10GBASE-R Test Patterns

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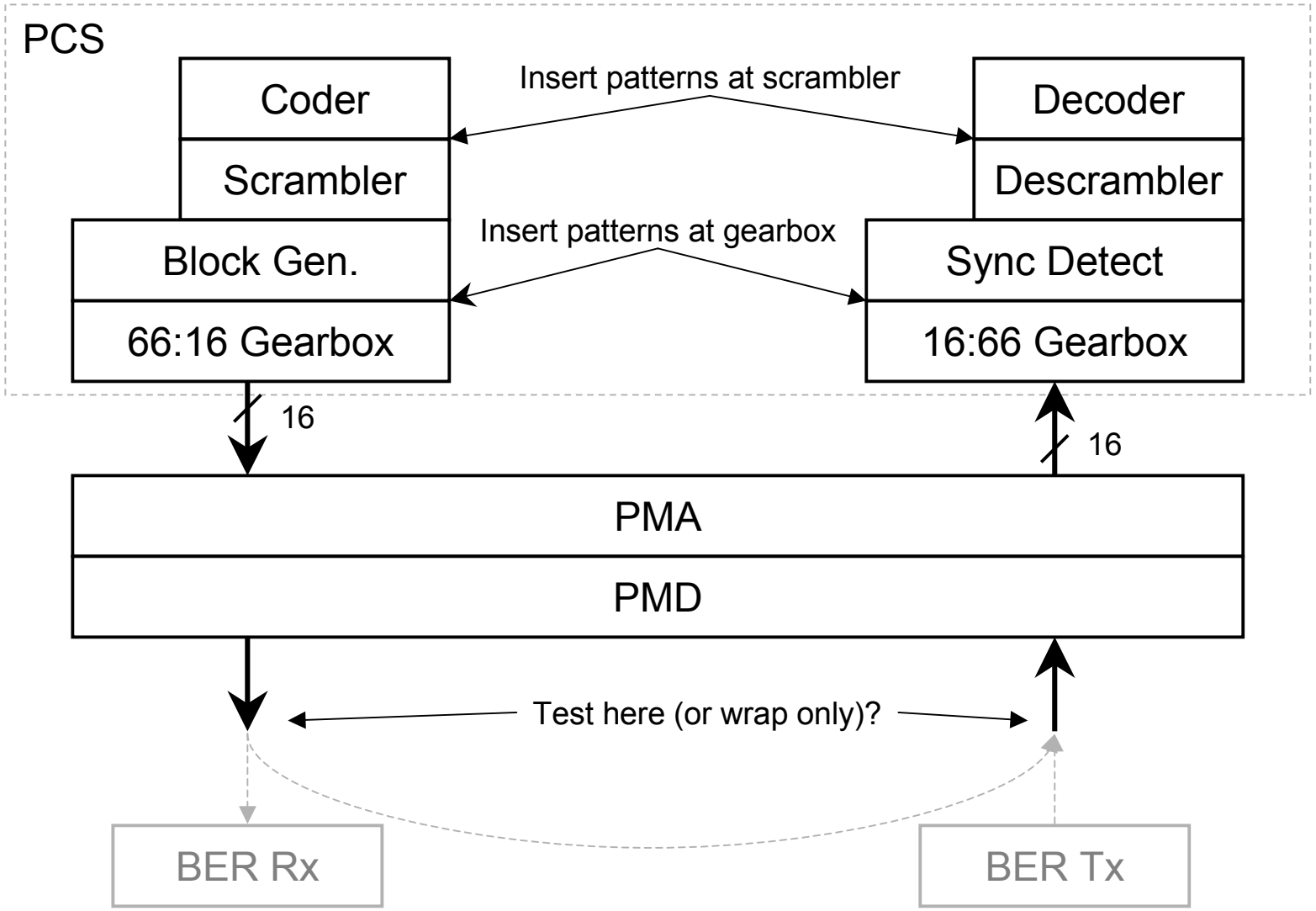
Test Pattern

- Want to evaluate “pathological” events that occur on average once per day
- At 10Gb/s “once per day” is equivalent to a probability of $1.1\times10^{-15} \sim 1/2^{50}$
  - Equivalent to 7.9σ for a Gaussian distribution
- $2^{31} – 1$ PRBS repeats ~ 200ms
  - Sufficient to meet worst case criteria of once per day?
- $2^{58} – 1$ PRBS repeats in ~ 1 year
  - Too long for practical testing

Test Pattern Function

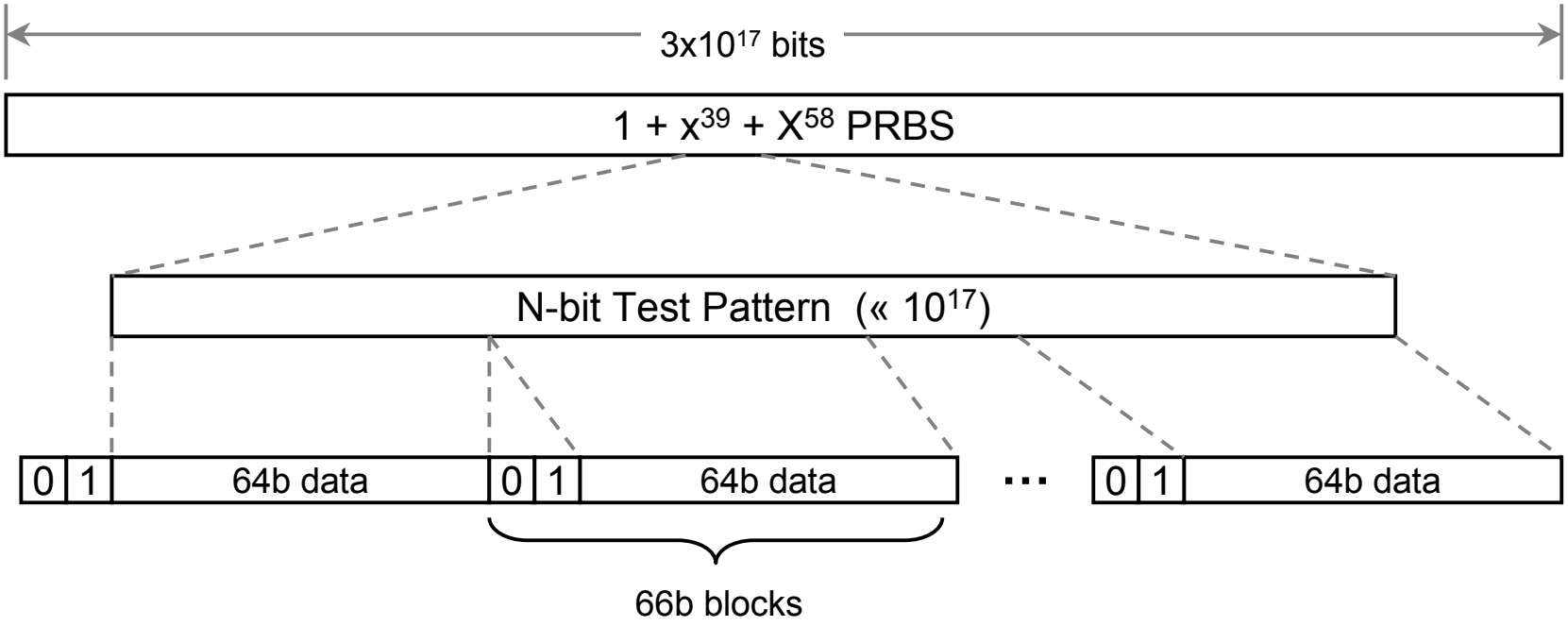


Proposed Test Sequence

- Use existing $1 + x^{39} + x^{58}$ scrambler
  - Seed register with defined value
  - Run for N bits (propose $N= 2^{16}$)
    - Allow non-zero scrambler data inputs for additional flexibility
  - Reset scrambler & repeat
    - Can use scrambler data input to reset its state (pseudo-seed)
    - Seed can be set via management registers
- Seed chosen to stress:
  - Maximum run-length
  - Minimum transition density
  - Maximum baseline wander
- N arbitrary, but …
  - Choose power of 2 for easy implementation
  - Choose N < memory depth of typical BERT
- Periodically resetting the scrambler implies the pattern is no longer “random”

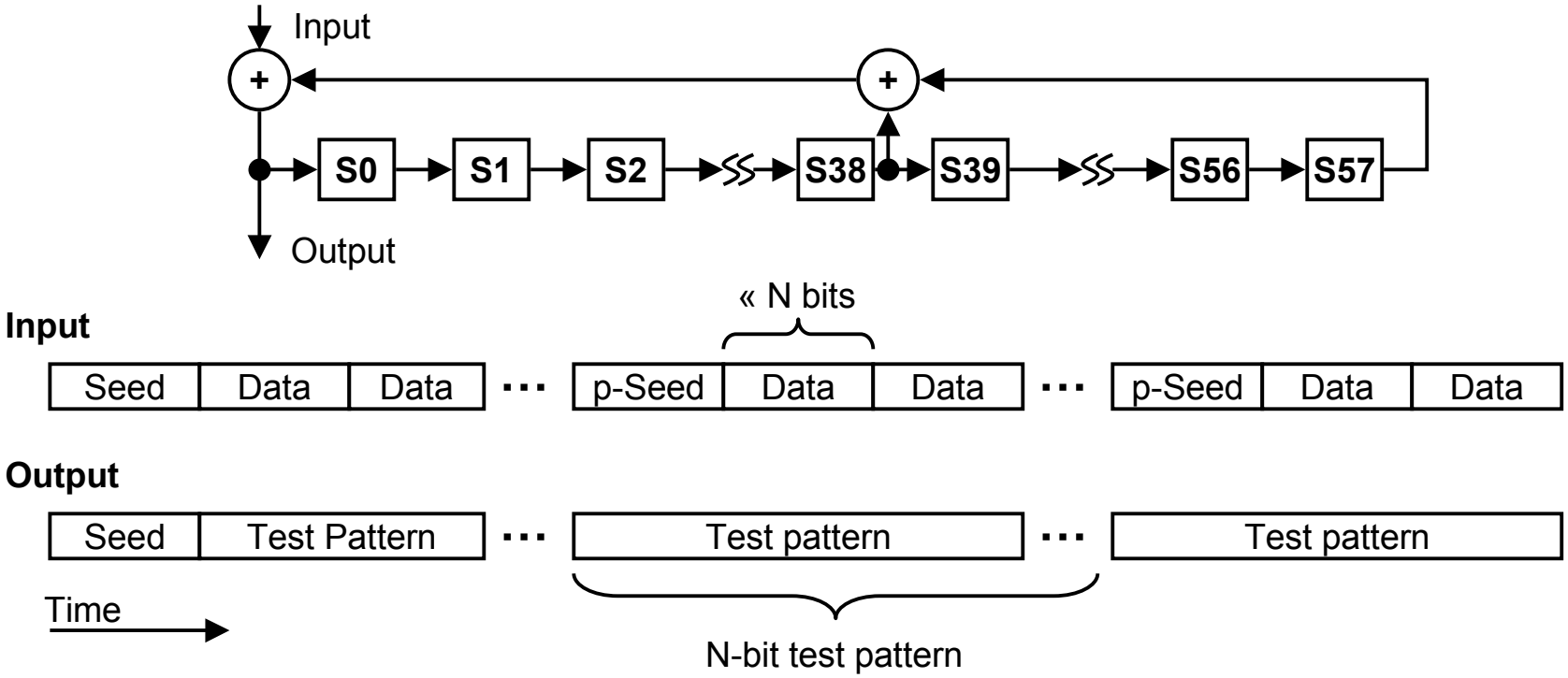
Test Pattern Structure

- Select a subset of the 2^{58}–1 PRBS using appropriate seed
- Map the test pattern into the payload of the 66-bit blocks
- Repeat the test pattern



Test Pattern Generation

- Seed the scrambler
- Apply, short, repetitive data pattern (e.g. all zero's)
- Apply pseudo-seed after N bits to transition to pattern beginning
- Repeat



Example

- Choose 1 + x^6 + x^7 PRBS,
  - N= 16-bits
  - Pattern = 0 1 1 1 1 1 1 1 0 0 0 0 0 0 1 0 (longest run-length)
- Initial Seed = 1 0 1 0 1 0 0
- To force scrambler to repeat the 16-bit pattern:
  - "Data" = 0 1 1 1 0 0 1 0 0 0 0 0 0 0 0 0

7bits reset the scrambler All zeros otherwise

- ∴Seed= 1010100, Pseudo-seed= 0111001
- For M^{th}-order scrambler, need M-bits to reset the scrambler

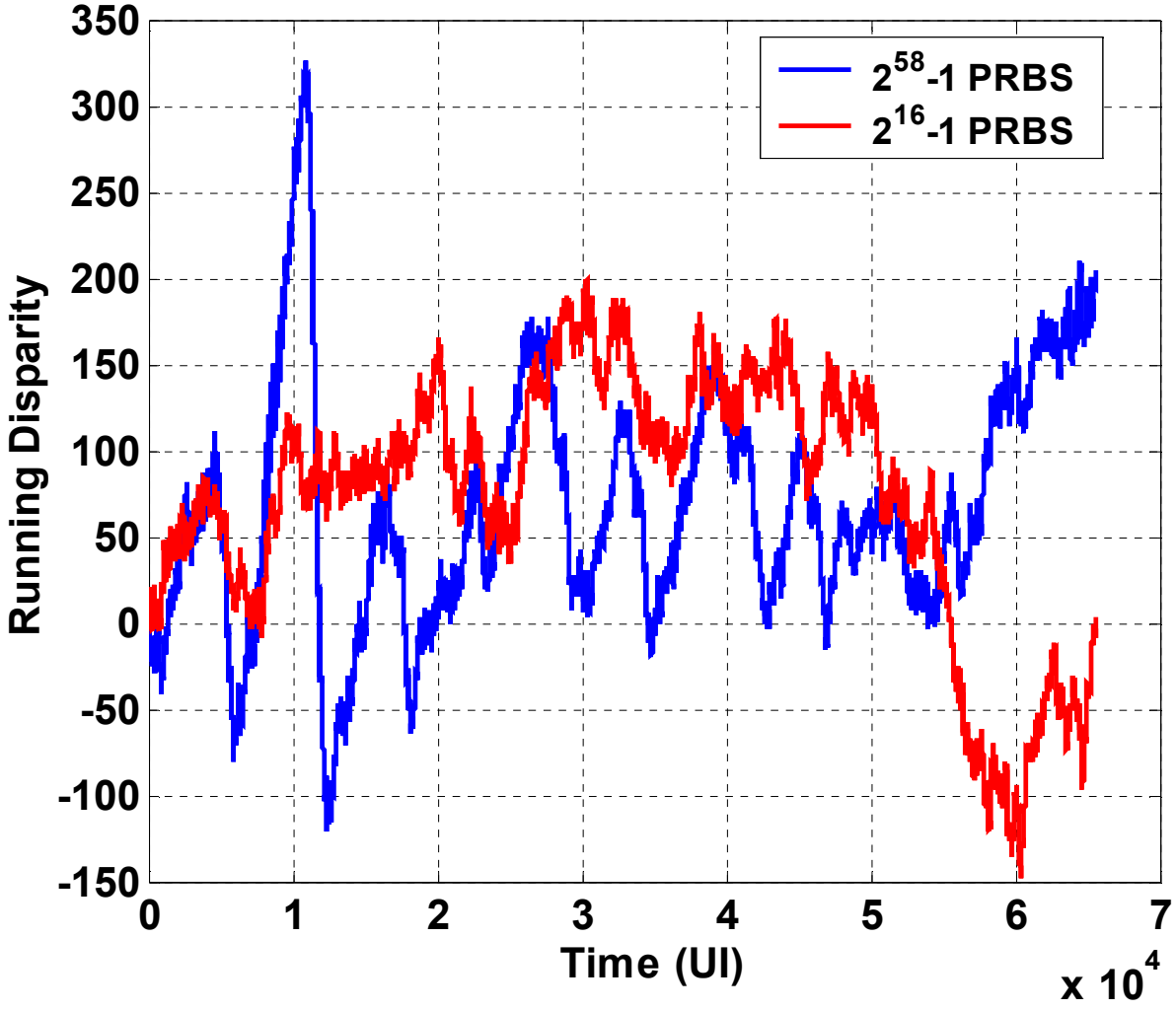
Error Detection

- Only using a subset of the full $2^{58}-1$ sequence
- Self-synchronous descrambler will generate “errors” at pattern boundary
  - “Errors” are deterministic due to pattern mismatch
    - The “error” pattern at the descrambler equals the “data” pattern used to reset the scrambler to generate the test pattern
  - Can be taken into account to compute real error rate
  - Increases somewhat the complexity at the error detector

Pattern Characteristics

- Compare proposed pattern with a 2^{16} –1 PRBS
  - PRBS choice is arbitrary
  - Want “random” pattern of ~2^{16} length for comparison
  - $1+ x + x^3 + x^{12} + x^{16}$ is convenient choice
- Evaluate
  - Running disparity
  - Transition density
  - Autocorrelation
  - Power spectral density
  - Baseline wander

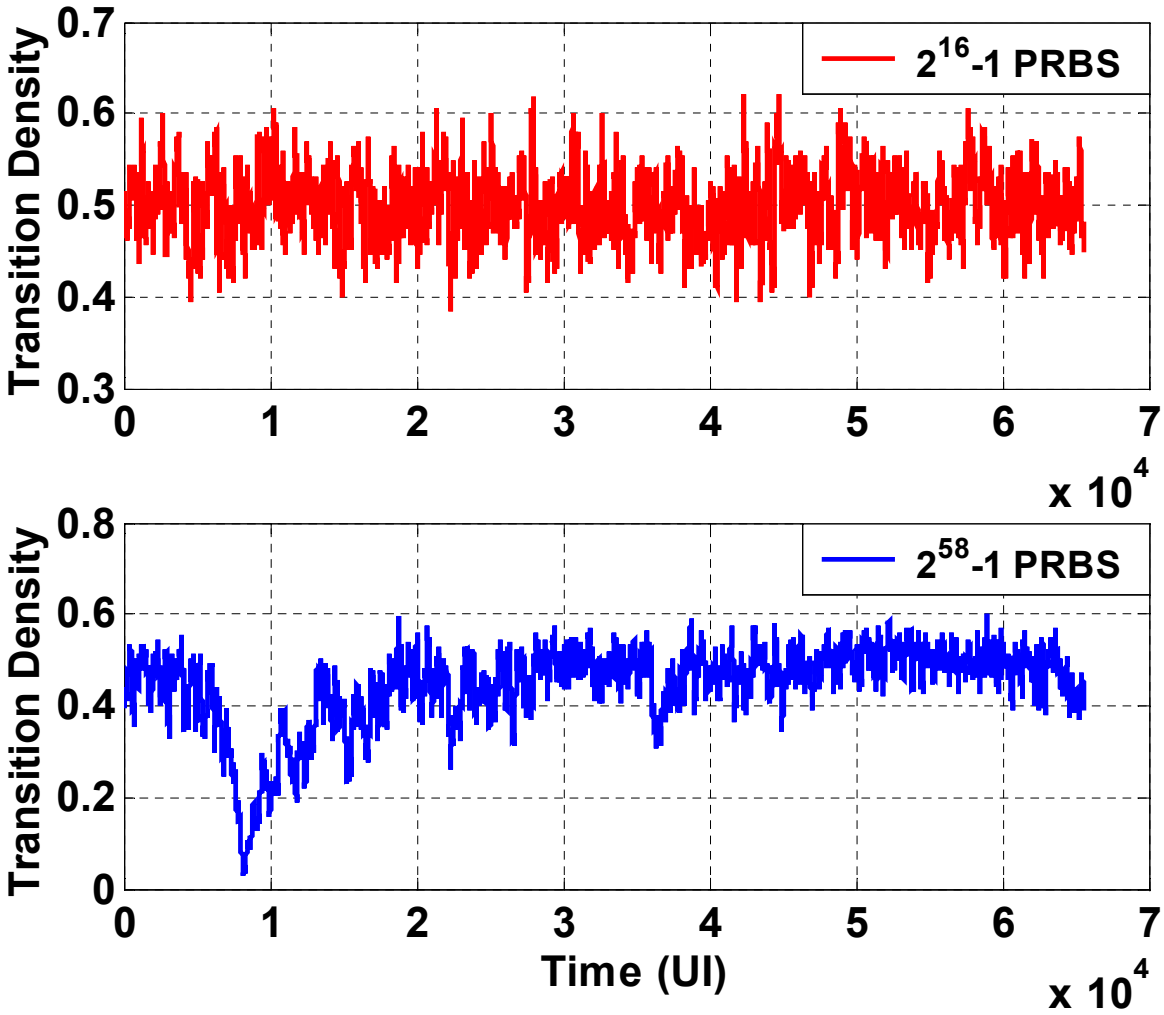
Running Disparity



Nomenclature

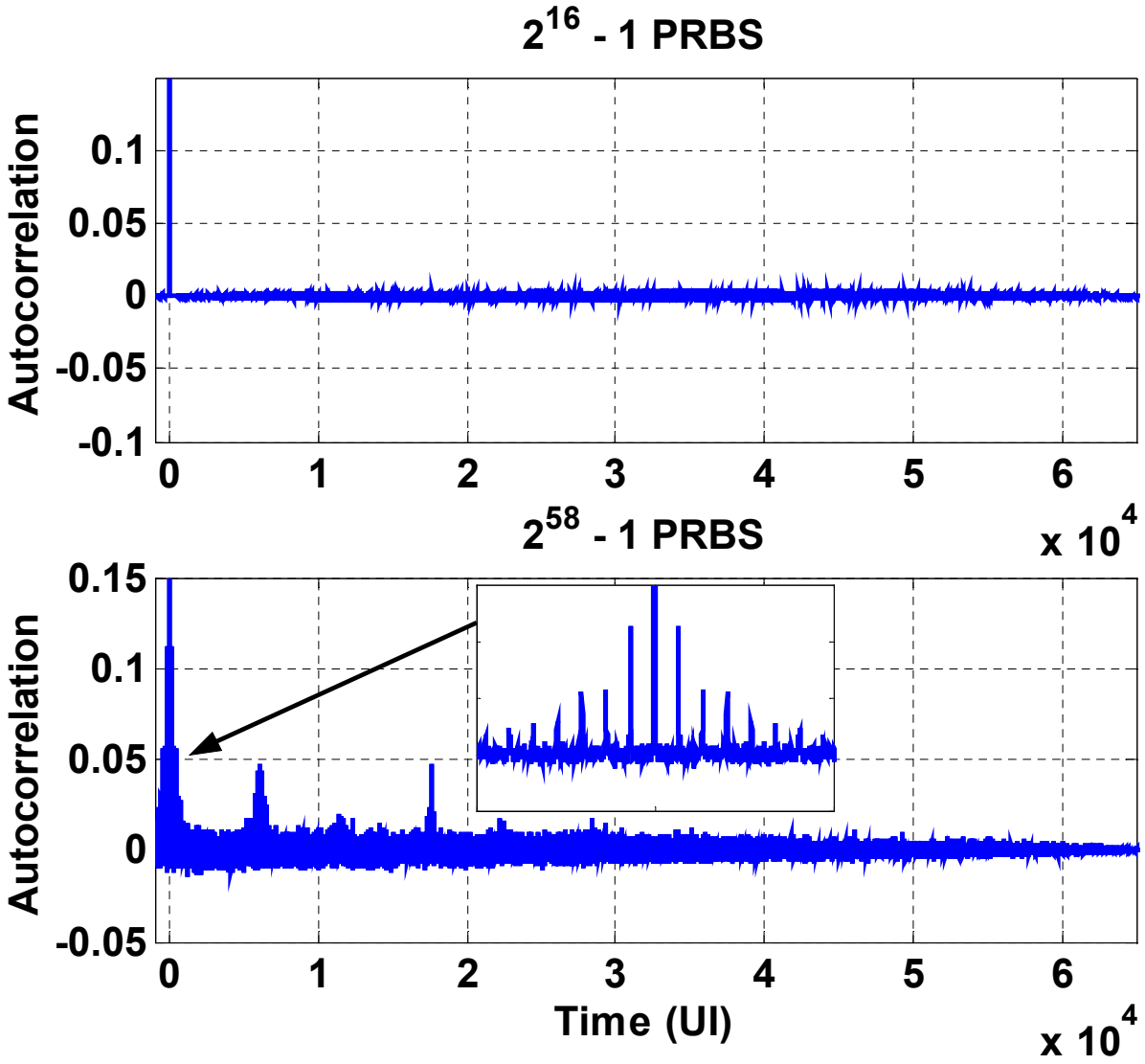
- "2^{16}–1 PRBS":
  - 2^{16} bits long (one cycle + 1 bit)
  - $1 + x + x^3 + x^{12} + x^{16}$
- "2^{58}–1 PRBS":
  - 2^{16} bits long (« one cycle)
  - $1 + x^{39} + x^{58}$
  - Seed chosen for max run-length ~8kb from pattern beginning

Transition Density



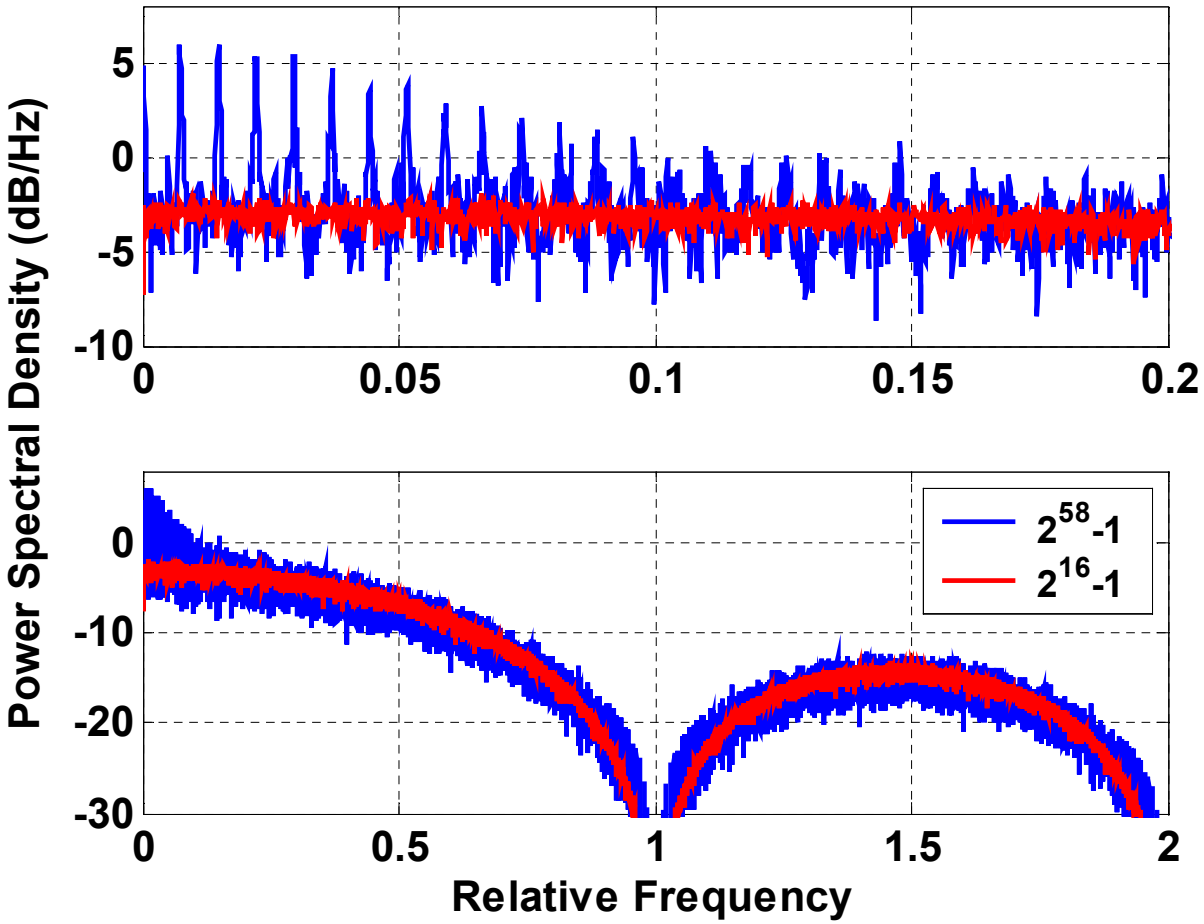
- Transition density averaged over 200 UI
- $2^{16}-1$
  - 16 UI max run-length
  - 50% average density
  - 38% minimum density
- $2^{58}-1$
  - 58 UI max run-length
  - 44% average density
  - 3% minimum density

Autocorrelation



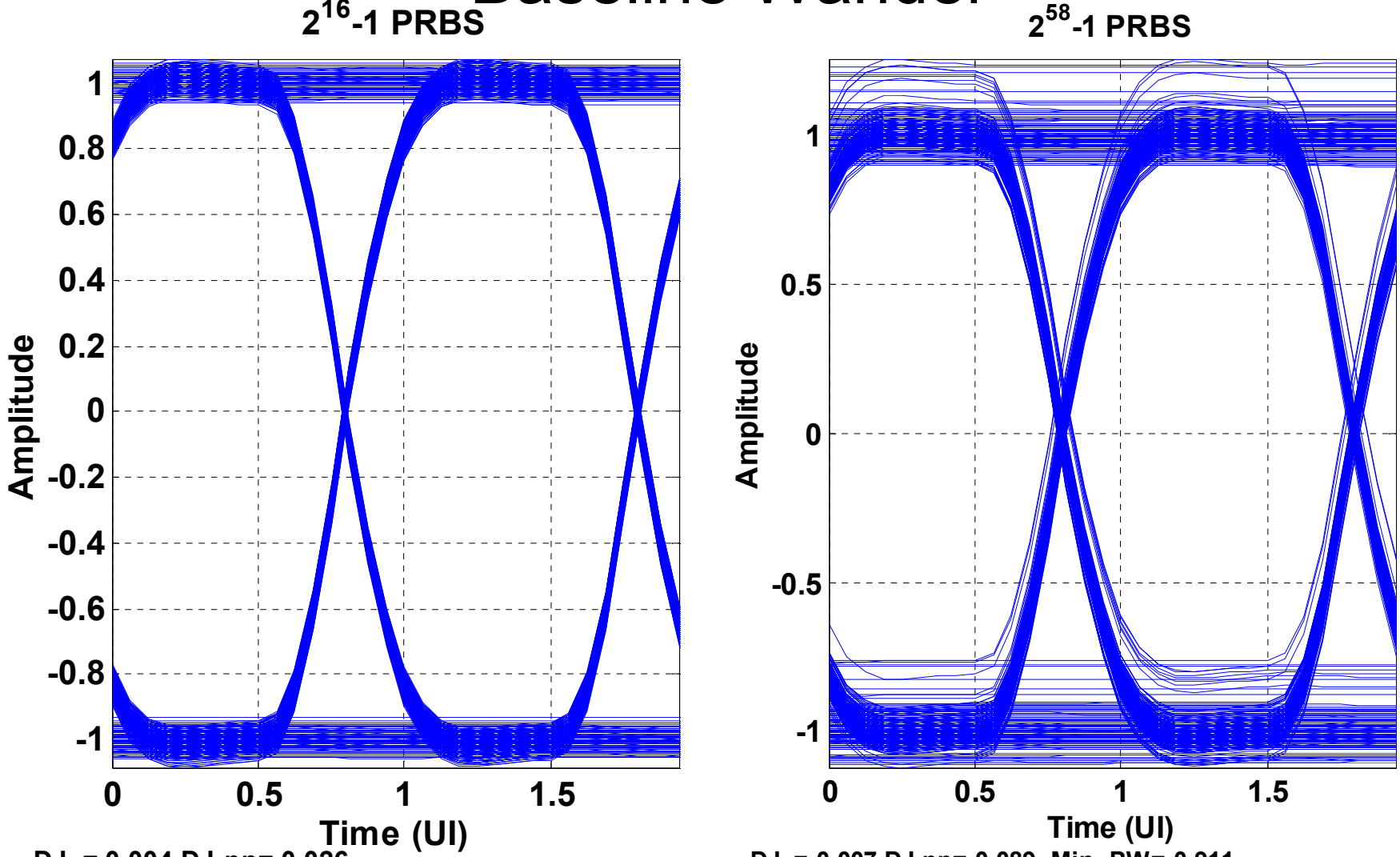
- Random data = delta function
- Full PRBS closely approximates random data
- Partial PRBS more correlated than random data

Power Spectral Density



- Increased low frequency content in partial PRBS pattern
- Tones due to correlation in sequence

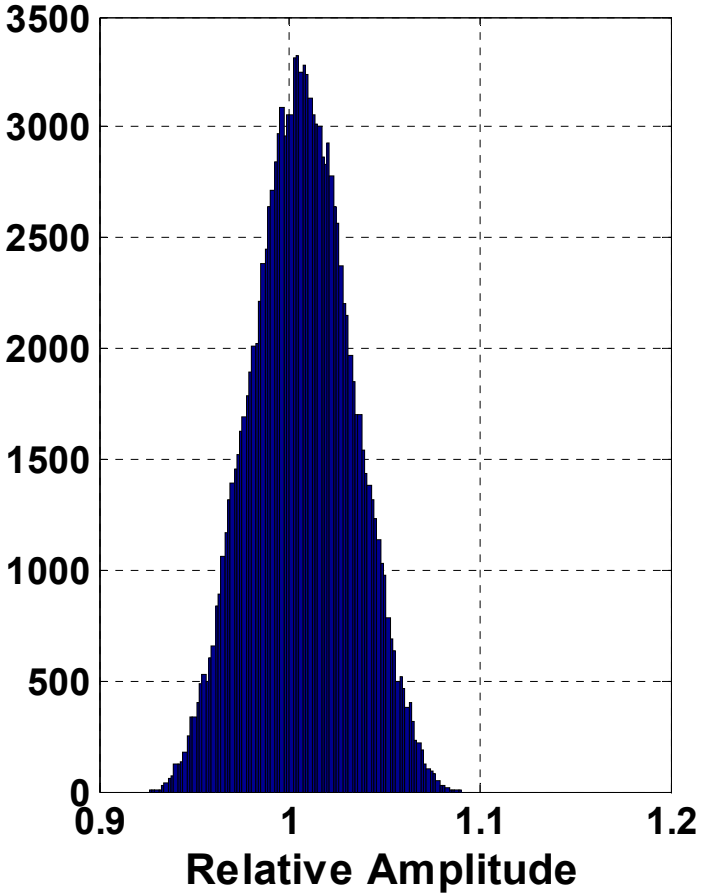
Baseline Wander

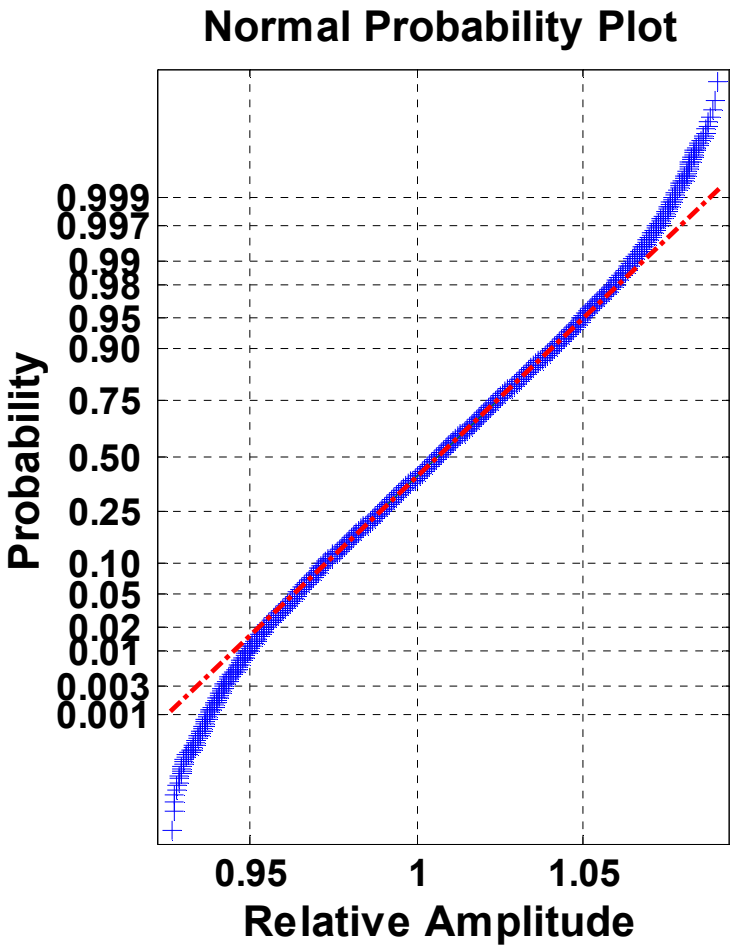


DJ_σ= 0.004,DJ-pp= 0.026
Total ISI= -0.33 dB, Penalty= -0.03 dB, BLW_σ= 0.02442

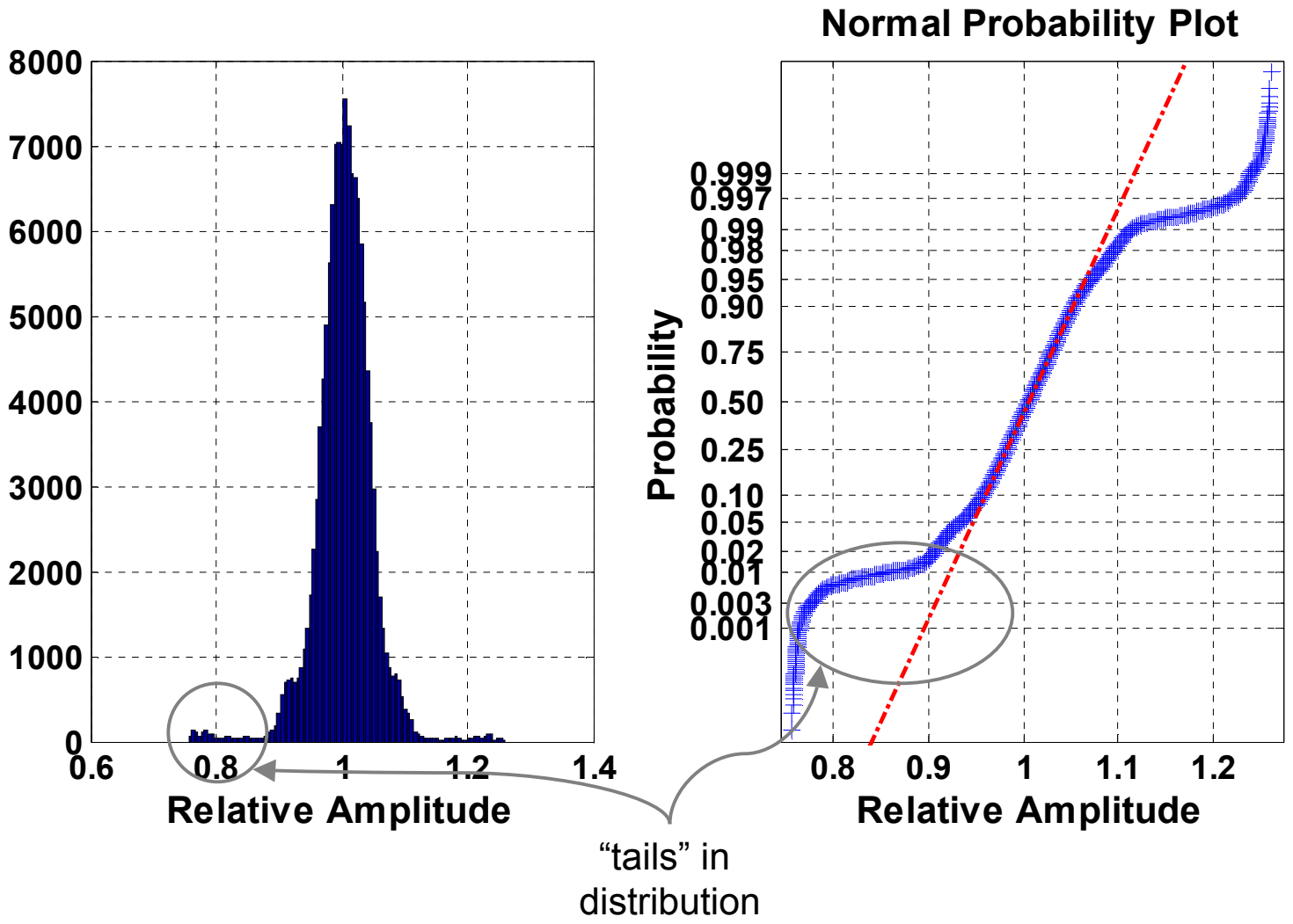
DJ_σ= 0.007,DJ-pp= 0.089, Min. PW= 0.911
Total ISI= -0.88 dB, Penalty= -0.62 dB, BLW_σ= 0.04551

|Amplitude| Histogram (2^{16}–1 PRBS)

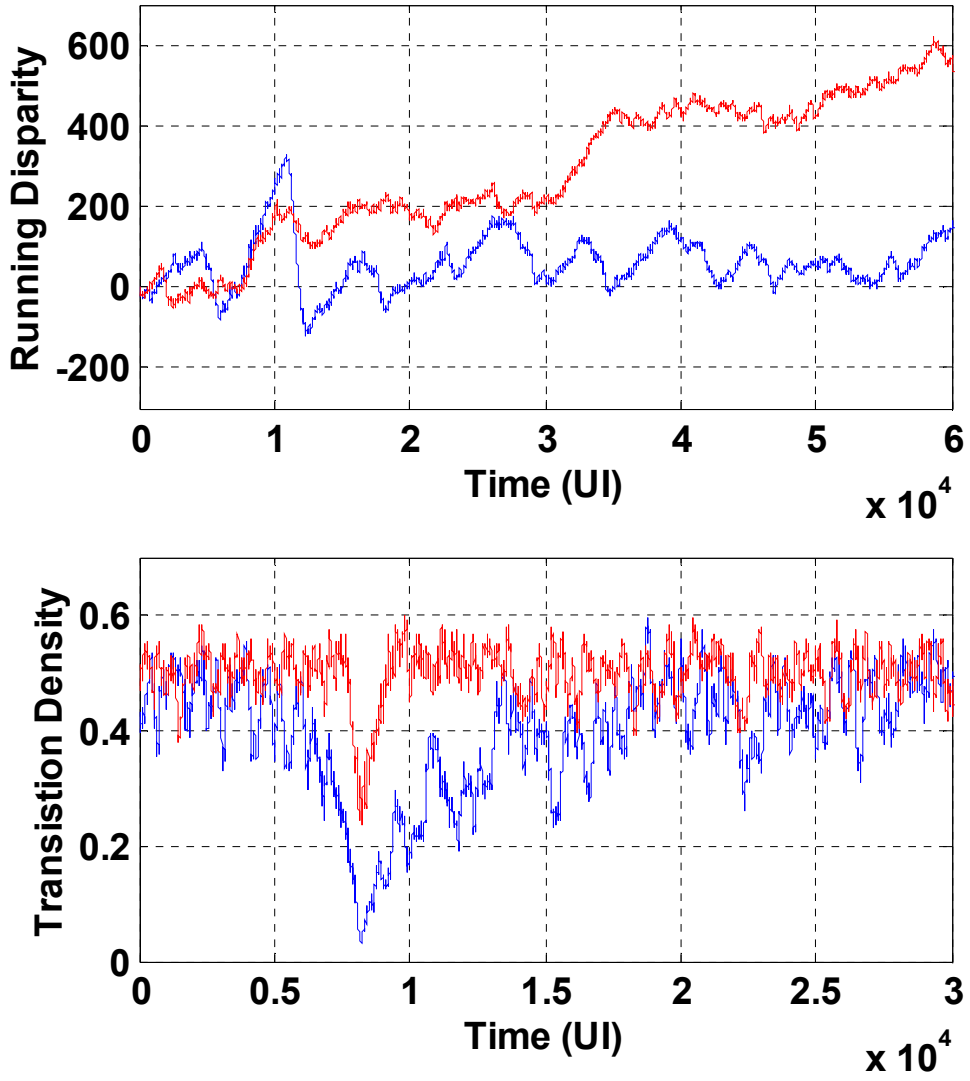




|Amplitude| Histogram (2^{58}–1 PRBS)

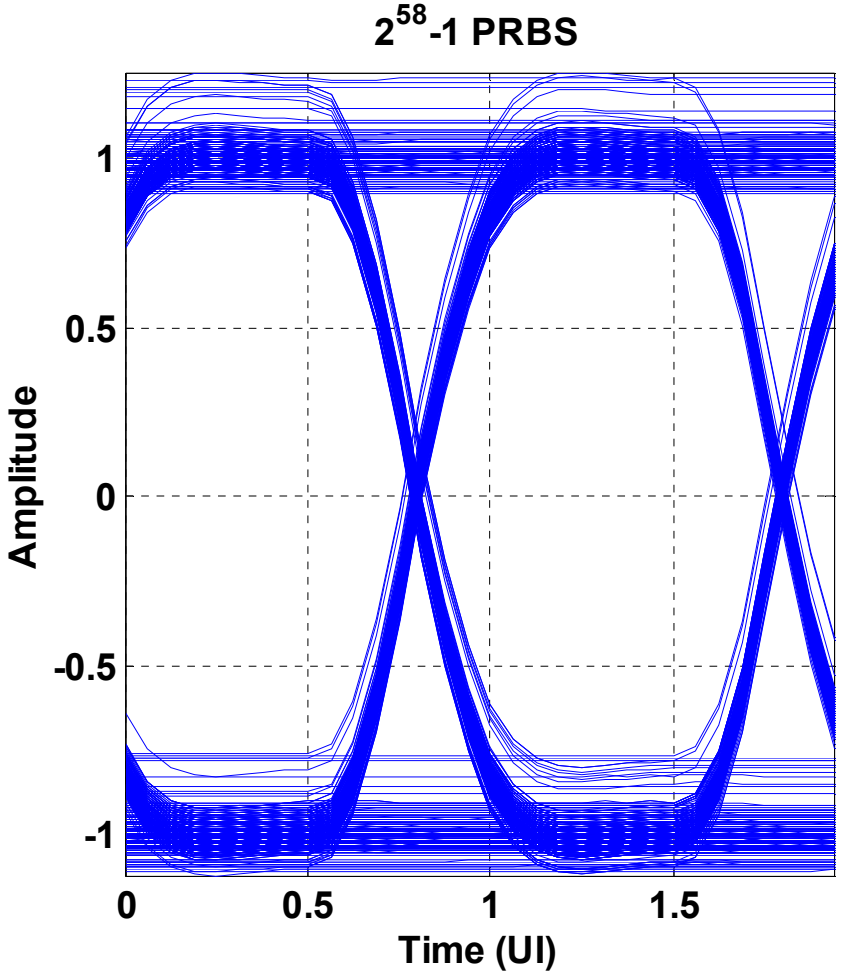


Alternate 2^{58}–1 PRBS Segments

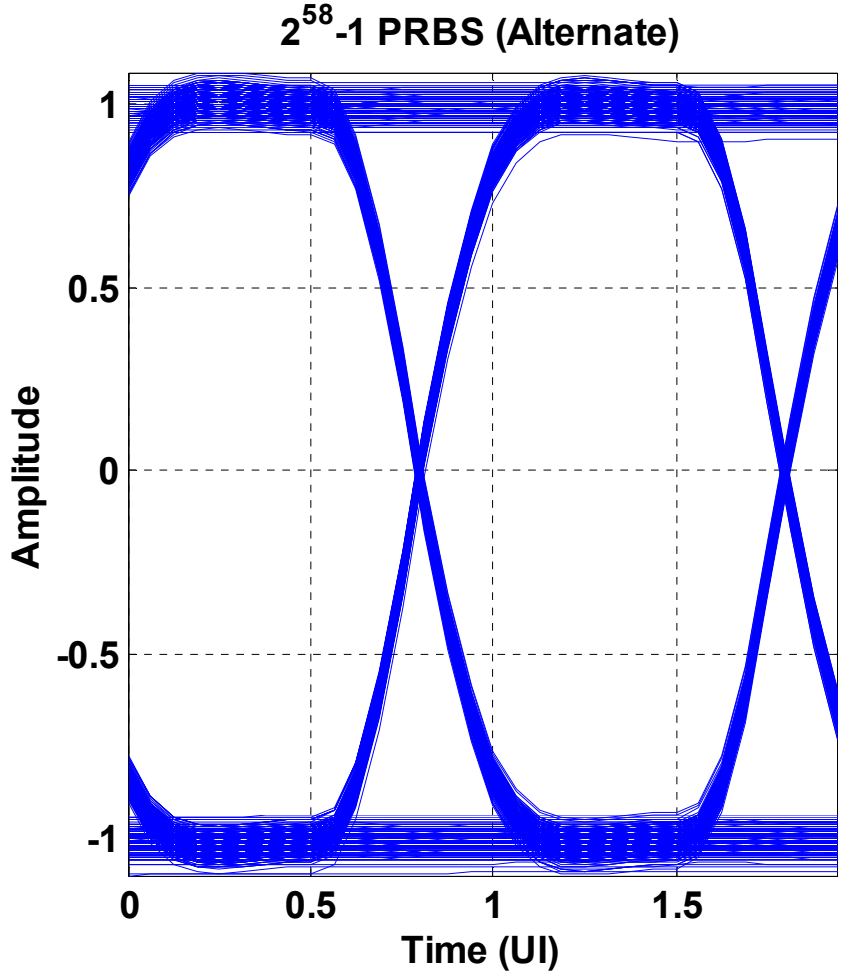


- "2^{58}–1 PRBS":
  - 2^{16} bits long (« one cycle)
  - $1 + x^{39} + x^{58}$
  - Seed chosen for run-length of 58 ~8kb from pattern start
- "2^{58}–1 Alternate"
  - 2^{16} bits long (« one cycle)
  - $1 + x^{39} + x^{58}$
  - Seed chosen for run-length of 50 ~8kb from pattern start

Baseline Wander

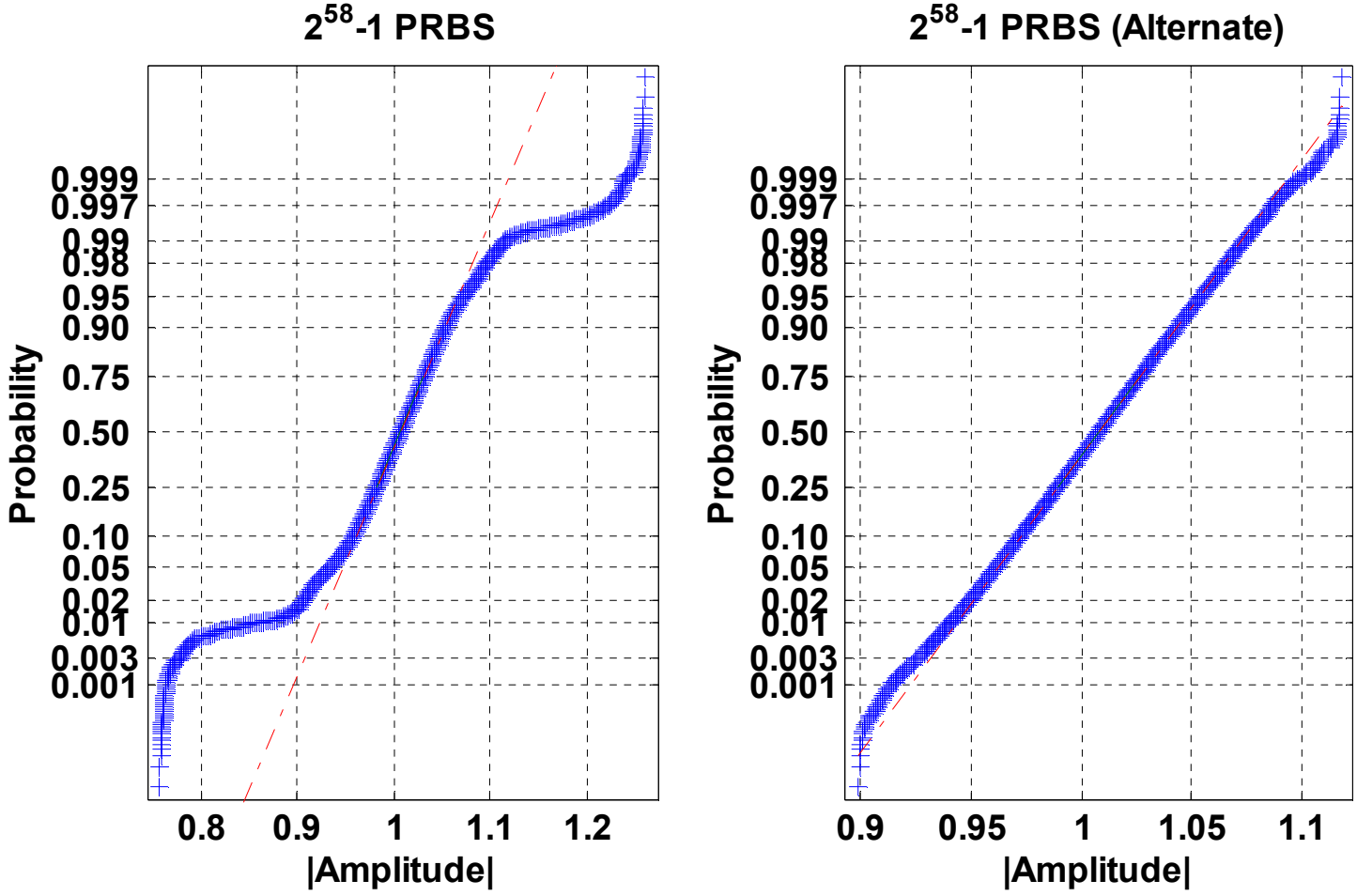


DJ_σ= 0.007,DJ-pp = 0.089, Min. PW = 0.911
Total ISI = -0.88 dB, Penalty = -0.62 dB
BLW_σ = 0.0455, BLWpp = 0.365

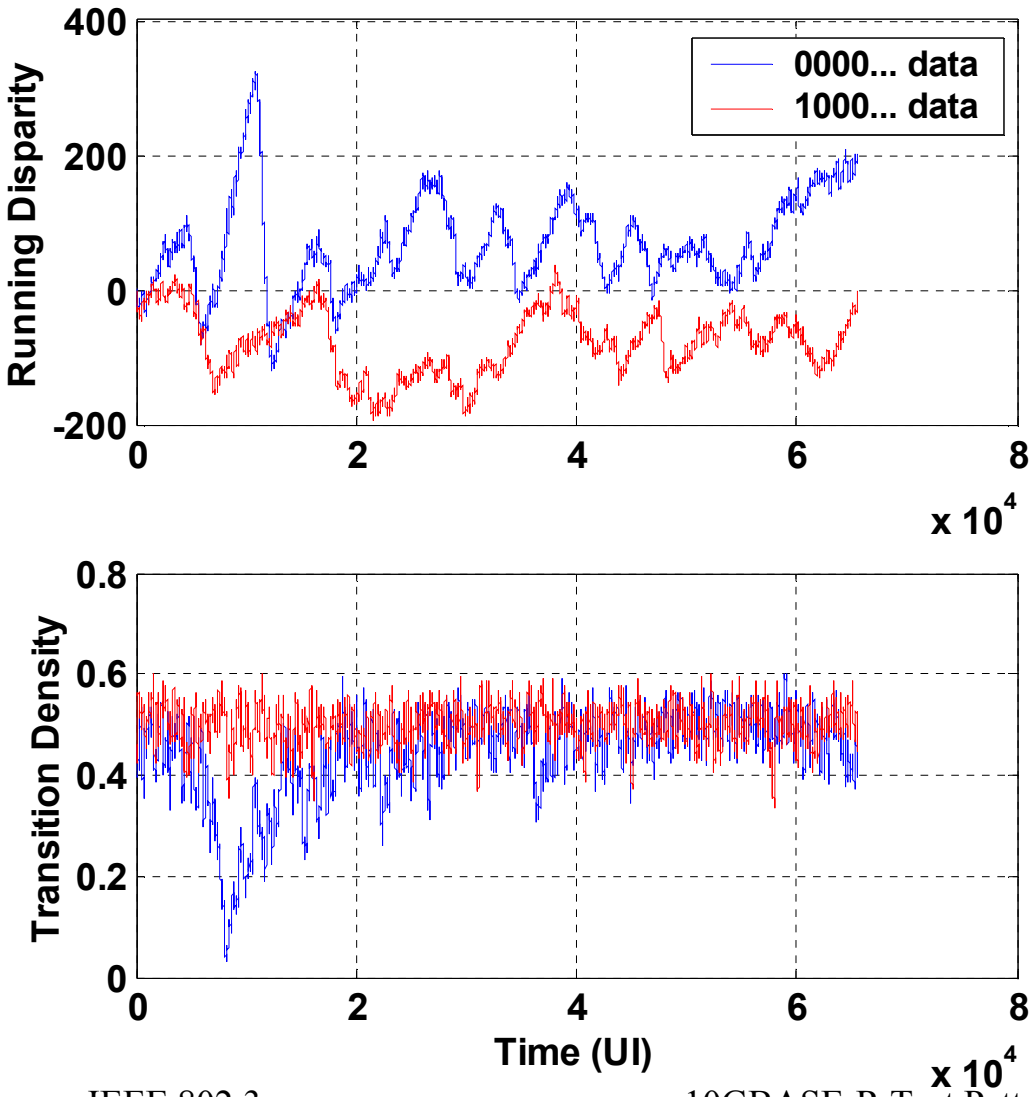


DJ_σ= 0.005,DJ-pp = 0.036, Min. PW = 0.964
Total ISI = -0.39 dB, Penalty = -0.05 dB
BLW_σ = 0.0255, BLWpp = 0.17

Baseline Wander



Alternate “Data” Inputs



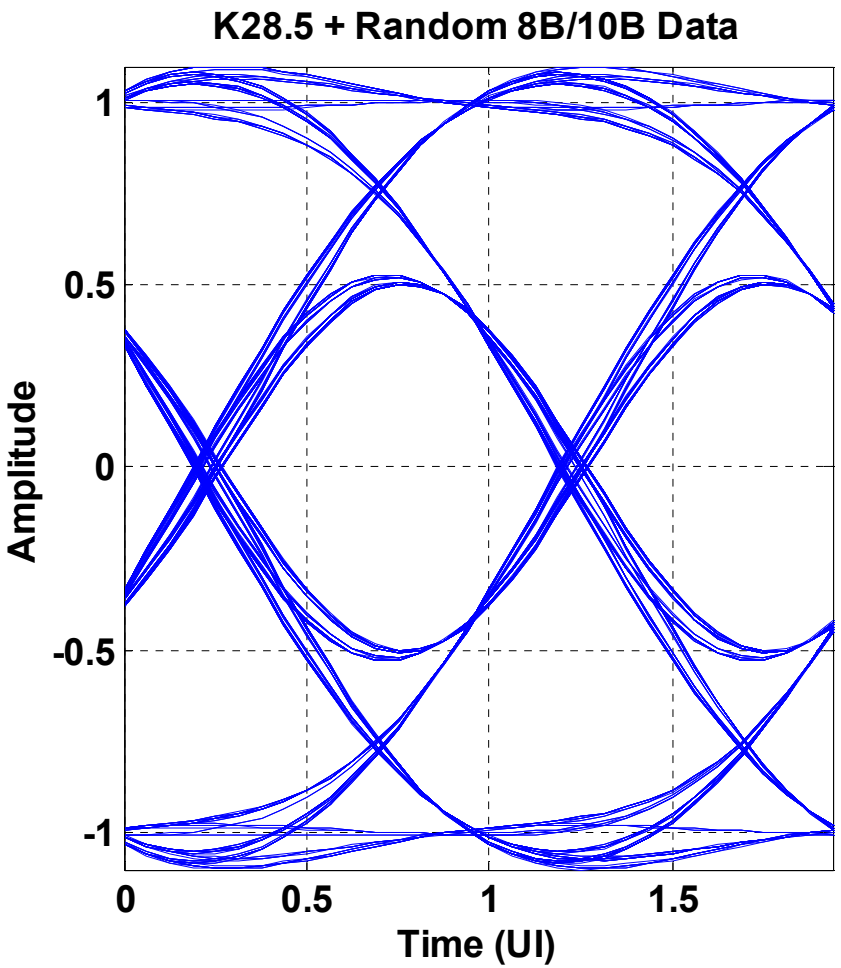
- “0000… data”
  - Seed chosen for max run-length ~8kb from pattern start
  - Data input to scrambler all zeros
- “1000… data”
  - Seed chosen for max run-length
  - Data input to scrambler = 1 + 63 zeros
  - 64-bit data pattern repeats

Summary

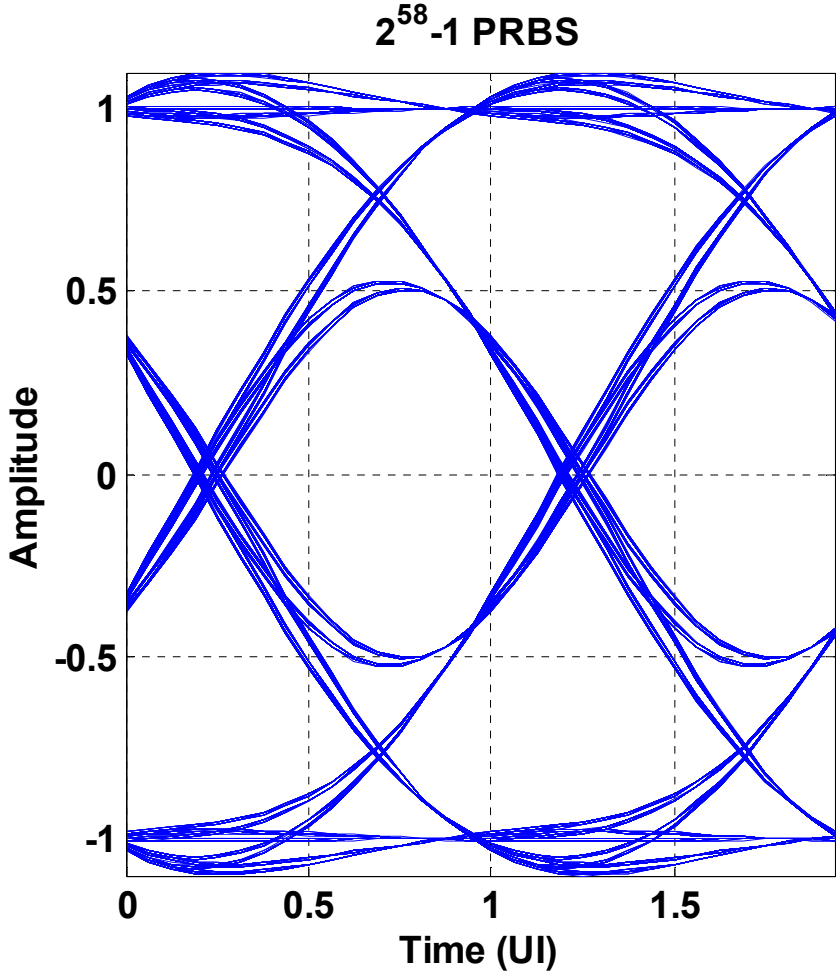
- Use existing scrambler / descrambler to generate and check test patterns
- Wide variety of pattern characteristics available
  - Select long PRBS segments using short seed values
- Pattern can be set via management registers
  - New patterns can be defined in the future without modifying hardware
- Cost: increased complexity in the pattern checker

Backup Material

Stressed Eye

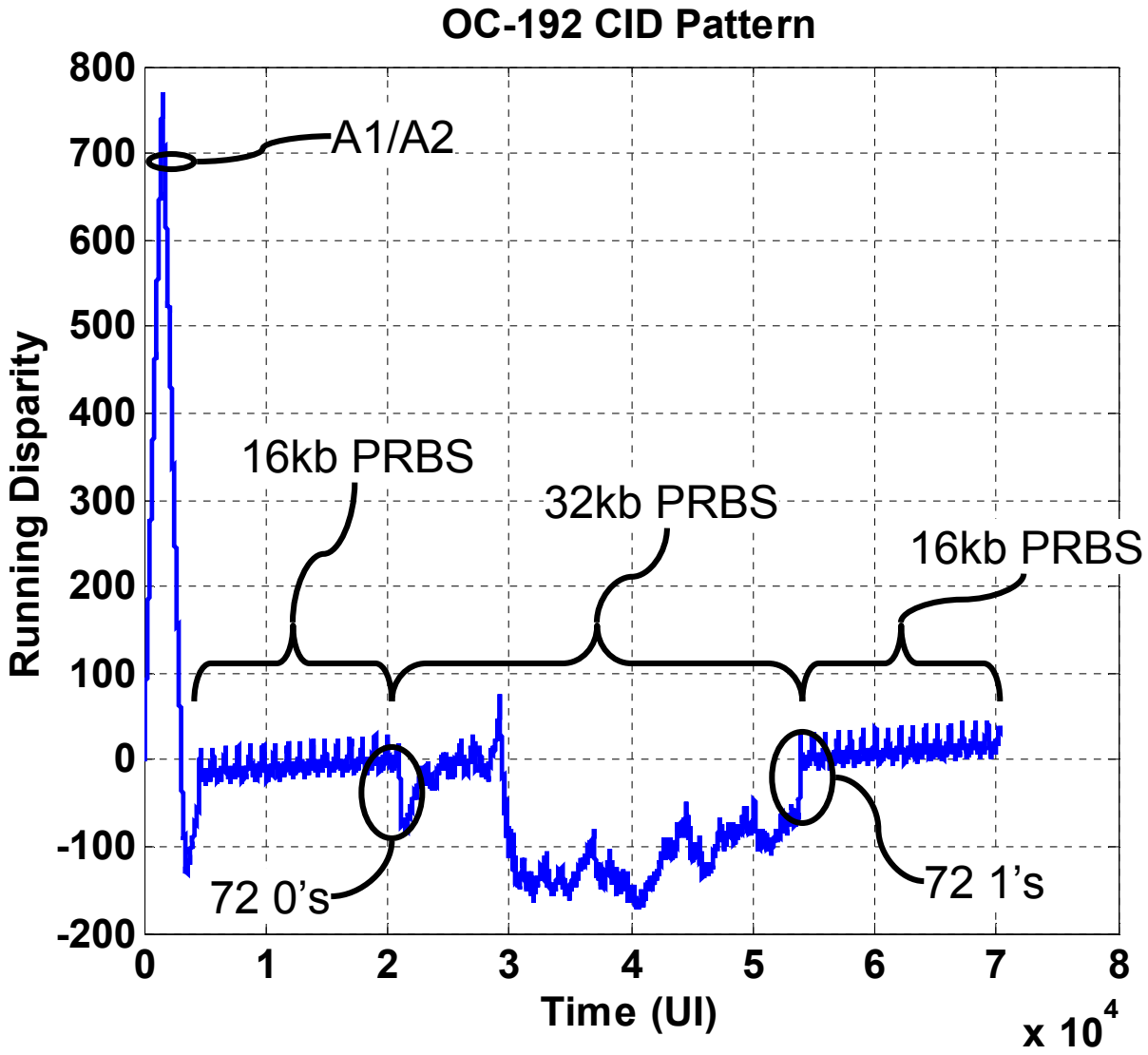


DJ_σ= 0.030,DJ-pp = 0.084, Min. PW = 0.986
Total ISI = 3.01 dB, Penalty = -2.84 dB



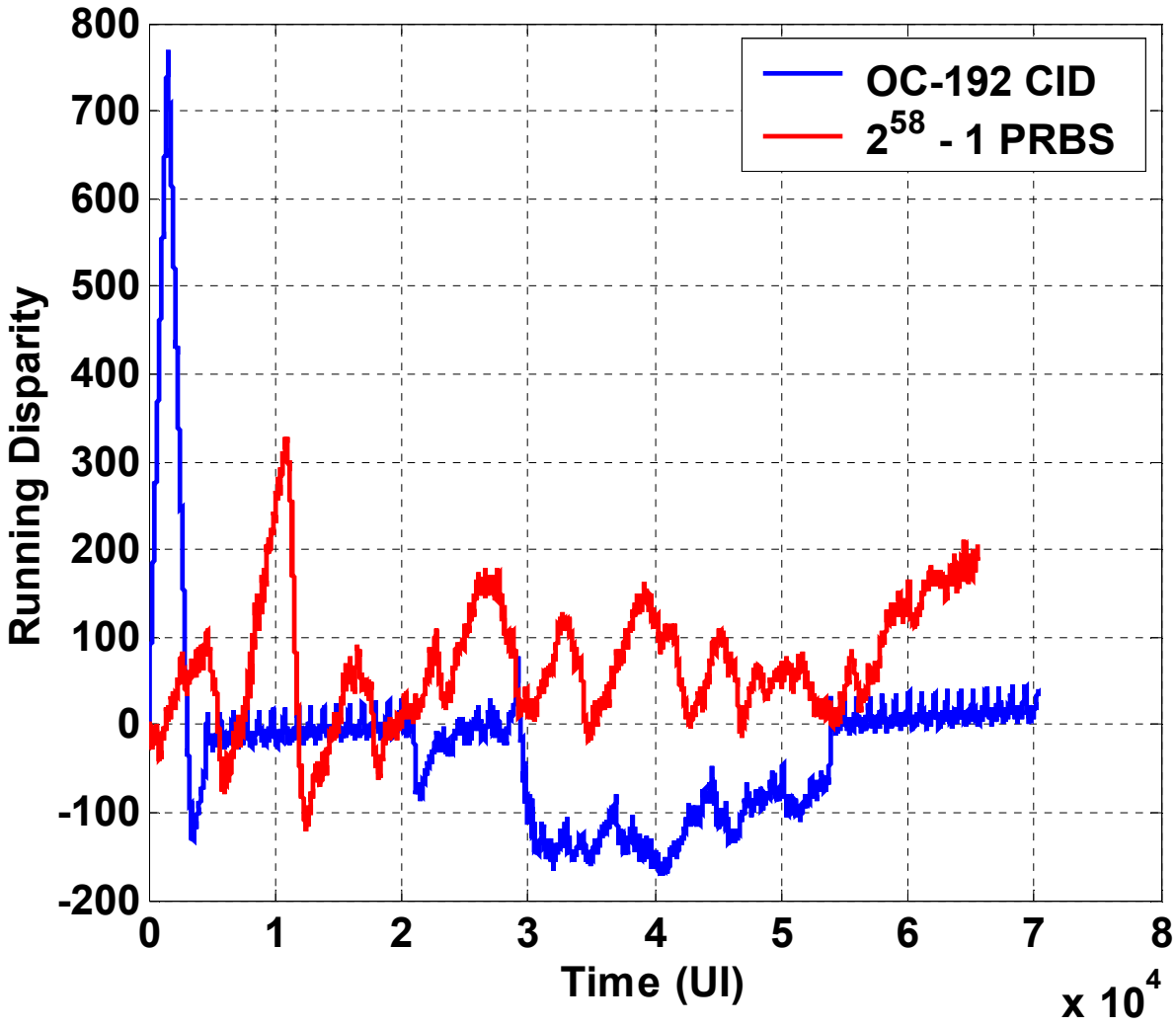
DJ_σ= 0.028,DJ-pp = 0.089, Min. PW = 0.981
Total ISI = -2.99 dB, Penalty = -2.76 dB

OC-192 “CID” Pattern

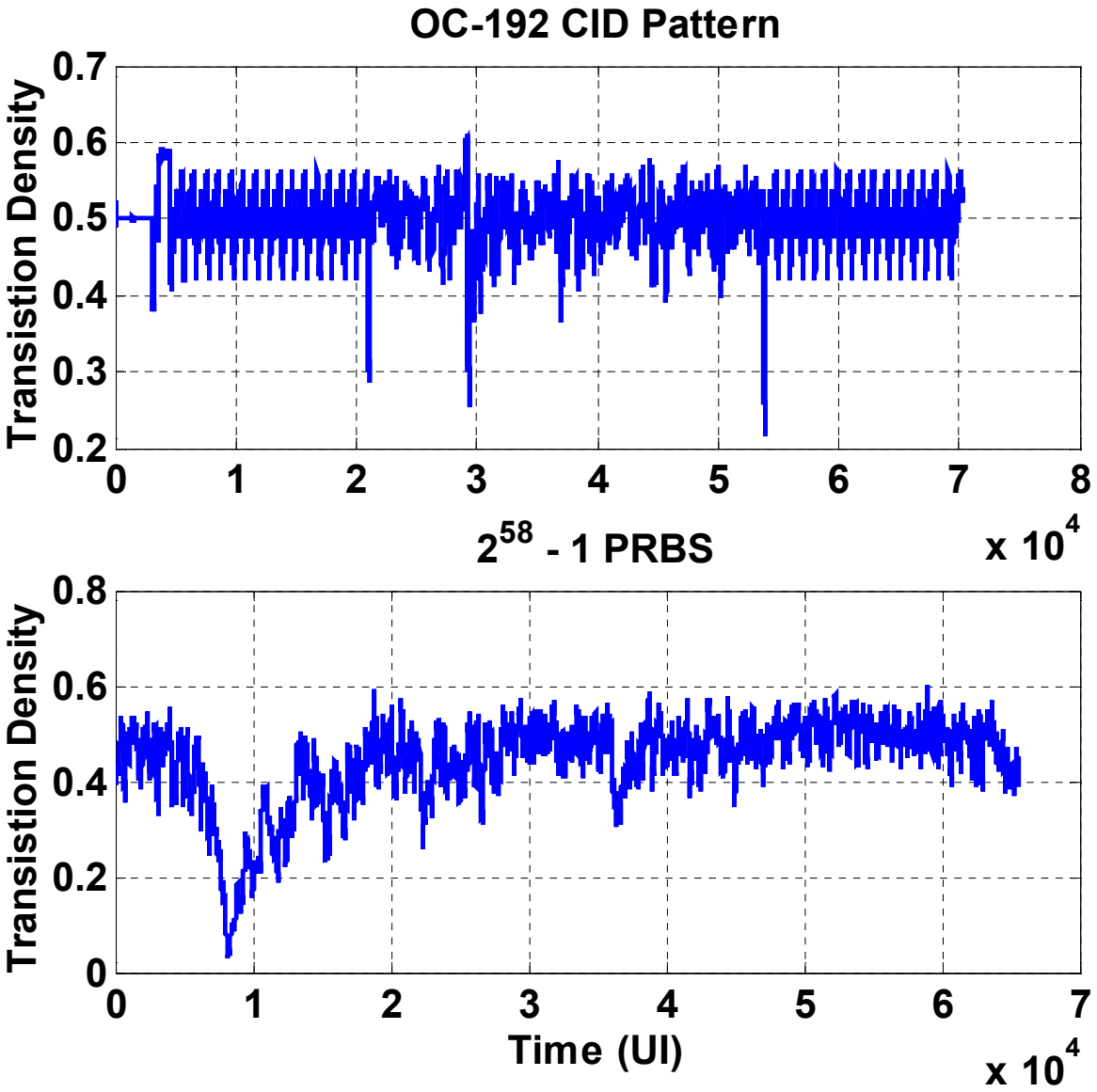


- 192 bytes A1
- 192 bytes A2
- 64 bytes C1
- 128 bytes of “stuff” (return disparity to 0 with 50% transition density)
- 16kb PRBS ($x^{10}+ x^{7}+1$)
- 72 zeros
- 32kb PRBS ($x^{15}+ x^{14}+1$)
- 72 ones
- 16kb PRBS ($x^{10}+ x^{7}+1$)

Running Disparity

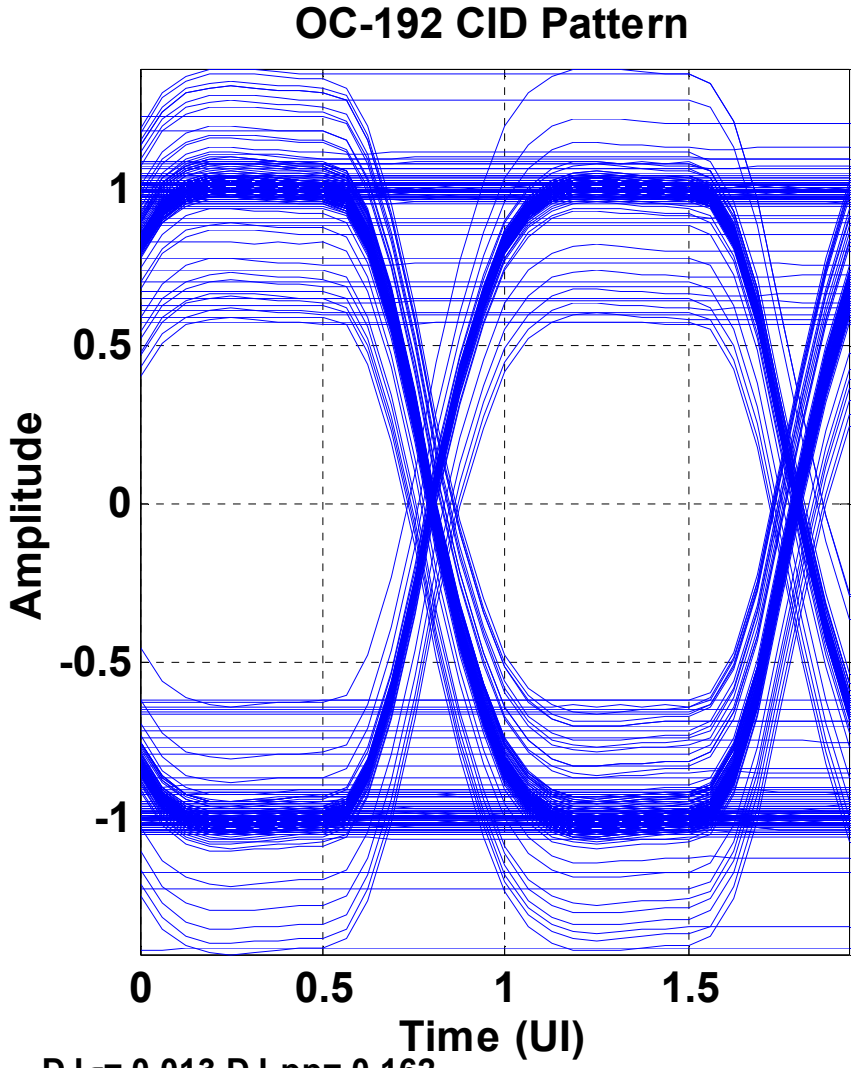


Transition Density

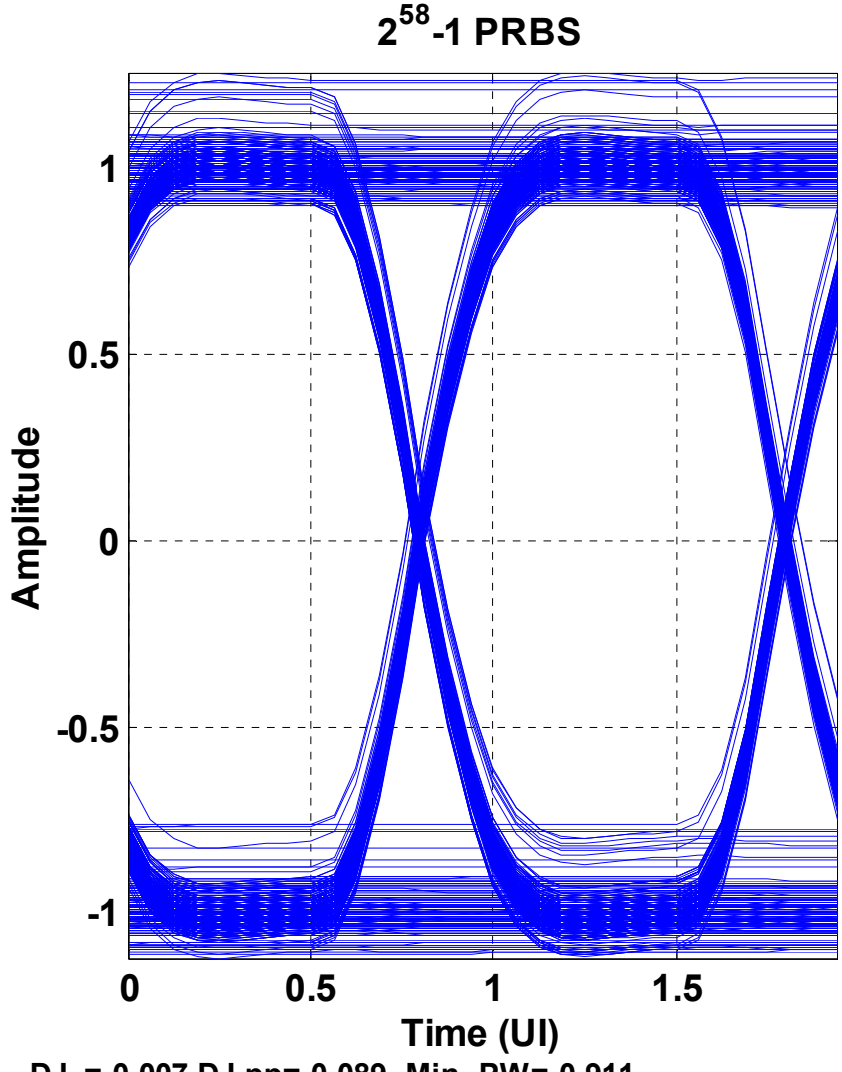


- Transition density averaged over 200 UI
- OC-192 CID
  - 72 UI max run-length
  - 50% average density
  - 21% minimum density
- $2^{58}-1$
  - 58 UI max run-length
  - 44% average density
  - 3% minimum density

Baseline Wander



DJσ= 0.013,DJ-pp= 0.162
Total ISI= -2.25 dB, Penalty= -1.76 dB, BLWσ= 0.06953



DJσ= 0.007,DJ-pp= 0.089, Min. PW= 0.911
Total ISI= -0.88 dB, Penalty= -0.62 dB, BLWσ= 0.04551

Baseline Wander (OC-192 CID)