Deployed 100Mb/s One Pair OABR PHY

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Overview

Twisted-pair (TP) Ethernet development is proliferating Automotive applications beyond ...

→ *100BASE-TX OBD*

→ *OPEN Alliance BR-PHY*

→ *802.3bp 1000BASE-T1*

→ *802.3 1TPCE SG* → *...*

- Ethernet Development for Automotive Area Networks
- Framework for One-Pair 100Mb/s
- Technical Overview of OABR-PHY for One-Pair 100Mb/s
- Conclusions

Ethernet Development for AAN

- **Essential Elements of Ethernet Success**
  - Ethernet ecosystem, using several media specifications spans speeds of 10Mb/s to 100Gb/s over distances of 1m to >10km …
  - New media specifications for each new Ethernet speed
  - Each Ethernet media specification is optimum for a certain range
  - Cabling & PHY standards were coherently developed for successful 802.3 projects
- **Constraints of Automotive Ethernet for Automotive Area Networks (AAN)**
  - Low cost & lightweight cabling, low-power & cost-efficient components (PHYs, connectors, magnetics, on-board components and etc.) → TP cabling
  - Robust operation under severe noise conditions → Need to be well-defined for TP cabling
- **Challenges for Automotive Ethernet**
  - A variety of different cables & connectors are being used → No standard among OEMs. Can handle it by defining the channel characteristics. The good news is the cable reach is relatively short
  - As shown in 802.3bp, EMC is an interesting challenge → Achieving good symmetry requires good engineering practices
  - EMC Test Methods & Limit lines vary between different OEMs → Vendor challenge

TP Ethernet PHY Implementations

	10BASE-T	100BASE-TX	100Mb/s OABR	1TPCE	1000BASE-T	10GBASE-T	1000BASE-T1
Reference	802.3i	802.3u	OPEN Alliance	802.3	802.3ab	802.3an	802.3bp
Rate	10 Mb/s	100 Mb/s	100 Mb/s	100 Mb/s	1 Gb/s	10 Gb/s	1 Gb/s
Bandwidth	20 MHz	62.5 MHz	33.3 MHz	TBD	62.5 MHz	400 MHz	300 MHz
Modulation	Binary Manchester	MLT3	PAM3	TBD	PAM5	DSQ-128	PAM3
BER	$<10^{-10}$	$<10^{-10}$	$<10^{-10}$	$<10^{-10}$	$<10^{-10}$	$<10^{-12}$	$<10^{-10}$
# of Pairs	2	2	1	1	4	4	1
Reach	100m	100m	15m	TBD	100m	100m	15m/40m
Category	CAT 3	CAT 5	1-pair UTP	1-pair UTP	CAT 5e	CAT 6A	1-pair UTP

Ethernet PHY Evolution

- As data rates increase, Ethernet PHYs must become increasingly more sophisticated to operate over UTP cabling

10BASE-T
20Msps
Manchester
MII

100BASE-TX
125Msps
MLT-3
SMII/S3MII
Scrambling
Equalization

1000BASE-T
125Msps
PAM-5
SGMII/RGMII
Scrambling
Equalization
4 Lane FDX
Loop Timing
Echo Canc.
NEXT Canc.
FEC (CC)

10GBASE-T
800Msps
128-DSQ
XAUI/XFI
Scrambling
Equalization
4 Lane FDX
Loop Timing
Echo Canc.
NEXT Canc.
FEC (LDPC)
Matrix FEXT Suppression
EMI Mitigation
TH Precoding
PCS Frames
Training sequence
Power back-off
Digital Calibration

…

One-Pair OABR
100Mb/s

IEEE 802.3bp
1000BASE-T1

… but so is silicon capacity increasing (Moore’s Law)

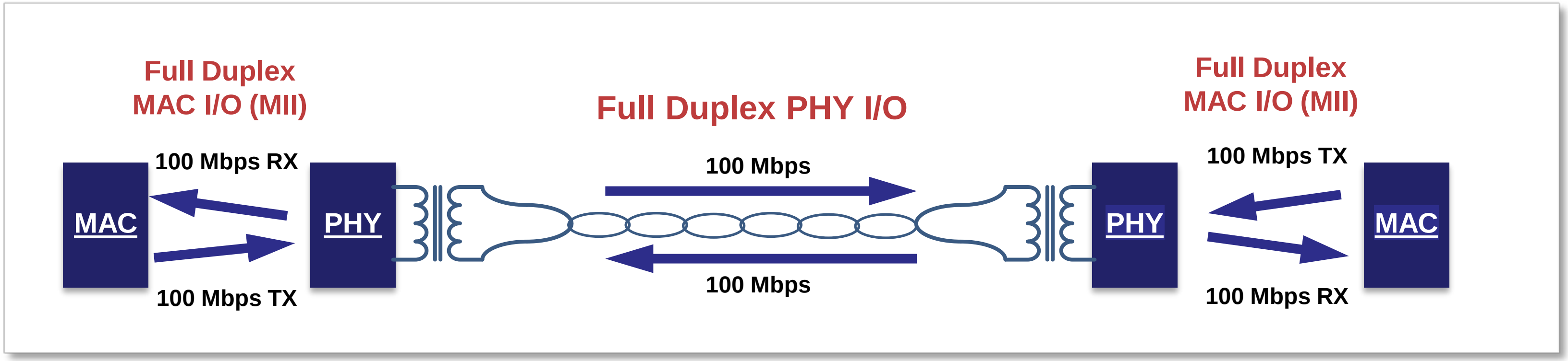
Technical Feasibility for 100Mb/s PHY

- Traditional (successful) BASE-T approach: baseband, Full Duplex
- Cables + connectors + magnetics have sufficient channel capacity
  - Bandwidth, attenuation, crosstalk, balance, noise
- Digital feasibility:
  - Advanced Communication Theory
  - Well known DSP techniques to achieve a power efficient solution
  - Advanced CMOS processing to achieve the target speed 100 Mb/s
- Analog Front Ends for High Speed Transceivers: (already available, mature technology)
  - Low power ADCs
  - Low power DACs
  - Low jitter PLLs

Objectives of OABR PHY

- Provide a PHY that supports full duplex operation at 100 Mb/s over one pair unshielded twisted pair (UTP) or better cable for at least 15m.
- Provide compatibility with the MII (IEEE 802.3 Clause 22) and IEEE 802.3 MAC operating at 100 Mb/s.
- Maintain a bit error ratio (BER) of less than or equal 10^-10 at the MAC interface (over a one pair UTP cabling)
- Support a start-up procedure which enables the time from power_on=FALSE to valid data to be less than 200ms.
- Support 100Mb/s operation in automotive and industrial environments (e.g., EMC, temperature).

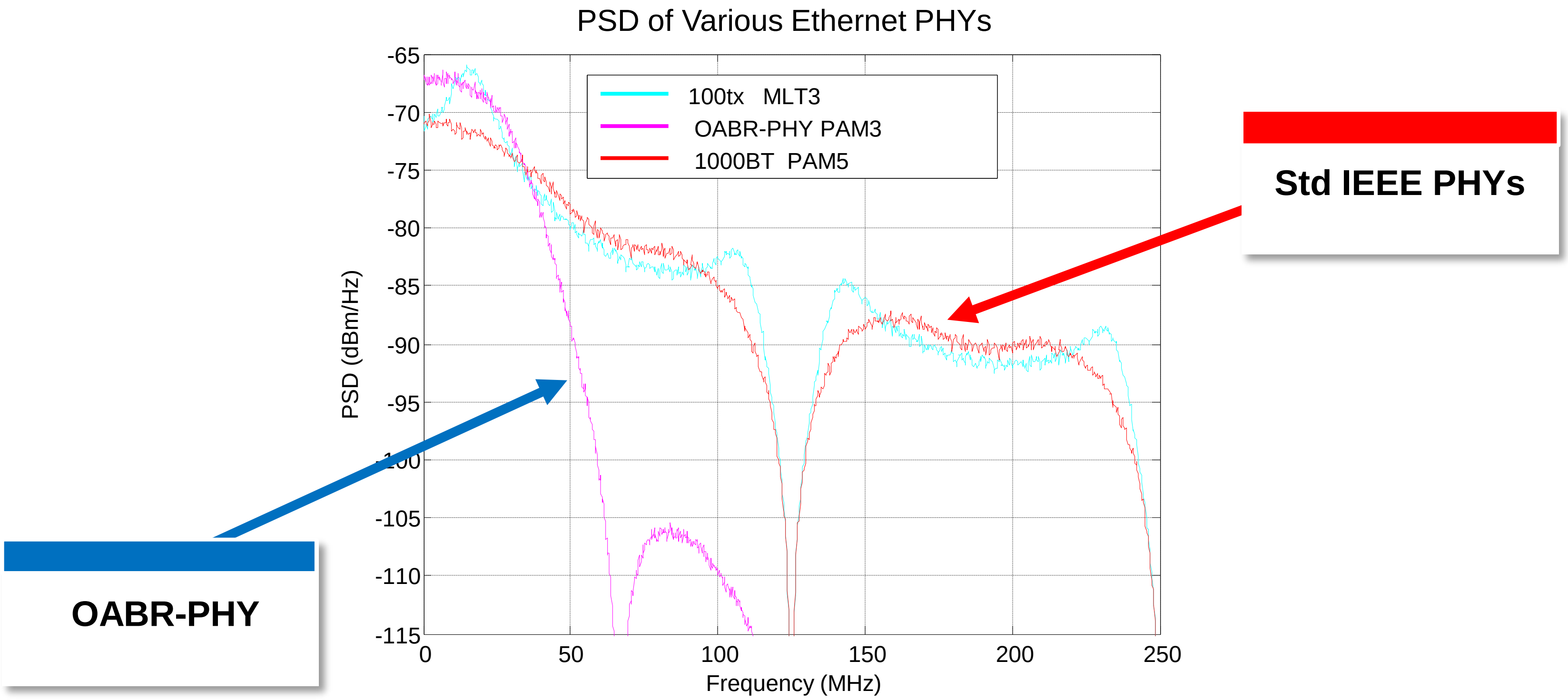
What is OABR PHY?



- Operates with bi-directional transmission over one-pair UTP
- Is adopted by One-Pair Ethernet Alliance (OPEN) SIG
- OABR Automotive PHY
  - Leverages technology already proven in IEEE standard BASE-T PHYs
  - Supports single pair Automotive Cabling
  - Has a shorter channel reach objective (15m over UTP channels)
  - Is optimized for Automotive EMC requirements
- Mitigating EMC Performance
  - TX-PSD shaping targets Automotive Emissions Masks
  - PAM-3 modulation for high noise immunity
  - DSP-based Receiver utilizing DFE & Echo Cancellation for FDX operation
- Maintains IEEE Standard MAC Interfaces
  - Directly supports higher layer Ethernet ecosystem

The Importance of BW Efficiency

- **100Mbps in 33.3MHz bandwidth over 1-pair UTP cabling**



- **Interference & Emissions increase with frequency**
- **Impairments degrade with frequency**
- **Lower emissions, improved immunity**

SYSTEM OVERVIEW

Parameter	Definition
Modulation	PAM3
Baud Rate	66.6Mbaud
Channel	15m UTP cabling & connectors
Mode of Operation	FDX w/Echo Cancellation
TX-PSD	Lower and Upper Masks
Signal Mapping	3bits-2 Ternary Symbols(3B2T)
Equalization	Receiver-based equalization
PHY synchronization	Loop timing
Start-up Time	< 200ms

OABR-PHY OVERVIEW

- BR-PHY includes
  - PCS (TX/RX)
  - PMA (TX/RX)
  - PHY CONTROL
  - LINK MONITOR
  - CLOCK RECOVERY

which are analogous to 802.3-2012 Clause-40 with differences for line coding & mapping, lower BW operation.

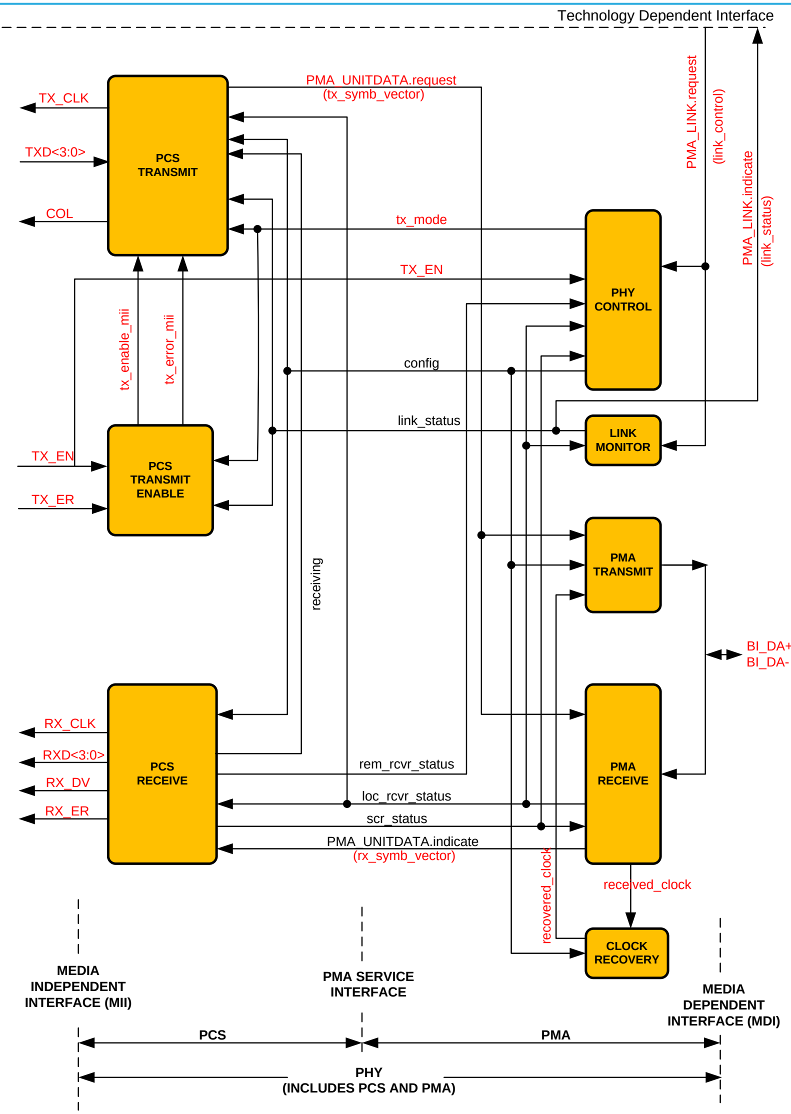


Figure 1-2 Functional Block Diagram, noting the differences from IEEE 802.3 Figure 40-3

BR-PCS

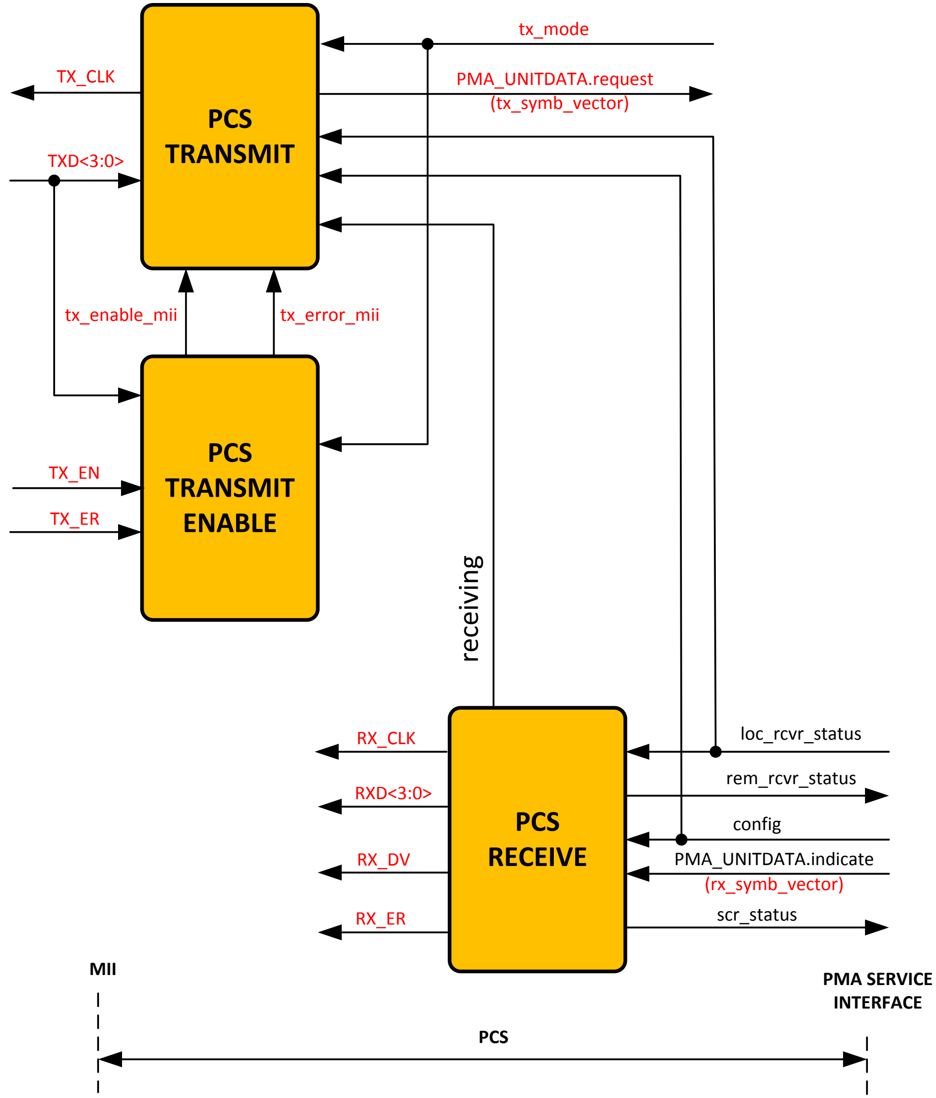


Figure 3-1: BR-PCS reference diagram, noting differences from IEEE 802.3-2012 Figure 40-5

Transmit Symbol Generation

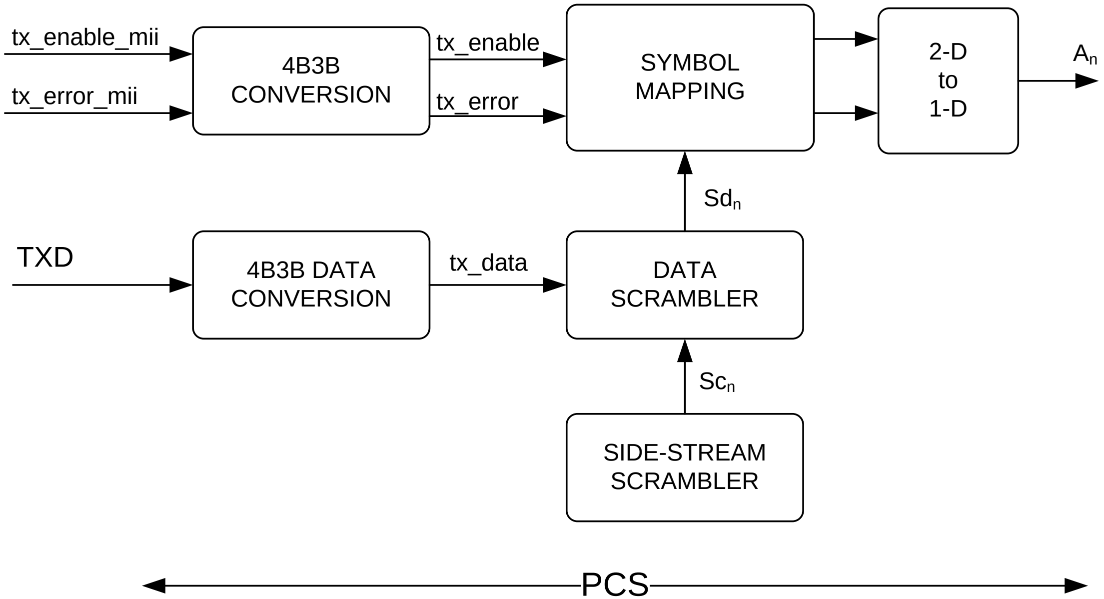


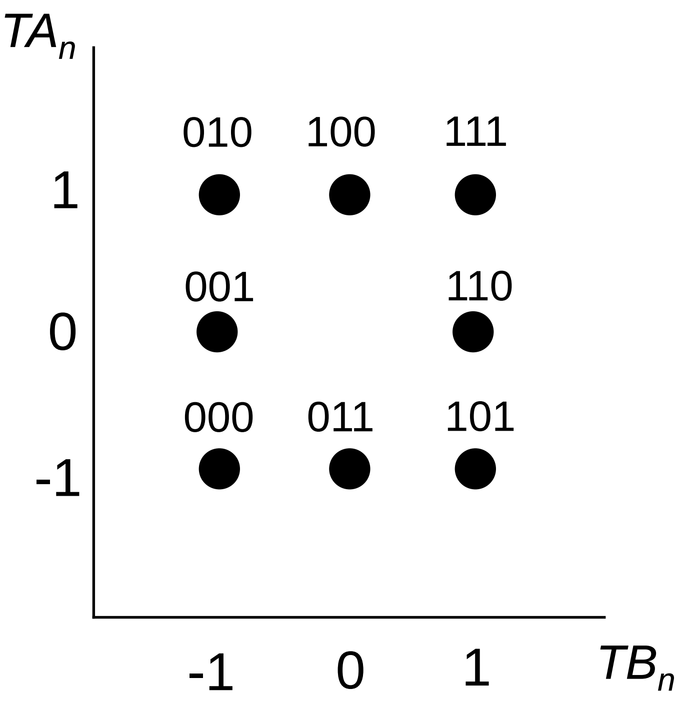
Figure 3-5: PCS Transmit Symbol Mapping

- 4bit-3bit (4B3B) Conversion (25Mhz domain → 33.3MHz domain)
- Scrambling
- Signal Mapping (3B2T)
- 2-D to 1-D Interleaving

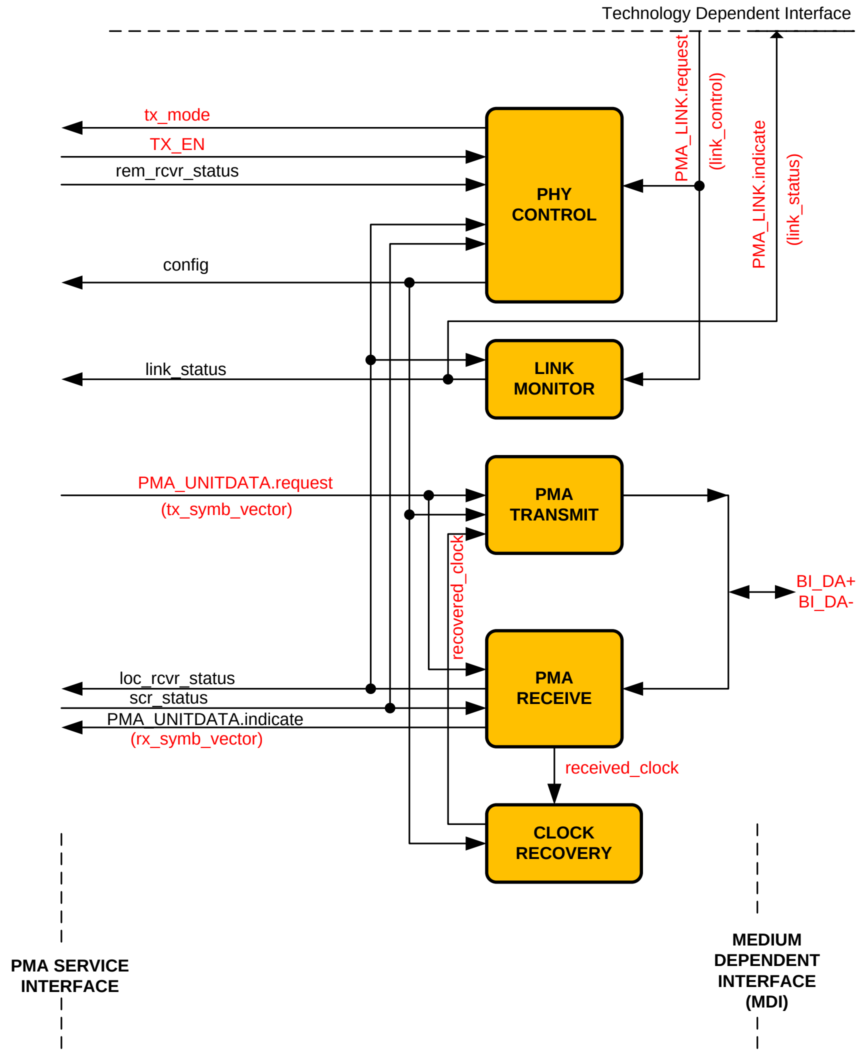
Signal Mapping

Table 3-7 :Data symbols when TXMODE=SEND_N

$Sd_{n[2:0]}$	Ternary A	Ternary B
000	-1	-1
001	-1	0
010	-1	1
011	0	-1
Used for SSD/ESD	**0**	**0**
100	0	1
101	1	-1
110	1	0
111	1	1



BR-PMA

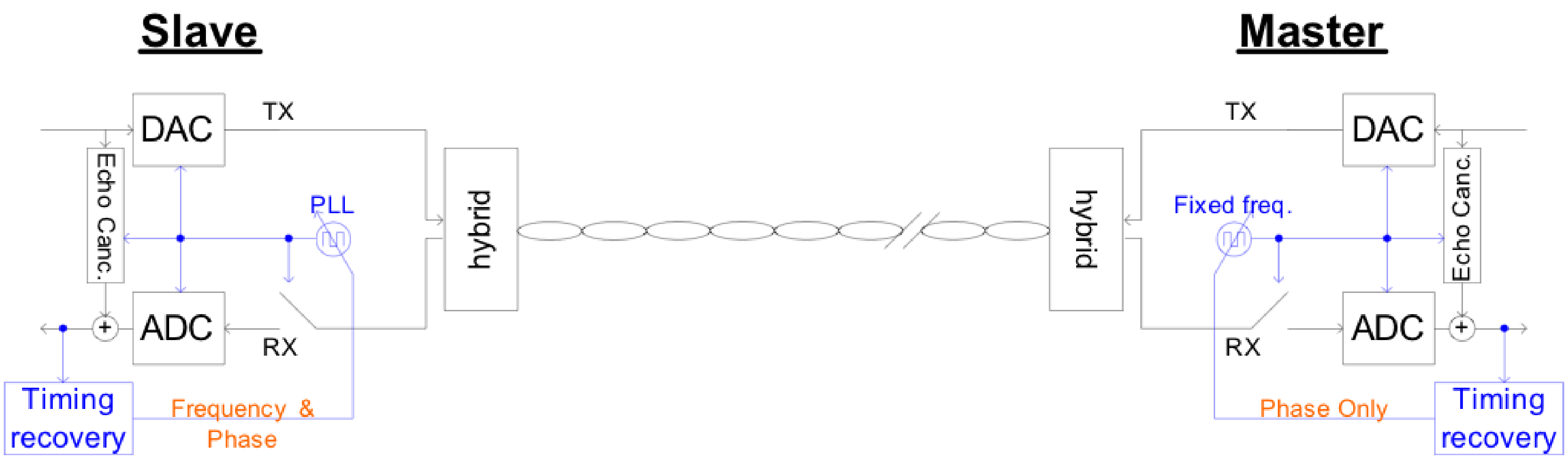


NOTE: The recovered_clock shown indicates delivery of the recovered clock back to PMA TRANSMIT for loop timing.

Figure 4-1: BR-PMA Differences from PMA Reference IEEE 802.3-2012 Figure 40-14

Synchronization: Loop Timing

- Echo cancellation requires the transmitter and receiver to be clocked from the same source



- Master side driven from a fixed frequency clock
- Slave side recovers clock from Master
  - Transmits with recovered clock

Start-up

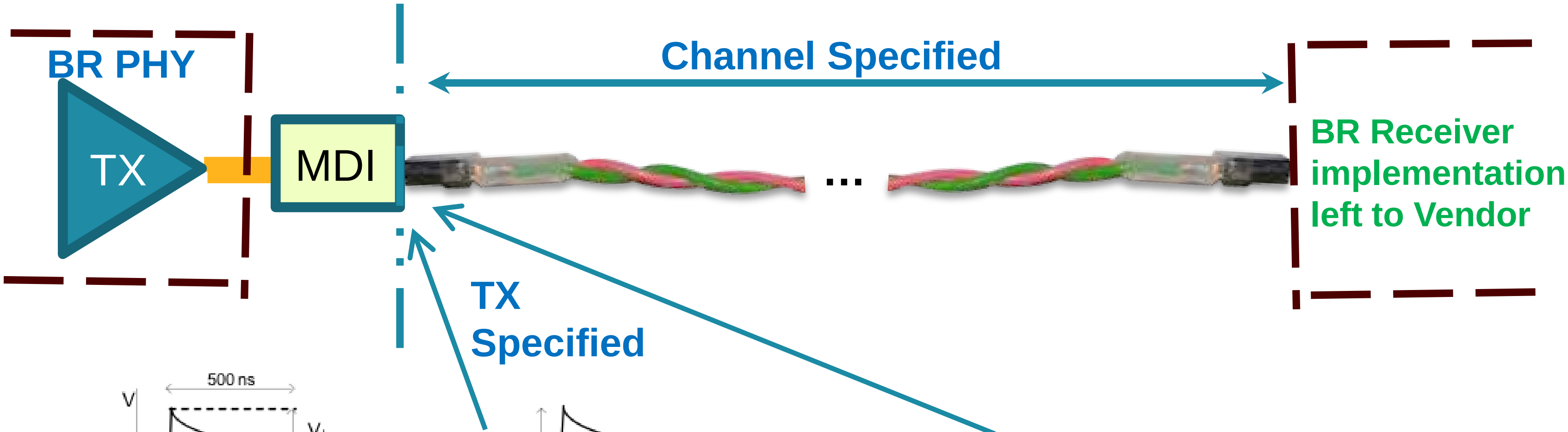
- A start-up procedure is required to bring both ends of the link into operational status
  - Timing recovery
  - Echo cancellation
  - Equalization
  - Scrambler Synchronization
  - Handshake via local and remote receiver status exchange
- Analogous to IEEE 802.3 Clause 40.4.2.4 “PHY Control”

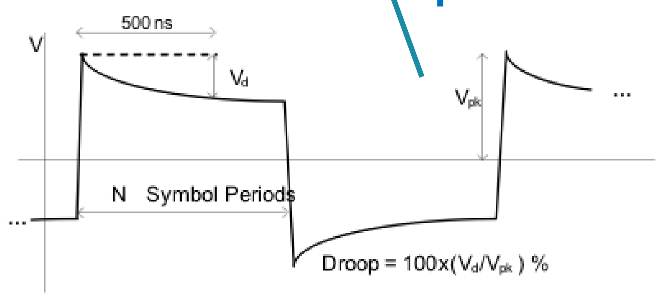
Master	**Transmit Idle** - Adapt Echo Canceller	**Transmit Idle** - Adapt Equalizer - Recover Scrambler Seq. - Adapt AGC	**Transmit Idle** - Refine adaptation	**Transmit data** - Refine adaptation
Slave	**Transmitter Silent** - Recover Clock & Scrambler - Adapt Equalizer - Adapt AGC	**Transmit Idle** - Adapt Echo Canceller - Adapt AGC	**Transmit Idle** - Recover Scrambler Seq. - Refine adaptation	**Transmit data** - Refine adaptation

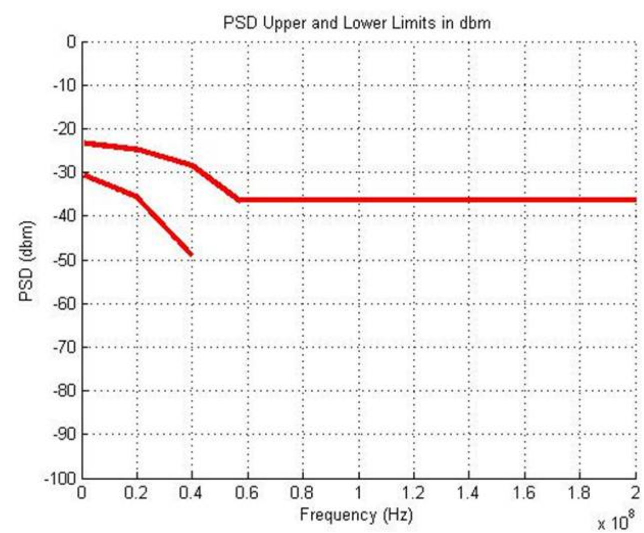
Other Requirements

- Delay constraints
  - Analogous to IEEE 802.3-2012 Clause 40.11
  - TX path delay (from MII input to the MDI) shall be less than 240ns
  - RX path delay (from MDI to MII output) shall be less than 780ns

Electrical Signal Specification





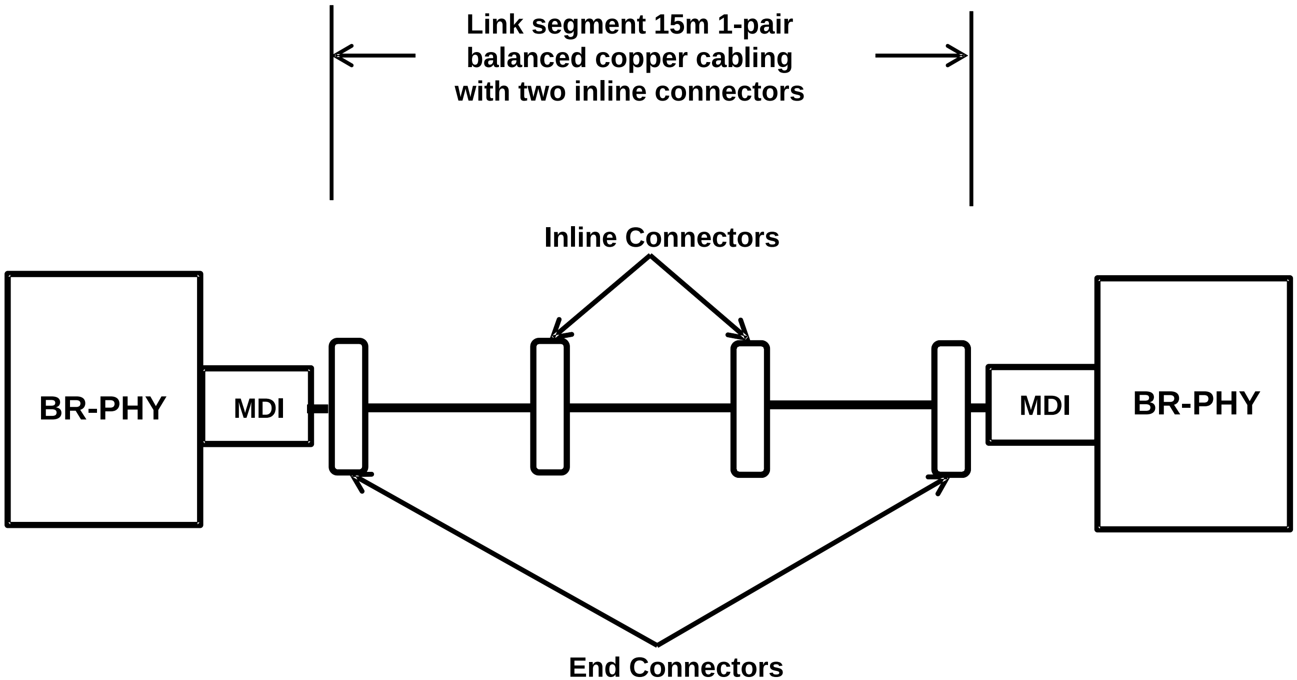


- **TX Electrical Specs:**
  - Time Domain Droop
  - Distortion
  - Power Spectral Density vs. freq.
  - Timing jitter
  - Return Loss

- For more details, please refer to:

  http://www.ieee802.org/3/1TPCESG/public/BroadR_Reach_Automotive_Spec_V3.0.pdf

Link Segment Definition



- Different UTP cables & connectors exist for automotive applications today
- Channel characteristics are defined for one-pair UTP cabling system
- End/inline connectors can be 2-pin or multi-pin depending on the application
- EMC properties of the channel are well-defined in order to ensure a robust operation under severe noise conditions or emission restrictions

Channel Definition & Impairments

- **PHYs must tolerate signal attenuation and noise in the channel**
  - Equalization/cancellation where possible
  - Sufficient SNR margin where not
- **Differential channel impairments from the [cable + connectors]**
  - Loss: signal attenuation and ISI after traversing the cable
    - Compensated by equalizer
  - Crosstalk: signal on one wire-pair coupling to another wire-pair (alien crosstalk for one wire-pair systems)
  - Echo (return loss): signal from local transmitter reflected back to local receiver
    - Cancelled by echo canceller
  - Interference: external signals coupling into cable
    - Primarily a balance issue (CM-DM conversion)
  - Background Noise: Thermal noise, electronic noise
    - Not a significant issue for this application

Channel Parameters

- **For a given 100Ω terminated segment over a specified range:**
  - Differential Insertion loss
  - Differential Characteristic Impedance
  - Differential Return Loss
  - Differential A-XTALK
  - CM-to-DM Conversion
- These parameters
  - Will apply to the entire channel (any segment of the cable, mated connectors, magnetics)

Channel Parameters (cntd.)

- UTP Cables (up to 15m)

Parameter		Limit line	
CI_diff	Z_{rf}	100 Ω +/- 10 %,	
IL	S_{dd21}	0.06 dB/m 0.16 dB/m 0.31 dB/m 0.45 dB/m	f = 1 MHz f = 10 MHz f = 33 MHz f = 66 MHz
RL	S_{dd11} , S_{dd22}	20.0 dB 20.0 dB 17.3 dB 14.6 dB	f = 1 MHz f = 10 MHz f = 33 MHz f = 66 MHz
TCL **ELTCTL**	(S_{cd11} , S_{cd22},S_{cd21}) (S_{cd21} , S_{cd12}-S_{dd12}, , S_{cd21}-S_{dd21})	46 dB 46 – 10*log10(f/66) dB	f = 1 - 66 MHz f = 66 - 200 MHz

Channel Parameters (cntd.)

- 2-pin Connectors

Parameter		Limit line	
CI_diff	Z_{rf}	100 Ω +/- 10 %,	
IL	S_{dd21}	0.025 dB 0.038 dB 0.050 dB 0.075 dB	f = 1 MHz f = 10 MHz f = 33 MHz f = 66 MHz
RL	S_{dd11} , S_{dd22}	30.0 dB 30.0 dB 26.8 dB 22.5 dB	f = 1 MHz f = 10 MHz f = 33 MHz f = 66 MHz
TCL ELTCTL	(S_{cd11} , S_{cd22},S_{cd21}) (S_{cd21} , S_{cd12}-S_{dd12}, , S_{cd21}-S_{dd21})	46 dB 46 – 10*log10(f/66) dB	f = 1 - 66 MHz f = 66 - 200 MHz

- Link Segment

Parameter		Limit line	
CI_diff	Z_{rf}	100 Ω +/- 10 %,	
IL	S_{dd21}	1.0 dB 2.6 dB 4.9 dB 7.2 dB	f = 1 MHz f = 10 MHz f = 33 MHz f = 66 MHz
RL	S_{dd11} , S_{dd22}	18 dB 18 – 10*log10(f/20) dB	f = 1 - 20 MHz f = 20 - 66 MHz
TCL ELTCTL	(S_{cd11} , S_{cd22},S_{cd21}) (S_{cd21} , S_{cd12}-S_{dd12}, , S_{cd21}-S_{dd21})	46 dB 46 – 10*log10(f/66) dB	f = 1 - 66 MHz f = 66 - 200 MHz

* Under discussion in Open Alliance

EMC Performance

- Robust emissions and immunity performance is essential (similar to 802.3bp. However, 100 Mb/s utilizes lower bandwidth which helps!)
- Eco-system (cables, connectors, magnetics) for OABR-PHY meeting the EMC requirements is available & shipping.
- 3-levels of "vigorous" EMC testing were conducted and passed:
  - IC-level testing (IEC62132-4 DPI & IEC61967-4 150Ohm emissions)
  - System-level testing (CISPR-25 Stripline and ISO11452-4 Bulk Current Injection)
  - In-car radiated emissions & immunity (custom limits based on OEM requirements)
- OABR-PHY EMC performance has been proven for in-car testing.

Conclusions

- OABR-PHY technology was developed for, and adapted by, Automotive Ethernet ecosystem in conjunction with automotive cabling, connectors, magnetics, test equipments, interoperability test suites and etc.
  - Eco-system was developed & available
  - PHY interoperability has been proven between different PHY vendors
  - OABR is qualified and deployed for production vehicles today
- OABR-PHY meets key “draft” objectives of 1TPCE
  - Preserve the IEEE 802.3/Ethernet frame format at the MAC client service interface
  - Preserve minimum and maximum frame size of the current IEEE 802.3 standard
  - Support full duplex operation only
  - Support a speed of 100 Mbit/s at the MAC/PLS service interface
  - Maintain a bit error ratio (BER) of less than or equal to 10^-10 at the MAC/PLS service interface
  - Support 100 Mbit/s operation in automotive & industrial environments (e.g., EMC, temperature)
  - Define startup procedure which enables from time from power_on=FALSE to valid data to be less than 100ms/200ms (w/o speed discovery)
- For more details, please refer to:

  http://www.ieee802.org/3/1TPCESG/public/BroadR_Reach_Automotive_Spec_V3.0.pdf

Thank you for you attention!

Questions?