Baseline Proposal for In-band training functions for 200 Gb/s per lane Electrical Interfaces

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Introduction

- Link Training (LT) continues to be a key tool to maximize electrical SERDES performance
- LT in use since 10G/lane rates for backplane and copper cables
  - LT on AUI C2C starting at 50G/lane
- Many contributions on electrical link training, including but not limited to:
  - lusted_3dj_02a_2303
  - ghiasi_3dj_01_230116
  - mehta_3dj_elec_01a_230831
  - ran_3dj_elec_01a_240104
  - Straw Poll from 4 January 2024 Electrical ad hoc showed support
- We are not discussing the "optical link training" topic

Agenda

- Brief description of the PMD control function defined in clause 136 (with additional updates in clause 162)
- Lay out the benefit of in-band training on electrical interfaces
- Propose adopting the Cl 162 PMD control function as the basis of the baseline for backplane and copper cable PMDs
  - All the pieces are there. Update as needed in D1.x
- Propose defining an in-band PMA training function as the basis of the baseline for electrical interfaces at 200 Gb/s per lane

Benefits of in-band training

- Enables optimization of joint performance of the transmitter, receiver, and channel.
- Allows a wide range of receiver implementations.
- Provides well-defined startup process and conditions for detection of a valid signal.
- Enables decentralized optimization of SerDes without requiring pervasive management
  - Providing shorter power-up time.
  - Simplifying software development and system integration.
- An established method is available (clause 136 PMD control)
  - The training frame structure (Figure 136-3) can be re-used.

PMD Control Function Usage

- The PMD control function is currently specified for use with most of the backplane and passive copper cable PHYs (e.g., 50GBASE-CR, 800GBASE-KR8, etc.)
  - P802.3dj should follow the same approach for these types of PHYs
- Some AUI C2C (e.g. Annex 120D, Annex 120F, etc.) provide a method to configure by management a transmit equalizer using a set of control and status variables based on the PMD Control Function
  - No training frames are used
  - P802.3dj could follow the same approach for these types of electrical interfaces
- Not used (to date) in IEEE on AUI C2M interfaces

Elements of the Cl 136 PMD Control Function

- Exchange training frames consisting of
  - Marker, used for alignment
  - Message portion – control and status field, using Differential Manchester Encoding (DME)
  - Training pattern
- Asynchronous request/acknowledge messaging
- “Link-up” process defined by state diagrams

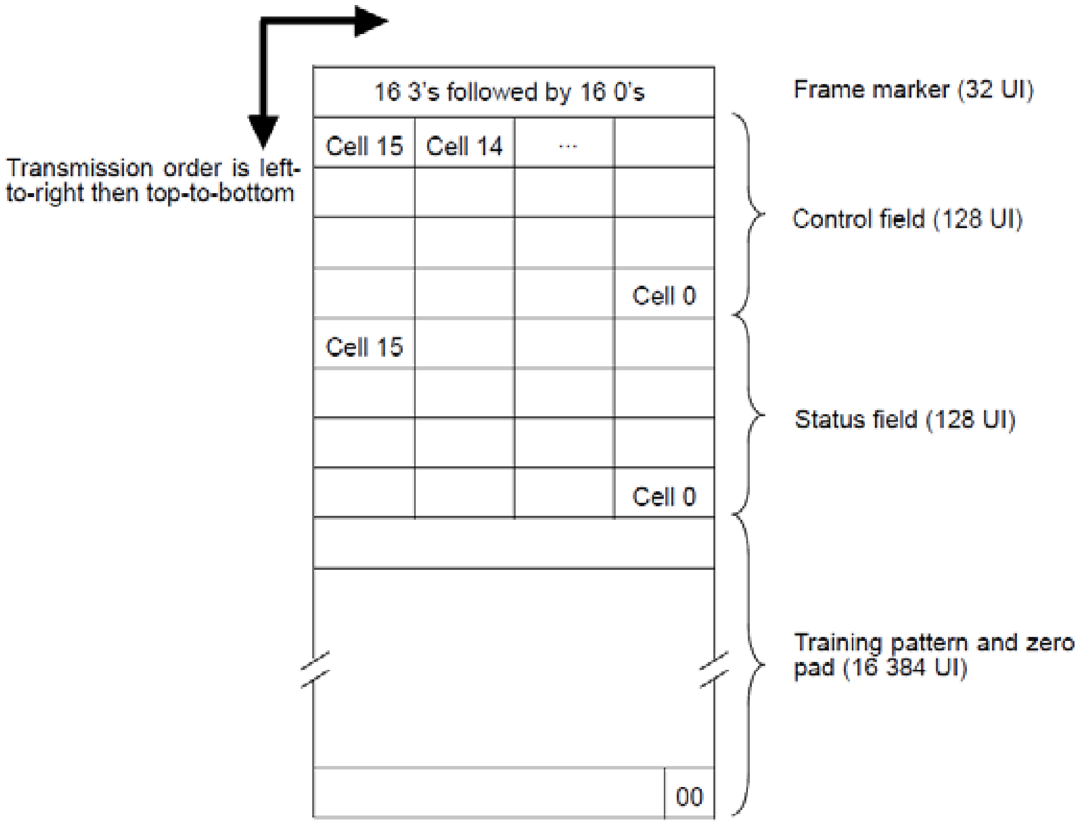

Figure 136–3—Training frame structure

Control and status fields (Clause 162, 802.3ck)

Table 162–9—Control field structure

Bit(s)	Name	Description
15:14	Reserved	Transmit as 0, ignore on receipt
13:11	Initial condition request	13 12 11 1 1 1 = Reserved 1 0 1 = Reserved 0 1 1 = Preset 5 0 0 1 = Preset 4 1 1 0 = Preset 3 1 0 0 = Preset 2 0 1 0 = Preset 1 0 0 0 = Individual coefficient control
10	Reserved	Transmit as 0, ignore on receipt
9:8	Modulation and precoding request	9 8 1 1 = PAM4 with precoding 1 0 = PAM4 0 1 = Reserved 0 0 = PAM2
7:5	Reserved	Transmit as 0, ignore on receipt
4:2	Coefficient select	4 3 2 1 0 0 = Reserved 1 0 1 = $c(-3)$ 1 1 0 = $c(-2)$ 1 1 1 = $c(-1)$ 0 0 0 = $c(0)$ 0 0 1 = $c(1)$ 0 1 x = Reserved
1:0	Coefficient request	1 0 1 1 = No equalization 1 0 = Decrement 0 1 = Increment 0 0 = Hold

Table 162–10—Status field structure

Bit(s)	Name	Description
15	Receiver ready	1 =Training is complete and the receiver is ready for data 0 =Request for training to continue
14:12	Reserved	Transmit as 0, ignore on receipt
11:10	Modulation and precoding status	11 10 1 1 = PAM4 with precoding 1 0 = PAM4 0 1 = Reserved 0 0 = PAM2
9	Receiver frame lock	1 = Frame boundaries identified 0 = Frame boundaries not identified
8	Initial condition status	1 = Updated 0 = Not updated
7	Parity	Even parity bit
6	Reserved	Transmit as 0, ignore on receipt
5:3	Coefficient select echo	5 4 3 1 0 1 = $c(-3)$ 1 1 0 = $c(-2)$ 1 1 1 = $c(-1)$ 0 0 0 = $c(0)$ 0 0 1 = $c(1)$
2:0	Coefficient status	2 1 0 1 1 1 = Reserved 1 1 0 = Coefficient at limit and equalization limit 1 0 1 = Reserved 1 0 0 = Equalization limit 0 1 1 = Coefficient not supported 0 1 0 = Coefficient at limit 0 0 1 = Updated 0 0 0 = Not updated

Clause 136 state diagrams

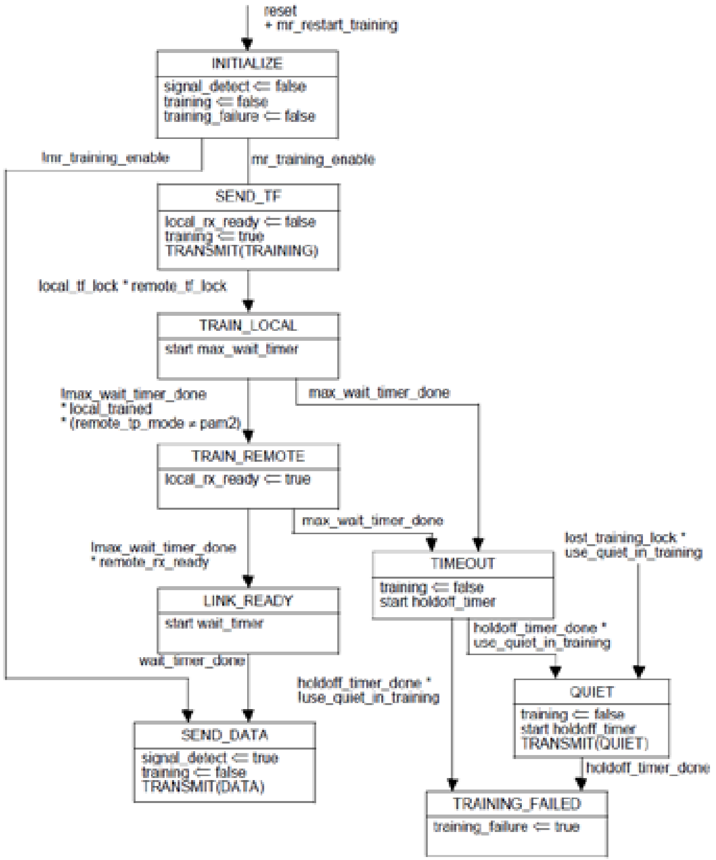

Figure 136–7—PMD control state diagram

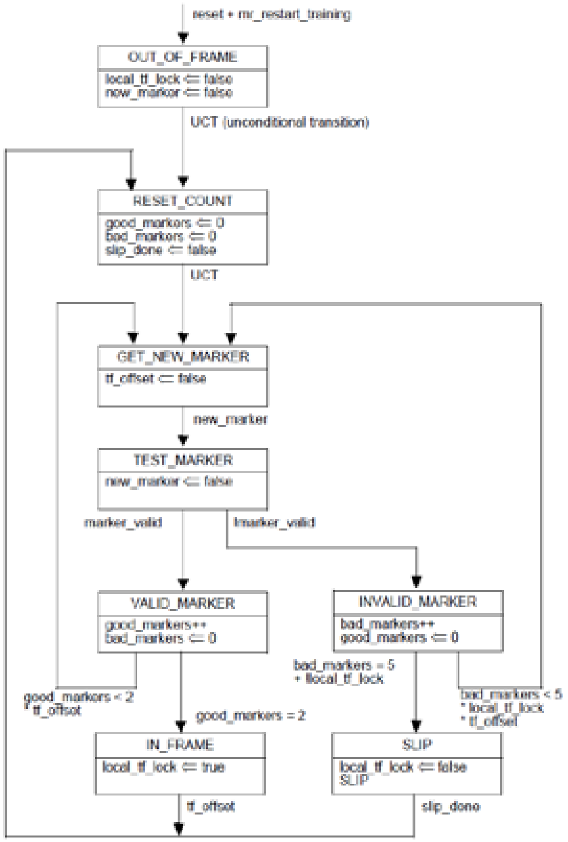

Figure 136–8—Training frame lock state diagram

For Backplane and Copper Cable PMDs

- IEEE Std. 802.3ck-2022, Cl 162.8.11 can be used as the training baseline for 200G/lane Backplane and Copper Cable PMDs
  - Some changes will likely be required, e.g. max_wait_timer value
  - But this is a good starting point.

162.8.11 PMD control function

The PMD control function performs the PMD start-up protocol. This protocol facilitates timing recovery and equalization while providing a mechanism through which the receiver can configure the transmitter to optimize performance. The protocol supports these functions through the continuous exchange of fixed-length training frames.

The PMD shall implement one instance of the PMD control function described in 136.8.11 for each lane with the following exceptions:

a) The control field structure is specified in Table 162–9 and the status field structure is specified in Table 162–10.

b) For k_list as specified in 136.8.11.4.4, the set of valid transmitter equalizer coefficient indices is {–3, –2, –1, 0, +1}.

c) For the initial condition request as described in 136.8.11.2.1, five predefined transmitter equalizer settings are specified in 162.9.4.1.3.

d) The "No equalization" value (see 136.8.11.2.4) of $c(-3)$ is 0.

e) The terminal count of max_wait_timer as specified in 136.8.11.7.3 is 12 s.

f) A receiver is expected to assert local_tf_lock within 275 ms from entry into the AN_GOOD_CHECK state in Figure 73–11 provided that there is a compliant signal containing valid training frames at the PMD input.

g) The value of use_quiet_in_training (see 136.8.11.7.1) is TRUE.

For AUI C2M and C2C – PMA Training

- Ethernet links defined in this project typically consist of multiple segments
  - Optical links: optical (PMD to PMD) and electrical (AUI) segments
  - Electrical links can also be segmented with AUI-C2C
- Optimization of the electrical output signal on each of these segments has proven to be beneficial even at existing rates
  - IEEE Std. 802.3ck-2022 introduced “AUI-S” and “AUI-L”
  - OIF is adding CMIS Support for Host-Module Link Training on 112G links
- AUI C2M, in particular, are much more challenging that in the past
  - 3bs: Annex 120E ~13 dB (die-to-die)
  - 3ck: Annex 120G ~= 22dB (die-to-die)
  - 3dj: discussing the range of 30-36 dB (die-to-die)
- We should consider in-band **PMA training**
  - Or “PMA output control function”

Reuse for PMA output control function

- The PMD control function has a great architecture for the PMA output control function
- Establishes:
  - Commonality across electrical PMDs and electrical interfaces
  - Reusable building blocks within implementations, which increases interoperability
- All PMAs with physically instantiated interfaces (AUIs) at 200 Gb/s per lane (within type 1/2 PHYs and extenders) should use the same definitions.
- Propose to adopt the Cl 136-3 Training Frame structure as the basis of the PMA output control function
  - Control Field and Status Field bit definitions may need modifications.

Necessary updates for in-band PMA training (training over AUIs)

- Operation across multiple segments
  - The PMD training function does not address segmented links
- Consideration of different segment types
  - AUIs in the link may be of different speeds, with/without support for in-band training
  - Unknown number of AUIs on each side of the link
  - Optical segments may or may not have a training function
- Considerations of out-of-band management, e.g., CMIS
  - Detection of module type, control of PMD output, etc.
  - Observability, debugging
- Effects on electrical specification methodology
- All these are future work items that should be addressed during the project.
  - There may be others, based on contributions.

Summary

- Reviewed existing PMD control function
- In-band PMA training has a lot of potential benefits
  - There is a good starting point (PMD control function)
  - Some changes may be required for PMAs, e.g. message content and state diagrams
- Recommend to **adopt link training based on IEEE Std. 802.3ck-2022, Cl 162.8.11 as the baseline for 200G/lane Backplane and Copper Cable PMDs**
- Recommend to **adopt in-band training based on the clause 136 training frame structure (Figure 136-3) for all AUI segments with electrical interfaces at 200 Gb/s per lane**.

Straw Poll results from 4 January 2024 Electrical ad hoc:

Straw Poll #1

I would support adopting link training based on IEEE Std. 802.3ck-2022, Cl 162.8.11 as the baseline for 200G/lane Backplane and Copper Cable PMDs

Results (all): Y: 34, N: 1, A: 15

Straw Poll #2

I would support adopting in-band training based on the clause 136 training frame structure (Figure 136-3) for all AUI segments with electrical interfaces at 200 Gb/s per lane

Results (all): Y: 36, N: 2, A: 15

https://www.ieee802.org/3/dj/public/adhoc/electrical/24_0104/3dj_elec_adhoc_Straw_Polls_240104.pdf