The Technical Challenges and Solutions for Asymmetric Ethernet Communication Systems

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Introduction

- As the Automotive Ethernet symmetric solutions are further maturing, a new demand and opportunity is emerging for standardized, asymmetric Ethernet solutions, especially for automotive camera and display applications.

- Non-Ethernet asymmetric high-speed solutions are available in the marketplace today. However, these “incumbents” have two important limitations: they are proprietary, i.e., non-interoperable single source, and they have certain EMC performance shortcomings as the data rates increase.

- In this presentation, the technical challenges of asymmetric high-speed Ethernet communication are addressed. In particular, the complexity, power consumption, and EMC behavior of in-vehicle applications for some of the proposed architectures are discussed.

- Established standardization bodies such as IEEE 802.3 provide a forum in which industry experts can effectively study and discuss the respective challenges and solutions. However, the full eco-system needs to be established to go to full production where IEEE 802.3 only provides a conformance and interoperability specification.

Agenda

- Challenges of Automotive High-speed Communications
- Automotive EMC
- Data Communication Techniques & Complexity Analysis
- Existing and Upcoming Standards
- IEEE P802.3dm Proposals
- Automotive Ethernet Eco-system Development
- Summary and Conclusions

Challenges of Automotive High-speed Communications

- With increasing frequency & data rates, the channel attenuation & noise impairments increase → the PHY performance (decision-point SNR [dp-SNR]) decreases.

- Lower dp-SNR means more susceptible to EMC immunity. The Transmit Signal levels can be increased for better dp-SNR which can be an issue for emissions. So, there is a trade-off.

- Therefore, innovative designs are needed for the PHY to compensate for this dp-SNR loss.

- EMC in cars is particularly challenging:
  - Typically, the in-car test results are quite different than lab results.
  - Well known 1000BASE-T1 UTP case → Worked in the lab but not in the car…
  - Therefore, achieving the best EMC performance is the key.

- While optimizing for a robust EMC, the cost competitiveness is essential for the design choice.

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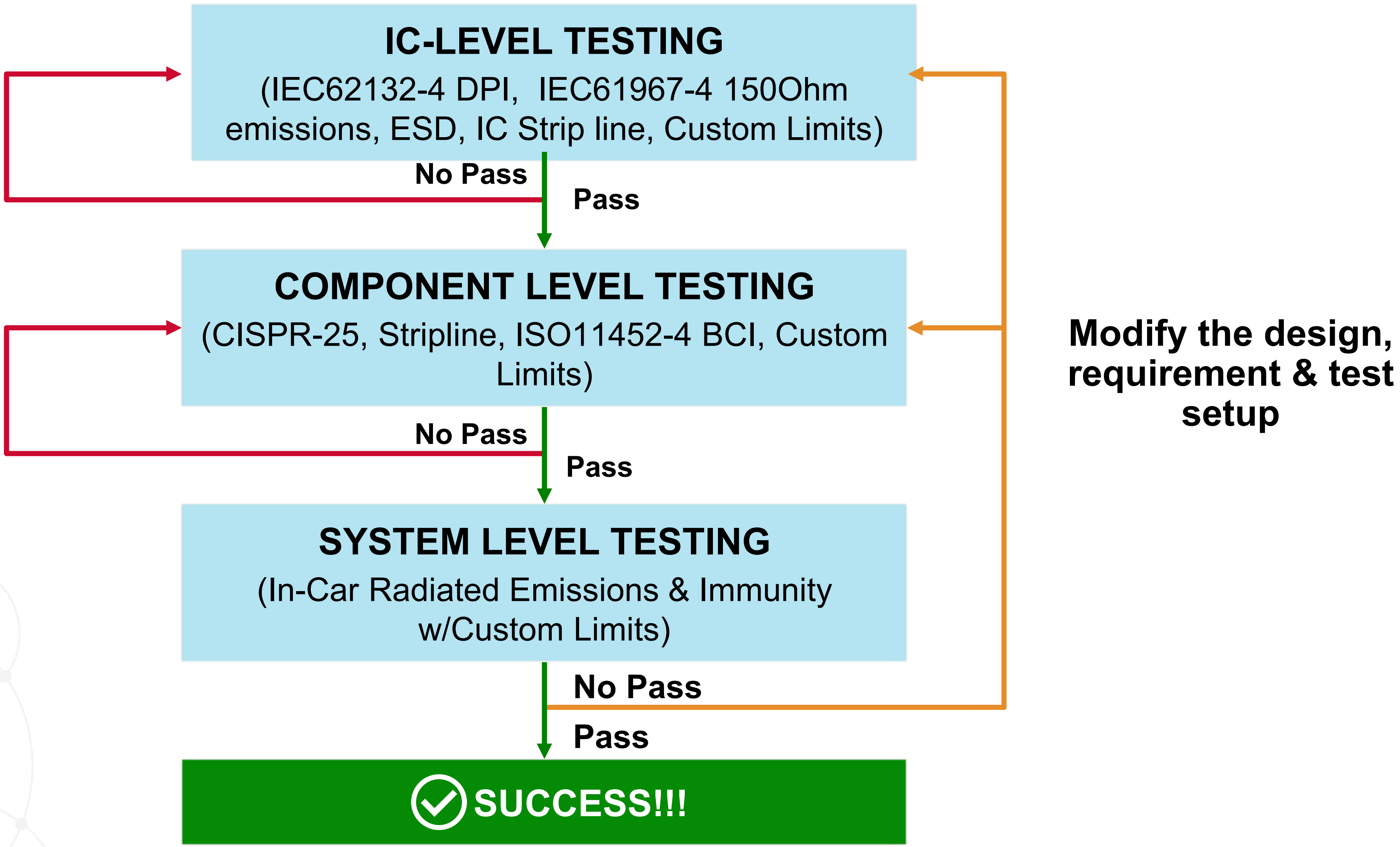
EMC Validation for Automotive



Automotive EMC Impact

- Component Level testing is the intermediary step for EMC performance verification and the requirements and set up are not the same for all OEMs.

- The final judgement on EMC performance is in-car test results.

- The effect of aging (mechanical + temperature) on **screening attenuation** of the flexible portion of link segment is shown to be severe. So, the EMC conditions can change over time.

- **Therefore, it is essential to optimize for best EMC performance practically possible to minimize the risk of emissions or the immunity for the longer period.**

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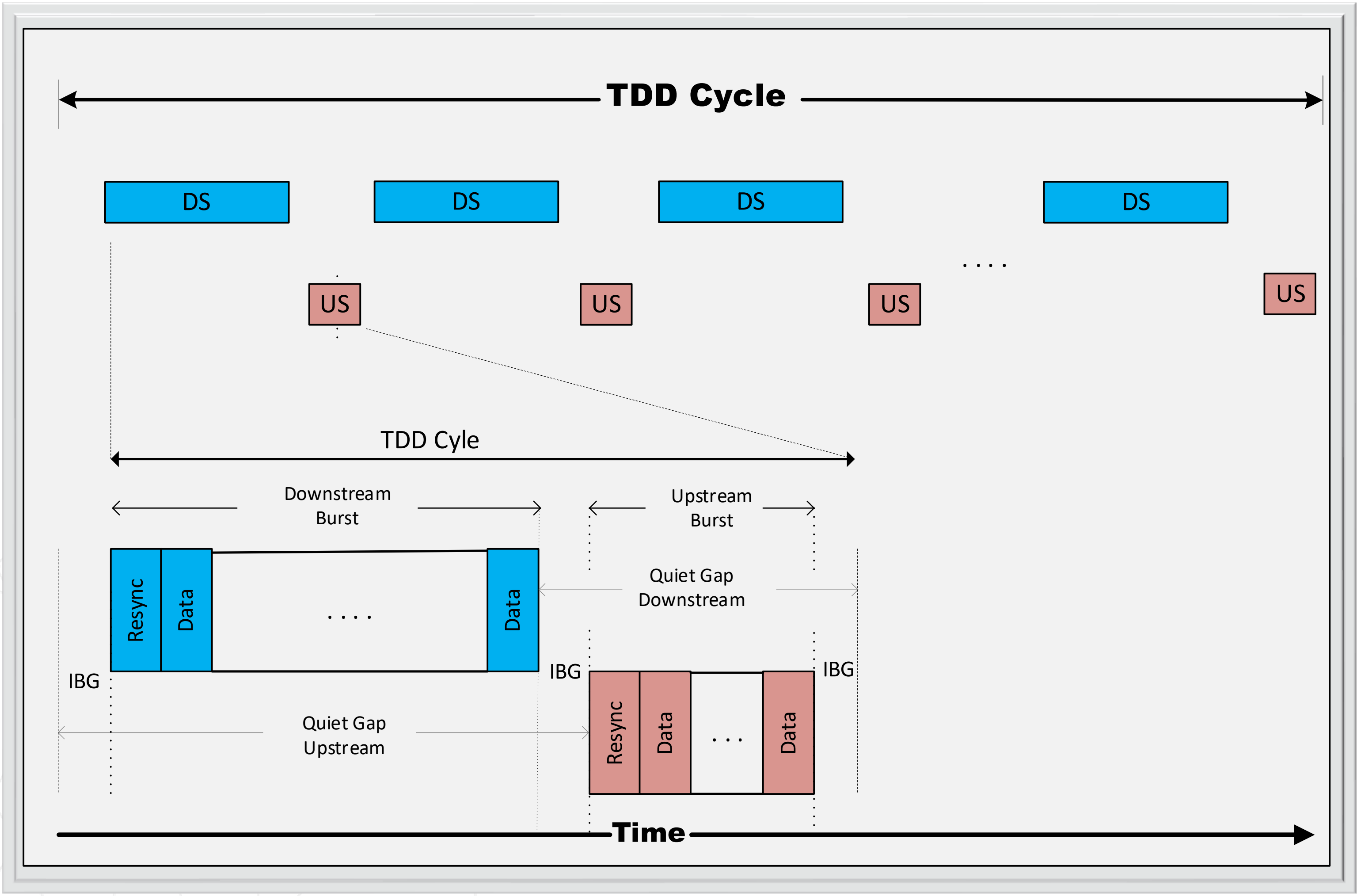
Data Communication Techniques

Processing Domain	TDD	FDD	FDX
Time	TRANSMIT RECEIVE	TRANSMIT & RECEIVE	TRANSMIT & RECEIVE
Frequency	TRANSMIT & RECEIVE	TRANSMIT | RECEIVE	TRANSMIT & RECEIVE

	TDD	FDD	FDX
Simultaneous TX/RX	No	Yes	Yes
Time Use	Alternating TX/RX slots	Continuous TX & RX simultaneously	Continuous TX & RX simultaneously
Frequency Use	One shared band	Two separate frequency bands	One shared band
Spectral Efficiency	Moderate	Good	High
Echo Interference Handling	None	Some self-interference and it requires sharp duplex filters	Must cancel strong self-interference from own transmission – a technical challenge
Hardware Complexity	Low	Medium	High
Use Cases	5G NR, GSM, LTE-TDD, Wi-Fi, ASA-ML, EPOC, EPON	GSM, LTE-FDD, 3G, MIPI-APHY, Incumbent Automotive SerDes Solutions	802.3 Ethernet PHYs such as 100/1000/ MGIGBASE-T1

TDD Operation Basics



- TDD was proposed for IEEE 802.3dm with alternating transmit direction (leveraged from ASA-ML).
- Periodic TDD cycles (fixed and configurable) with increased line rate.
- TDD is not affected by echo and thus provides best SNR performance without need for the extra complexity of sharp filters and an echo canceller.
- The same SerDes PHY architecture can be used for both camera and ECU → Single PHY
- A configurable TDD supports low to high upstream data rates by adjusting upstream/downstream directions.
- Both symmetrical and asymmetrical data rates can be supported.

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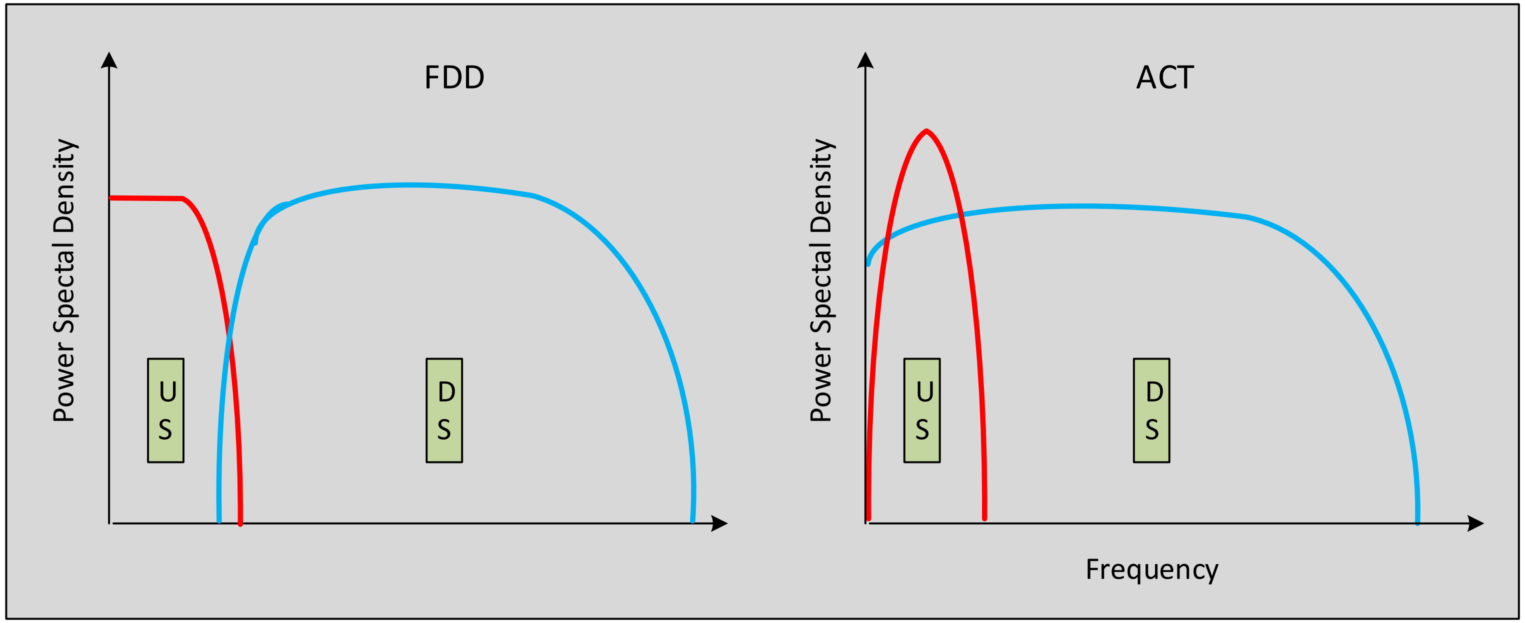
ACT Operation Basics



- The second modulation scheme proposed for P802.3dm is called Asymmetric Concurrent Transmission (ACT).
- ACT has full spectral overlap of the two transmit directions but utilizes the narrow bandwidth of the Low Data Rate (LDR) signal where FDD has little overlap.
- ACT uses different modulations for upstream (DME) and downstream data transfer (PAM2).
- Time & frequency overlap causes echo → Performance loss without cancellation and need for higher order filters.
- ACT increases the TX peak PSD level for US. This can cause in-car emission issues, especially in FM & DAB band.

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PHY Input Signal Analysis

- ***The modulation scheme must be considered first when comparing different communication technologies.***
- ***The input dynamic of the PHY comprises RX signal plus impairments. Various signal processing techniques are utilized to maximize the SNR to achieve the best performance against EMC.***

TDD

- More SNR margin due to absence of echo interference.
- Better immunity performance for downstream because there is more margin for RX signal against the interference.
- Wideband signaling and no signal overlap helps with reduced emission levels as compared to ACT in the FM & DAB band.

ACT

- Less SNR margin due to echo interference.
- Inferior immunity performance, especially if there is no echo cancellation.
- Higher level of emission in the FM band is a serious risk which requires in-car testing for the links that are closer to FM antenna.

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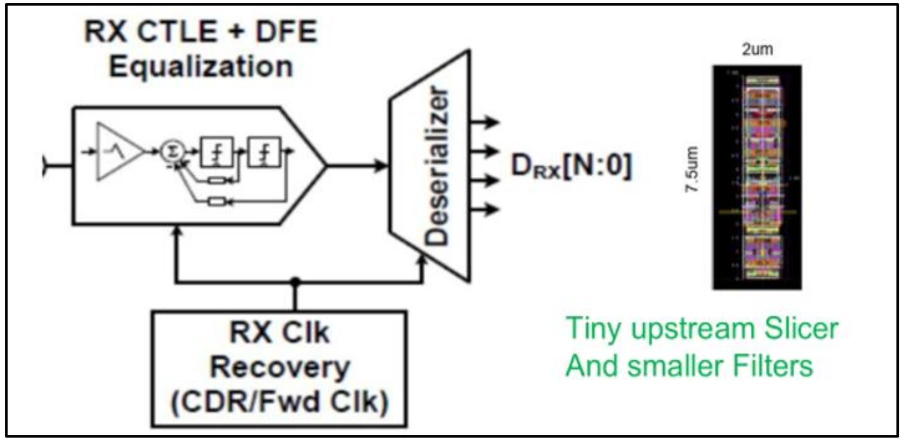
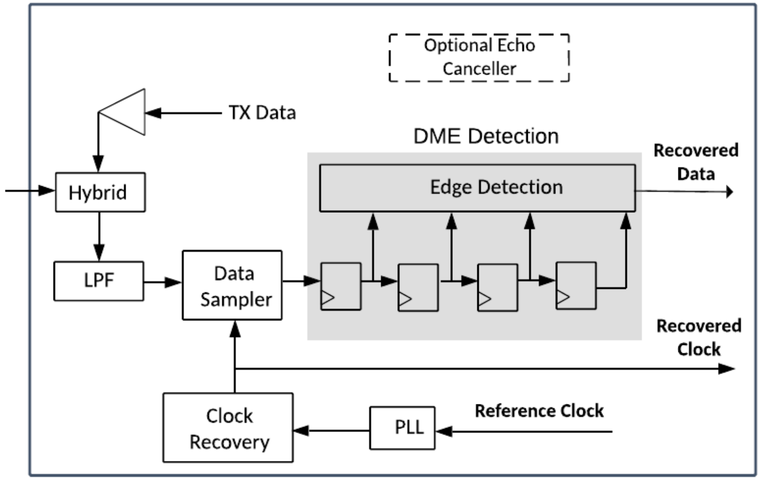
Camera PHY Receiver Complexity

TDD PMA Architecture*



ACT Architecture**



Camera Receiver Only	TDD*	ACT**
Area (complexity in 16nm)	~0.006mm^2 - 0.012mm^2	0.012mm^2
Power	<3mW	3mW

<u>However, the camera PHY is NOT only PMA, it includes PCS, FEC, EMC protection, IOs, ESD, etc. but overall, still much smaller than the camera sensor (40mm^2)</u>

* Reference: https://www.ieee802.org/3/dm/public/0725/Chini_3dm_02_07272025.pdf

**Reference: https://www.ieee802.org/3/dm/public/0125/Lo_3dm_02a_0125.pdf

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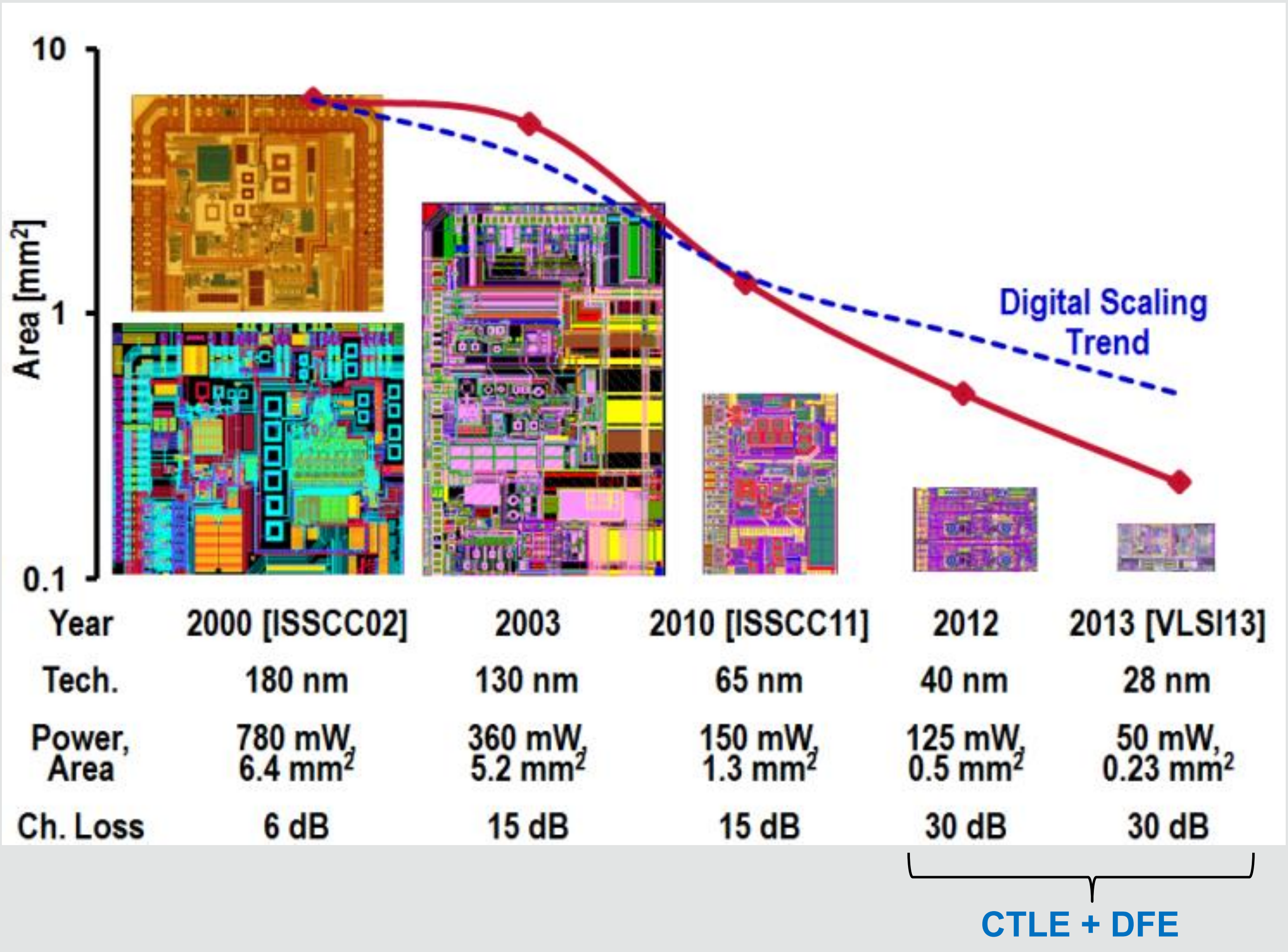
Why is TDD PHY receiver so small in both Camera and ECU?



- Removing the effect of echo signal allows TDD PHY to use the conventional 10Gbit Analog SerDes technology -that has been developed over more than two decades-.
- The simple CTLE + DFE architecture used in Analog SerDes allows PHY design that is a small fraction of a millimeter square at very low power level.
- This plot shows the Analog SerDes developments until year 2013. The area and power is further reduced in 16nm process node. Further area and power optimization is achieved using latest implementation techniques.

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Existing Multi-Gig Automotive Communication Solutions

	ADI	TI	MIPI	IEEE	ASA
Protocol	GMSL2/3	FPDLINK IV	A-PHY	802.3ch	ASA-ML/MLE
Standard	No	No	Yes	Yes	Yes
Multi-vendor	No	No	Yes	Yes	Yes
Line Rates	Downlink: 6-12Gbps Uplink: 187.5Mps	Downlink: 13Gbps Uplink: 50Mps	Downlink: 2/4/8/12/16Gbps Uplink: 100/200Mps	Downlink = Uplink: 2.8/5.6/11.2Gbps	Downlink: 2/4/8/12/16Gbps Uplink: 2/4Gbps
Modulation	FDD	FDD	FDD	FDX	TDD
Echo Compensation	Yes	Yes	Yes	Yes	No
Channel	10m? STP 15m? Coax	10m? STP 15m? Coax	10m STP 15m Coax	15m STP	10m STP 15m Coax
Security	No link layer security	No link layer security	No link layer security	MACsec	ASAsec or MACsec
Network	Point-to-Point	Point-to-Point	Point-to-Point	Ethernet	Point-to-Point & Ethernet support
Applications	Cameras, displays, sensors	Cameras, displays, sensors	Cameras, displays, sensors	Mainly for backbone	Cameras, displays, sensors

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Existing versus Upcoming Standards

	A-PHY	IEEE 802.3ch	ASA-ML	IEEE 802.3dm TDD Proposal	IEEE 802.3dm ACT Proposal
Modulation	FDD (w/echo cancellation)	FDX (w/echo cancellation)	TDD (no echo cancellation)	TDD (no echo cancellation)	ACT (w/wo echo cancellation)
In-car EMC	Pass	Pass	Pass	**Pass (based on ASA-ML)**	**To be proven**
Security	None on link layer	MACSec	ASASec	MACSec	MACSec
Harness	STP, Coax	STP	STP, Coax	STP, Coax (leveraged from ASA)	STP, Coax
PoC	Multiple inductors	Larger single inductor	Small single inductor	**Small single inductor***	**Larger single inductor***
XTAL-less solution	Not feasible	Not feasible	Feasible	Feasible	Feasible
Cost for camera integration	Medium	High	Low	Low	Low
Integration to Imager	Feasible	Costly	Feasible	Feasible	Feasible
Ecosystem	Ready	Ready	Ready	**Ready**	**Not ready**
Multivendor	2 for Mode-1 1 for Mode-2	Yes	Yes (6+ silicon vendors)	**Yes (based on ASA-ML)**	**Currently, Single Vendor**

*Reference: https://www.ieee802.org/3/dm/public/0725/Chini_3dm_01c_07272025.pdf

IEEE P802.3dm Proposals

Pros/Cons	TDD	ACT
Duplexing Method (PMA)	Half-duplex	Full-duplex
Medium Usage	Alternates direction per time slot	Concurrent transmission
Interference from Echo	**No**	**Yes**
GPIO Synchronization	**Feasible**	**Not at PHY layer**
Power over Coax	**Small inductor**	**Large inductor**
Crystal-less Camera PHY	Yes	Yes
FEC complexity	Low on the camera side Low on the ECU side (8b FEC)	Low on the camera side **Higher on the ECU side (10b FEC)**
EMI risk	**Low** (non-overlapping signals and wideband)	**High** (overlapping and narrowband for upstream)
In-car EMC results available	**Yes**	**No**

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IEEE P802.3dm Proposals (cntd.)

Pros/Cons	TDD	ACT
PHY Usage	**Same SerDes PHY can be used for both camera and ECU**	**Requires different PHYs for the camera and ECU**
Camera Side Complexity	Low	Low (if there is no echo cancellation)
ECU Side Complexity	**Low** (Analog SerDes, 8b RS FEC)	**Higher** (ADC/DFE/Filtering, 10b RS FEC)
Power Consumption	**Low** (Analog SerDes on both sides)	**Higher** (ECU RX)
Implementation Cost	**Low** (Analog SerDes on both sides)	**Higher** (ECU RX)
Eco-system	**Fully developed & leveraged from ASA-ML**	**To be developed**
Functional Safety	**ASIL-B**	**To be developed**
Multi-vendor interoperability	**Yes (6+ vendors)**	**NA**

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Automotive Ethernet Eco-system

- BroadR-Reach was started in 2009 and became IEEE P802.3bw 100BASE-T1 in 2015. Then, several Automotive BASE-T1 PHY standards were specified over the last 10 years.

- OPEN Alliance was formed in 2011 to quickly develop a necessary eco-system and **gap-fill & complement IEEE 802.3**:
  - This symbiotic relationship has been going on for all IEEE 802.3 BASE-T1 PHY speed grades.
  - Various technical committees exist for addressing automotive industry requirements.
  - 10+ silicon vendors exist today for BASE-T1 products.

- ASA was formed in December 2019 with this in mind, hence developing the full eco-system within one organization:
  - With 180+ members that includes OEMs, Tier1s, Tier2s.
  - 6+ silicon vendors w/ASA-ML products exist today.
  - In-car EMC test results are available and passing.

- The fully operational eco-system has been developed for ASA.

Summary and Conclusions

- A cost effective and high-performance Ethernet-based solution is sought for asymmetric automotive imaging systems in IEEE 802.3dm.
- EMC, complexity and power should be optimized in both camera and ECU side for a competitive solution.
- Since there is no echo and only because there is no echo, the half duplex TDD system allows to implement well-established low complexity & competitive analog signal processing techniques for high-speed communications on both sides.
- ASA-ML TDD solution is leveraged & optimized for 802.3dm for a single PHY solution. The same PHY architecture can be configured for both camera & ECU since the same modulation type is used.
- The ACT proposal does not achieve best SNR performance without echo cancellation in our analysis. Moreover, it requires different PHYs for camera and ECU side.
- Total cost of ownership must be considered & optimized; ergo a single PHY solution needs to be aimed for wide adoption and easier interoperability.
- A readily-available eco-system is critical for a successful technology deployment.

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