Partial Response Signaling for Backplane Applications

IEEE 802.3ap Task Force
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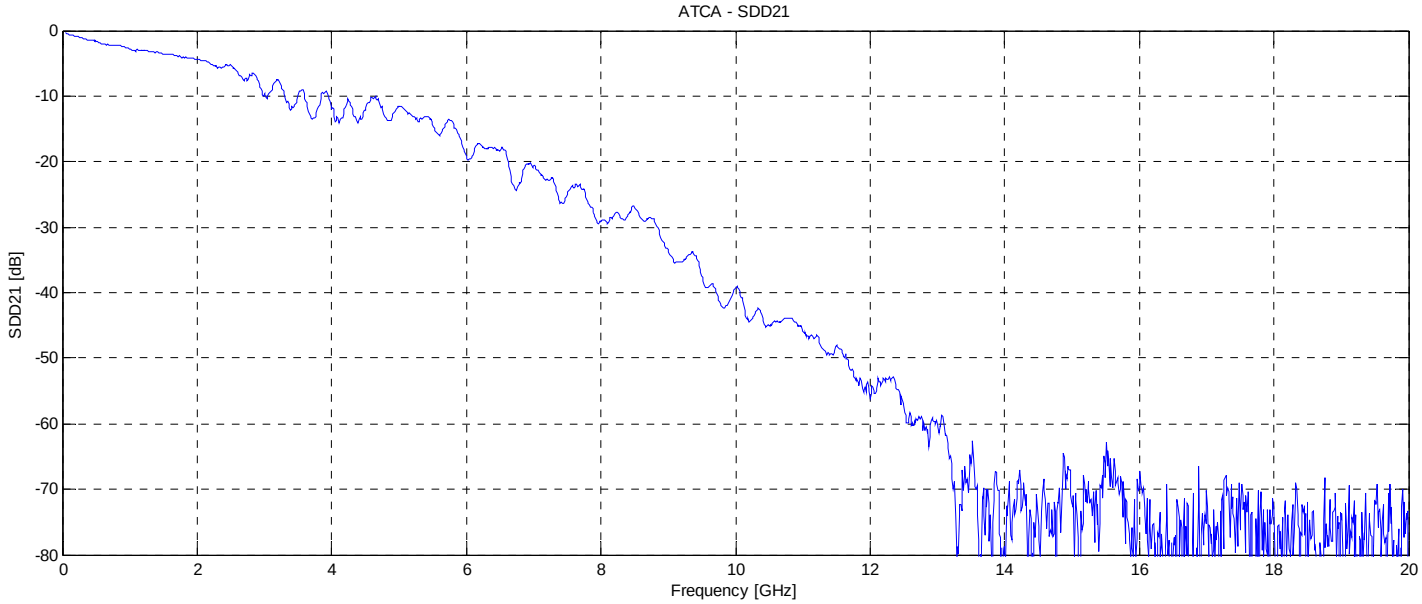
Agenda

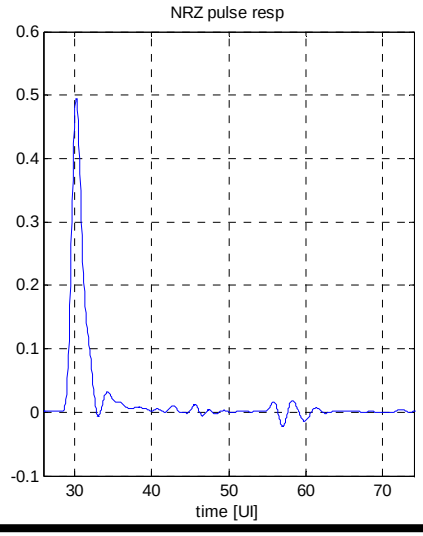
- Introduction
- Line coding alternatives for BP Ethernet
  - Current candidates
  - Partial Response codes
- Partial response line codes
  - History
  - Time & spectrum characteristics
  - Performance against other codes

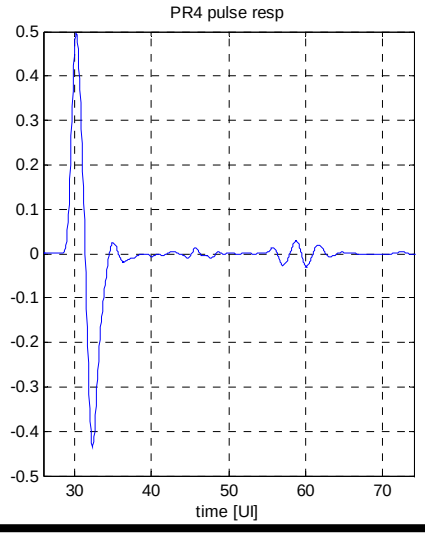
Introduction

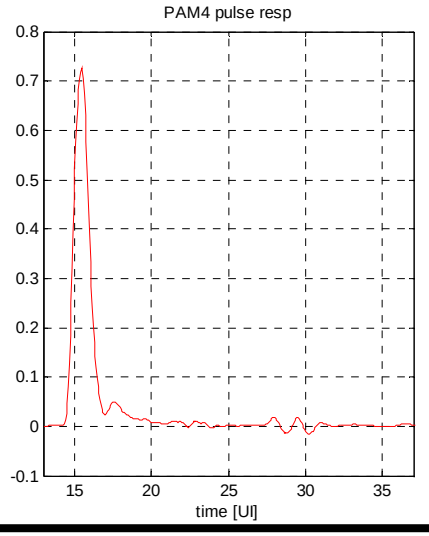
- Low speed interfaces generally use NRZ signaling for simplicity
- At higher speeds, Rx data eye is closed and equalization is needed to reliably recover data
- Many line codes are possible to assist equalization and reduce equalizer complexity
- Useful line code properties
  - Reduce symbol rate
  - Reduce spectral content at high frequencies
    - Reduce EMI
    - Reduce Xtalk
  - DC Balancing
    - Reduce baseline wander from series cap
  - Coding redundancy
    - Error detection/correction possibility
    - In-band control channel

802.3ap Physical Channel









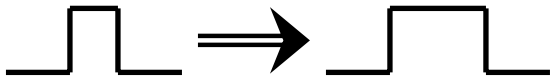
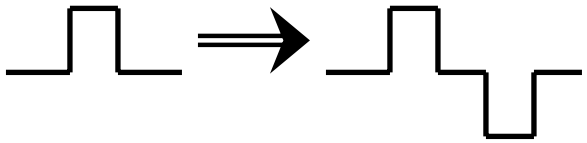
Current Line Code Proposals

- NRZ
  - Obvious choice, simplest to implement for high speed links
    - Minimum of 3 comparators to decode data & control equalizer adaption
  - Can be coded to alter spectrum & control disparity
    - Requires increased bit-rate and channel BW
  - Requires an equalized channel BW > bit-rate/2
  - Sensitive to deep channel nulls <8GHz
- 4-PAM (generic: M-PAM)
  - Multi-level signaling
  - Requires 2M-1 comparators to extract data and timing
  - 50% BW requirements from NRZ
  - Nyquist filtering at bit-rate/4 possible to limit Xtalk
- Duobinary
  - Current proposals considered as min design delta for NRZ solutions

Partial Response Codes

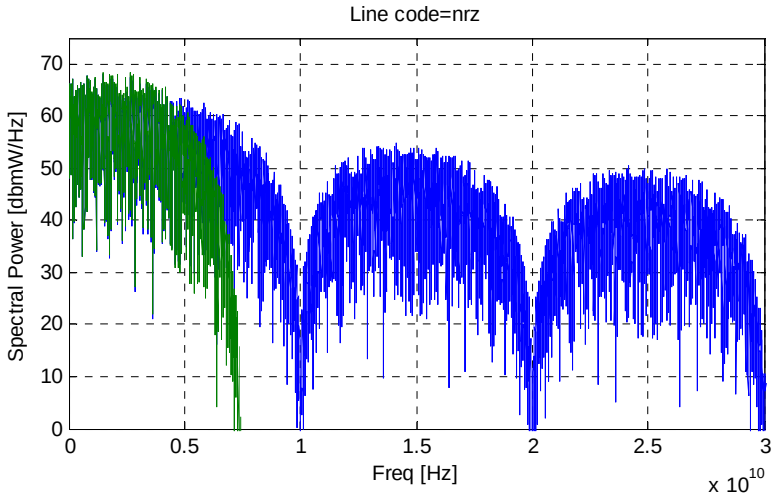
- Long history in disk drive industry
- Simplest classes use short generator polynomials
  - PR-2 (duobinary) and PR-4 (modified duobinary)
- Intentionally adds ISI to shorten channel pulse response
- Adds levels compresses spectrum
  - Adds redundancy to easily enable ML/Viterbi detection

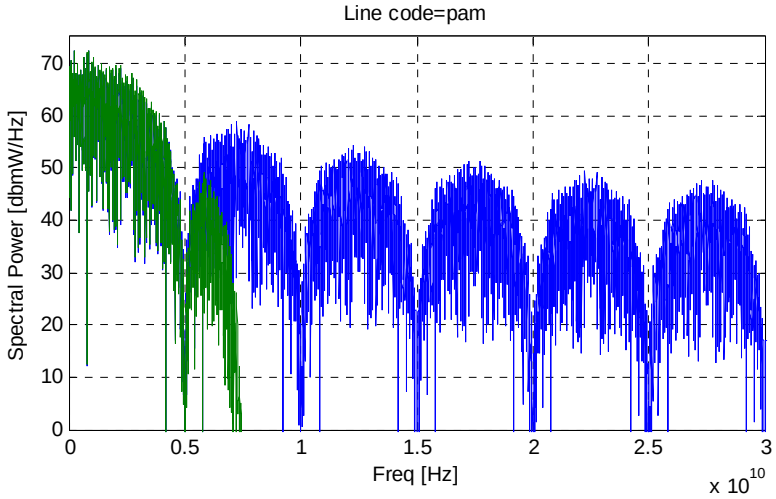
Partial Response Codes

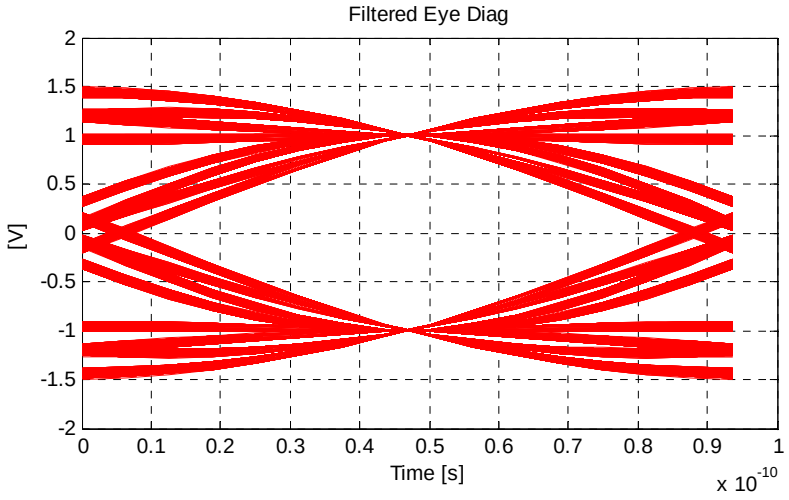
- **Partial response codes use correlation to cancel ISI**
  - **Unit data pulses are modified with specific filter functions**
  - **PR2: $Y=(1+D)X$** 
  - **PR4: $Y=(1-D^2)X$** 
  - **Ref: *Partial Response Signaling*, Kabal & Pasupathy, IEEE Trans on Comms, Sept'75**
- **Duobinary (PR2)**
  - **Uses channel ISI to self-cancel**
  - **Natural spectral null at bit-rate/2**
  - **Less critical Nyquist filtering due to spectral null**
- **Modified Duo-binary (PR4)**
  - **Better ISI cancellation than PR2 ($1-D^2$ polynomial)**
  - **Spectral null at DC (balanced) and bit-rate/2**

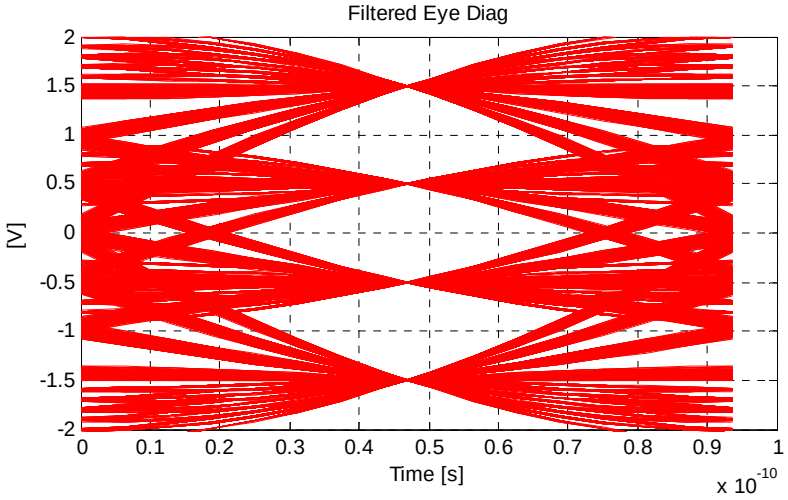
Line Code Spectra – PAM Codes

- **Line codes characterized by both spectral & time-domain properties**

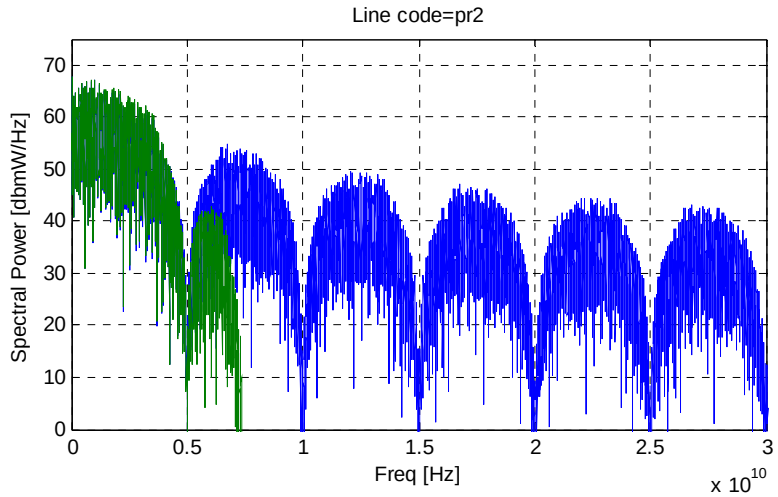


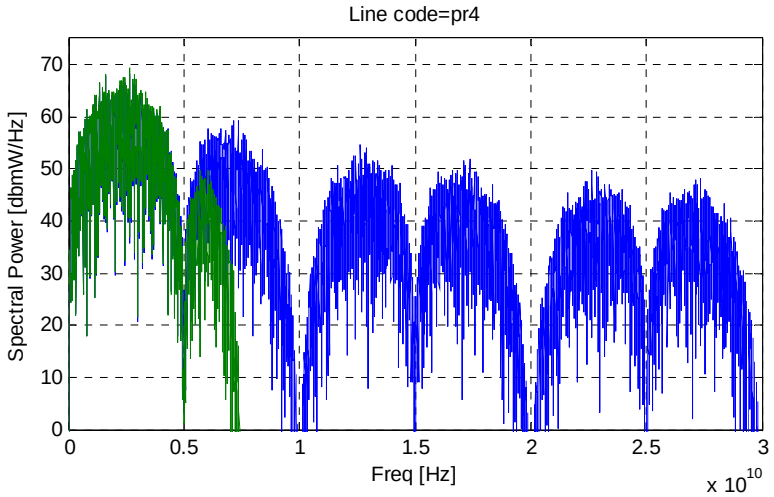


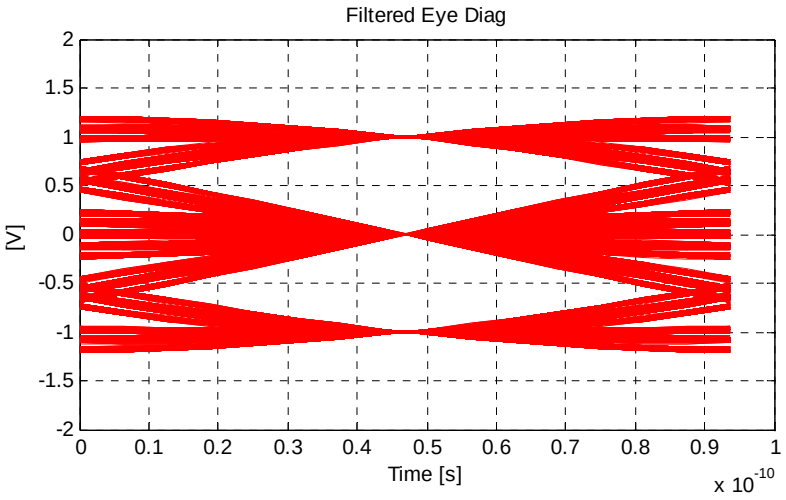


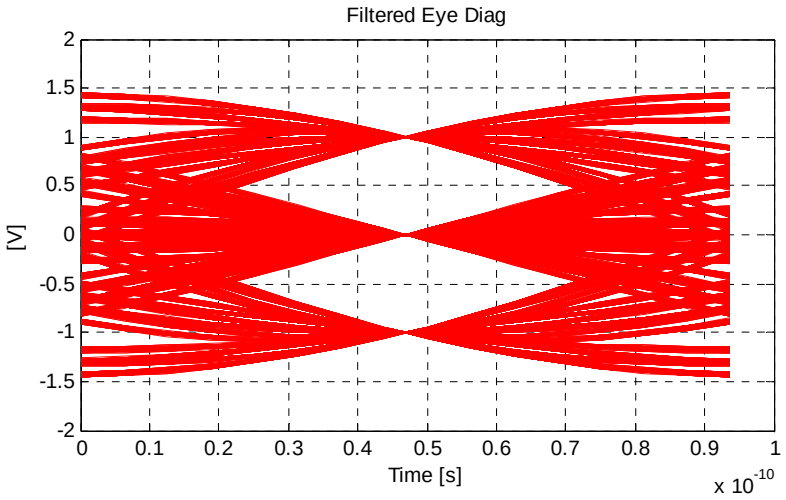


Line Code Spectra – PR Codes





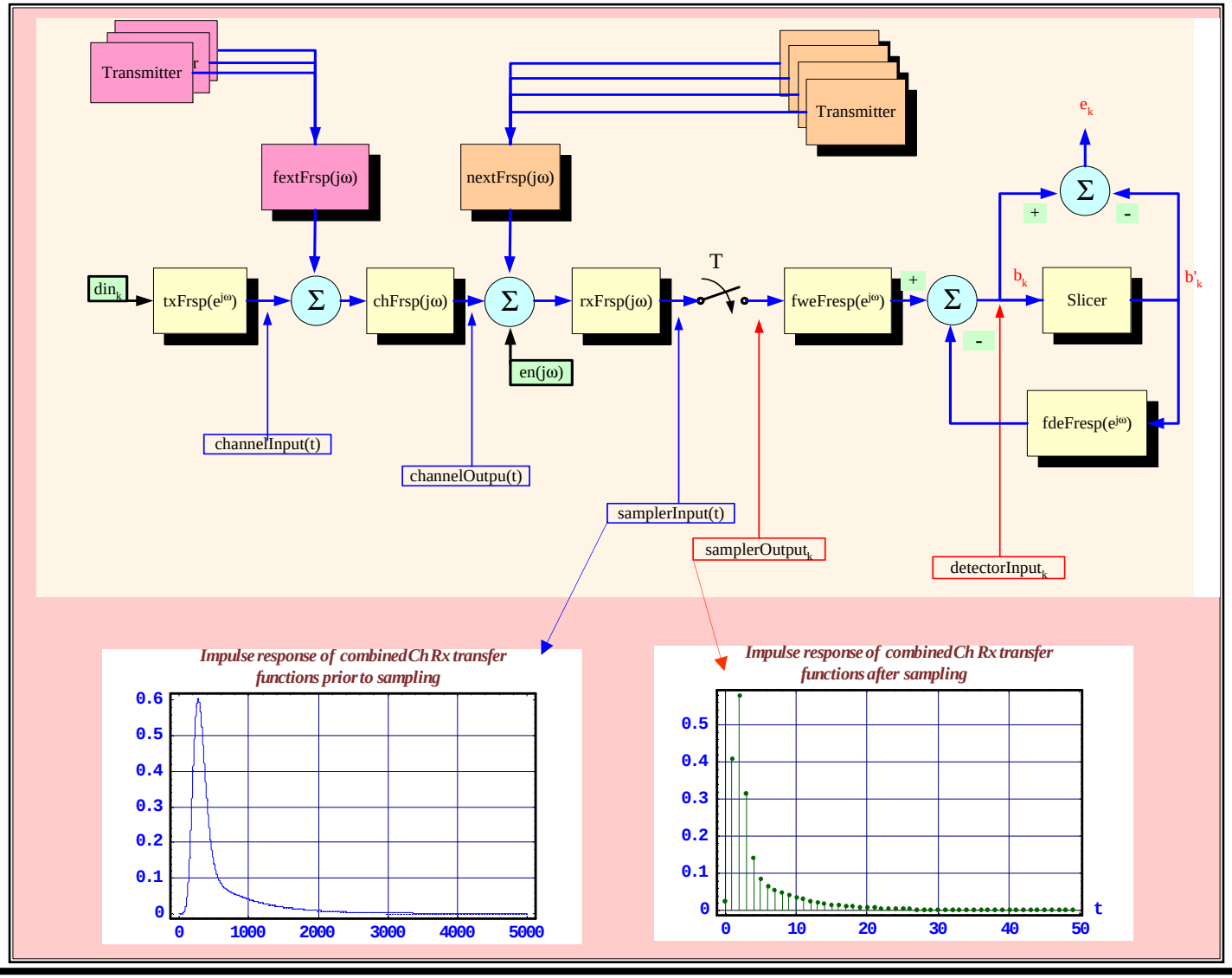




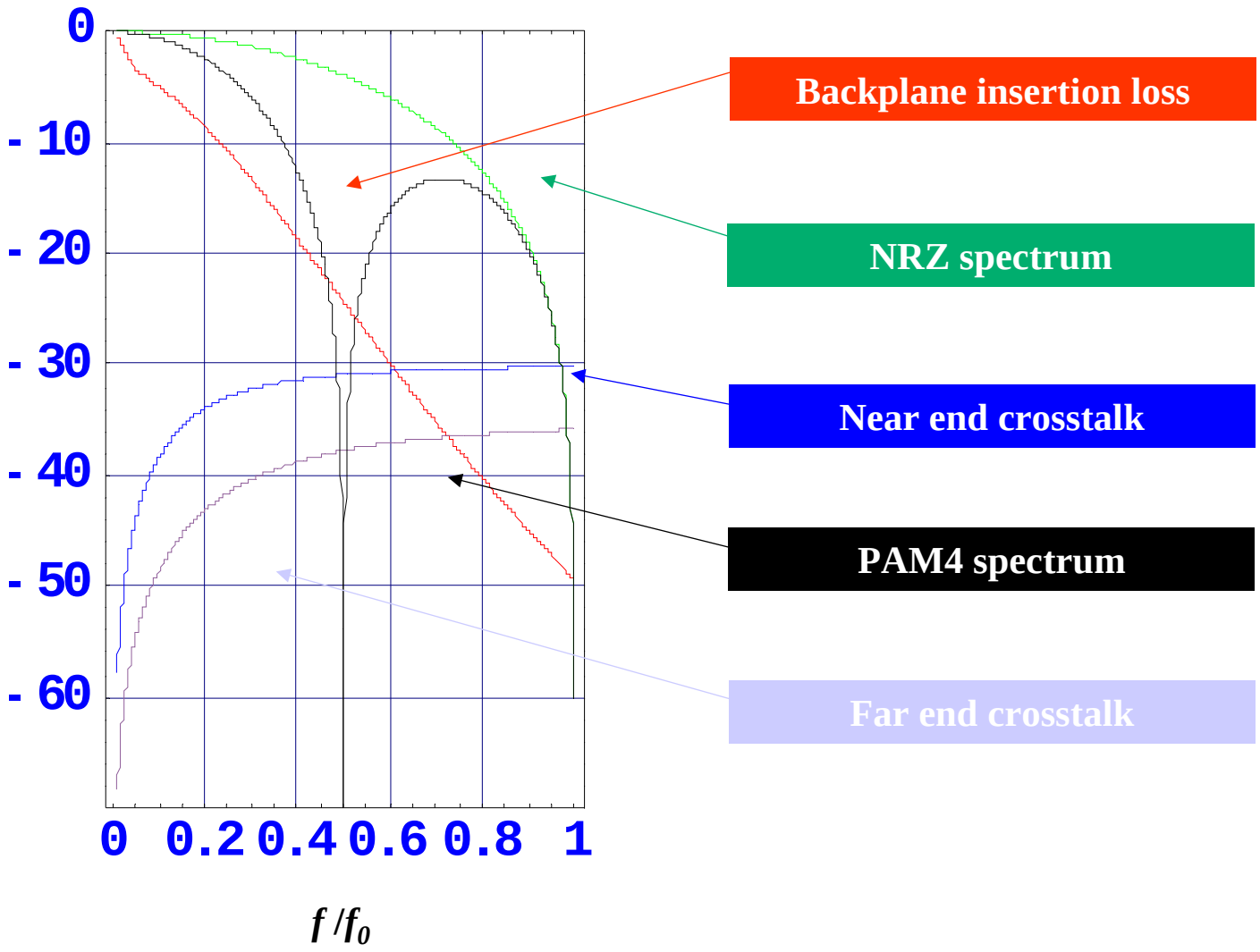
Coding Evaluation

- **Structural systems simulation**
  - **sampled Tx**
  - **Linear channel, NEXT/FEXT, equalizer**
  - **Sampled Rx**
- **Evaluate potential line code performance in comms channel model**
  - **SNR evaluation for 4 signaling candidates (NRZ, PAM4, PR2, PR4)**
  - **NEXT, FEXT, AWGN major noise sources. Treated as statistically uncorrelated Gaussian noise**
  - **Calculate SNR-optimized equalization for each line code**

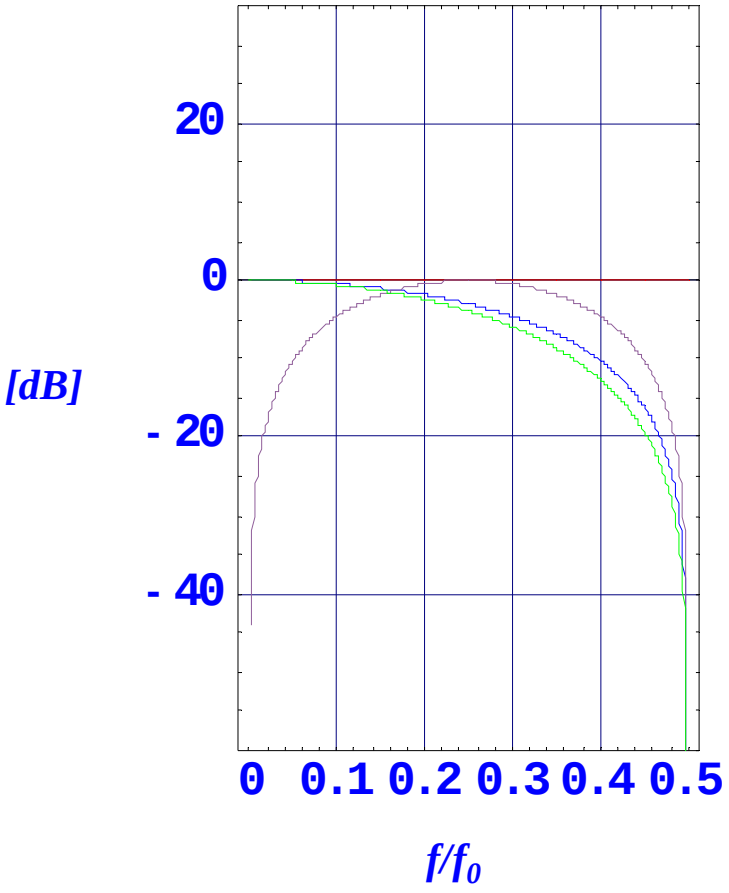
Evaluation Setup



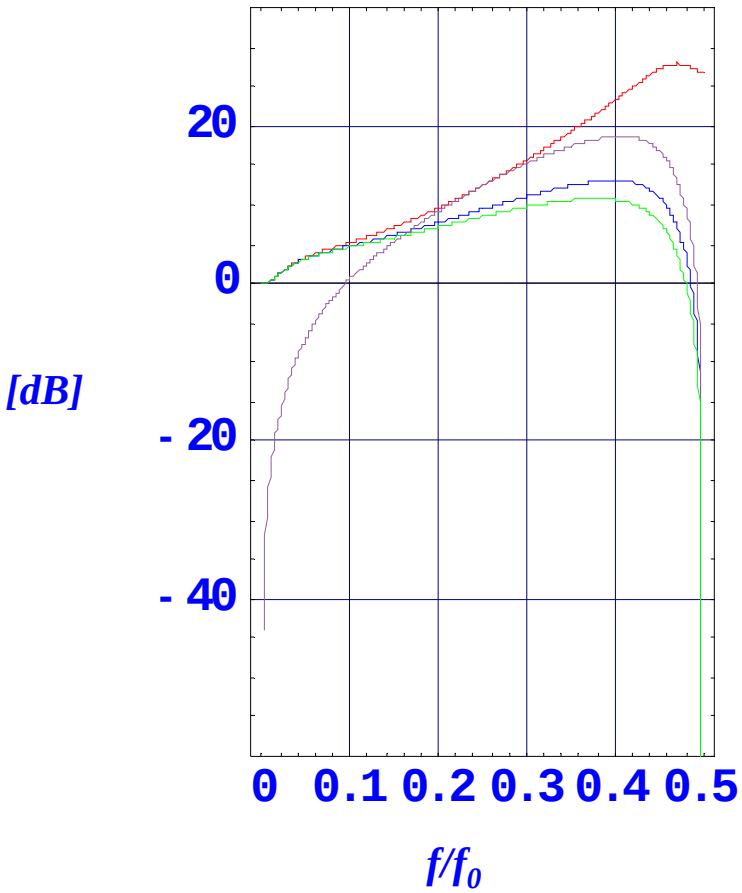
Channel Templates vs. NRZ and PAM4 Spectra



Equalization Targets and Optimal Corrections



Target equalization



Optimal correction

NRZ | PR4 | Duobinary | PAM4

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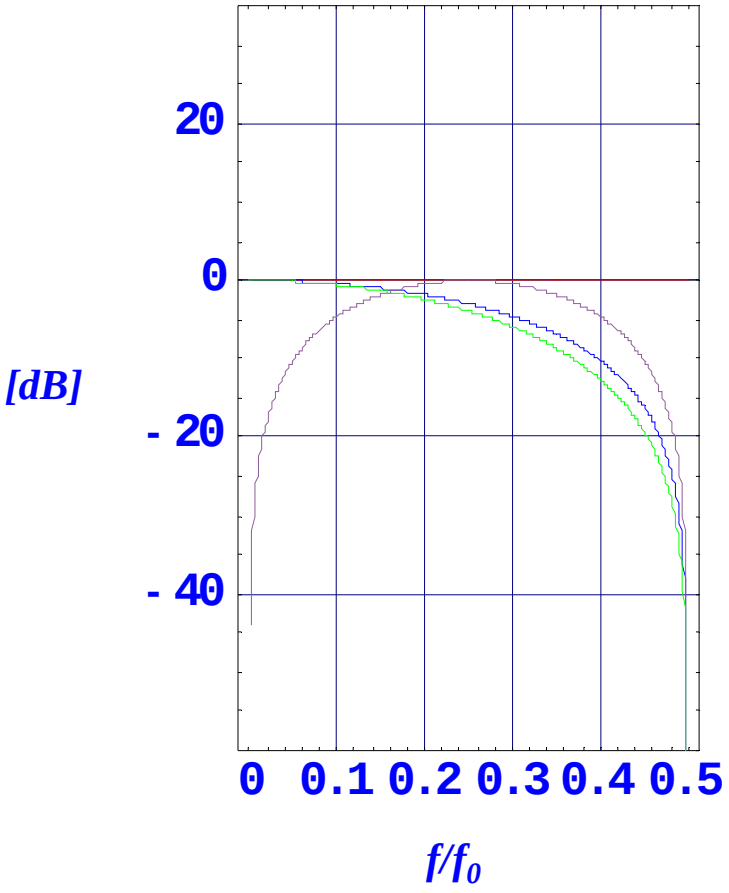
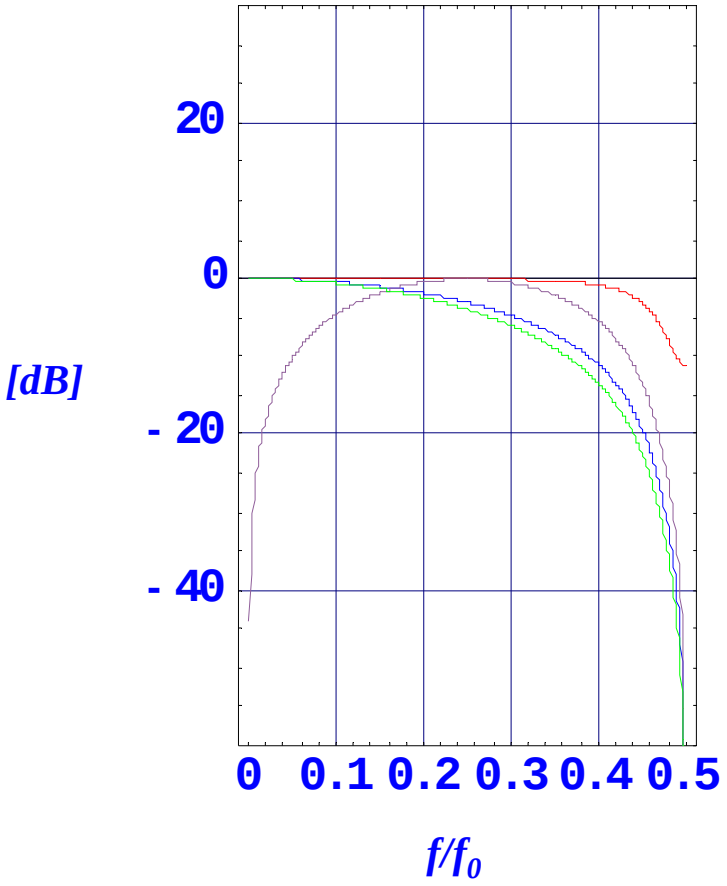


Target equalization



Optimal correction

NRZ | PR4 | Duobinary | PAM4

Coding Performance Measures

- PR Equalization
  - PR2 requires generally less signal 'boost' then PR4
  - PR4 amenable to half-rate Rx & Tx architectures
    - Properly equalized, it has no odd-even bit interaction
- Data recovery
  - MLSE data recovery to enable error detection/correction
- Implementation complexity
  - Adds weighting range for Tx/Rx equalizer
  - Spectral null2 at $f_{bit}/2$ reduces noise filter sensitivity
- Other Coding weighting considerations for line codes
  - Timing recovery sensitivity
  - ISI sensitivity