PHY Interface For the PCI Express* and USB 3.0 Architectures

Version 3.0

Legal Disclaimers

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Dedicated to the memory of Brad Hosler, the impact of whose accomplishments made the Universal Serial Bus one of the most successful technology innovations of the Personal Computer era.

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1 Preface

1.1 Scope of this Revision

The PCI Express* and USB SuperSpeed PHY Interface Specification has definitions of all functional blocks and signals. This revision includes support for PCI Express implementations conforming to the PCI Express Base Specification, Revision 2.0 and implementations conforming to the Universal Serial Bus Specification, Revision 3.0.

1.2 Revision History

Revision Number	Date	Description
0.1	7/31/02	Initial Draft
0.5	8/16/02	Draft for industry review
0.6	10/4/02	Provides operational detail
0.7	11/4/02	Includes timing diagrams
0.8	11/22/02	More operational detail. Receiver detection sequence changed.
0.9	12/16/02	Minor updates. Solid enough for implementations to be finalized.
0.95	4/25/03	Updates to reflect 1.0a Base Spec. Added multilane suggestions.
1.00	6/19/03	Stable revision for implementation.
1.70	11/6/05	First pass at Gen. 2 PIPE
1.81	12/4/2005	Fixed up areas based on feedback.
1.86	2/27/2006	Fixed up more areas based on feedback. Added a section on how to handle CLKREQ#.
1.87	9/28/2006	Removed references to Compliance Rate determination. Added sections for TX Margining and Selectable De-emphasis. Fixed up areas (6.4) based on feedback.
1.90	3/24/2007	Minor updates, mostly editorial.
2.00	7/21/2007	Minor updates, stable revision for implementation.
2.7	12/31/2007	Initial draft of updates to support the USB specification, revision 3.0.
2.71	1/21/2008	Updates for SKP handling and USB SuperSpeed PHY power management.
2.75	2/8/08	Additional updates for SKP handling.
2.90	8/11/08	Added 32 bit data interface support for USB SuperSpeed mode, support for USB SuperSpeed mode receiver equalization training, and support for USB SuperSpeed mode compliance patterns that are not 8b/10b encoded. Solid enough for implementation architectures to be finalized.
3.0	3/11/09	Final update

2 Introduction

The **P**HY **I**nterface for the **P**CI **E**xpress and USB SuperSpeed Architectures (**PIPE**) is intended to enable the development of functionally equivalent PCI Express and USB SuperSpeed PHY's. Such PHY's can be delivered as discrete IC's or as macrocells for inclusion in ASIC designs. The specification defines a set of PHY functions which must be incorporated in a PIPE compliant PHY, and it defines a standard interface between such a PHY and a Media Access Layer (MAC) & Link Layer ASIC. It is not the intent of this specification to define the internal architecture or design of a compliant PHY chip or macrocell. The PIPE specification is defined to allow various approaches to be used. Where possible the PIPE specification references the PCI Express base specification or USB 3.0 Specification rather than repeating its content. In case of conflicts, the PCI-Express Base Specification and USB 3.0 Specification shall supersede the PIPE spec.

This spec provides some information about how the MAC could use the PIPE interface for various LTSSM states and Link states. This information should be viewed as ‘guidelines for’ or as ‘one way to implement’ base specification requirements. MAC implementations are free to do things in other ways as long as they meet the corresponding specification requirements.

One of the intents of the PIPE specification is to accelerate PCI Express endpoint and USB SuperSpeed device development. This document defines an interface to which ASIC and endpoint device vendors can develop. Peripheral and IP vendors will be able to develop and validate their designs, insulated from the high-speed and analog circuitry issues associated with the PCI Express or USB SuperSpeed PHY interfaces, thus minimizing the time and risk of their development cycles.

Figure 2-1 shows the partitioning described in this spec for the PCI Express Base Specification. Figure 2-2 shows the portioning described in this spec for the USB 3.0 Specification.

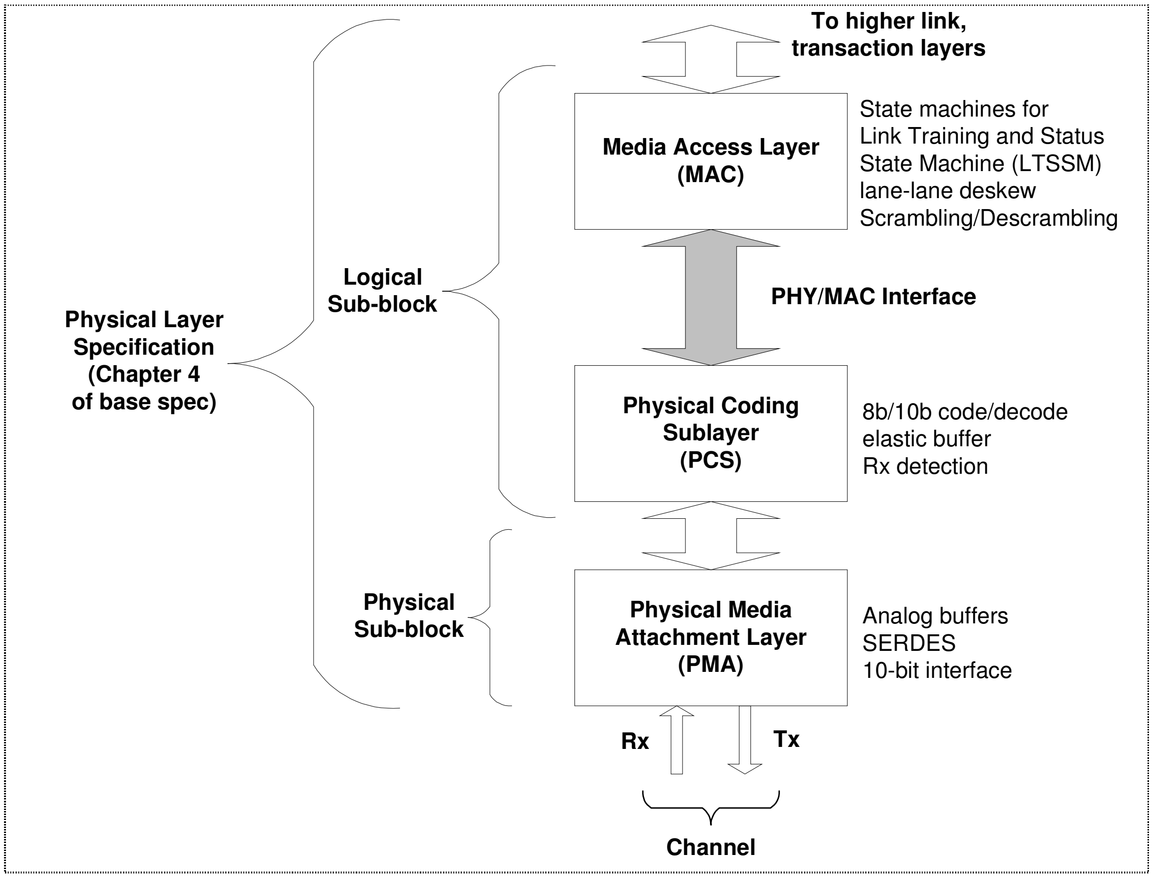


Figure 2-1: Partitioning PHY Layer for PCI Express

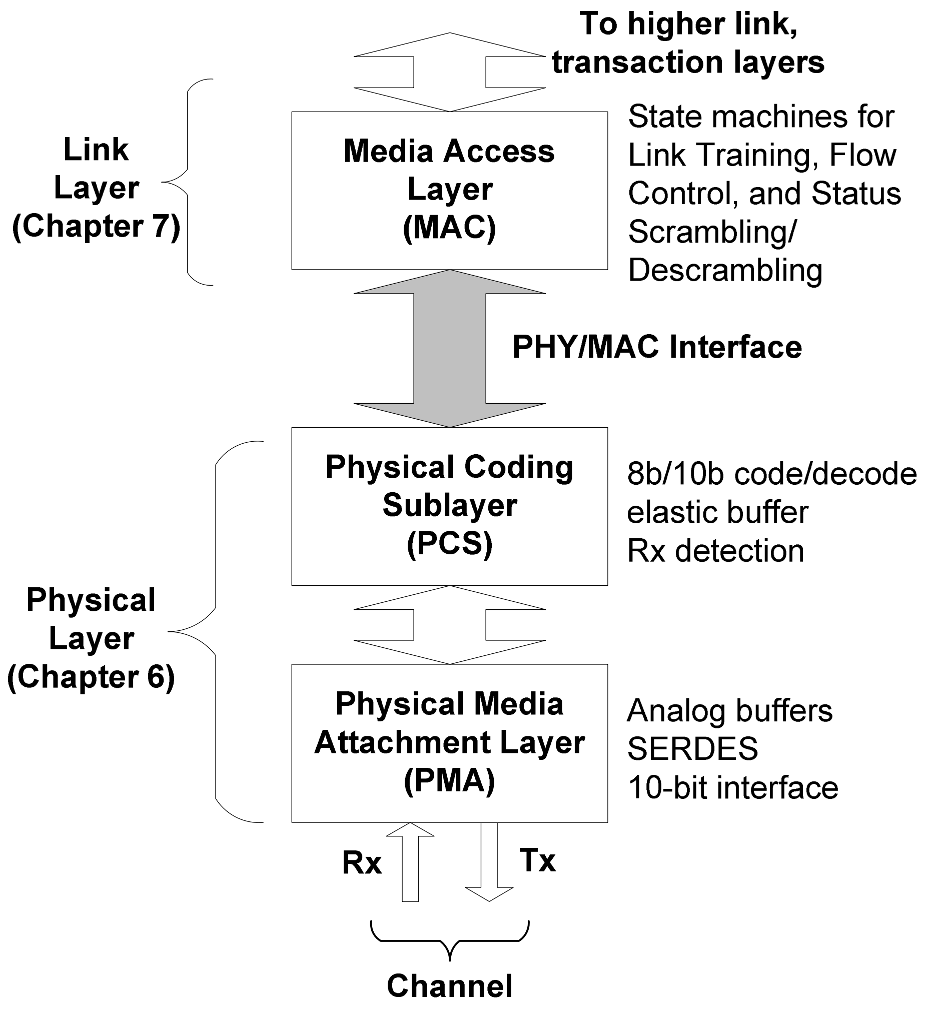

To higher link, transaction layers
Link Layer (Chapter 7)
Media Access Layer (MAC)
State machines for Link Training, Flow Control, and Status Scrambling/ Descrambling
PHY/MAC Interface
Physical Coding Sublayer (PCS)
8b/10b code/decode
elastic buffer
Rx detection
Physical Layer (Chapter 6)
Physical Media Attachment Layer (PMA)
Analog buffers
SERDES
10-bit interface
Rx
Tx
Channel

Figure 2-2 Partitioning PHY Layer for USB SuperSpeed

2.1 PCI Express PHY Layer

The PCI Express PHY Layer handles the low level PCI Express protocol and signaling. This includes features such as; data serialization and de-serialization, 8b/10b encoding, analog buffers, elastic buffers and receiver detection. The primary focus of this block is to shift the clock domain of the data from the PCI Express rate to one that is compatible with the general logic in the ASIC.

Some key features of the PCI Express PHY are:

- Standard PHY interface enables multiple IP sources for PCI Express Logical Layer and provides a target interface for PCI Express PHY vendors.
- Supports 2.5GT/s only or 2.5GT/s and 5.0 GT/s serial data transmission rate
- Utilizes 8-bit, 16-bit or 32 -bit parallel interface to transmit and receive PCI Express data
- Allows integration of high speed components into a single functional block as seen by the endpoint device designer
- Data and clock recovery from serial stream on the PCI Express bus
- Holding registers to stage transmit and receive data
- Supports direct disparity control for use in transmitting compliance pattern(s)
- 8b/10b encode/decode and error indication

- Receiver detection
- Beacon transmission and reception
- Selectable Tx Margining, Tx De-emphasis and signal swing values

2.2 USB SuperSpeed PHY Layer

The USB SuperSpeed PHY Layer handles the low level USB SuperSpeed protocol and signaling. This includes features such as; data serialization and de-serialization, 8b/10b encoding, analog buffers, elastic buffers and receiver detection. The primary focus of this block is to shift the clock domain of the data from the USB SuperSpeed rate to one that is compatible with the general logic in the ASIC.

Some key features of the USB SuperSpeed PHY are:
- Standard PHY interface enables multiple IP sources for USB SuperSpeed Link Layer and provides a target interface for USB SuperSpeed PHY vendors.
- Supports 5.0 GT/s serial data transmission rate
- Utilizes 8-bit, 16-bit or 32-bit parallel interface to transmit and receive USB SuperSpeed data
- Allows integration of high speed components into a single functional block as seen by the device designer
- Data and clock recovery from serial stream on the USB SuperSpeed bus
- Holding registers to stage transmit and receive data
- Supports direct disparity control for use in transmitting compliance pattern(s)
- 8b/10b encode/decode and error indication
- Receiver detection
- Low Frequency Periodic Signaling (LFPS) Transmission
- Selectable Tx Margining

3 PHY/MAC Interface

Figure 3-1 shows the data and logical command/status signals between the PHY and the MAC layer. These signals are described in Section 5. Full support of PCI Express mode requires 12 control signals and 6 Status signals. Full support of USB SuperSpeed mode requires 16 control signals and 7 status signals. Refer to Section 5.1 for details on which specific signals are required for each operating mode.

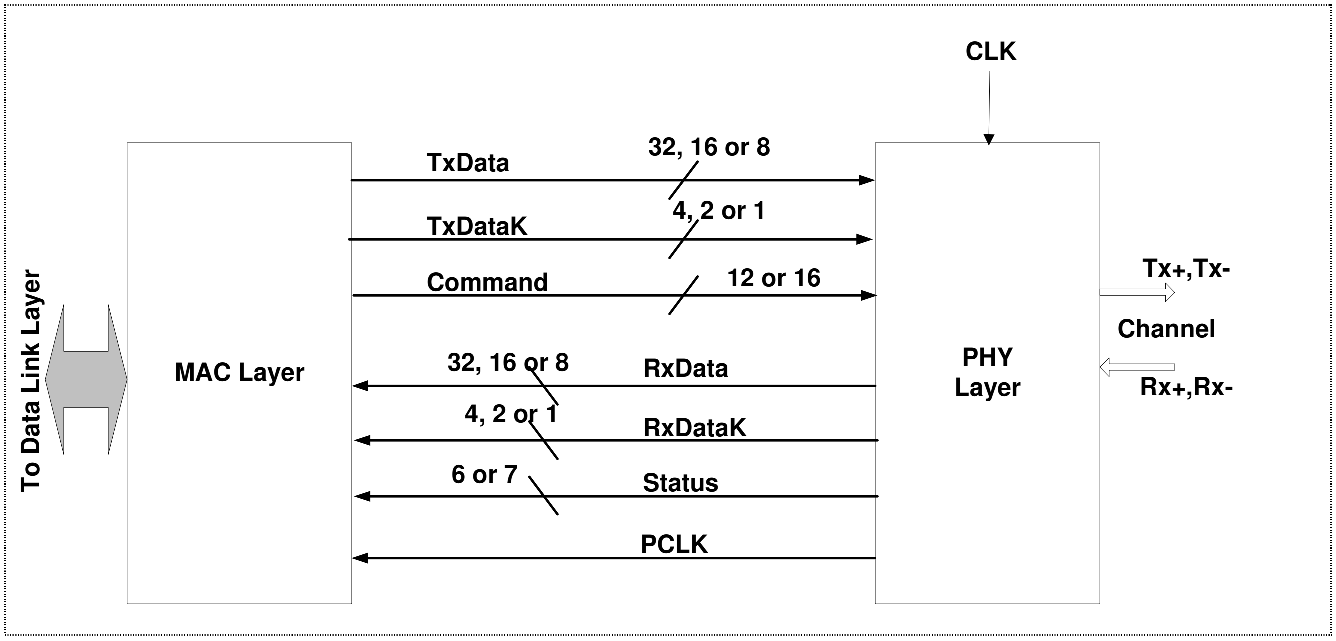


Figure 3-1: PHY/MAC Interface

This specification allows several different PHY/MAC interface configurations to support various signaling rates. For PIPE implementations that support only the 2.5 GT/s signaling rate in PCI Express mode implementers can choose to have 16 bit data paths with PCLK running at 125 MHz, or 8 bit data paths with PCLK running at 250 MHz.
PIPE implementations that support 5.0 GT/s signaling and 2.5 GT/s signaling in PCI Express mode, and therefore are able to switch between 2.5 GT/s and 5.0 GT/s signaling rates, can be implemented in several ways. An implementation may choose to have PCLK fixed at 250 MHz and use 8-bit data paths when operating at 2.5 GT/s signaling rate, and 16-bit data paths when operating at 5.0 GT/s signaling rate. Another implementation choice is to use a fixed data path width and change PCLK frequency to adjust the signaling rate. In this case, an implementation with 8-bit data paths would provide PCLK at 250 MHz for 2.5 GT/s signaling and provide PCLK at 500 MHz for 5.0 GT/s signaling. Similarly, an implementation with 16-bit data paths would provide PCLK at 125 MHz for 2.5 GT/s signaling and 250 MHz for 5.0 GT/s signaling.
For PIPE implementations that support only 5.0 GT/s (USB SuperSpeed mode) implementers can choose to have 32 bit data paths with PCLIK running at 125 MHz, or 16 bit data paths with PCLK running at 250 MHz,or 8 bit data paths with PCLK running at 500 MHz.

While outside the scope of this specification, there may be PIPE implementations that support multiples of the above configurations. The mechanism for choosing the configuration to be used is implementation specific.

4 PCI Express PHY Functionality

Figure 4-1 shows the functional block diagram of the PHY. The functional blocks shown are not intended to define the internal architecture or design of a compliant PHY but to serve as an aid for signal grouping.

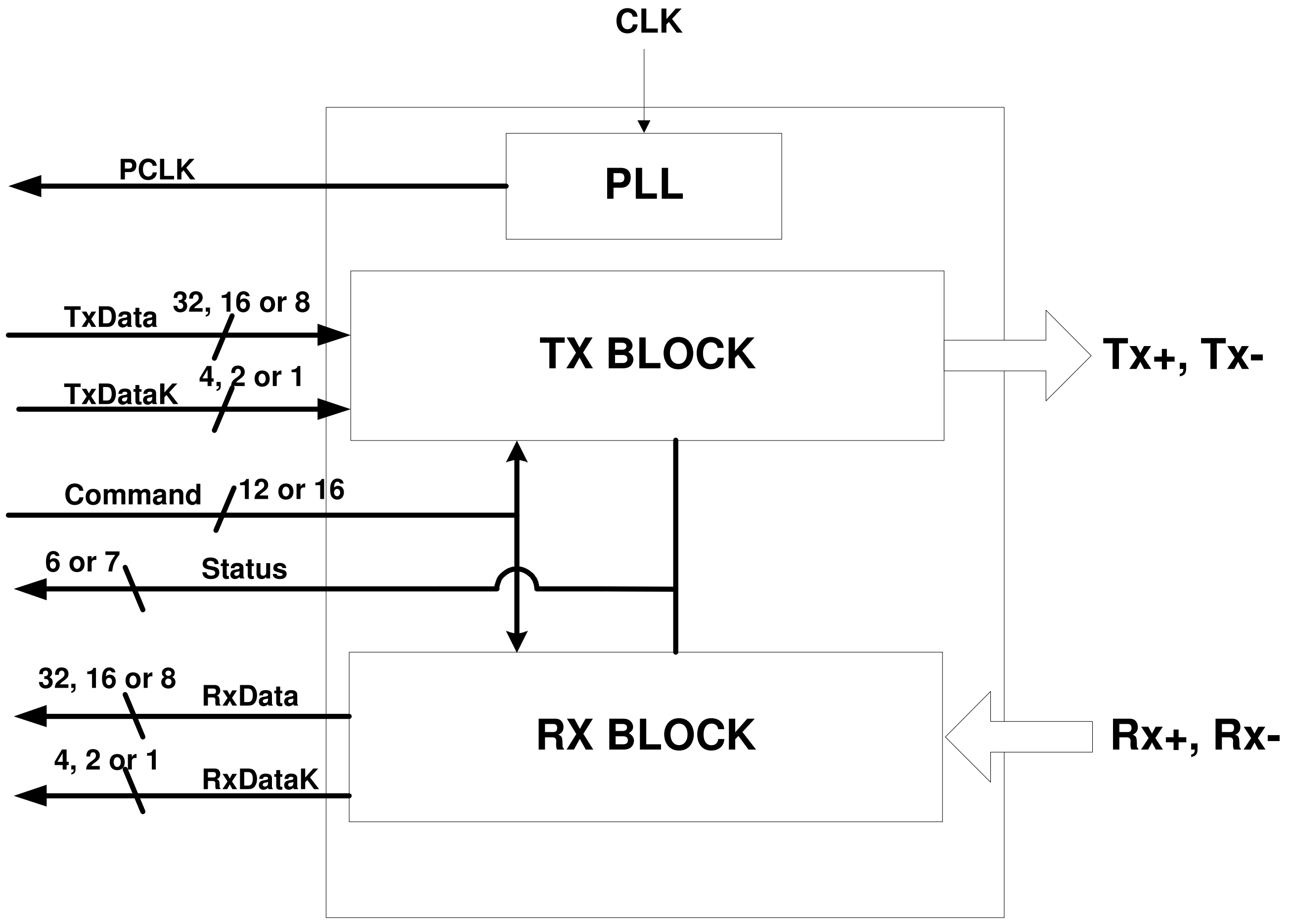


Figure 4-1: PHY Functional Block Diagram

Sections below provide descriptions of each of the blocks shown in Figure 4-1: PHY Functional Block Diagram. These blocks represent high-level functionality that is required to exist in the PHY implementation. These descriptions and diagrams describe general architecture and behavioral characteristics. Different implementations are possible and acceptable.

4.1 Transmitter Block Diagram

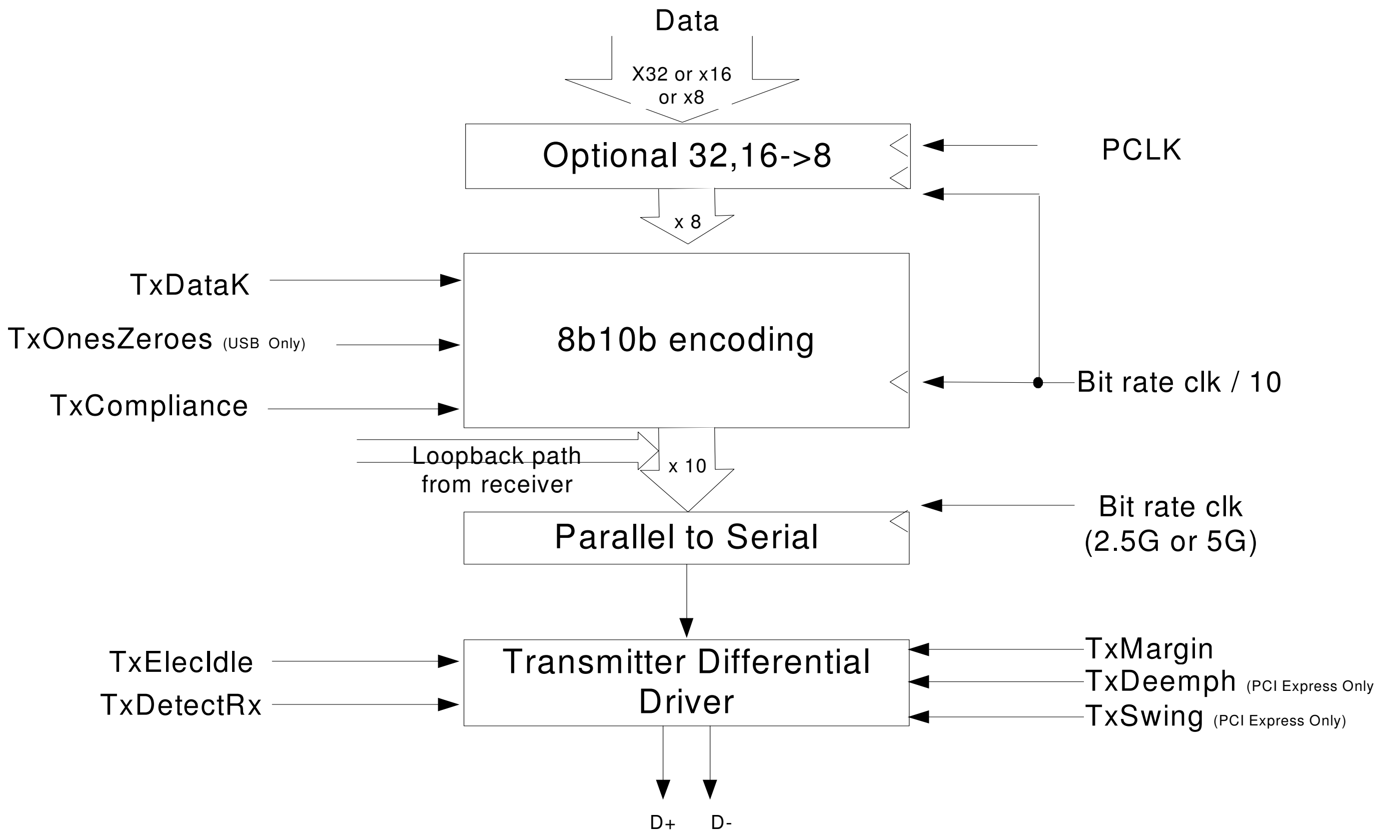


Figure 4-2: Transmitter Block Diagram

4.2 Receiver Block Diagram

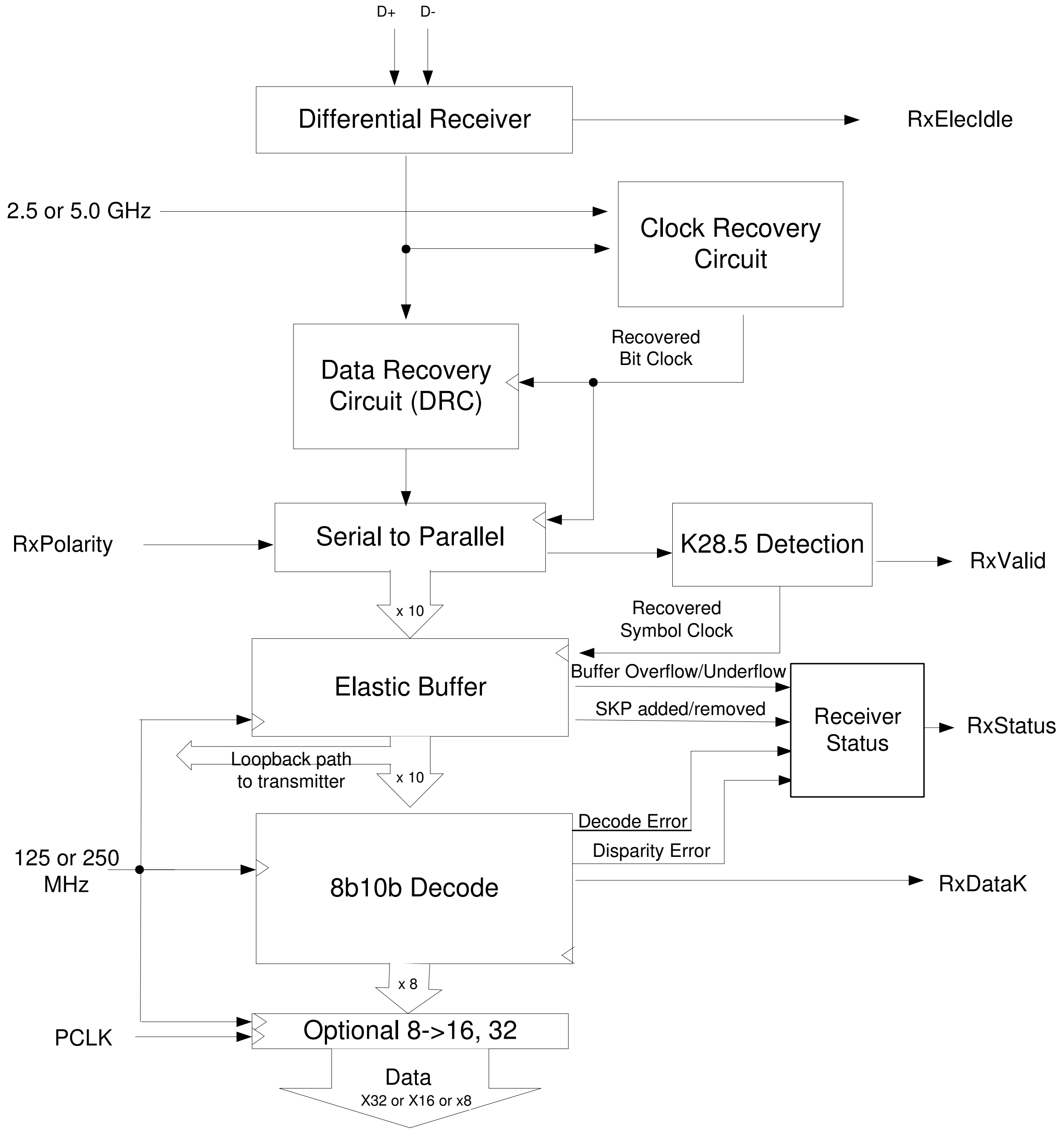


Figure 4-3: Receiver Block Diagram

4.3 Clocking

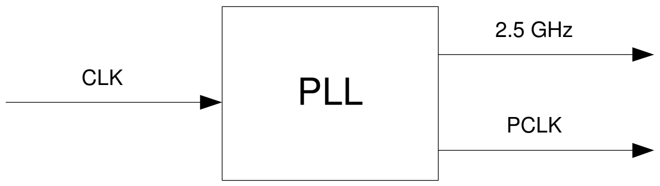


Figure 4-4: Clocking and Power Block Diagram

5 PIPE Interface Signal Descriptions

5.1 PHY/MAC Interface Signals

The PHY input and output signals are described in the following tables. Note that Input/Output is defined from the perspective of a PIPE compliant PHY component. Thus a signal described as an "Output" is driven by the PHY and a signal described as an "Input" is received by the PHY. A basic description of each signal is provided. More details on their operation and timing can be found in following sections. All signals on the 'parallel' side of a PIPE implementation are synchronous with PCLK, with exceptions noted in the tables below.

Table 5-1: Transmit Data Interface Signals

Name	Direction	Active Level	Description
Tx+, Tx-	Output	N/A	The PCI Express or USB SuperSpeed differential outputs from the PHY. All transmitters shall be AC coupled to the media. See section 4.3.1.2 of the PCI Express Base Specification or section 3.2.1 of the USB 3.0 Specification.
TxData[31:0] for 32-bit interface TxData[15:0] for 16-bit interface TxData[7:0] for 8-bit interface	Input	N/A	Parallel PCI Express or USB SuperSpeed data input bus. For the 16-bit interface, 16 bits represent 2 symbols of transmit data. Bits [7:0] are the first symbol to be transmitted, and bits [15:8] are the second symbol. For the 32-bit interface, 32 bits represent the 4 symbols of transmit data. Bits [23:16] are the third symbol to be transmitted, and bits [31:24] are the fourth symbol.
TxDataK[3:0] for 32-bit interface TxDataK[1:0] for 16-bit interface TxDataK for 8-bit interface	Input	N/A	Data/Control for the symbols of transmit data. For 32-bit interfaces, Bit 0 corresponds to the low-byte of TxData, Bit3 corresponds to the upper byte. For 16-bit interfaces, Bit 0 corresponds to the low-byte of TxData, Bit 1 to the upper byte. A value of zero indicates a data byte, a value of 1 indicates a control byte.

Table 5-2: Receive Data Interface Signals

Name	Direction	Active Level	Description
Rx+, Rx-	Input	N/A	The PCI Express or USB SuperSpeed differential inputs to the PHY.
RxData[31:0] for 32-bit interface RxData[15:0] for 16-bit interface or RxData[7:0] for 8-bit interface	Output	N/A	Parallel PCI Express data output bus. For 16-bit interface, 16 bits represents 2 symbols of receive data. Bits [7:0] are the first symbol received, and bits [15:8] are the second symbol. For the 32 bit interface, 32 bits represent the 4 symbols of receive data. Bits [23:16] are the third symbol received, and bits [31:24] are the fourth symbol received.
RxDataK[3:0] for 32-bit interface RxDataK[1:0] for 16-bit interface RxDataK for 8-bit interface	Output	N/A	Data/Control bit for the symbols of receive data. For 32-bit interfaces, Bit 0 corresponds to the low-byte of RxData, Bit3 corresponds to the upper byte. For 16-bit interface, Bit 0 corresponds to the low-byte of RxData[15:0], Bit 1 to the upper byte. A value of zero indicates a data byte; a value of 1 indicates a control byte.

Table 5-3: Command Interface Signals

Name	Direction	Active Level	Description
PHY Mode[1:0]	Input	N/A	Selects PHY operating mode. Value / Description: 0 – PCI Express 1 – USB SuperSpeed 2 – Reserved 3 – Reserved Implementation of this signal is not required for PHYs that only support PCI Express mode.
Elasticity Buffer Mode	Input	N/A	Selects Elasticity Buffer operating mode. Value / Description: 0 – Nominal Half Full Buffer mode 1 – Nominal Empty Buffer Mode Implementation of this signal is only required for PHYs that support USB SuperSpeed mode.
TxDetectRx/ Loopback	Input	High	Used to tell the PHY to begin a receiver detection operation or to begin loopback or to signal LFPS during P0 for USB Polling state. Refer to Sections 6.20 and 6.21 for details on the required values for all control signals to perform loopback and receiver detection operations and to signal Polling.LFPS.
TxElecIdle	Input	High	See Section 6.20 (PCI Express Mode) or Section 6.21 (USB SuperSpeed mode) for the description and usage of this pin.
TxCompliance	Input	High	PCI Express Mode: Sets the running disparity to negative. Used when transmitting the PCI Express compliance pattern. Implementation of this signal is only required for PHYs that support PCI Express mode.
TxOnesZeros	Input	High	USB SuperSpeed Mode: Used only when transmitting USB SuperSpeed compliance patterns CP7 or CP8. Causes the transmitter to transmit an alternating sequence of 50-250 ones and 50-250 zeros – regardless of the state of the TxData interface. Implementation of this signal is only required for PHYs that support USB SuperSpeed mode.
RxPolarity	Input	High	Tells PHY to do a polarity inversion on the received data. Value / Description: 0 – PHY does no polarity inversion 1 – PHY does polarity inversion

RxEqTraining	Input	High	USB SuperSpeed Mode: Used to instruct the receiver to bypass normal operation to perform equalization training. While performing training the state of the RxData interface is undefined. Implementation of this signal is only required for PHYs that support USB SuperSpeed mode.
Reset#	Input	Low	Resets the transmitter and receiver. This signal is asynchronous.
PowerDown[1:0]	Input	N/A	Power up or down the transceiver. Power states PCI Express Mode: [1] | [0] | Description 0 | 0 | P0, normal operation 0 | 1 | P0s, low recovery time latency, power saving state 1 | 0 | P1, longer recovery time latency, lower power state 1 | 1 | P2, lowest power state When transitioning from P2 to P1, the signaling is asynchronous (since PCLK is not running). USB SuperSpeed Mode: [1] | [0] | Description 0 | 0 | P0, normal operation 0 | 1 | P1, low recovery time latency, power saving state 1 | 0 | P2, longer recovery time latency, lower power state 1 | 1 | P3, lowest power state When transitioning from P3 to P0, the signaling is asynchronous (since PCLK is not running).
Rate	Input	N/A	Control the link signaling rate. Value | Description 0 | Use 2.5 GT/s signaling rate 1 | Use 5.0GT/s signaling rate PIPE implementations that only support one signaling rate do not implement this signal.

TxDeemph[1:0]	Input	N/A	Selects transmitter de-emphasis.

Value	Description
0	-6dB de-emphasis
1	-3.5dB de-emphasis
2	No de-emphasis
3	Reserved

PIPE implementations that only support a single de-emphasis level do not implement this signal.

TxMargin[2:0]	Input	N/A	Selects transmitter voltage levels.

[2]	[1]	[0]	Description
0	0	0	TxMargin value 0 = Normal operating range
0	0	1	TxMargin value 1 = 800-1200mV for Full swing* OR 400-700mV for Half swing*
0	1	0	TxMargin value 2 = required and vendor defined
0	1	1	TxMargin value 3 = required and vendor defined
1	0	0	TxMargin value 4 = required and 200-400mV for Full swing* OR 100-200mV for Half swing* if the last value or vendor defined
1	0	1	TxMargin value 5 = optional and 200-400mV for Full swing* OR 100-200mV for Half swing* if the last value OR vendor defined OR Reserved if no other values supported
1	1	0	TxMargin value 6 = optional and 200-400mV for Full swing* OR 100-200mV for Half swing* if the last value OR vendor defined OR Reserved if no other values supported
1	1	1	TxMargin value 7 = optional and 200-400mV for Full swing* OR 100-200mV for Half swing* if the last value OR Reserved if no other values supported

PIPE implementations that only support PCI Express mode and the 2.5GT/s signaling rate do not implement this signal.

TxSwing	Input	N/A	Controls transmitter voltage swing level <table><tr><td>Value</td><td>Description</td></tr><tr><td>0</td><td>Full swing</td></tr><tr><td>1</td><td>Low swing (optional)</td></tr></table> Implementation of this signal is optional if only Full swing is supported.
RX Termination	Input	High	Controls presence of receiver terminations: <table><tr><td>Value</td><td>Description</td></tr><tr><td>0</td><td>Terminations removed</td></tr><tr><td>1</td><td>Terminations present</td></tr></table> Implementation of this signal is only required for PHYs that support USB SuperSpeed mode.

Table 5-4: Status Interface Signals

Name	Direction	Active Level	Description
RxValid	Output	High	Indicates symbol lock and valid data on *RxData* and *RxDataK*.
PhyStatus	Output	High	Used to communicate completion of several PHY functions including stable PCLK after Reset# deassertion, power management state transitions, rate change, and receiver detection. When this signal transitions during entry and exit from P2 (PCI Express mode) or P3 (USB SuperSpeed mode) and PCLK is not running, then the signaling is asynchronous. In error situations (where the PHY fails to assert PhyStatus) the MAC can take MAC-specific error recovery actions.
RxElecIdle	Output	High	Indicates receiver detection of an electrical idle. While deasserted with the PHY in P2 (PCI Express mode) or the PHY in P0, P1, P2, or P3 (USB SuperSpeed Mode), indicates detection of either: PCI Express Mode: a beacon. USB SuperSpeed Mode : LFPS This is an asynchronous signal.

RxStatus[2:0]	Output	N/A	Encodes receiver status and error codes for the received data stream when receiving data.			
			[2]	[1]	[0]	Description
			0	0	0	Received data OK
			0	0	1	PCI Express Mode: 1 SKP added USB SuperSpeed Mode: 1 SKP Ordered Set added
			0	1	0	PCI Express Mode: 1 SKP removed USB SuperSpeed Mode: 1 SKP Ordered Set removed
			0	1	1	Receiver detected
			1	0	0	Both 8B/10B decode error and (optionally) Receive Disparity error
			1	0	1	Elastic Buffer overflow
			1	1	0	Elastic Buffer underflow. This error code is not used if the elasticity buffer is operating in the nominal buffer empty mode.
			1	1	1	Receive disparity error (Reserved if Receive Disparity error is reported with code 0b100)
PowerPresent	Output	High	USB SuperSpeed Mode: Indicates the presence of VBUS. Implementation of this signal is only required for PHYs that support USB SuperSpeed mode.			

5.2 External Signals

Table 5-5: External Signals

Name	Direction	Active Level	Description
CLK	Input	Edge	This differential Input is used to generate the bit-rate clock for the PHY transmitter and receiver. Specs for this clock signal (frequency, jitter, …) are implementation dependent and must be specified for each implementation. This clock may have a spread spectrum modulation.
PCLK	Output	Rising Edge	Parallel interface differential data clock. All data movement across the parallel interface is synchronized to this clock. This clock operates at 125MHz, 250MHz, or 500 MHz depending on the *Rate* and *PHY Mode* control inputs and the data interface width. The rising edge of the clock is the reference for all signals. Spread spectrum modulation on this clock is allowed.
DataBusWidth[1:0]	Output	N/A	This field reports the width of the data bus that the PHY is configured for. [1] | [0] | Description 0 | 0 | 32-bit mode 0 | 1 | 16-bit mode 1 | 0 | 8-bit mode 1 | 1 | Reserved

6 PIPE Operational Behavior

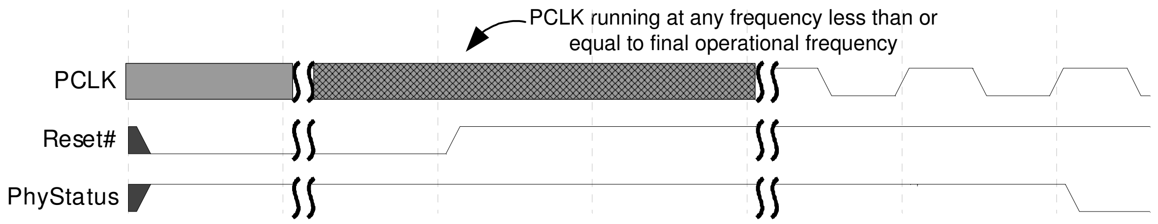
6.1 Clocking

There are two clock signals used by the PHY Interface component. The first (*CLK*) is a reference clock that the PHY uses to generate internal bit rate clocks for transmitting and receiving data. The specifications for this signal are implementation dependent and must be fully specified by vendors. The specifications may vary for different operating modes of the PHY. This clock may have spread spectrum modulation that matches a system reference clock (for example, the spread spectrum modulation could come from REFCLK from the Card Electro-Mechanical Specification).

The second clock (*PCLK*) is an output from the PHY and is the parallel interface clock used to synchronize data transfers across the parallel interface. This clock runs at 125MHz, 250MHz, or 500 MHz depending on the *Rate* and *PHY Mode* control inputs and data interface width. The rising edge of this clock is the reference point. This clock may also have spread spectrum modulation.

6.2 Reset

When the MAC wants to reset the PHY (e.g.; initial power on), the MAC must hold the PHY in reset until power and *CLK* to the PHY are stable. The PHY signals that *PCLK* is valid (i.e. PCLK has been running at its operational frequency for at least one clock) and the PHY is in the specified power state by the deassertion of *PhyStatus*. While *Reset#* is asserted the MAC should have *TxDetectRx/Loopback* deasserted, *TxElecIdle* asserted, *TxCompliance* deasserted, *RxPolarity* deasserted, *PowerDown* = P1 (PCI Express mode) or *PowerDown* = P2 (USB SuperSpeed Mode), *TxMargin* = 000b, *TxDeemp* = 1, *PHY Mode* set to the desired PHY operating mode, and *Rate* set to 2.5GT/s signaling rate for a PHY in PCI Express mode or 5.0 GT/s for a PHY in USB SuperSpeed 3.0 mode. The state of *TxSwing* during *Reset#* assertion is implementation specific. *RxTermination* is asserted in USB SuperSpeed 3.0 mode.


PCLK running at any frequency less than or equal to final operational frequency
PCLK
Reset#
PhyStatus

Reset

6.3 Power Management – PCI Express Mode

The power management signals allow the PHY to minimize power consumption. The PHY must meet all timing constraints provided in the PCI Express Base Specification regarding clock recovery and link training for the various power states. The PHY must also meet all terminations requirements for transmitters and receivers.

Four power states are defined, P0, P0s, P1, and P2. P0 state is the normal operational state for the PHY. When directed from P0 to a lower power state, the PHY can immediately take whatever power saving measures are appropriate.

In states P0, P0s and P1, the PHY is required to keep *PCLK* operational. For all state transitions between these three states, the PHY indicates successful transition into the designated power state by a single cycle assertion of *PhyStatus*. Transitions into and out of P2 are described below. For all power state transitions, the MAC must not begin any operational sequences or further power state transitions until the PHY has indicated that the initial state transition is completed.

Mapping of PHY power states to states in the Link Training and Status State Machine (LTSSM) found in the base specification are included below.

- P0 state: All internal clocks in the PHY are operational. P0 is the only state where the PHY transmits and receives PCI Express signaling.
  P0 is the appropriate PHY power management state for most states in the Link Training and Status State Machine (LTSSM). Exceptions are listed below for each lower power PHY state.

- P0s state: *PCLK* output must stay operational. The MAC may move the PHY to this state only when the transmit channel is idle.
  P0s state can be used when the transmitter is in state *Tx_L0s.Idle*.

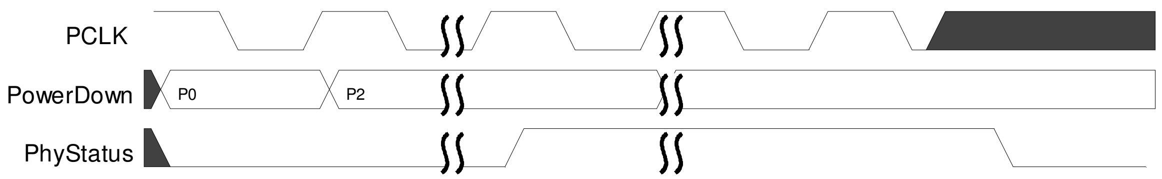
  While the PHY is in either P0 or P0s power states, if the receiver is detecting an electrical idle, the receiver portion of the PHY can take appropriate power saving measures. Note that the PHY must be capable of obtaining bit and symbol lock within the PHY-specified time (N_FTS with/without common clock) upon resumption of signaling on the receive channel. This requirement only applies if the receiver had previously been bit and symbol locked while in P0 or P0s states.

- P1 state: Selected internal clocks in the PHY can be turned off. *PCLK* output must stay operational. The MAC will move the PHY to this state only when both transmit and receive channels are idle. The PHY must not indicate successful entry into P1 (by asserting *PhyStatus*) until PCLK is stable and the operating DC common mode voltage is stable and within specification (as per the base spec).
  P1 can be used for the *Disabled* state, all *Detect* states, and *L1.Idle* state of the Link Training and Status State Machine (LTSSM).

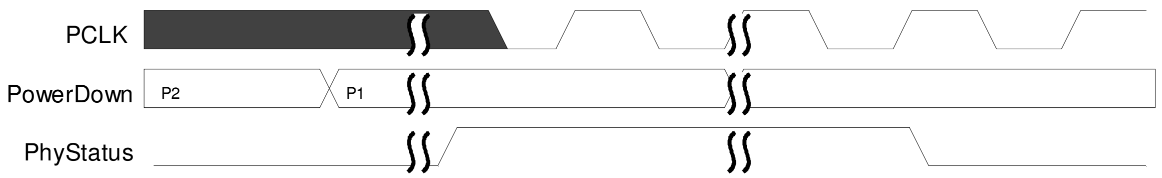
- P2 state: Selected internal clocks in the PHY can be turned off. The parallel interface is in an asynchronous mode and *PCLK* output is turned off. The MAC must ensure that the PHY is in 2.5 GT/s signaling mode prior to moving the PHY to P2 state or direct the signaling mode change and PHY power state change at the same time.

When transitioning into P2, the PHY must assert *PhyStatus* before *PCLK* is turned off and then deassert *PhyStatus* when PCLK is fully off and when the PHY is in the P2 state. When transitioning out of P2, the PHY asserts *PhyStatus* as soon as possible and leaves it asserted until after *PCLK* is stable. PHYs should be implemented to minimize power consumption during P2 as this is when the device will have to operate within Vaux power limits (as described in the PCI Express Base Specification).

P2 state can be used in LTSSM states *L2.Idle* and *L2.TransmitWake*.



P2 Entry



P2 Exit

There is a limited set of legal power state transitions that a MAC can ask the PHY to make. Referencing the main state diagram of the LTSSM in the base spec and the mapping of LTSSM states to PHY power states described in the preceding paragraphs, those legal transitions are: P0 to P0s, P0 to P1, P0 to P2, P0s to P0, P1 to P0, and P2 to P0. The base spec also describes what causes those state transitions.

6.4 Power Management – USB SuperSpeed Mode

The power management signals allow the PHY to minimize power consumption. The PHY must meet all timing constraints provided in the USB 3.0 Specification regarding clock recovery and link training for the various power states. The PHY must also meet all termination requirements for transmitters and receivers.

Four power states are defined, P0, P1, P2, and P3. The P0 state is the normal operational state for the PHY. When directed from P0 to a lower power state, the PHY can immediately take whatever power saving measures are appropriate.

In states P0, P1 and P2, the PHY is required to keep *PCLK* operational. For all state transitions between these three states, the PHY indicates successful transition into the designated power state by a single cycle assertion of *PhyStatus*. Transitions into and out of P3 are described below. For all power state transitions, the MAC must not begin any operational sequences or further power state transitions until the PHY has indicated that the initial state transition is completed.

Mapping of PHY power states to states in the Link Training and Status State Machine found in the USB specification are included below.

- P0 state: All internal clocks in the PHY are operational. P0 is the only state where the PHY transmits and receives USB SuperSpeed signaling.
  P0 is the appropriate PHY power management state for all cases where the link is in U0 and all other link state except those listed below for P1, P2, and P3.
- P1 state: *PCLK* output must stay operational. The MAC will move the PHY to this state only when the PHY is transmitting idles and receiving idles. The P1 state can be used for the *U1* link state.

- P2 state: Selected internal clocks in the PHY can be turned off. *PCLK* output must stay operational. The MAC will move the PHY to this state only when both transmit and receive channels are idle. The PHY must not indicate successful entry into P2 (by asserting *PhyStatus*) until PCLK is stable and the operating DC common mode voltage is stable and within specification (as per the base spec).
- P2 can be used for the *U2, Rx.Detect, and SS.Inactive*.
- P3 state: Selected internal clocks in the PHY can be turned off. The parallel interface is in an asynchronous mode and *PCLK* output is turned off. When transitioning into P3, the PHY must assert *PhyStatus* before *PCLK* is turned off and then deassert *PhyStatus* when PCLK is fully off and when the PHY is in the P3 state. When transitioning out of P3, the PHY asserts *PhyStatus* as soon as possible and leaves it asserted until after *PCLK* is stable. PHYs should be implemented to minimize power consumption during P3 as this is when the device will have to operate within power limits described in the USB 3.0 Specification.
- The P3 state shall be used in states *SS.disabled and U3.*
- There is a limited set of legal power state transitions that a MAC can ask the PHY to make. Referencing the main state diagram in the USB spec and the mapping of link states to PHY power states described in the preceding paragraphs, those legal transitions are: P0 to P1, P0 to P2, P0 to P3, P1 to P0, P2 to P0, P3 to P0, and P1 to P2. The base spec also describes what causes those state transitions.

6.5 Changing Signaling Rate – PCI Express Mode

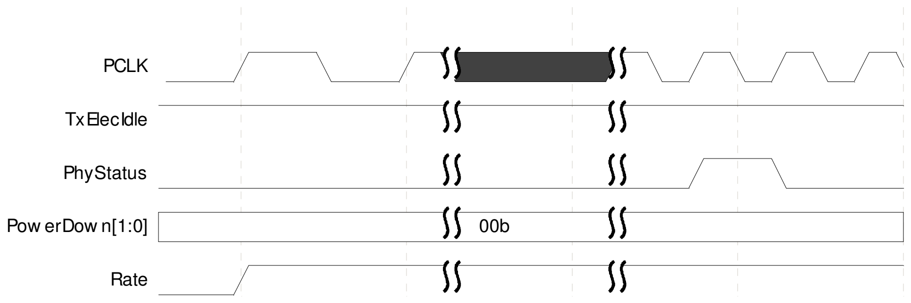
The signaling rate of the link can be changed only when the PHY is in the P0 or P1 power state and *TxElecIdle* is asserted. When the MAC changes the *Rate* signal, the PHY performs the rate change and signals its completion with a single cycle assertion of *PhyStatus*. The MAC must not perform any operational sequences, power state transitions, deassert *TxElecIdle,* or further signaling rate changes until the PHY has indicated that the signaling rate change has completed.

There are instances where LTSSM state machine transitions indicate both a speed change and a power state change for the PHY. One of these instances is when the LTSSM transitions to Detect. In this case, the MAC must change (if necessary) the signaling rate to 2.5 GT/s before changing the power state to P1. Another instance is when the LTSSM transitions to L2.Idle. Again, the MAC must change (if necessary) the signaling rate to 2.5 GT/s before changing the power state to P2.

Some PHY architectures may allow a speed change and a power state change to occur at the same time. If a PHY supports this, the MAC must change the rate to 2.5 GT/s at the same PCLK edge that it changes the *PowerDown* signals. This can happen when transitioning the PHY from P0 to either P1 or P2 states. The completion mechanisms are the same as previously defined for the power state changes and indicate not only that the power state change is complete, but also that the rate change is complete.

6.5.1 Fixed data path implementations

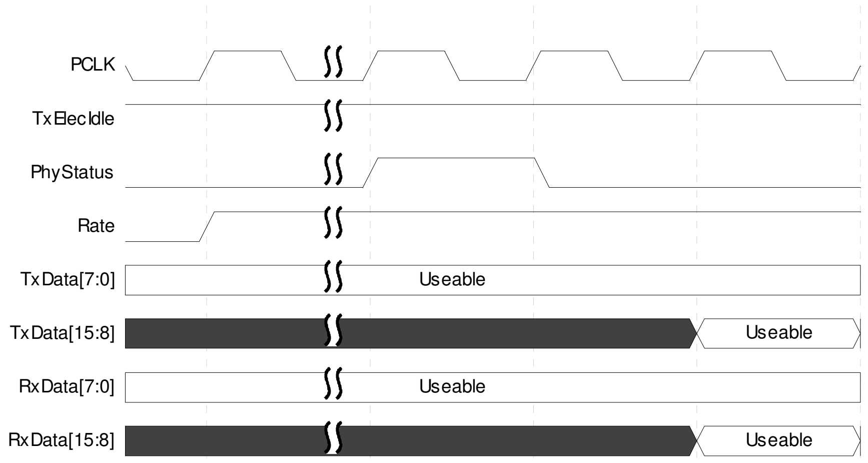
The figure below shows logical timings for implementations that change PCLK frequency when the MAC changes the signaling rate. Implementations that change the *PCLK* frequency when changing signaling rates must change the clock such that the time the clock is stopped (if it is stopped) is minimized to prevent any timers using *PCLK* from exceeding their specifications. Also during the clock transition period, the frequency of *PCLK* must not exceed the PHY's defined 5.0 GT/s clock frequency. The amount of time between when *Rate* is changed and the PHY completes the rate change is a PHY specific value.



Rate change with fixed data path

6.5.2 Fixed PCLK implementations

The figure below shows logical timings for implementations that change the width of the data path for different signaling rates. PCLK may be stopped during a rate change.

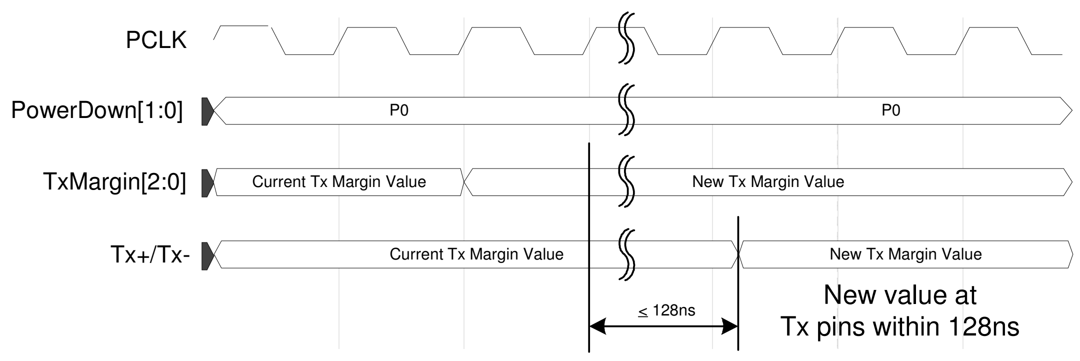


Rate change with fixed PCLK frequency

6.6 Transmitter Margining

While in the P0 power state, the PHY can be instructed to change the value of the voltage at the transmitter pins. When the MAC changes *TxMargin[2:0],* the PHY must be capable of transmitting with the new setting within 128 ns.

There is a limited set of legal *TxMargin[2:0]* and *Rate* combinations that a MAC can select. Refer to the PCIe Base Specification for a complete description of legal settings when the PHY is in PCI Express Mode. Refer to the USB specification for a complete description of the legal settings when the PHY is in USB SuperSpeed mode.



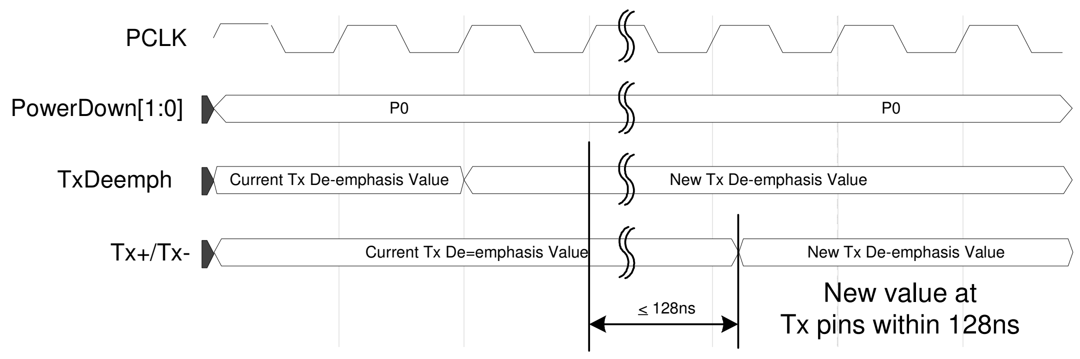
Selecting Tx Margining value

6.7 Selectable De-emphasis – PCI Express Mode

While in the P0 power state and transmitting at 5.0GT/s, the PHY can be instructed to change the value of the transmitter de-emphasis. When the MAC changes *TxDeemph,* the PHY must be capable of transmitting with the new setting within 128 ns.

There is a limited set of legal *TxDeemph* and *Rate* combinations that a MAC can select. Refer to the PCIe Base Specification for a complete description.

The MAC must ensure that *TxDeemph* is selecting -3.5db whenever *Rate* is selecting 2.5 GT/s.



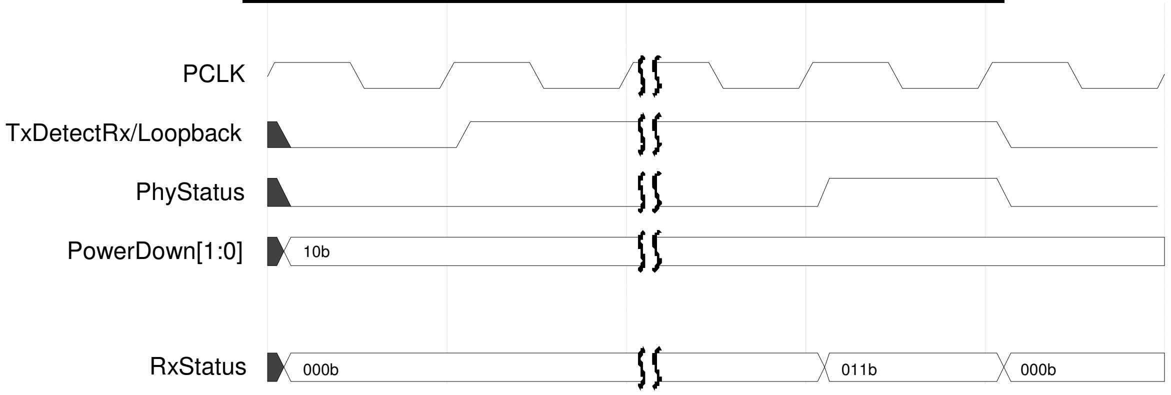
Selecting Tx De-emphasis value

6.8 Receiver Detection

While in the P1 power state and PCI Express mode or in the P2 or P3 power state and USB SuperSpeed mode, the PHY can be instructed to perform a receiver detection operation to determine if there is a receiver at the other end of the link. Basic operation of receiver detection is that the MAC requests the PHY to do a receiver detect sequence by asserting *TxDetectRx/Loopback*. When the PHY has completed the receiver detect sequence, it asserts *PhyStatus* for one clock and drives the *RxStatus* signals to the appropriate code. After the receiver detection has completed (as signaled by the assertion of *PhyStatus*), the MAC must

deassert *TxDetectRx/Loopback* before initiating another receiver detection, a power state transition, or signaling a rate change.
Once the MAC has requested a receiver detect sequence (by asserting *TxDetectRx/Loopback*), the MAC must leave *TxDetectRx/Loopback* asserted until after the PHY has signaled completion by the assertion of *PhyStatus*. When receiver detection is performed in USB SuperSpeed mode with the PHY in P3 the PHY asserts PhyStatus and signals the appropriate receiver detect value until the MAC deasserts TxDetectRx/Loopback.

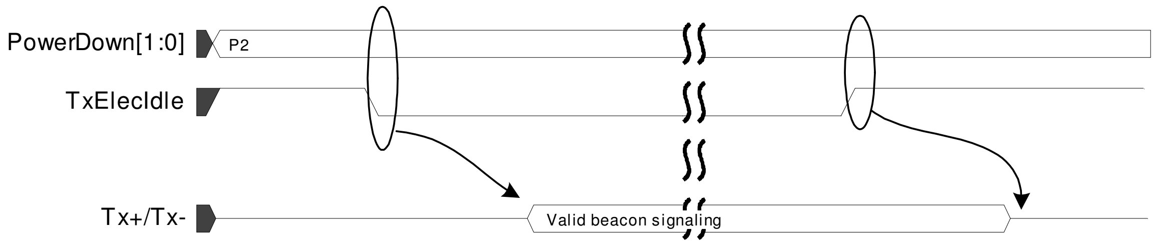
Detected Condition	*RxStatus* code
Receiver not present	000b
Receiver present	011b



Receiver Detect - Receiver present

6.9 Transmitting a beacon – PCI Express Mode

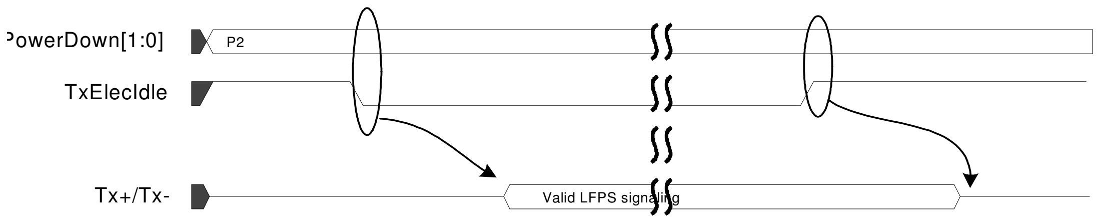
When the PHY has been put in the P2 power state, and the MAC wants to transmit a beacon, the MAC deasserts *TxElecIdle* and the PHY should generate a valid beacon until *TxElecIdle* is asserted. The MAC must assert *TxElecIdle* before transitioning the PHY to P0.



Beacon Transmit

6.10 Transmitting LFPS – USB SuperSpeed Mode

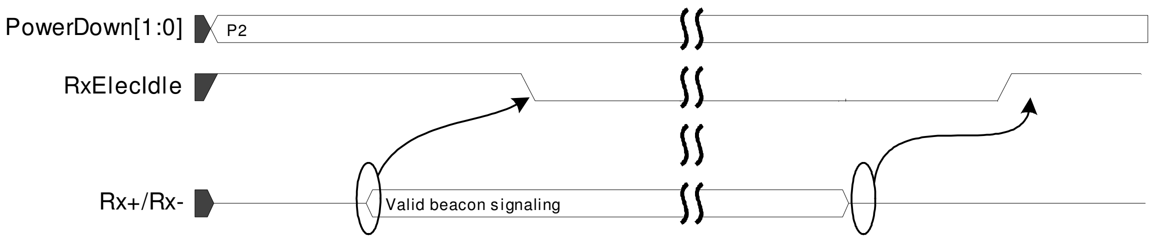
When the PHY is in P1, P2, or P3 and the MAC wants to transmit LFPS, the MAC deasserts *TxElecIdle* and the PHY should generate valid LFPS until *TxElecIdle* is asserted. The MAC must assert *TxElecIdle* before transitioning the PHY to P0. The length of time *TxElecIdle* is deasserted is varied for different events. When the PHY is in P0 and the MAC wants to transmit LFPS for Polling, the MAC must assert both *TxElecIdle* and *TxDetectRx/Loopback* for the duration defined for a Polling.LFPS burst. Refer to chapter 5 in the USB 3.0 specification for more details.



LFPS Transmit

6.11 Detecting a beacon – PCI Express Mode

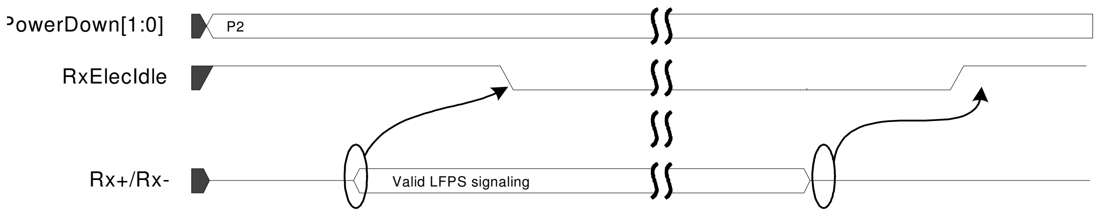
The PHY receiver must monitor at all times (except during reset) for electrical idle. When the PHY is in the P2 power state, and *RxElecIdle* is deasserted, then a beacon is being detected.



Beacon Receive

6.12 Detecting Low Frequency Periodic Signaling – USB SuperSpeed Mode

The PHY receiver must monitor at all times (except during reset and when RX terminations are removed) for LFPS. When the PHY is in the P0, P1, P2, or P3 power state, and *RxElecIdle* is deasserted, then LFPS is being detected. The length of time *RxElecIdle* is deasserted indicates the length of time Low Frequency Periodic Signaling is detected. Refer to chapter 5 in the USB 3.0 specification for more details on the length of Low Frequency Periodic Signaling (LFPS) for various events.



LFPS Receive

6.13 Clock Tolerance Compensation

The PHY receiver contains an elastic buffer used to compensate for differences in frequencies between bit rates at the two ends of a Link. The elastic buffer must be capable of holding enough symbols to handle worst case differences in frequency and worst case intervals between SKP ordered-sets as shown in Table 6-1

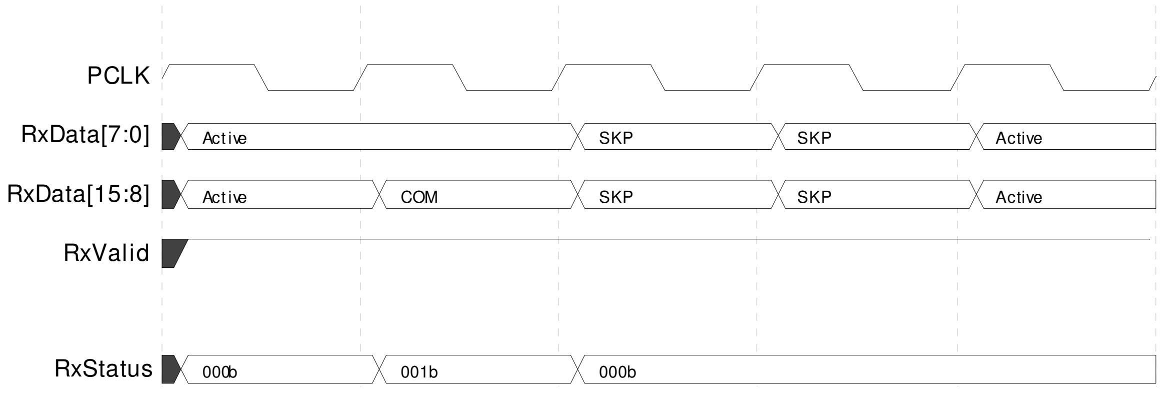
Phy Mode	Worst Case Frequency	Symbol Depth –	Symbol Depth –

	Offset	Nominal Half Full Buffer	Nominal Empty Buffer
PCI Express	600 ppm	7 symbols	N/A
USB SuperSpeed	5600 ppm	16 symbols (8 SKP ordered sets)	8 symbols (4 SKP ordered sets)

Table 6-1 Minimum Elasticity Buffer Size

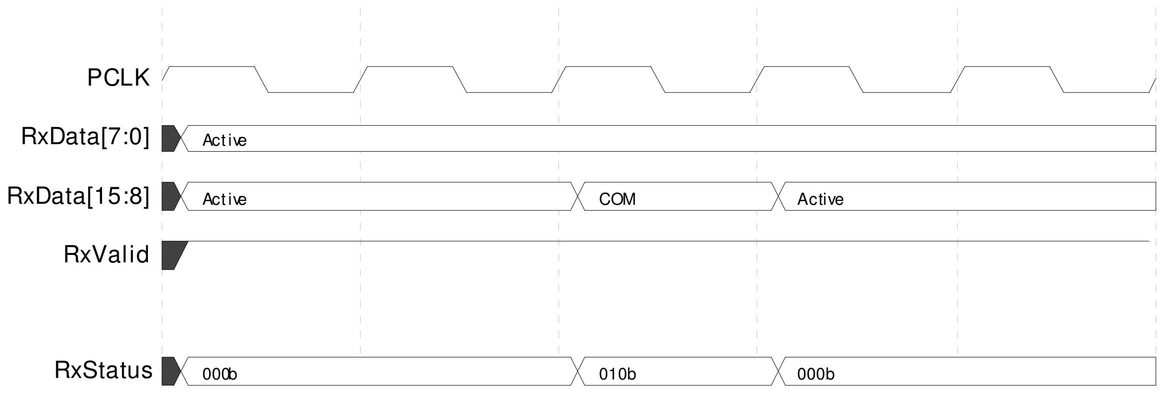
Two models are defined for the elastic buffer operation in the PHY. The PHY may support one or both of these models. The Nominal Empty buffer model is only supported in USB SuperSpeed mode.
For the Nominal Half Full buffer model, the PHY is responsible for inserting or removing SKP symbols in the received data stream to avoid elastic buffer overflow or underflow. The PHY monitors the receive data stream, and when a Skip ordered-set is received, the PHY can add or remove one SKP symbol (PCI Express Mode) or one SKP ordered set (USB SuperSpeed Mode) from each SKP as appropriate to manage its elastic buffer to keep the buffer as close to half full as possible. In USB SuperSpeed mode the PHY shall only add or remove SKP ordered sets. Whenever a SKP symbol or ordered set is added to or removed, the PHY will signal this to the MAC using the *RxStatus[2:0]* signals. These signals have a non-zero value for one clock cycle and indicate whether a SKP symbol or ordered set was added to or removed from the received SKP ordered-set(s). In PCI Express Mode, *RxStatus* shall be asserted during the clock cycle when the COM symbol of the SKP ordered-set is moved across the parallel interface.
For the Nominal Empty buffer model the PHY attempts to keep the elasticity buffer as close to empty as possible. This means that the PHY will be required to insert SKP ordered sets into the received data stream when no SKP ordered sets have been received. The Nominal Empty buffer model provides a smaller worst case and average latency then the Nominal Half Full buffer model, but requires the MAC to support receiving SKP ordered sets any point in the data stream.

The figure below shows a sequence where a PHY operating in PCI Express Mode added a SKP symbol in the data stream.



Clock Correction - Add a SKP

The figure below shows a sequence where a PHY operating in PCI Express mode removed a SKP symbol from a SKP ordered-set that only had one SKP symbol, resulting in a ‘bare’ COM transferring across the parallel interface.



Clock Correction - Remove a SKP

6.14 Error Detection

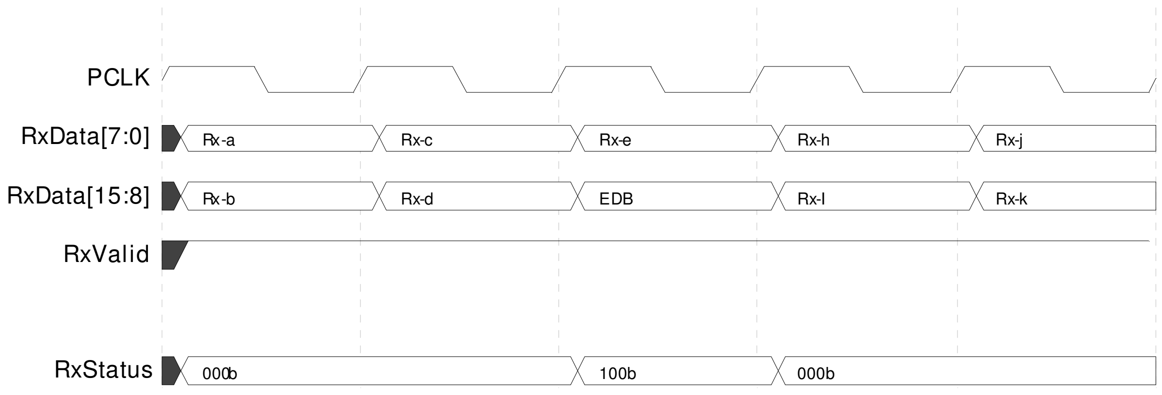
The PHY is responsible for detecting receive errors of several types. These errors are signaled to the MAC layer using the receiver status signals (*RxStatus[2:0]*). Because of higher level error detection mechanisms (like CRC) built into the Data Link layer there is no need to specifically identify symbols with errors, but reasonable timing information about when the error occurred in the data stream is important. When a receive error occurs, the appropriate error code is asserted for one clock cycle at the point in the data stream across the parallel interface closest to where the error actually occurred. There are four error conditions that can be encoded on the *RxStatus* signals. If more than one error should happen to occur on a received byte (or set of bytes transferred across a 16-bit interface or 32-bit interface), the errors should be signaled with the priority shown below.

1. 8B/10B decode error
2. Elastic buffer overflow
3. Elastic buffer underflow (Cannot occur in Nominal Empty buffer model)
4. Disparity errors

If an error occurs during a SKP ordered-set, such that the error signaling and SKP added/removed signaling on *RxStatus* would occur on the same CLK, then the error signaling has precedence.

6.14.1 8B/10B Decode Errors

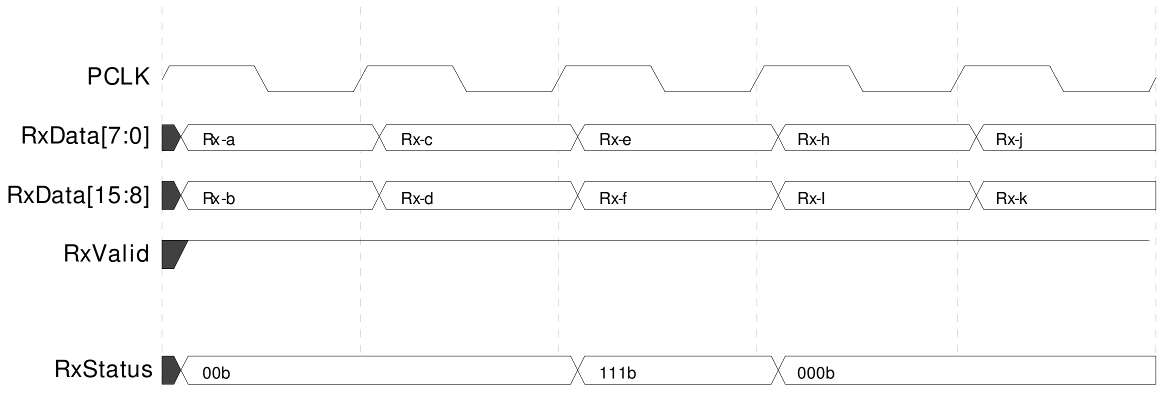
For a detected 8B/10B decode error, the PHY should place an EDB symbol (for PCIe) or SUB symbol (for USB) in the data stream in place of the bad byte, and encode *RxStatus* with a decode error during the clock cycle when the effected byte is transferred across the parallel interface. In the example below for PCIe, the receiver is receiving a stream of bytes Rx-a through Rx-z, and byte Rx-f has an 8B/10B decode error. In place of that byte, the PHY places an EDB (for PCIe) or SUB (for USB) on the parallel interface, and sets *RxStatus* to the 8B/10B decode error code. Note that a byte that can't be decoded may also have bad disparity, but the 8B/10B error has precedence. Also note that for a 16-bit or 32-bit interface, if the bad byte is on the lower byte lane, one of the other bytes may have bad disparity, but again, the 8B/10B error has precedence.



8B/10B Decode Error

6.14.2 Disparity Errors

For a detected disparity error, the PHY should assert *RxStatus* with the disparity error code during the clock cycle when the affected byte is transferred across the parallel interface. For 16-bit interfaces, it is not possible to discern which byte (or possibly both) had the disparity error. In the example below, the receiver detected a disparity error on either (or both) Rx-e or Rx-f data bytes, and indicates this with the assertion of *RxStatus*. Optionally, the PHY can signal disparity errors as 8B/10B decode error (using code 0b100). (MACs often treat 8B/10B errors and disparity errors identically.). When operating in USB SuperSpeed mode signaling disparity errors is optional.

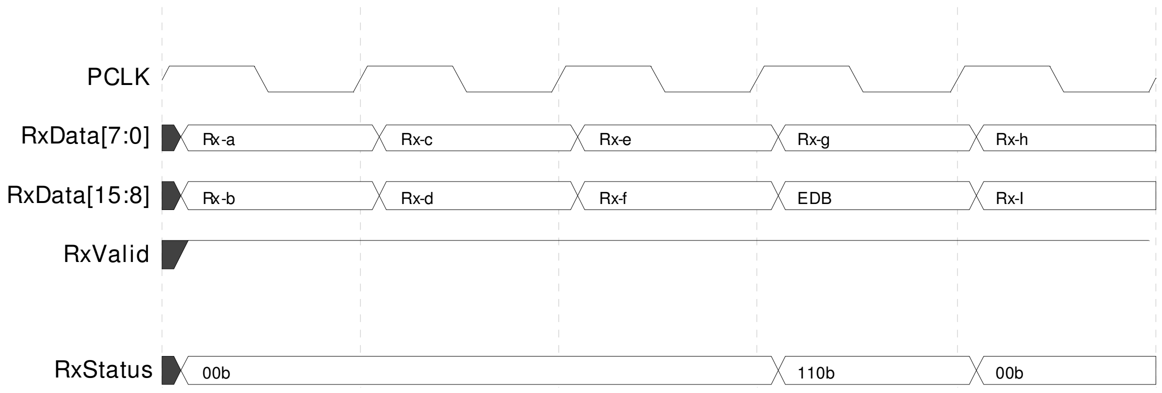


Disparity Error

6.14.3 Elastic Buffer Errors

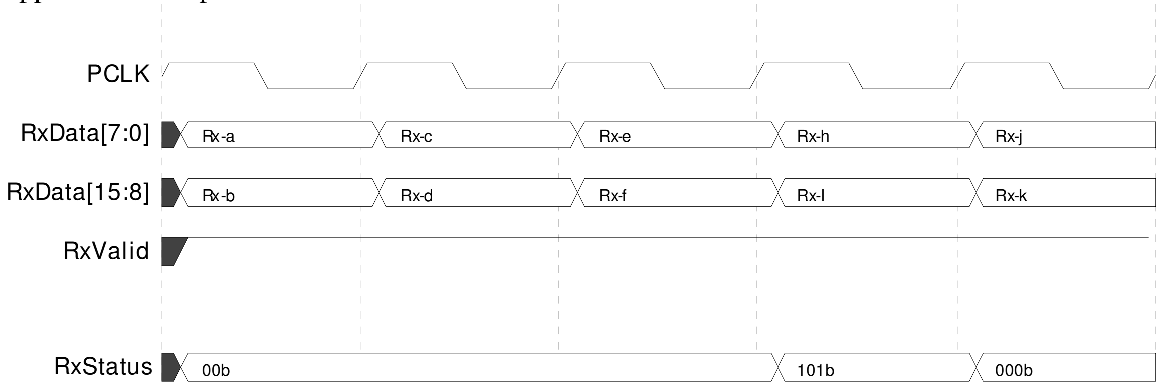
For elastic buffer errors, an underflow should be signaled during the clock cycle or clock cycles when a spurious symbol is moved across the parallel interface. The symbol moved across the interface should be the EDB symbol (for PCIe) or SUB symbol (for USB). In the timing diagram below, the PHY is receiving a repeating set of symbols Rx-a thru Rx-z. The elastic buffer underflows causing the EDB symbol (for PCIe) or SUB symbol (for USB) to be inserted between the Rx-g and Rx-h Symbols. The PHY drives *RxStatus* to indicate buffer underflow during the clock cycle when the EDB (for PCIe) or SUB (for USB) is presented on the parallel interface.

Note that underflow is not signaled when the PHY is operating in Nominal Empty buffer mode. In this mode SKP ordered sets are moved across the interface whenever data needs to be inserted.



Elastic Buffer Underflow

For an elastic buffer overflow, the overflow should be signaled during the clock cycle where the dropped symbol or symbols would have appeared in the data stream. For the 16-bit interface it is not possible, or necessary, for the MAC to determine exactly where in the data stream the symbol was dropped. In the timing diagram below, the PHY is receiving a repeating set of symbols Rx-a thru Rx-z. The elastic buffer overflows causing the symbol Rx-g to be discarded. The PHY drives *RxStatus* to indicate buffer overflow during the clock cycle when Rx-g would have appeared on the parallel interface.



Elastic Buffer Overflow

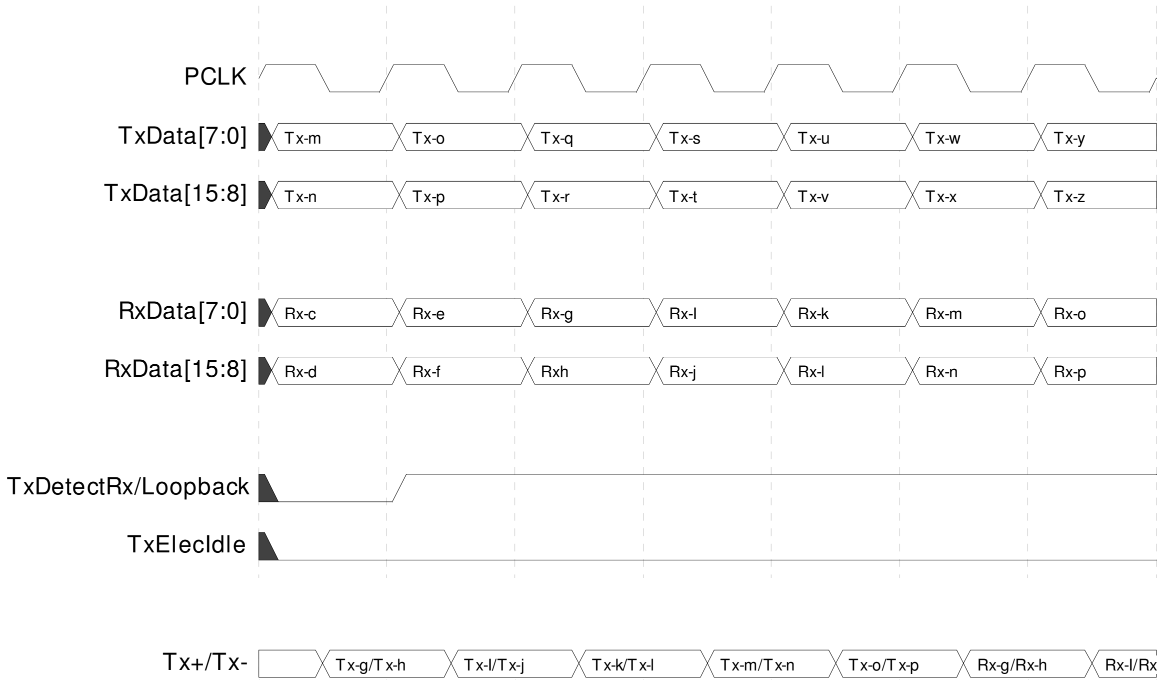
6.15 Loopback

- The PHY must support an internal loopback as described in the corresponding base specification.

The PHY begins to loopback data when the MAC asserts *TxDetectRx/Loopback* while doing normal data transmission (i.e. when *TxElecIdle* is deasserted). The PHY must, within the specified receive and transmit latencies, stop transmitting data from the parallel interface, and begin to loopback received symbols. While doing loopback, the PHY continues to present received data on the parallel interface.

The PHY stops looping back received data when the MAC deasserts *TxDetectRx/Loopback*. Transmission of data on the parallel interface must begin within the specified transmit latency.

The timing diagram below shows example timing for beginning loopback. In this example, the receiver is receiving a repeating stream of bytes, Rx-a thru Rx-z. Similarly, the MAC is causing the PHY to transmit a repeating stream of bytes Tx-a thru Tx-z. When the MAC asserts *TxDetectRx/Loopback* to the PHY, the PHY begins to loopback the received data to the differential *Tx+/Tx-* lines. Timing between assertion of *TxDetectRx/Loopback* and when Rx data is transmitted on the Tx pins is implementation dependent.

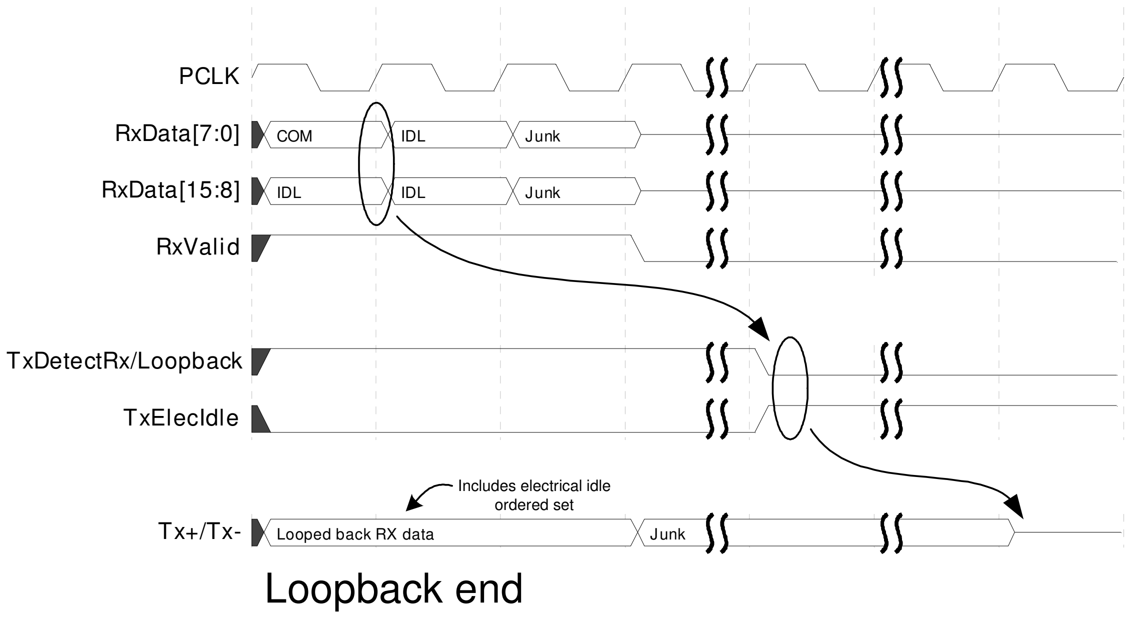


Loopback start

The next timing diagram shows an example of switching from loopback mode to normal mode when the PHY is operating in PCI Express Mode.

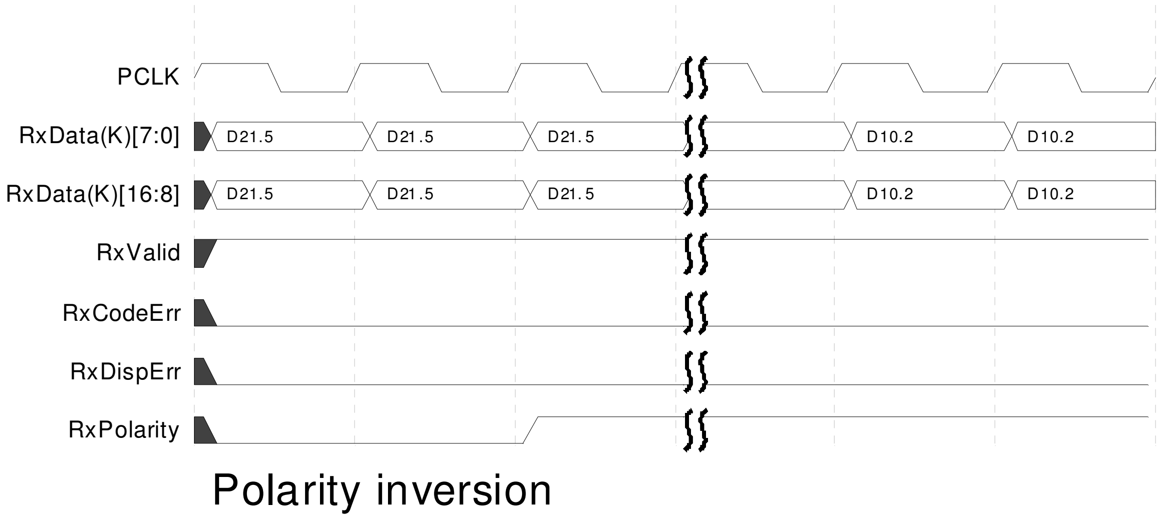
In PCI Express Mode, when the MAC detects an electrical idle ordered-set, the MAC deasserts *TxDetectRx/Loopback* and asserts *TxElecIdle*. The PHY must transmit at least three bytes of the electrical idle ordered-set before going to electrical idle. (Note, transmission of the electrical idle ordered-set should be part of the normal pipeline through the PHY and should not require the PHY to detect the electrical idle ordered-set). The base spec requires that a Loopback Slave be able to detect and react to an electrical idle ordered set within 1ms. The PHY's contribution to this time consists of the PHY's Receive Latency plus the PHY's Transmit Latency (see section 6.13).

When the PHY is operating in USB SuperSpeed Mode, the device shall only transition out of loopback on detection of LFPS signaling (reset) or when VBUS is removed. When valid LFPS signaling is detected, the MAC transitions the PHY to the P2 power state in order to begin the LFPS handshake.



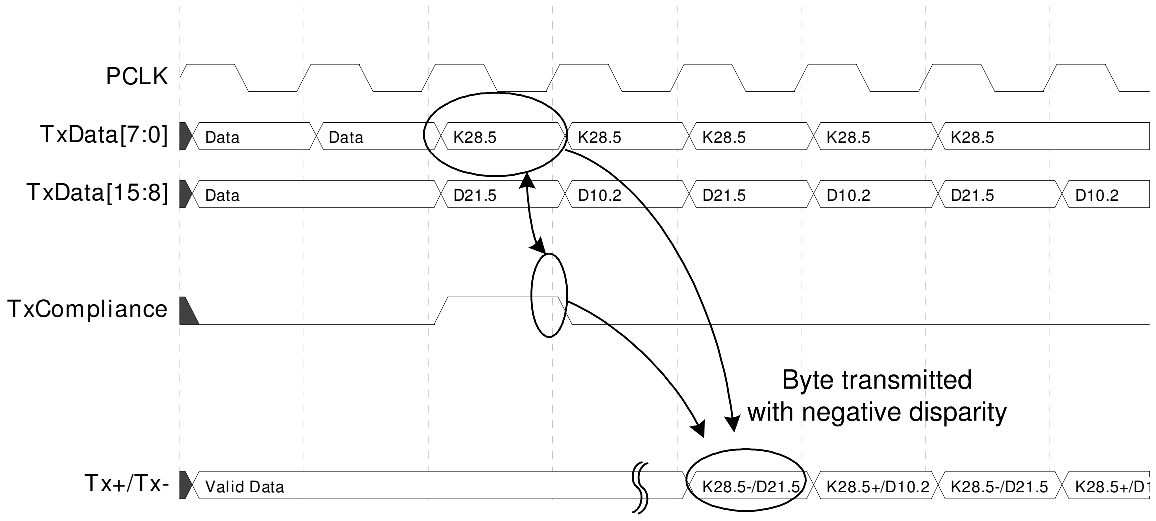
6.16 Polarity Inversion

To support lane polarity inversion, the PHY must invert received data when *RxPolarity* is asserted. Inversion can happen in many places in the receive chain, including somewhere in the serial path, as symbols are placed into the elastic buffer, or as symbols are removed from the elastic buffer. Inverted data must begin showing up on *RxData[]* within 20 PCLKs of when *RxPolarity* is asserted.



6.17 Setting negative disparity (PCI Express Mode)

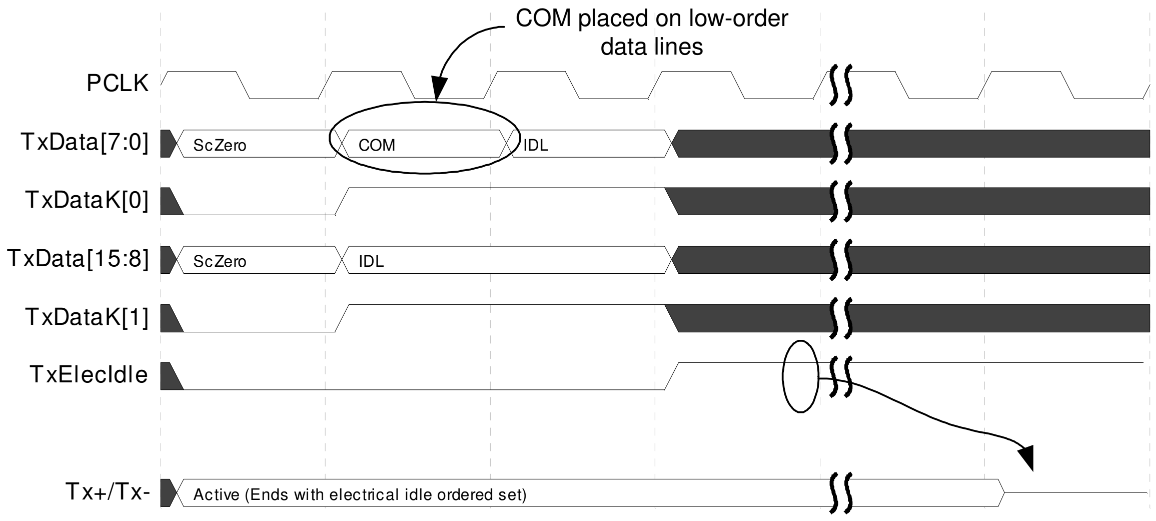
To set the running disparity to negative, the MAC asserts *TxCompliance* for one clock cycle that matches with the data that is to be transmitted with negative disparity. For a 16-bit interface, the low order byte will be the byte transmitted where running disparity is negative. The example shows how *TxCompliance* is used to transmit the PCI Express compliance pattern in PCI Express mode. *TxCompliance* is only used in PCI Express mode.



Setting negative disparity

6.18 Electrical Idle – PCI Express Mode

The base spec requires that devices send an Electrical Idle ordered set before Tx+/Tx- goes to the electrical idle state. For a 16-bit interface or 32-bit interface, the MAC must always align the electrical idle ordered set on the parallel interface so that the COM symbol is on the low-order data lines (*TxDataK[7:0]*).



Electrical Idle

6.19 Implementation specific timing and selectable parameter support

PHY vendors (macrocell or discrete) must specify typical and worst case timings for the cases listed in the table below.

Transmit Latency	Time for data moving between the parallel interface and the PCI Express or USB SuperSpeed serial lines. Timing is measured from when the data is transferred across the parallel interface (i.e. the rising edge of *PCLK*)

	and when the first bit of the equivalent 10-bit symbol is transmitted on the *Tx+/Tx-* serial lines. The PHY reports the latency for each operational mode the PHY supports.
Receive Latency	Time for data moving between the parallel interface and the PCI Express serial lines. Timing is measured from when the first bit of a 10-bit symbol is available on the *Rx+/Rx-* serial lines to when the corresponding 8-bit data is transferred across the parallel interface (i.e. the rising edge of *PCLK*). The PHY reports the latency for each operational mode the PHY supports.
Loopback enable latency	Amount of time it takes the PHY to begin looping back receive data. Timed from when *TxDetectRx/Loopback* is asserted until the receive data is being transmitted on the serial pins. The PHY reports the latency for each operational mode the pHY supports.
Transmit Beacon – PCI Express Mode.	Timed from when the MAC directs the PHY to send a beacon (power state is P2 and *TxElecIdle* is deasserted) until the beacon signaling begins at the serial pins.
Receive Beacon – PCI Express Mode	Timed from when valid beacon signaling is present at the receiver pins until *RxElecIdle* is deasserted.
Transmit LFPS – USB SuperSpeed Mode	Timed from when the MAC directs the PHY to send LFPS signaling until the LFPS signaling begins at the serial pins. Times are reported for each possible P state if the times are different for different power states.
Receive LFPS – USB SuperSpeed Mode	Timed from when valid LFPS signaling is present at the receiver pins until *RxElecIdle* is deasserted.
N_FTS with common clock (PCI Express Mode)	Number of FTS ordered sets required by the receiver to obtain reliable bit and symbol lock when operating with a common clock.
N_FTS without common clock (PCI Express Mode)	Number of FTS ordered sets required by the receiver to obtain reliable bit and symbol lock when operating without a common clock.
PHY lock time	Amount of time for the PHY receiver to obtain reliable bit and symbol lock after valid TSx ordered-sets are present at the receiver. The PHY reports the time for each operational mode the PHY supports.
P0s to P0 transition time PCI Express Mode.	Amount of time for the PHY to return to P0 state, after having been in the P0s state. Time is measured from when the MAC sets the *PowerDown* signals to P0 until the PHY asserts *PhyStatus*. PHY asserts *PhyStatus* when it is ready to begin data transmission and reception.
P1 to P0 transition time. PCI Express Mode.	Amount of time for the PHY to return to P0 state, after having been in the P1 state. Time is measured from when the MAC sets the *PowerDown* signals to P0 until the PHY asserts *PhyStatus*. PHY asserts *PhyStatus* when it is ready to begin data transmission and reception.
P2 to P1 transition time PCI Express Mode.	Amount of time for the PHY to go to P1 state, after having been in the P2 state. Time is measured from when the MAC sets the *PowerDown* signals to P1 until the PHY deasserts *PhyStatus*.
P1 to P0 transition time. USB SuperSpeed Mode.	Amount of time for the PHY to return to P0 state, after having been in the P1 state. Time is measured from when the MAC sets the *PowerDown* signals to P0 until the PHY asserts *PhyStatus*. PHY asserts *PhyStatus* when it is ready to begin data transmission and reception.

P2 to P0 transition time. USB SuperSpeed Mode.	Amount of time for the PHY to return to P0 state, after having been in the P2 state. Time is measured from when the MAC sets the *PowerDown* signals to P0 until the PHY asserts *PhyStatus*. PHY asserts *PhyStatus* when it is ready to begin data transmission and reception.
P3 to P0 transition time USB SuperSpeed Mode.	Amount of time for the PHY to go to P0 state, after having been in the P3 state. Time is measured from when the MAC sets the *PowerDown* signals to P0 until the PHY deasserts *PhyStatus*. PHY asserts *PhyStatus* when it is ready to begin data transmission and reception.
Reset to ready time	Timed from when *Reset#* is deasserted until the PHY deasserts *PhyStatus*.
Data Rate change time PCI Express Mode.	Amount of time the PHY takes to perform a data rate change. Time is measured from when the MAC changes *Rate* to when the PHY signals rate change complete with the single clock assertion of *PhyStatus*. There may be separate values for changing from 2.5 GT/s to 5.0 GT/s or changing from 5.0 GT/s to 2.5 GT/s.
Transmit Margin values supported	Transmitter voltage levels.

[2]	[1]	[0]	Description
0	0	0	TxMargin value 0 =
0	0	1	TxMargin value 1 =
0	1	0	TxMargin value 2 =
0	1	1	TxMargin value 3 =
1	0	0	TxMargin value 4 =
1	0	1	TxMargin value 5 =
1	1	0	TxMargin value 6 =
1	1	1	TxMargin value 7 =

6.20 Control Signal Decode table – PCI Express Mode

The following table summarizes the encodings of four of the seven control signals that cause different behaviors depending on power state. For the other three signals, *Reset#* always overrides any other PHY activity. *TxCompliance* and *RxPolarity* are only valid, and therefore should only be asserted, when the PHY is in P0 and is actively transmitting. Note that these rules only apply to lanes that have not been 'turned off' as described in section 8 (Multi-lane PIPE).

PowerDown[1:0]	*TxDetectRx/ Loopback*	*TxElecIdle*	Description
P0: 00b	0	0	PHY is transmitting data. MAC is providing data bytes to be sent every clock cycle.
	0	1	PHY is not transmitting and is in electrical idle.
	1	0	PHY goes into loopback mode.
	1	1	Illegal. MAC should never do this.
P0s: 01b	Don't care	0	Illegal. MAC should always have PHY doing electrical idle while in P0s. PHY behavior is undefined if *TxElecIdle* is deasserted while in P0s or P1.
		1	PHY is not transmitting and is in electrical idle.

P1: 10b	Don’t care	0	Illegal. MAC should always have PHY doing electrical idle while in P1. PHY behavior is undefined if *TxElecIdle* is deasserted while in P0s or P1.
	0	1	PHY is idle.
	1	1	PHY does a receiver detection operation.
P2: 11b	Don’t care	0	PHY transmits Beacon signaling
		1	PHY is idle.

6.21 Control Signal Decode table – USB SuperSpeed Mode

The following table summarizes the encodings of four of the seven control signals that cause different behaviors depending on power state. For the other three signals, *Reset#* always overrides any other PHY activity. *RxPolarity* is only valid, and therefore should only be asserted, when the PHY is in P0 and is actively transmitting.

PowerDown[1:0]	*TxDetectRx/ Loopback*	*TxElecIdle*	Description
P0: 00b	0	0	PHY is transmitting data. MAC is providing data bytes to be sent every clock cycle.
	0	1	PHY is not transmitting and is in electrical idle.
	1	0	PHY goes into loopback mode.
	1	1	PHY transmits LFPS signaling.
P1: 01b	Don't care	0	PHY transmits LFPS signaling
		1	PHY is not transmitting and is in electrical idle.
P2: 10b or P3: 11b	Don't care	0	PHY transmits LFPS signaling
	0	1	PHY is idle.
	1	1	PHY does a receiver detection operation.

6.22 Required synchronous signal timings

To improve interoperability between MACs and PHYs from different vendors the following timings for synchronous signals are required:

Setup time for input signals	No greater than 25% of cycle time
Hold time for input signals	0ns
PCLK to data valid for outputs	No greater than 25% of cycle time

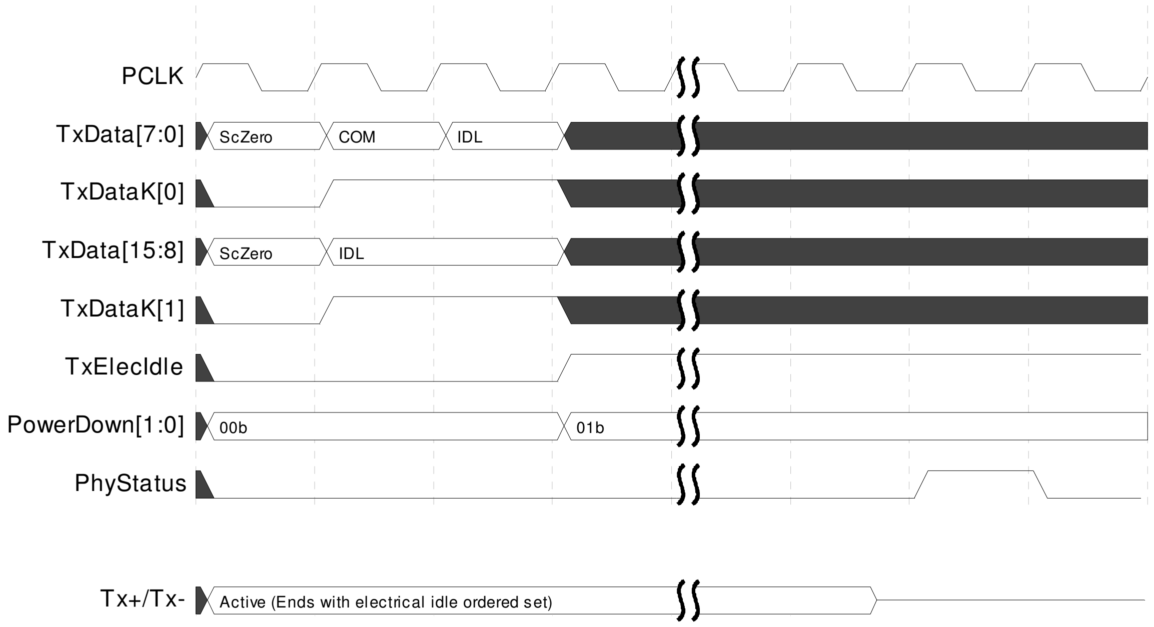
7 Sample Operational Sequences

These sections show sample timing sequences for some of the more common PCI Express and USB SuperSpeed operations. These are *sample* sequences and timings and are not required operation.

7.1 Active PM L0 to L0s and back to L0 – PCI Express Mode

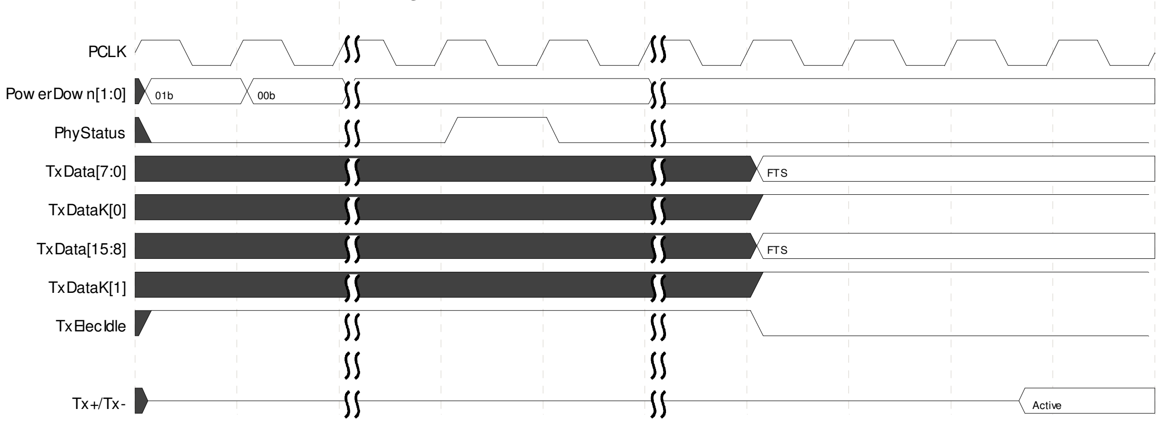
This example shows one way a PIPE PHY can be controlled to perform Active State Power Management on a link for the sequence of the link being in L0 state, transitioning to L0s state, and then transitioning back to L0 state.

When the MAC and higher levels have determined that the link should transition to L0s, the MAC transmits an electrical idle ordered set and then has the PHY transmitter go idle and enter P0s. Note that for a 16-bit or 32-bit interface, the MAC should always align the electrical idle on the parallel interface so that the COM symbol is in the low-order position (*TxDataK[7:0]*).



L0 to L0s

To cause the link to exit the L0s state, the MAC transitions the PHY from the P0s state to the P0 state, waits for the PHY to indicate that it is read to transmit (by the assertion of *PhyStatus*), and then begins transmitting Fast Training Sequences (FTS). Note, this is an example of L0s to L0 transition when the PHY is running at 2.5GT/s.

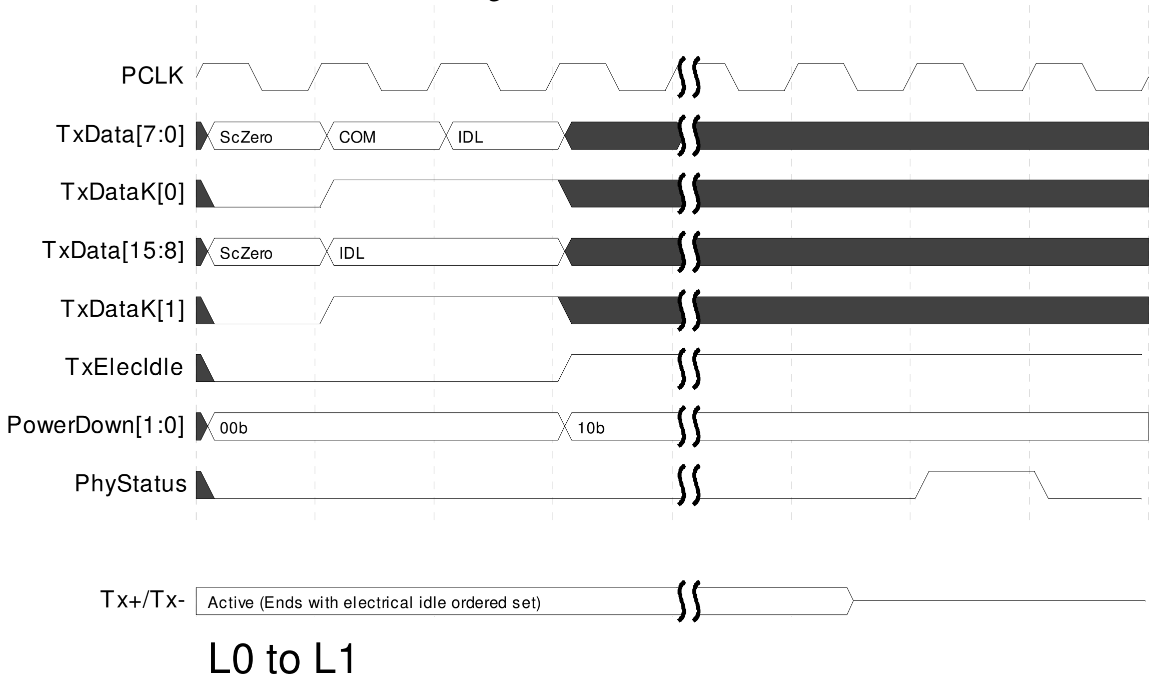


L0s to L0

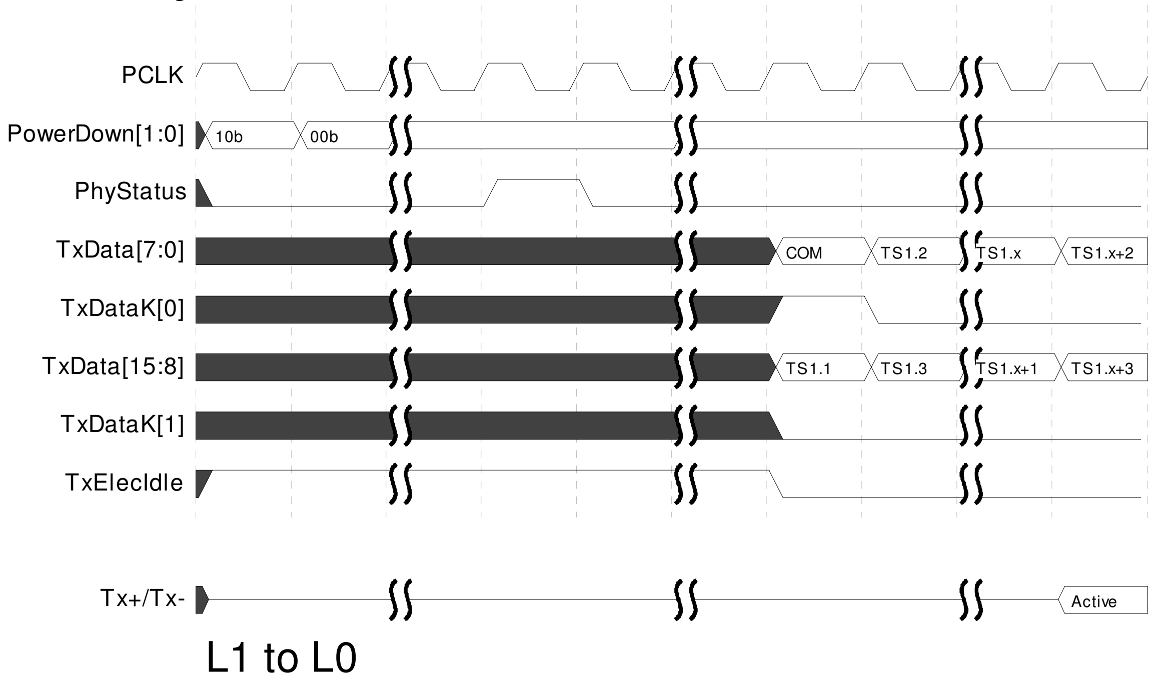
7.2 Active PM to L1 and back to L0 - – PCI Express Mode

This example shows one way a PIPE PHY can be controlled to perform Active State Power Management on a link for the sequence of the link being in L0 state, transitioning to L1 state, and then transitioning back to L0 state. This example assumes that the PHY is on an endpoint (i.e. it is facing upstream) and that the endpoint has met all the requirements (as specified in the base spec) for entering L1.

After the MAC has had the PHY send PM_Active_State_Request_L1 messages, and has received the PM_Request_ACK message from the upstream port, it then transmits an electrical idle ordered set, and has the PHY transmitter go idle and enter P1.



To cause the link to exit the 1 state, the MAC transitions the PHY from the P1 state to the P0 state, waits for the PHY to indicate that it is ready to transmit (by the assertion of *PhyStatus*), and then begins transmitting training sequence ordered sets (TS1s). Note, this is an example when the PHY is running at 2.5GT/s.

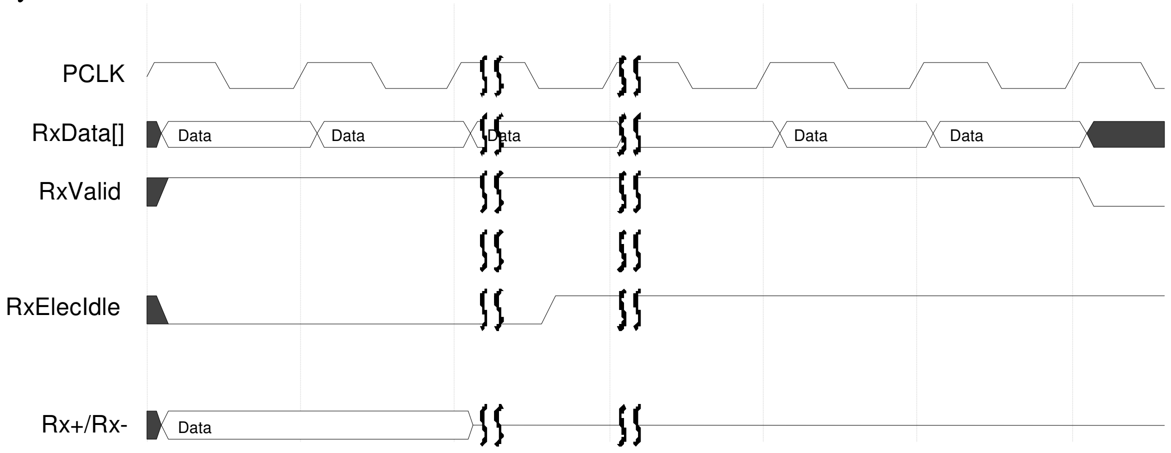


7.3 Receivers and Electrical Idle

This section only applies to a PHY operating to 2.5GT/s. Note that when operating at 5.0 GT/s signaling rates, *RxElecIdle* may not be reliable. MACs should refer to the PCI Express Revision

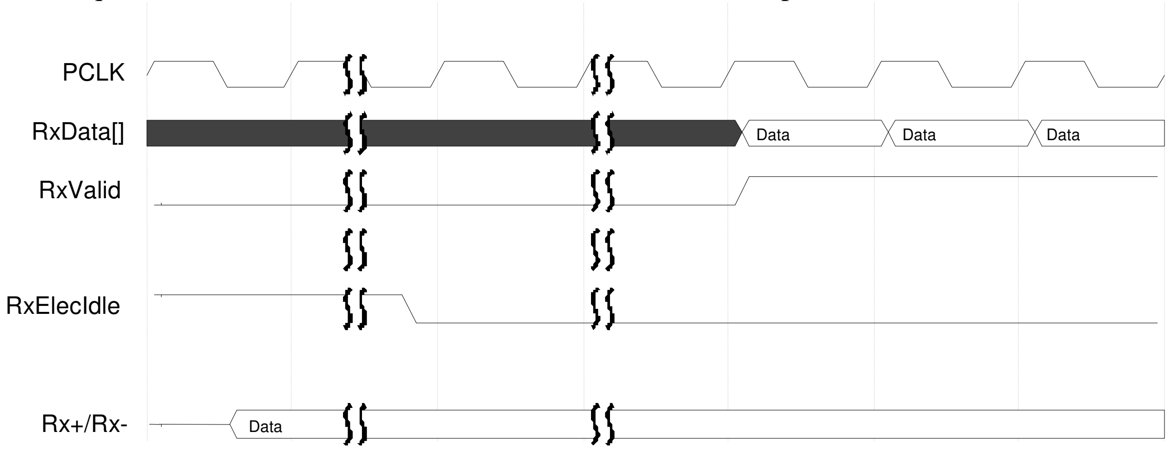
2.0 Base Specification or USB 3.0 Specification for methods of detecting entry into the electrical idle condition. Refer to Table 5-4 for the definition of *RxElecIdle* when operating at 5.0 GT/s. This section shows some examples of how PIPE interface signaling may happen as a receiver transitions from active to electrical idle and back again. In these transitions there may be a significant time difference between when *RxElecIdle* transitions and when *RxValid* transitions.

The first diagram shows how the interface responds when the receive channel has been active and then goes to electrical idle. In this case, the delay between *RxElecIdle* being asserted and *RxValid* being deasserted is directly related to the depth of the implementations elastic buffer and symbol synchronization logic. Note that the transmitter that is going to electrical idle may transmit garbage data and this data will show up on the *RxData[]* lines. The MAC should discard any symbols received after the electrical idle ordered-set until RxValid is deasserted.



Receiver Active to Idle

The second diagram shows how the interface responds when the receive channel has been idle and then begins signaling again. In this case, there can be significant delay between the deassertion of *RxElecIdle* (indicating that there is activity on the *Rx+/Rx-* lines) and *RxValid* being asserted (indicating valid data on the *RxData[]* signals). This delay is composed of the time required for the receiver to retrain as well as elastic buffer depth.



Receiver Idle to Active

7.4 Using CLKREQ# with PIPE – PCI Express Mode

CLKREQ# is used in some implementations by the downstream device to cause the upstream device to stop signaling on REFCLK. When REFCLK is stopped, this will typically cause the CLK input to the PIPE PHY to stop as well. The PCI Express CEM spec allows the downstream device to stop REFCLK when the link is in either L1 or L2 states. For implementations that use CLKREQ# to further manage power consumption, PIPE compliant PHYs can be used as follows:

The general usage model is that to stop REFCLK the MAC puts the PHY into the P2 power state, then deasserts CLKREQ#. To get the REFCLK going again, the MAC asserts CLKREQ#, and then after some PHY and implementation specific time, the PHY is ready to use again.

CLKREQ# in L1

If the MAC is moving the link to the L1 state and intends to deassert CLKREQ# to stop REFCLK, then the MAC follows the proper sequence to get the link to L1, but instead of finishing by transitioning the PHY to P1, the MAC transition the PHY to P2. Then the MAC deasserts CLKREQ#.

When the MAC wants to get the link alive again, it can:

- Assert CLKREQ#
- Wait for REFCLK to be stable (implementation specific)
- Wait for the PHY to be ready (PHY specific)
- Transition the PHY to P0 state and begin training.

CLKREQ# in L2

If the MAC is moving the link to the L1 state and intends to deassert CLKREQ# to stop REFCLK, then the MAC follows the proper sequence to get the link to L2. Then the MAC deasserts CLKREQ#.

When the MAC wants to get the link alive again, it can:

- Assert CLKREQ#
- Wait for REFCLK to be stable (implementation specific)
- Wait for the PHY to be ready (PHY specific)
- Transition the PHY to P0 state and begin training.

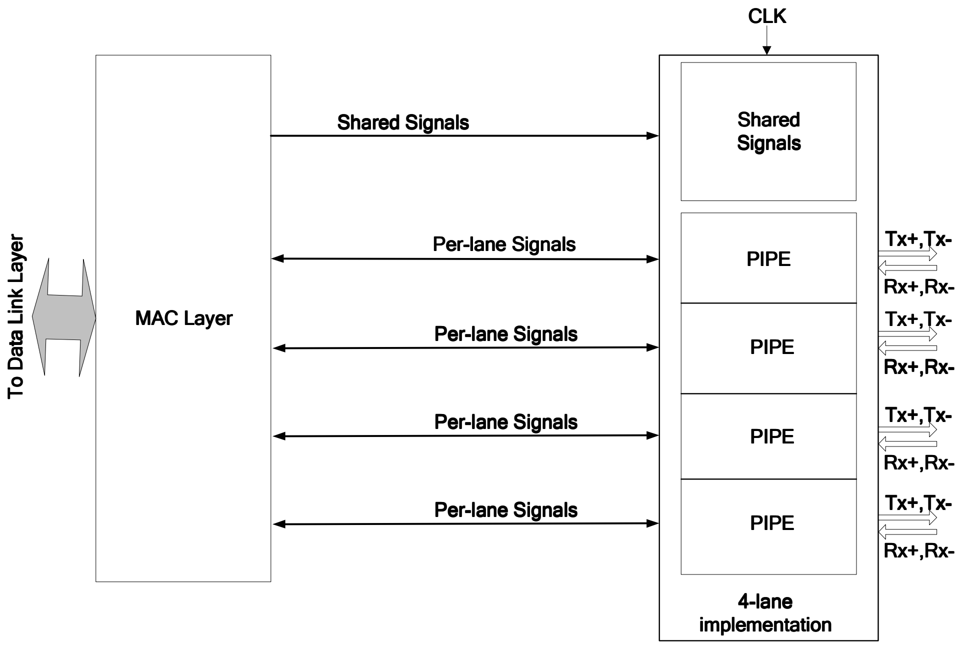
Delayed CLKREQ# in L1

The MAC may want to stop REFCLK after the link has been in L1 and idle for awhile. In this case, the PHY is in the P1 state and the MAC must transition the PHY into the P0 state, and then the P2 state before deasserting CLKREQ#. Getting the link operational again is the same as the preceding cases.

8 Multi-lane PIPE – PCI Express Mode

This section describes a suggested method for combining multiple PIPEs together to form a multi-lane implementation. It describes which PIPE signals can be shared between each PIPE of a multi-lane implementation, and which signals should be unique for each PIPE. This description primarily applies to multi-lane links where lanes that become disassociated from an LTSSM during training are unused, and they don't associate with a new LTSSM. This is the common case for most upstream facing ports, like those found in PCI Express endpoints.

The figure shows an example 4-lane implementation of a multilane PIPE solution. The signals that can be shared are explicitly shown in the figure while signals that replicated for each lane are shown as 'Per-lane signals'.



4-lane PIPE implementation

The MAC layer is responsible for handling lane-to-lane deskew and it may be necessary to use the per-lane signaling of SKP insertion/removal to help perform this function.

Shared Signals	Per-lane Signals
CLK	TxData[], TxDataK[]
PCLK	RxData[], RxDataK[]
TxDetectRx/Loopback	TxElecIdle
Reset#	TxCompliance
PowerDown[1:0]	RxPolarity
PhyStatus	RxValid
Rate	RxElecIdle
TxMargin[2:0]	RxStatus[2:0]
TxDeemph	
TxSwing	

In cases where a multi-lane has been 'trained' to a state where not all lanes are in use (like a x4 implementation operating in x1 mode), a special signaling combination is defined to 'turn off' the unused lanes allowing them to conserve as much power as the implementation allows. This special 'turn off' signaling is done using the *TxElecIdle* and *TxCompliance* signals. When both are asserted, that PHY can immediately be considered 'turned off' and can take whatever power saving measures are appropriate. The PHY ignores any other signaling from the MAC (with the exception of *Reset#* assertion) while it is 'turned off'. Similarly, the MAC should ignore any signaling from the PHY when the PHY is 'turned off'. There is no 'handshake' back to the MAC to indicate that the PHY has reached a 'turned off' state.

There are two normal cases when a lane can get turned off:

1. During LTSSM Detect state, the MAC discovers that there is no receiver present and will 'turn off' the lane.
2. During LTSSM Configuration state (specifically Configuration.Complete), the MAC will 'turn off' any lanes that didn't become part of the configured link.

As an example, both of these cases could occur when a x4 device is plugged into a x8 slot. The upstream device (the one with the x8 port) will not discover receiver terminations on four of its lanes so it will turn them off. Training will occur on the remaining 4 lanes, and let's suppose that the x8 device cannot operate in x4 mode, so the link configuration process will end up settling on x1 operation for the link. Then both the upstream and downstream devices will 'turn off' all but the one lane configured in the link.

When the MAC wants to get 'turned off' lanes back into an operational state, there are two cases that need to be considered:

1. If the MAC wants to reset the multi-lane PIPE, it asserts *Reset#* and drives other interface signals to their proper states for reset (see section 6.2). Note that this stops signaling 'turned off' to all lanes because *TxCompliance* is deasserted during reset. The multi-lane PHY asserts *PhyStatus* in response to *Reset#* being asserted, and will deassert *PhyStatus* when *PCLK* is stable.
2. When normal operation on the active lanes causes those lanes to transition to the LTSSM Detect state, then the MAC sets the *PowerDown[1:0]* signals to the P1 PHY power state at the same time that it deasserts 'turned off' signaling to the inactive lanes. Then as with normal transitions to the P1 state, the multi-lane PHY will assert *PhyStatus* for one clock when all internal PHYs are in the P1 state and *PCLK* is stable.