Comparing Modulation Schemes

Contribution to 802.3dm Task Force

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Introduction

- This presentation will compare ASA-MLE and Asymmetric Continuous Transmission (ACT) modulation scheme for
  - The equalizer complexity
  - The echo suppression
- It helps to look at specific examples when comparing different modulation schemes
- The comparison shows that ACT is a better option than ASA-MLE

- Asymmetric Continuous Transmission (ACT) as described in jonsson_3dm_01_09_15_24.pdf
- Automotive SerDes Alliance (ASA) Specification 2.0 as described in https://www.ieee802.org/3/private/liaison_docs/ASA/ASA_Technical_Specification_ver2.0.pdf

ASA-MLE Modulation Summary

Data Rates	High Data Rate				Low Data Rate			
	Line Rate [Gbps]	Signal Levels	Symbol Rate [Gbaud]	Bandwidth [GHz]	Line Rate [Gbps]	Signal Levels	Symbol Rate [Gbaud]	Bandwidth [GHz]
2.5G/100M	4	2	4	2	4	2	4	2
5G/100M	8	2	8	4	8	2	8	4
10G/100M	12	4	6	3	12	4	6	3

The table above summarizes information from [1] and [2]

- ASA-MLE uses base-band PAM modulation (see slide 6 in [1])
- ASA-MLE uses same line rate in both directions (see slide 4 in [2])
- ASA-MLE uses line rates of 4Gbps, 8Gbps, and 12Gbps, for data rates of 2.5Gbps, 5Gbps, and 10Gbps, respectively (see slide 4 in [2])

ACT Modulation Summary

Data Rates	High Data Rate				Low Data Rate			
	Line Rate [Gbps]	Signal Levels	Symbol Rate [Gbaud]	Bandwidth [GHz]	Line Rate [Mbps]	Signal Levels	Symbol Rate [Mbaud]	Bandwidth [MHz]
2.5G/100M	2.8125	4	1.40625	0.703125	117.1875	2	117.1875	234.375
5G/100M	5.625	4	2.8125	1.40625	117.1875	2	117.1875	234.375
10G/100M	11.25	4	5.625	2.8125	117.1875	2	117.1875	234.375

The table above summarizes the ACT modulation as described in jonsson_3dm_01_09_15_24.pdf

- ACT uses the same base-band PAM modulation as 802.3ch in the high data rate direction
- ACT uses Differential Manchester Encoding (DME) for the low data rate direction
- The 100Mbps line rate is 24 times lower than the 2.5Gbps line rate

Camera side

ASA-MLE vs ACT Low Data Rate

Data Rates	ASA-MLE				ACT			
	Line Rate [Gbps]	Signal Levels	Symbol Rate [Gbaud]	Bandwidth [GHz]	Line Rate [Mbps]	Signal Levels	Symbol Rate [Mbaud]	Bandwidth [MHz]
2.5G/100M	4	2	4	2	117.1875	2	117.1875	234.375
5G/100M	8	2	8	4	117.1875	2	117.1875	234.375
10G/100M	12	4	6	3	117.1875	2	117.1875	234.375

The table above shows the modulation parameters for ASA-MLE and ACT low data rate

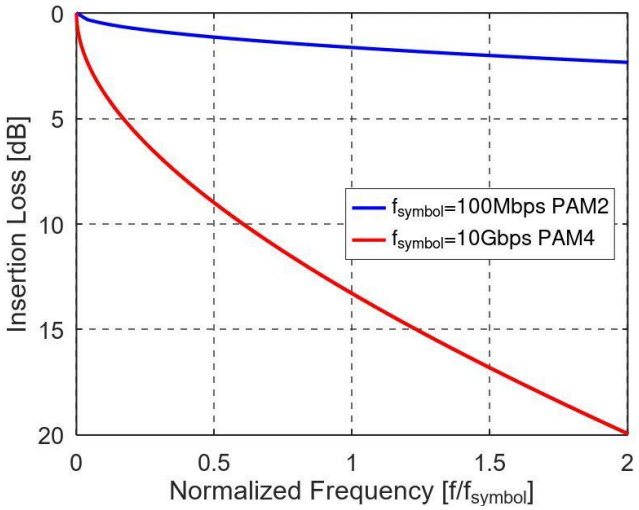
- ASA-MLE uses multi-Gbps line codes, which requires complex receivers on the camera side
- ACT uses 117Mbps line code that allows very simple receiver on the camera side of the link

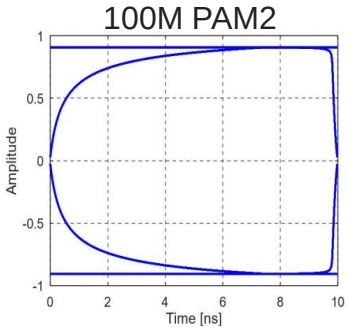
Low Data Rate : Line Rate Comparison

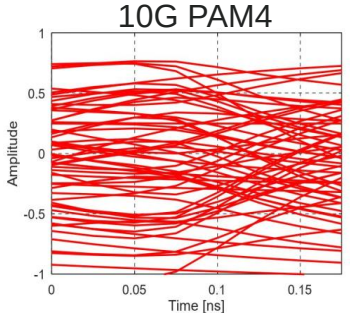
Data Rates	ASA-MLE Line Rate [Gbps]	ACT Line Rate [Gbps]	ASA/ACT Line Rate Ratio
2.5G/100M	4	0.117188	34.13
5G/100M	8	0.117188	68.27
10G/100M	12	0.117188	102.40

- ASA-MLE has significantly higher line rate, which increases PHY complexity
- ACT low data rate speed is independent of high data rate speed

Low Line Rate Has Open Eye





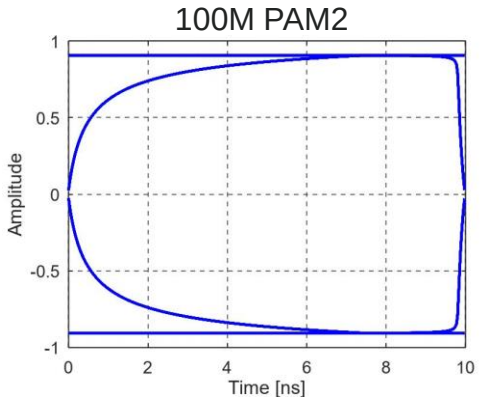


Low data rate signal

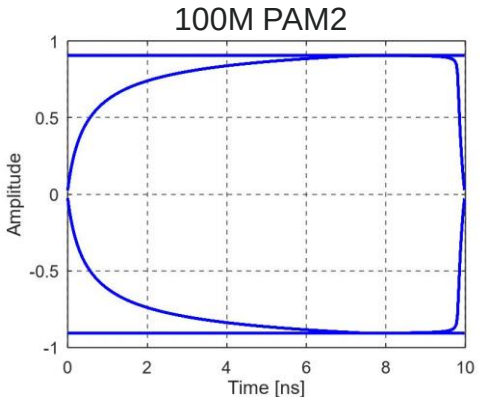
High data rate signal

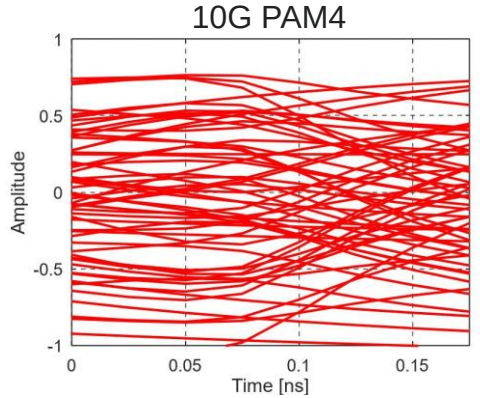
high line rate has closed eye

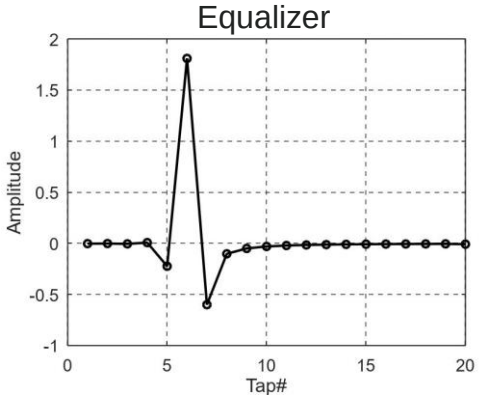
Equalization of Low vs High Line Rate

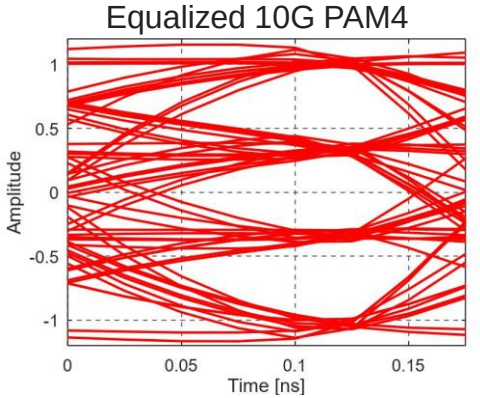


No Equalization Needed

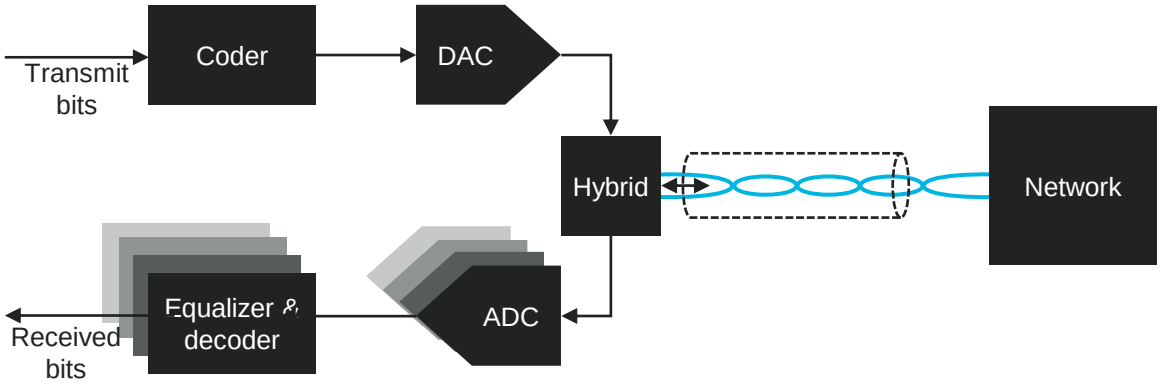








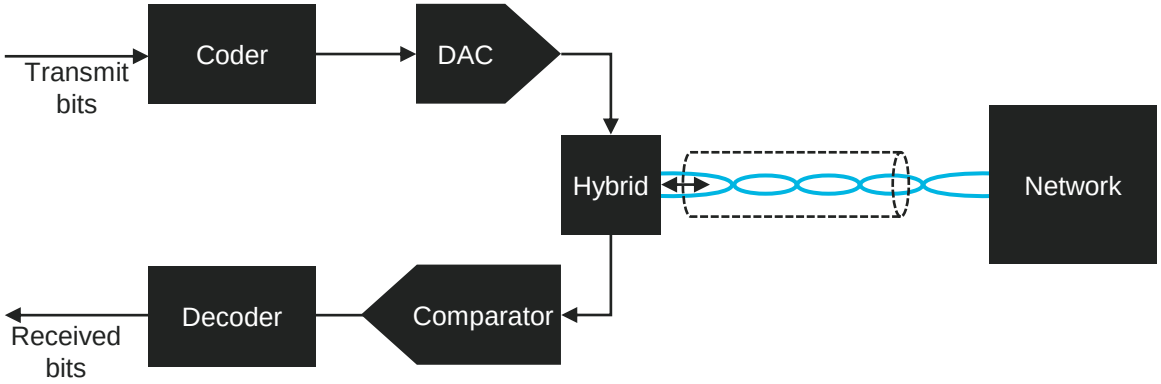
High Line Rate Receivers Require **Parallelism**



- The ASA-MLE and ACT high line rate use multi-GBaud line codes
- The digital processing in the PHY implementation will typically run at several-hundred MHz
- This means that the digital processing implementation require parallelism

Higher line rate means more parallelism, and increased relative cost

The Low Data Rate ACT Receiver is Very Simple



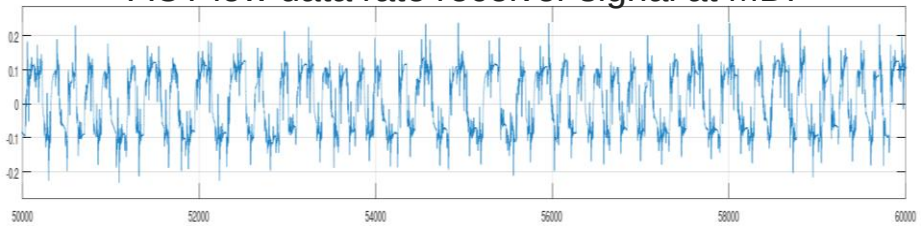
- The ACT low data rate uses 117MBaud line code that requires no equalization
- The ACT low data rate receiver can be as simple as an analog LP-filter and a single comparator
- If PHY designers choose to do digital processing, it can easily be implemented without parallelism

The camera PHY receiver is **several orders of magnitude** simpler for ACT than ASA-MLE

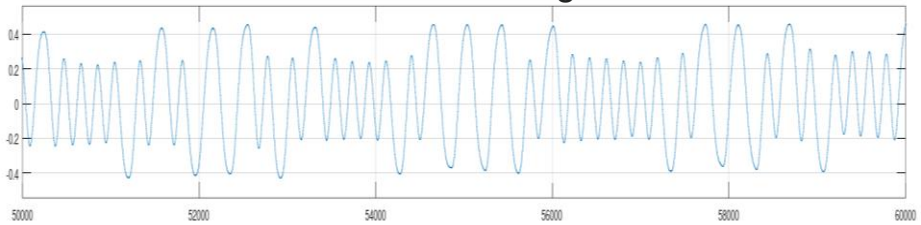
ACT Low Data Rate Echo Suppression

- The low data rate ACT receiver can sufficiently suppress echo using simple low-pass filtering
- Most of the echo is out of band for the low data rate signal and low-pass filtering will remove almost all the echo
- Echo suppression is practically free for the low data rate ACT signal

ACT low data rate receiver signal at MDI



ACT low data rate receiver signal after LP filter



ASA-MLE Echo Suppression

- ASA-MLE (TDD) suppresses the echo by only transmitting in one direction at the time
- While this will mostly eliminate the echo, it comes at the cost of higher line rate (and bandwidth) being required
- The higher line rate results in more difficult equalization and requires more parallelism in digital implementation, so echo suppression is not free in TDD

Data Rates	ASA-MLE Line Rate [Gbps]	ACT Line Rate [Gbps]	ASA/ACT Line Rate Ratio
2.5G/100M	4	0.117188	34.13
5G/100M	8	0.117188	68.27
10G/100M	12	0.117188	102.40

ASA-MLE uses 34-102 times higher line rate to suppress echo

Camera PHY Takeaway

- The ACT camera PHY receiver is **several orders of magnitude** simpler the ASA-MLE camera PHY receiver
- This makes ACT a much better candidate for integration of the PHY with the imager

Switch side

ASA-MLE vs ACT High Data Rate

Data Rates	ASA-MLE				ACT			
	Line Rate [Gbps]	Signal Levels	Symbol Rate [Gbaud]	Bandwidth [GHz]	Line Rate [Gbps]	Signal Levels	Symbol Rate [Gbaud]	Bandwidth [GHz]
2.5G/100M	4	2	4	2	2.8125	4	1.40625	0.703125
5G/100M	8	2	8	4	5.625	4	2.8125	1.40625
10G/100M	12	4	6	3	11.25	4	5.625	2.8125

The table above shows the modulation parameters for ASA-MLE and ACT high data rate

- For 10Gbps the two modulation schemes are very similar, with ACT only marginally simpler
- For 2.5Gbps and 5Gbps, there is slightly larger difference, with ACT clearly being simpler
  - ASA-MLE uses almost three times higher bandwidth than ACT
  - ASA-MLE uses PAM2 while ACT uses PAM4

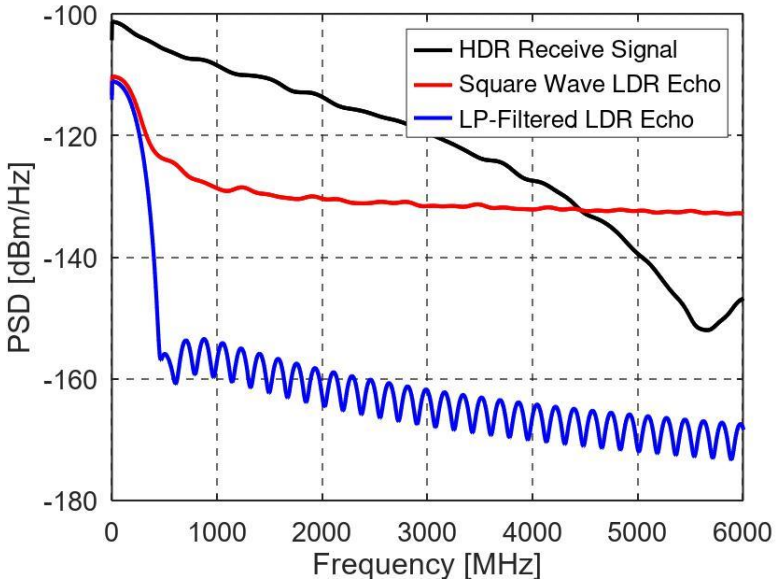
High Data Rate : Symbol Rate Comparison

Data Rates	ASA-MLE Line Rate [Gbps]	ACT Line Rate [Gbps]	ASA/ACT Line Rate Ratio
2.5G/100M	4	2.8125	1.42
5G/100M	8	5.625	1.42
10G/100M	12	11.25	1.07

- ASA_MLE has higher symbol rate

ACT High Data Rate Echo Suppression

- The high data rate ACT receiver PHY can significantly suppress echo using simple low-pass filtering of it's transmit signal
- The return loss is typically much lower at the low frequencies, so much of the echo is removed by eliminating the over-tones of the LDR transmit signal
- If needed, additional echo suppression can be achieved with relatively low complexity poly-phase echo cancelers [4]



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ASA-MLE uses 7% - 42% higher line rate to suppress echo through TDD

Switch Side Takeaway

- ASA-MLE does not need echo canceler in switch side, but requires higher line rate
- ACT may an echo suppression method, but it is much simpler than traditional echo canceler

Conclusion

- Modulation schemes of ASA-MLE and ACT were compared
- Compared to ACT, ASA-MLE requires significantly more complexity, size, and power for camera receiver
- The difference between ASA-MLE and ACT is not as significant on the switch side
- The ACT is a much better candidate for integration of the PHY with the imager

References

In this presentation information about ASA-MLE is based on publicly available sources:

[1] K. Dalmia, “ASA MotionLink – Tutorial,” ***Automotive SerDes Alliance***, Sep. 29, 2021. https://auto-serdes.org/wp-content/uploads/2022/08/ASA-tutorial-Sep-2021.pdf

[2] S. Kang and S. Gorshe, “Considerations on power consumption for IEEE 802.3dm PHY,” ***IEEE 802.3 Ethernet Working Group***, Jul. 15, 2024. https://www.ieee802.org/3/dm/public/0724/kang_3dm_01b_2407.pdf

Additional references are

[3] R. Jonsson, “Asymmetric modulation scheme,” ***IEEE 802.3 Ethernet Working Group***, Sep. 2024. https://www.ieee802.org/3/dm/public/0924/jonsson_3dm_01_09_15_24.pdf

[4] H. Sedarat, “Echo in Asymmetric Frequency-Multiplexed Systems,” ***IEEE 802.3 Ethernet Working Group***, Jul. 2024. https://www.ieee802.org/3/dm/public/0724/sedarat_3dm_202407.pdf

The “ASA Transceiver Specification” Version 2.0 from 30 April 2024 is also privately available to members of IEEE 802.3: ht

tps://www.ieee802.org/3/private/liaison_docs/ASA/ASA_Technical_Specification_ver2.0.pdf

Asymmetric Continuous Transmission (ACT) as described in jonsson_3dm_01_09_15_24.pdf

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