BASE-AU 980nm/OM3 baseline Definition of the optical parameters and test methods

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Clock recovery unit (CRU)

CRU (clock recovery unit) specification

- CRU is going to be used in some test setups to generate a low jitter clock recovered from the transmitter signal under test, to be used as input trigger signal to a pattern triggered oscilloscope
- The CRU OJTF (observed jitter transfer function) needs to be specified according to the communications system requirements (TX and RX)
- BASE-AU PHYs support optional EEE capability, as specified in 802.3cz/D1.2, where RS-FEC CWs are replaced with Refresh CWs during LPI operation, which are used by the link partner to keep the receiver aligned while power consumption can be reduced
- As stated in [1], after detected LPI, while receiving Refresh codewords, the receiver only needs to sample, equalize and detect a small portion of symbols of each CW (last n 65-bit blocks plus the first m repeated 20-bit PHD sub-blocks for Wake detection and robust decoding of PHD)
- Both clocks, TX and RX, should experience small deviation during Refresh CW transmission. The minimum clock recovery actuation period is equivalent to a CW (5440 bits) transmission time
    - For 50 Gb/s, CW transmission time = 108.8 ns
    - For 2.5 Gb/s, CW transmission time = 2176 ns
- In order to simplify clock recovery implementation, a CRU corner frequency of less one fourth the CW transmission rate is proposed:
    - For 50 Gb/s: $f_{CRU} \simeq$ 2 MHz
    - For 2.5 Gb/s: $f_{CRU} \simeq$ 100 kHz
- Multi-rate BASE-AU PHYs implementation is expected, all the rates using a common PLL, so the low frequency jitter characteristic will be common. Therefore, a single corner is proposed:

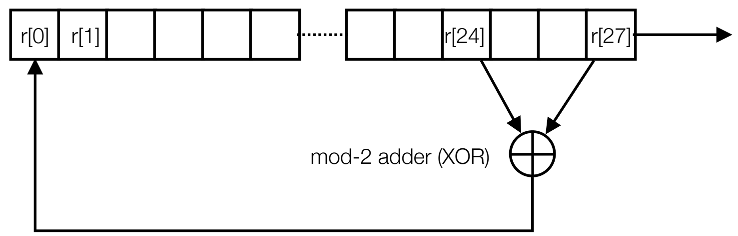
  The clock recovery unit (CRU) shall have a corner frequency of 0.1 MHz and a slope of 20 dB/decade. The CRU can be implemented in hardware or software depending on oscilloscope technology.
- This specification applies to all the test-setups where CRU is used

Test patterns

Test patterns for PMD validation

- Normal operation
- BER test mode operation
- SSPR-NRZ: short stress pattern random for NRZ scheme
  - SSPR defined by IA OIF-CEI-4.0 has been used by the industry to replace PRBS31, allowing shorter test time with baseline wander and clock wander statistically at least as stressful as 10.000 years of random binary
  - SSPR uses PRBS28, with several initialisation seeds, differential encoding, and CID sequences of 72 0's or 72 1's
  - Proposed SSPR-NRZ reuses most part of OIF SSPR (polynomials, seeds, differential encoding), however it limits to a maximum of 31 continuous 0's and 1's.
- SSPR-PAM4: short stress pattern random for PAM4 scheme
  - SSPRQ defined in 802.3 C/120 has been adopted for PAM4 PMD testing
  - SSPRQ design followed similar considerations of OIF SSPR about baseline and clock wanders
  - Proposed SSPR-PAM4 reuses most part of C/120 SSPRQ (polynomials, seeds, etc), however it uses the PAM4 mapper in C/166 of 802.3cz D1.2, the sequence length is even, max CID length for all the digits is the same
- SSQWP: slow square wave pattern:
  - PMA generates a square wave test pattern: n_{sq} {+1} followed by n_{sq} {-1} toward the service interface PMD_COMSIGNAL.request, where parameter n_{sq} depends on PHY rate:
    - 50GBASE-AU and 25GBASE-AU, $n_{sq} = 16$,
    - 10GBASE-AU, $n_{sq} = 8$,
    - 5GBASE-AU, $n_{sq} = 4$,
    - 2.5GBASE-AU, $n_{sq} = 4$
- FSQWP: fast square wave pattern:
  - PMA generates a square wave test pattern with $n_{sq} = 1$

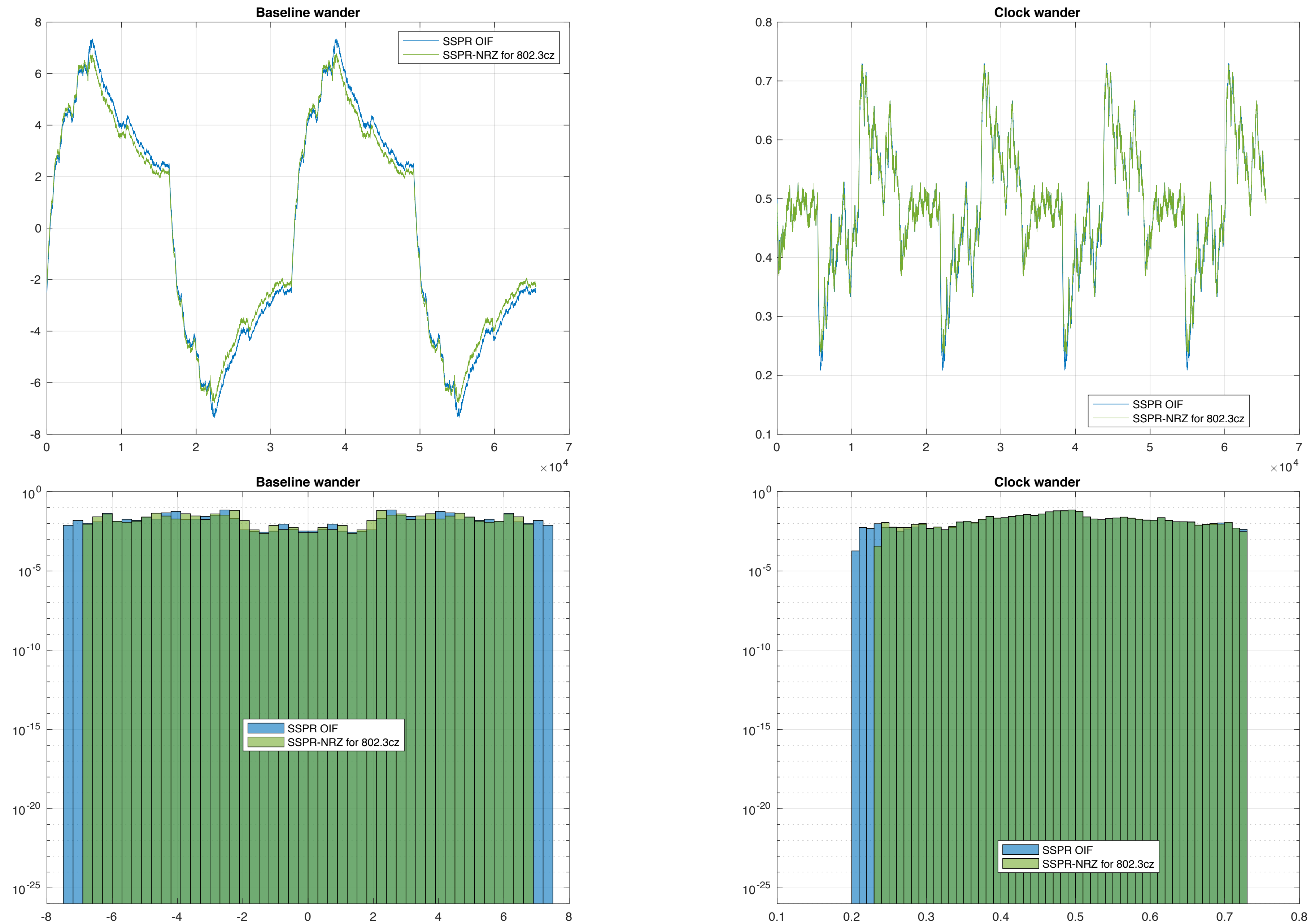
Test patterns for PMD validation: SSPR-NRZ



PRBS28 Seed = 0x0100100 5462 bits	PRBS28 Seed = 0xFFFFFFF 5460 bits	PRBS28 Seed = 0x0100100 Diff encoded 5462 bits	NOT PRBS28 Seed = 0x0100100 5462 bits	NOT PRBS28 Seed = 0xFFFFFFF 5460 bits	NOT PRBS28 Seed = 0x0100100 Diff encoded 5462 bits

- Total length 32768 NRZ symbols
- Block 1 is 5462 bits of PRBS28 seed = 0x0100100 and begins with 8 x 0, 1, 11 x 0, 1, 12 x 0, 1 ...
- Block 2 is 5460 bits of PRBS28 seed = 0xFFFFFFF and begins with 28 x 1, 25 x 0, 3 x 1, 22 x 0 ...
- Block 3 takes the same sequence as block 1 and encodes it as follows:
  - A zero causes a change of the output
  - A one causes no change of output
  - The output before the first bit is assumed to have been zero
  - This block begins 101010100101010101011010101010101011011010
- Blocks 4 to 6 are the binary inverse of blocks 1 to 3 respectively
- Leftmost hexadecimal digit of a seed corresponds to the initial value of register element r[0]. Therefore, the rightmost bit of the rightmost digit corresponds to the initial value of register element r[27].
- The initial value of r[27] is the first bit generated by the LFSR for each initialisation
- The binary sequence is mapped by PMA transmit function to {-1, +1} symbols as specified in 802.3cz/D1.2, Table 166-5 for parameter G = 1.

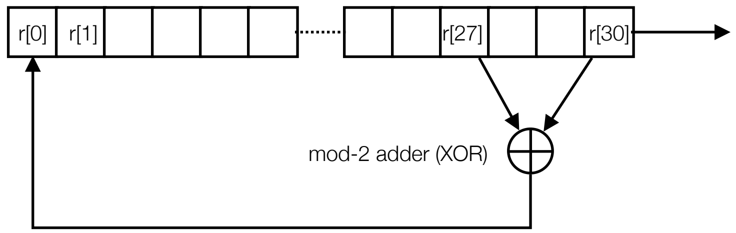
Test patterns for PMD validation: SSPR-NRZ



OK

Same considerations of [3]. Baseline wander was assessed with a cut-off frequency of baudrate/10000 and clock content was assessed with a corner frequency of baudrate/1667. From [3], baseline wander limit that will be exceeded only once in 10000 years (10 years, 1000 random streams) at 10 Gb/s is +/- 6.8%. Limits for clock wander are [0.3, 0.7]. For 25 Gb/s, it is equivalent to 4000 years.

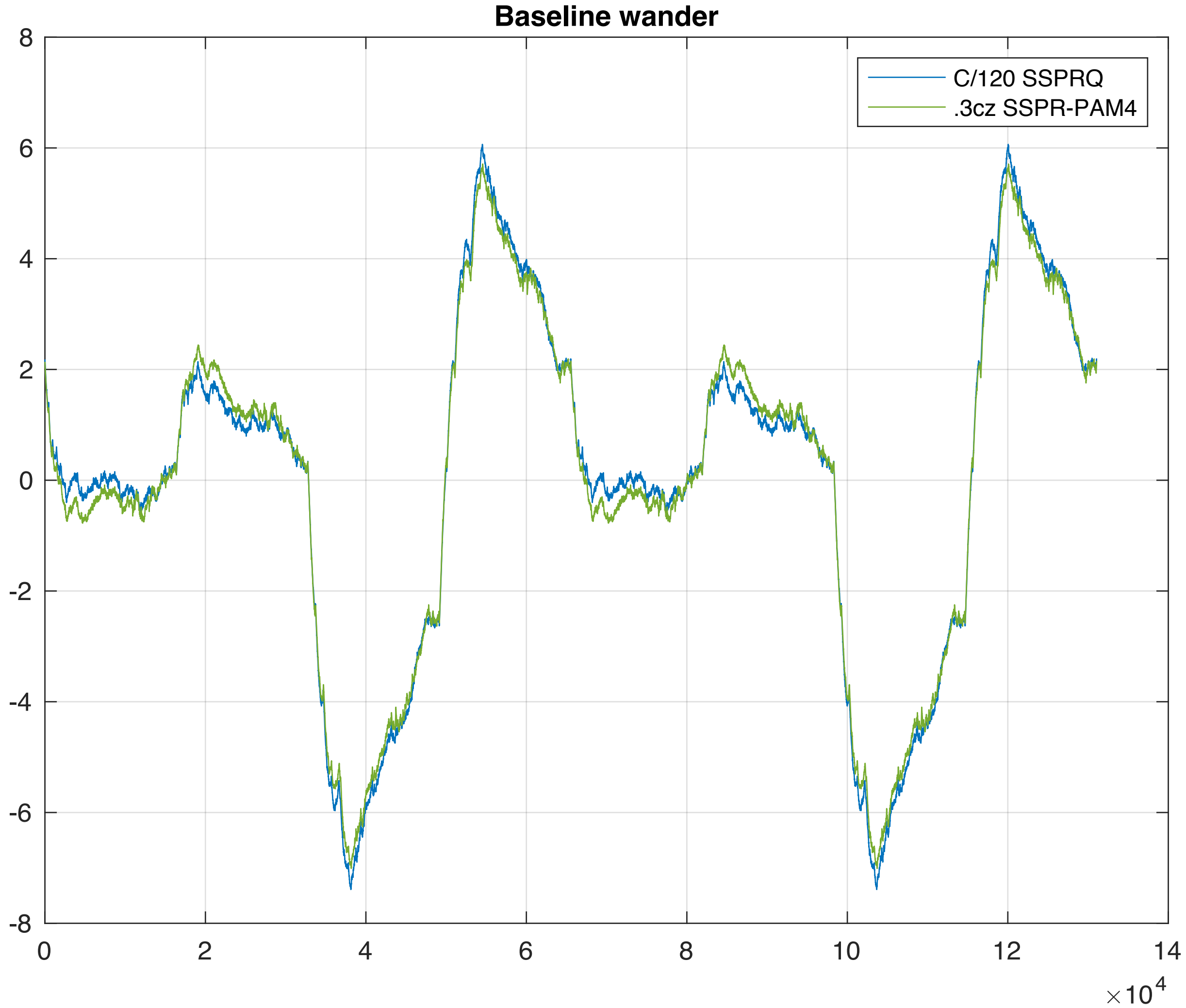
Test patterns for PMD validation: SSPR-PAM4

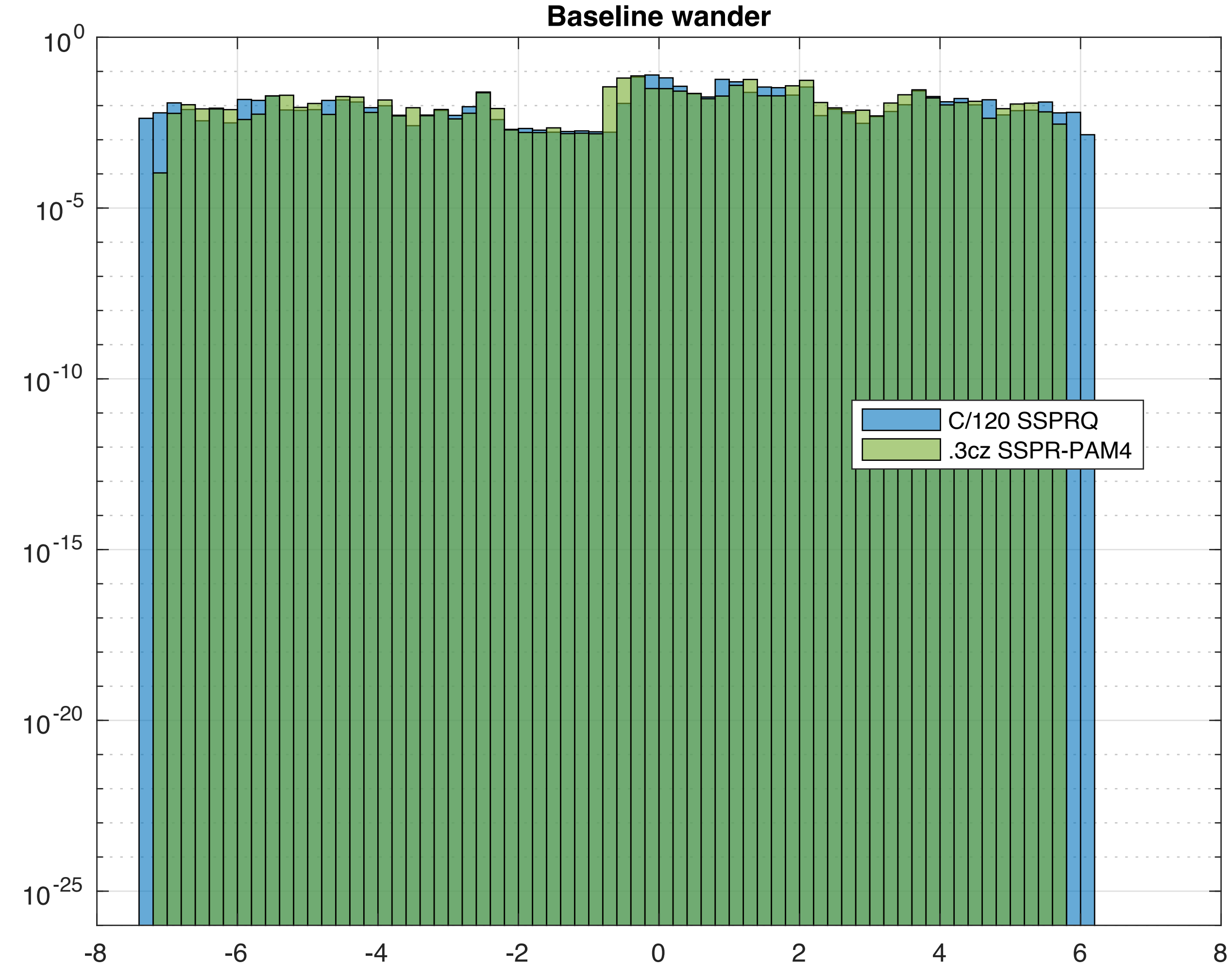


Block S1 16384 PAM4 symbols	S2 = -S1	Block S3 16383 PAM4 symbols	Block S4 16385 PAM4 symbols

- Total length 65536 PAM4 symbols
- Block A1 is 10924 bits of PRBS31 seed = 0x20000000 and begins with 29 x 0, 1, 27 x 0, 1, 0, 0, 1, 24 x 0, 1, 5 x 0, 1 …
- Block A2 is 10922 bits of PRBS31 seed = 0x77FE4016 and begins with 0, 1, 1, 0, 1, 9 x 0, 1, 0, 0, 10 x 1 …
- Block A3 is 10922 bits of PRBS31 seed = 0x19999998 and begins with 0, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1, 1, 0, 0, 1 …
- Block A is the binary inverse of the concatenation of A1, A2, A3
- Block B is a 65536-bit length sequence formed by removing the first bit from a sequence consisting of two repetitions of binary block A and appending a bit = 0 to the end
- Leftmost hexadecimal digit of a seed corresponds to the initial value of register element r[0]. Therefore, the rightmost bit of the rightmost digit corresponds to the initial value of register element r[30].
- The initial value of r[30] is the first bit generated by the LFSR for each initialisation
- The binary block A is PAM4 mapped by PMA transmit function to {-1, -1/3, +1/3, +1} symbols as specified in 802.3cz/D1.2, Table 166-5 for parameter G = 2, to form 16384-symbol block S1
- 16384-symbol block S2 is generated from block S1 inverting the sign for each symbol
- 16383-symbol block S3 results from PAM4 mapping of the first 32766 bits of the binary block B
- 16385-symbol block S4 results from PAM4 mapping of the last 32770 bits of the binary block B, and inverting the sign of each PAM4 symbol

Test patterns for PMD validation: SSPR-PAM4





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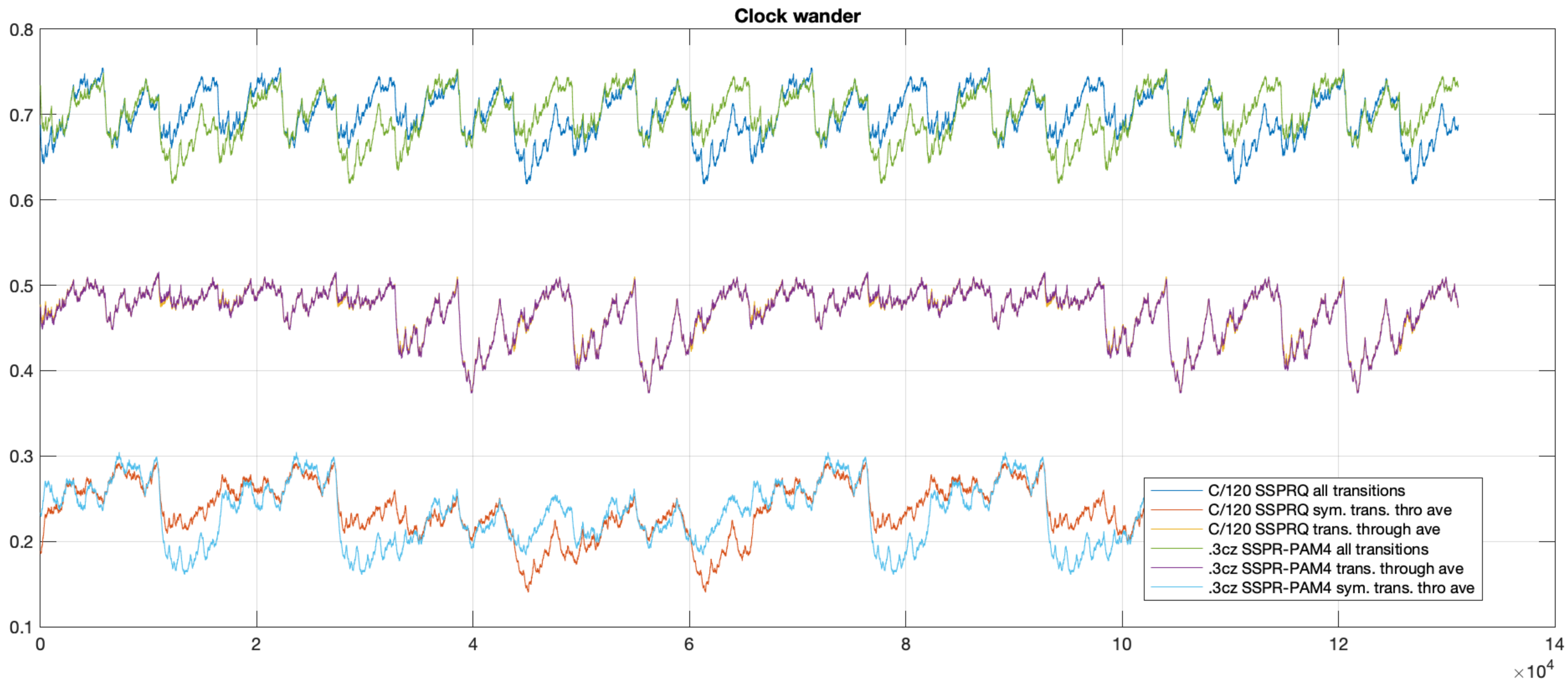
Same considerations of [4]. Baseline wander was assessed with a cut-off frequency of baudrate/10000. From [4], baseline wander limit that will be exceeded only once in 10000 years at 50 Gb/s random stream is +/- 5.2%.

Test patterns for PMD validation: SSPR-PAM4



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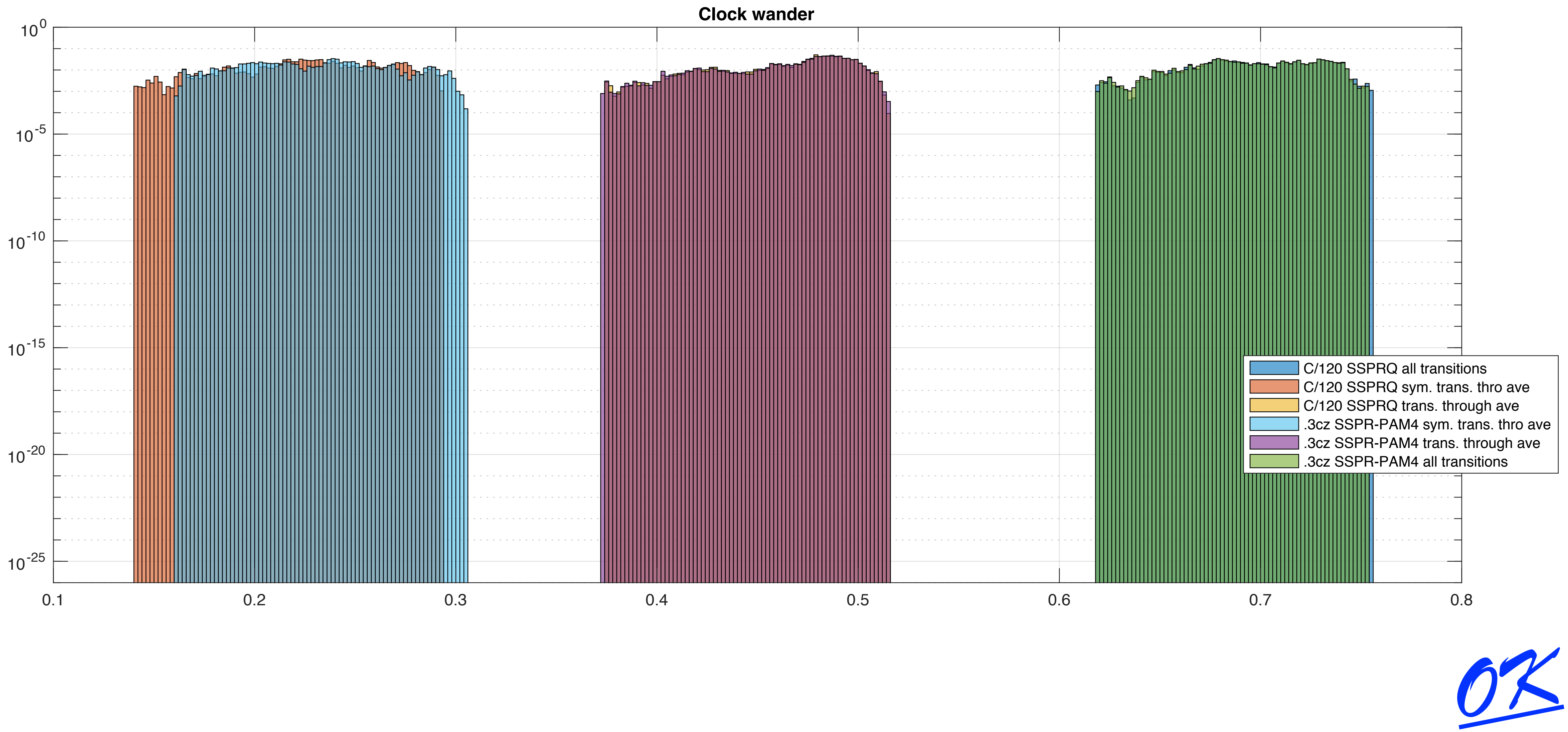
Same considerations of [4]. Clock wanders for the three types of transitions were assessed with corner frequency of baudrate/6641. From [4], clock wander limits that will be exceeded only once in 10000 years at 50 Gb/s of random stream are: [**0.16**, 0.34] for symmetric transitions through average, [**0.39**, 0.60] for transitions through average, [**0.66**, 0.84] for all the transitions.

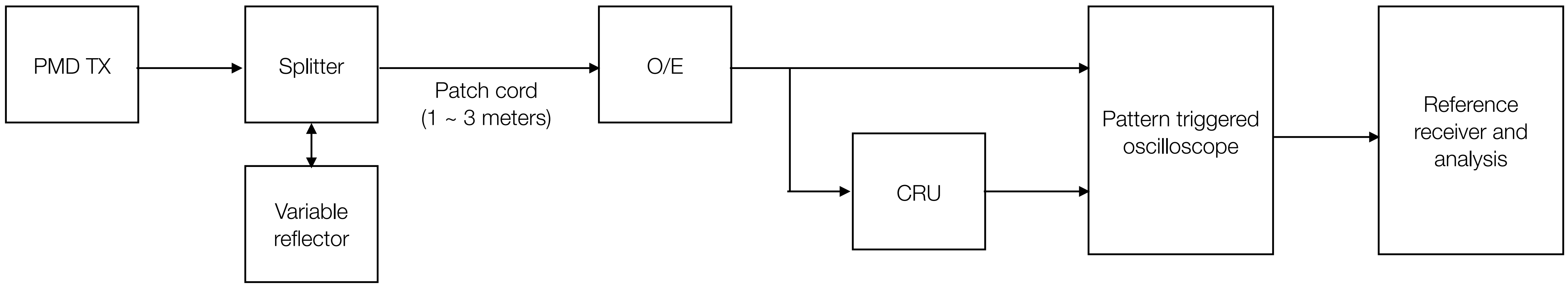
Test patterns for PMD validation: SSPR-PAM4



Same considerations of [4]. Clock wanders for the three types of transitions were assessed with corner frequency of baudrate/6641. From [4], clock wander limits that will be exceeded only once in 10000 years at 50 Gb/s of random stream are: [**0.16**, 0.34] for symmetric transitions through average, [**0.39**, 0.60] for transitions through average, [**0.66**, 0.84] for all the transitions.

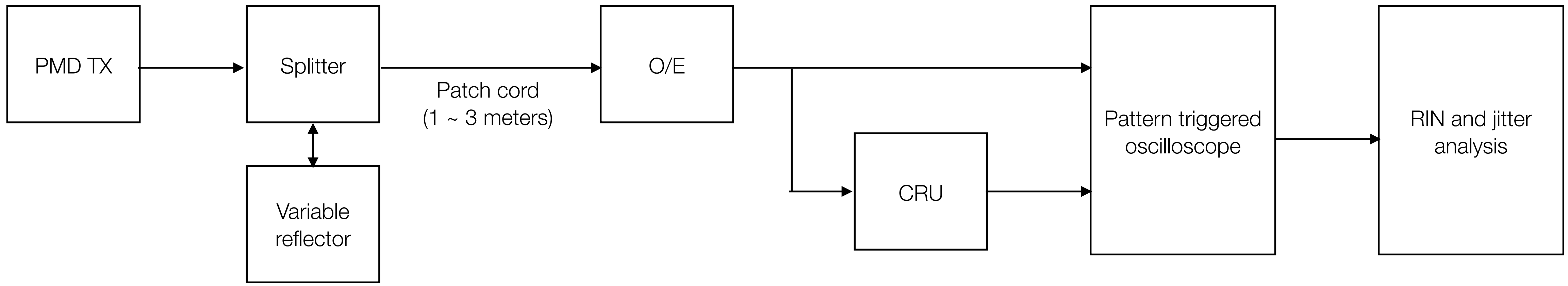
Parameters and test methods

TDFOM setup and test method



- PHY TX under test is configured to generate SSPR-NRZ (for 25, 10, 5, 2.5 Gb/s operation of a BASE-AU PHY) or SSPR-PAM4 (for 50GBASE-AU)
- Variable reflector is adjusted to generate optical return loss equal to the max value specified of 12 dB
- Equivalent response of O/E converter plus oscilloscope is configured as specified in [2]
- Reference receiver and analysis specified in [2] is used to calculate TDFOM, and optionally OMA, ER and AOP

OMA, ER, RIN and t_J. Setup and test method



- SSQWP is generated by the PHY TX under test
- Variable reflector is adjusted to generate optical return loss equal to the max value specified of 12 dB
- Equivalent response of O/E plus oscilloscope is configured to be 4th order Bessel-Thomson low pass filter with BW_{-3dB} as following. Equivalent noise bandwidth is $BW_n = 1.04 \cdot BW_{-3dB}$
  - BW_{-3dB} = 20 GHz for 25GBASE-AU and 50GBASE-AU
  - BW_{-3dB} = 8 GHz for 10GBASE-AU
  - BW_{-3dB} = 4 GHz for 5GBASE-AU
  - BW_{-3dB} = 2 GHz for 2.5GBASE-AU
- P_1 is measured as the mean value of signal over the center 3% of the time interval where the signal is in the high state
- P_0 is measured as the mean value of signal over the center 3% of the time interval where the signal is in the low state
- RN_1 is measured as the standard deviation of signal over the same interval where P_1 is measured
- RN_0 is measured as the standard deviation of signal over the same interval where P_0 is measured
- Uncorrelated random jitter is measured in rise and fall edges using two horizontal measurement windows placed at the average power level of the pattern with a height of 2% (P_1 - P_0)
  - Standard deviations of both distributions are the random jitter in rise edge σ_{rise}, and fall edge σ_{fall}.
- OMA, ER, and $RIN_{12}OMA$ are defined as:

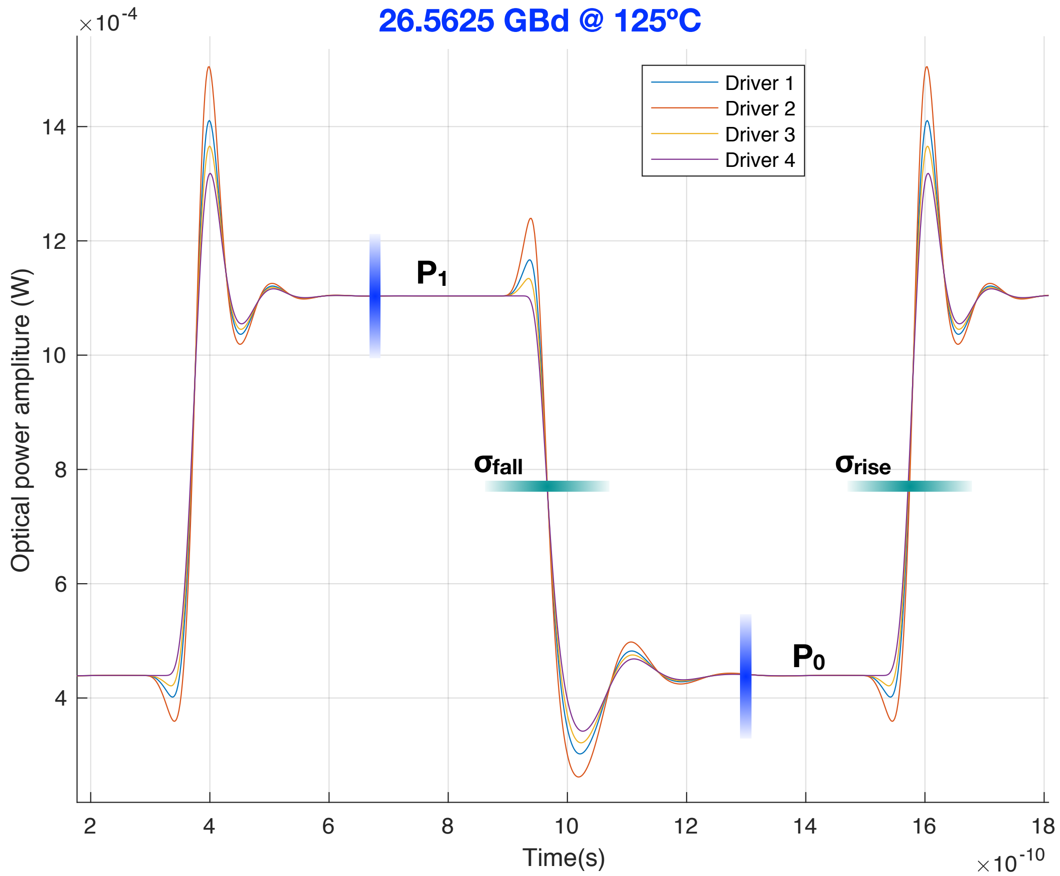
$OMA = P_1 - P_0$ (watts);

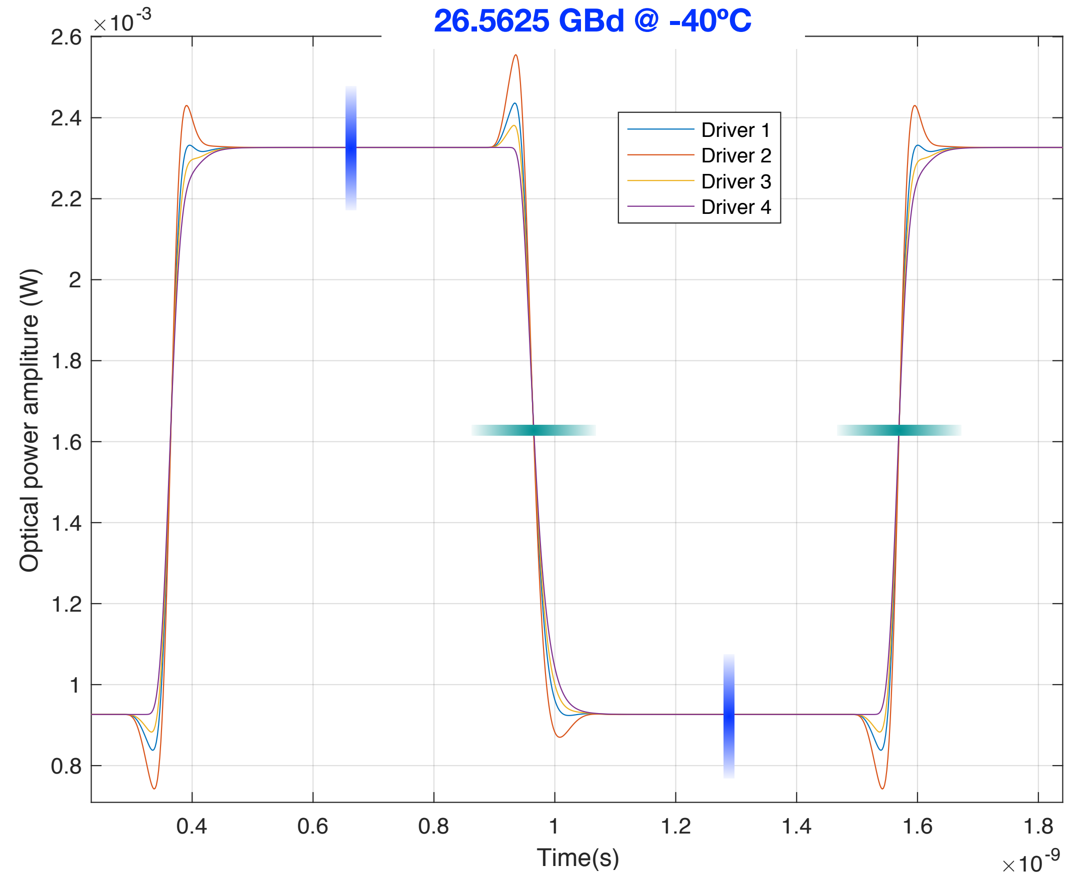
$ER = 10 \cdot \log_{10}\left(\frac{P_1}{P_0}\right)$ (dB);

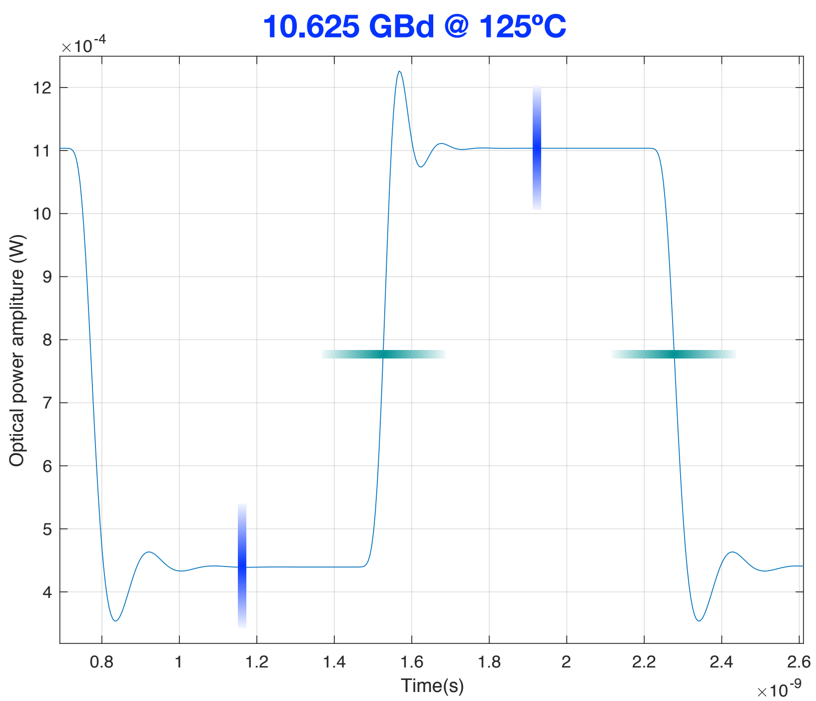
$RIN_{12}OMA = 10 \cdot \log_{10}\left(\frac{(RN_1 + RN_0)^2}{OMA^2 \cdot BW_N}\right)$ (dB/Hz)

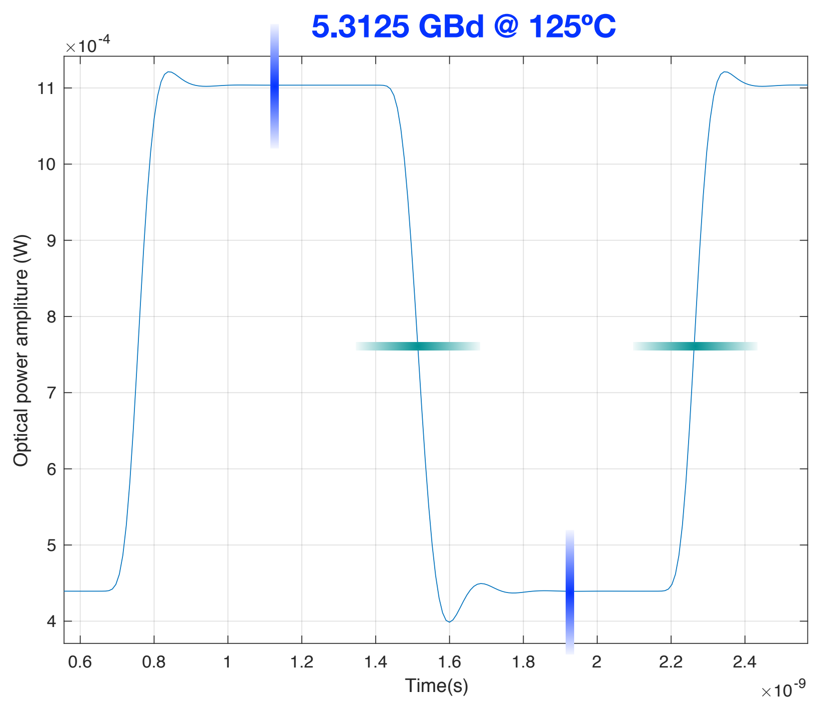
- Random jitter is defined as: $t_J = \sqrt{\left(\sigma_{rise}^2 + \sigma_{fall}^2\right)/2}$
- Alternatively, OMA and ER can also be measured as defined in TDFOM method in [2]
- Alternatively, random jitter can also be measured with FSQWP

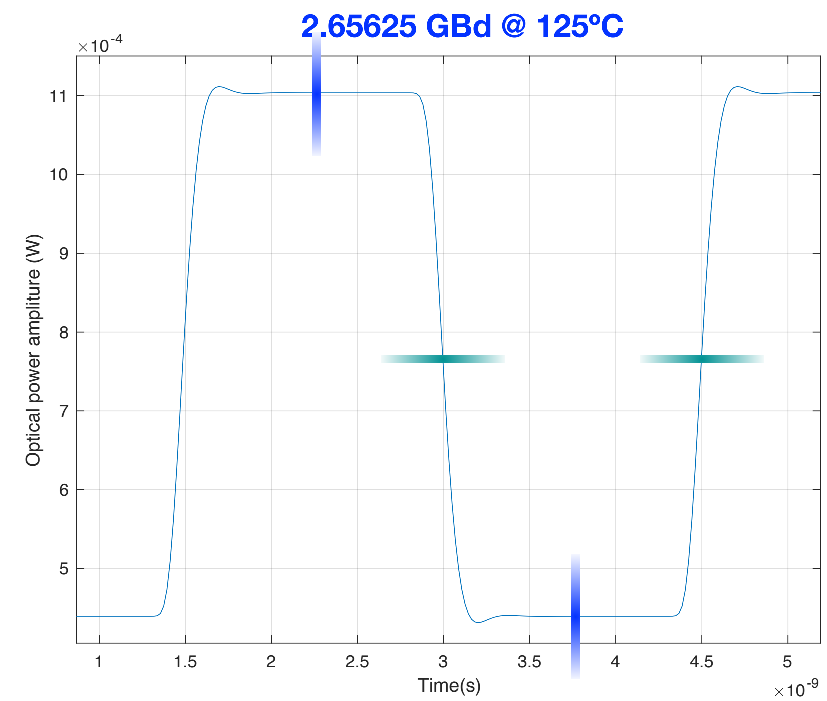
OMA, ER, RIN and t_J — illustration for different rates







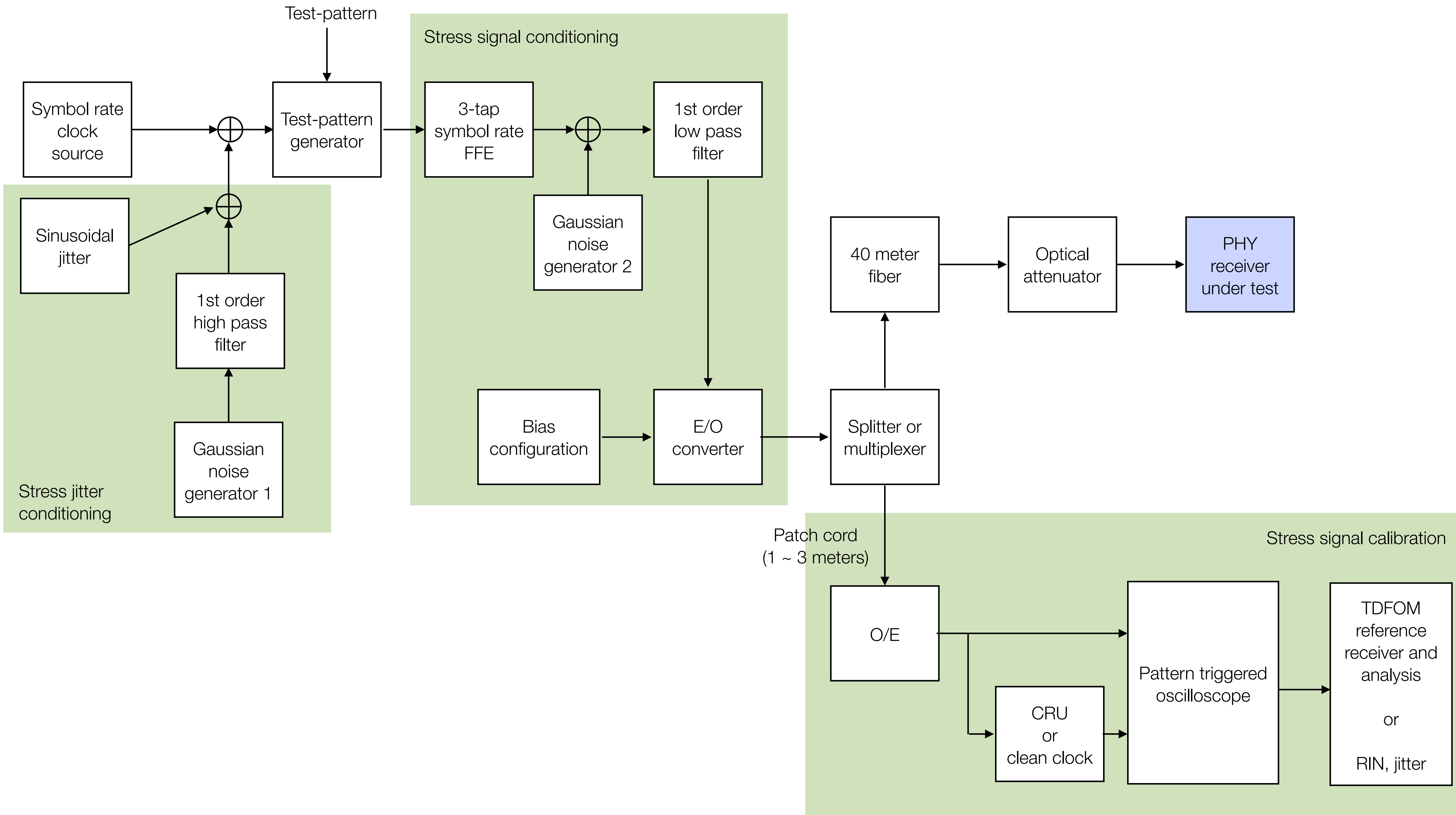




Spectrum, AOP. Setups and methods

- The center wavelength and RMS spectral width shall be within the specified range measured per IEC 61280-1-3. The center wavelength and RMS spectral width are measured with the PHY generating SSPR-NRZ, SSPR-PAM4 or in normal transmission
- The average optical power (AOP) shall be within the specify limits measured using the methods given in IEC 61280-1-1. The average optical power is measured with the PHY generating SSPR-NRZ, SSPR-PAM4 or in normal transmission
- Alternatively, AOP can also be measured as defined in TDFOM method in [2]

Stress receiver sensitivity test setup



Stress receiver sensitivity method

- Step 0 — preconditioning
  - Gaussian noise generators and sinusoidal jitter generator are turned off
- Step 1 — stress signal conditioning calibration (TDFOM and ER)
  - Test pattern generator is programmed to generate continuously SSPR-NRZ (for 25, 10, 5, 2.5 Gb/s) or SSPR-PAM4 (for 50Gb/s) with symbol rate in the specified limits
  - E/O converter produces optical signal with spectral characteristics under the specified limits
  - E/O converter is connected to O/E converter, CRU, oscilloscope, reference receiver and TDFOM analysis block as specified in [2]
  - Bias, 1st order low pass filter and FFE are adjusted to get receiver test TDFOM condition
    - E/O bias can be used to speed-up or slow-down the optical signal, so decreasing or increasing TDFOM. E/O bias can be reduced, provided that RIN and jitter specifications are met
    - 1st order low pass filter bandwidth can also be adjusted to produce ISI, so increasing TDFOM
    - The 3-tap symbol-rate FFE with coefficients *[-a, (1+2a), -a]*, the parameter *a* can be adjusted to produce peaking close to Nyquist frequency (resonance emulation), so decreasing TDFOM
  - Modulation amplitude of test pattern generator is adjusted to obtain min ER condition
  - Record OMA to AOP ratio Γ_{tx}
- Step 2 — stress signal conditioning calibration (RIN and jitter)
  - Test pattern generator is programmed to generate continuously SSQWP with symbol rate in the specified limits
  - O/E plus oscilloscope is configured for RIN and jitter analysis
  - Sinusoidal jitter is adjusted according to the table for the selected frequency, and using a clean clock in place of the CRU to trigger the oscilloscope
  - 1st order high pass filter is set for -3dB bandwidth of 200 kHz, and gaussian noise generator 1 is adjusted in amplitude to obtain max uncorrelated random jitter condition
  - Gaussian noise generator 2 is adjusted in amplitude to obtain max RINOMA condition
- Step 3 — stress signal conditioning calibration (TDFOM refinement)
  - With the same setup of step 1, FFE and low pass filter will be refined to get the objective TDFOM

Applied sinusoidal jitter

Frequency range	Sinusoidal jitter peak-to-peak (UI)	
	25, 10, 5, 2.5 Gb/s	50 Gb/s
f < 1 kHz	Not specified	Not specified
1 kHz ≤ f ≤ 100 kHz	15000/f	6000/f
100 kHz < f ≤ 200 kHz	0.15	0.06
f > 200 kHz	0	0

f is in Hz

Stress receiver sensitivity method

- Step 4 — stress receiver sensitivity measurement
  - Test pattern generator is programmed to generate continuously normal transmit block in BER test mode configuration with symbol rate in the specified limits, with the following PHD content:
    - PHD.TX.NEXT.MODE = 1
    - PHD.RX.LINKSTATUS = 1
    - PHD.RX.HDRSTATUS = 1
    - PHD.RX.LINKMARGIN = 0x7F
    - PHD.CAP.LPI = 0
    - PHD.CAP.OAM = 0
    - All the PHD.OAM fields = 0
  - E/O converter is connected to the receiver through 40 meters of OM3 fiber and optical attenuator configuration for minimum attenuation
  - Optical attenuation is increased until PHY RX under test reports one of the following conditions:
    - RFER is over the limit. RFER is calculated as the ratio of BASE-U PCS status 5 register RS-FEC codeword error counter and number of RS-FEC CWs transmitted during the time between BASE-U PCS status 5 register readings
    - Local link margin reported in BASE-U PCS status 2 register is < 0
    - BASE-U PCS status 1 register reports Local receiver status = 0, or Link status = 0, or Local PHD reception status = 0, or PHD lock status = 0
  - Optical attenuation is increased is small steps until none of the above conditions are met
  - Receiver sensitivity OMA can be measured in one of the following three ways:
    - AOP at TP3 is measured, and OMA at TP3 calculated as $OMA_{TP3} = AOP_{TP3} \cdot \Gamma_{tx}$
    - OMA at TP3 is directly measured using SSQWP pattern, TP3 connected to O/E and oscilloscope configured for RIN and jitter analysis
    - OMA at TP3 is directly measured using SSPR-NRZ or SSPR-PAM4 pattern, TP3 connected to O/E and oscilloscope configured for TDFOM analysis
- Steps 1 to 4 are carried out for the two stress conditions (1 and 2)

Parameters and test patterns relation

Parameters and related test-patterns

Parameter	Pattern
Wavelength, spectral width. 50 Gb/s	SSPR-PAM4 or valid 50GBASE-AU signal
Wavelength, spectral width. 25, 10, 5, 2.5 Gb/s	SSPR-NRZ or valid 25GBASE-AU, 10GBASE-AU, 5GBASE-AU or 2.5GBASE-AU signal
Average optical power (AOP). 50 Gb/s	SSPR-PAM4 or valid 50GBASE-AU signal
Average optical power (AOP). 25, 10, 5, 2.5 Gb/s	SSPR-NRZ or valid 25GBASE-AU, 10GBASE-AU, 5GBASE-AU or 2.5GBASE-AU signal
Optical modulation amplitude (OMA). 50 Gb/s	SSPR-PAM4, SSQWP
Optical modulation amplitude(OMA). 25, 10, 5, 2.5 Gb/s	SSPR-NRZ, SSQWP
Transmitter and distortion figure of merit (TDFOM). 50 Gb/s	SSPR-PAM4
Transmitter and distortion figure of merit (TDFOM). 25, 10, 5, 2.5 Gb/s	SSPR-NRZ
Extinction ratio (ER). 50 Gb/s	SSPR-PAM4, SSQWP
Extinction ratio (ER). 25, 10, 5, 2.5 Gb/s	SSPR-NRZ, SSQWP
Relative intensity noise ($RIN_{12}OMA$)	SSQWP
Uncorrelated random jitter (t_J)	SSQWP, FSQWP
Stress receiver sensitivity	valid 50GBASE-AU, 25GBASE-AU, 10GBASE-AU, 5GBASE-AU or 2.5GBASE-AU signat, operating in BER test mode or normal mode
Stress receiver calibration. 50 Gb/s	SSPR-PAM4
Stress receiver calibration. 25, 10, 5, 2.5 Gb/s	SSPR-NRZ

Conclusions

- Definition of the optical parameters and test methods have been provided for BASE-AU 980nm/OM3
- These are proposed to be included in the BASE-AU 980nm/OM3 PMD baseline

References

- [1] R. Pérez-Aranda, "BASE-U EEE proposal," July 2021, [Online], Available: https://www.ieee802.org/3/cz/public/jul_2021/perezaranda_3cz_04_0721_eee.pdf

- [2] R. Pérez-Aranda, "BASE-AU 980nm/OM3 baseline. Reference receiver and transmitter and distortion figure of merit," February 2022, [Online], Available: https://www.ieee802.org/3/cz/public/8_feb_2022/perezaranda_3cz_01_220208_TDFOM.pdf

- [3] P. Anslow et al., "CEI Short Stress Patterns White Paper," Optical Internetworking Forum (OIF)

- [4] P. Anslow, "SSPR generation," October 2016, [Online], Available: https://grouper.ieee.org/groups/802/3/bs/public/adhoc/logic/oct27_16/anslow_02a_1016_logic.pdf

Thank you