Energy Efficient Ethernet (EEE) specification for GEPOF

Rubén Pérez-Aranda
(rubenpda@kdpof.com)

Agenda

- Background and objectives
- 802.3 EEE introduction
- EEE specification for GEPOF

Background & Objectives

- In 802.3bv TF interim meeting of January 2015, the FEC and modulation schemes proposed in [1] were adopted for the baseline together with the transmission scheme defined in [2]
- Based on the transmission scheme of [2], an specification to implement Low Power Idle (LPI) mode is provided here

802.3 EEE introduction

802.3 EEE introduction (based on Clause 78)

- The optional EEE capability combines the MAC sublayer with a PHY defined to support the operation in the Low Power Idle (LPI) mode. When the LPI mode is enabled, systems on both sides of the link can save power during periods of low link utilization.
- EEE protocol is defined to coordinate transitions to or from low power and does this without changing the link status and without dropping or corrupting Ethernet frames.
- LPI signaling allows to LPI client to indicate to the PHY, and to the link partner, that a break in the data stream is expected, and the LPI client can use it to enter power-saving modes that require additional time to resume normal operation.
- PHY LPI TX operation:
  - The LPI client requests the PHY to transition to its low power state by encoding "Assert LPI" on the GMII, then the PHY signals sleep to its link partner to indicate that the local transmitter is entering LPI mode
  - After local PHY signals sleep during a time, the local PHY transmitter goes quiet
  - The transmit function of the local PHY is enabled periodically to transmit refresh signals that are used by the link partner to maintain link integrity (keep aligned timing, equalizer circuits)
  - The quiet-refresh cycle continues until the reception of normal interframe encoding on the GMII, which is communicated by the local PHY to its link partner with wake signal for a predefined period of time. Then the PHY enters in normal operation mode.

802.3 EEE introduction

- PHY LPI RX operation:
  - Entering the LPI mode is triggered by the reception of a sleep signal from the link partner. After sending the sleep signal, the link partner will cease transmission.
  - When the receiver detect sleep signal, the local PHY indicates “Assert LPI” in the GMII and the local receiver can disable some functionality to reduce power consumption.
  - Local PHY will use the refresh signals periodically sent by the link partner to update equalization and timing.
  - When wake signal sent by the link partner is detected by the receiver, the local PHY prepares for normal operation and transition from “Assert LPI” encoding to normal interframe encoding on the GMII.
  - After specified amount of time for recovery, the link supports the nominal operational data rate
- The EEE proposal for GEPOF presented here allows independent LPI mode operation of the two communication directions, being possible to independently save power as function of the link utilization of each direction

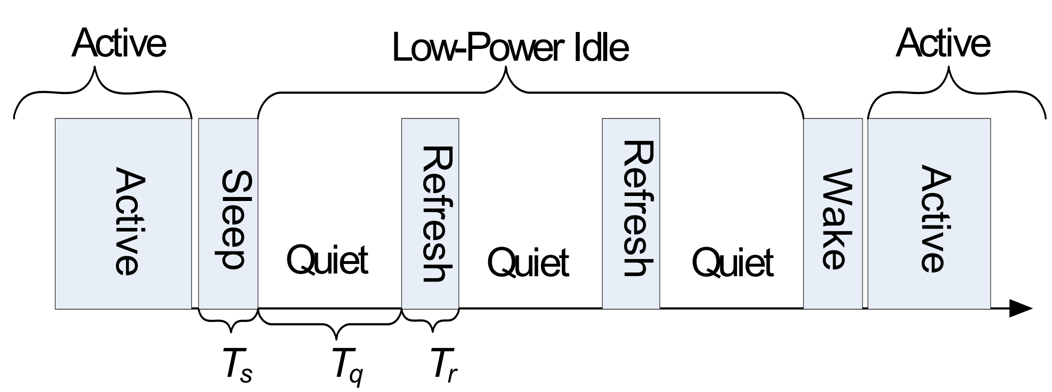


Figure 78–3—Overview of EEE LPI operation

802.3 EEE introduction - GMII encoding

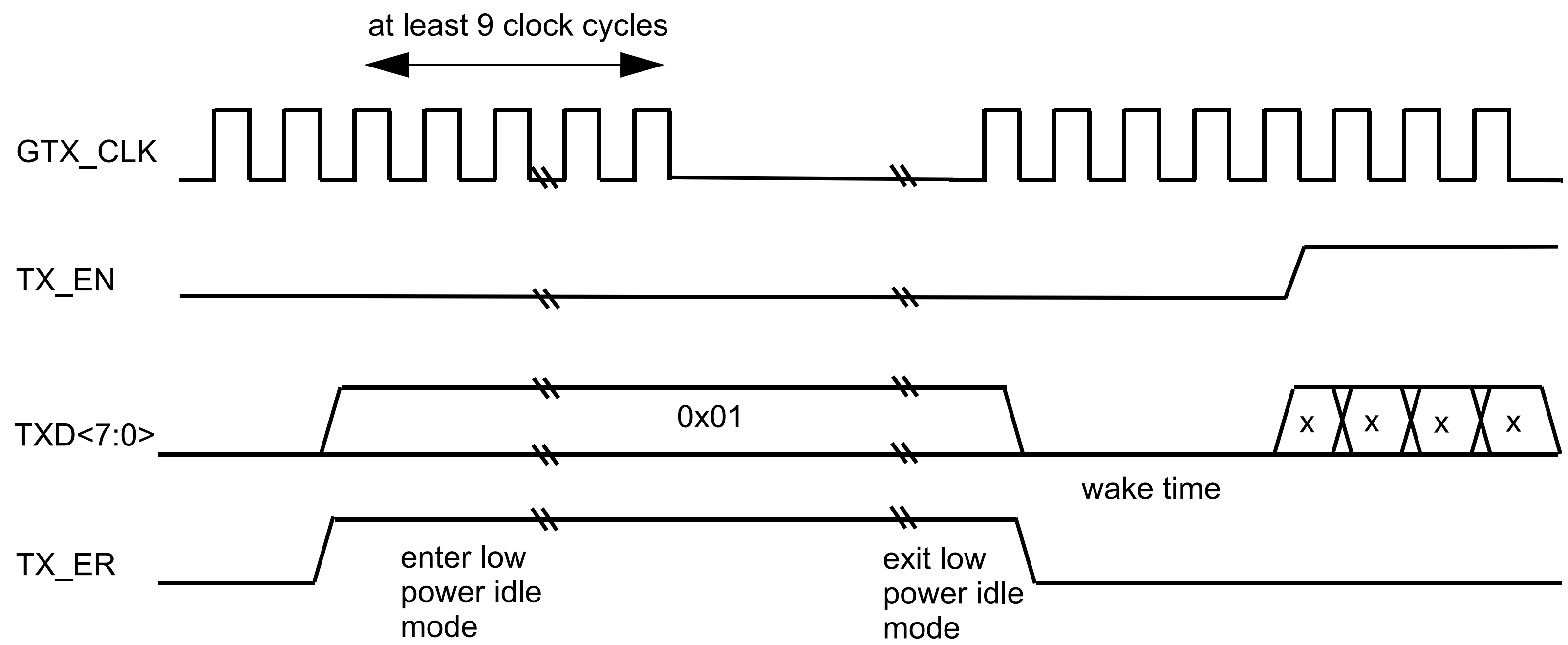


Figure 35–8—LPI transition

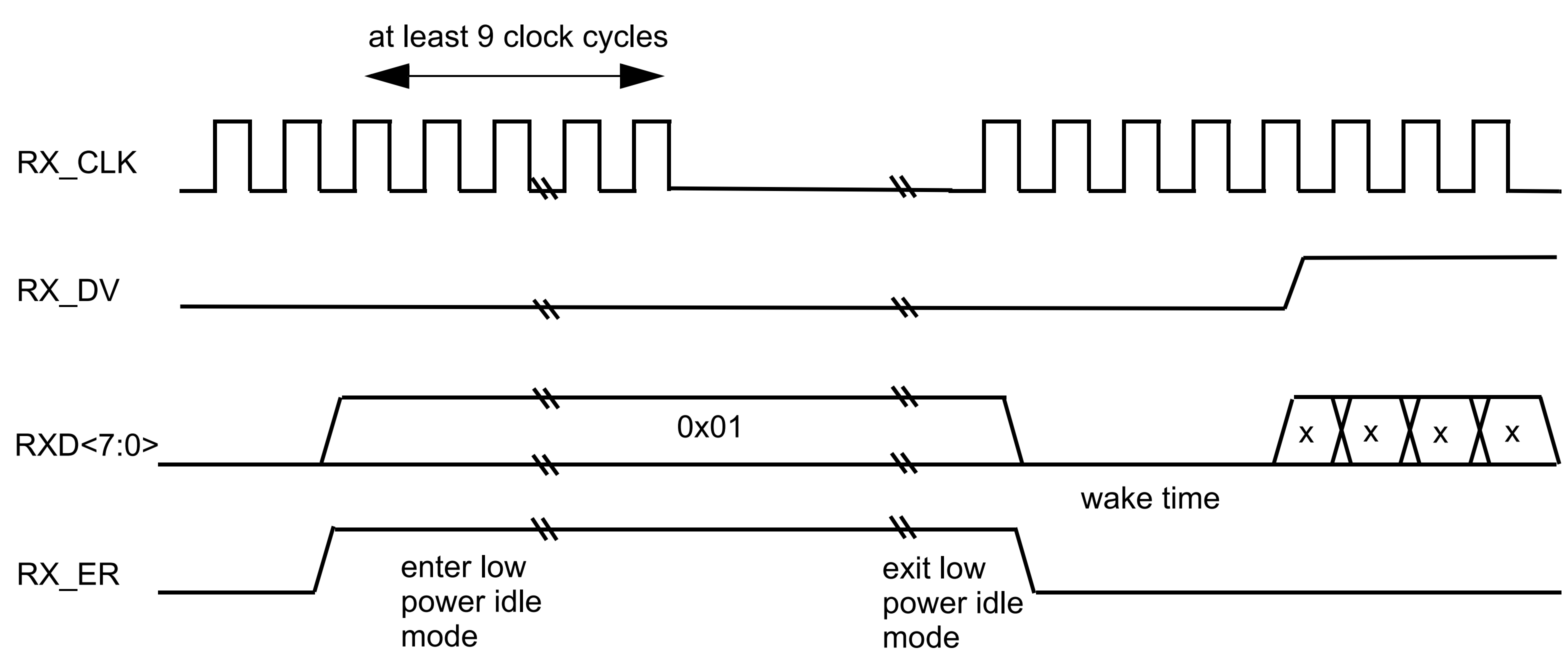


Figure 35–14—LPI transitions (receive)

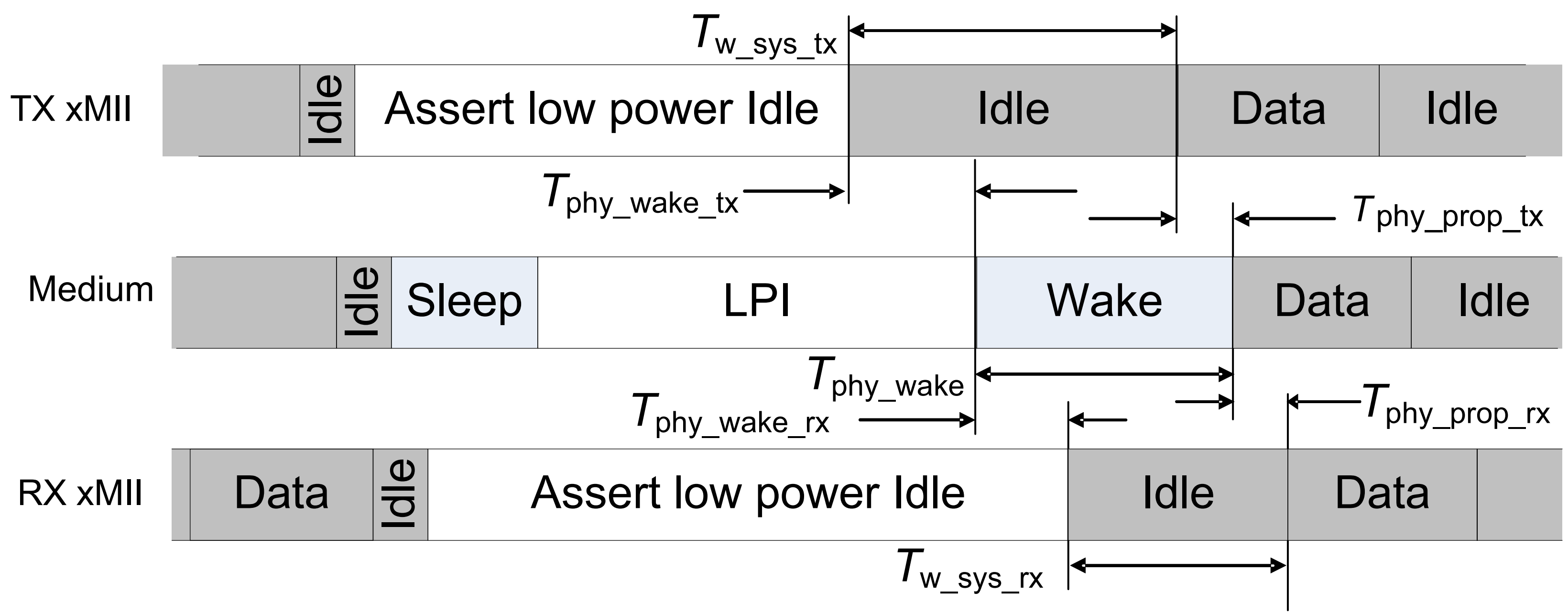
802.3 EEE introduction - timing

- For a technically complete EEE proposal for GEPOF, we need to define a set of timing parameters to be included within the Clause 78 (tables 78-2 and 78-4)

78.2 LPI mode timing parameters description

T_s The period of time that the PHY transmits the sleep signal before turning all transmitters off
T_q The period of time that the PHY remains quiet before sending the refresh signal
T_r Duration of the refresh signal
$T_{phy\_prop\_tx}$ The propagation delay of a given unit of data from the xMII to the MDI
$T_{phy\_prop\_rx}$ The propagation delay of a given unit of data from the MDI to the xMII
$T_{phy\_shrink\_tx}$ Transmitter shrinkage time, defined as the absolute time difference between the following two timing parameters:
—Delay between a transition from the "Assert LPI" to "Normal Idle" at the xMII and the corresponding start of the wake signal at the MDI
—$T_{phy\_prop\_tx}$
$T_{phy\_shrink\_rx}$ Receiver shrinkage time, defined as the absolute time difference between the following two timing parameters:
—Delay between start of the wake signal at the MDI and the corresponding transition from "Assert LPI" to "Normal Idle" at the xMII
—$T_{phy\_prop\_rx}$
T_{w_phy} Parameter employed by the system that corresponds to the behavior of the PHY. It is the period of time between reception of an IDLE signal on the xMII and when the first data code-words are permitted on the xMII. The wake time of a compliant PHY does not exceed T_{w_phy} (min).
$T_{w\_sys\_tx}$ Parameter employed by the system that corresponds to its requirements. It is the longest period of time the system has to wait between a request to transmit and its readiness to transmit.
$T_{w\_sys\_rx}$ Parameter employed by the system that corresponds to its requirements. It is the minimum time required by the system between a request to wake and its readiness to receive data.

802.3 EEE introduction - timing



$T_{w\_sys\_tx}$ (min) $= T_{w\_sys\_rx}$ (min) $+ T_{phy\_shrink\_tx}$ (max) $+ T_{phy\_shrink\_rx}$ (max)
T_{w_phy} (min) $= T_{phy\_wake}$ (min) $+ T_{phy\_shrink\_tx}$

$T_{w\_sys\_res}$ (min) is greater of $T_{w\_sys\_tx}$ (min) and T_{w_phy} (min)

$T_{phy\_shrink\_tx}$ (max) $= (T_{phy\_wake\_tx}$ (max) $- T_{phy\_prop\_tx}$ (min))
$T_{phy\_shrink\_rx}$ (max) $= (T_{phy\_wake\_rx}$(max) $- T_{phy\_prop\_rx}$ (min))

where

$T_{phy\_wake\_tx}$ = xMII start of wake to MDI start of wake delay
$T_{phy\_prop\_tx}$ = xMII to MDI data propagation delay
$T_{phy\_wake\_rx}$ = MDI start of wake to xMII start of wake delay
$T_{phy\_prop\_rx}$ = MDI to xMII data propagation delay
T_{phy_wake} = Minimum wake duration required by PHY

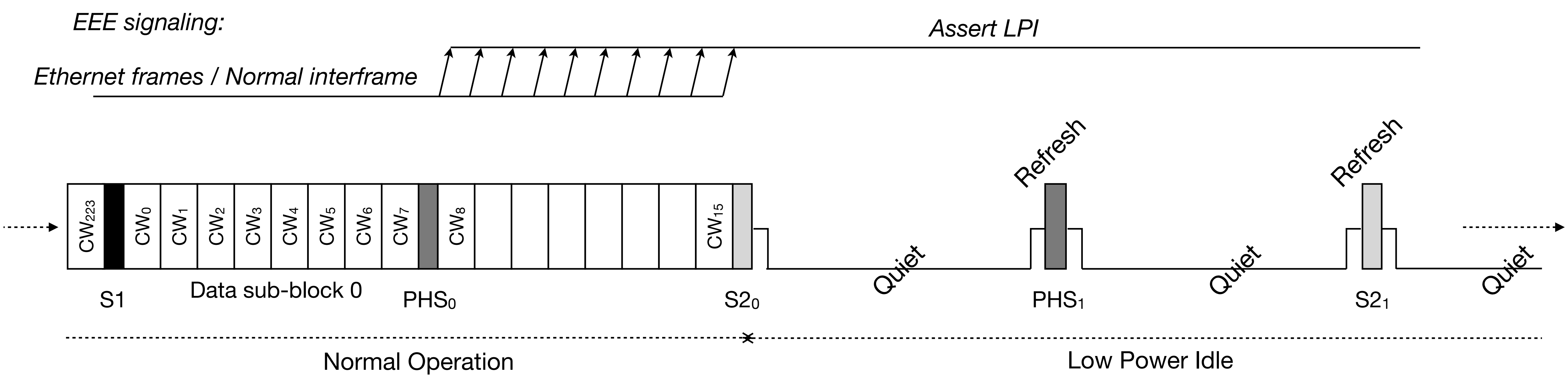
Figure 78–4—LPI mode timing parameters and their relationship to minimum system wake time

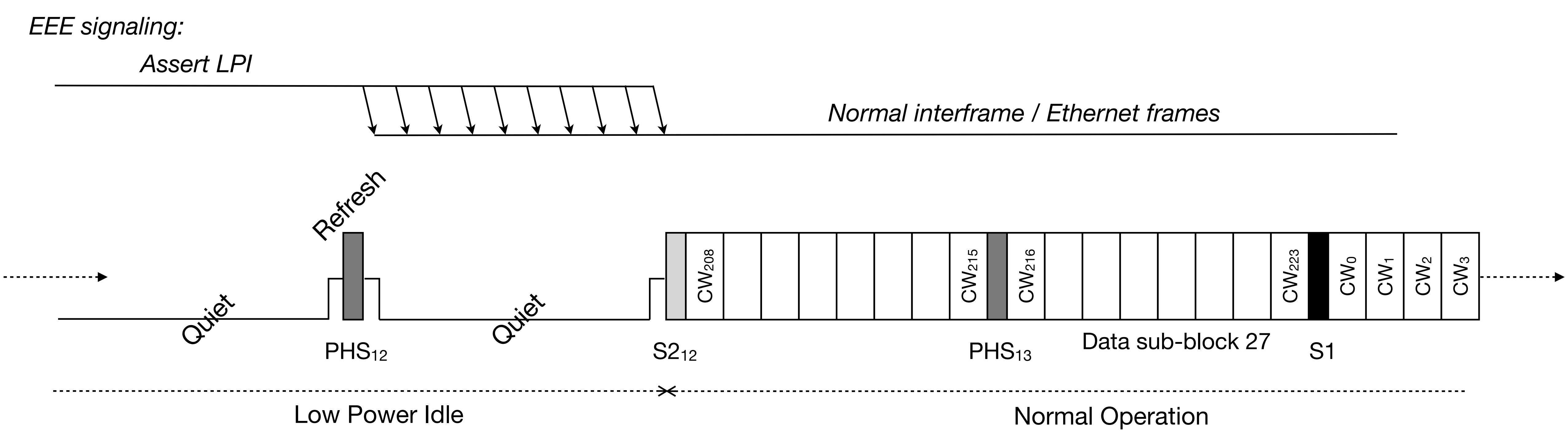
EEE specification for GEPOF

LPI in GEPOF - introduction

- Physical header PHD is used by both link partners to agree the capability to accept and generate transmission blocks implementing LPI mode during the startup (PHD.CAP.LPI [3])
- Basic idea behind LPI proposal for GEPOF:
  - The PHY partially turns off the PCS, PMA and PMD TX functionalities during the payload sub-blocks when LPI is asserted from LPI client, so that no optical power is injected into the fiber during these periods of time
  - On the other side, the receiver of the remote PHY, which has established the link and is aligned in timing with the local PHY, detects after every pilot and PHS sub-block, the state of its partner based on the signal received during the first symbols of the payload sub-blocks
  - Because both PHYs are synchronized, the receiver knows the timing for each element of the received signal, therefore is able to enable the PCS, PMA and PMD circuitry just for the reception of the pilot and PHS sub-blocks
- In both, normal and LPI operation modes, all the pilot and PHS sub-blocks are transmitted, although in LPI mode the transmission is switched off during the data sub-blocks
- The receiver is able to use pilots and PHS to keep aligned equalizers and timing
- The LPI mode always affects complete payload data sub-blocks, therefore it is not possible to stop or restart the transmission in the middle of a payload sub-block

LPI in GEPOF - operation





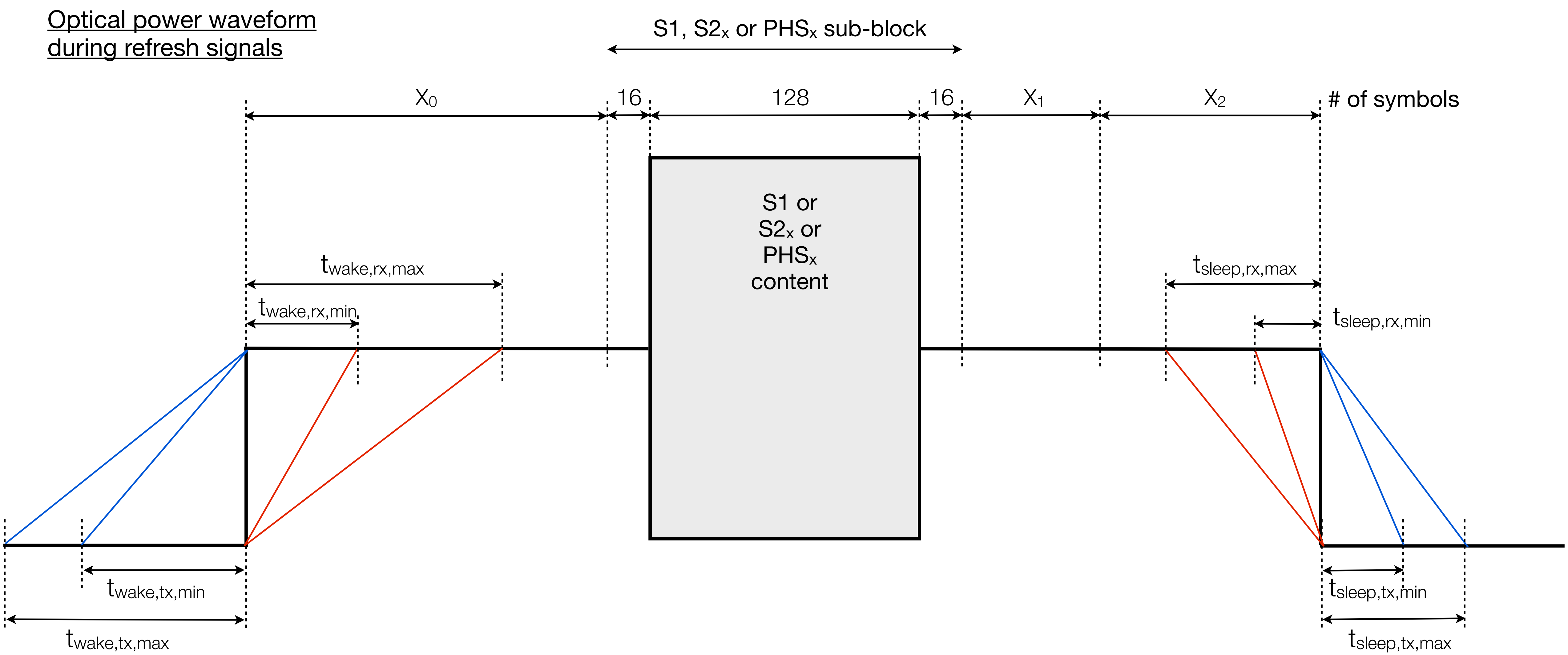
LPI in GEPOF - operation

- PHY LPI TX operation:
  - The LPI client requests the PHY transmit function to transition to low power state by encoding “Assert LPI” on the GMII
  - The PHY TX function encodes the “Assert LPI” signal on the PDB blocks as defined in [5]
  - Once at least one “Assert LPI” encoded on a PDB has been transmitted to the link partner, the transmit function of the local PHY shall be able to go quiet state aligned to the beginning of the next data payload sub-block if no transition to normal inter-frame is signaled before the end of the current data payload sub-block
  - The transmit function of the local PHY is enabled periodically to transmit pilot and PHS sub-blocks (refresh signals), which are transmitted just in the same instants of time corresponding to normal operating mode
  - The PHY transmitter indicates to receiver it is entering quiet period in each payload sub-block time slot by the transmission of 130 contiguous zero value symbols. These 130 zero symbols are appended to the zero post-fix of the preceding pilot or PHS sub-block, composing a total of 146 zero symbols. After zeroes sequence the transmitter shall instruct to PMD TX to switch off the optical power until 130 symbol times before the end of the payload data sub-block period.
  - The transmitter shall insert 130 zero value symbols before the transmission of the corresponding pilot or PHS sub-block to prepare the reception of refresh signals.
  - The quiet-refresh cycle continues until the reception of normal inter-frame encoding on the GMII
  - When normal inter-frame is signaled, the transmit function of the local PHY starts the normal operation aligned to the beginning of the next payload sub-block, therefore transmitting FEC codewords after the corresponding pilot or PHS sub-block

LPI in GEPOF - operation

- PHY LPI RX operation:
  - Entering the LPI mode is triggered by the detection of the sequence of zero symbols after the reception of a pilot or PHS sub-block
  - When the receiver detects this event, the local PHY encodes “Assert LPI” on the GMII and disables some functionality to reduce power consumption: partial PMD, PMA and PCS Rx functionalities
  - Note that “Assert LPI” on the GMII can also be encoded due to the reception of PDBs containing LPI signaling from the link partner; this is the case of LPI assertion on the GMII Tx in the middle of a payload sub-block transmission
  - Local PHY shall use the pilots and PHS sub-blocks (refresh signals) periodically sent by the link partner to update equalization and timing and to determine the value of variable loc_rcvr_status. Therefore, in LPI mode, the receiver shall use the refresh signals to estimate the quality of decoding (i.e. link margin) of payload sub-blocks that is expected when normal operation re-enters
  - This quiet-refresh cycle continues until the presence of PAM TH precoded signal in the time slot corresponding to a payload sub-block is detected. Then, the local PHY receiver starts normal operation and sends to the GMII data contained on the PDBs received from the remote PHY. The PCS decoding shall start aligned to the boundary of the first complete PDB received from the beginning of the payload data sub-block.
  - At this moment, the local PHY shall start to send normal inter-frame encoding on the GMII, since this is the information received from the remote PHY and the link is ready to provide nominal data rate

LPI in GEPOF - PMD timing



- $X_0 \geq t_{wake,rx,max}$ (= 400 ns by Avago), therefore $X_0 \geq 130$ symbols
- $X_2 \geq t_{sleep,rx,max}$ (= 200 ns by Avago), therefore $X_2 \geq 65$ symbols
- $X_1 \geq$ the min length to detect quiet period with reliability (~32 by KDPOF)
- For symmetry, $X_0 = X_1 + X_2 = 130$

LPI in GEPOF - C/78 timing parameters

- Tables 78-2 and 78-4 timing parameters are based on:
  - $T_{pilot/PHS}$ = (16 + 128 + 16 + 130 + 130)/325 = 1.2923 µs
  - $T_{payload}$ = (8 * 988 - 130 - 130)/325 = 23.52 µs
  - $T_{pilot/PHS}$ + $T_{payload}$ = 24.8123 µs

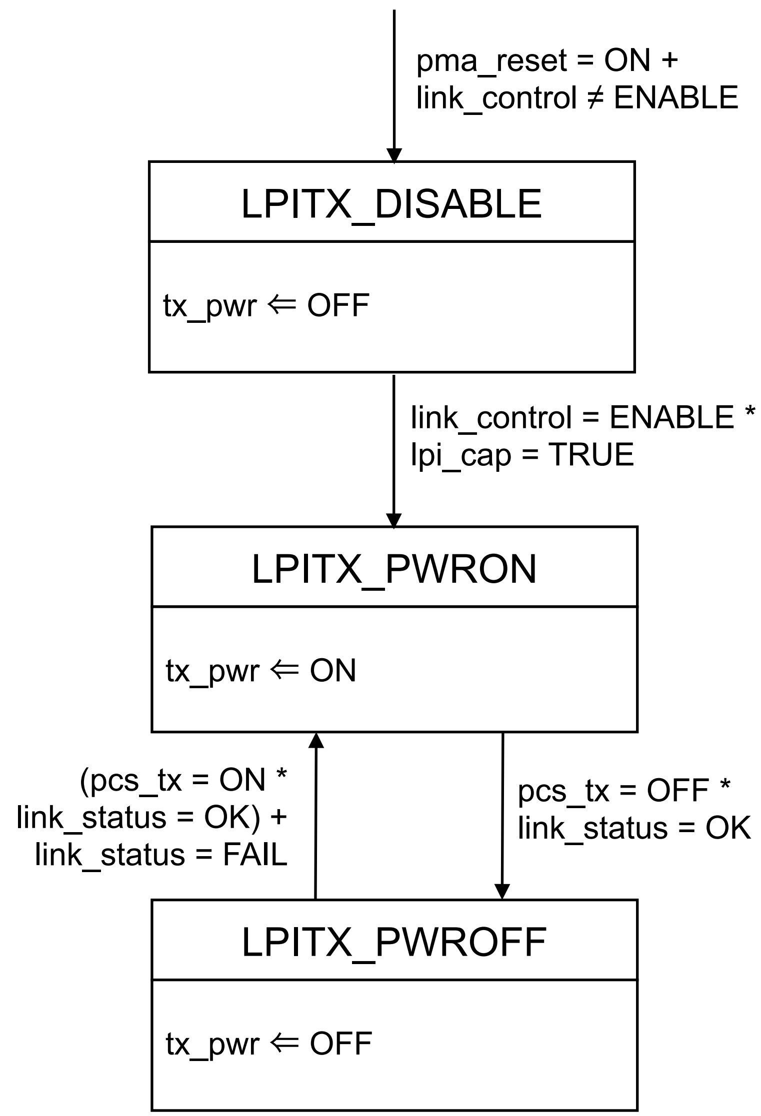
Table 78-2 — Summary of the key EEE parameters for supported PHYs or interfaces

PHY or interface type	T_s (µs)		T_q (µs)		T_r (µs)	
	Min	Max	Min	Max	Min	Max
1000BASE-RH	0	0	23.52	23.52	1.30	1.30

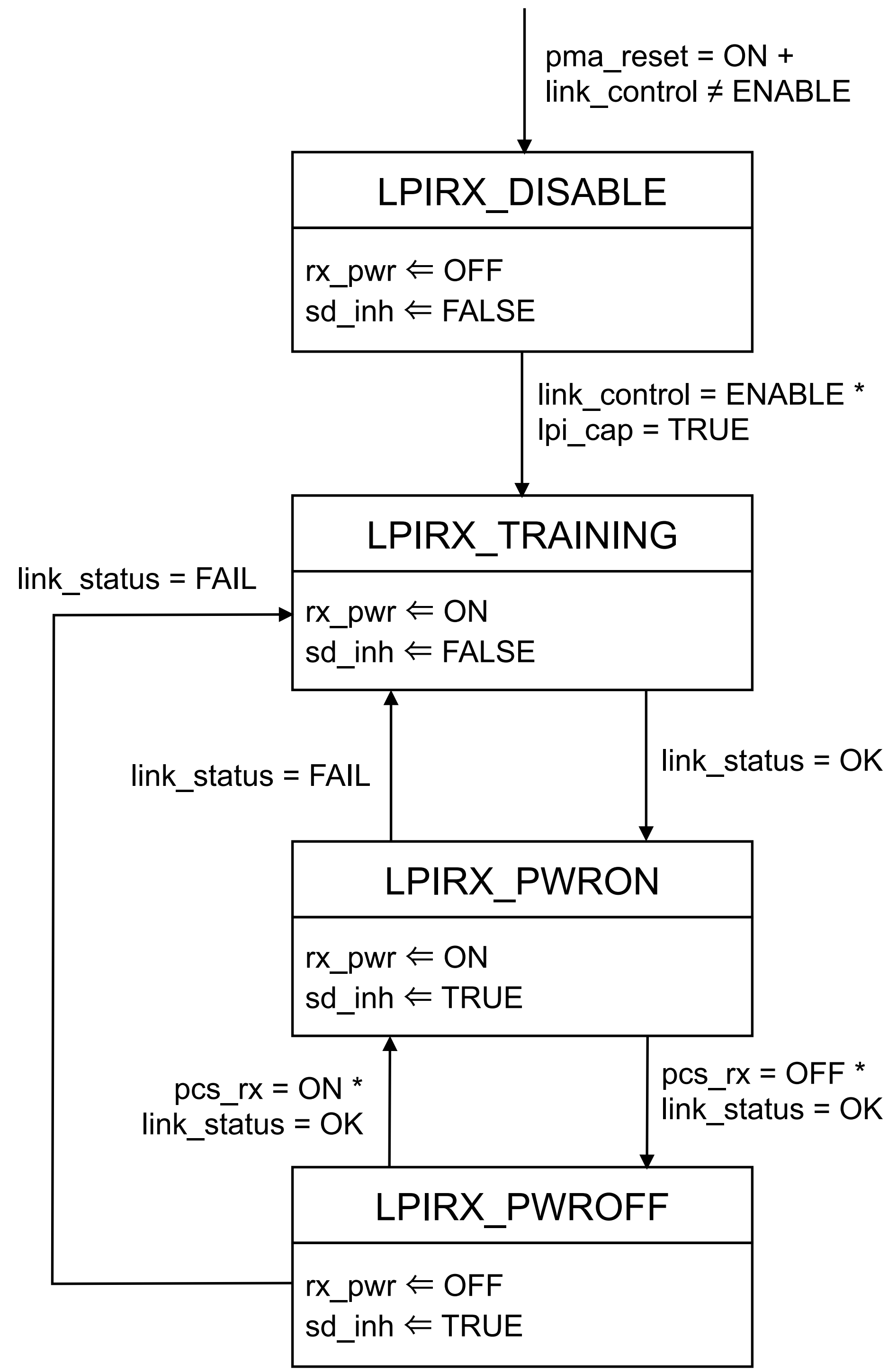
Table 78-4 — Summary of the LPI timing parameters for supported PHYs or interfaces

PHY or interface type	Case	$T_{w\_sys\_tx}$ (min) (µs)	T_{w_phy} (min) (µs)	$T_{phy\_shrink\_tx}$ (max) (µs)	$T_{phy\_shrink\_rx}$ (max) (µs)	$T_{w\_sys\_rx}$ (min) (µs)
1000BASE-RH		24.82	24.82	24.82	0	0

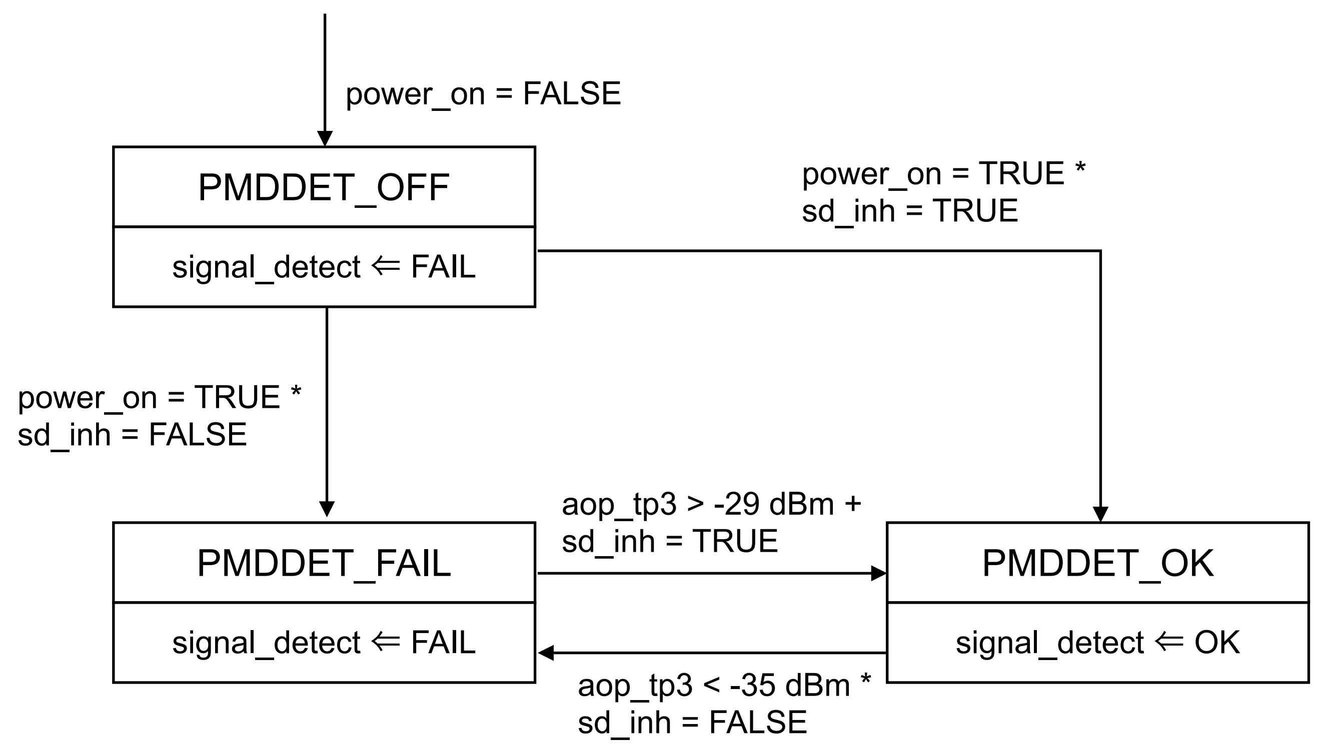
LPI in GEPOF - PCS state diagrams



LPI in GEPOF - PCS state diagrams



LPI in GEPOF - PMD state diagrams



References

- [1] *Rubén Pérez-Aranda, et al., “High spectrally efficient coded 16-PAM scheme for GEPOF based on MLCC and BCH”, IEEE 802.3bv TF, Interim Meeting, January 2014*
- [2] *Rubén Pérez-Aranda, “Transmission scheme for GEPOF”, IEEE 802.3bv TF, Interim Meeting, January 2014*
- [3] *Rubén Pérez-Aranda, et al., “Physical Header Data content for PCS encoding, PHY control and OAM implementation in GEPOF”, IEEE 802.3bv TF, Plenary Meeting, March 2014*
- [4] *Rubén Pérez-Aranda, et al., “OAM channel proposal for GEPOF”, IEEE 802.3bv TF, Plenary Meeting, March 2015*
- [5] *Rubén Pérez-Aranda, et al., “64B/65B PCS encoding for GEPOF”, IEEE 802.3bv TF, Plenary Meeting, March 2015*