Baseline proposals for electrical interfaces at 200 Gb/s per lane

Adee Ran, Cisco
Tobey Li, Mediatek
Adam Healey, Broadcom
Mike Dudek, Marvell
Howard Heck, Intel
Matt Brown, Alphawave
Chris DiMinico, PHY-SI/SenTekse
Kent Lusted, Intel

Preface

- Discussions and analysis of electrical interfaces in P802.3dj made significant progress over the recent months
  - A lot of innovative ideas were brought up
  - Many decisions have been made (see KeyMotions_3dj_231128)
- A baseline for the AUI-C2M annex has been presented (ran_3dj_01a_2309)
  - Showed annex structure, and listed decisions made, open topics and TBDs
  - No motion to adopt it was made yet
  - Similar “structure” baselines for C2C, CR, and KR have not been presented
- To make progress the 802.3dj project, it is preferable to have a draft that we can comment on!
  - It would show the agreed-upon content and help us focus on the gaps.
  - Drafts for task force review need not be complete, and can include many TBDs.
  - Draw from existing clause contents where possible. Changes to structure, headings, etc. can be discussed after a draft is available.

Goals of this presentation

- Present a proposed structure of clauses for KR and CR PMDs and annexes for AUI-C2C and AUI-C2M
- Enable task force members to see a full picture of where we are
  - Decisions already made and how they are reflected in standard text
  - Structure and content we can use from past clauses
  - TBDs
  - Major points that still require decisions (and contributions)
- Enable the editorial team to start working on text (informal Draft 0.1)
- Drive towards adoption of baseline proposals for creation of Draft 1.0

Notation

- Areas that need decisions and TBD values are marked in magenta in this presentation.
  - Areas that require major decisions are marked with ★
  - These do not preclude us from adopting baseline proposals. If necessary, several options can be listed in the initial drafts.
- Areas based on existing clauses without substantive changes are marked in blue.
- Magenta and blue notations are not intended to be used in drafts.
- As we do not have assigned numbers for new clauses and annexes yet, the labels C1, C2 are used for clauses, and A1, A2 are used for annexes.

CR PMD clause

200GBASE-CR1, 400GBASE-CR2, 800GBASE-CR4, 1.6TBASE-CR8

Outline

- CR PMDs will be specified in a single clause. It is labeled C1 in this presentation.
- The proposed structure is based on existing CR PMD Clause 162 (IEEE Std 802.3ck-2022).
- The major subclauses are:
    1. Overview, including a general error rate specification
    2. Conventions
    3. Service interface
    4. PCS requirements for Auto-Negotiation (AN) service interface
    5. Delay constraints
    6. Skew constraints
    7. MDIO function mapping
    8. Functional specifications
    9. PMD electrical characteristics
    10. Channel characteristics
    11. Cable assembly characteristics
    12. MDI specifications
    13. Environmental specifications
    14. PICS
- Details on some of the subclauses are included in the following slides.

C1 Subclauses: the easy parts

- C1.1 Overview
  - Introductory text based on 162.1 with addition of description of the host types and cable types (motion #11 in motions_3cwdfdj_2311)
  - Tables of Physical layer clauses associated with the PMDs.
  - Architectural diagram (as in Figure 162-1).
- C1.2 Conventions
  - As in 162.2, n denotes number of lanes, i takes values 0 to n-1, “PMD” refers to any of the 4 defined PMDs.
- C1.3 Service interface
  - PMD:IS_UNITDATA_i.request and PMD:IS_UNITDATA_i.indication, either as PAM4 symbols or as sampled analog values.
  - PMD:IS_SIGNAL.indication as in clause 162.
- C1.4 PCS requirements for Auto-Negotiation (AN) service interface - as in clause 162
- C1.5 Delay constraints, C1.6 Skew constraints – as in Clause 162, or TBD
- C1.7 MDIO function mapping, C1.8 Functional specifications – as in clause 162
- C1.12 MDI specifications: TBD (pending adoption of specific connectors)
- C1.13 environmental: boilerplate.

C1 Subclauses: electrical characteristics

- C1.9: Structure and general content based on 162.9 with addition of host classes (tracy_3dj_01a_2311 slide 12) which have different specifications
- Transmitter specifications at TP2:
  - Signal observation filter (Bessel-Thomson filter) bandwidth TBD
  - Signaling rate:
    - For 800GBASE-CR4 and 1.6TBASE-CR8, 106.25 GBd ± 50 ppm
    - For 200GBASE-CR1 and 400GBASE-CR2 PMDs in the same package as the PCS sublayer, 106.25 GBd ± 50 ppm; otherwise, derived from the adjacent PMA
  - ERL – value TBD
  - RLcc (min) and RLdc (min) – equations TBD
  - Linear fit pulse peak ratio R_{peak} – per host class, values TBD
- Receiver specifications at TP3:
  - Signaling rate: For 800GBASE-CR4 and 1.6TBASE-CR8, 106.25 GBd ± 50 ppm; for 200GBASE-CR1 and 400GBASE-CR2, 106.25 GBd ± 100 ppm
  - ERL – value TBD
  - RLcd (min) – equation TBD
  - Interference tolerance test channel and cable assembly losses – all per host class, values TBD
  - Test signal observation filter (Bessel-Thomson filter) bandwidth TBD
- For other parameters, e.g. output jitter, jitter tolerance, etc., use values from clause 162 (scaled to signaling rate where appropriate)
  - If there are concerns about specific parameters, they can be changed to TBD

C1 Subclauses: channel and cable assembly characteristics

- C1.10 Channel characteristics: new content describing the concept of host types and cable types and their possible combinations (tracy_3dj_01a_2311 slide 12)
- C1.11 Cable assembly characteristics:
  - Structure based on 162.11 but with 16 cable assembly types: 4 loss classes (CA-A, CA-B, CA-C, and CA-D)* × 4 lane widths (1,2, 4, and 8)
    - 162.11.2 will include an expanded loss table, with min/max loss equations and figures TBD
  - ERL, RLcd, ILcd, RLcc values/equations TBD
  - COM parameter values: see next slide.

* The cable loss classes listed using placeholder nomenclature per motion #11

C1 Subclauses: COM parameter values (C1.11.7)

- Signaling rate: 106.25 GBd
- Host device, package, and PCB parameters for signal/crosstalk path calculations:
  - New device and package models adopted only for KR/C2C
  - Division of the host loss budget between the components requires a separate proposal
  - For now, all these parameters are TBD
- COM reference receiver equalizer
  - CTLE parameters TBD (or scale existing parameters to the new signaling rate)
  - DER0 is 2e-4 (motion #12 in motions_3cwdfdj_2311)
  - Eta0, Tr are TBD
  - FFE + 1-tap DFE has not been formally adopted but seems to be in consensus
    - Assuming we adopt FFE+DFE: tap setting algorithm, sampling point selection, and output pulse response calculation method are required (some existing presentations can be used); left as TBD until adopted
    - Length, fixes vs. floating taps (number and range), coefficient limits TBD
  - MLSE is considered necessary for CR receivers, but has not been adopted yet
    - If detailed proposal for MLSE in the COM reference receiver is adopted, we can consider keeping a minimum COM (implementation margin) of 3 dB.
    - Alternatively, the minimum COM can be reduced by the expected coding gain of the MLSE.
    - It is suggested that minimum COM is listed as TBD.
- COM with FFE+DFE may become a new annex instead of amendment of 93A. Such annex is beyond the scope of this presentation.

KR PMD clause

200GBASE-KR1, 400GBASE-KR2, 800GBASE-KR4, 1.6TBASE-KR8

Outline

- KR PMDs will be specified in a single clause. It is labeled C2 in this presentation.
- The proposed structure is based on existing KR PMD Clause 163 (IEEE Std 802.3ck-2022).
- The major subclauses are:
    1. Overview, including a general error rate specification
    2. Conventions
    3. Service interface
    4. PCS requirements for Auto-Negotiation (AN) service interface
    5. Delay constraints
    6. Skew constraints
    7. MDIO function mapping
    8. Functional specifications
    9. PMD electrical characteristics
    10. Channel characteristics
    11. MDI specifications
    12. Environmental specifications
    13. PICS
- Details on some of the subclauses are included in the following slides.

C2 Subclauses: the easy parts

- C2.1 Overview
  - Introductory text based on 163.1 but with addition description of the two package classes.
  - Tables of Physical layer clauses associated with the PMDs.
  - Architectural diagram (as in Figure 163-1).
- C2.2 Conventions
  - As in 163.2, n denotes number of lanes, i takes values 0 to n-1, “PMD” refers to any of the 4 defined PMDs.
- C2.3 Service interface
  - PMD:IS_UNITDATA_i.request and PMD:IS_UNITDATA_i.indication, either as PAM4 symbols or as sampled analog values.
  - PMD:IS_SIGNAL.indication as in clause 163.
- C2.4 PCS requirements for Auto-Negotiation (AN) service interface - as in clause 163
- C2.5 Delay constraints, C2.6 Skew constraints – as in Clause 163, or TBD
- C2.7 MDIO function mapping, C2.8 Functional specifications – as in clause 163
- C2.12 MDI specifications – as in clause 163
- C2.13 environmental: boilerplate.

C2 Subclauses: electrical characteristics

- C2.9: Structure and general content based on 163.9, including TP0v/TP5v methodology (we may create a new methodology annex this project)
- Transmitter specifications at TP0v:
  - Signal observation (Bessel-Thomson filter) bandwidth TBD
  - Signaling rate:
    - For 800GBASE-KR4 and 1.6TBASE-KR8, 106.25 GBd ± 50 ppm
    - For 200GBASE-KR1 and 400GBASE-KR2 PMDs in the same package as the PCS sublayer, 106.25 GBd ± 50 ppm; otherwise, derived from the adjacent PMA
  - Reference values ($ERL^{(ref)}$, $v_f^{(ref)}$, $R_{peak}^{(ref)}$) are calculated based on the Tx package class that the device adheres to
- Receiver specifications at TP5v:
  - Signaling rate: For 800GBASE-CR4 and 1.6TBASE-CR8, 106.25 GBd ± 50 ppm; for 200GBASE-CR1 and 400GBASE-CR2, 106.25 GBd ± 100 ppm
  - For dERL, the reference value $ERL^{(ref)}$ is calculated based on the Rx package class that the device adheres to
  - RLcd (min) – equation TBD
  - Receiver test parameters:
    - Test signal calibration to the channel minimum COM (TBD) with the new parameters of this clause
    - Test signal observation filter (Bessel-Thomson filter) bandwidth TBD
    - Test channel ILdd at 53.125 GHz instead of 26.5625, separate for each Rx package class, values TBD
    - RSS_DFE4: remove or replace by another metric TBD (not adequate for FFE-based reference receiver)
- For other parameters, e.g. output jitter, jitter tolerance, etc., use values from clause 163 (scaled to signaling rate where appropriate)
  - If there are concerns about specific parameters, they can be changed to TBD

C2 Subclauses: channel characteristics

- C2.10 Channel characteristics: new content describing the concept of package classes and how they affect channel compliance (motion #9 in motions_3cwdfdj_2311, lusted_3dj_02_2311 slide 7)
  - Maximum ILdd at 53.125 GHz (recommended) – different per combination of package classes; values, equations and figures TBD
  - ERL, RLcd, ILcd, ILdc, values/equations TBD
  - COM parameter values: see next slide.

C2 Subclauses: COM parameter values (C2.10.7)

- Signaling rate: 106.25 GBd
- Host device and package parameters for signal/crosstalk path calculations:
  - New device model (motion #1 in motions_3dfdj_230720, lim_3dj_01a_2307 slides 6-7), parameters TBD (not included in the motion)
  - Two package models and parameter values (motion #10 in motions_3cwdfdj_2311, lim_3dj_01a_2311 slides 8-9), trace lengths and test cases TBD (not included in the motion)
  - Package class on each end of the channel is selected as part of the invocation of the COM procedure.
- COM reference receiver equalizer
  - Same as CR (see C1)
- COM with FFE+DFE may become a new annex instead of amendment of 93A. Such annex is beyond the scope of this presentation.

AUI-C2C

200GAUI-1 C2C, 400GAUI-2 C2C, 800GAUI-4 C2C, 1.6TAUI-8 C2C

Outline

- AUI-C2C will be specified in an annex that multiple PHY/PMD clauses can refer to. It is labeled Annex A1 in this presentation.
- The proposed structure is based on existing AUI-C2C annex 120F.
- The major subclauses are:
  1. Overview, including a general error rate specification
  2. Compliance point definitions
  3. Electrical characteristics
  4. Channel characteristics
  5. PICS
- Details on each subclause are included in the following slides.

A1.1 Overview

- General introductory text based on 120F.1, with the addition of Tx/Rx package classes, and interconnect length TBD
- Architectural diagram (as in Figure 120F-1), including usage within a PHY and within an xGMII Extender
- Composition of a C2C link, with a reference to the channel model subclause (A1.4)
- Nominal signaling rate 106.25 GBd, PAM4 modulation
- Transmitter output setting adjustment (aka link training) and communication method (in-band or out-of-band)
- Error ratio specifications
  - Based on a BER allocation assuming random uncorrelated error events (see ran_3dj_01_230817)
    - For AUI-C2C within a PHY: event ratio <5e-6 (based on DER0=0.67e-5; motions #1 and #2 in motions_3dj_230921)*
    - For AUI-C2C within an xGMII Extender: event ratio <TBD (options: 1e-4 / 5e-5)
  - Allowance of additional errors from other segments for each case
  - Measurement method and limits TBD (refer to a separate annex that will explain BER interpretations and test methodology).

* The adopted value of DER0 is for the case of AUI-C2C with AUI-C2M within a PHY. Values for other cases have not been proposed

A1.2 Compliance points

- Refer to the compliance points definitions in C2 (TP0v/TP5v methodology)
- Reference impedance: 100 Ohm differential, 25 Ohm common

A1 Subclauses: electrical characteristics

- A1.3: Structure and general content based on 120F.3 (and similar to C2)
- Transmitter specifications at TP0v:
  - Signal observation (Bessel-Thomson filter) bandwidth TBD
  - Signaling rate: 106.25 GBd ±50 ppm (for 400GAUI-2 and 200GAUI-1, applies only for a PMA in the same package as the PCS)
  - Reference values ($ERL^{(ref)}$, $v_f^{(ref)}$, $R_{peak}^{(ref)}$) are calculated based on the Tx package class that the device adheres to
- Receiver specifications at TP5v:
  - Signaling rate: 106.25 GBd (±100 ppm for 400GAUI-2 and 200GAUI-1, ±50 PPM otherwise)
  - For dERL, the reference value $ERL^{(ref)}$ is calculated based on the Rx package class that the device adheres to
  - RLcd (min) – equation TBD
  - Receiver test parameters: generally, as in C2, except for:
    - Test signal calibration with the COM parameters of this annex
    - Different test channel ILdd at 53.125 GHz, values TBD
- For other parameters, e.g. output jitter, jitter tolerance, etc., use values from Annex 120F (scaled to signaling rate where appropriate)
  - If there are concerns about specific parameters, they can be changed to TBD

A1 Subclauses: Channel characteristics

- A1.4: Based on the KR channel characteristics (C2) but with a separate table of parameters
  - Different DER_0 value – 0.67e-5 within a PHY with AUI-C2M, other cases TBD
  - Other parameters are suggested to be the same as those for KR in C2 (these may change later).

AUI-C2M

200GAUI-1 C2M, 400GAUI-2 C2M, 800GAUI-4 C2M, 1.6TAUI-8 C2M

Outline

- AUI-C2M will be specified in an annex that multiple PHY/PMD clauses can refer to. It is labeled Annex A2 in this presentation.
- The proposed structure is based on existing AUI-C2M annexes, such as 120G, with some modifications.
- The major subclauses are:
  1. Overview, including a general error rate specification
  2. Channel model (including recommended insertion loss)
  3. Compliance point definitions
  4. Electrical characteristics: host/module, output/input
  5. Measurement methodology
  6. PICS
- Details on each subclause are included in the following slides.

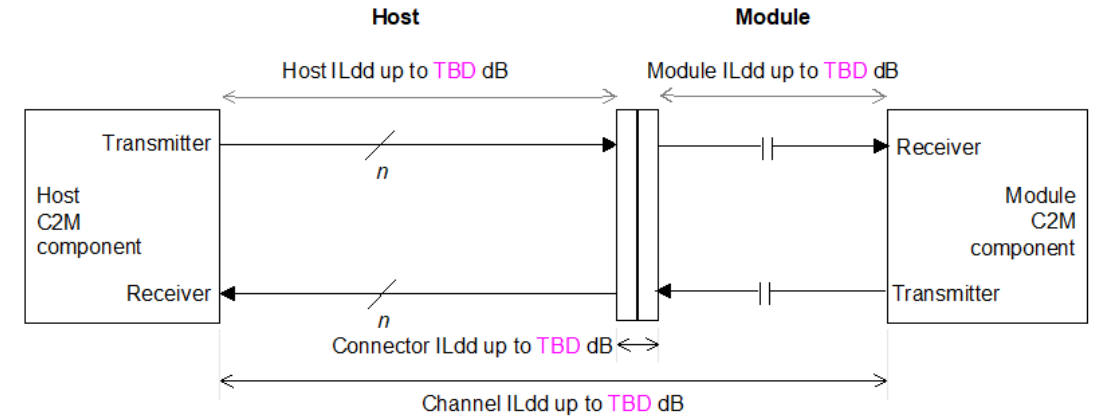
A2.1 Overview

- General introductory text based on 120G.1
- Architectural diagram (as in Figure 120G-1), including usage within a PHY and within an xGMII Extender
- Composition of a C2M link, with a reference to the channel model subclause (A2.2)
- Nominal signaling rate 106.25 GBd, PAM4 modulation
- Output specification:
  - Adjustable output equalization and differential swing, with method TBD
  - Or – a small number of fixed settings (as in Annex 120G)
- Error rate specifications
  - Based on BER allocation assuming random uncorrelated error events (see ran_3dj_01_230817)
    - For AUI-C2M within a PHY: event ratio <1.5e-5 (based on DER0=2e-5; motions #1 and #2 in motions_3dj_230921)
    - For AUI-C2M within an xGMII Extender: event ratio <TBD (options: 1e-4 / 2e-4)
  - Measurement method and limits TBD (refer to a separate annex that would explain BER interpretations and test methodology).

This decision has major implications on methodology

A2.2 Channel model

- Channel model figure with all losses TBD
  - Add text or graphics to clarify that host and module losses in the figure include packages



NOTE—The number of lanes *n* is equal to 1 for 200GAUI-1, 2 for 400GAUI-2, 4 for 800GAUI-4, and 8 for 1.6TAUI-8.
ILdd values are at 53.125 GHz.

Figure 999X–99—Channel model for AUI-C2M

- Channel insertion loss (recommended) TBD
  - Text, equation and figure based on 120G.4
- COM reference model (new) TBD
  - Includes reference transmitter and receiver for assumed capabilities (Tx FFE, Rx FFE+1-tap DFE, MLSE?)
  - Same as those used for normative input/output requirements that include reference Tx/Rx
  - Channel characterization using COM is informative

A2.3 Compliance point definitions

- Similar to 120G.2
- Reference to channel model in A2.2
- HCB/MCB characteristics (similar to 120G.5.4)
  - Refer to another annex with detailed HCB/MCB/MTF specifications (modeled after Annex 162B) – assuming the same test fixtures are used
  - Content of that annex has not been adopted – will be TBD

A2.4 Electrical characteristics: host/module, output/input

- Host and Module output:
  - Based on specifications in 120G, with the following exceptions:
    - Signaling rate value 106.25 GBd ± 50 ppm (for 400GAUI-2 and 200GAUI-1, ± 50 ppm applies only for a PMA in the same package as the PCS)
    - Transition time (min) value TBD
    - Steady-state voltage (max) defined with equalization off, value TBD
    - VEC and EH possibly replaced by output parameters for CR PMD (see "Measurement methodology")
    - ERL TBD
  - Details, equations, figures
- Host and Module input:
  - Based on specifications in 120G, with the following exceptions:
    - Signaling rate value 106.25 GBd
      - ± 50 ppm for 800GAUI-4 and 1.6TAUI-8
      - ± 100 ppm for 400GAUI-2 and 200GAUI-1
    - Stressed input tolerance
      - Calibration procedure and parameters TBD depending on to adjustable equalization or fixed settings
    - ERL TBD
  - Details, equations, figures

A2.5 Measurement methodology

- Major decision to be made is whether output setting (equalization, swing, etc.) is adjustable (aka link training) or fixed.
- For output specifications:
  - **A. If we assume the output setting is fixed** – we could continue using the EH and VEC methodology (as in Annex 120G)
  - **B. If we specify adjustable output equalization**, the EH/VEC methodology is inadequate (these characteristics will vary per output setting). Instead, we should specify the set of parameters that are used in CR/KR/C2C.
- For input specifications, method of calibrating stressed signal will be based on the output specification.
  - If output setting is negotiated, the DUT will be allowed to select it (as in CR/KR/C2C).
- If the methodology is common to all other interfaces, it will be placed in a dedicated annex that will be referenced.

Summary of major decisions required

- CR, KR, C2C COM reference equalizer: DFE, or FFE + 1-tap DFE? other?
- COM model for C2M?
- MLSE in COM reference receiver, or reduction in minimum COM? other?
  - KR/CR only, or also AUIs?
- AUI-C2M – adjustable equalization or small number of fixed settings?
  - Big effect on host and module output and input methodology
  - Related question: in-band or out-of-band training over AUIs?
- BER measurement method