# DFE error propagation on FEC for 1000Base-T1

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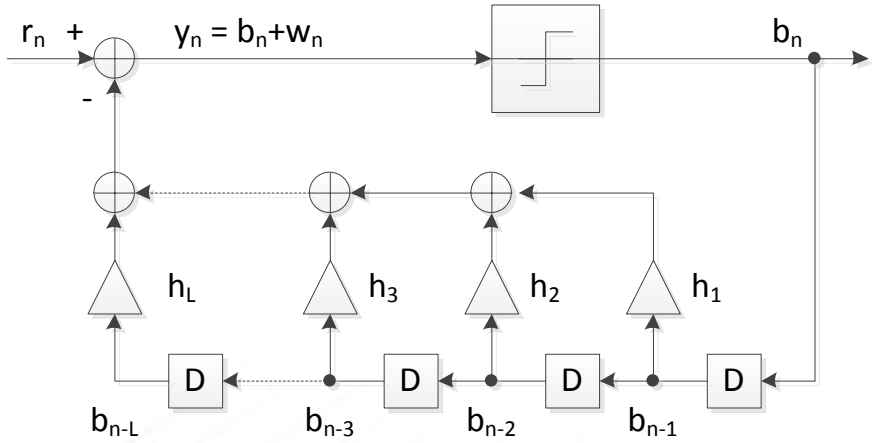
# Outline

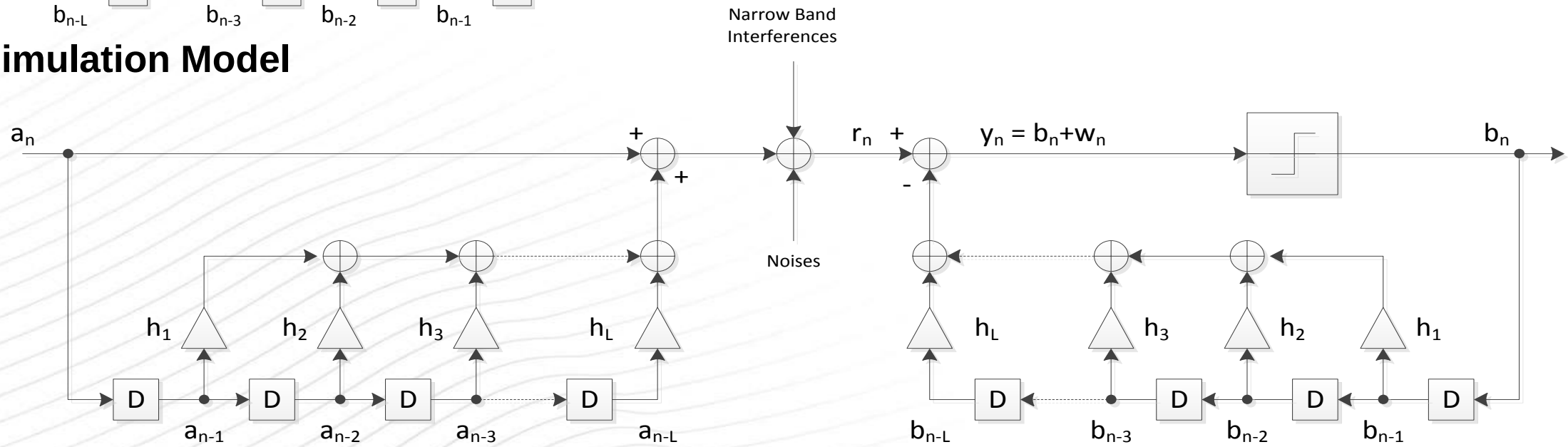
- Decision feedback equalizer (DFE) description and simulation model
- Methods to mitigate error propagation by DFE
- Burst noise after DFE error propagation
- Narrowband interference (NBI) performance after DFE error propagation
- Conclusion

# DFE description and simulation model

- **Decision feedback equalizer (DFE)**




- **Simulation Model**

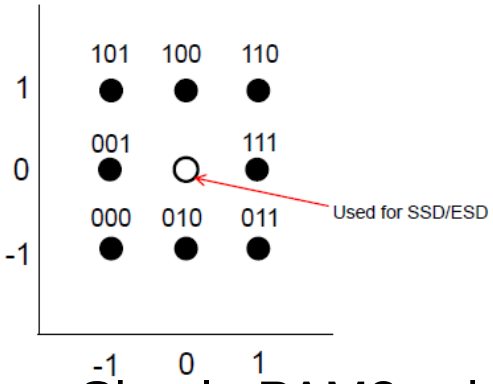


# Two proposed methods

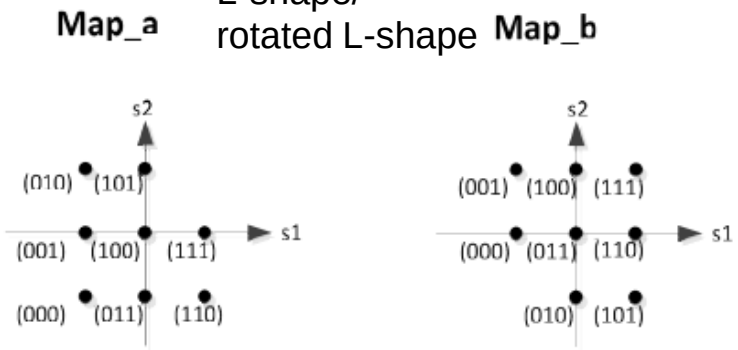
| Scheme | Constellation symbol | 2D-PAM3 Constellation | Bit per PAM symbol | RS code symbol size | FEC code rate | Information bits/ PAM symbol | Baud rate (MHz) | FEC correction | Maximal correctable erasure duration |
|---|---|---|---|---|---|---|---|---|---|
| **Simple PAM3*** | 2D-PAM3 | Donut-like | 1.5 | 9 (3 2D-PAM3) | 8/9 | 1.33 | 750 | 20 | 320ns |
| **PAM2-PAM3**** | PAM2, 2D-PAM3 | L shape/ rotated L-shape | 1.43 | 10 (1 PAM2+3 2D-PAM3) | 93% | 1.33 | 750 | 11 | 214ns |

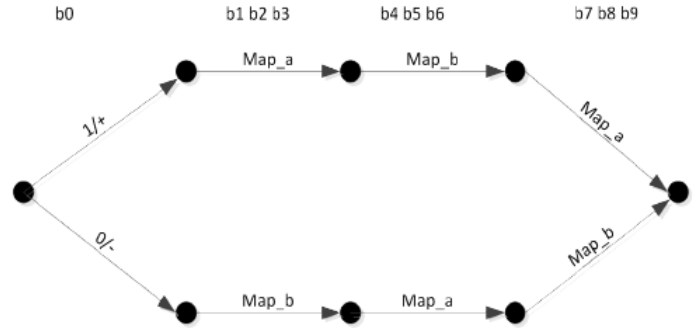
*shen_3bp_02_0314.pdf, ** xiaofeng_2bp_02_0314-1.pdf

Donut-like




L-shape/
rotated L-shape




PAM2 depended Mapping for PAM2-PAM3

- Simple PAM3 scheme: uses additional FEC power to mitigate error propagation
- PAM2-PAM3 scheme: uses additional Euclidean distance to mitigate error propagation

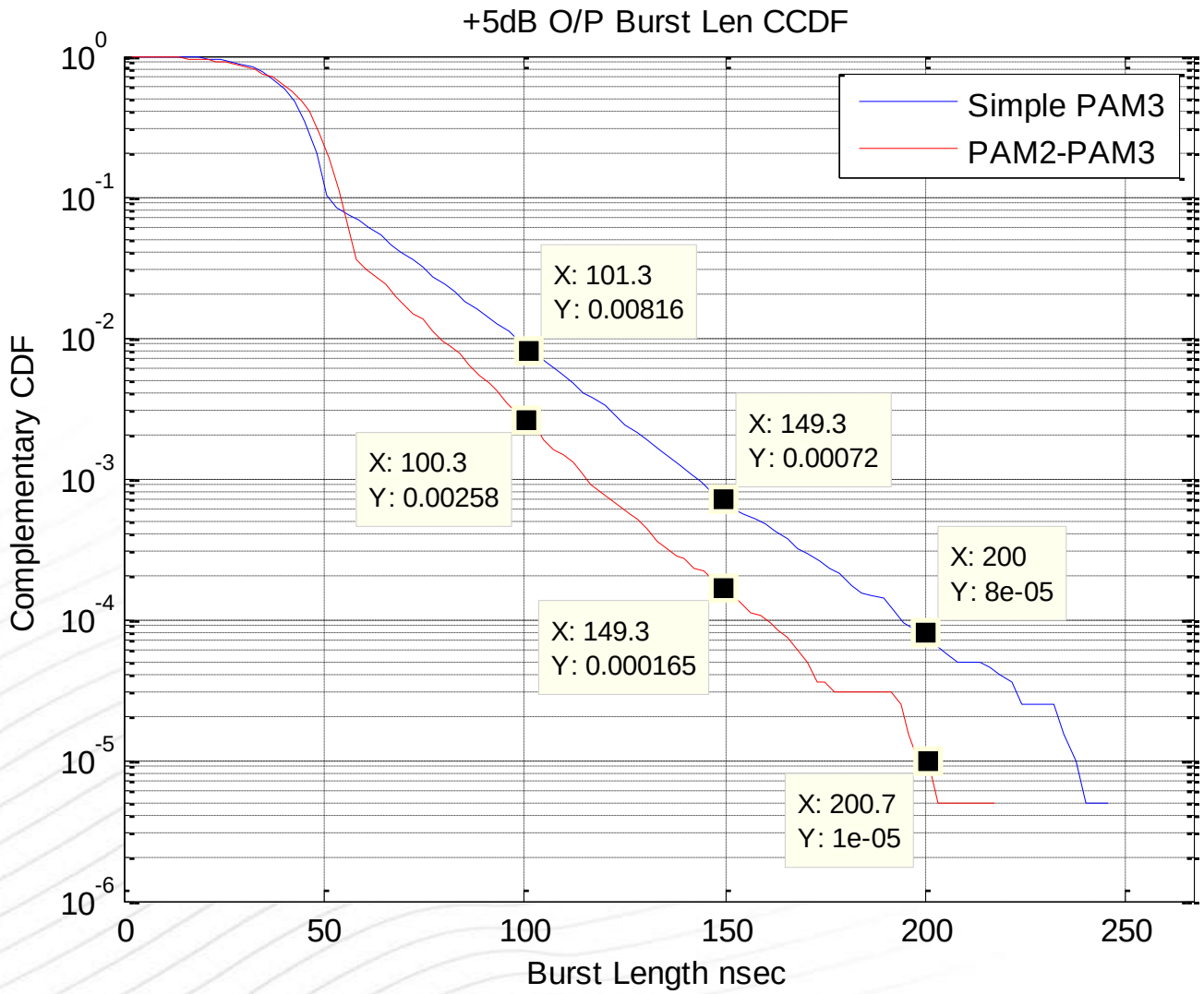
# RS code examples considered

- Codeword size in bit: 3240
- Simple PAM3 scheme:
  - Rate 8/9 (360,320,t=20) 9-bit RS (or equivalent interleaved ones)
  - Average bit per PAM symbol: 1.33 b/s
- PAM2-PAM3 scheme:
  - Rate 93% (324,301,t=11) 10-bit RS (or equivalent interleaved ones)
  - Average bit per PAM symbol: 1.33 b/s
    - Need higher rate code to compensate bits per PAM symbol loss

# Burst noise after DFE error propagation

- Input burst length = 50nsec
- Modeling burst noises:
  - Modeled as AWGN noises @ SNR= -10dB, -5dB, 0dB, and +5dB
  - No other noises
- Output burst length measured in nsec
- Simulated with DFE from 3 channel models
  - 2m IEEE UTP
  - 15m IEEE UTP
  - 10m measured UTP
- Simulated number of blocks in all cases: 200,000

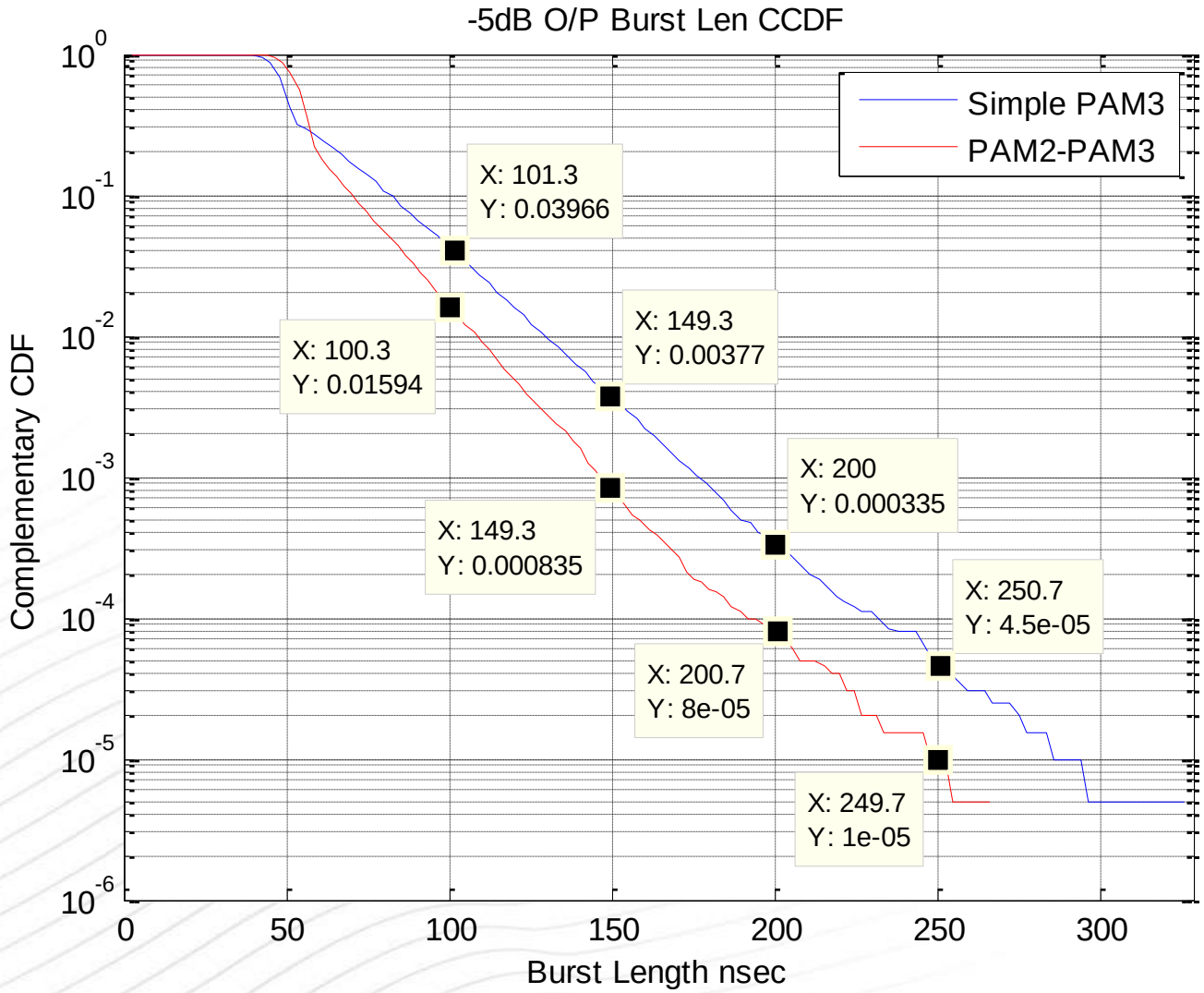
# Measured 10m UTP DFE SNR=+5dB




Simple PAM3 has strong burst correction capability

PAM2-PAM3 has smaller propagation but less burst correction capability

# Measured 10m UTP DFE SNR=-5dB



# Measured 10m UTP DFE summary

| Simple PAM3: 2D PAM3 | | | | |
|---|---|---|---|---|
| SNR | Max o/p burst len | Avg o/p burst len | Pr(LEN>=100nsec) | Pr(LEN>=150nsec) |
| 5 dB | 248 nsec | 43 nsec | 8.2e-3 | 7.2e-4 |
| 0 dB | 336 nsec | 54 nsec | 2.4e-2 | 2.2e-3 |
| -5 dB | 328 nsec | 58 nsec | 4.0e-2 | 3.8e-3 |
| -10 dB | 371 nsec | 61 nsec | 5.0e-2 | 5.0e-3 |

| PAM2-PAM3: PAM2 + 3x(2D PAM3) | | | | |
|---|---|---|---|---|
| SNR | Max o/p burst len | Avg o/p burst len | Pr(LEN>=100nsec) | Pr(LEN>=150nsec) |
| 5 dB | 219 nsec | 43 nsec | 2.6e-3 | 1.7e-4 |
| 0 dB | 243 nsec | 54 nsec | 9.7e-3 | 4.8e-4 |
| -5 dB | 268 nsec | 58 nsec | 1.6e-2 | 8.4e-4 |
| -10 dB | 334 nsec | 60 nsec | 2.0e-2 | 1.2e-3 |

# IEEE 2m UTP DFE summary

| Simple PAM3: 2D PAM3 | | | | |
|---|---|---|---|---|
| SNR | Max o/p burst len | Avg o/p burst len | Pr(LEN>=100nsec) | Pr(LEN>=150nsec) |
| 5 dB | 189 nsec | 41 nsec | 7.7e-4 | 4.5e-5 |
| 0 dB | 168 nsec | 50 nsec | 3.4e-3 | 6.0e-5 |
| -5 dB | 211 nsec | 54 nsec | 5.5e-3 | 1.2e-4 |
| -10 dB | 213 nsec | 55 nsec | 7.2e-3 | 1.5e-4 |

| PAM2-PAM3: PAM2 + 3x(2D PAM3) | | | | |
|---|---|---|---|---|
| SNR | Max o/p burst len | Avg o/p burst len | Pr(LEN>=100nsec) | Pr(LEN>=150nsec) |
| 5 dB | 117 nsec | 42 nsec | 7.0e-5 | -- |
| 0 dB | 145 nsec | 52 nsec | 3.5e-4 | -- |
| -5 dB | 133 nsec | 56 nsec | 5.9e-4 | -- |
| -10 dB | 166 nsec | 58 nsec | 8.9e-4 | 5.0e-6 |

# IEEE 15m UTP DFE summary

| Simple PAM3: 2D PAM3 | | | | |
|---|---|---|---|---|
| SNR | Max o/p burst len | Avg o/p burst len | Pr(LEN>=100nsec) | Pr(LEN>=150nsec) |
| 5 dB | 237 nsec | 42 nsec | 2.5e-3 | 1.6e-4 |
| 0 dB | 296 nsec | 51 nsec | 7.8e-3 | 3.5e-4 |
| -5 dB | 256 nsec | 55 nsec | 1.3e-2 | 5.1e-4 |
| -10 dB | 264 nsec | 57 nsec | 1.7e-2 | 6.4e-4 |

| PAM2-PAM3: PAM2 + 3x(2D PAM3) | | | | |
|---|---|---|---|---|
| SNR | Max o/p burst len | Avg o/p burst len | Pr(LEN>=100nsec) | Pr(LEN>=150nsec) |
| 5 dB | 142 nsec | 42 nsec | 4.1e-4 | -- |
| 0 dB | 161 nsec | 53 nsec | 1.6e-3 | 1.0e-5 |
| -5 dB | 229 nsec | 57 nsec | 3.1e-3 | 2.0e-5 |
| -10 dB | 194 nsec | 58 nsec | 4.2e-3 | 4.5e-5 |

# Comparison of burst noise correcting capability

- Based on known burst locations
  - Starting point and ending point
- Fact: RS code with minimum distance $d_{min}$ can correct $d_{min}$-1 erasure

- Testing results after 30,000,000 blocks ran

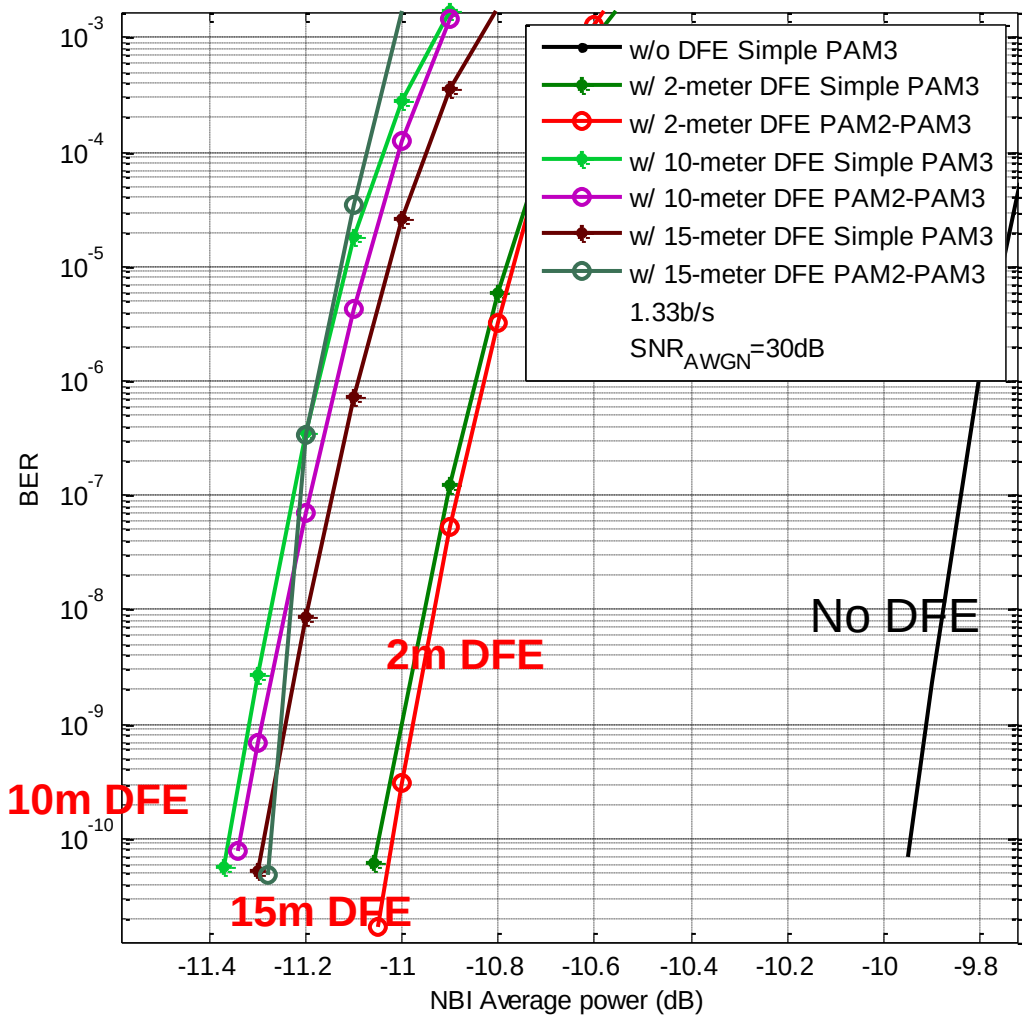
| Scheme | b/s | RS code | Maximal Erasure size | | | % Burst size after 10m DFE propagation > maximal erasure size | | |
|---|---|---|---|---|---|---|---|---|
| | | | RS symbols | PAM signals | Time Duration | 5dB | 0dB | -10dB |
| Simple PAM3 | 1.33 | 9-bit (360,320) | 40 | 120 (2-D) | 320ns | **2e-6** | **2e-6** | **2e-6** |
| PAM2-PAM3 | 1.33 | 10-bit (324,301) | 23 | 92 (combined) | 214ns | **5e-6** | **1.8e-5** | **3.6e-5** |

# Performance on DFE error propagation for NBI

- Simulation model

$$rx(k) = tx(k) + n_{AWGN}(\sigma_{AWGN}, k) + n_{NBI}(\sigma_{NBI}, k)$$

  - Fixed AWGN SNR = 30dB
  - Sweeping NBI average power $\sigma_{NBI}$
- Performances
  - Loss due to DFE error propagation
    - 1.4dB for 10m DFE @BER=1e-10
  - With DFE error propagation
    - Performance difference between two scheme is negligible



# Conclusion

- Simple PAM3 scheme is implementation friendly
- Almost the same NBI performance on DFE error propagation
- One order of magnitude better performance for burst noise than PAM2-PAM3 scheme
- We propose adopt Simple PAM3 scheme