Extending Link Configuration and Training to Optics

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IEEE 802.3dj Interim Meeting
Campinas, Brazil

September 11, 2023

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Overview

- **Background on Ethernet CR/KR link training**
- **Proposed 256G FC optics training**
- **Inner FEC mode and link training for optics**
- **Why optical link training is challenging**
- **DME control and status field tables**
  - Enable inner FEC to be tuned on/off
  - Enable pre-coder
  - Select preset
  - Tune TX FFE
- **Potential configuration for optics link training**
- **Summary.**

Background on Ethernet AN/LT

- **Ethernet AN/LT 1st developed in 10GBASE-KR project with link training in CL72 and Autoneg in CL73**
  - CL72/136/162 LT require the link to operate in point-point as two end stations
  - CL136/162 Control/status fields are transmitted with DME (Differential Manchester Encoding) at 1/8 the Baudrate followed by PRBS13Q as PAM4 training pattern
  - Proposed Optics-LT leverages CL136/162 training.

Original KR CL72 LT Frame

Octets		
4	Frame marker	
16	Coefficient update	Control channel
16	Status report	Control channel
512	Training pattern	

Figure 72–2—Training frame structure

Expanded CL136 LT Frame Supporting PAM4

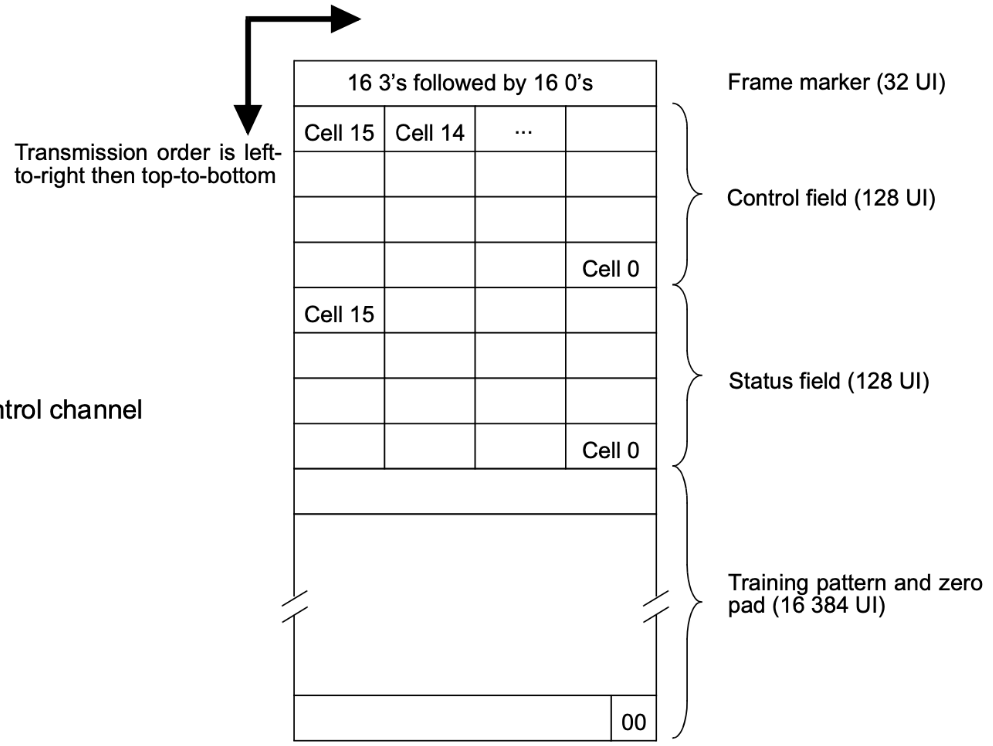
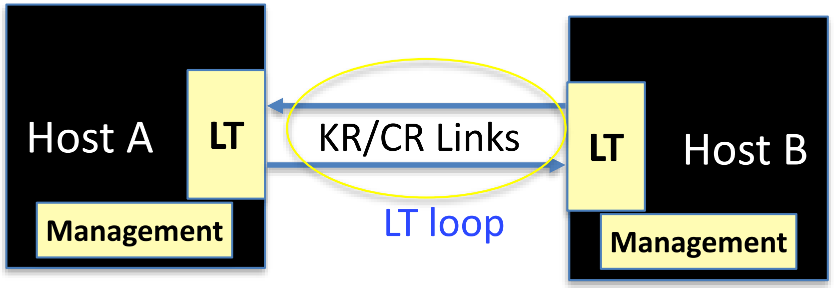


Figure 136–3—Training frame structure

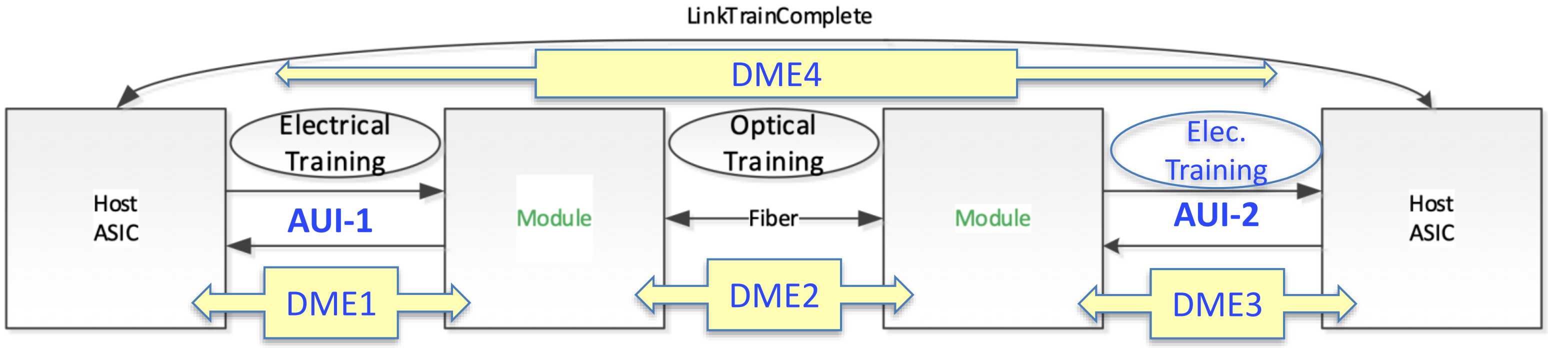


Related Contribution to Optics Training and FEC Modes

- **Previously ghiasi_3dj_01a_2307 presented a method to use inner FEC sideband for Optics-LT**
  - The overall feedback was that after inner FEC switched off sideband channel no longer exist and any further changes require going through a hard reset
- **mehta_3dj_elec_01_230831 contribution describes proposed 256 GFC link training for the optics based on Ethernet DME and CL136/162 but with addition of FC LSN operating at 32 GFC to determine link speed supported**
- **This contribution is based on proven Ethernet DME and CL136/162 but with addition of FEC Bypass and pre-coder on/off**
  - Mehta proposal is similar without inner FEC and pre-coder controls but with some FC specific features.

Proposed 256 GFC Optics Training

- **This contribution is similar and will work to align registers to [mehta_3dj_elec_01_230831]**
  - Assumes FC LSN (32 GFC) to establish link speed supported
  - To establish LSN require end-end host-host link to be established 1st (not Ethernet Applicable)
  - AUI-1, optics, and AUI-2 training can’t progress till all 3 segments connected and LSN starts
  - Mehta proposal starts with DME1, DME2, and DME3 engines after all 3 segments trained DME2 is bypassed in the modules where DME1 communicates with DME3 “DME4” (needed for FC)
    - Ethernet modules can avoid this additional complication which won’t work on Ethernet host with 100G-AUI
    - Considering Ethernet module require CMIS datapath initialization and DME can only start after module is in ready state remote ready signal available through DME2 without requiring DME4 mode if there is no critical timing.



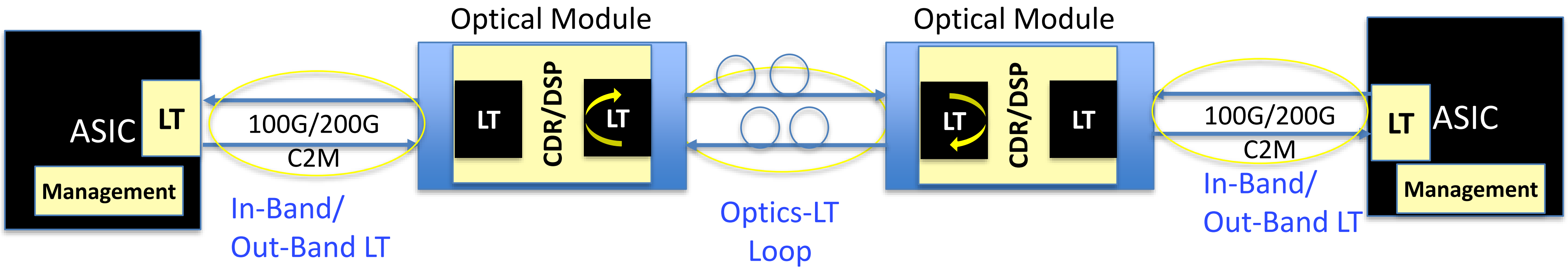
Blue text are annotations to Mehta Contribution

Optics Link Training to Manage FEC and Pre-coder Modes

- **Managing inner FEC on/off has been hot topic since adoption of motion #9 in July with the task force exploring all options dambrosia_3dj_optx_01a_230829**
- **Options for managing FEC modes and pre-coder on/off**
  - Option-I Manually configuring both modules into inner FEC on/off and manage precoder on/off
  - Option-II Mechanisam based on parallel detect (receiver would toggles between Inner FEC on/off) and manually mange pre-coder on/off
    - Define a CMIS register "InnerFECoff" where either host A or B may request Inner FEC On/Off
    - Remote module would have to have capability for parallel detect turn inner FEC on/off
    - If after X amount of time inner FEC is not turned off then local module will go back to inner FEC mode
    - For any reason (may include unacceptable FLR or corrected FEC code words) either hosts may remove the inner FEC Off capability
  - Option-III Based on proven DME link training in CL136/162
    - Provides a nicer method for inner FEC control - Required for DJ to make progress
    - Provides a method for pre-coder on/off – Required for DJ to make progress
    - Optics link training – The DME method can also provide optics LT if we want to take advantage of it now or in future (powerful tool that require time to fully develop) – Is it needed for DJ PMDs?

How to Leverage Ethernet LT for FEC Modes and Optics Training

- **This proposal defines mechanisam for inner FEC/pre-coder control and Optics-LT on a single optical segment based on 802.3 CL136/162**
  - Proposal makes minor modification to CL136/162 to support Optics-LT by segmenting optical link as another CR/KR point-point link
    - Approach keeps the current CR/KR adaptation model where receiver control the transmitter FFE taps or presets
  - Proposal assumes 100G/200G C2M-AUI links maybe get trained either by in-band/out-band method
  - Optics DME/training can be driven by recovered clock from the host or the module reference clock
  - After the optical link is trained (inner FEC on/off, pre-coder on/off, or transmit tuning) CDR/DSP in the module switches to mission/pass-through mode.



Key Benefits of Optical Link Training

- **A key benefit of optical link training is the ability to exchange local to remote transceiver capabilities such as:**
  - Control inner FEC
  - Control pre-coder
- **Link training also provide adjustment to the optical transmitter based on receiver requests either through presets or direct control**
  - Given the single setting most optical transmitters today are over-emphasized which result in excess distortion on low CD/shorter links
  - Outer eyes compression is a major penalty for optical links and TDECQ tries to get around this issue by allowing to adjust thresholds by ± 2% but doesn't solve the problem
  - Linearity is major issue for PAM4 optical links just a modest optical power signal control will reduce distortions.

Why Optical TX Link Training is Challenging

- **Unlike CR/KR optical devices may require specific adjustment based on the device type**
  - VCSEL/DML – asymmetrical turn-on/off
  - MZM – cosine compression
  - Electro-absorbers EA – non-linear transfer response
  - Combination of chirp and dispersion on SMF - may create pulse compression
- **Transmit FFE adjustment only provides linear frequency compensation**
  - Proposed Optic-LT will not provide non-linear adjustments specific to different class of optics
  - Different presets may include aspect of non-linear compensation based on device type
  - But all presets must be known good setting that operate with the reference equalizer otherwise receiver may lose lock
- **Optical link training may provide significant benefit for some optical PMDs**
  - Need to quantify the benefit of optics training for the adopted SMF PMDs
  - Need to define the presets and the FFE tap ranges/step/weight for each of the optical PMDs
- **The method of Optics-LT based on CL136/162 to provide a mechanisam for inner FEC On/Off and pre-coder on/off is straight forward.**

Leveraging CL136 Link Training for Optics-LT

- **Training frame structure based on 136.8.11.1**
- **Training pattern and training PRBS pattern based on 136.8.11.1.3**
- **Control field structure and status field structure generally follows 162.8.11 with the difference captured in this contribution**
  - If 802.3dj modifies KR/CR PMD control then will follow those changes when possible.

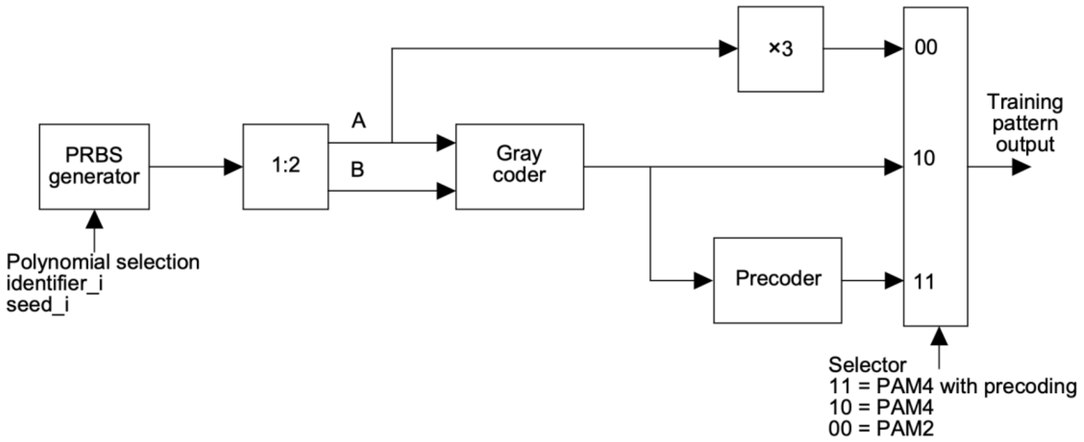


Figure 136–4—Training pattern generator

Table 136–8—Training patterns

p	Polynomial_*p*, *G*(*x*)	Default seed bits[a]	Initial output, PAM2	Initial output, PAM4	Initial output, PAM4 with precoding
0	$1+x+x^2+x^{12}+x^{13}$	0000010101011	0030330330000	1031320220111[b]	1301200200101
1	$1+x^2+x^3+x^7+x^{13}$	0011101000001	3030303030333	3030213021333	3122012201212
2	$1+x^2+x^4+x^8+x^{13}$	1001000101100	0303333033030	1212332133031	1102120121301
3	$1+x^2+x^5+x^9+x^{13}$	0100010000010	3330300030330	2231210121221	2032013201110

Leveraging CL 136/162 Control Field Structure for Optics-LT

Bit(s)	Name	Description
15:14	Reserved	Transmit as 0, ignore on receipt
13:11	Initial condition request	13 12 11 1 1 1 = Preset 7 1 0 1 = Preset 6 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 (Default) 0 0 0 = Individual coefficient control
10	Inner FEC mode	0 = Inner FEC on 1 = Inner FEC off
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	
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 0 = c(2) 0 1 1 = Reserved
1:0	Coefficient request Highlighted text indicate change or addition to CL162 table 162-9.	1 0 1 1 = No equalization 1 0 = Decrement 0 1 = Increment 0 0 = Hold

Leveraging CL 136/162 Status Field Structure for Optics-LT

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
10	Inner FEC mode	0 = Inner FEC on 1 = Inner FEC off
11:10	Modulation and precoding status	9 8 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	Inner FEC mode echo	0 = Inner FEC on 1 = Inner FEC off
5:3	Coefficient select echo	4 3 2 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 0 = c(2)
2:0	Coefficient request Highlighted text indicate change or addition to CL162 table 162-10.	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

Potential Configuration for Optics Link Training

- **Optical link training solve current DJ problem how to perform inner FEC On/Off and how to turn pre-coder on/off**
  - Full Development of optics-LT require close collaboration with optics experts
- **Total number of presets need to be limited due to test time possibly to more than 4 in addition of the default setting**
  - Preset1 – Default
  - Preset2 - Increase pre-emphasis by X%
  - Preset3 - Decrease pre-emphasis by X%
  - Preset4 - Increase outer eye amplitude Y%
  - Preset5 - Decrease outer eye amplitude by Y%
  - Preset6 - Increase OMA by Z dB
  - Preset7 - Decrease OMA by Z dB

Bandwidth compensation

Compression/non-linear compensation

Optical signal power control

- **Autonomous driven FFE adjustment of an optical transmitter has several challenges**
  - FFE adjustment may drive optical TX to unsafe or untested region
    - FFE range may get limited due to qualified range of OMA
  - Presets are not expected to drive the transmitter into unsafe or untested region
  - Do we need to define echo signals to indicate min or max OMA reached?
- **Any optical link configuration or training must support hosts with either 100G-AUI or 200G-AUI.**

Items for Further Study and Investigation

- **Clocking**
  - Can we assume that AUI links are trained 1st so the optical transmitter operates with host recovered clock instead of module reference clock?
  - The advantage of using recovered clock is that optical receiver/DSP gets trained with the real clock
  - However regardless which clock is used for optics link segment to train the host, the Ingress AUI link won't get trained with the real remote host clock unless one does secondary CMIS-LT training
- **Optical TX Presets/control**
  - Can we define set of generalized presets or each optical PMD require its own set of presets
  - Presets need to be well behaved and carefully defined without significantly increasing test time
    - Can we allow non-default presets settings to exceed TDECQ limit by 0.5-1.0 dB
    - Need to investigate if TDECQ for non default presets can be computed from default TDECQ on the scope
  - If TX FFE adjusted should the module try to keep the OMA constant
  - Given the OMA control transmitter need to stay laser safe unless interlock implemented
- **What are the key potential benefits of optical link training**
  - FEC mode control, pre-coder on/off
  - Pulse shaping, amplitude control, compression control
- **After agreeing KP4/inner FECs behavior then would be added to CL 136.8.11.7.5 state diagrams**
- **Do the benefit of optical link training outweighing the potential complexity it may bring?**