# 4 Lanes Muxing Limited Clock Content Analysis

IEEE P802.3bs Task Force Logic Ad-Hoc

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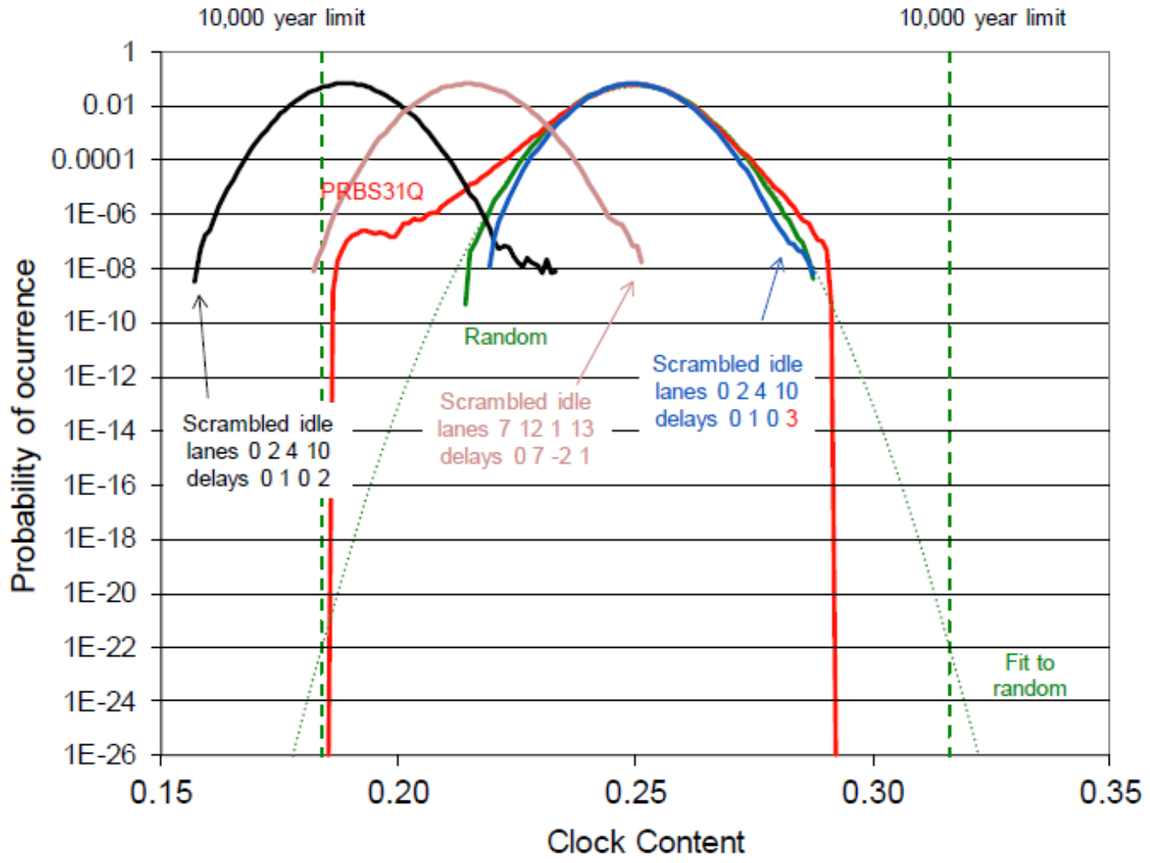
Oded Wertheim
Mellanox Technologies

# 400G 53GBd PAM4 Clock Content Issue

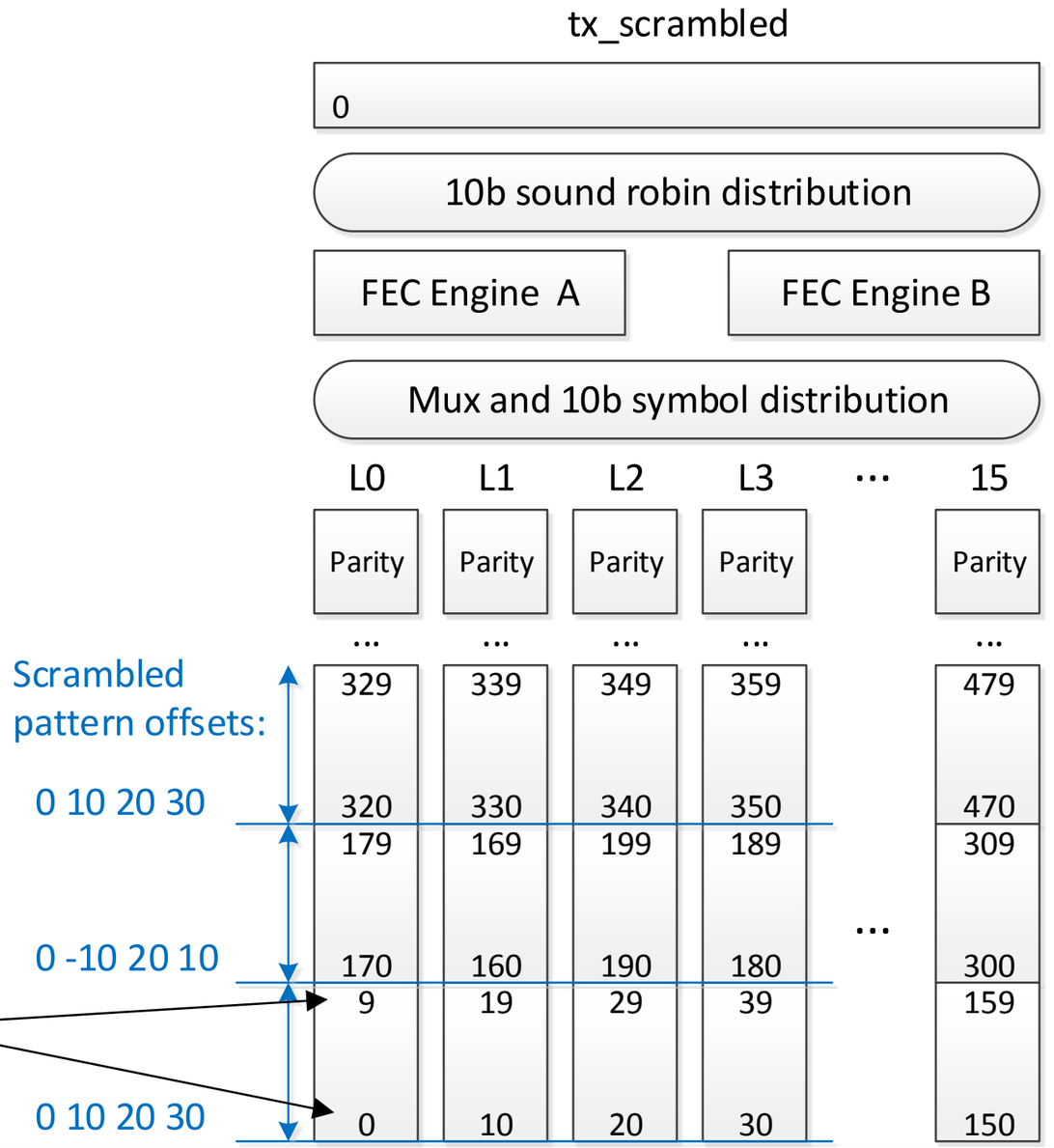
- When muxing 4 PCS lanes into a 53GBd PAM4 lane, we observe a lower clock content for scrambled idles on specific lanes and delays combination.
- The issues was presented in anslow_01_121916_elect and in wong_01_0117_logic, and possible solutions were proposed in gustlin_01_0117_logic.
- The presentation attempts to provide a better understanding of the issue.




- From anslow_01_121916_elect

# From the 400G PCS Scrambler to the Lanes Distribution

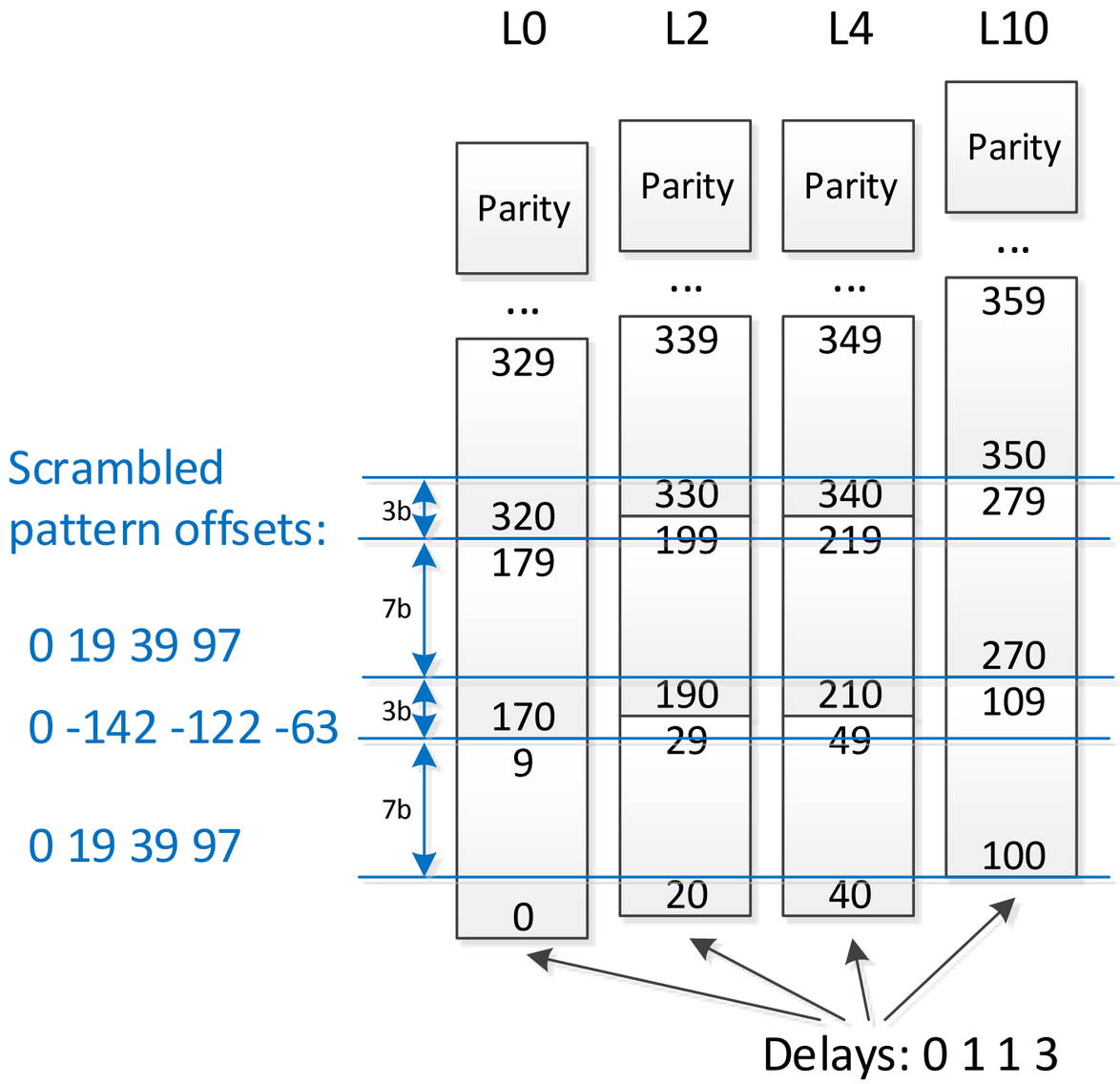
- tx_scrambled – the scrambler output, bit 0 is the first bit of the scrambled idles
- Following the scrambled pattern to the lanes output, we get for lanes 0-3:
  - 10 bit with offsets between the lanes of: 0 10 20 30
  - 10 bit with offsets between the lanes of: 0 -10 20 10
- The 20b cycle relates to the checkerboard distribution
- The distributed FEC parity does not follow the scrambled pattern offset cycle
  - The parity has random data clock content
- As the FEC codeword size (5440b) is divisible by 16x20, after the start of the next codeword we get the exact same scrambled pattern offset.




The bit numbers in the drawing represent the bit offset in the scrambled pattern (tx_scrambled)

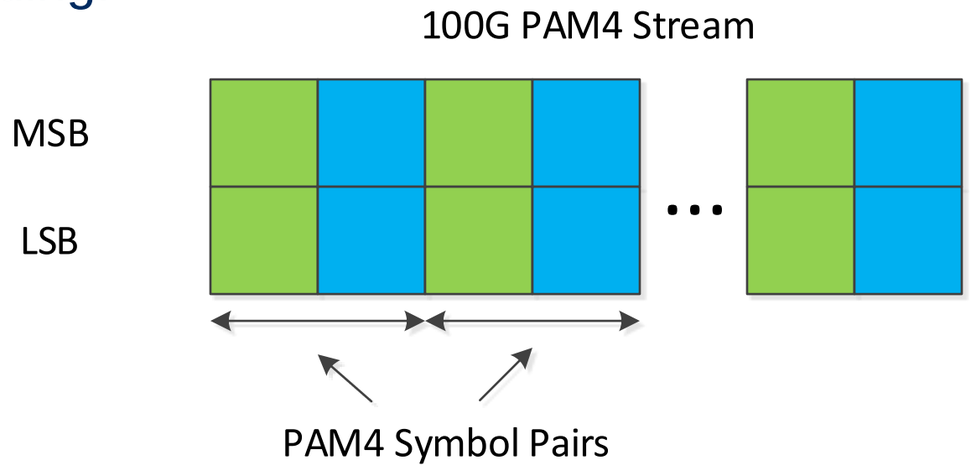
# Scrambled Pattern Offsets For Lanes: 0 2 4 10, Delays: 0 1 1 3

- Looking at the scrambled pattern offsets on one of the problematic {lanes, delays} combinations, we get a cycle of:
  - 7b with offset 0 19 39 97
  - 3b with other offsets:
    - 1bit with 0 -142 -122 -63, 2bits with 0 19 39 -63



# Scrambled Pattern Offsets For Lanes: 0 2 4 10, Delays: 0 1 1 3

- Muxing the lanes to a PAM4 stream, we get due to Gray coding:
  - Odd LSBs = Lane0 ⊕ Lane2
  - Even LSBs = Lane4 ⊕ Lane10



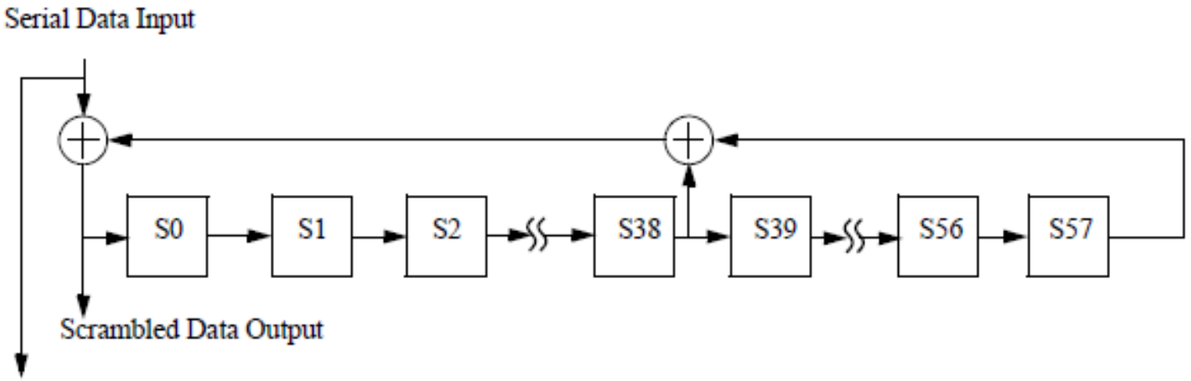

- Looking at the scrambled pattern offsets we get:
  - 7 pairs of PAM4 symbols built from offset 0 19 39 97
  - 3 pairs of PAM4 symbols built from other offsets

- PRBS58 offsets [0 19 39 97] are linearly dependent
  - $PRBS_{58}[n] \oplus PRBS_{58}[n+19] \oplus PRBS_{58}[n+39] \oplus PRBS_{58}[n+97] = 0$

- As a result we get
  - 7 pairs of PAM4 symbols with the same LSB (Odd LSBs ⊕ Even LSBs = 0)
  - 3 pairs of random PAM4 symbols

- Transitions between 2 PAM4 symbols with the same LSB (0/2⇔0/2,1/3⇔1/3) are either a-symmetric transitions or no transition.

# Scrambler & PRBS58



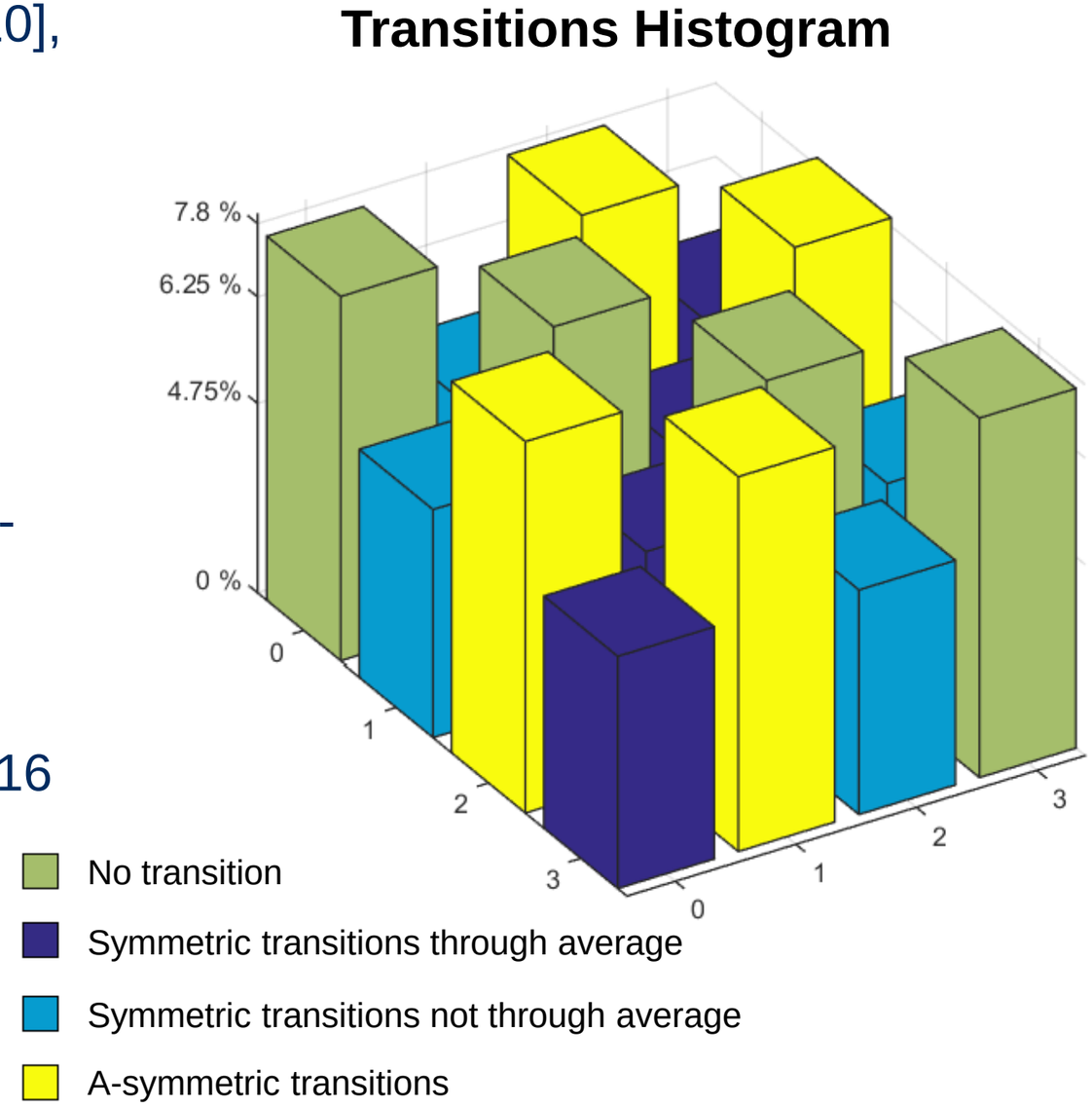

$$G(x) = 1 + x^{39} + x^{58}$$

- For a cyclic input data (transcoded idles), the scrambler output is PRBS58 ⊕ D
  - D - the cyclic pattern of transcoded idles
- PRBS is a linear function, i.e. PRBS(init A) + PRBS(init B) = PRBS(init A + init B)F
- For PRBS58, there is a set of offsets [K1 k2 k3 k4] where
  - $PRBS_{58}[n + k1] \oplus PRBS_{58}[n + k2] \oplus PRBS_{58}[n + k3] \oplus PRBS_{58}[n + k4] = 0$

    For any n
- {Lanes, Delays} that include these scrambled pattern offsets will suffer from the limited clock content.

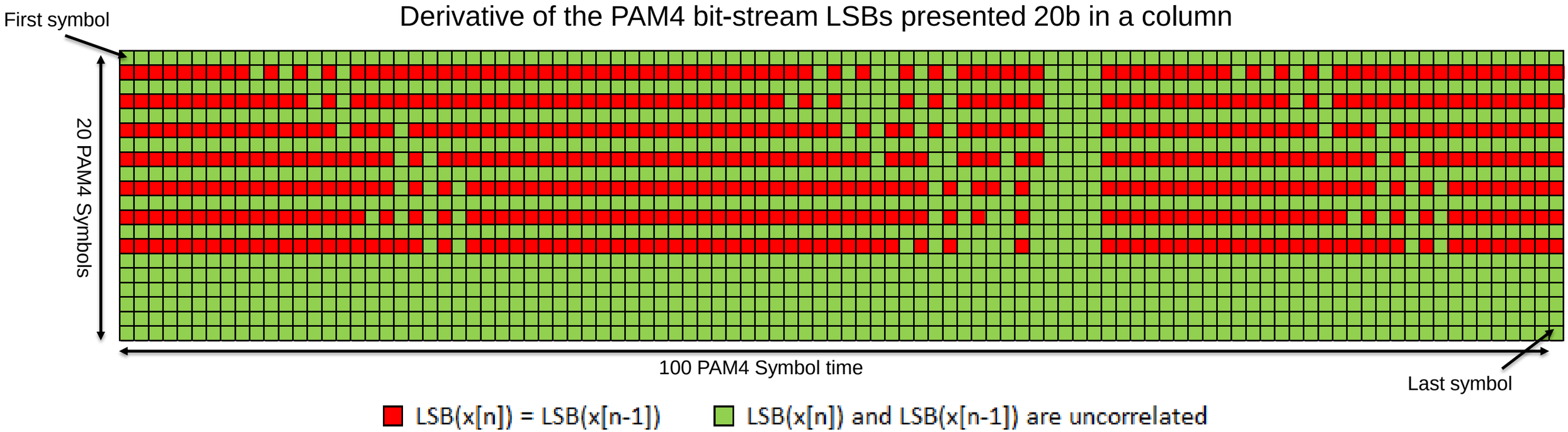
# Simulation Results - Transitions Histogram

- Analyzing the transition histogram for lanes [0 2 4 10], delays [0 1 1 3]
- The transitions histogram shows:
  - No transitions: 30.7%
  - Symmetric transitions through the average: 19%
  - Symmetric transitions not through average : 19.8%
  - A-symmetric transitions: 31.5%
- The transitions with the same LSB (No transition, A-symmetric transitions) account for 61.2% of the transitions.
- For a random pattern we expect 6.25% for each of 16 possible transitions.
- The observed transition histogram is approximately symmetric (a→b / b→a have similar statistics)



# Simulation Results – 100G PAM4 Pattern

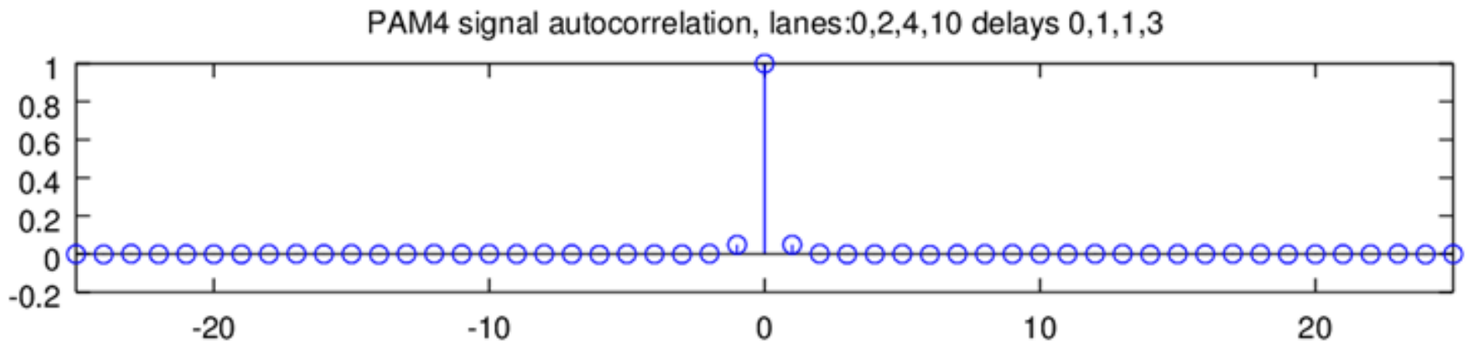
- The PAM4 pattern for lanes [0 2 4 10], delays [0 1 1 3] is mostly comprised:
  - 3 pairs of PAM4 symbols with random data
  - 7 pairs of PAM4 symbols with the same LSB (random MSB)
- The uncorrelated area result from the scrambled idles constant (D)

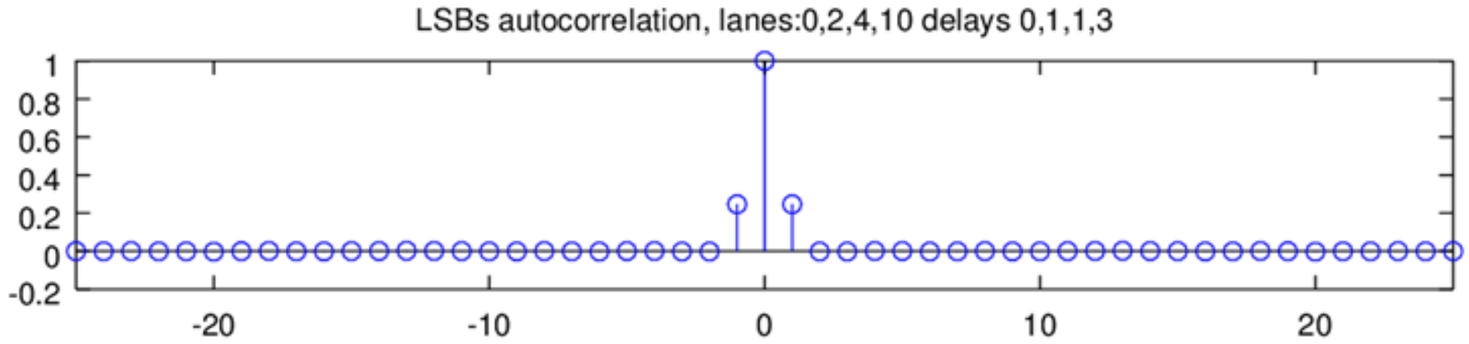


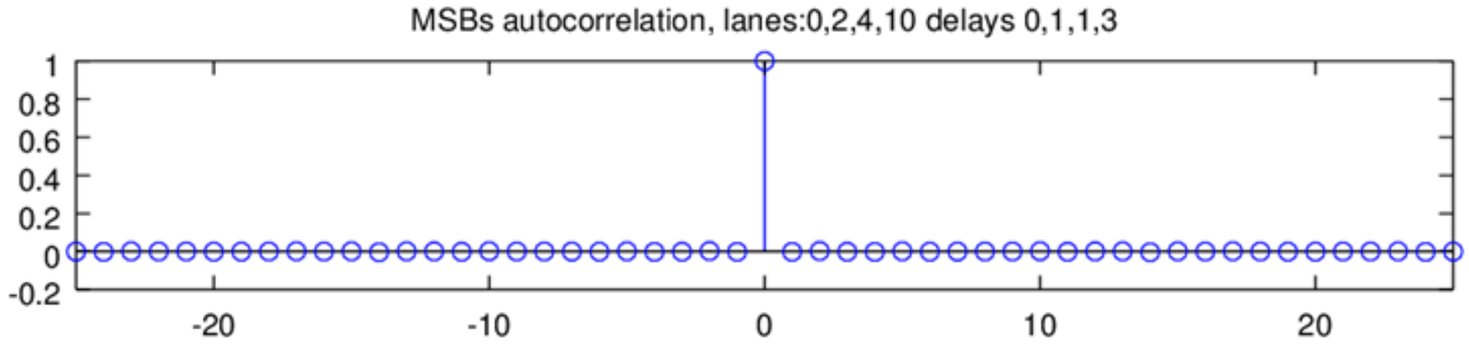

- The pattern was generated by 30 iterations with a random scrambler seed, performing OR on the LSB derivative.

# Simulation Results – Autocorrelation

- Correlation > 0 between neighbor PAM4 symbols
- No correlation between the MSBs
- Clear correlation between neighbor LSBs.



# Analysis of the Data in anslow_02_121916_elect.xlsx

- All the {Lanes, Delays} in the table correspond to linearly dependent scrambled pattern offsets.
- The number of same LSB pairs in the pattern varies between 7 to 3 is correlated to the measured clock content values
- The number of the same LSB pairs results from the different delays between the lanes which shifts the 10b symbols.

- Examples:

| Lanes | Delays | Sym transitions through avg CC | Transitions CC | # of same LSB pairs | Scrambled pattern offsets: k1 k2 k3 k4 |
|---|---|---|---|---|---|
| 0 2 4 10 | 0 1 0 2 | 0.18923 | 0.690081 | 5 | 0 19 39 97 |
| 0 2 4 13 | 0 0 0 7 | 0.19094 | 0.690896 | 7 | 0 38 58 77 |
| 0 2 7 13 | 0 0 5 8 | 0.20934 | 0.709221 | 6 | 0 57 96 116 |
| 0 2 8 15 | 0 0 1 8 | 0.18816 | 0.687165 | 7 | 0 19 39 97 |
| 0 2 11 15 | 0 1 7 9 | 0.18229 | 0.682288 | 7 | 0 38 58 77 |
| 0 6 15 13 | 0 2 9 8 | 0.18606 | 0.686222 | 6 | 0 19 39 97 |

# Summary & Conclusions

- The limited clock content results from patterns with high percentage of PAM4 symbol pairs with the same LSB.
- The pattern is generated for {lanes, delays} combinations the correspond to linearly dependent scrambled pattern offsets.
- The transitions histogram is approximately symmetric
- While the PAM4 stream LSBs are correlated, the MSBs are random / not correlated
- If needed, we can generate a test pattern with the same characteristics.

# Thank You