

# **PRBS9Q Pattern and PAM4 Symbols Used for Jitter/EOJ Measurement**

(A presentation in support of draft 2.0 comments # 236)

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# PRBS9Q may be used for Jitter/EOJ measurement

## 162.9.3.4 Output jitter

Output jitter is characterized by three parameters,  $J_{3u}$ ,  $J_{RMS}$ , and even-odd jitter. These parameters are calculated from measurements with a single transmit equalizer setting to compensate for the loss of the transmitter package and host channel. The equalizer setting is chosen to minimize any or all of the jitter parameters.

$J_{3u}$  and  $J_{RMS}$  are calculated using the measurement method specified in 120D.3.1.8.1.  $J_{3u}$  is defined as the time interval that includes all but  $10^{-3}$  of  $f_J(t)$ , from the 0.05th to the 99.95th percentile of  $f_J(t)$ .

Even-odd jitter is calculated using the measurement method specified in 120D.3.1.8.2. with the following exceptions:

- a) The test pattern is either PRBS13Q or alternatively PRBS9Q. PRBS9Q is defined in a similar way to PRBS13Q (see 120.5.11.2.1) except that the polynomial in Table 68-6 is used instead of the polynomial in Equation 94-3. Meeting the even-odd jitter requirement with only one pattern is sufficient.
- b) The corner frequency of the clock recovery unit (CRU) may be set lower than 4 MHz. Meeting the even-odd jitter requirement with only one CRU bandwidth is sufficient.

NOTE—If the measuring instrument is triggered by a clock based on the signaling rate divided by an even number, the even-odd jitter may not be correctly observed.

# PRBS9 Generating Polynomial

**Table 68–6—Test-pattern definitions and related subclauses (*continued*)**

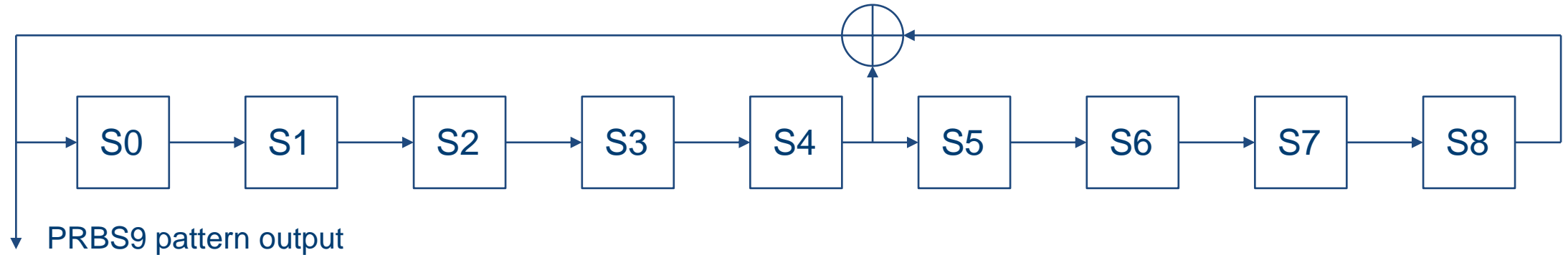
Test	Pattern	Related subclause
Calibration of noise for receiver tests	Square, eight ONEs and eight ZEROs	68.6.9
Transmitter noise	Square	68.6.7
Transmitter uncorrelated jitter	1, 2, or PRBS9 <sup>a</sup>	68.6.8
Extinction ratio	1 or 3	68.6.3
Average optical power	1 or 3	52.9.3
Transmitted waveform (eye mask)	1 or 3	68.6.5
Transmitter waveform and dispersion penalty (TWDP)	1 or PRBS9 <sup>a</sup>	68.6.6
Pattern 1 subsequence Pattern 1 subsequence key	348 bits, beginning at bit 3258 101010111011011, beginning immediately before the subsequence at bit 3243	
Encircled flux	Not specified here	See IEC 61280-1-4
Wavelength, spectral width	1 or 3	52.9.2
Receiver jitter tolerance	1 or 3	68.6.11
Comprehensive stressed receiver sensitivity	2 or 3	68.6.9
Comprehensive stressed receiver overload	1 or 3	68.6.9
Simple stressed receiver sensitivity	1 or 3	68.6.10
Simple stressed receiver overload	1 or 3	68.6.10

$$G(x) = 1 + x^5 + x^9$$

<sup>a</sup>The PRBS9 pattern is optional. If used, it is generated by the polynomial  $x^9 + x^5 + 1$  as specified in ITU-T O.153. The binary (0,1) data sequence  $d(n)$  is given by  $d(n) = d(n-9) + d(n-5)$ , modulo 2. The pattern has a run of nine ones in its length of 511 bits.

# PRBS9 Generator and PRBS9Q PAM4 Symbols

$$G(x) = 1 + x^5 + x^9$$



## Gray mapped PRBS9Q



Example of bits to PAM4 symbols (Gray) mapping

Bits: 0000 0111 1011 1110 ...  
PAM4: 0 0 1 2 3 2 2 3 ...

# 12 Edge Transition Determination for PRBS9Q

- First identify the two identical “trailing” symbols, and then looking for the longest “leading” identical different symbols, for
  - Least correlated jitter, stable edge transition, and UJ/EOJ accuracy/repeatability
  - Aligned with the method used for existing PRBS13Q
  - Implemented and tested in a real pattern generator

# PRBS9Q Pattern Symbols for Jitter/EOJ Measurement

Label	Description	Gray coded PAM4 symbols	Index of first symbol	Index transition begins	Index transition ends	Index of last symbol	Threshold level
REF	Reference for symbol index	33333	1	-	-	5	-
R03	0 to 3 rise	1000 331	260	263	264	266	$(V_0+V_3)/2$
F30	3 to 0 fall	233333 001	511	5	6	8	
R12	1 to 2 rise	311 2221	464	466	467	470	$(V_1+V_2)/2$
F21	2 to 1 fall	122 11110	254	256	257	261	
R01	0 to 1 rise	200 113	503	505	506	508	$(V_0+V_1)/2$
F10	1 to 0 fall	21111 0003	256	260	261	264	
R23	2 to 3 rise	3222 330	210	213	214	216	$(V_2+V_3)/2$
F32	3 to 2 fall	133 223	507	509	510	1	
R02	0 to 2 rise	200 22223	63	65	66	70	$(V_0+V_2)/2$
F20	2 to 0 fall	12222 001	321	325	326	328	
R13	1 to 3 rise	0111 331	166	169	170	172	$(V_1+V_3)/2$
F31	3 to 1 fall	033 1112	263	265	266	269	

# Summary

- PRBS9Q definition is provided, including
  - PRBS9 polynomial and bit sequence generation
  - PAM4 symbols definition for EOJ measurement



# Appendix-A

## PRBS13Q Pattern and PAM Symbols Used for Jitter Measurement

### 120.5.11.2.1 PRBS13Q test pattern

A PMA may optionally include a PRBS13Q pattern generator as specified in this subclause. The ability to perform this function is indicated by the PRBS13Q\_gen\_Tx\_ability and PRBS13Q\_gen\_Rx\_ability status variables, reflecting the ability to send this test pattern in the direction towards the PMD and towards the MAC, respectively. If a Clause 45 MDIO is implemented, the PRBS13Q\_gen\_Tx\_ability and PRBS13Q\_gen\_Rx\_ability status variables are accessible through the PRBS13Q Tx generator ability and PRBS13Q Rx generator ability bits 1.1500.11 and 1.1500.10 (see 45.2.1.123).

When the PRBS13Q test pattern enabled, it replaces the signal on the output lane(s) for which it is enabled. The PRBS13Q test pattern is a repeating 8191-symbol sequence formed by Gray coding pairs of bits from two repetitions of the PRBS13 pattern into PAM4 symbols as described in 120.5.7. The PRBS pattern generator produces the same result as the implementation shown in Figure 94-6, which implements the generator polynomial shown in Equation (94-3). Since the PRBS13 pattern is an odd number of bits in length, bits which are mapped as the first bit of a PAM4 symbol during one repetition of the PRBS13 sequence are mapped as the second bit of a PAM4 symbol during the next repetition of the PRBS13 sequence, and bits which are mapped as the second bit of a PAM4 symbol are mapped as the first bit of the following symbol in the next repetition of the PRBS13 sequence. For example, if the PRBS13 generator used to create the PRBS13Q sequence is initialized to a seed value of 0000010101011 (with the leftmost bit in S0 and the rightmost in S12), the PRBS13Q sequence begins with the following Gray coded PAM4 symbols, transmitted left to right: 1031320220111130103121231210012102121023131112.

### 94.3.10.8 Training pattern

The training pattern shall be encoded as specified in this subclause.

The training pattern is mapped into a series of 338 training frame words. Each training frame words is encoded as a PMA signal as specified in 94.2.2 with the exception that the input is from a PRBS13 generator rather than from the PMA service interface and no PMA overhead (94.2.2.2) is inserted.

For each training frame, the PRBS13 generator is used to produce 31096 bits. Three full cycles of 8191 bits and one truncated cycle of 6523 bits are concatenated to form the 31096 bit sequence, R(1:31096). Bits in the first and third cycle, R(1:8191) and R(16383:24573), are not inverted and bits in the second and fourth cycles, R(8192:16382) and R(24574:31096), are inverted.

The PRBS13 pattern generator produces the same result as the implementation shown in Figure 94–6, which implements the generator polynomial shown in Equation (94–3). The PRBS13 pattern generator is initialized for each frame using a unique seed for each lane. The 13-bit seed and the initial 16 bits for each lane are annotated in Table 94–11.

$$G(x) = 1 + x + x^2 + x^{12} + x^{13} \quad (94-3)$$

The PRBS13 pattern is mapped into the 92 bits of each training frame word. The first 2 bits of each training frame word form the termination bits (94.2.2.4) and each training frame word in the training pattern is equivalent to a termination block (94.2.2.4). The resulting termination blocks are Gray-mapped (94.2.2.5), precoded (94.2.2.6), and mapped to PAM4 levels (94.2.2.7).

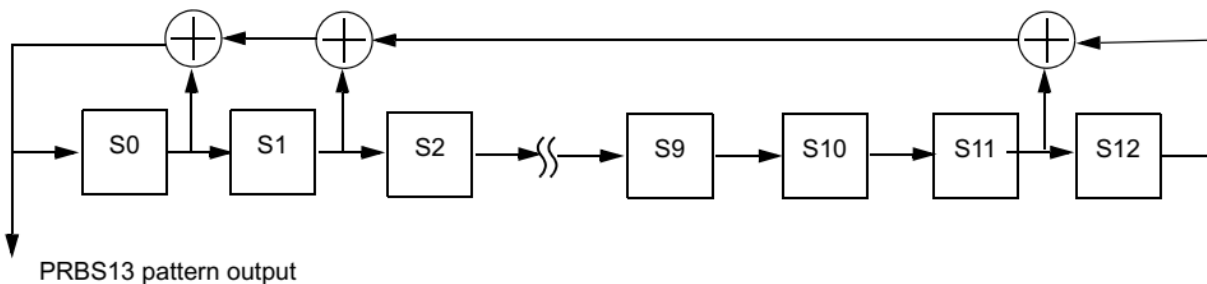


Figure 94–6—PRBS13 pattern generator

### Example of bits to PAM4 symbols (Gray) mapping

Bits: 0100 1001 1011 0001 ...  
PAM4: 1 0 3 1 3 2 0 1 ...

The outputs of PRBS13 generator, Gray mapper, and precoder for the first two training frame words are provided in Table 94–12.

Table 94–11—PRBS13 seeds and initial output

PMD Lane	Seed bits (leftmost bit in S0, rightmost in S12)	Initial 16 bits (in order of transmission)
0	0000010101011	0100100110110011
1	0011101000001	1101111101010100
2	1001000101100	1100101111000011
3	0100010000010	0110111101000111

PMD Lane	Output of	Contents of first (top) and second (bottom) training frame words transmitted left to right
0	PRBS13	0100100110110011110001010101100001001001110111100111010000011 1010011011101001110011001010111 000111111101011101101111110100010110111110100111011001010110 0111001001110000111100001101011
	Gray code	1031320220111130103121231210012102121023131112 0122211213222101132233123203320231023012301332
	Precoder	1301200200101031003201123322233220110021032320 0111101103333223211121021130331123112233001211
1	PRBS13	1101111101010100000010010011011001111000101010110000100100111 0111100111010000011101001101110 10011100110010101110001111110101110110111110100010110111110 1001111011001010110011100100111
	Gray code	2122111000310213123033320031023220233002331323 3120203323022233232122330321221022131113120312
	Precoder	2333232222100230112212113123112022030002123021 3200221203111121120111213023332202301012331233
2	PRBS13	1100101111000011111011101110110011001100111000111000110000110 0001110111000001100110000001110 0011011000011000101011000110010011101010100011001001000011100 1111011101010110011001001010101
	Gray code	2032200223232320202023023020020023230020200023 0213013033201310233330203100231232333202031111
	Precoder	2211131112033022002203112200022203300022000021 0230012212001231121213312313301120303311301010
3	PRBS13	0110111101000111101111101011001101111110001111011010111011110 0100001011000101100101011111000 1001011010111100101001011000100111110000101011010110010011111 1000101011011101001000101111100
	Gray code	1322101232233202122302213323220301130320332230 3113322033113031220033211310222011132331011220
	Precoder	1202310211121133202133321203331223213022120213 3230333121012210200030232100202232302123101113

$J_{4u}$ ,  $J_{RMS}$ , and Even-odd jitter are defined by measurements of 12 specific transitions in a PRBS13Q pattern (see 120.5.11.2.1) in order to exclude correlated jitter. The 12 transitions represent all possible combinations of four identical symbols followed by two different identical symbols as shown in Table 120D–4. The sequences are located by the symbol indices given in the table where symbols 1 to 7 are the run of seven 3s.

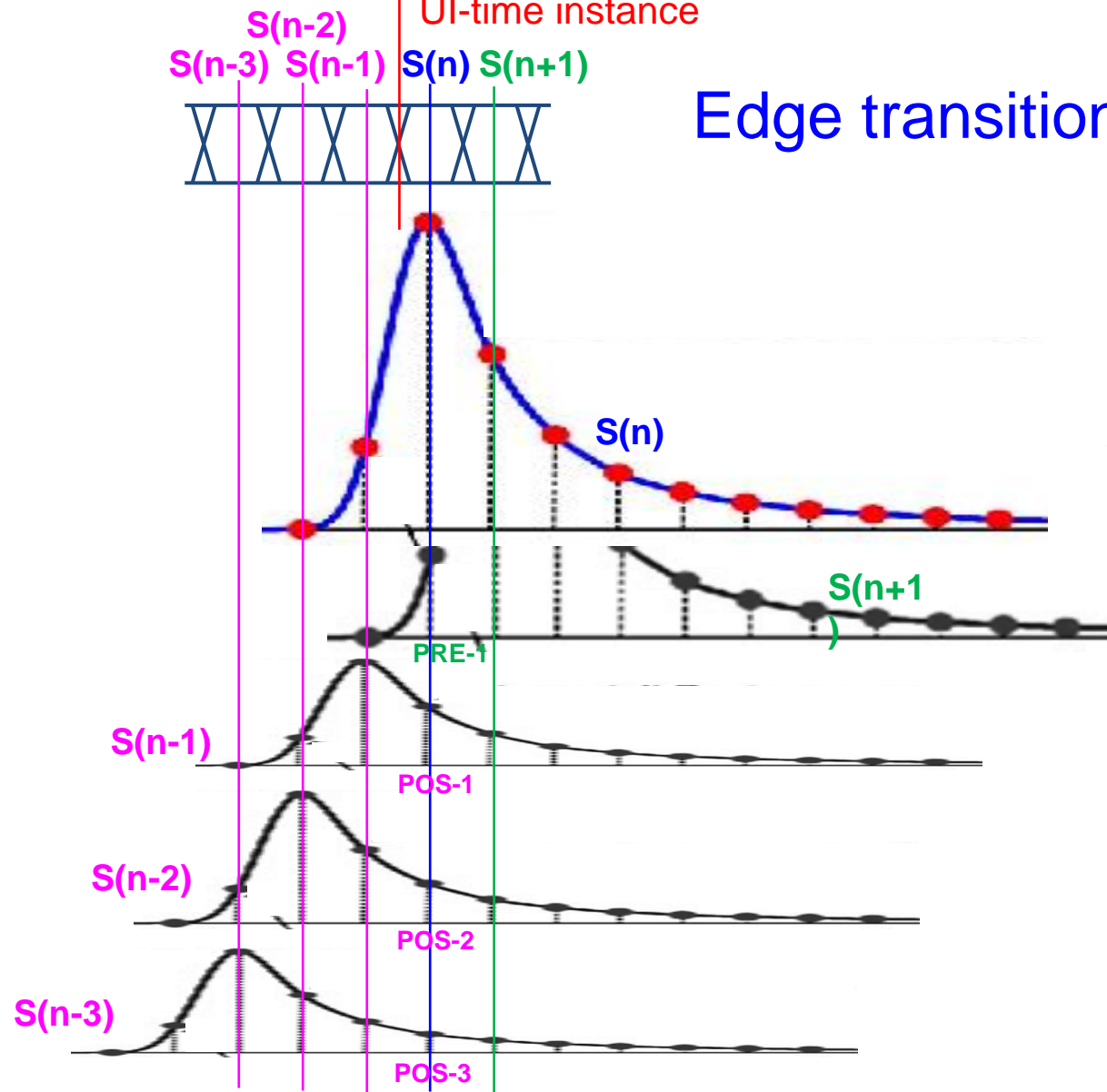
**Table 120D–4—PRBS13Q pattern symbols used for jitter measurement**

Label	Description	Gray coded PAM4 symbols	Index of first symbol	Index transition begins	Index transition ends	Index of last symbol	Threshold level
REF	Reference for symbol index	3333333	1	—	—	7	—
R03	0 to 3 rise	10000 330	1830	1834	1835	1837	$(V_0+V_3)/2$
F30	3 to 0 fall	23333 001	1269	1273	1274	1276	
R12	1 to 2 rise	0111111 2222221	3638	3644	3645	3651	$(V_1+V_2)/2$
F21	2 to 1 fall	022222 113	1198	1203	1204	1206	
R01	0 to 1 rise	100000 113	6835	6840	6841	6843	$(V_0+V_1)/2$
F10	1 to 0 fall	21111 003	2992	2996	2997	2999	
R23	2 to 3 rise	32222 330	6824	6828	6829	6831	$(V_2+V_3)/2$
F32	3 to 2 fall	033333 2222223	7734	7739	7740	7746	
R02	0 to 2 rise	10000 223	3266	3270	3271	3273	$(V_0+V_2)/2$
F20	2 to 0 fall	122222 0000002	7282	7287	7288	7294	
R13	1 to 3 rise	011111 331	133	138	139	141	$(V_1+V_3)/2$
F31	3 to 1 fall	23333 112	7905	7909	7910	7912	

# Appendix-B

## Effect of Leading and Trailing CIDs

$S(i)$ : PAM4 Symbol at  $i$ -th UI-time instance



- Leading symbols ( $n-1$ ,  $n-2$ ,  $n-3$ , ...) affects the target edge timing via their post cursors
- Trailing symbols ( $n+1$ ,  $n+2$ , ...) affects the target edge timing via their pre cursors