Baseline wander with FEC

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Introduction

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dawe_3bs_01a_0317 used the average BER caused by baseline wander as a metric to judge whether the SSPRQ test pattern is too onerous or not.

This contribution looks at the performance of links that would be allowed if this metric were used and also compares the BER penalty from the SSPRQ pattern with the FLR penalty from the PRBS31Q pattern, both due to baseline wander.

Note: slides with a "*" in the top right corner are new or have changed compared to anslow_02_0417_smf.

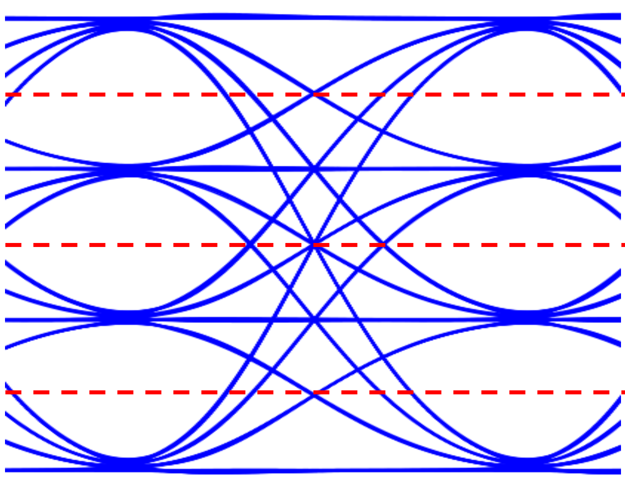
Baseline wander

In this contribution “baseline wander” is defined as:

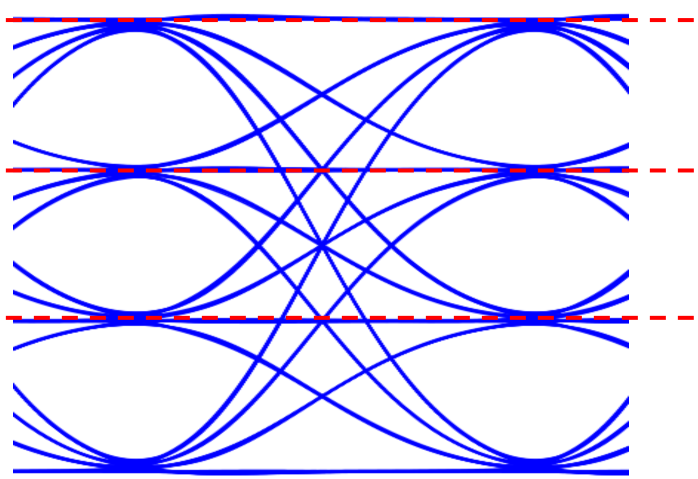
> Baseline wander is the instantaneous offset (in %) in the signal generated by AC coupling at Baud/X.

If the transmitted data was a continuous run of 3 symbols, then after a long period of time the baseline wander would be -100%. Similarly, if the transmitted data was a continuous run of 0 symbols, then after a long period of time the baseline wander would be +100%.

Ideal pattern with
no baseline wander



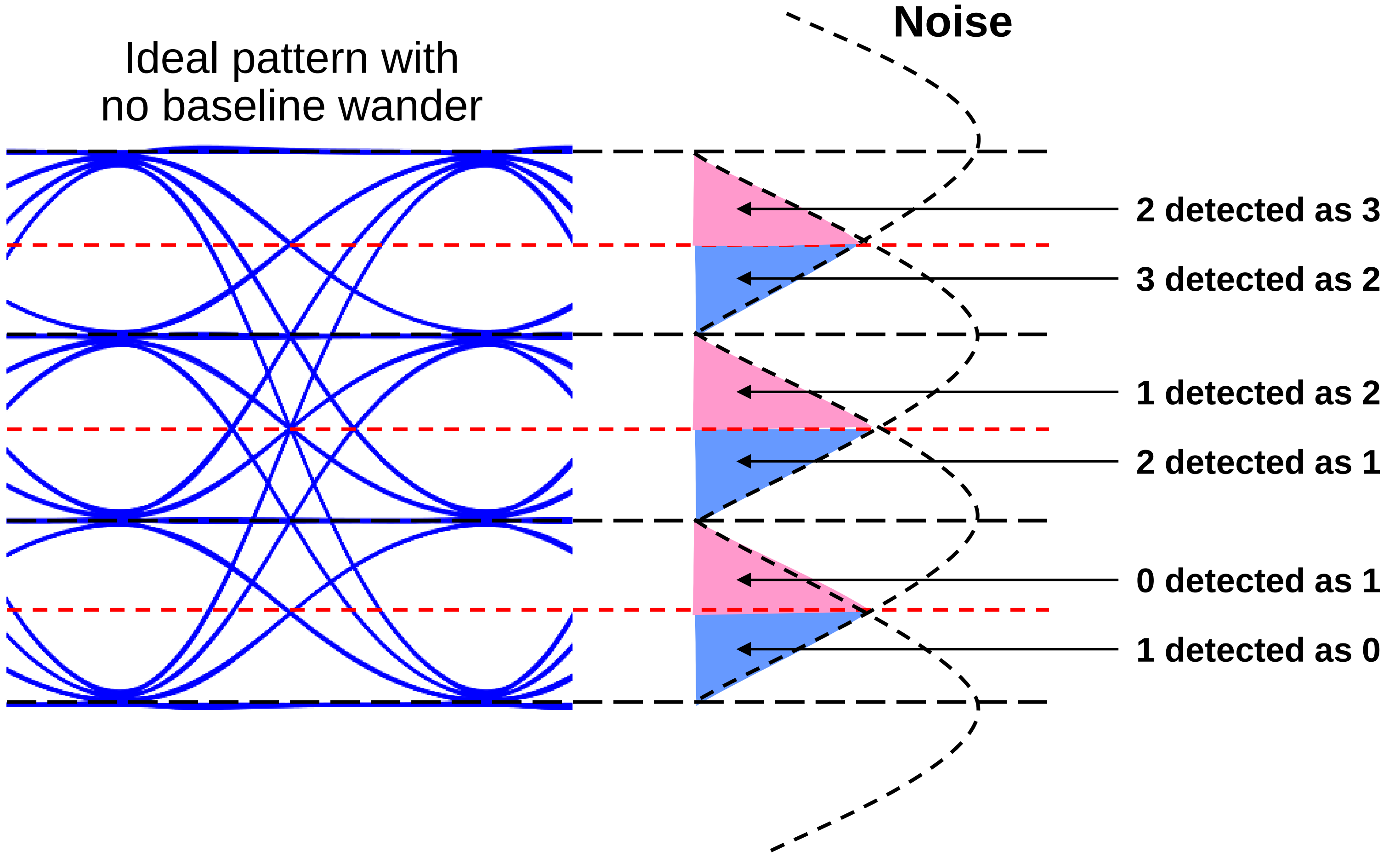
Ideal pattern with
-33% baseline wander



LF cut frequency analysis 1

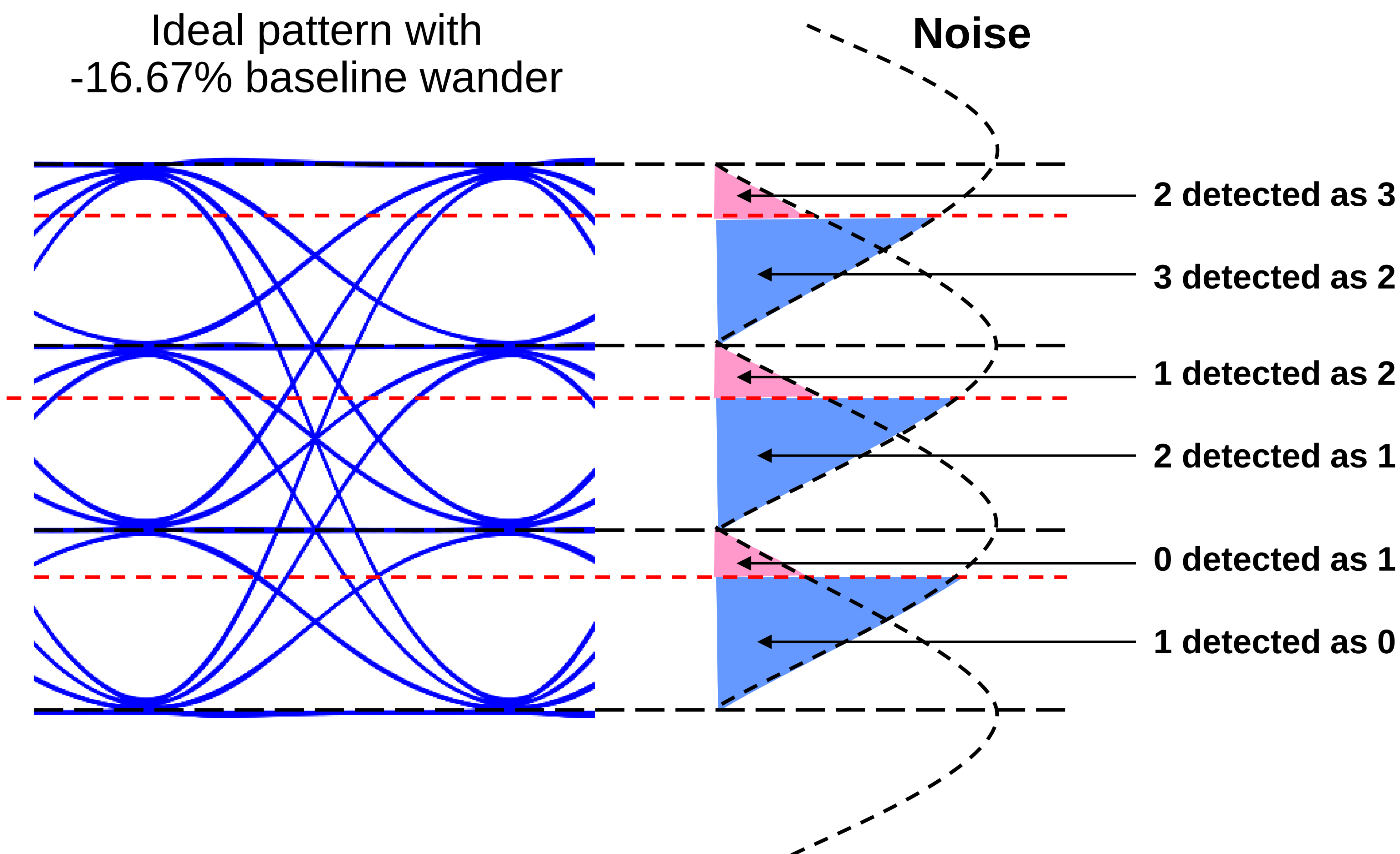
dawe_3bs_01a_0317 slide 3 showed an average optical penalty for patterns up to PRBS23Q of 0.2 dB.

To analyze this, for Gray coded PAM4 there are six possible error types:



LF cut frequency analysis 2

Baseline wander causes an offset between the eyes and the decision points. Three of the error types become more probable and three become less probable:



LF cut frequency analysis 3

For each error type we have:

$$SER = \frac{1}{4} \times \frac{1}{2} erfc\left(\frac{Q_{BW}}{\sqrt{2}} \right)$$

Where Q_{BW} is the Q taking baseline wander into account (3 higher and 3 lower than without BW) and the factor 1/4 comes from each level occurring with a probability of one in four symbols. If there is no baseline wander, then all 6 SERs are equal and the formula contracts to:

$$BER = \frac{1}{2} SER = \frac{1}{2} \times 6 \times \frac{1}{4} \times \frac{1}{2} erfc\left(\frac{Q}{\sqrt{2}} \right) = \frac{3}{8} erfc\left(\frac{Q}{\sqrt{2}} \right) = 2.4\mathrm{E}-4 \text{ for } Q = 3.414$$

Now simulate the entire PRBS23Q sequence, calculating the BER symbol-by-symbol and thereby calculate the average BER over the sequence. For an optical penalty of 0.2 dB, increase the Q value before BW is applied to 3.575 and find the LF cut frequency that returns the average BER to 2.4E-4.

To give an optical penalty of 0.2 dB, the LF cut frequency has to be about Baud/2400.

PRBS31Q with LF cut of Baud/2400

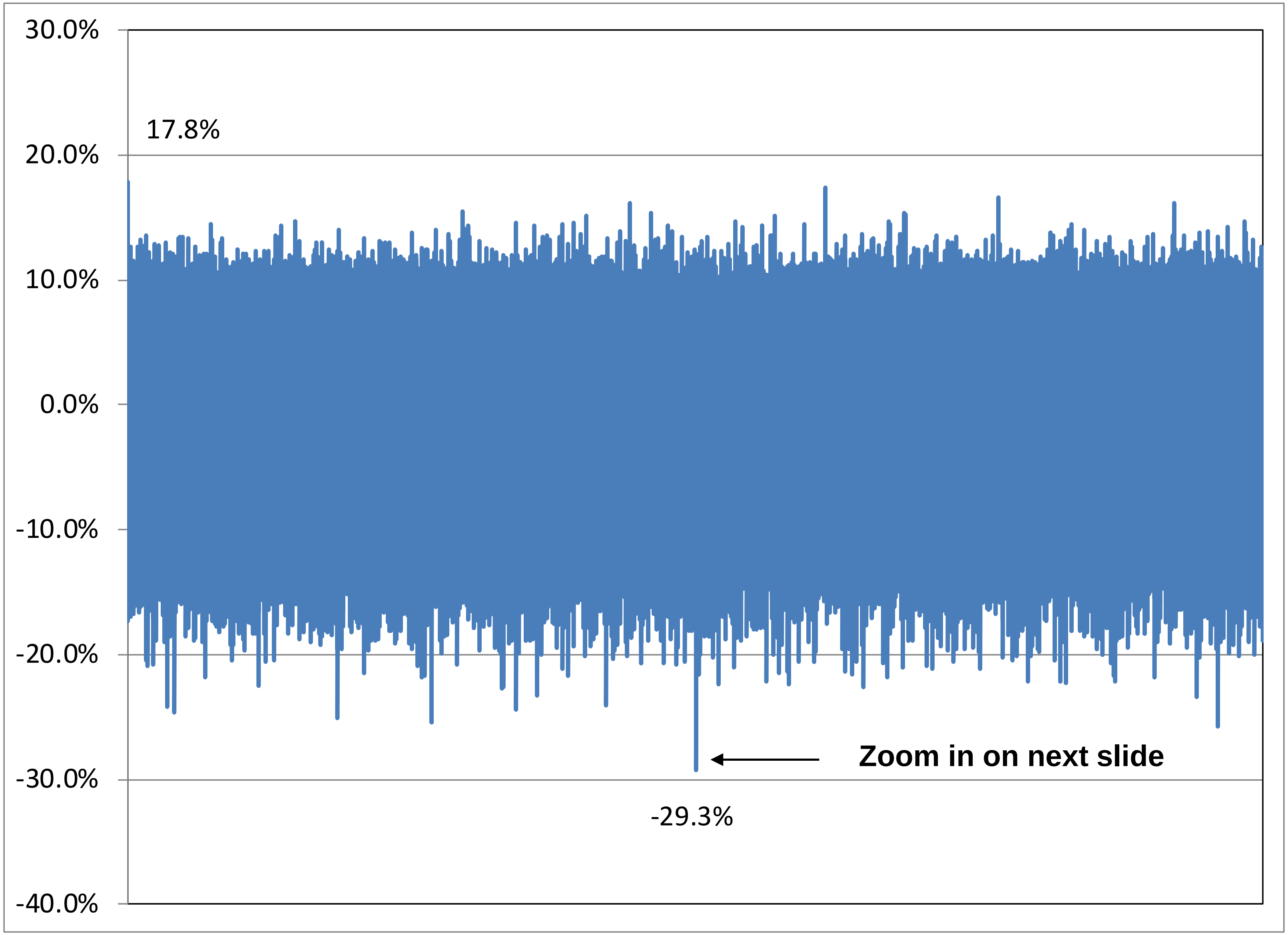
What happens if the transmitter has an LF cut frequency of Baud/2400 and is tested with PRBS31Q?

The next slide shows the time evolution of baseline wander over the entire PRBS31Q sequence.

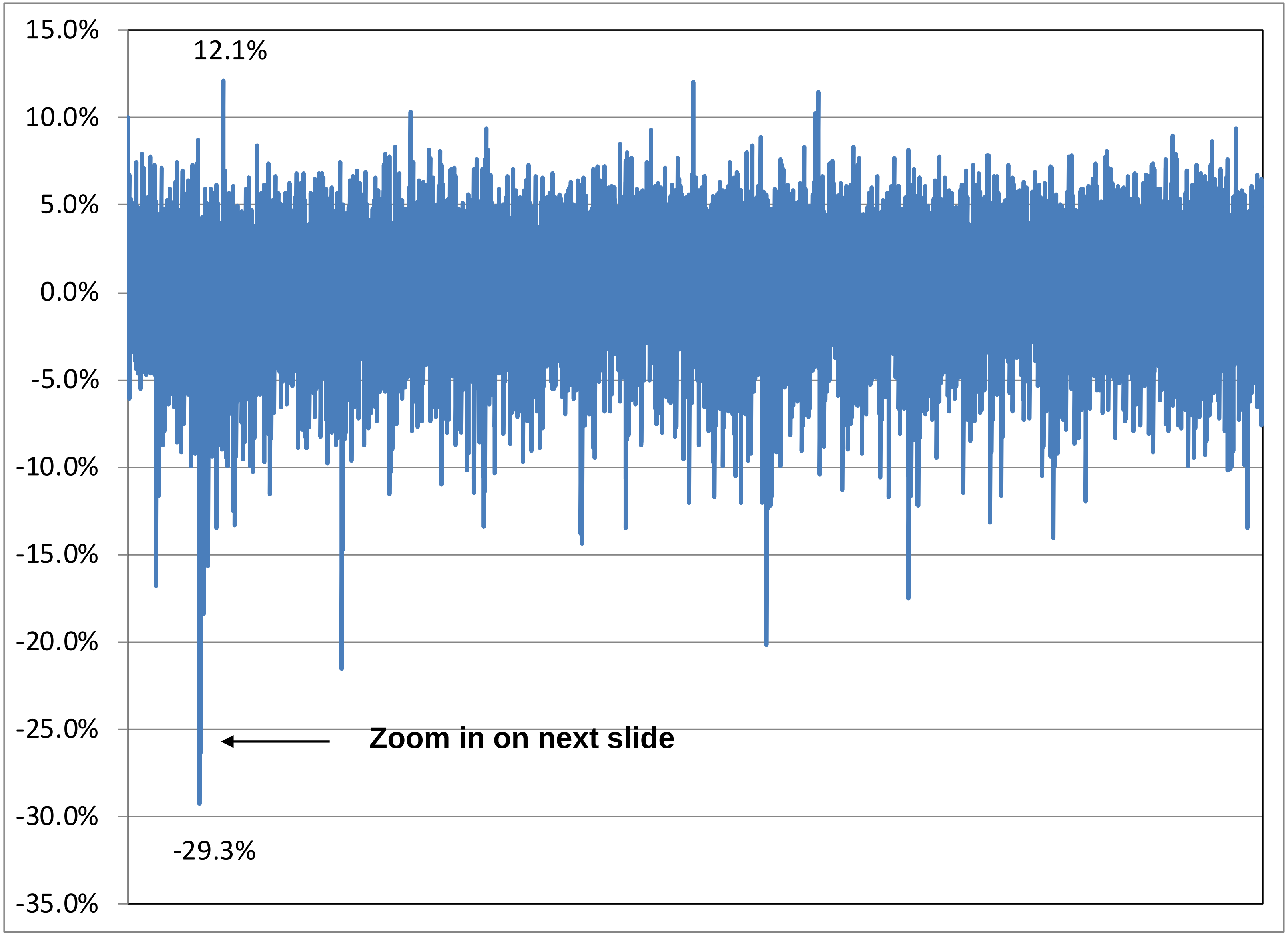
The slide following that shows 1/1024 of the sequence (2,097,152 symbols) around the point of the largest spike.

The slide after that zooms in again to show 10,240 symbols around the largest spike. Superimposed on this is a diagram showing parts of three codeword pairs and also the BER that signals with particular baseline wander values would have.

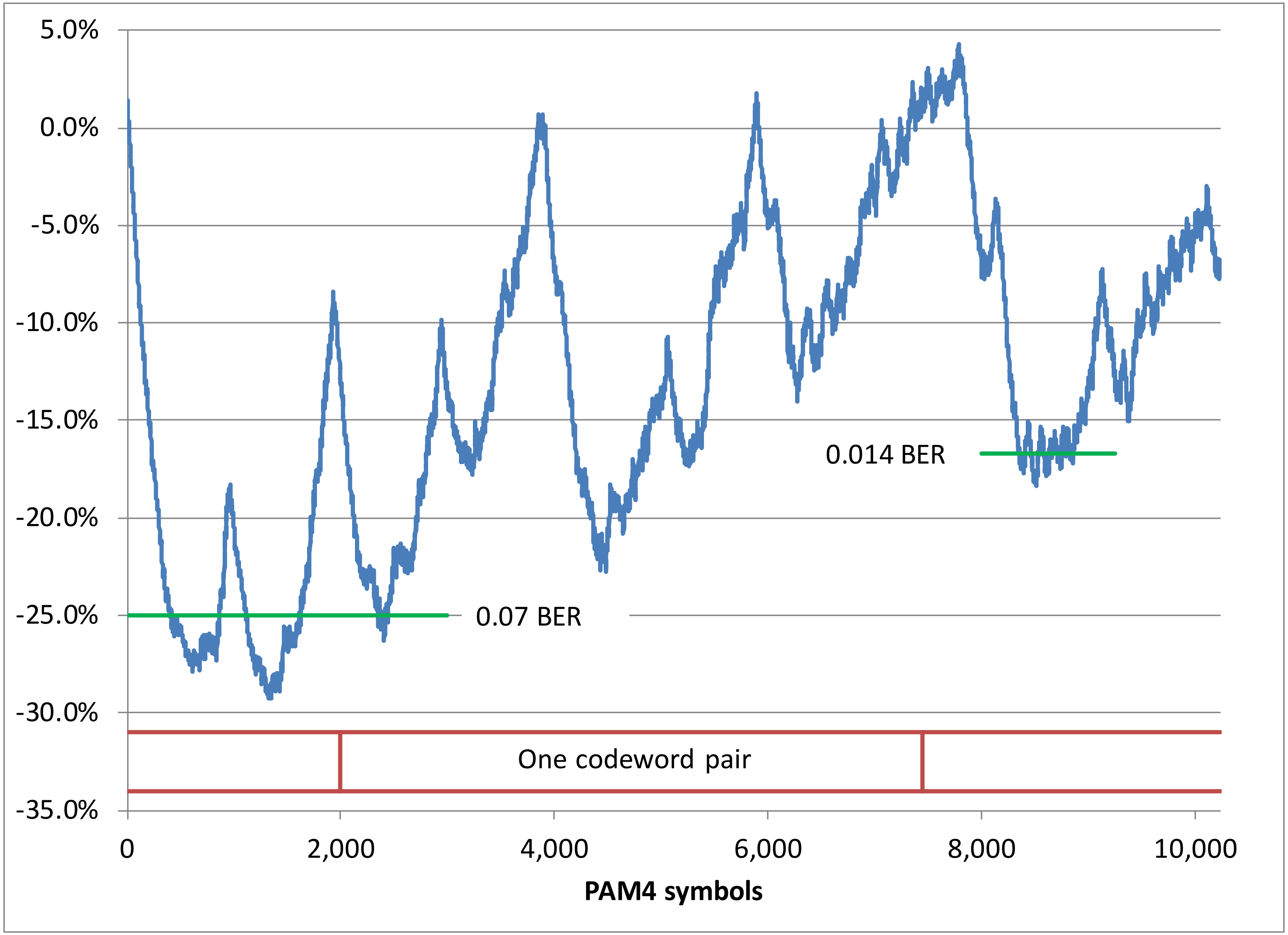
PRBS31Q with LF cut of Baud/2400, all



PRBS31Q with LF cut of Baud/2400, 1/1024



PRBS31Q with LF cut of Baud/2400 10,240 sym



Lane performance

What would happen if a PAM4 lane with an LF cut frequency of Baud/2400 was driven with a FEC encoded signal that had the same baseline wander characteristics as the PRBS31Q sequence?

To find out, a simulation was performed that divided the PRBS31Q sequence into blocks of 5440 symbols (sized to contain one codeword pair) and, taking into account the 10-bit FEC symbols and the chequerboard FEC symbol distribution, calculated the probability of at least one of the two FEC codewords being uncorrectable.

The result was that instead of an FLR of 1.7E-12 as required for the PMD clauses, the FLR is 2.8E-4 (8 orders of magnitude too high).

Loss of synchronization

As can be seen on an earlier slide, the worst part of the PRBS31Q sequence has a duration that is long enough to affect 3 codeword pairs in a row if the alignment between the 5440 symbol blocks and the PRBS31Q pattern is unfortunate. To investigate this simulations were done with a range of offsets between the codeword start and the sequence start.

Offset (symbols)	**Frame loss ratio**	**Time to loss of synch**
0	2.8E-4	4.3 hours
1000	3.0E-4	1.6 seconds
2000	2.9E-4	0.2 seconds
3000	2.9E-4	0.18 seconds
4000	3.0E-4	39 seconds

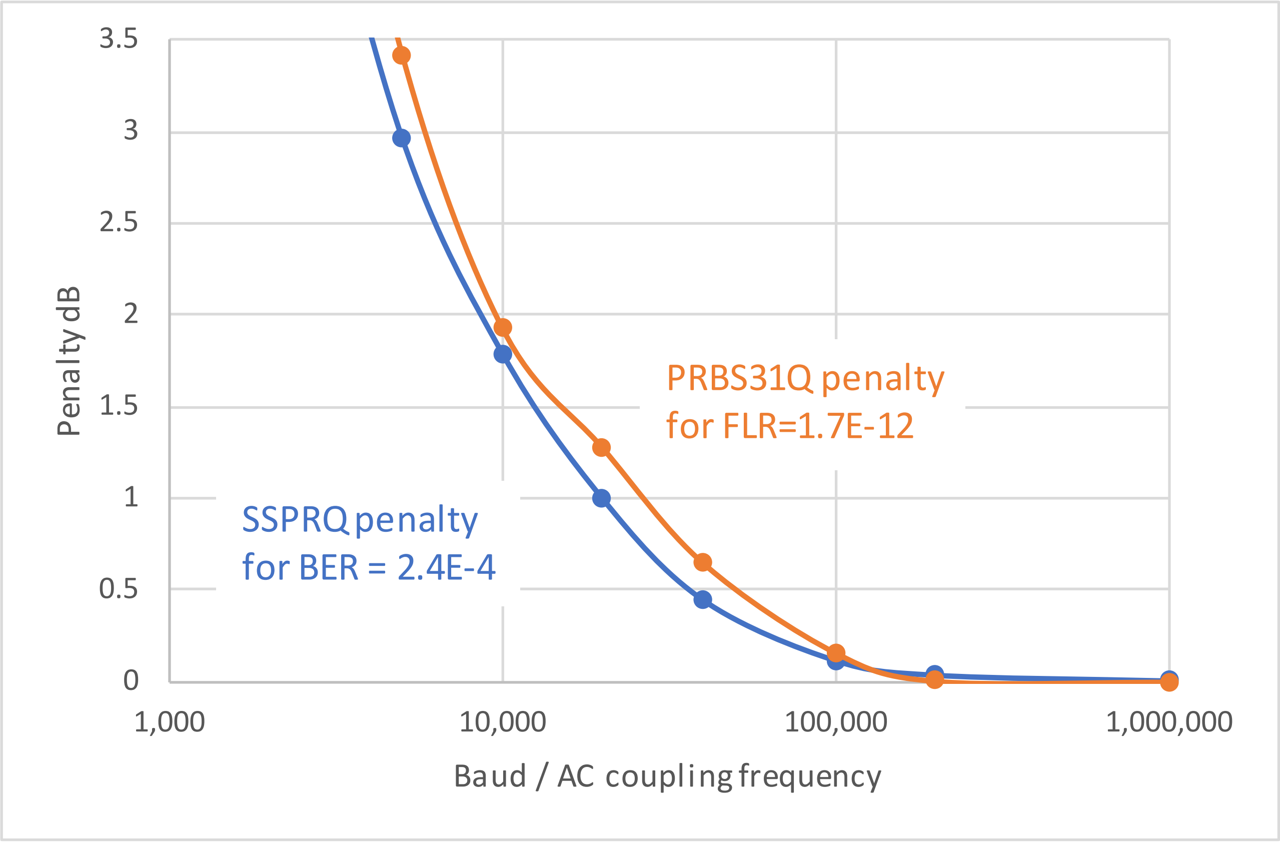
Further investigation

To investigate further, calculations were performed with a range of different LF cut frequencies.

X	AC coupling frequency	SSPRQ penalty for BER=2.4E-4	PRBS31Q FLR for BER=2.4E-4	PRBS31Q penalty for FLR=1.7E-12
2,400	11.1 MHz	5.06 dB	3.0E-4	5.98 dB
5,000	5.31 MHz	2.96 dB	5.9E-5	3.42 dB
10,000	2.66 MHz	1.79 dB	1.4E-5	1.93 dB
20,000	1.33 MHz	1.0 dB	3.4E-6	1.28 dB
40,000	664 kHz	0.45 dB	6.8E-7	0.65 dB
100,000	266 kHz	0.12 dB	1.3E-10	0.16 dB
200,000	133 kHz	0.04 dB	1.9E-12	0.0048 dB
1,000,000	26.6 kHz	0 dB	1.7E-12	0 dB

Penalties vs X

Comparison of the optical penalty for SSPRQ with BER = 2.4E-4 and PRBS31Q assuming FEC with FLR = 1.7E-12



Loss of sync vs X

For the same range of LF cut frequencies, the mean time to loss of synch (MTTLS) was calculated for BER = 2.4E-4 and for FLR = 1.7E-12.

X	AC coupling frequency	PRBS31Q FLR for BER=2.4E-4	PRBS31Q MTTLS for BER=2.4E-4	PRBS31Q MTTLS for FLR=1.7E-12
2,400	11.1 MHz	3.0E-4	0.12 sec	1.3E191 years
5,000	5.31 MHz	5.9E-5	0.82 sec	5.0E80 years
10,000	2.66 MHz	1.4E-5	1.9 sec	3.8E38 years
20,000	1.33 MHz	3.4E-6	19 min	2.3E33 years
40,000	664 kHz	6.8E-7	6.3 days	1.1E19 years
100,000	266 kHz	1.3E-10	1.6E7 years	1.3E13 years
200,000	133 kHz	1.9E-12	7.9E14 years	1.0E15 years
1,000,000	26.6 kHz	1.7E-12	5.9E21 years	5.9E21 years

Further comments

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Comments r01-48 and r01-32 against P802.3bs D3.1 propose: “Change the first seed in Table 120-2 to one for which a minimally compliant transmitter with 0.4 dB baseline wander penalty after FEC with a random payload measures as minimally compliant (i.e. also 0.4 dB baseline wander penalty) on a pre-FEC BER basis with SSPRQ.”

Question - what baseline wander causes “0.4 dB baseline wander penalty after FEC with a random payload”?

Answer – for 2000,000,000 symbols of random data X = 2291 or 11.6 MHz

As shown on earlier slides, an AC coupling frequency this high is unacceptable.

Conclusion

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Choosing a short stress pattern on the basis of causing the same average baseline wander pre-FEC BER penalty as a long PRBSQ sequence has been proposed. This would result in a test pattern that would allow a transmitter to have sufficient baseline wander to cause the FLR to be 8 orders of magnitude outside the limit and to declare loss of sync when tested with a FEC encoded sequence with the same baseline wander as PRBS31Q.

The optical penalty for SSPRQ with pre-FEC BER = 2.4E-4 has been compared with the optical penalty for PRBS31Q assuming FEC with FLR = 1.7E-12 over a wide range of ratios between the symbol rate and AC coupling frequency showing very close agreement between the two penalties.

Changing the SSPRQ seed using the metric proposed in comments r01-48 and r01-32 against P802.3bs D3.1 would lead to unacceptable baseline wander.

Thanks!