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Proposal for Training and PHY Control State Diagram for 100BASE-T1L

Brian Murray
Philip Curran
Jacobo Riesco

Introduction

- This a proposal for the Training and PHY Control State Diagram for 100BASE-T1L

Operation of the PCS During Training

- The PCS generates and detects specific sequence of symbols for link acquisition
  - Initially the PCS generates sequences of PAM2 symbols to train the signal processing functions
    - The Follower embeds its *loc_rcvr_status* in the transmitted sequence
    - The Leader detects *rem_rcvr_status* from the received sequence
  - Once the PHYs have achieved *loc_rcvr_status* OK the PCS generates formatted training frames for PCS frame alignment
    - The Follower aligns its transmitted training frame to the training frame received from the Leader
    - This ensures that the Energy Efficient Ethernet LPI quiet / refresh cycles are offset
  - The training frame includes an InfoField which is used to exchange the PHY Capabilities between the link partners

Scrambler

- The training mode uses the same 33 bits side-stream scrambler as for normal operation
  - Generator polynomials for Leader and Follower are:
    - Leader: $g_L(x) = 1 + x^{13} + x^{33}$
    - Follower: $g_F(x) = 1 + x^{20} + x^{33}$
- Scrambling is done per 6-tuple
  - The bits stored in the scrambler shift register delay line at time n are denoted by $\mathrm{Scr}_n[32:0]$
  - At each 6-tuple period, the shift register is advanced by one bit, and a new bit represented by $\mathrm{Scr}_n[0]$ is generated
  - Scrambling rules are based on the generation, at time n, of nine bits: $\mathrm{Sx}_n[3:0]$, $\mathrm{Sy}_n[3:0]$ and Sg_n
    - The four $\mathrm{Sy}_n[3:0]$ bits are used to generate an uncorrelated bit stream during training
    - The eight $\mathrm{Sx}_n[3:0]$ and $\mathrm{Sy}_n[3:0]$ bits are used to generate an uncorrelated bit stream during idle
    - Sg_n is used to randomize the sign of the non-negative disparity (NND) 6-tuple for running disparity control

Generation of $Sx_n[7:0]$, $Sy_n[7:0]$ and Sg_n

- $Sx_n[3:0]$, $Sy_n[3:0]$ and Sg_n are generated using three uncorrelated bits, X_n, Y_n and $Scr_n[0]$, and an auxiliary generator polynomial, g(x), as in Clause 40:
  - The bits X_n and Y_n derived from elements of the same maximum-length shift register sequence of length 2^{33}-1 as $Scr_n[0]$, but shifted in time
  - The associated delays are all large and different so that there is no short-term correlation among the bits X_n, Y_n and $Scr_n[0]$
  - They are generated as follows:

$$\begin{aligned} X_n &= Scr_n[4] \wedge Scr_n[6] \\ Y_n &= Scr_n[1] \wedge Scr_n[5] \end{aligned}$$

  - The generator polynomial is:

$$g(x) = x^3 \wedge x^8$$

  - $Sx_n[3:0]$, $Sy_n[3:0]$ and Sg_n are generated as follows:

$$\begin{aligned} Sy_n[0] &= Scr_n[0] \\ Sy_n[1] &= g(Scr_n[0]) = Scr_n[3] \wedge Scr_n[8] \\ Sy_n[2] &= g^2(Scr_n[0]) = Scr_n[6] \wedge Scr_n[16] \\ Sy_n[3] &= g^3(Scr_n[0]) = Scr_n[9] \wedge Scr_n[14] \wedge Scr_n[19] \wedge Scr_n[24] \\ Sg_n &= Y_n = Scr_n[1] \wedge Scr_n[5] \end{aligned}$$

$$\begin{aligned} Sx_n[0] &= X_n = Scr_n[4] \wedge Scr_n[6] \\ Sx_n[1] &= g(X_n) = Scr_n[7] \wedge Scr_n[9] \wedge Scr_n[12] \wedge Scr_n[14] \\ Sx_n[2] &= g^2(X_n) = Scr_n[10] \wedge Scr_n[12] \wedge Scr_n[20] \wedge Scr_n[22] \\ Sx_n[3] &= g^3(X_n) = Scr_n[13] \wedge Scr_n[15] \wedge Scr_n[18] \wedge Scr_n[20] \\ &\qquad \wedge Scr_n[23] \wedge Scr_n[25] \wedge Scr_n[28] \wedge Scr_n[30] \end{aligned}$$

PAM2 Unformatted Training Sequence

▶ **SEND_U** – transmit unformatted training sequence of PAM2 symbols

- The first stage of training transmits PAM2 with no format or frame structure
- This sequence is used to train all of the signal processing functions
- The PAM2 6-tuple is selected using bits $\mathrm{Sd}_n[3:0]$ generated as shown below using the table of 4b6B NND PAM2 6-tuples

▶ **PMA training**

- When the tx_mode parameter is SEND_U, the PCS Transmit function generates unformatted training sequences of symbols that are used to train the local echo canceler and the remote receiver
- At each code-group time n, bits $\mathrm{Sd}_n[3:0]$ are generated from scrambler bits $\mathrm{Sy}_n[3:0]$ as follows:

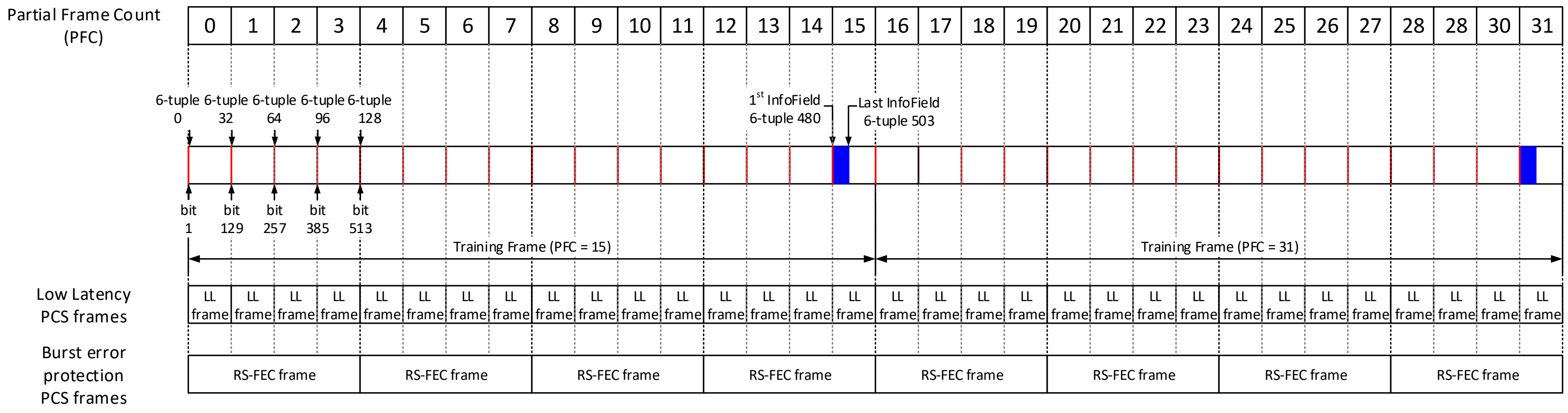
$$Sd_n[3] = \begin{cases} Sy_n[3] \wedge 1 & \text{if (config } = \text{ FOLLOWER} * \text{loc\_rcvr\_status} = \text{OK)} \\ Sy_n[3] & else \end{cases}$$

$$Sd_n[2:0] = Sy_n[2:0]$$

- Bits $Sd_n[3:0]$ are converted to a code-group with non-negative disparity $\{TA_n, TB_n, TC_n\ TD_n, TE_n, TF_n\}$

PAM2 Formatted Training Frame

- **SEND_F** – transmit formatted training frames
  - The second stage of training transmits PAM2 formatted training frames
  - The training frame is used for PCS frame alignment and exchange of PHY capabilities
  - Each training frame is composed of 16 PCS partial frames and each PCS partial frame is 32 6-tuples long
- All the bits in the training frame are zero except for:
  - The second bit in all PCS partial frames is set to 1, as shown in red
  - The InfoField, as shown in blue



Formatted Training Frame - InfoField

- An InfoField is transmitted in the 16th PCS partial frame of every training frame
  - The InfoField is used to exchange the PHY Capabilities between the link partners

- Format of the InfoField

Octet 1 <7:0>	Octet 2 <7:0>	Octet 3 <7:0>	Octet 4 <7:0>	Octet 5 <7:0>	Octet 6 <7:0>	Octet 7 <7:0>	Octet 8 <7:0>	Octet 9 <7:0>	Octet 10 <7:0>	Octet 11 <7:0>	Octet 12 <7:0>
0xEE	0xA7	0x00	Reserved (0x00000000)				PHY Capability			CRC16	

  - The InfoField has a Start Delimiter, a PHY Capability field and a CRC
    - *rs_adv* advertises support for RS-FEC
    - *eee_adv* advertises support for Energy Efficient Ethernet
    - *lpi_adv* advertises support for Low Power Idle
    - *seq_adv* advertises support for sequence ordered sets
  - The CRC16 is generated as per clause 165.4.2.4.8

Octet 8								Octet 9								Octet 10							
7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0	7	6	5	4	3	2	1	0
Reserved (0x0000)																seq_adv	lpi_adv	eee_adv	rs_adv	Reserved (0x0)			

Frame Alignment

- When the Leader has trained its receiver and has received *loc_rcvr_status* = OK from the Follower it starts to transmit PAM2 formatted frames
  - The formatted frames allow the Follower to synchronize its PCS frame
  - When the Follower starts receiving formatted frames and detects a valid InfoField it can synchronize its training frame to the Leader
  - The start of the Follower training frame is delayed by not more than one PCS partial frame with reference to the start of the Leader training frame as seen at the Follower MDI
    - This aligns the Follower frame to the Leader frame
    - This ensures that the Energy Efficient Ethernet LPI quiet / refresh cycles are offset
  - This occurs when the Follower is in the PAM2_TRAINING state
- The Follower only starts sending formatted frames to the Leader after it has synchronized its frame structure to that of the Leader

PHY Capability Exchange

- PHY capabilities are exchanged using the InfoField during training
  - The capability bits are specified by MDIO registers
- Each PHY advertises its capabilities to the link partner in the InfoField
    - *rs_adv* advertises support for RS-FEC
    - *eee_adv* advertises support for Energy Efficient Ethernet
    - *lpi_adv* advertises support for Low Power Idle
    - *seq_adv* advertises support for sequence ordered sets
  - Each PHY determines the capabilities of the link partner when it receives a valid InfoField
    - An InfoField is considered valid if the start delimiter is correct and the CRC is correct
  - The PHY Control function resolves the abilities
    - An ability is only enabled if advertised by both sides
    - The resolved abilities are communicated by PHY Control to the PCS
    - The link partner’s advertised capabilities and the resolved abilities are accessible via MDIO
- This occurs when the PHY is in the INFO_EXCHANGE state

PMA Training Frame

- The PAM2 6-tuple is selected using bits $\mathrm{Sd}_n[3:0]$ generated as shown below using the table of 4b6B NND PAM2 6-tuples
  - At each code-group time n, bits $\mathrm{Sd}_n[3:0]$ are generated from scrambler bits $\mathrm{Sy}_n[3:0]$ as follows:

$$Sd_n[3] = \begin{cases} Sy_n[3] \wedge InfoField[(4n+3) mod\ 128] & if\ (480 \leq (n\ mod\ 512) \leq 503) \\ Sy_n[3] & else \end{cases}$$

$$Sd_n[2] = \begin{cases} Sy_n[2] \wedge InfoField[(4n+2) mod\ 128] & if\ (480 \leq (n\ mod\ 512) \leq 503) \\ Sy_n[2] & else \end{cases}$$

$$Sd_n[1] = \begin{cases} Sy_n[1] \wedge InfoField[(4n+1) mod\ 128] & if\ (480 \leq (n\ mod\ 512) \leq 503) \\ Sy_n[1] \wedge 1 & else\ if\ (n\ mod\ 32 = 0) \\ Sy_n[1] & else \end{cases}$$

$$Sd_n[0] = \begin{cases} Sy_n[0] \wedge InfoField[(4n) mod\ 128] & if\ (480 \leq (n\ mod\ 512) \leq 503) \\ Sy_n[0] & else \end{cases}$$

  - Bits $Sd_n[3:0]$ are converted to a code-group with non-negative disparity $\{TA_n, TB_n, TC_n\ TD_n, TE_n, TF_n\}$

Table of 4b6B NND PAM2 6-Tuples

- The table of 4b6B NND PAM2 6-tuples is shown below
  - The bits $Sd_n[3:0]$ select the NND code-group $\{TA_n, TB_n, TC_n\ TD_n, TE_n, TF_n\}$

Index	$Sd_n[3:0]$	TA_n	TB_n	TC_n	TD_n	TE_n	TF_n	DS_n	Pattern
0	0000	-1	1	-1	1	-1	1	0	-+-+-+
1	0001	-1	-1	1	1	-1	1	0	--++-+
2	0010	-1	1	1	1	1	1	4	-+++++
3	0011	1	-1	1	-1	1	1	2	+-+-++
4	0100	-1	1	-1	1	1	-1	0	-+-++-
5	0101	1	1	1	-1	1	-1	2	+++-+-
6	0110	-1	1	1	-1	-1	1	0	-++--+
7	0111	-1	1	-1	-1	1	1	0	-+--++
8	1000	1	1	1	1	-1	-1	2	++++--
9	1001	-1	-1	-1	1	1	1	0	---+++
10	1010	-1	-1	1	-1	1	1	0	--+-++
11	1011	-1	-1	1	1	1	-1	0	--+++-
12	1100	1	1	-1	1	1	-1	2	++-++-
13	1101	-1	1	1	-1	1	-1	0	-++-+-
14	1110	-1	1	1	1	-1	-1	0	-+++--
15	1111	1	1	-1	-1	1	1	2	++--++

Running Disparity During Training

- The Running Disparity Control process maintains a running disparity value RD$_n$
  - At each code-group time n, the value RD$_{n-1}$ is combined with the values of the symbols in the non-negative disparity code-group to generate a sign value SX$_n$, as shown in the following equations:

$$DS_n = TA_n + TB_n + TC_n + TD_n + TE_n + TF_n$$

$$SX_n = \begin{cases} -1 & if\ ((DS_n > 0 * RD_{n-1} > 0) + ((DS_n = 0\ +\ RD_{n-1} = 0) * Sg_n = 1)) \\ +1 & otherwise \end{cases}$$

  - A balanced code-group is generated by applying the sign value to each of the symbols in the non-negative disparity code-group as shown in the following equations:

$$\begin{aligned} A_n &= SX_n \times TA_n & \qquad D_n &= SX_n \times TD_n \\ B_n &= SX_n \times TB_n & \qquad E_n &= SX_n \times TE_n \\ C_n &= SX_n \times TC_n & \qquad F_n &= SX_n \times TF_n \end{aligned}$$

  - The running disparity value is computed using the following equations:

$$RD_{n-1} = 0 \qquad \text{when } tx\_mode \text{ is SEND\_Z}$$

$$RD_n \quad = \mathrm{RD}_{\mathrm{n-1}} + A_n + B_n +\ C_n +\ D_n +\ E_n +\ F_n$$

  - The symbols {A_n, B_n, C_n D_n, E_n, F_n} are presented to the PMA for transmission, with A_n being transmitted first

PHY Control State Diagram Formal Description

- The following is a formal definition of the PHY Control state diagram
  - A list of services primitives, state diagram variables and the timers are included as part of the formal definition
    - Many of these are standard variables used in many previous standards
    - Newly introduced variables are highlighted in another color

PMA Functions

- The PMA sublayer comprises one PMA Reset function and five simultaneous and asynchronous operating functions
  - The PMA operating functions are PHY Control, PMA Transmit, PMA Receive, Link Monitor, and Clock Recovery
    - A Refresh Monitor function is required in PHYs that support LPI
  - All operating functions are started immediately after the successful completion of the PMA Reset function
  - The PMA Reset function shall be executed on the receipt of a request for reset from the management entity or on power-up
- PMA Transmit and Receive Functions
    - The PMA Transmit function comprises a transmitter to generate a three-level modulated signal on the single balanced pair of conductors
    - The PMA Receive function comprises a receiver for PAM3 signals on the balanced pair

PHY Control Function

- PHY Control generates the control actions that are needed to bring the PHY into a mode of operation during which frames can be exchanged with the link partner
  - During training, when the PHY Control state diagram is in the INFO_EXCHANGE state or the INFO_COUNTDOWN state, the PHY capabilities are communicated to the link partner with a 12-octet InfoField, which is incorporated into the sequence of transmitted training symbols by the PCS Transmit function
  - The capabilities that are advertised to the link partner are communicated to PHY Control by the parameters *rs_adv*, *seq_adv*, *eee_adv* and *lpi_adv*
  - During training, when the PCS Receive function detects a valid InfoField in the sequence of received symbols, the PHY capabilities of the link partner are extracted from this InfoField
  - The capabilities that are advertised by the link partner are communicated to PHY Control by the parameters *lp_rs_adv*, *lp_seq_adv*, *lp_eee_adv* and *lp_lpi_adv*
- When the PHY Control state diagram transitions from the INFO_EXCHANGE state into the INFO_COUNTDOWN state, the PHY Control function resolves the abilities that are enabled for the link
  - The resolved abilities are passed to the PCS by the variables *rs_en*, *seq_en*, *eee_en* and *lpi_en*

Link Monitor Function

- The Link Monitor function determines the status of the link and sets the *link_status* variable accordingly
  - This variable is communicated to the PCS, the PHY Control function, and the Auto-Negotiation function through the PMA_LINK.indication primitive
- The Link Monitor function shall comply with the link monitor state diagram
  - Upon power on, reset, or release from power down, the Auto-Negotiation function sets *link_control* to DISABLE, and the Link Monitor function sets *link_status* to FAIL
  - When the Auto-Negotiation function establishes the presence of a remote 100BASE-T1L PHY, *link_control* is set to ENABLE, and the Link Monitor state diagram begins monitoring the *tx_mode* variable from the PHY Control state diagram
  - As soon as the PHY Control state diagram achieves reliable communication, it sets *tx_mode* to SEND_N, and the Link Monitor state diagram sets *link_status* to OK, upon which further PHY operations can take place
  - If the PHY Control state diagram detects a link failure, it sets *tx_mode* to SEND_Z, and the Link Monitor state diagram sets *link_status* to FAIL, which in turn causes the clients of the PMA to stop exchanging frames, and restarts the Auto-Negotiation process

Refresh Monitor Function

- The Refresh Monitor is required for a PHY that supports the LPI capability
  - The Refresh Monitor operates when the PHY is in the LPI receive mode
  - The Refresh Monitor sets the *pma_refresh_status* variable to FAIL if a refresh signal is not reliably detected within a moving time window equivalent to 50 complete quiet-refresh cycles (nominally equal to 11.52 ms), when the PHY is in the LPI receive mode
  - The PHY Control state diagram enters the LINK_FAIL state, when the *pma_refresh_status* variable is FAIL
    - This causes the link to drop

Technology Dependent Interface

- 100BASE-T1L uses the following service primitives to exchange status indications and control signals across the Technology Dependent Interface

TDI Service Interface Primitive	Parameter
PMA_LINK.request	link_control
PMA_LINK.indication	link_status
AN_CONFIG.request	an_config

TDI Service Interface Primitives

Service Interface Primitive	Description
PMA_LINK.request	This primitive allows the Auto-Negotiation function to enable and disable operation of the PHY, as specified in clause 98.4.2. The link_control parameter can take on one of two values: DISABLE or ENABLE. DISABLE: Used by the Auto-Negotiation function to disable the PHY. ENABLE: Used by the Auto-Negotiation function to enable the PHY.
PMA_LINK.indication	This primitive is generated by the PMA to indicate the status of the underlying medium as specified in clause 98.4.1. This primitive informs the PCS, the PHY Control function, and the Auto-Negotiation function about the status of the underlying link. The link_status parameter can take on one of two values: FAIL or OK. FAIL: A valid 100BASE-T1L link is not established. OK: A valid 100BASE-T1L link is established.
AN_CONFIG.request	This primitive allows the Auto-Negotiation function to convey the result of LEADER-FOLLOWER resolution, as specified in clause 98.2.1.2.5. The an_config parameter can take on one of two values: LEADER or FOLLOWER. LEADER: The PHY is to operate as a LEADER PHY. FOLLOWER: The PHY is to operate as a FOLLOWER PHY

PMA Service Interface

- 100BASE-T1L uses the following service primitives to exchange symbol vectors, status indications, and control signals across the PMA service interface

PMA Service Interface Primitive	Parameter
PMA_CONFIG.indication	config
PMA_TXMODE.indication	tx_mode
PMA_PCSRXMODE.indication	pcs_rx_mode
PMA_UNITDATA.request	tx_symb
PMA_UNITDATA.indication	rx_symb
PMA_SCRSTATUS.request	scr_status
PMA_PCSSTATUS.request	pcs_status
PMA_RXSTATUS.indication	loc_rcvr_status
PMA_REMRXSTATUS.request	rem_rcvr_status
PMA_RXINFOFRAME.request	rx_info_frame
PMA_REMPHYIDLE.request	rem_phy_idle
PMA_REMPHYREADY.request	rem_phy_ready
PMA_TXINFOFRAMEEND.request	tx_info_frame_end

PMA Service Interface Primitive	Parameter
PMA_RSADV.request	rs_adv
PMA_EEEADV.request	eee_adv
PMA_LPIADV.request	lpi_adv
PMA_SEQADV.request	seq_adv
PMA_LP_RSADV.request	lp_rs_adv
PMA_LP_EEEADV.request	lp_eee_adv
PMA_LP_LPIADV.request	llp_pi_adv
PMA_LP_SEQADV.request	lp_seq_adv
PMA_RSEN.indication	rs_en
PMA_EEEEN.indication	eee_en
PMA_LPIEN.indication	lpi_en
PMA_SEQEN.indication	seq_en

PMA Service Interface Primitives 1

Service Interface Primitive	Description
PMA_CONFIG.indication	This primitive indicates to the PCS and the PMA Clock Recovery function via the config parameter whether the PHY operates as a LEADER PHY or as a FOLLOWER PHY. The config parameter can take on one of two values: LEADER or FOLLOWER. LEADER: The PHY operates as a LEADER PHY. FOLLOWER: The PHY operates as a FOLLOWER PHY
PMA_TXMODE.indication	This primitive indicates the transmit mode to the PCS and the functions of the PMA via the tx_mode parameter. The tx_mode parameter can take on one of five values: SEND_Z, SEND_U, SEND_F, SEND_I, or SEND_N. SEND_Z: Transmission of zero symbols takes place. SEND_U: Transmission of unformatted training sequences of symbols takes place. SEND_F: Transmission of formatted training sequences of symbols takes place. SEND_I: Transmission of sequences of symbols representing control information corresponding to the idle mode takes place. SEND_N: Transmission of sequences of symbols representing a MII stream of data and control, or control information corresponding to the idle mode takes place.
PMA_PCSRXMODE.indication	This primitive specifies the PCS receive mode to the PCS Receive function. The pcs_rx_mode parameter can take on one of two values: TRAIN, or NORMAL TRAIN: The PCS Receive function operates in training mode. NORMAL: The PCS Receive function operates in normal mode.

PMA Service Interface Primitives 2

Service Interface Primitive	Description
PMA_UNITDATA.request	This primitive transfers symbols from the PCS to the PMA via the tx_symb parameter. The symbols are obtained in the PCS Transmit function using the encoding rules defined in to represent an MII stream of data and control or other sequences. During transmission, the PMA_UNITDATA.request conveys to the PMA via the tx_symb parameter the value of the symbol to be sent over the MDI. The tx_symb parameter takes on one of the following values: 0 when zeros are to be transmitted {-1, +1} when the PHY is in training mode {-1, 0, +1} when the PHY is in idle mode or in normal operation
PMA_UNITDATA.indication	This primitive transfers symbols from the PMA to the PCS via the rx_symb parameter. During reception, the PMA_UNITDATA.indication conveys to the PCS via the rx_symb parameter the value of symbols detected on the MDI.
PMA_SCRSTATUS.request	This primitive allows the PCS Receive function to communicate the status of the descrambler to the PMA. The scr_status parameter can take on one of two values: OK, or NOT_OK. OK: The descrambler is synchronized. NOT_OK: The descrambler is not synchronized.
PMA_PCSSTATUS.request	This primitive allows the PCS Receive function to communicate the status of the PCS to the PMA. The pcs_status parameter can take on one of two values: OK, or NOT_OK. OK: The PCS is operating reliably. NOT_OK: The PCS is not operating reliably.

PMA Service Interface Primitives 3

Service Interface Primitive	Description
PMA_RXSTATUS.indication	This primitive is generated by the PMA Receive function to indicate reliable or unreliable operation of the receive link for the local PHY. The loc_rcvr_status parameter can take on one of two values: OK, or NOT_OK OK: Operation of the receive link for the local PHY is reliable. NOT_OK: Operation of the receive link for the local PHY is unreliable.
PMA_REMRXSTATUS.request	When the config parameter is LEADER, this primitive is generated by the PCS Receive function to indicate whether reliable operation of the receive link for the remote PHY is detected. The remote PHY communicates the status of its receive link by encoding its loc_rcvr_status when its config is FOLLOWER, and its tx_mode is SEND_U. The rem_rcvr_status parameter can take on one of two values: OK, or NOT_OK OK: Reliable operation of the receive link for the remote PHY is not detected. NOT_OK: Reliable operation of the receive link for the remote PHY is detected. The rem_rcvr_status parameter is set to NOT_OK when the loc_rcvr_status parameter is NOT_OK. Once rem_rcvr_status is set to OK, it remains OK while loc_rcvr_status is OK.
PMA_RXINFOFRAME.request	This primitive is generated by the PCS Receive function to indicate whether a training frame incorporating a valid InfoField is detected. The rx_info_frame parameter can take on one of two values: TRUE, or FALSE TRUE: A training frame incorporating a valid InfoField is detected. FALSE: A training frame incorporating a valid InfoField is not detected. The rx_info_frame parameter is set to FALSE when the loc_rcvr_status parameter is NOT_OK. Once rx_info_frame is set to OK, it remains OK while loc_rcvr_status is OK. A received InfoField is valid if the first 3 octets of the received InfoField match the first 3 octets of the transmitted InfoField, and a CRC check performed on the last 9 octets of the received InfoField passes.

PMA Service Interface Primitives 4

Service Interface Primitive	Description
PMA_REMPHYIDLE.request	This primitive is generated by the PCS Receive function to indicate whether a sequence of symbols representing idle mode is detected. The rem_phy_idle parameter can take on one of two values: TRUE or FALSE TRUE: A sequence of symbols representing idle mode is detected. FALSE: A sequence of symbols representing idle mode is not detected. The rem_phy_idle parameter is set to FALSE when the pcs_rx_mode parameter is TRAIN. A sequence of symbols representing idle mode is detected if 256 consecutive control characters are received, each of which is either /I/ or /Ix/.
PMA_REMPHYREADY.request	This primitive is generated by the PCS Receive function to indicate whether a sequence of symbols representing idle mode with PHY ready encoding is detected. The rem_phy_ready parameter can take on one of two values: TRUE, or FALSE TRUE: A sequence of symbols representing idle mode with PHY ready encoding is detected. FALSE: A sequence of symbols representing idle mode with PHY ready encoding is not detected. The rem_phy_ready parameter is set to FALSE when the pcs_rx_mode parameter is TRAIN. A sequence of symbols representing idle mode with PHY ready encoding is detected if 4 consecutive control characters are received, each of is /I/.
PMA_TXINFOFRAMEEND.request	This primitive is generated by the PCS Transmit function to indicate whether the parameter tx_symb conveys the last symbol of a training frame incorporating an InfoField. The tx_info_frame_end parameter can take on one of two values: TRUE, or FALSE TRUE: The parameter tx_symb conveys the last symbol of a training frame incorporating an InfoField. FALSE: The parameter tx_symb does not convey the last symbol of a training frame incorporating an InfoField.

PMA Service Interface Primitives 5

Service Interface Primitive	Description
PMA_RSADV.request	This primitive is generated by the PCS Transmit function to indicate whether RS-FEC capability is advertised to the link partner. The rs_adv parameter can take on one of two values: TRUE or FALSE. TRUE: RS-FEC capability is advertised to the link partner. FALSE: RS-FEC capability is not advertised to the link partner.
PMA_EEEADV.request	This primitive is generated by the PCS Transmit function to indicate whether EEE capability is advertised to the link partner. The eee_adv parameter can take on one of two values: TRUE or FALSE. TRUE: EEE capability is advertised to the link partner. FALSE: EEE capability is not advertised to the link partner.
PMA_LPIADV.request	This primitive is generated by the PCS Transmit function to indicate whether LPI capability is advertised to the link partner. The lpi_adv parameter can take on one of two values: TRUE or FALSE. TRUE: LPI capability is advertised to the link partner. FALSE: LPI capability is not advertised to the link partner.
PMA_SEQADV.request	This primitive is generated by the PCS Transmit function to indicate whether SEQ capability is advertised to the link partner. The seq_adv parameter can take on one of two values: TRUE or FALSE. TRUE: SEQ capability is advertised to the link partner. FALSE: SEQ capability is not advertised to the link partner.

PMA Service Interface Primitives 6

Service Interface Primitive	Description
PMA_LP_RSADV.request	This primitive is generated by the PCS Transmit function to indicate whether RS-FEC capability is advertised by the link partner. The lp_rs_adv parameter can take on one of two values: TRUE or FALSE. TRUE: RS-FEC capability is advertised by the link partner. FALSE: RS-FEC capability is not advertised by the link partner.
PMA_LP_EEEADV.request	This primitive is generated by the PCS Transmit function to indicate whether EEE capability is advertised by the link partner. The lp_eee_adv parameter can take on one of two values: TRUE or FALSE. TRUE: EEE capability is advertised by the link partner. FALSE: EEE capability is not advertised by the link partner.
PMA_LP_LPIADV.request	This primitive is generated by the PCS Transmit function to indicate whether LPI capability is advertised by the link partner. The lpi_adv parameter can take on one of two values: TRUE or FALSE. TRUE: LPI capability is advertised by the link partner. FALSE: LPI capability is not advertised by the link partner.
PMA_LP_SEQADV.request	This primitive is generated by the PCS Transmit function to indicate whether SEQ capability is advertised by the link partner. The lp_seq_adv parameter can take on one of two values: TRUE or FALSE. TRUE: SEQ capability is advertised by the link partner. FALSE: SEQ capability is not advertised by the link partner.

PMA Service Interface Primitives 7

Service Interface Primitive	Description
PMA_RSEN.indication	This primitive is generated by the PHY Control function to indicate whether RS-FEC ability is enabled. The rs_en parameter can take on one of two values: TRUE or FALSE. TRUE: RS-FEC ability is enabled. FALSE: RS-FEC ability is disabled.
PMA_EEEEN.indication	This primitive is generated by the PHY Control function to indicate whether EEE ability is enabled. The eee_en parameter can take on one of two values: TRUE or FALSE. TRUE: EEE ability is enabled. FALSE: EEE ability is disabled.
PMA_LPIEN.indication	This primitive is generated by the PHY Control function to indicate whether LPI ability is enabled. The lpi_en parameter can take on one of two values: TRUE or FALSE. TRUE: LPI ability is enabled. FALSE: LPI ability is disabled.
PMA_SEQEN.indication	This primitive is generated by the PHY Control function to indicate whether SEQ ability is enabled. The seq_en parameter can take on one of two values: TRUE or FALSE. TRUE: SEQ ability is enabled. FALSE: SEQ ability is disabled.

State Diagram Variables 1

State Diagram Variable	Description
config	Variable set by the PHY Control function and communicated through the PMA_CONFIG.indication primitive.
loc_rcvr_status	Variable set by the PMA Receive function and communicated through the PMA_RXSTATUS.indication primitive.
link_control	Parameter set by the Auto-negotiation function and communicated through the PMA_LINK.request primitive.
link_status	Variable set by the Link Monitor and communicated through the PMA_LINK.indication primitive.
pam3_detected	Variable set by the PMA receive function. Indicates that a signal is detected that is compatible with PAM3 signaling from the remote PHY and is not compatible with PAM2 signaling from the remote PHY. FALSE: A signal is not detected that is compatible with PAM3 signaling from the remote PHY, and is not compatible with PAM2 signaling from the remote PHY . TRUE: A signal is detected that is compatible with PAM3 signaling from the remote PHY, and is not compatible with PAM2 signaling from the remote PHY.
pcs_rx_mode	Variable set by the PHY Control function and communicated through the PMA_PCSRXMODE.indication primitive.
pma_refresh_status	Variable set by the Refresh Monitor function if the PHY supports LPI. Indicates the status of the Refresh Monitor. OK: A refresh failure has not been detected. FAIL: A refresh signal is not reliably detected within the allowed time window.

State Diagram Variables 2

State Diagram Variable	Description
ready_to_transmit	Variable set by the PHY Control function. When the parameter config is FOLLOWER. It indicates whether the PHY is ready to start transmitting. The criterion for setting this variable is left to the implementer. FALSE: The PHY is not ready to start transmitting. TRUE: The PHY is ready to start transmitting.
rem_phy_idle	Parameter set by the PCS Receive function and communicated through the PMA_REMPHYIDLE.request primitive.
rem_phy_ready	Parameter set by the PCS Receive function and communicated through the PMA_REMPHYREADY.request primitive.
rem_rcvr_status	Parameter set by the PCS Receive function and communicated through the PMA_REMRXSTATUS.request primitive.
rx_info_frame	Parameter set by the PCS Receive function and communicated through the PMA_REMRXSTATUS.request primitive.
timing_locked	Variable set by the PMA Receive function when the parameter config is FOLLOWER. It indicates whether the timing of the PHY is locked to the timing of the link partner sufficiently for reliable operation of the link. The criterion for setting this variable is left to the implementer. FALSE: The timing of the PHY is not locked to the timing of the link partner sufficiently for reliable operation of the link. TRUE: The timing of the PHY is locked to the timing of the link partner sufficiently for reliable operation of the link.

State Diagram Variables 3

State Diagram Variable	Description
tx_info_countdown_done	Variable set by the PHY Control function. Indicates the end of the countdown. When the PHY Control state diagram is in the INFO_COUNTDOWN state, a countdown is implemented by transmitting 3 training frames incorporating InfoField data. The tx_info_countdown_done variable is set to FALSE, when the PHY Control state diagram enters the INFO_COUNTDOWN state, and it is set to TRUE when the transmission of the 3rd of the 3 training frames associated with the countdown begins.
tx_info_frame_end	Parameter set by the PCS Transmit function and communicated through the PMA_TXINFOFRAMEEND.request primitive.
tx_mode	Variable set by the PHY Control function and communicated through the PMA_TXMODE.indication primitive.

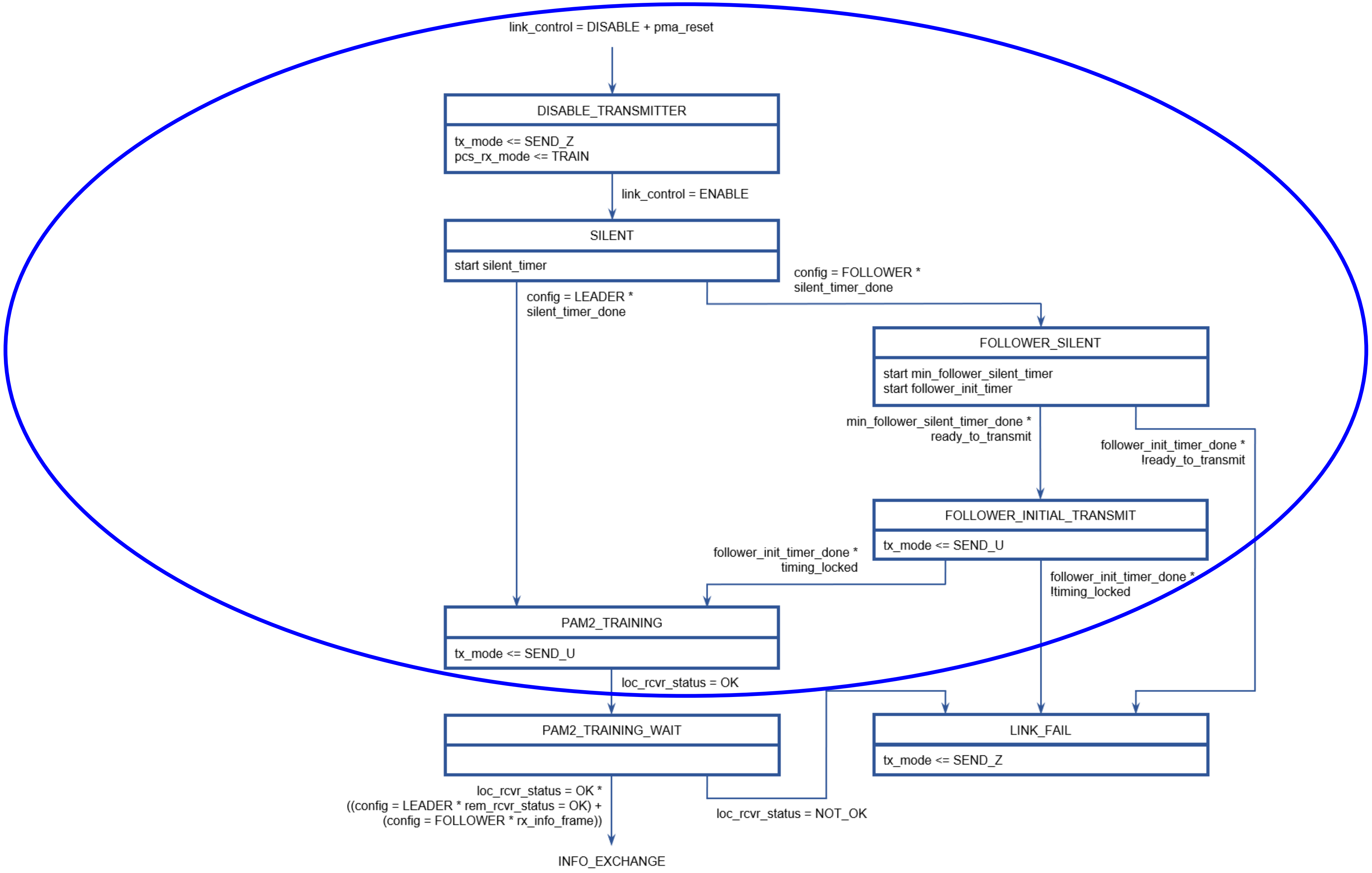
State Diagram Variables 4

State Diagram Variable	Description
rs_adv	Variable set by the PHY Control function and communicated through the PMA_RSADV.request primitive.
eee_adv	Variable set by the PHY Control function and communicated through the PMA_EEEADV.request primitive.
lpi_adv	Variable set by the PHY Control function and communicated through the PMA_LPIADV.request primitive.
seq_adv	Variable set by the PHY Control function and communicated through the PMA_SEQADV.request primitive.
lp_rs_adv	Variable set by the PHY Control function and communicated through the PMA_LP_RSADV.request primitive.
lp_eee_adv	Variable set by the PHY Control function and communicated through the PMA_LP_EEEADV.request primitive.
llp_pi_adv	Variable set by the PHY Control function and communicated through the PMA_LP_LPIADV.request primitive.
lp_seq_adv	Variable set by the PHY Control function and communicated through the PMA_LP_SEQADV.request primitive.
rs_en	Variable set by the PHY Control function and communicated through the PMA_RSEN.request primitive.
eee_en	Variable set by the PHY Control function and communicated through the PMA_EEEEN.request primitive.
lpi_en	Variable set by the PHY Control function and communicated through the PMA_LPIEN.request primitive.
seq_en	Variable set by the PHY Control function and communicated through the PMA_SEQEN.request primitive.

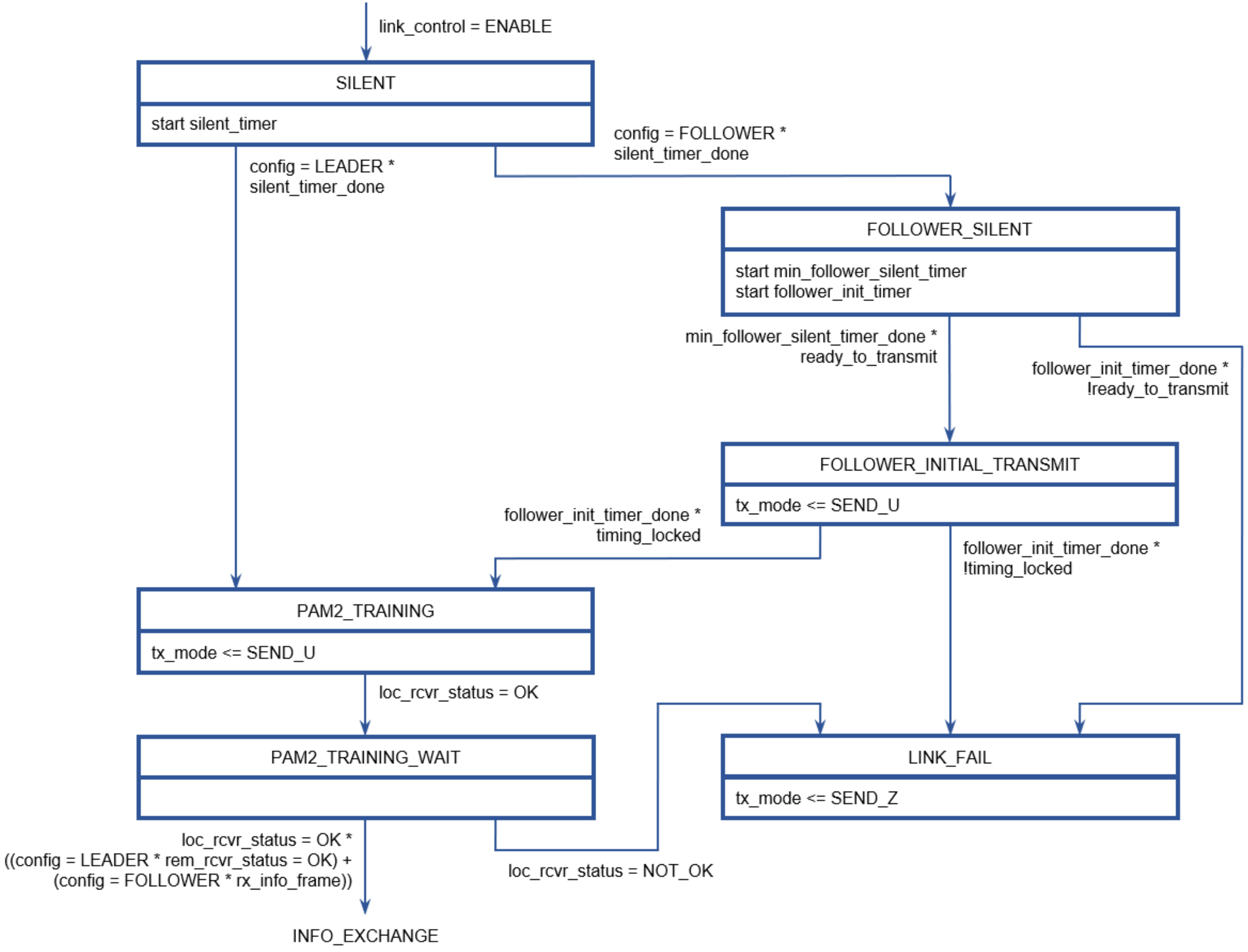
Timers

Timer	Description
silent_timer	A timer used to determine the amount of time the PHY Control state diagram stays in the SILENT state. The timer shall expire 1 ms ± 1 µs after being started.
min_follower_silent_timer	A timer used to determine the minimum amount of time the PHY Control state diagram stays in the FOLLOWER_SILENT state. The timer shall expire 15 ms ± 15 µs after being started.
follower_init_timer	A timer used to determine the amount of time the PHY Control state diagram stays in either the FOLLOWER_SILENT state or the FOLLOWER_INITIAL_TRANSMIT state. The timer shall expire 40 ms ± 40 µs after being started.
min_pam3_tuning_timer	A timer used to determine the minimum amount of time the PHY Control state diagram stays in the PAM3_TUNING state. The timer shall expire 5 ms ± 5 µs after being started.
lpi_refresh_rx_timer	This timer is used to monitor link quality when the PHY is in the LPI receive mode. If the PHY does not detect reliable refresh signaling before this timer expires then the PHY Control state diagram enters the LINK_FAIL state, which causes the link to drop. This timer shall expire 11.52 ms ± 12 µs after being started.

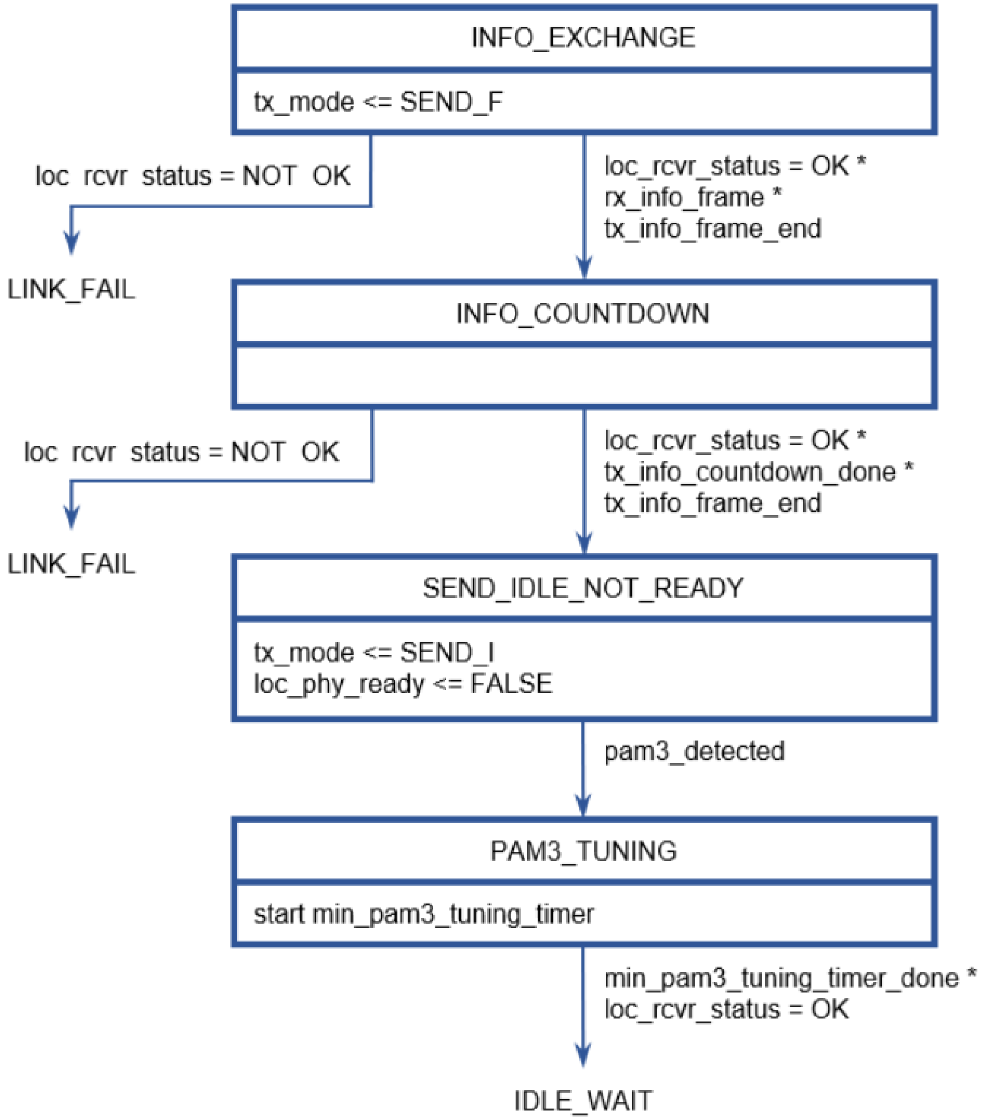
PHY Control State Diagram – DISABLE_TRANSMITTER → PAM2_TRAINING



PHY Control State Diagram – SILENT → PAM2_TRAINING_WAIT



PHY Control State Diagram – INFO_EXCHANGE → PAM3_TUNING



INFO_EXCHANGE

tx_mode <= SEND_F

loc rcvr status = NOT OK

LINK_FAIL

loc_rcvr_status = OK *
rx_info_frame *
tx_info_frame_end

INFO_COUNTDOWN

loc rcvr status = NOT OK

LINK_FAIL

loc_rcvr_status = OK *
tx_info_countdown_done *
tx_info_frame_end

SEND_IDLE_NOT_READY

tx_mode <= SEND_I
loc_phy_ready <= FALSE

pam3_detected

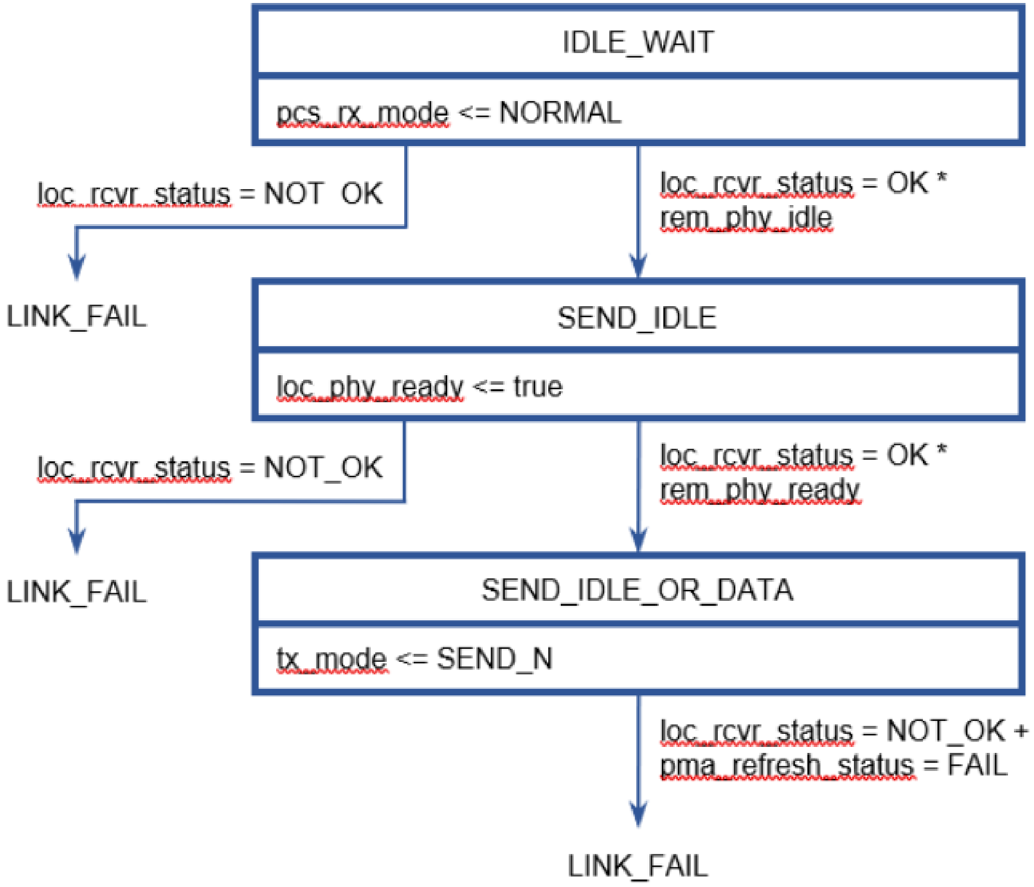
PAM3_TUNING

start min_pam3_tuning_timer

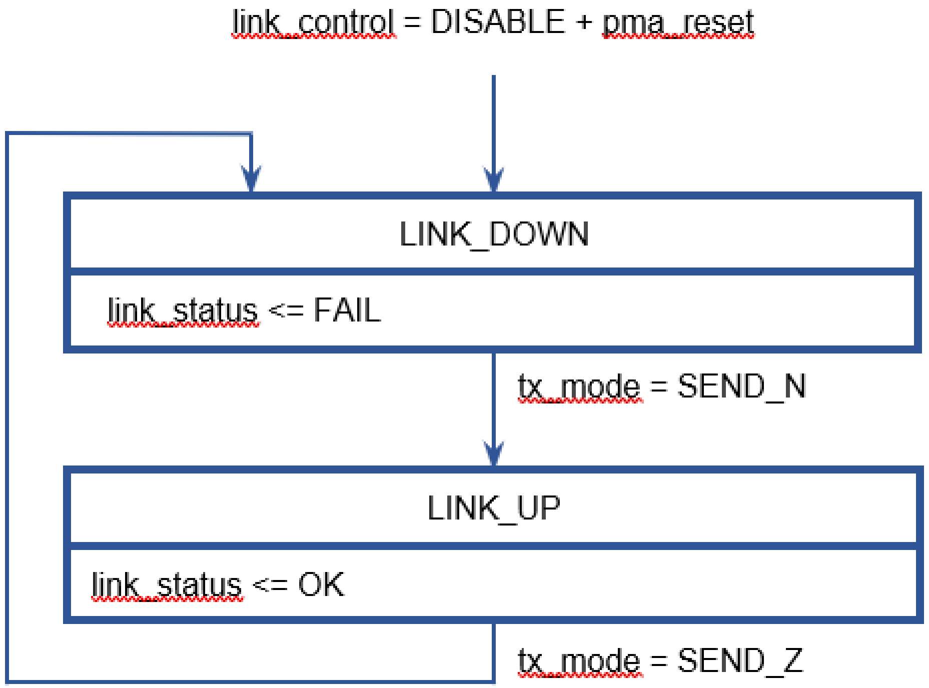
min_pam3_tuning_timer_done *
loc_rcvr_status = OK

IDLE_WAIT

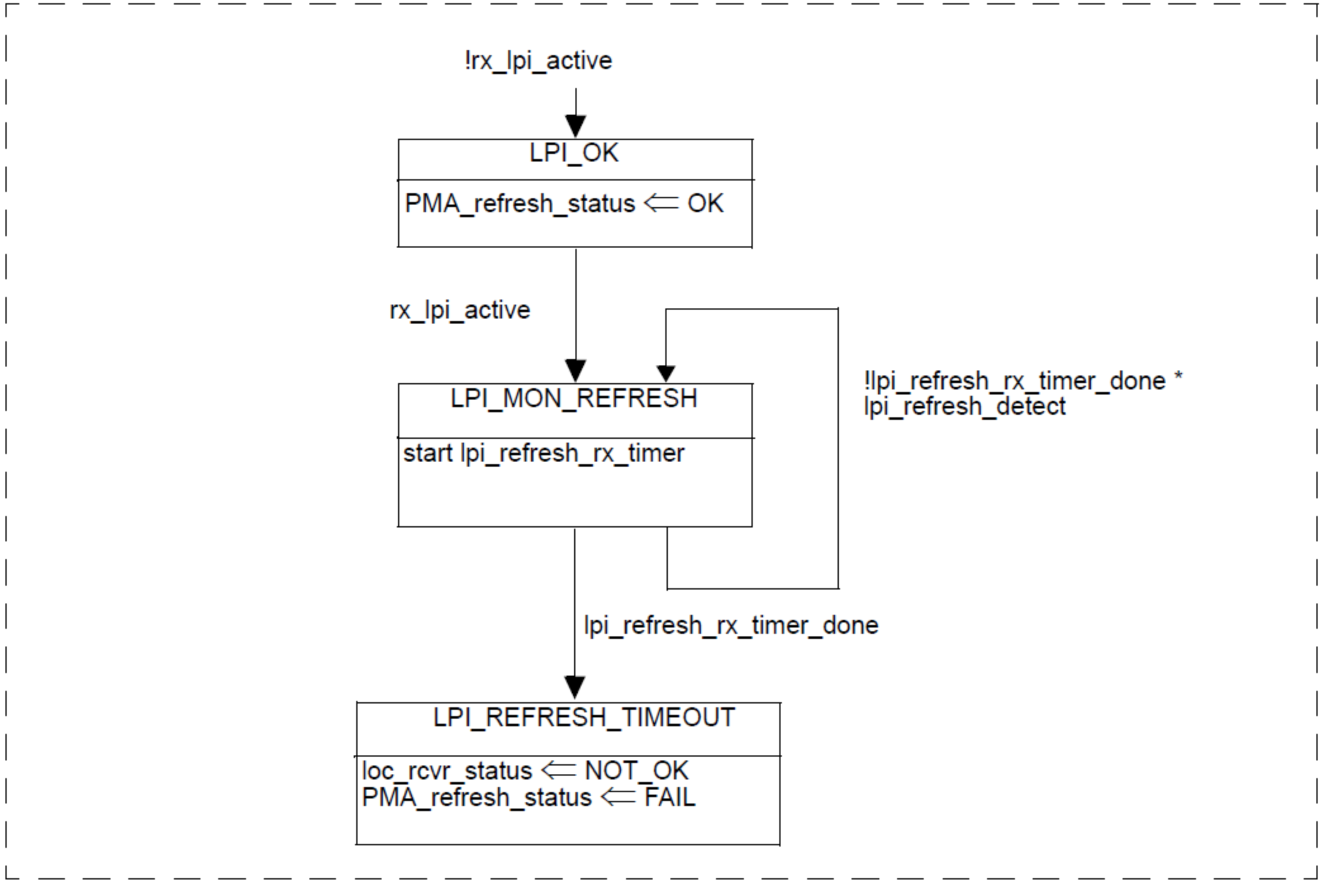
PHY Control State Diagram – IDLE_WAIT → SEND_IDLE_OR_DATA



Link Monitor State Diagram – LINK_DOWN → LINK_UP



Refresh Monitor State Diagram



NOTE—The functionality of this state diagram is only required when the PHY supports EEE.

Figure 165–24—EEE Refresh monitor state diagram

Clause 45 100BASE-T1L Capabilities Register

- The assignment of bits in the 100BASE-T1L capabilities register (Register 3.YYYY) is shown in the following Table

Bit(s)	Name	Description	R/W
3.YYYY.15:4	Reserved	Value always 0	RO
3.YYYY.3	100BASE-T1L SEQ capability	1 = PHY has 100BASE-T1L SEQ capability 0 = PHY does not have 100BASE-T1L SEQ capability	R/O
3.YYYY.2	100BASE-T1L LPI capability	1 = PHY has 100BASE-T1L LPI capability 0 = PHY does not have 100BASE-T1L LPI capability	R/O
3.YYYY.1	100BASE-T1L EEE capability	1 = PHY has 100BASE-T1L EEE capability 0 = PHY does not have 100BASE-T1L EEE capability	R/O
3.YYYY.0	100BASE-T1L RS-FEC capability	1 = PHY has 100BASE-T1L RS-FEC capability 0 = PHY does not have 100BASE-T1L RS-FEC capability	R/O

- 100BASE-T1L SEQ capability (3.YYYY.3)
  - When read as a one, this bit indicates that the PHY supports 100BASE-T1L SEQ. When read as a zero, this bit indicates that the PHY does not support 100BASE-T1L SEQ.
- Same text for LPI, EEE and RS-FEC

Clause 45 100BASE-T1L Advertisement Register

- The assignment of bits in the 100BASE-T1L advertisement register (Register 3.YYYY) is shown in the following Table

Bit(s)	Name	Description	R/W
3.YYYY.15:4	Reserved	Value always 0	RO
3.YYYY.3	100BASE-T1L SEQ advertisement	1 = 100BASE-T1L SEQ capability advertised to link partner 0 = 100BASE-T1L SEQ capability not advertised to link partner	R/W
3.YYYY.2	100BASE-T1L LPI advertisement	1 = 100BASE-T1L LPI capability advertised to link partner 0 = 100BASE-T1L LPI capability not advertised to link partner	R/W
3.YYYY.1	100BASE-T1L EEE advertisement	1 = 100BASE-T1L EEE capability advertised to link partner 0 = 100BASE-T1L EEE capability not advertised to link partner	R/W
3.YYYY.0	100BASE-T1L RS-FEC advertisement	1 = 100BASE-T1L RS-FEC capability advertised to link partner 0 = 100BASE-T1L RS-FEC capability not advertised to link partner	R/W

- 100BASE-T1L LPI advertisement (3.YYYY.2)
  - When set as a one, this bit indicates to the link partner that the 100BASE-T1L PHY is advertising 100BASE-T1L LPI capability. When set as a zero, this bit indicates to the link partner that the 100BASE-T1L PHY is not advertising 100BASE-T1L LPI capability.
  - This bit shall be set to zero if the 100BASE-T1L PHY does not support 100BASE-T1L LPI or when bit 3.YYYY.1 is set to 0.

Clause 45 100BASE-T1L Link Partner Advertisement

- The assignment of bits in the 100BASE-T1L link partner advertisement register (Register 3.YYYY) is shown in the following Table

Bit(s)	Name	Description	R/W
3.YYYY.15:4	Reserved	Value always 0	RO
3.YYYY.3	100BASE-T1L SEQ advertisement	1 = 100BASE-T1L SEQ capability advertised by link partner 0 = 100BASE-T1L SEQ capability not advertised by link partner	R/W
3.YYYY.2	100BASE-T1L LPI advertisement	1 = 100BASE-T1L LPI capability advertised by link partner 0 = 100BASE-T1L LPI capability not advertised by link partner	R/W
3.YYYY.1	100BASE-T1L EEE advertisement	1 = 100BASE-T1L EEE capability advertised by link partner 0 = 100BASE-T1L EEE capability not advertised by link partner	R/W
3.YYYY.0	100BASE-T1L RS-FEC advertisement	1 = 100BASE-T1L RS-FEC capability advertised by link partner 0 = 100BASE-T1L RS-FEC capability not advertised by link partner	R/W

- 100BASE-T1L LPI link partner advertisement (3.YYYY.2)
  - When read as a one, this bit indicates that the 100BASE-T1L link partner is advertising 100BASE-T1L LPI capability. When read as a zero, this bit indicates that the 100BASE-T1L link partner is not advertising 100BASE-T1L LPI capability.
- Same text for SEQ, EEE and RS-FEC

Conclusion

- The PHY Control State Diagram for 100BASE-T1L has been presented including the following
  - The operation of the PCS during training and the training frame format
  - The details of the PMA functions, the TDI and PMA service interface primitives, the state diagram variables, the timers and detailed state diagrams
  - A description of the PCS functions required during training, the generation of the sequences of PAM2 symbols and the formatted training frames
  - The equations to generate the sequence of PAM2 symbols and training frame, the table of 4b6B NND PAM2 6-tuples and the equations for running disparity
  - The resolution of the optional PHY abilities
- The authors will follow with additional text to accompany this presentation

History

- The scrambler definition on slides 4 and 5 is as adopted in Motion #6 on 9/17/2024 from Murray_3dg_02_09172024
- The table of 4b6B NND PAM2 6-tuples on slide 10 is from Tingting_3dg_01_18_12_2024
- The equations for the running disparity calculation on slide 11 is equivalent to the scheme in Tingting_3dg_01_18_12_2024
- The Refresh Monitor state diagram on slide 34 is from 802.3cy Figure 165-24
- The order and content of the presentation in general follows clause 165.4 (802.3cy)

Questions ?