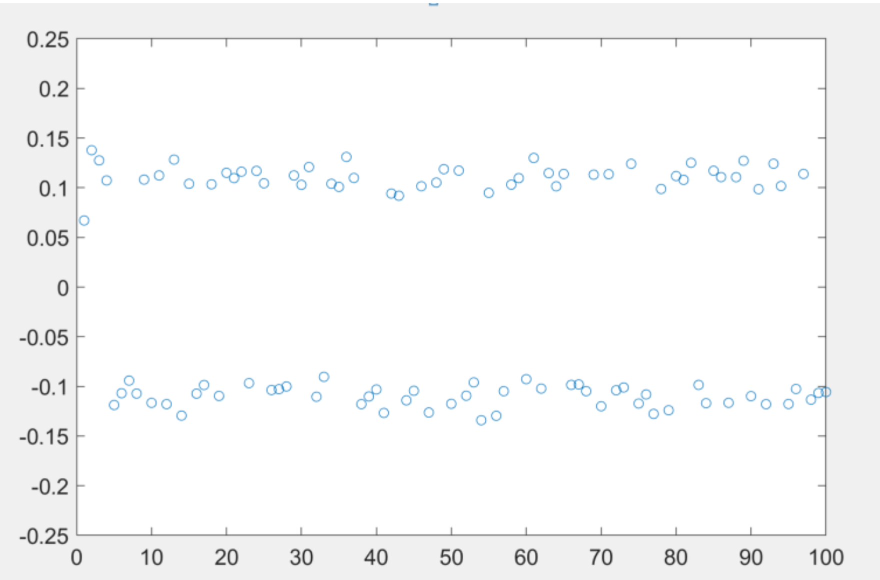
Waveform after S&H MF, assuming clock is recovered, and it is at the best sampling phase.



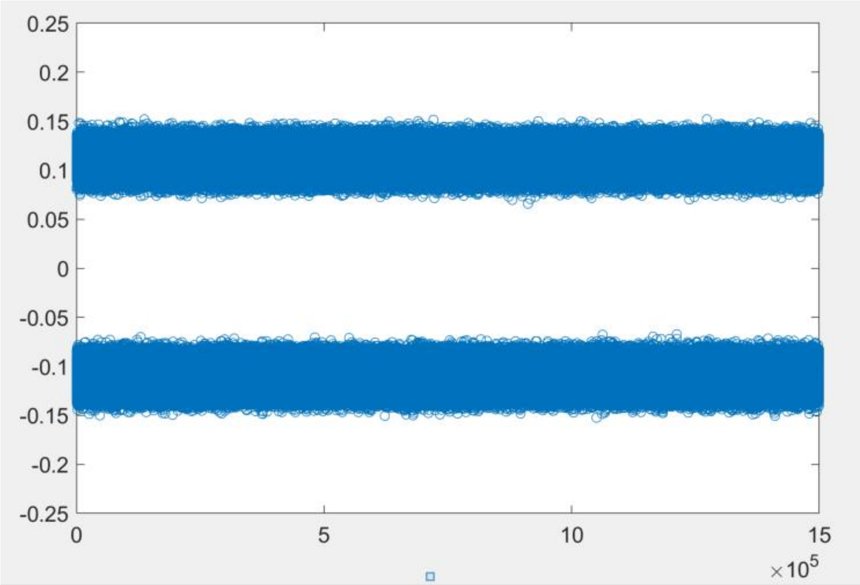
- Note the signal distortion and the data dependent jitter in the eye diagram.
- The best sampling phase shown is obtained with manual phase search. The distorted and jittery waveforms before MF must be used to extract the sampling clock phase.
- **How well is the clock sampling phase extracted from the distorted received signal? (not a burst with a preamble)**
- **The Clock frequency tracking circuit, given large jitter before MF? Does it reach 1ps downstream clock accuracy?**
- **What if crystal less camera clock shifts to the next symbol? (wrong Manchester phase does not happen in FDD or TDD).**

ACT BER with 7dB SNR Margin, upstream

- For this simulation, an SNR of 24dB is assumed (7dB SNR margin for BER of 1e-12). It is also assumed that the clock is perfectly recovered, and the best sampling phase is known.



Looking at the samples (at the best sampling point), it appears initially there is a large distance, and no error will ever happen.

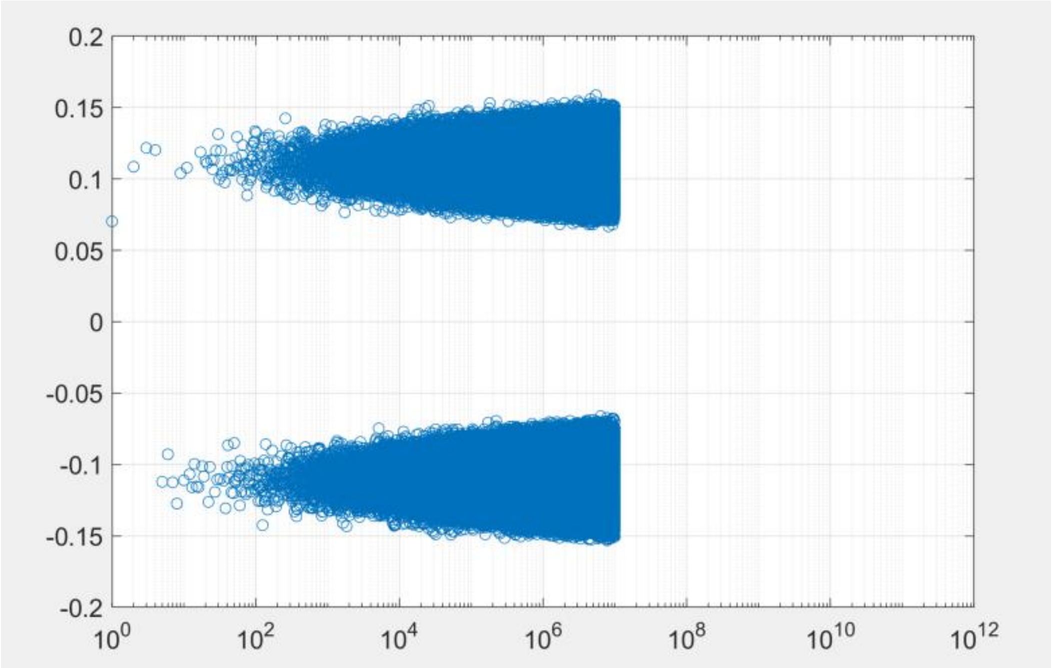


the longer the simulation runs, the less distance is seen.

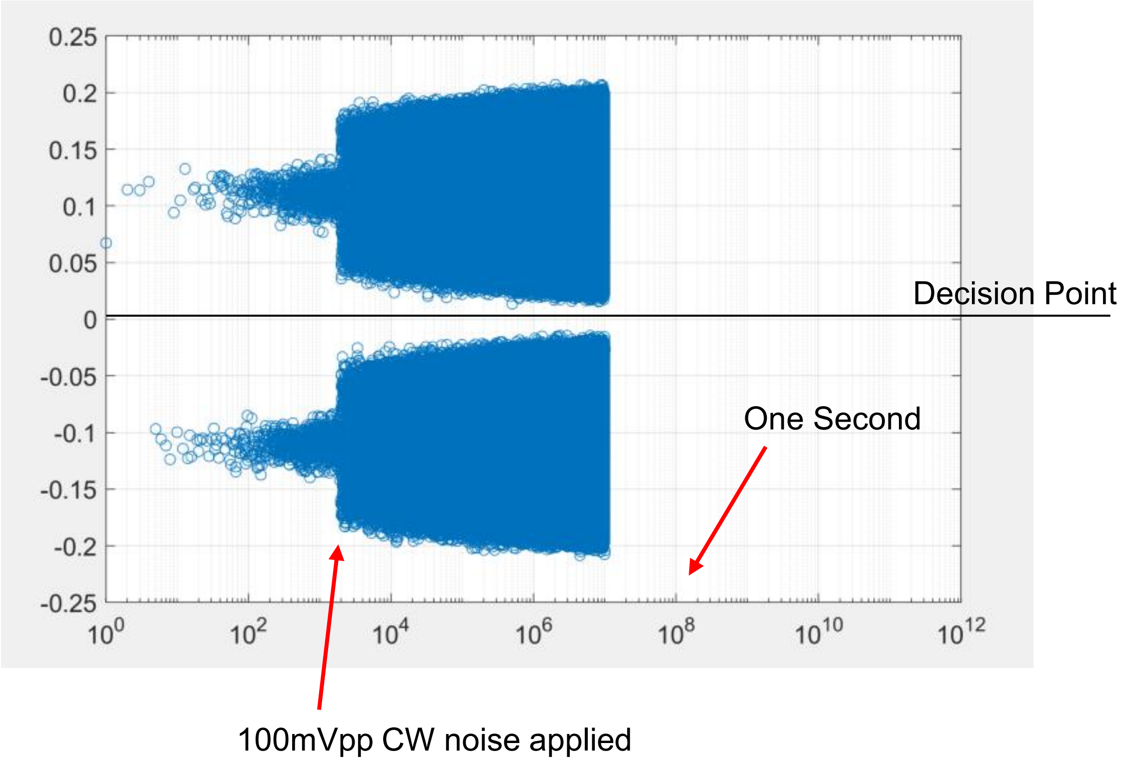
ACT-DME BER assuming 7dB SNR Margin with/without CW Noise

- The BER performance is best seen in a logarithmic scale.

No CW noise



With CW noise



- The longer it takes, more noise is showing up. How many seconds does it take for 100mVpp CW noise (70MHz) to cause error for ACT-DME with 24dB SNR?

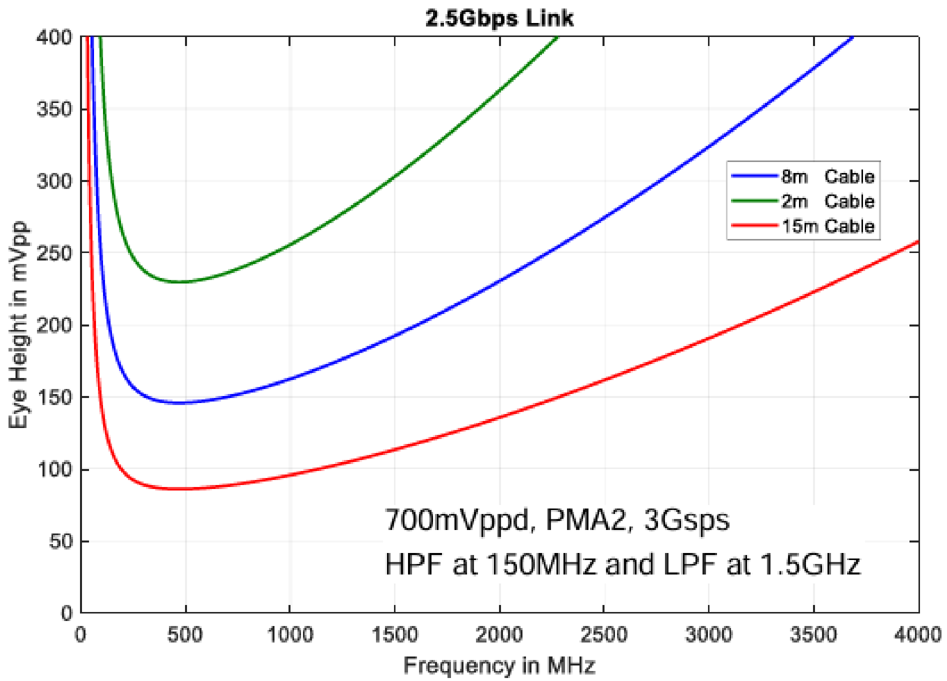
Burst-type DME versus ACT-DME

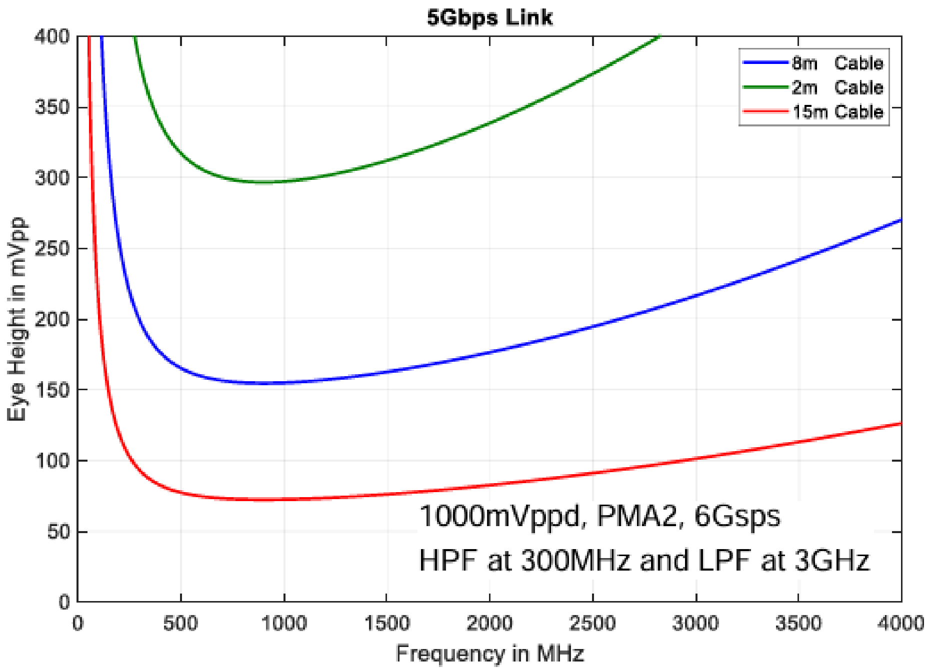
DME in 10BASE-T1S and Autoneg	**ACT-DME**
Short Bursts	Continuous
Half Duplex PMA No echo	Full Duplex PMA echo present
Preamble	No Preamble
Crystal Based	No Crystal
No need to generate a clean clock	Need to generate 1ps Downstream clock
Not in FM band	In the FM band

- Although DME is well known for burst type communications. The use case for a full duplex communication and crystal-less clock recovery with 1ps jitter needs more discussion and analysis. Without that, the actual cost and performance boundaries remain unknown.

EMC performance, ACT versus TDD

TDD, Ingress noise Tolerance[1]





Ingress noise tolerance when there is 10dB SNR margin	2.5Gbps DS & 100Mbps US	5Gbps DS
2m, Scaled from IL limit line	150mVpp	190mVpp
8m, Scaled from IL limit line	100mVpp	100mVpp
15m, IL limit line	55mVpp	50mVpp

The cable lengths are based on the coax insertion loss limit line. A new cable of same length tolerates more noise (less IL).

The plots are for typical TX power (not the maximum level).

1. https://www.ieee802.org/3/dm/public/0125/Chini_3dm_02a_0125.pdf

TDD versus ACT, w/max Transmit Signal Swing

TDD
Transmit Power (dBm)

	Coax		STP	
	Min	Max	Min	Max
10G	-3	-1	0	2
5G	-1	1	2	4
2.5G	-3	-1	0	2
100M	-3	-1	0	2

ACT
Transmit Power (dBm)

	Coax		STP	
	Min	Max	Min	Max
10G	-4	-1	-1	2
5G	-4	-1	-1	2
2.5G	-7	-4	-4	-1
100M	-6	-3	-3	0

Max Vppd	TDD	ACT
5G	1000mVpp	800mVpp
2.5G	800mVpp	560mVpp

ACT transmit levels are specified lower than incumbents and TDD for 2.5G & 5G speeds.

Lower downstream power for ACT helps to reduce the echo energy in the camera receiver but it reduces the noise tolerance in the downstream as well.

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

1. Scaled form IL limit line suggested for TDD. A new cable is expected to have a better performance.

TDD versus ACT, Ingress Noise Tolerance, Combined Down and Up Streams

- The EMC performance of the link depends on both sides (upstream and downstream). The link can fail by either direction.

	TDD - 2.5G/100M	ACT- 2.5G/100M	TDD- 5G/100M	ACT- 5G/100M
2m Coax	171mVpp	97mVpp	171mVpp	100mVpp
8m Coax	114mVpp	65mVpp	100mVpp	65mVpp
15m Coax	64mVpp	36mVpp	50mVpp	33mVpp

- TDD always outperforms ACT ingress noise tolerance when both sides of the link is analyzed. The comparison is made for the same cable IL. Practically, the lower noise tolerance limits the cable reach for ACT.
- While the numbers for component level testing (<2m) may be sufficient for both solutions, certain in-car links and long-term performance will show the differences between the two solutions for EMI noise immunity.
- For 10Gbps link -not shown in this analysis-, the component level testing (<2m) may show satisfactory results, but some of the longer cable performances can be challenging over RG175+RTK031 type Coaxial cables for automotive applications. RTK044 would help in those cases.

TDD versus ACT Emission Performance

- ACT has about 10dB higher peak PSD than TDD. While certain component level testing may show a passing results for ACT, the in-car and long-term emissions performance is still questionable.
- There are good reasons to be concerned about ACT emission for automotive applications. In car EMC, (Emission and Immunity) the performance is not the same as the component level testing may indicate.
- For instance, the component level measurements presented in 802.3ch task force[1,2] suggest noise level varies from 1mV to 5 mV for STP depending on the type of cable and connector. The in-car testing however suggested noise may exceed 10mV (rms)[3] and that is for the test level of up to 100V/m.
- 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.

1. www.ieee802.org/3/ch/public/nov17/Cohen_Shirani_3ch_01_1108.pdf
2. https://www.ieee802.org/3/ch/public/may18/mueller_3ch_03_0518.pdf
3. RF Ingress Automotive Immunity Measurement on STP Cable in the Vehicle up to 6 GHz, Sanaz Mortazavi, et al. Volkswagen AG, Wolfsburg, Germany, **2019 IEEE International Symposium on Electromagnetic Compatibility, Signal & Power Integrity (EMC+SIPI)**

Conclusion

- While DME is known for the burst communications in half duplex format and with certain header/preamble, its use in a full duplex camera link and the requirements for this application needs further analysis to establish performance boundaries and expectations.
- Incumbents' solutions transmit at higher power level than ACT and some of them use echo cancellation on both sides of the link. The ACT cable reach is practically limited due to lower ingress noise tolerance. Would a solution with lower transmit power and no echo canceller be able to compete with the incumbents’ solutions on EMC?
- The ingress noise immunity analysis suggests TDD largely outperforms ACT when the performance of the link is analyzed for both directions.
- The emission is a concern for ACT when in-car and long-term performance is considered. The peak PSD of ACT is larger than TDD by about 10dB.
- Supporting TDD in 802.3dm ensures the EMC competitiveness for automotive applications in addition to all other unique features and future extensions to support the display and other applications with higher upstream data rates.

Thank you

Questions?