Line Code and FEC Performance

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Line Codes Considered

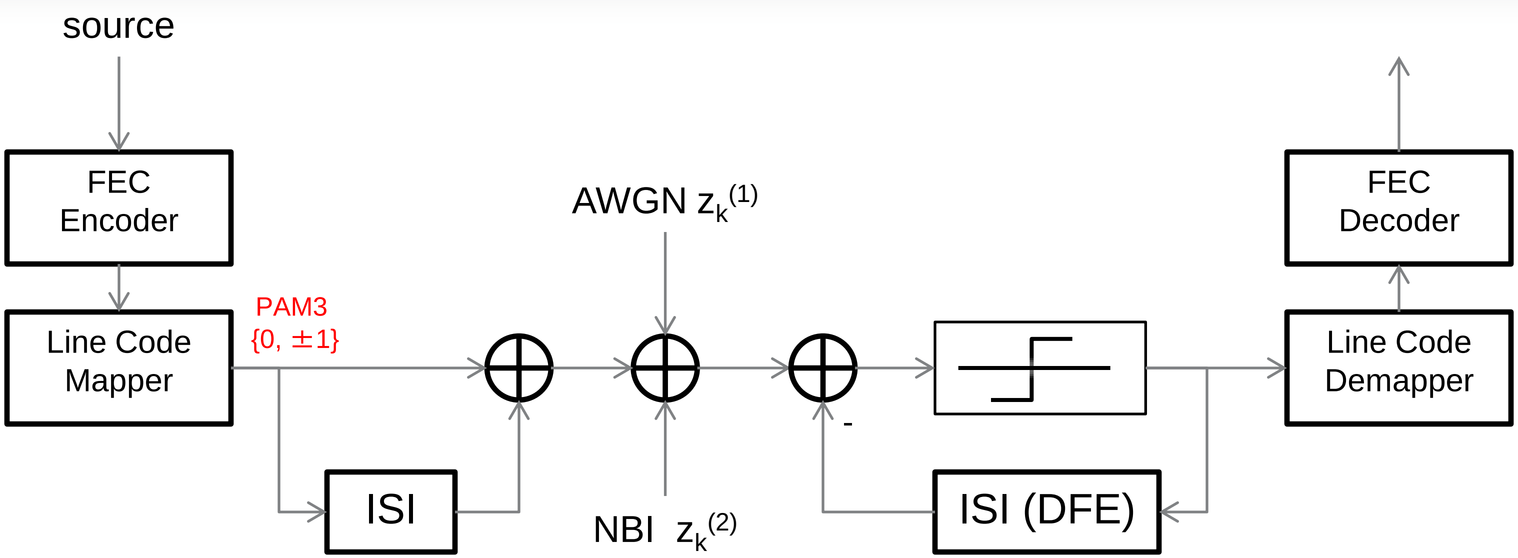
- **11B7T**
  - liu_3bp_01_0714.pdf, liu_3bp_01_0314.pdf
- **3B2T**
  - shen_3bp_01_0314.pdf
- **10B7T**
  - xiaofeng_3bp_02_0314.pdf

Coding Schemes

- Only RS codes are considered
- Comparison between codes with the similar FEC block size

Line Code	8N/(8N+1) Encoder	FEC	FEC N-K	FEC Block Size (ns)
11B7T	120/121	RS(360, 308, 2^{11})	52	3360
3B2T	80/81	RS(420, 378, 2^{9})	42	3360
10B7T	112/113	RS(360, 339, 2^{10})	21	3360

Simulation Setup

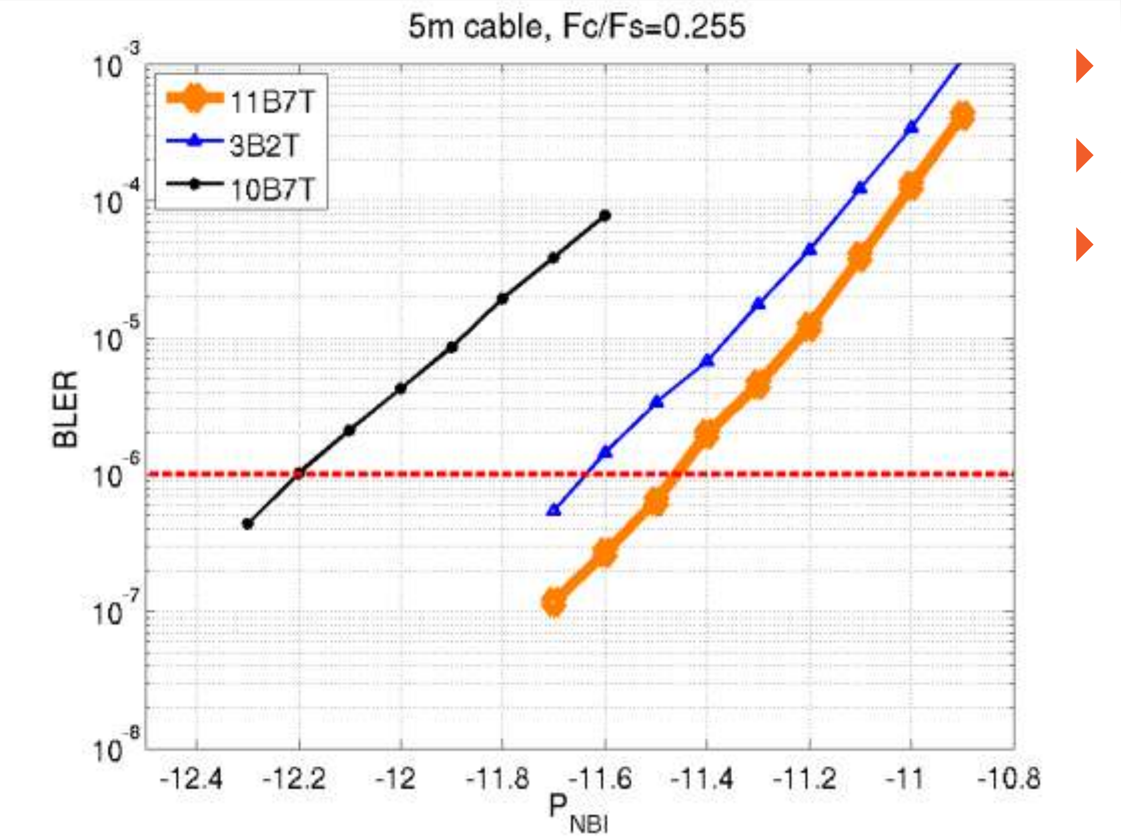


- DFE only equalizer, completely cancel ISI
- AWGN $z_k^{(1)} \sim N(0, \sigma^2)$
  - *$P_{AWGN}=10\log_{10}(\sigma^2/(2/3))$ (dB)*
- NBI $z_k^{(2)}=A\cos(2\pi(F_c/F_s)k+p_0)$
  - *$P_{NBI}=10\log_{10}(A^2/2)$ (dB)*
  - *NBI phase p_0 is randomized every 1000 FEC blocks*

Simulation Setup

- Only invalid line code is considered as erasure in RS decoder.
  - Each erasure is counted as 0.5 error
- Block error rate (BLER) after FEC is compared for performance.
- Equalizer is not adaptive
  - No “notch filter” to suppress NBI
- Baud rate = 750MHz
- 1D slicer used

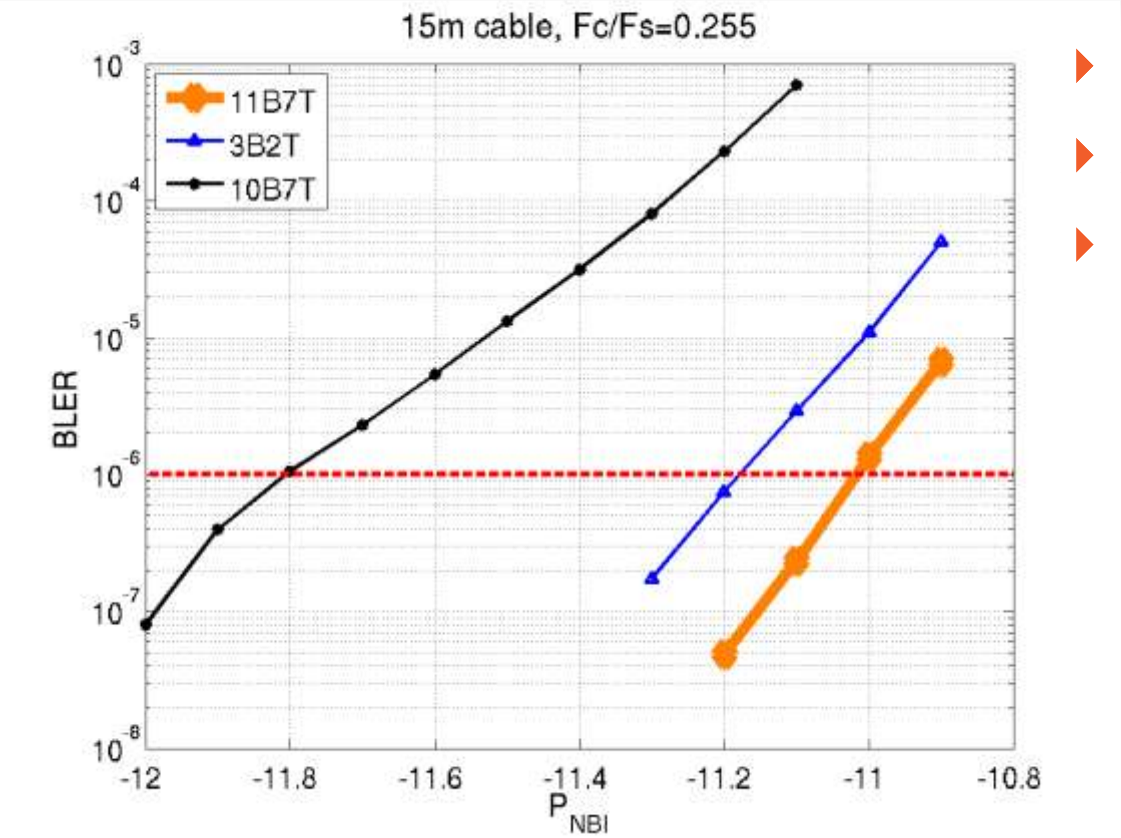
NBI Tolerance: 5m Cable



- DFE for 5m cable
- AWGN power = -26dB
- F_c = 191.25MHz

- 11B7T has the best performance
  - 0.7dB gain over 10B7T
  - 0.15dB gain over 3B2T

NBI Tolerance: 15m Cable



- DFE for 15m cable
- AWGN power = -26dB
- F_c = 191.25Mhz

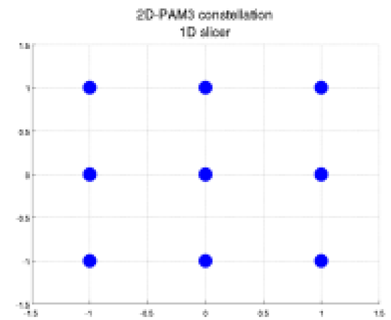
- 11B7T has the best performance
  - 0.8dB gain over 10B7T
  - 0.15dB gain over 3B2T

2-D Slicer

- Delay cancellation of 1st tap of DFE for each pair of received PAM3 symbols
- Decide two PAM3 symbols together
- 1-D Slicer:

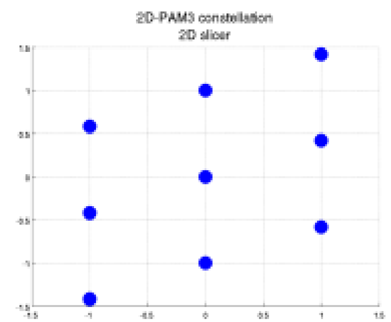
$$y_k = x_k + n_k$$
$$\hat{x}_k = \arg \min_{x \in \{0, \pm 1\}} C(y_k,\ x)$$

y: slicer input
x: TX symbol
$\hat{x}$: slicer output
n: noise
C: Cost function
w_0:1st DFE tap



- 2-D Slicer:

$$\begin{aligned} y_k &= x_k + n_k \\ y_{k+1} &= x_{k+1} + x_k * w_0 + n_{k+1} \\ \hat{x}_k, \hat{x}_{k+1} &= \arg \min_{x_{0,1} \in \{0, \pm 1\}^2} C[(y_k, y_{k+1}), (x_0, x_1)] \end{aligned}$$



2-D Slicer

- Pros
  - Reduce error propagation from 1st DFE tap
  - Cost function well defined for AWGN (Euclidian distance)
  - Can be applied to all line codes
- Cons
  - Increased complexity
  - For NBI noise, optimum cost function depends on frequency
  - If NBI noise treated as AWGN, negative performance gain may happen

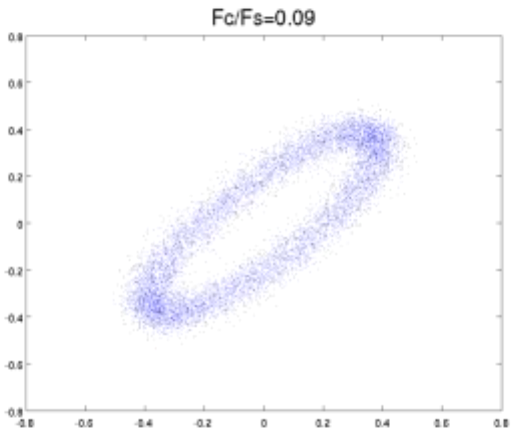
2-D Slicer for Different Line Codes

- 3B2T: 8 possible candidates for (x_0, x_1) in the slicer.
  - Maximum likelihood detector for each 2D-PAM3 symbol.
- 11B7T: 9 Possible candidates for (x_0, x_1) in the slicer
  - 7x 2-D slicer outputs are combined to 2x 7-D PAM3 symbols
  - Invalid 7-D PAM3 symbols can appear, but they only consist 6.7% of all possible 7-D symbols*
- 10B7T: 1x PAM2 slicer + 3x 2D-PAM3 slicer (L-shape)
  - Similar to 3B2T case
  - Not simulated due to time limit

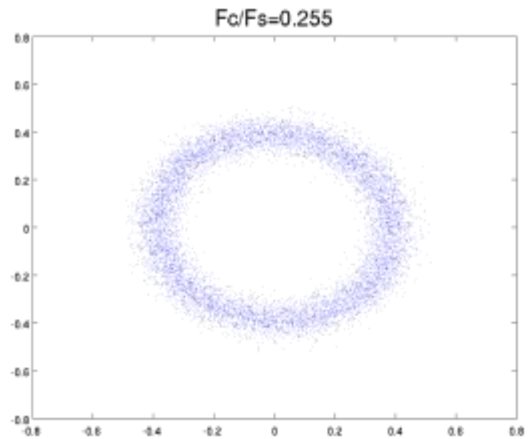
*Invalid 7-D symbols can always be marked as erasure, but even for decoders without erasure capability, performance hit should be minimal.

2-D Eye Diagram with NBI

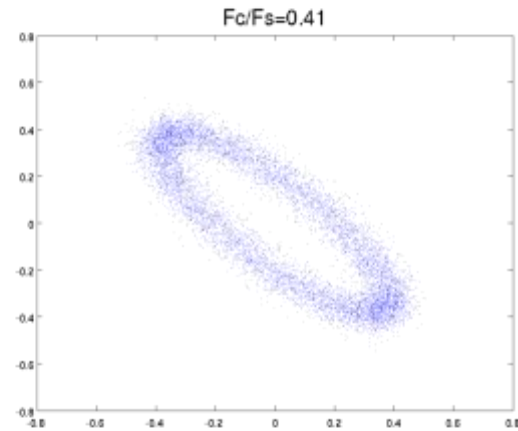
- The different “constellation” of NBI on 2-D plane
  - Phase randomized
  - Some AWGN added



45º rotated ellipse



Close to circle



-45º rotated ellipse

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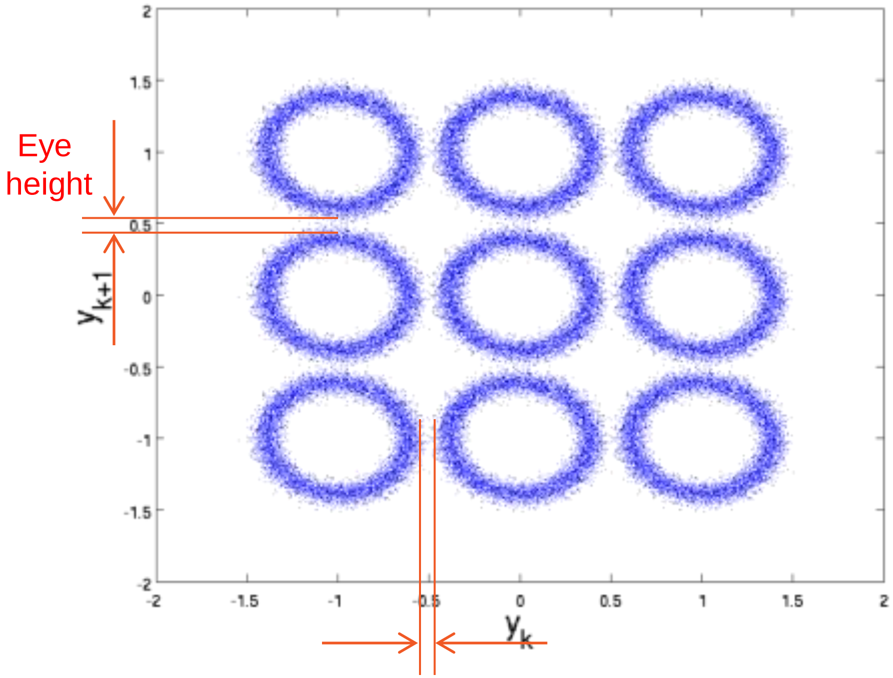
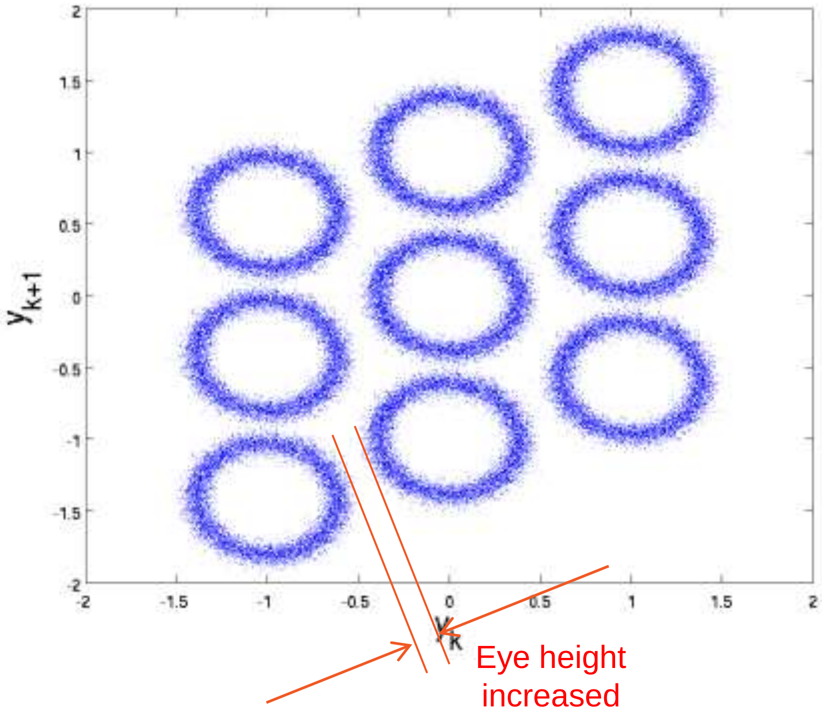
2-D Eye Diagram with NBI

- 2-D Eye diagram for 1D slicer and 2D slicer
  - P_{NBI}=-11.2dB, P_{AWGN}=-26dB, F_c=191.25MHz
  - w_0=0.42

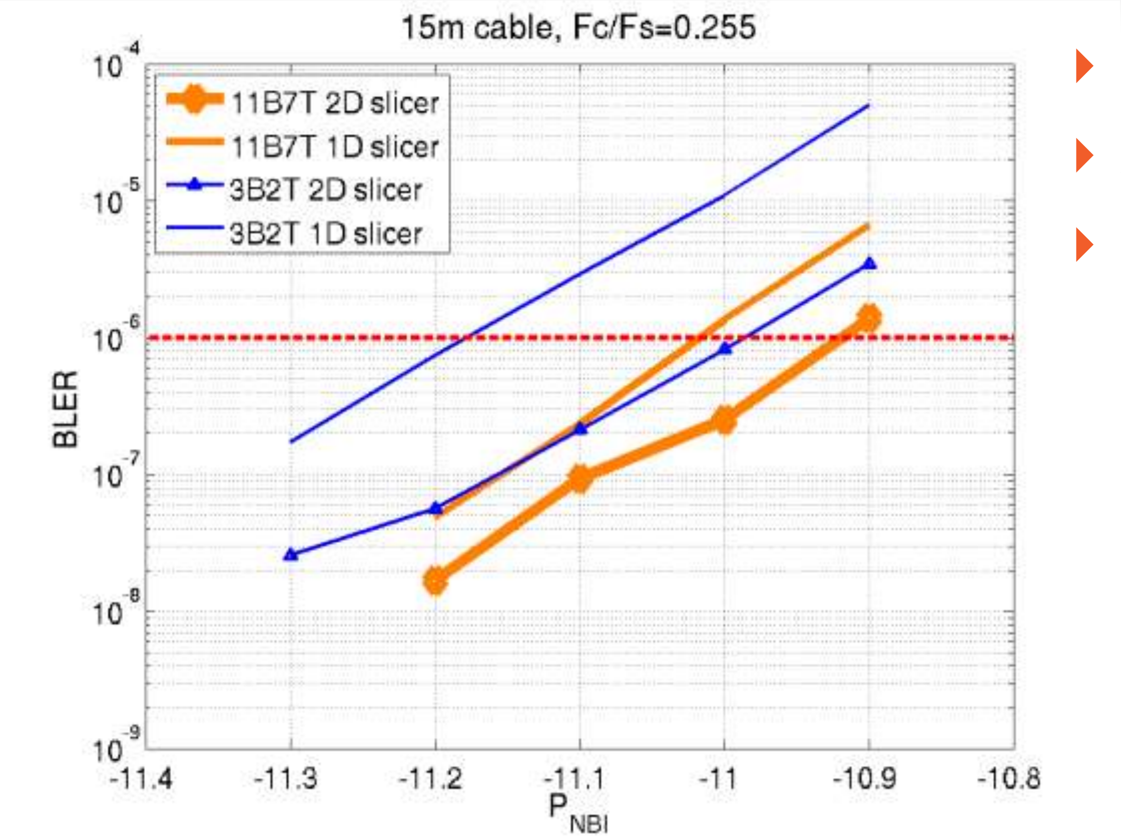


1-D Slicer used



2-D Slicer used

Performance of 2D slicer

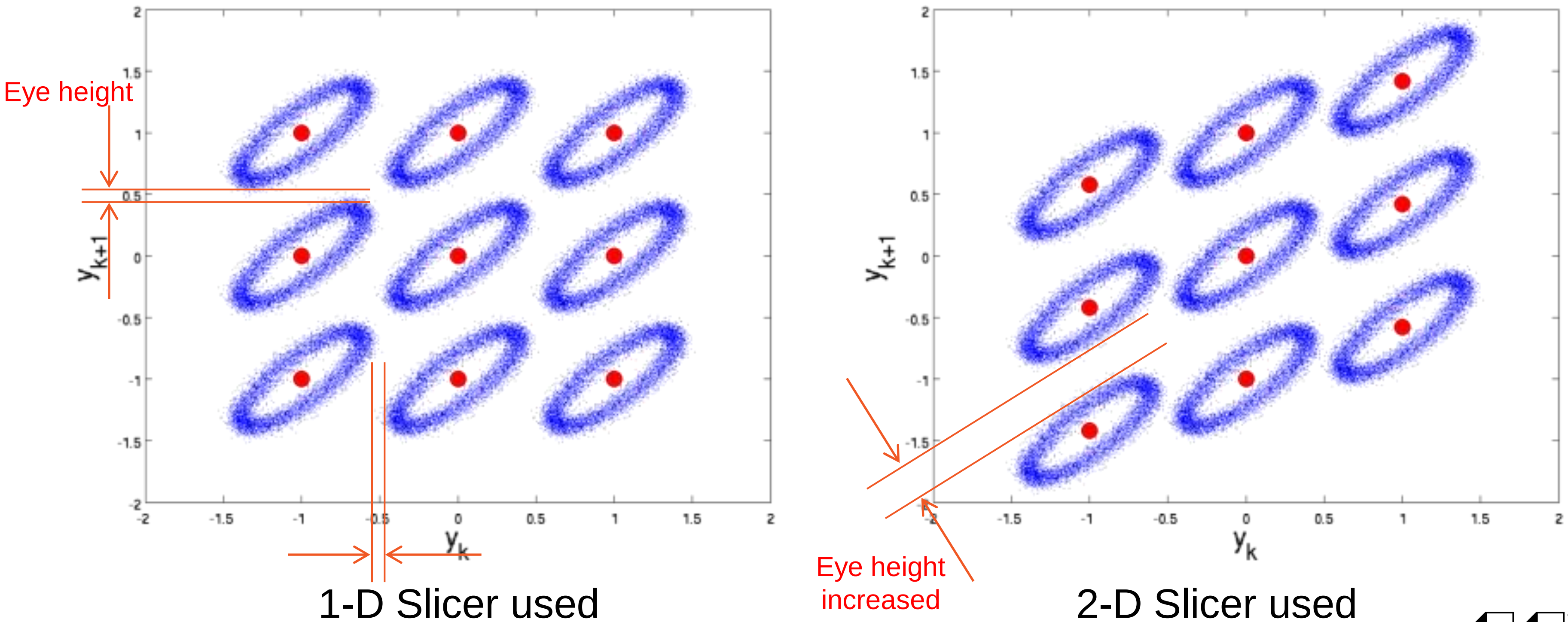


- DFE for 15m cable
- AWGN power = -26dB
- F_c = 191.25MHz

- 11B7T/2D slicer overperforms 3B2T/2D slicer

2-D Eye Diagram with NBI

- 2-D eye diagram for 1D slicer and 2D slicer
  - P_{NBI}=-11.2dB, P_{AWGN}=-26dB, F_c=67.5MHz
  - w_0=0.42
- For optimum performance, some information about NBI is needed



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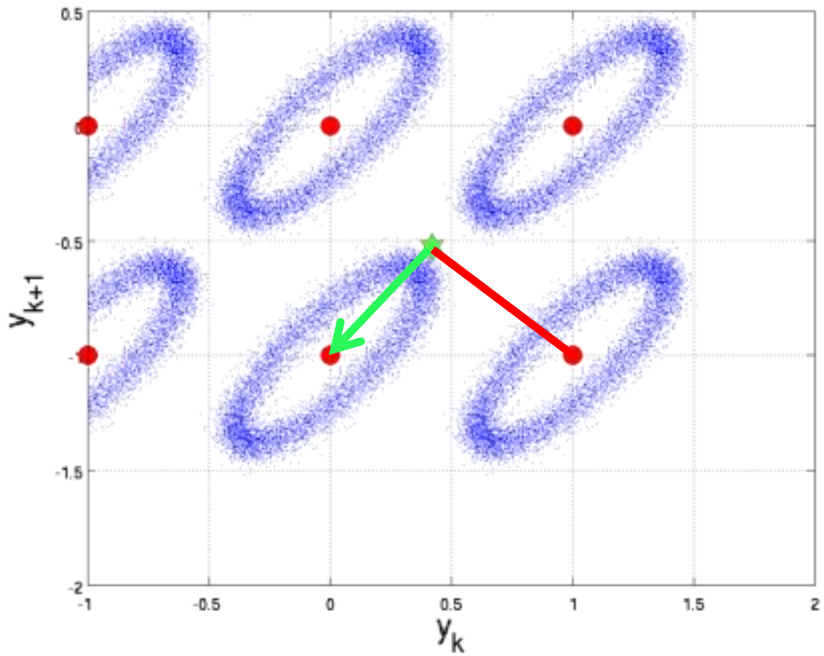
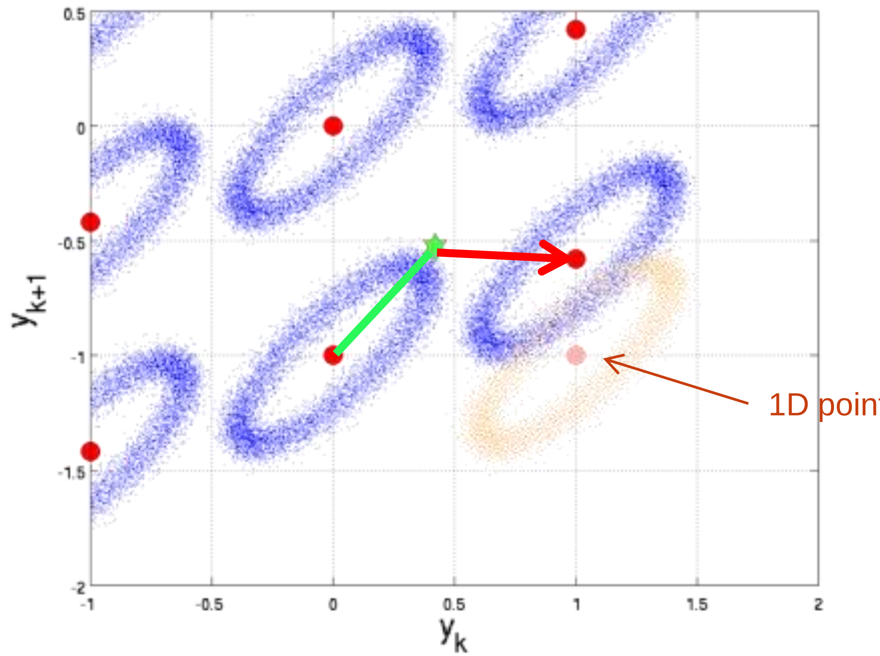
If Euclidian Distance is Used…

- If NBI property is unknown, additional wrong decision could be made with 2-D slicer



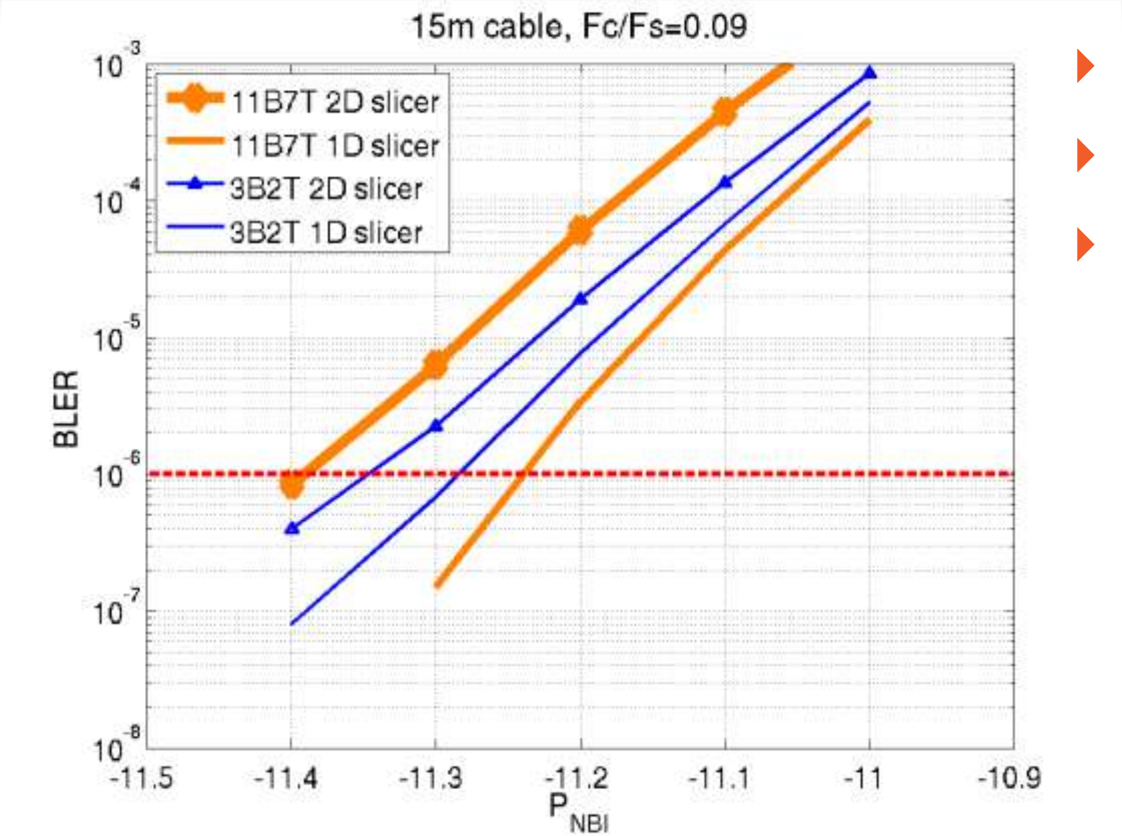
1-D Slicer used
Right Decision



2-D Slicer used
Wrong Decision as 2D slicing point not optimized for given NBI

Received point
Distance for correct decision
Distance for wrong decision (reduced with 2d slicer)

2D slicer worse than 1D slicer in some cases!



- DFE for 15m cable
- AWGN power = -26dB
- F_c=67.5MHz

- **Euclidian distance used as cost function**

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Burst Correction

- Burst simulated as 250ns of -10dB AWGN
- Only FEC correction capability is considered
  - No “mark of erasure” information from slicer
- DFE for 2m cable
- Background AWGN -26dB

Line Code	BLER after FEC
11B7T	4.0×10^{-7}
3B2T	7.2×10^{-5}
10B7T	5.7×10^{-2}

Burst Correction with Erasure

- If erasure information is considered…

Line Code	Maximum Erasure Length (ns)
11B7T	485
3B2T	336
10B7T	196

Conclusion

- 11B7T and RS(360, 308, 2^{11}) has the lowest FEC block error rate for NBI noise simulations.
- 11B7T can deal with longest burst noise with or without erasure information.
- 2D slicer can be used for any PAM3 mapping, but may not always yield the best results.

THANK YOU