Asymmetric Physical Layer
A Feasibility Overview

Hossein Sedarat

September 2023

IEEE 802.3 ISAAC

ETHERNOVIA®

Overview

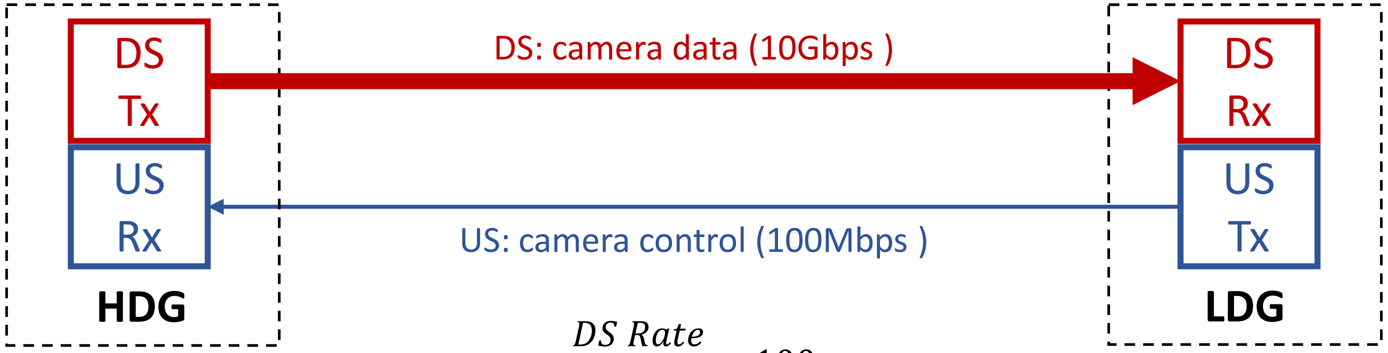
Review high-level schemes for asymmetric Ethernet

- Automotive application
- History of asymmetry in 802.3 automotive
- EEE
- Low power data (LPD)
- Frequency-domain duplexing
- Time-domain duplexing
- Code multiplexing
- Summary

Asymmetric Data Rate

Automotive data links to cameras/displays are asymmetric in nature:

- Camera node is a high data-rate generator (HDG): High volume of data is streamed down from camera in the down-stream (DS) direction
- Aggregator (link-partner of camera) is a low data-rate generator (LDG): Small amount control data is transmitted up to the camera in the up-stream (US) direction



$$\frac{DS\ Rate}{US\ Rate} = 100$$

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 PHY complexity: silicon area, relative cost
- Lower overall system cost
  - Lower complexity of cooling system
  - Simpler power delivery system
  - Easier integration with other components

PHY Complexity – PMA Layer

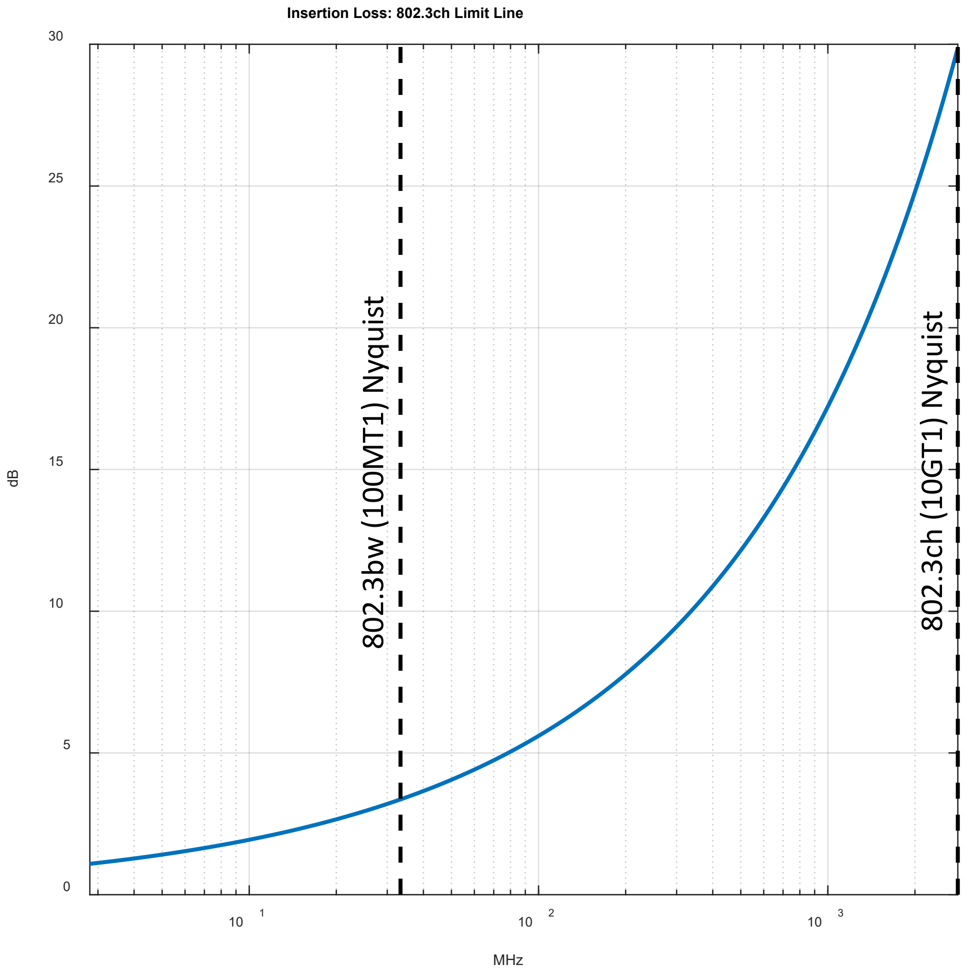
- PMA receive functions are usually the most complex within a high-data-rate PHY
  - Equalization
  - Echo cancellation
  - EMC

- Complexity of these functions grow as the data rate and signaling bandwidth increases

PHY Complexity – Equalization

To support higher data rates:

- Signaling bandwidth is wider and channel loss is higher, demanding
  - Nonlinear equalization
  - Transmit precoding
- Equalizing filters are run at higher frequencies with higher resolution
- The analog front-end (AFE) is required to support higher dynamic range over wider bandwidth
- Smaller phase error is tolerated



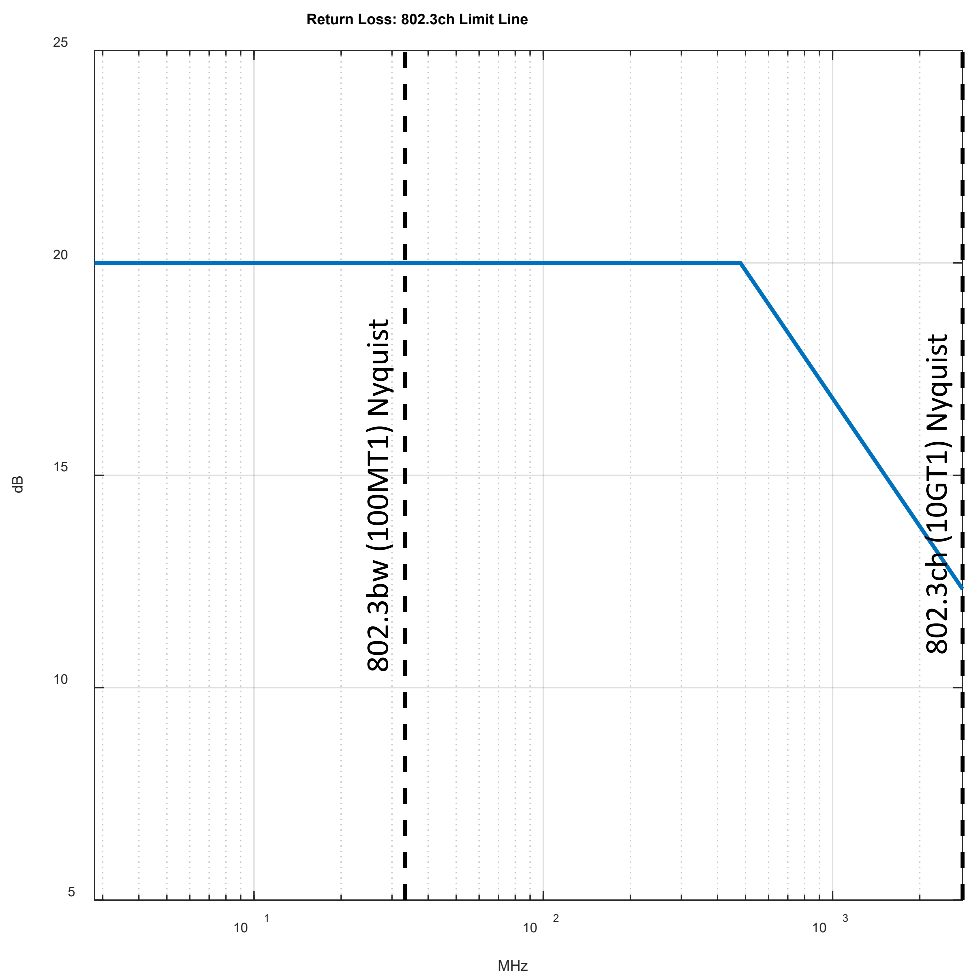
ETHERNOVIA®
VIRTUALIZING VEHICLE COMMUNICATION

PHY Complexity – Echo Cancellation

At higher data rates:

- Echo power is stronger and echo pulse response covers more symbols
- AFE dynamic range and linearity need to be higher over a wider bandwidth
- Lower clock jitter is tolerated
- Echo cancelling filter has to run faster with higher resolution
  - Complexity grows quadratically

  (growth is mostly linear with time-domain echo limits)



ETHERNOVIA®
VIRTUALIZING VEHICLE COMMUNICATION

PHY Complexity – EMC

- Susceptibility: At higher data rates, the receiver frequency bandwidth is wider, exposing it to:
  - More sources of in-band RF interference
  - Stronger RF interferers due to lower coupling/shielding attenuation
- Emission: At higher data rates, transmit emission control is more challenging due to wider transmit bandwidth and lower balance, coupling and shielding attenuation

Methods to Support Asymmetry

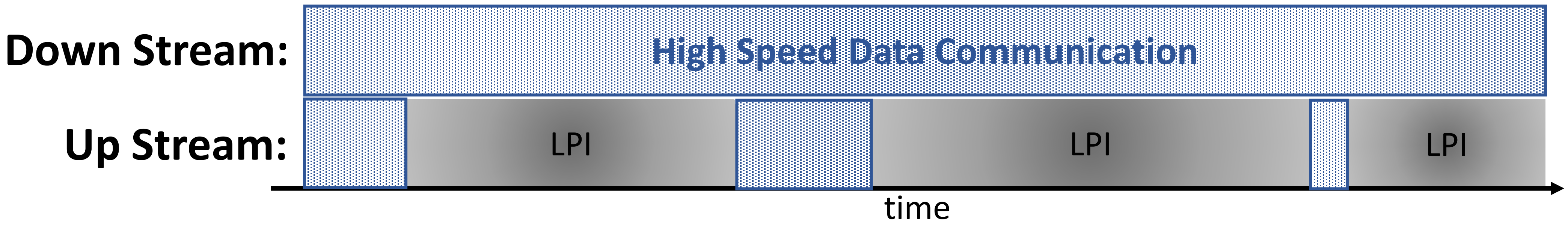
1. EEE in its original form
2. Low-Power Data (LPD): a modified version of EEE
3. Frequency-domain duplexing
4. Time-domain duplexing
5. Code multiplexing

Asymmetry: History in 802.3 Automotive

- 802.3bp: OAM data over LPI signaling
    - https://www.ieee802.org/3/bp/public/jan15/graba_3bp_01_0115.pdf
- 802.3ch: Large number of contributions from many PHY designers
    - https://www.ieee802.org/3/ch/public/sep17/dalmia_3ch_01_0917.pdf
    - https://www.ieee802.org/3/ch/public/jul18/souvignier_3ch_01a_0718.pdf
    - https://www.ieee802.org/3/ch/public/sep18/souvignier_3ch_01_0918.pdf
    - https://www.ieee802.org/3/ch/public/nov18/souvignier_3ch_02_1118.pdf
    - https://www.ieee802.org/3/ch/public/adhoc/Lo_3ch_01_1218.pdf
    - https://www.ieee802.org/3/ch/public/adhoc/Lo_3ch_03_1218.pdf
    - https://www.ieee802.org/3/ch/public/adhoc/sedarat_3chah_01_013019.pdf
    - https://www.ieee802.org/3/ch/public/adhoc/Lo_3ch_01_adhoc_0119.pdf
    - https://www.ieee802.org/3/ch/public/adhoc/Lo_3ch_01_adhoc_0219.pdf
    - https://www.ieee802.org/3/ch/public/jan19/Lo_3ch_01_0119.pdf
    - https://www.ieee802.org/3/ch/public/mar19/Lo_3ch_03a_0319.pdf
    - https://www.ieee802.org/3/ch/public/mar19/sedarat_3ch_01a_0319.pdf
  - Asymmetry through EEE and extensions to LPI signaling
  - Studies covered PMA, PCS, RS, and beyond
- 802.3cy: Early contribution covering different schemes beyond EEE
    - https://www.ieee802.org/3/B10GAUTO/public/jan20/sedarat_3B10G_01_0120.pdf

Method 1: EEE

- EEE is the implicit method of choice to achieve asymmetry in some current Ethernet standards
- EEE sends the low-throughput information over bursts of high-speed data transmission
- Transceiver goes to low-power idle mode (LPI) between these bursts



ETHERNOVIA®
VIRTUALIZING VEHICLE COMMUNICATION

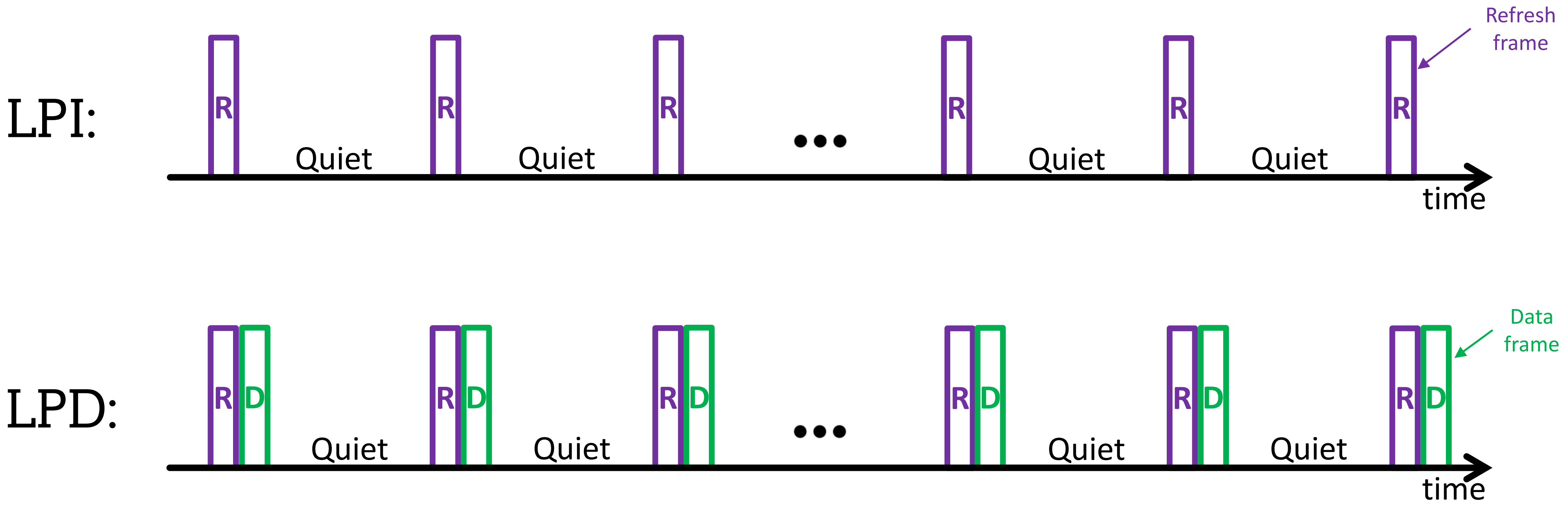
Method 1: EEE – cont’d

- Average power consumption scales with upstream data rate

- EEE does not offer any silicon cost reduction

Method 2: Low-Power Data (LPD)

The upstream operates in LPD mode, a variant of LPI which includes periodic insertion of one or more frames of data after Refresh frames



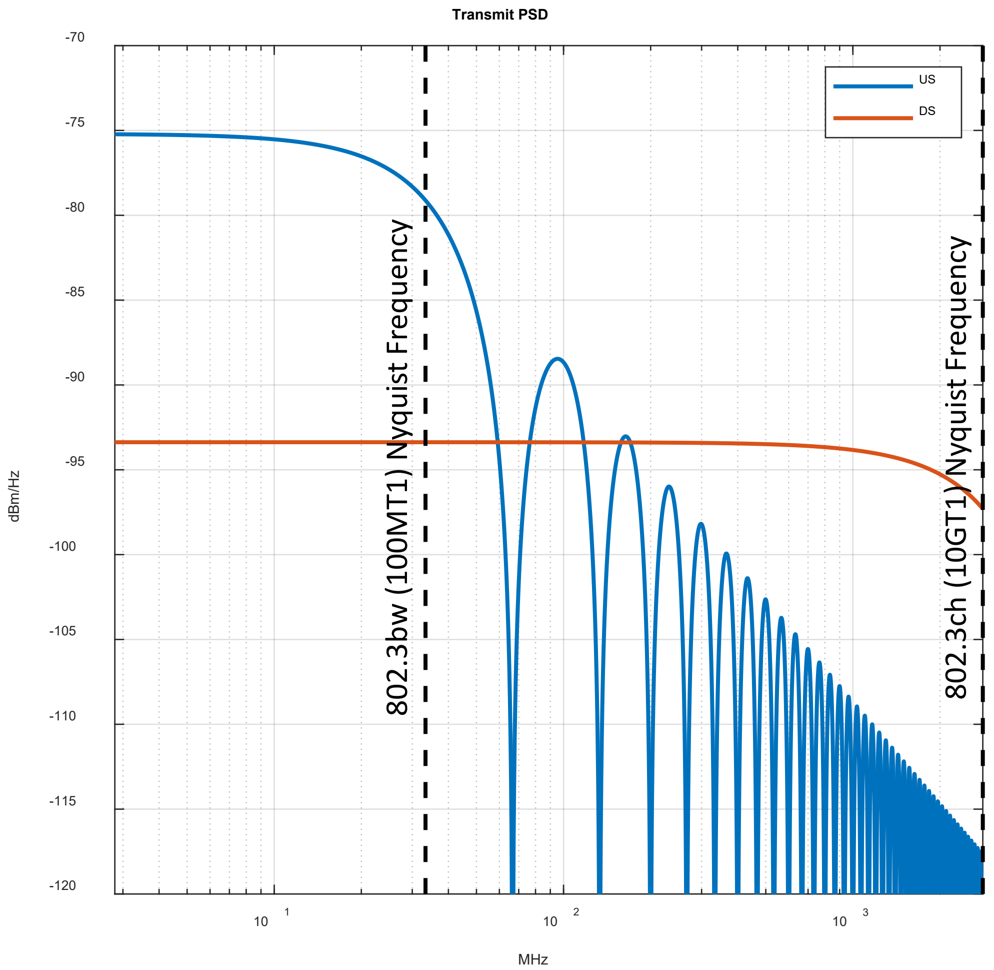
ETHERNOVIA®
VIRTUALIZING VEHICLE COMMUNICATION

Method 2: LPD – cont'd

- Average power consumption scales with upstream data rate
- No need for Alert detection
- More regular flow of data traffic

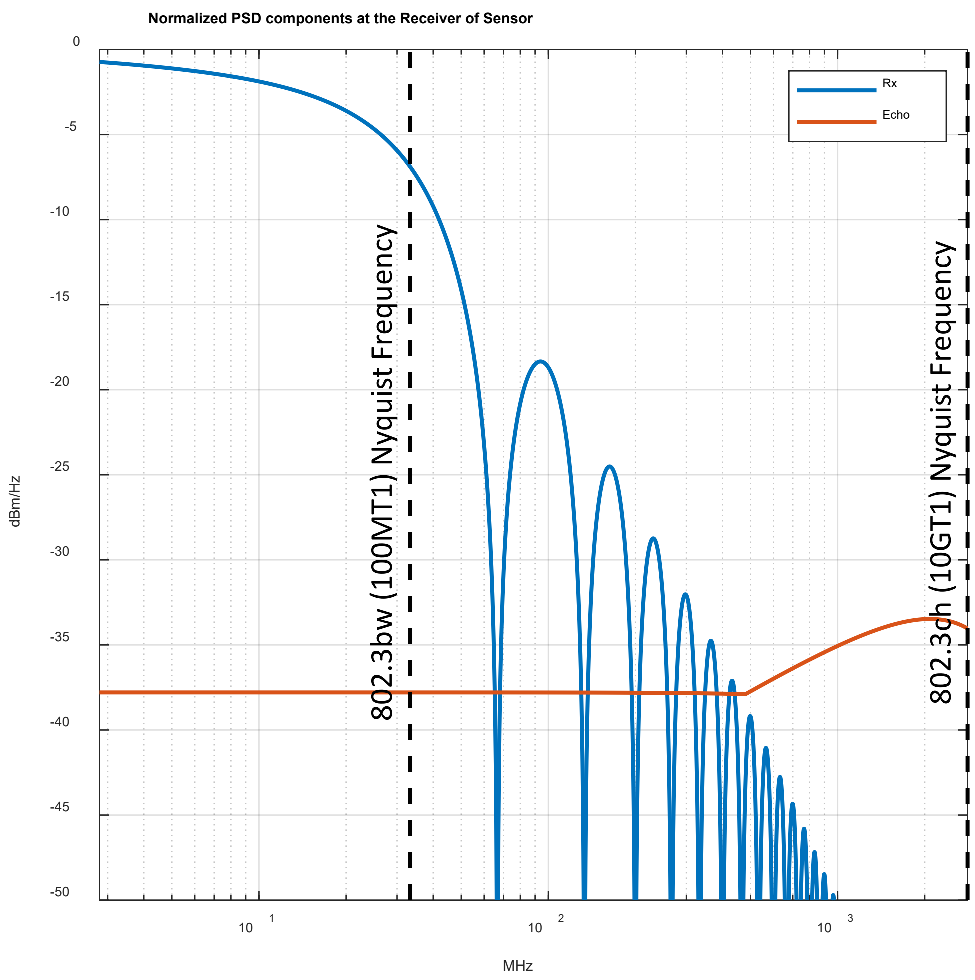
Method 3: Frequency-Domain Duplexing

- Symbol rate and signal bandwidth scales with DS and US data rates
- Complexity of the entire upstream receiver scales with data rate
- The echo from one frequency band to another may be small enough to eliminate or simplify the echo canceller



Frequency-Domain Duplexing – HDG

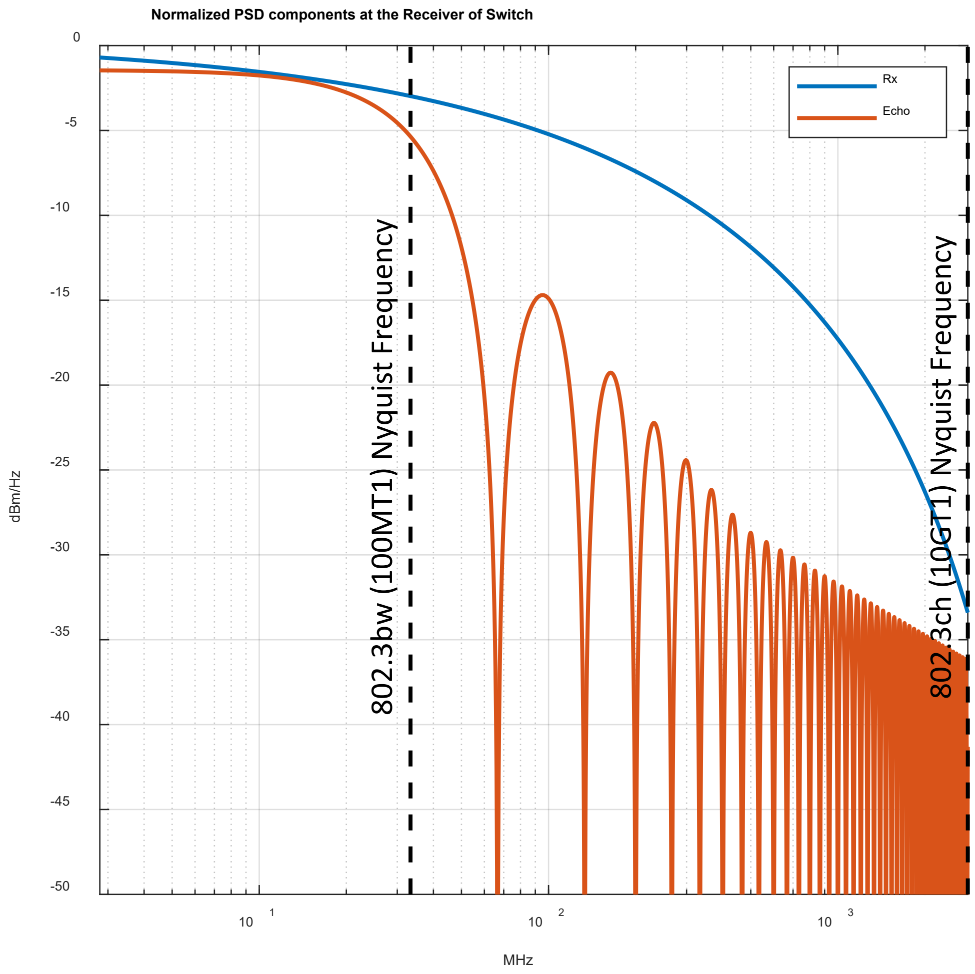
- HDG (camera) transmits at higher baud rate and receives at low rate
- Echo power is mostly at high frequency while the receive signal from link-partner is low frequency
- The receiver anti-aliasing filter blocks most of the high-frequency echo
- Signal-to-Echo Ratio = 35 dB
  - echo cancellation may not be needed!



ETHERNOVIA®
VIRTUALIZING VEHICLE COMMUNICATION

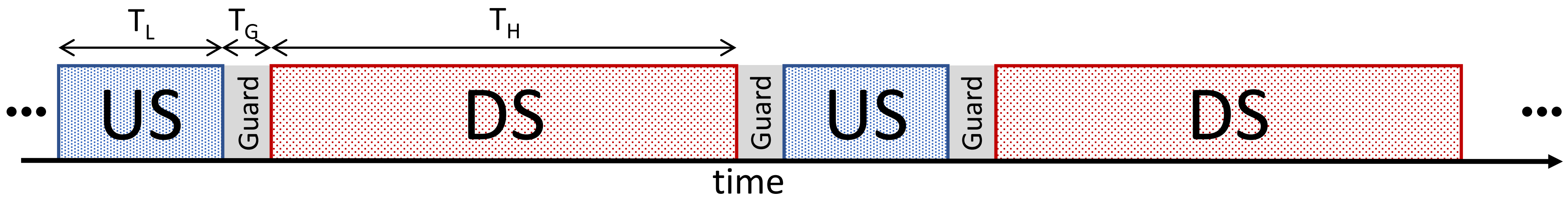
Frequency-Domain Duplexing – LDG

- LDG (aggregator) transmits at lower baud rate and receives at high rate
- Transmit signal is mostly low frequency resulting in small echo power covering a fraction of the receiver bandwidth
  - Partial echo cancellation may be needed
  - Polyphase implementation reduces the complexity by the ratio of DS/US data rates



Method 4: Time-Domain Duplexing

- HDR and LDR signals are transmitted at high symbol rate but over nonoverlapping periodic timeslots



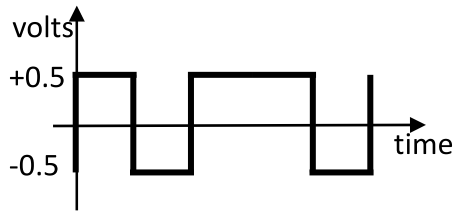
- When the local transmitter is ON the remote transmitter is OFF eliminating echo into remote receiver (and vice versa)

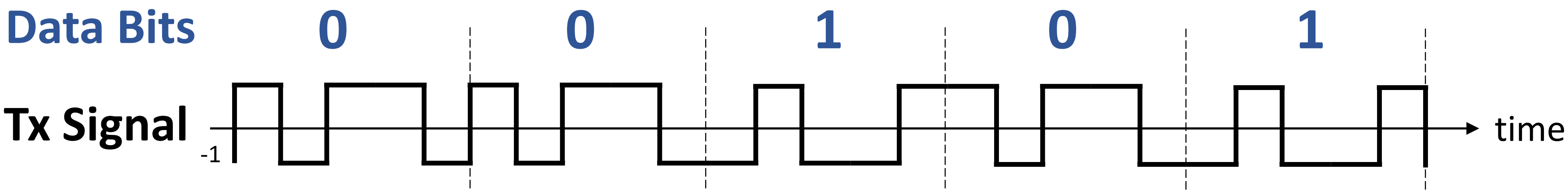
- Guard bands, where both transmitters are off, is needed at transition between US and DS to eliminate echo from far-end reflection points

Method 5: Code Multiplexing

- Low-frequency upstream data 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

Carrier:





ETHERNOVIA®
VIRTUALIZING VEHICLE COMMUNICATION

Code Multiplexing – Spreading Gain

- Every data bit is spread over multiple PAM symbols
- Spreading results in SNR gain
- Example: DS = 10 Gbps (PAM4), US = 100 Mbps (PAM2)

  ⇒ Spreading factor ≈ 50

  ⇒ SNR gain ≈ 20 dB

  ⇒ Required input SNR ≈ 0 dB

- Upstream receiver may be as trivial as an Alert detector
  - No equalizer, no echo canceler, simple analog components

- Downstream receiver requires a simple, polyphase echo canceller

Conclusion

- There are a number of different methods to achieve asymmetry at the physical layer

- An asymmetric PHY is very much feasible with widely known techniques


ETHERNOVIA®
Thank You