CAUI-4 C2C transmitter equalization, feedback, and MDIO control
(In support of comment #i-9)

Adee Ran
Intel Corporation

Contributors:

- Pete Anslow
- Mike Dudek

Supporters:

- Rick Rabinovich
- Ryan Latchman

Objectives

- Per comment #i-9, create an MDIO-based mechanism for enabling closed-loop transmitter equalization tuning.
- Correct the current incomplete specification of equalization settings.

Cl **83D** *SC* **83D.3.1.1** *P* **154** *L* **4** # i-9

RAN, ADEE — Intel Corporation

Comment Type **T** *Comment Status* **X**

The current method for setting the transmitter equalization coefficient is unidirectional. There is no standardized method for a receiver to indicate whether the current transmitter equalization coefficients are good or not, or to request a change to the coefficients in use. Configuring a multi-port system without such methods is difficult if at all possible.

Using a back channel for transmitter equalization tuning as in Clause 72 is a powerful feature. Since CAUI-4 does not use the clause 72 training, to avoid adding complexity it is suggested to add an optional back-channel through MDIO control.

Having a standardized MDIO-based method will help multi-port systems integration and tuning and promote interoperability.

SuggestedRemedy

A proposal was discussed in the CAUI-4 ad hoc. Presentation and detailed text, tables and figure will be supplied.

Proposed Response *Response Status* **O**

Closed-loop transmitter equalization tuning: outline of solution

- Publish current TX settings to the corresponding RX
- Check the RX for a request for a different setting
  - A device that implements **transmitter equalization feedback** can use the published TX setting + internal information to generate a new setting request.
  - A device that doesn't implement it won't signal a request.
- If a request is found, apply the requested setting to the TX.
- Lather, rinse, repeat…

Can be performed by Station Management (STA) over MDIO.

Summary of proposed changes

- **Clause 45:**
  - Extend CAUI-4 C2C transmitter equalization registers to include remote settings, requested settings and request flag
- **Annex 83D:**
  - Define specifications of 4×6 tap combinations
  - Add named variables, optionally mapped to MDIO registers
  - New subclause 83D.3.3.2: Transmitter equalization feedback (optional)
  - New subclause 83D.5: Example usage of the optional transmitter equalization feedback
  - New Figure 83D-5 depicting register mapping

Clause 45 changes

(Further details in anslow_02_0714_optx)

Current MDIO register definition

Table 45–71b—CAUI-4 chip-to-chip transmitter equalization, receive direction, lane 0 register bit definitions

Bit(s)	Name	Description	R/W[a]
1.180.15:5	Reserved	Value always 0, writes ignored	RO
1.180.4:2	Post-cursor setting	4 3 2 1 1 1 = Reserved 1 1 0 = Reserved 1 0 1 = –0.25 1 0 0 = –0.2 0 1 1 = –0.15 0 1 0 = –0.1 0 0 1 = –0.05 0 0 0 = 0	R/W
1.180.1:0	Pre-cursor setting	1 0 1 1 = –0.15 1 0 = –0.1 0 1 = –0.05 0 0 = 0	R/W

Proposed bit allocation (sample)

Bit(s)	Name	Variable	R/W
1.180.15	Request flag	*Request_flag*	RO
1.180.14:12	Post-cursor request	*Requested_eq_c1*	RO
1.180.11:10	Pre-cursor request	*Requested_eq_cm1*	RO
1.180.9:7	Post-cursor remote setting	*Remote_eq_c1*	R/W
1.180.6:5	Pre-cursor remote setting	*Remote_eq_cm1*	R/W
1.180.4:2	Post-cursor local setting	*Local_eq_c1*	R/W
1.180.1:0	Pre-cursor local setting	*Local_eq_cm1*	R/W

Summary of Table 45–71b – see anslow_02_0714_OPTX for full tables and definitions

Annex 83D changes

Overview subclause

- Transmitter equalization feedback may be used to achieve the required BER.
- In **83D.1**, change the sentence that starts in line 54 of page 151 to the following:

The CAUI-4 transmitter on each end of the link is adjusted to an appropriate setting based on channel knowledge. If implemented, the transmitter equalization feedback mechanism described in 83D.3.3.2 may be used to identify an appropriate setting. The adaptive or adjustable receiver performs the remainder of the equalization.

Transmitter equalization settings

- Change text in 83D.3.1.1 as in the next slide.
  - Add variables corresponding to the c(–1) and c(1) tap weights.
  - Remove ratio definitions from the text (new weight definitions appear in the tables).
- Change tables 83D-2 and 83D-3 to specify the tap weights.
  - Use ratios calculated from c(-1), c(0), c(1) – coefficients measured by the method in 93.8.1.5.1.
  - The effect of each tap setting is defined without requiring another tap to be set to zero.
  - This way all 4×6 combinations are addressed.
  - Each variable value has a specified and measurable effect.

Transmitter equalization settings

Change the text in 83D.3.1.1 as follows:

The CAUI-4 chip-to-chip transmitter includes programmable equalization to compensate for the frequency-dependent loss of the channel and to facilitate data recovery at the receiver. The functional model for the transmit equalizer is the three tap transversal filter shown in Figure 83D–4. The transmitter output equalization is characterized using the linear fit method described in 93.8.1.5.1 where the state of the CAUI-4 transmit output is manipulated via management.

The variable *Local_eq_cm1* controls the weight of the pre-cursor tap c(–1). The valid values of *Local_eq_cm1* and their effect are specified in Table 83D-2. The variable *Local_eq_c1* controls the weight of the post-cursor tap c(1). The valid values of *Local_eq_c1* and their effect are specified in Table 83D-3. *Local_eq_cm1* and *Local_eq_c1* are independent of each other, and independent on each lane.

If a Clause 45 MDIO is implemented, *Local_eq_cm1* and *Local_eq_c1* for each lane (0 through 3) and direction (transmit and receive) are accessible through registers 1.180 through 1.187 (see 45.2.1.92b through 45.2.1.92e).

Table 83D-2 – Pre-cursor equalization

Replace with the following table:

***Local_eq_cm1* value**	$\frac{c(-1)}{\lvert c(-1)\rvert + \lvert c(0)\rvert + \lvert c(1)\rvert}$
0	0 ± 0.025
1	−0.05 ± 0.025
2	−0.1 ± 0.025
3	−0.15 ± 0.025

Table 83D-3 – Post-cursor equalization

Replace with the following table:

***Local_eq_c1* value**	$\frac{c(1)}{\lvert c(-1)\rvert + \lvert c(0)\rvert + \lvert c(1)\rvert}$
0	0 ± 0.025
1	−0.05 ± 0.025
2	−0.1 ± 0.025
3	−0.15 ± 0.025
4	−0.2 ± 0.025
5	−0.25 ± 0.025

Transmitter equalization feedback (optional)

Insert a new subclause after 83D.3.3.1 (Receiver interference tolerance) :

83D.3.3.2 Transmitter equalization feedback (optional)

Transmitter equalization feedback is an optional capability for a CAUI-4 chip-to-chip receiver. If implemented, it shall be as described in this subclause.

Transmitter equalization feedback is generated for each lane (0 through 3) and direction (transmit and receive) independently. The variables that control transmitter equalization feedback are specific for each lane and direction.

A CAUI-4 chip-to-chip receiver may generate a request to change the transmit equalization coefficients of the remote transmitter to new values by setting the *Request_flag* variable to 1. The variables *Requested_eq_cm1* and *Requested_eq_c1* indicate the requested values of *Local_eq_cm1* and *Local_eq_c1*, respectively, in the remote transmitter (see Table 83D-2 and Table 83D-3). The requested setting may be generated from the remote CAUI-4 chip-to-chip transmitter's equalization setting, which is stored in the variables *Remote_eq_cm1* and *Remote_eq_c1*, and from information internal to the receiver, in an implementation specific manner.

When a CAUI-4 chip-to-chip receiver does not request a change of the remote transmitter's transmit equalization setting, it sets the *Request_flag* variable to 0. A CAUI-4 chip-to-chip receiver that does not implement transmitter equalization feedback always sets *Request_flag* to 0.

If a Clause 45 MDIO is implemented, the variables *Request_flag*, *Requested_eq_cm1*, *Requested_eq_c1*, *Remote_eq_cm1* and *Remote_eq_c1* for each lane and direction are accessible through registers 1.180 through 1.187 (see 45.2.1.92b through 45.2.1.92e).

Example usage of the optional transmitter equalization feedback

Insert a new subclause 83D.5:

83D.5 Example usage of the optional transmitter equalization feedback

83D.5.1 Overview

If implemented, transmitter equalization feedback from a CAUI-4 chip-to-chip receiver may be used to tune the equalization settings of the transmitter at the other end of the CAUI-4 chip-to-chip link to the values requested by the receiver. An example of a possible transmitter equalization tuning process using transmitter equalization feedback is provided in this subclause.

In this example, two components, A and B, are connected by a CAUI-4 chip-to-chip link, such that A is closest to the PCS and B is closest to the PMD. Clause 45 MDIO is implemented by both components, with component A at device address 11 and component B at device address 10. Transmitter equalization feedback is implemented by either component A, component B, or both. One Station Management (STA) controls both components.

Figure 83D-5 depicts the components of the CAUI-4 chip-to-chip link and the registers used during the tuning procedure.

(insert Figure 83D-5 here)

The STA performs the procedures described in 83D.5.2 and 83D.5.3 to tune lane 0 equalization settings in both sides of the CAUI-4 chip-to-chip link. When these procedures are completed, the STA uses similar procedures to tune equalization settings in lanes 1 through 3. When all lanes are tuned, the STA may repeat the process with another pair of components connected by CAUI-4 chip-to-chip.

NOTE – Using non-optimal transmitter equalization settings (or changing them) during the tuning procedure may interrupt data communication. The CAUI-4 bit error ratio is assumed to meet the requirements of 83D.3.3.1 upon completion of the tuning process.

Example procedure for tuning equalization settings on lane 0, Transmit direction

83D.5.2 Tuning equalization settings on lane 0 in the Transmit direction

1. Read Local_eq_cm1 (11.184.1:0) and Local_eq_c1 (11.184.4:2) from component A.
2. Write Local_eq_cm1 and Local_eq_c1 read from component A to Remote_eq_cm1 (10.184.6:5) and Remote_eq_c1 (10.184.9:7), respectively, in component B.
3. Read Request_flag (10.184.15), Requested_eq_cm1 (10.184.11:10) and Requested_eq_c1 (10.184.14:12) from component B.
4. If Request_flag is 0, go to tuning equalization settings on lane 0 in the Receive direction (83D.5.3)
5. If Request_flag is 1, write Requested_eq_cm1 and Requested_eq_c1 read from component B to Local_eq_cm1 (11.184.1:0) and Local_eq_c1 (11.184.4:2), respectively, in component A.
6. Go to step 1.

Example procedure for tuning equalization settings on lane 0, Receive direction

83D.5.3 Tuning equalization settings on lane 0 in the Receive direction

1. Read Local_eq_cm1 (10.180.1:0) and Local_eq_c1 (10.180.4:2) from component B.
2. Write Local_eq_cm1 and Local_eq_c1 read from component B to Remote_eq_cm1 (11.180.6:5) and Remote_eq_c1 (11.180.9:7), respectively, in component A.
3. Read Request_flag (11.180.15), Requested_eq_cm1 (11.180.11:10) and Requested_eq_c1 (11.180.14:12) from component A.
4. If Request_flag is 0, proceed to tuning lane 1.
5. If Request_flag is 1, write Requested_eq_cm1 and Requested_eq_c1 read from component A to Local_eq_cm1 (10.180.1:0) and Local_eq_c1 (10.180.4:2), respectively, in component B.
6. Go to step 1.

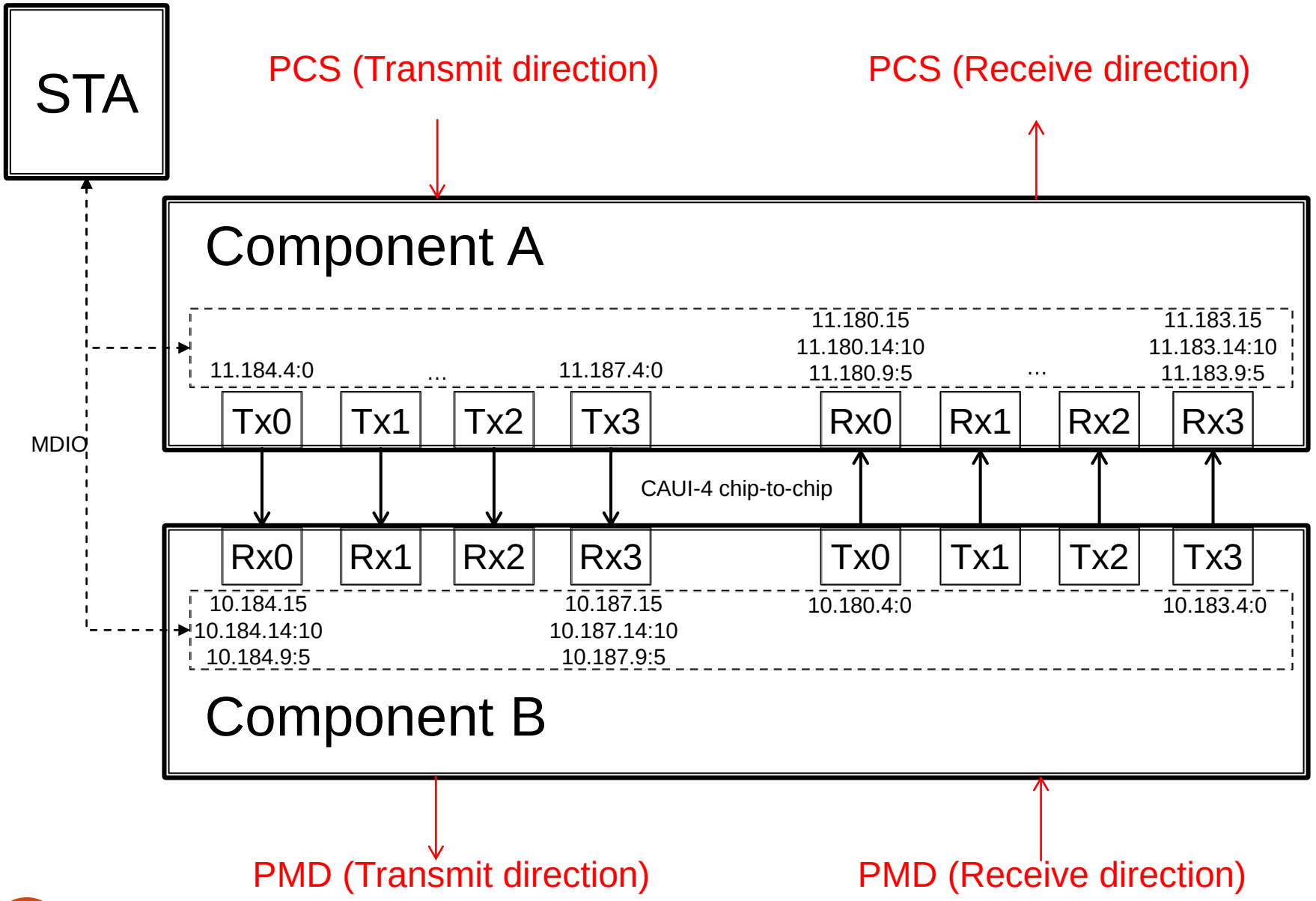
STA
PCS (Transmit direction)
PCS (Receive direction)
Component A
11.184.4:0
...
11.187.4:0
11.180.15
11.180.14:10
11.180.9:5
...
11.183.15
11.183.14:10
11.183.9:5
Tx0
Tx1
Tx2
Tx3
Rx0
Rx1
Rx2
Rx3
MDIO
CAUI-4 chip-to-chip
Rx0
Rx1
Rx2
Rx3
Tx0
Tx1
Tx2
Tx3
10.184.15
10.184.14:10
10.184.9:5
10.187.15
10.187.14:10
10.187.9:5
10.180.4:0
10.183.4:0
Component B
PMD (Transmit direction)
PMD (Receive direction)

Figure 83D-5