Optimized Asymmetric Operation

Technical Feasibility

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Overview

- Car OEMs and Tier 1s expect >80% of links for B10G to be asymmetric in nature (mash_B10GAUTO_1_0719.pdf)

- Support for asymmetrical operation is included in B10G PAR

- This presentation explores technical feasibility of several methods to support asymmetry in automotive Ethernet and investigate approaches that optimize for this use case

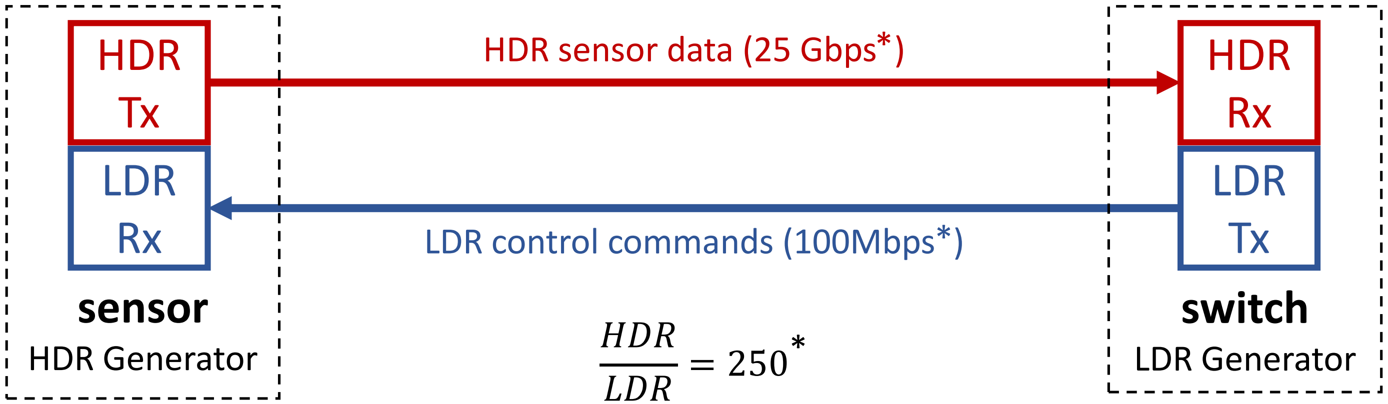
Technical Feasibility vs Baseline Proposals

- Study Group does Technical Feasibility
  - Theory, analysis, simulations showing reasons to believe we CAN get to a solution
  - Often done with Shannon Capacity, Measurements, and Architecture discussions
- Task Force does Baseline Proposals
  - Specific proposals for modulation, coding, bandwidths, IL
  - NOT until we get to Task Force

- THE FOLLOWING IS FOR TECHNICAL FEASIBILITY AND NOT A PROPOSAL

Asymmetric Data Rate

- Automotive data links to sensors/displays are asymmetric in nature:
  - Sensor node is a High Data-Rate (HDR) generator: High volume of data is streamed down from sensor (HDR direction)
  - Sensor link-partner is a Low Data-Rate (LDR) generator: Small amount control data is transmitted up to the sensor (LDR direction)



$$\frac{HDR}{LDR} = 250^{*}$$

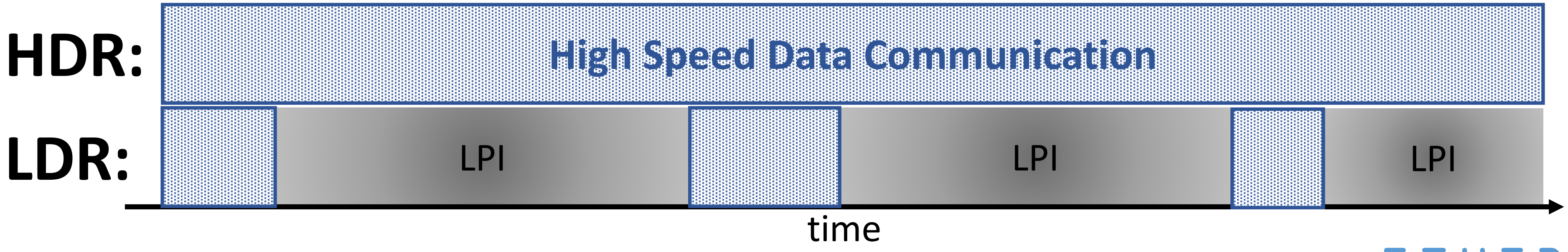
* These are just example data rates

Asymmetry and PHY Complexity

- Asymmetry in data rates may be leveraged to lower the complexity of the communication system resulting in
  - Lower power consumption
  - Lower relative silicon cost / complexity
  - Lower overall relative system cost with simpler power delivery

EEE for Asymmetry

- EEE is the implicit method of choice to achieve asymmetry in some current Ethernet standards
  - Technical feasibility for B10G: zimmerman_3B10G_01_1119.pdf
- EEE sends the low-throughput information over bursts of high-speed data transmission
- Transceiver goes to low-power mode (LPI) between these bursts



EEE for Asymmetry: Power and Cost

- Average power consumption scales with data rate
- Max power during training and data transmission remains high requiring more complex and relatively costlier power supply system:
  - More complex regulators supporting higher maximum current
  - Relatively Costlier PoDL solutions with thicker cable or higher supply voltage
- EEE does not offer any relative silicon cost reduction as the transceiver has to be designed for full symmetric speed

Asymmetry With Simpler Receiver

- While EEE provides a mechanism to reduce average power, it still relies on all functional blocks in a complex receiver
  - High relative silicon cost / complexity
  - High relative system cost

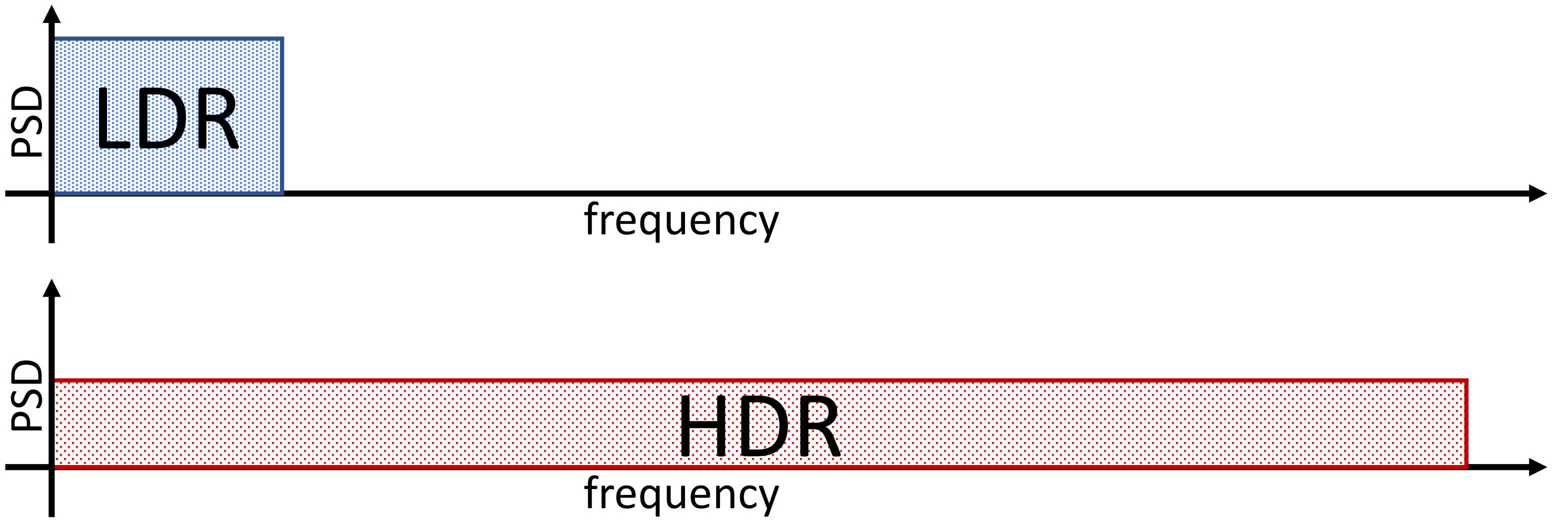
- Methods based on simplified receiver not only lower the average power consumption, but they also may offer
  - Reduction in the complexity and the relative cost of PHY
  - Reduction in overall relative system cost

Asymmetry With No Echo Cancellation

- Echo cancellation is one of the most complex functions in a high-speed full-duplex transceiver
  - Relative power and complexity grow by square of baud-rate
- An asymmetric scheme with no (or simplified) echo canceller can achieve both goals in lowering the relative cost and power
- Without echo-canceller, both average and max power are optimized
- Potential asymmetric methods with no (or simplified) echo cancellation:
  - Frequency multiplexing
  - Time multiplexing
  - Code multiplexing

Method 1: Frequency Multiplexing

- The HDR and LDR signals are specified to have different frequency contents
- The echo from one frequency band to another may be small enough to eliminate or simplify the echo canceller



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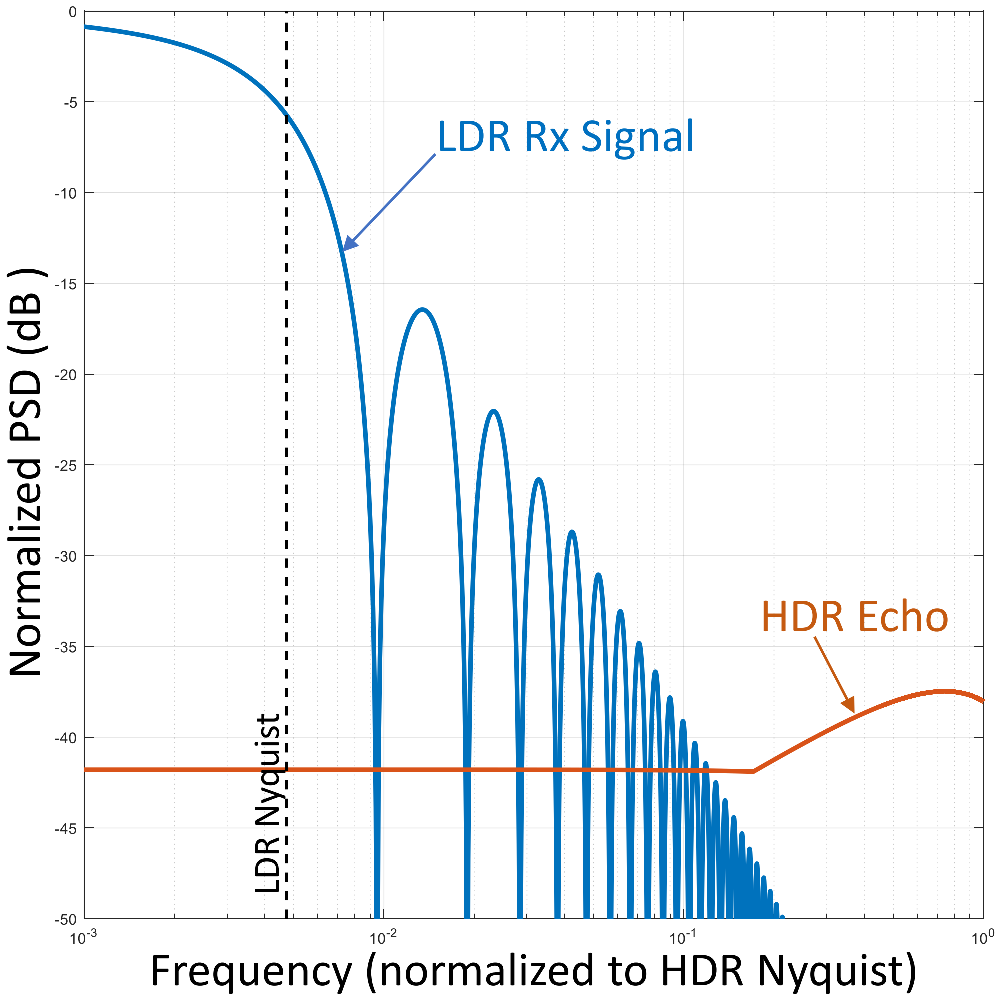
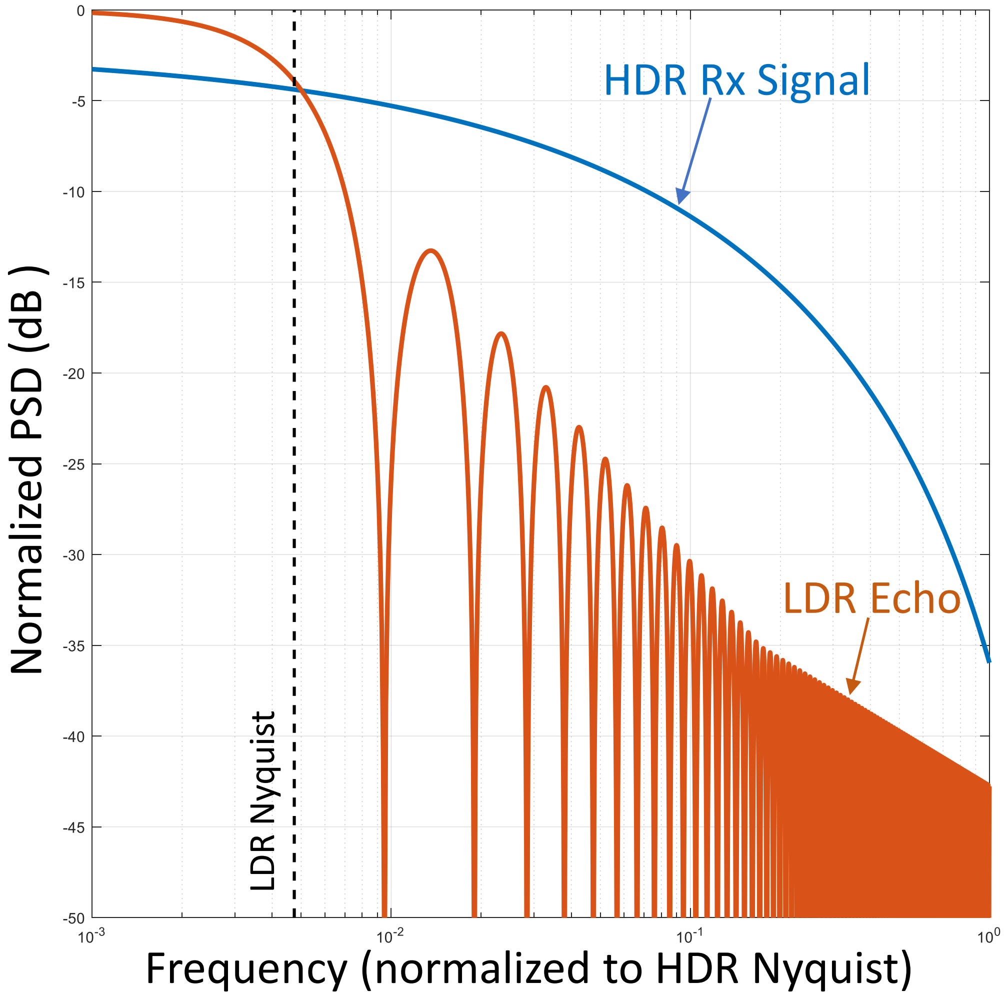
Frequency Multiplexing – HDR Generator

- The HDR generator (sensor) transmits at higher baud rate and receives at low rate
- Echo power is mostly at high frequency while the receive signal from link-partner is low frequency
- The receiver anti-aliasing filter blocks most of the high-frequency echo



Frequency Multiplexing – LDR Generator

- The LDR generator transmits at lower baud rate and receives at high rate
- Transmit signal is mostly low frequency resulting in relatively small echo
- Additional transmit filtering may be required to reduce the echo power

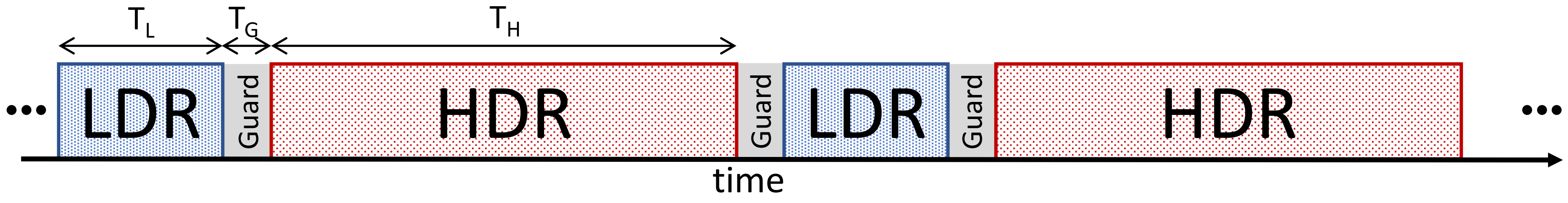


Frequency Multiplexing – considerations

- Additional filters may be needed in LDR transmitter
- HDR receiver may need simplified residual echo cancellation
- The very low frequency LDR signal may present a challenge in high resolution timing recovery needed for HDR generator
  - LDR receiver (sensor) may not operate well when configured as Slave

Method 2: Time Multiplexing

- HDR and LDR signals are transmitted over nonoverlapping periodic timeslots



- When the local transmitter is ON the remote transmitter is OFF eliminating echo into remote receiver (and vice versa)
- Guard bands, where both transmitters are off, may be needed at transition between LDR and HDR to eliminate echo from far-end reflection points

Time Multiplexing – overhead

- Transmission time intervals are proportional to the corresponding data rate
  - $\frac{T_H}{T_L} = \frac{HDR}{HDL} = 250$
- If the LDR receiver (sensor) is configured as Slave, it cannot be off for long period of time as its clock drifts too much
  - $\boldsymbol{T_H < 100\ \mu s \quad \Rightarrow \quad T_L < 400\ ns}$
- Guard band is in the order of the round-trip propagation delay
  - $\boldsymbol{T_G \approx 100\ ns}$

Time Multiplexing – other considerations

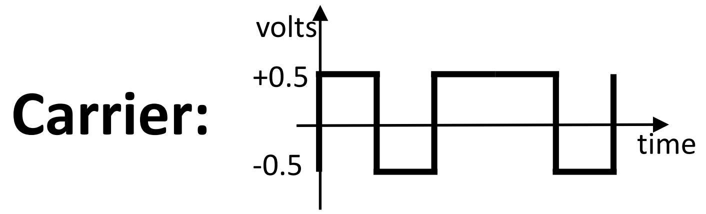
- To limit the maximum power, a modified training is needed to prevent simultaneous activation of both transmitters

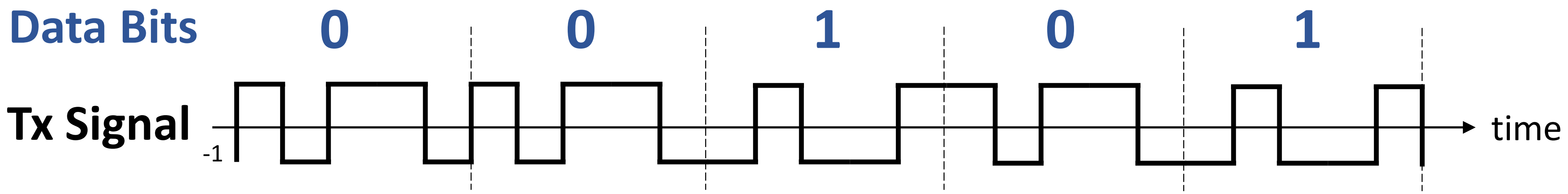
- Transmitters are non-stationary sources of alien crosstalk

- Data is transmitted in burst which may have to be regulated with potentially large FIFOs

Method 3: Code Multiplexing

- Low-frequency LDR bits modulate high-frequency pseudo-random carrier before launched on cable
- The carrier is a sequence of uncorrelated PAM2 symbols transmitted at high symbol rate (much higher than LDR)
  - Example: Alert symbol from EEE





Code Multiplexing – Spreading Gain

- Every data bit is spread over multiple PAM symbols
- Spreading results in SNR gain
- Example: spreading factor of 125
  - HDR = 25 Gbps (PAM4) ⇒ LDR = 100 Mbps (PAM2)
  - SNR gain ≈ 20 dB ⇒ Required input SNR ≈ 0 dB

Code Multiplexing – Receiver Complexity

- LDR receiver as trivial as Alert detector
  - No equalizer
  - No echo canceler
  - Simpler analog components

  ⇒Very low power

  ⇒Relatively very low cost

- HDR receiver requires a polyphase echo canceller
  - Power/complexity is linearly reduced by spreading factor (e.g. a factor of 125)

Code Multiplexing – Summary

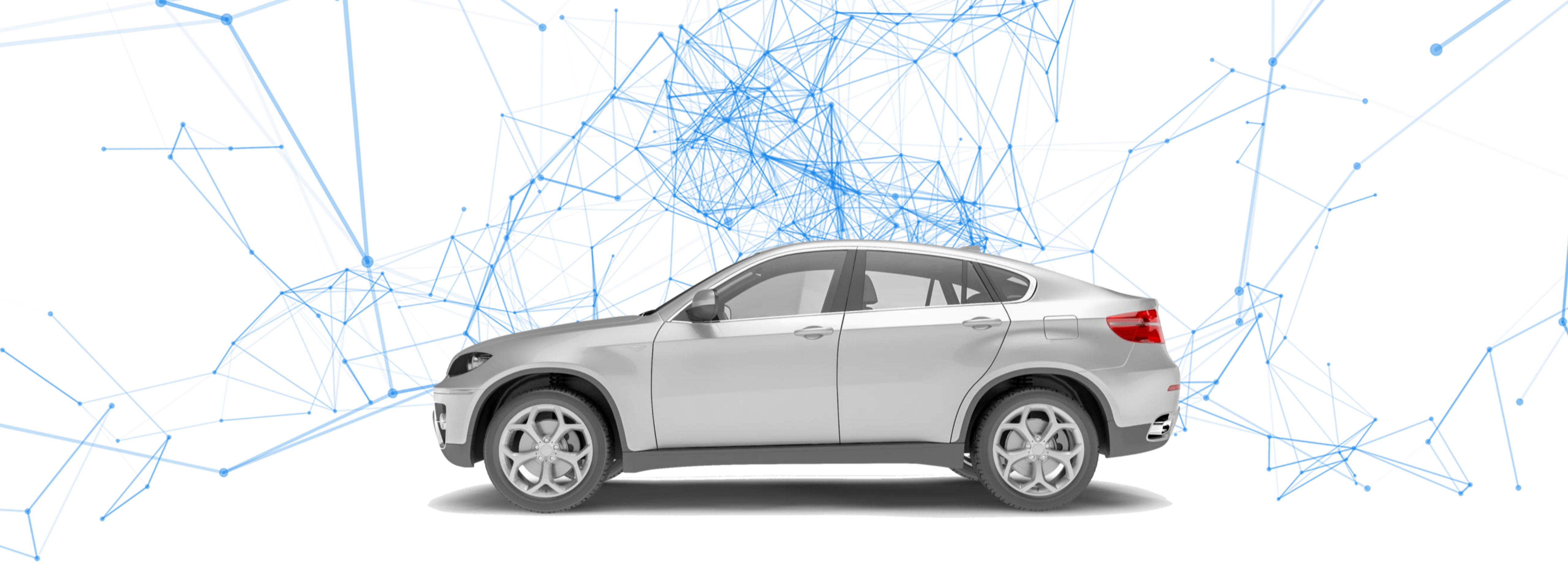
- Max power is as low as average power
- LDR signal is wide band, presenting enough information for high resolution timing recovery
  - Sensor may be configured as Slave
- LDR receiver is based on the proven concept of Alert detection
  - no additional elements to decouple in frequency or time, no need for deep buffers to regulate bursts, no nonstationary crosstalk

Summary

- Asymmetry is a feasible mode of operation

- Besides EEE, there are other feasible frameworks for optimized asymmetric operation to lower the relative cost, power and complexity
  - Frequency multiplexing
  - Time multiplexing
  - Code multiplexing

- We welcome the coming discussions in our Task Force!



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