Manoj Sharma Tanikella, Sr. R&D Engineer
Amitkumar Shrichand Gound, Sr. R&D Engineer
Synopsys

Overcoming Inter-Symbol Interference with MIPI PHYs using Training Sequences
Agenda

• Training sequence requirements
• ADAPT sequence in MIPI M-PHY®
• Alternate sequence in MIPI D-PHY℠
• Calibration sequences in MIPI C-PHY℠
• Summary
Training Sequence Requirements

• Overview on adaptive equalizer
• Purpose of training sequences
Adaptive Equalizer Overview

Transmitter \rightarrow Equalizer \rightarrow Receiver

Filter \rightarrow Adaptive Equalizer \rightarrow Data Processing

Training Sequence

01010011001110101010
High-speed DATA

Synopsys
Purpose of Training Sequences

- Bit patterns used in adaptive equalizer module are known as training sequences
- Receiver must realize sequences well in advance, so that receiver can compare and optimize its co-efficient for proper DATA reception
- System can send DATA once training sequence is complete
- Most commonly used training sequences are Pseudo Random Bit Sequences (PRBS)
- Example: PRBS9, PRBS32, etc.

Synopsys
ADAPT Sequence in MIPI M-PHY

- What is ADAPT?
- Why and when ADAPT sequence is required?
- PRBS9 handling
- ADAPT operation
- Future scope

Synopsys
What is ADAPT?

- The training sequence used to optimize the equalizer settings of the receiver, in this case M-RX, is known as ADAPT.
- ADAPT was introduced in MIPI M-PHY v4.0 for higher data rate HS_G4 gear.
- ADAPT consists of MK0 + Pseudo Random Bit Sequence + bit 1'b0.
- PRBS with equation $X^9 + X^5 + 1$ (PRBS9) is used.
Why and When ADAPT Sequence is Required?

- As MIPI M-PHY started supporting higher speed HS_G4 gear, inter symbol interference and noise increased.
- In-order to re-tune equalizer settings, ADAPT sequence was introduced as training sequence.
- ADAPT sequence or ADAPT sub-state is used before starting with HS-G4 DATA.
- ADAPT Sequence: PREPARE → ADAPT PATTERN → BURSTEND

PREPARE | ADAPT PATTERN (MK0 +encoded PRBS9 + 1b0) | BURSTEND
PRBS9 Handling

- PRBS9 is a combination of 9 linear-shift registers where output of 5\(^{th}\) and 9\(^{th}\) registers are xored and feedback is provided to input; Generates \(2^9 - 1 = 511\) bits
- As per standard ITU-T recommendation 0.150 and 0.153, pattern begins with first 1’b1 of 9 consecutive ONEs
If PRBS9 is initialized with all 1’s (1_1111_1111) on every 8 clock, output will be:

• Bit formation1: 11111111_10000011_11011111_00110010_00001001 i.e., ‘hFF → ‘h83 → ‘hDF → ‘h17 → ‘h32 → ‘h09
• Bit formation2: 11111111_11000001_11111011_01001100_10010000 i.e., ‘hFF → ‘hC1 → ‘hFB → ‘h4C → ‘h90

Synopsys
ADAPT Operation

- ADAPT operation requirements:
  - Link should be in HS_G4 gear
  - M-RX attribute RX_ADAPT_Control should be programmed to 2'bX0
    - Where X can be 0 = Initial ADAPT length or 1 = Refresh ADAPT length
  - On receiving ADAPTSTART.req from protocol, PHY moves to ADAPT sub-state after PREPARE and starts driving ADAPT sequence for $T_{ADAPT}$ length; ADAPT sub-state is ended by BURSTEND SAP

Wave Snippet from Synopsys M-PHY VIP

Synopsys
ADAPT Operation

- Duration for which complete ADAPT sequence takes is known as $T_{ADAPT}$
- M-RX has two 8-bit capability attribute for ADAPT length
  - RX_HS_ADAPT_REFRESH_Capability
  - RX_HS_ADAPT_INITIAL_Capability
- M-TX TX_HS_ADAPT_Length should be greater or equal to above capability values
- As per MIPI M-PHY specification $T_{ADAPT}$ length is calculated as the following:

<table>
<thead>
<tr>
<th>Attribute or Parameter</th>
<th>Value</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$T_{ADAPT}$</td>
<td>IF (ADAPT_type = FINE) $T_{ADAPT} = 650 \times (ADAPT_length + 1)$</td>
<td>bit</td>
</tr>
<tr>
<td></td>
<td>ELSE (IF ADAPT_type = COARSE) $T_{ADAPT} = 650 \times 2^{ADAPT_length}$, where $ADAPT_length &lt; 18$</td>
<td></td>
</tr>
</tbody>
</table>

Source: MIPI Alliance M-PHY v4.1
Future Scope

• Improve performance by skipping SAVE state between ADAPT and DATA burst
  – i.e., PREAPRE $\Rightarrow$ ADAPT $\Rightarrow$ SYNC $\Rightarrow$ DATA
Alternate Sequence in MIPI D-PHY

- What is alternate sequence?
- Why and when alternate sequence is required?
- PRBS9 handling
- Alternate operation
- State flow
- Future scope

Synopsys
What is Alternate Sequence?

• Training sequence for optimization of receiver equalizer settings in MIPI D-PHY using PRBS pattern is known as alternate sequence

• Alternate sequence was introduced in MIPI D-PHY v2.1

• PRBS with equation $X^9 + X^5 + 1$ (PRBS9) is used

• Used in combination with initial skew calibration
Why and When Alternate Sequence is Required?

• Similar to MIPI M-PHY, MIPI D-PHY started supporting higher DATA rate 2.5Gbps or above; This leads to same inter symbol inference and noise
• In order to re-tune equalizer setting, alternate sequence is introduced as training sequence
• Its mandatory for DATA transmission above 2.5 Gbps; designer may choose to support alternate sequence at or below 2.5 Gbps
• Used at link power up and/or on link re-initialization
• Alternate sequence divided into three part HS0 → Calibration Sync → Calibration Pattern (PRBS9)
PRBS9 Handling

- MIPI D-PHY was second PHY to introduce PRBS9 for calibration
- PRBS9 is initialized with 9-bit value 000000001
- For 8-bit data width on every 8 shifts, output is formed; As shown in figure Data[7:0] is the output from shift register 8 to 1

- For 16/32bit data width, same PRBS9 will be shifted 16/32 times to form Data[15:0]/Data[31:0] output respectively
Alternate Operation

- Initial skew calibration is followed by alternate calibration when link is above 2.5Gbps speed
- After Initial skew links stop state LP11, followed by HS-request LP01 → LP-00 → HS0
- Alternate calibration consists of calibration sync and PRBS9 pattern

Source: MIPI Alliance D-PHY v2.1

© 2017 MIPI Alliance, Inc.
State Flow

HS-Prpr LP-00 → HS-Rqst LP-01 → Stop LP-11

Initial Skew & Alternate Calibration

- Skew Cal Sync HS-1-1-1-1-1-1-1-1-1-1-1-1
- Skew Calibration HS-1-0-1-0-1-0-1-0-1-0-1-0
- EOT HS-1/HS-0
- HS-Zero HS-0
- HS-Prpr LP-00 → HS-Rqst LP-01 → Stop LP-11
- Alternate Cal Sync HS-1-1-1-0-0-0-0
- Alternate Calibration HS-PRBS9
- EOT HS-1/HS-0

Source: MIPI Alliance D-PHY v2.1

Synopsys
Future Scope

• Alternate sequence can start as soon as initial skew pattern ends, instead of going to STOP state

Reference: MIPI Alliance DPHY Version 2.1
Calibration Sequences in MIPI C-PHY

• What is calibration sequence?
• Types of calibration sequence
• Preamble handling and operation
• Alternate calibration handling and operation
• User-defined calibration handling and operation
• State flow
• Future scope

Synopsys
What is Calibration Sequence?

- Similar to MIPI M-PHY and MIPI D-PHY, in MIPI C-PHY, training sequence used to optimize receiver equalizer settings is known as Calibration sequence
- Calibration sequences were introduced in MIPI C-PHY v1.2
- There are three different calibration sequences that were introduced in MIPI C-PHY
- Calibration sequence will be transmitted along with DATA burst
- Calibration sequences are used when system operates above 3.0 Gsps
- System may support calibration below 3.0 Gsps DATA transmission
Types of Calibration Sequence

- MIPI C-PHY introduced three type of calibration sequence
  - Preamble calibration
  - Alternate calibration
  - User-define calibration

- Preamble calibration
  - series of 1’s symbol
  - It’s different from normal preamble pattern – all 3’s – so receiver can easily identify difference between normal and calibration preamble

- Alternate Calibration
  - Starts right after preamble calibration
  - Begins with alternate ID followed by alternate pattern (PRBS9) similar as other two PHYs

- User-define Calibration
  - Starts right after preamble calibration
  - Begins with user-define ID followed by user-define pattern
This calibration type only consists of preamble sequence which is sequence of 1s symbol
- Sequence of 1 symbol transmission duration of $t_{3\text{-CALPREAMBLE}}$
- $t_{3\text{-CALPREAMBLE}}$ should be minimum of one group (7UI) to a maximum of 256 groups (7 X 256 = 1792 UI)
- Once preamble sequence completes, followed by SYNC and DATA

$t_{3\text{-CALPREAMBLE}}$ for transmitter ranges from 7UI to 1792 UI
- Receiver should specify minimum value by which it can detect sequence of 1 symbol
- Max for receiver is 1792UI

Wave Snippet from Synopsys C-PHY VIP

Synopsys
Alternate Sequence Handling

- Alternate calibration is divided into three parts
  - Preamble calibration
  - Alternate ID
  - Alternate sequence (PRBS9)

- Preamble Calibration
  - Alternate calibration first starts with preamble calibration
  - Preamble calibration (symbol of 1) is transmitted for \( t_{3\text{-CALPREAMBLE}} \) duration

- Alternate ID
  - In-order to identify which type of calibration receiver is receiving, after preamble calibration seven “3” symbol is transmitted to indicate start of alternate calibration for \( t_{3\text{-ASID}} \) duration which is fixed at 7UI

- Alternate sequence
  - Similar to MIPI M-PHY and MIPI D-PHY, MIPI C-PHY also uses PRBS9 sequence
  - Sequence is encoded in symbols using the MIPI C-PHY 3-phase mapper and encoder
  - Transmitted for \( t_{3\text{-CALALTSEQ}} \) duration with minimum of one group (7UI) to 2048 groups (7 X 2048 = 14336 UI)
Alternate Sequence Handling (Continued...)

- Data0 to Data15 represent 16-bit output data Data\[15:0\]; data output is collected on every 16 clock shift
- There is no fix value for initial seed; below graphic shows when PRBS9 is initialized with seed value 0x0001
Alternate Calibration Operation

For transmitter it ranges from 7UI to 14336 UI; receiver should specify required minimum; max for receiver is 14336UI

Wave Snippet from Synopsys C-PHY VIP
User-Defined Sequence Handling

- User-defined calibration is divided into three parts:
  - Preamble calibration
  - User-defined ID
  - User-defined sequence

- Preamble calibration
  - User-defined calibration also first starts with preamble calibration as discussed last
  - Preamble calibration (symbol of 1) is transmitted for \( t_{3-CALPREAMBLE} \) duration

- User-defined ID
  - In-order to identify which type of calibration receiver receiving, after preamble calibration “3333313” symbol is transmitted to indicate start of user-defined calibration for \( t_{3-UDID} \) duration which is fixed at 7UI

- User-defined sequence
  - As name suggests it consists of user define sequence
  - Driven for \( t_{3-CALUDEFSEQ} \) duration which can be minimum of one group (7UI) to 2048 group (14336 UI)

Synopsys
User-Defined Calibration Operation

**t₃-CALUDEFSEQ** For transmitter ranges from 7UI to 14336 UI; receiver should specify required minimum; max for receiver is 14336UI

Wave Snippet from Synopsys C-PHY VIP

Synopsys
State Flow

Cal. Preamble

Alternate ID 3333333
Alternate Sequence PRBS9

User-Defined ID 33333313
User-Defined Sequence

Sync

HS Data

Synopsys

© 2017 MIPI Alliance, Inc.
Future Scope

• To reduce clock cycle instead of sending calibration in each burst, we can send calibration in first burst (when driving above 3Gsps)

Reference: MIPI Alliance DPHY Version 2.1
Summary

- As discussed, training sequences are introduced to re-tune the receiver equalizer circuits for proper data reception at high speed
- These patterns are used before actual data transmission so that receiver can self tune itself

<table>
<thead>
<tr>
<th>MIPI M-PHY</th>
<th>MIPI D-PHY</th>
<th>MIPI C-PHY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Used at SPEED</td>
<td>HS-G4 gear</td>
<td>Speed above 2.5 Gbps</td>
</tr>
<tr>
<td>Lower speed support</td>
<td>NO</td>
<td>May support</td>
</tr>
<tr>
<td>Patterns used</td>
<td>PRBS9</td>
<td>PRBS9</td>
</tr>
<tr>
<td>Calibration flow</td>
<td>Before actual Data</td>
<td>Along with Initial skew before actual Data</td>
</tr>
</tbody>
</table>

Synopsys
VC VIP & TestSuite for MIPI

• MIPI CSI-2
  – CSI-2 1.1, 1.2
  – D-PHY 1.1, 1.2
  – CSI-2 1.3 compliant with C-PHY 1.0 and DPHY 1.2
  – CSI-2 2.0 compliant with C-PHY 1.1 and DPHY 2.0
• MIPI CSI-3 v1.0
• MIPI DSI
  – DSI 1.1, 1.2 compliant with D-PHY 1.1
  – DSI 1.3 compliant with D-PHY 1.2
  – DSI 2.0 compliant with C-PHY 1.0 and DPHY 2.0
• MIPI DigRF v4 1.10, 1.00 and 0.64
  • MIPI HSI
  • MIPI DBI 2.0 Specification
  • MIPI DPI 2.0 Specification
  • MIPI UniPro
  • MIPI I3C
  • MIPI RFFE
  • MIPI SoundWire
  • MIPI SPMI 2.0
  • MIPI M-PHY v4.1

© 2017 MIPI Alliance, Inc.
Synopsys® DesignWare® MIPI IP Portfolio