A Comparison of Equalizers for Compensating Polarization-Mode Dispersion in 40-Gb/s Optical Systems

Jonathan Sewter & Tony Chan Carusone
University of Toronto
www.eecg.utoronto.ca/~tcc

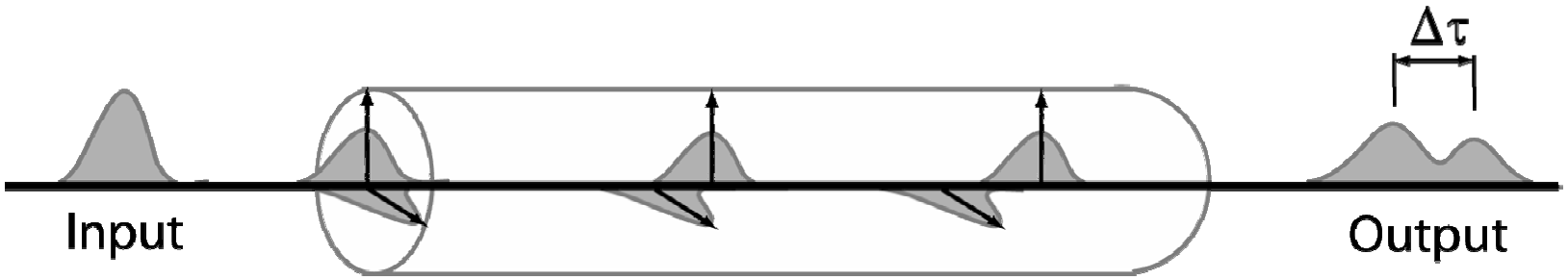
May 24, 2005

Outline

- Modeling polarization-mode dispersion in single mode fibres
- Equalizer simulation and evaluation methodology
- Results for a decision feedback equalizer

Polarization-Mode Dispersion

- Results from birefringence of optical fibers
- To a first-order, causes pulse-splitting
- Has been identified as a major factor limiting the reach of high-speed optical systems



Polarization-Mode Dispersion

- Impulse response of fiber with PMD is:

$$h_{PMD}(t) = \gamma\delta(t) + (1-\gamma)\delta(t-\Delta\tau)$$

where:

γ is the proportion of power in the fast state of polarization (SOP)

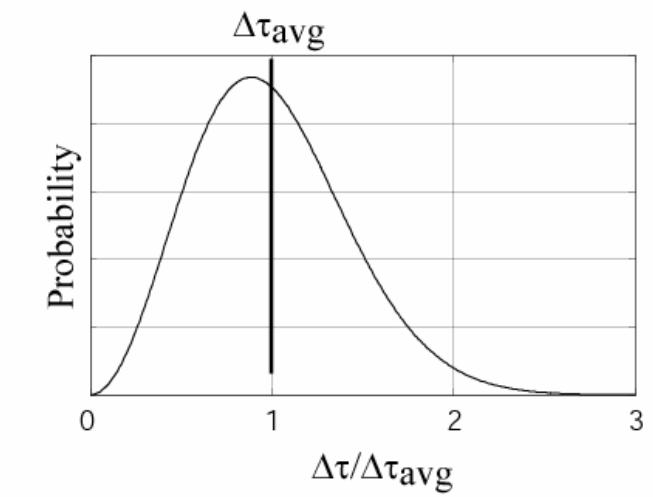
1- γ is the proportion of power in the slow SOP

$\Delta\tau$ is the differential group delay (DGD) between the fast and slow SOPs

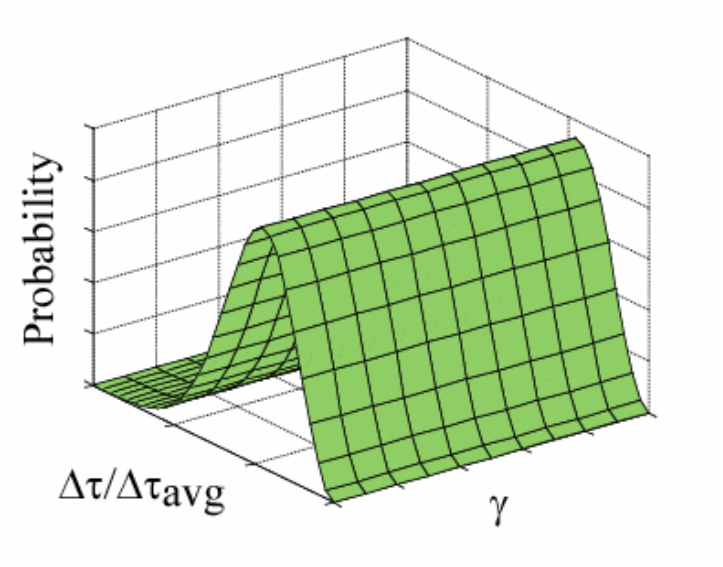
- γ and $\Delta\tau$ vary according to the particular fiber and its associated stresses

Polarization-Mode Dispersion

- $\Delta\tau$ and has a Maxwellian probability distribution

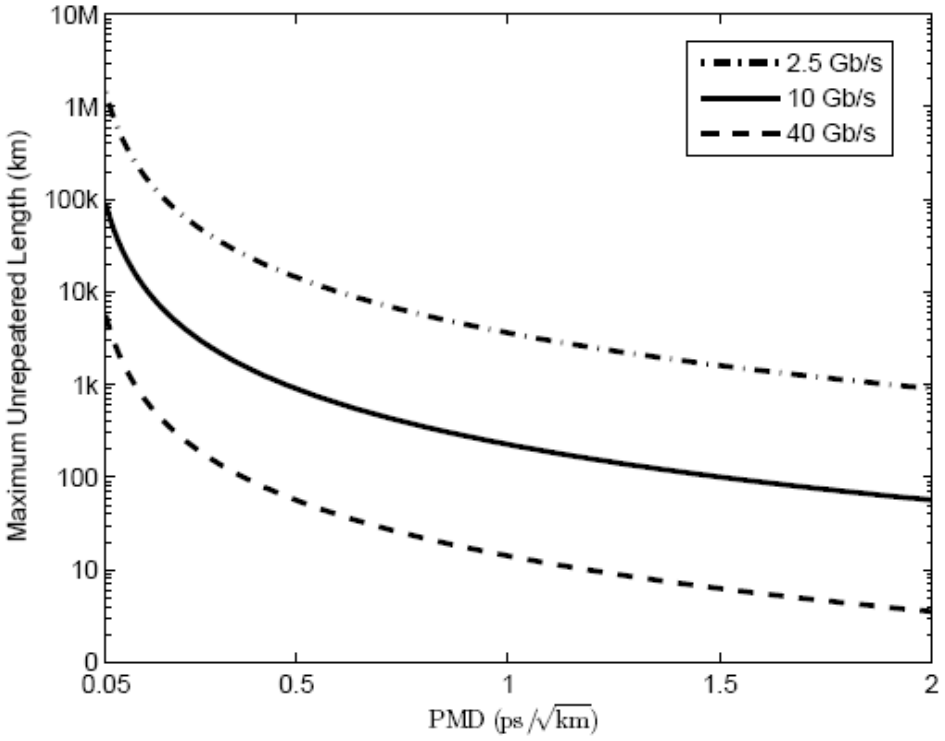


- γ has uniform probability distribution



Polarization-Mode Dispersion

- Average DGD ($\Delta\tau_{avg}$) increases with the square root of fibre length
  - Installed fibres: 0.5 to 2.0 ps/√km
  - "Best" new fibres: as low as 0.05 ps/√km



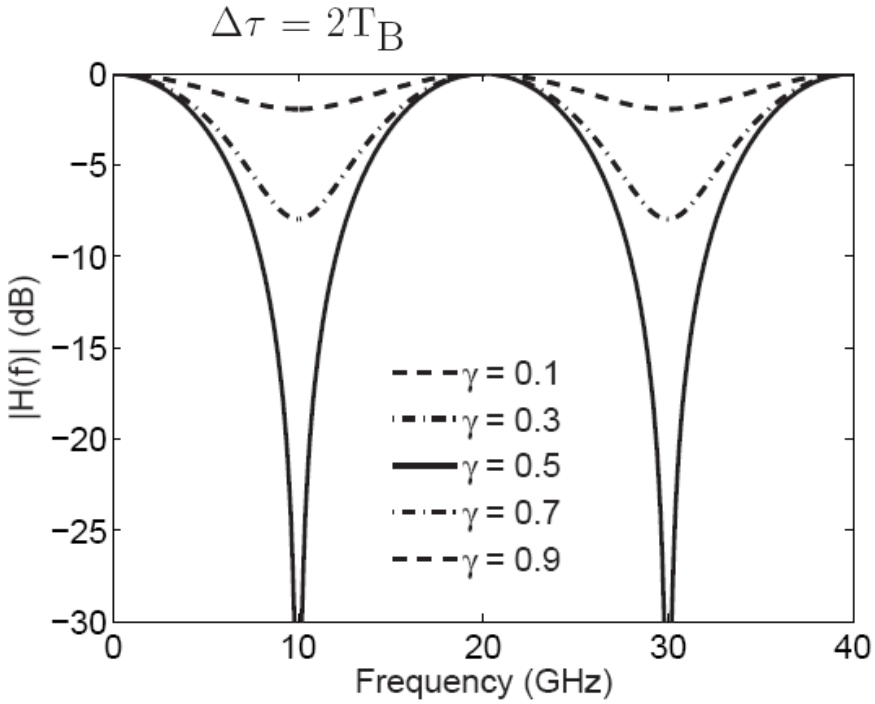
Polarization-Mode Dispersion

- Resulting frequency response:

$$H_{\mathrm{PMD}}(f) = \gamma + (1-\gamma)e^{-j2\pi f \Delta\tau}$$

- Has nulls with a frequency depending on $\Delta\tau$ and depth depending on γ

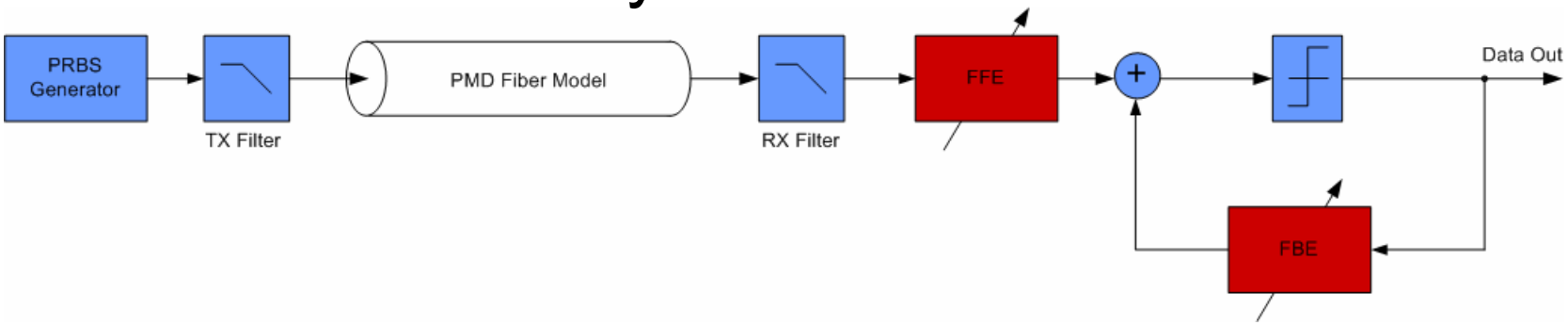
$\Rightarrow$Difficult to equalize linearly



System-Level Analysis

- Compares equalizer architectures quantitatively to identify promising configurations for implementation

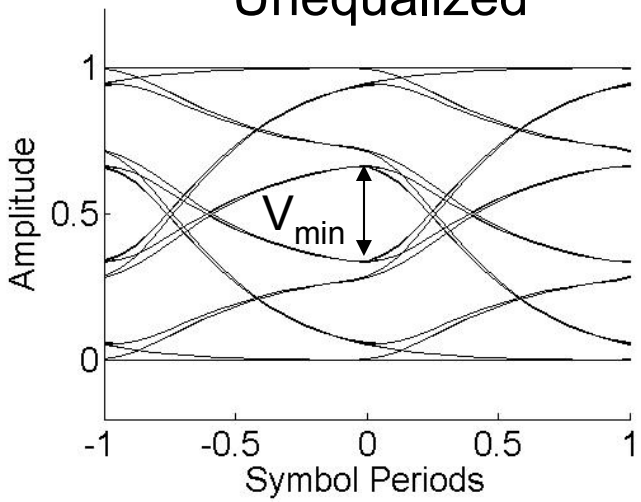
System Model



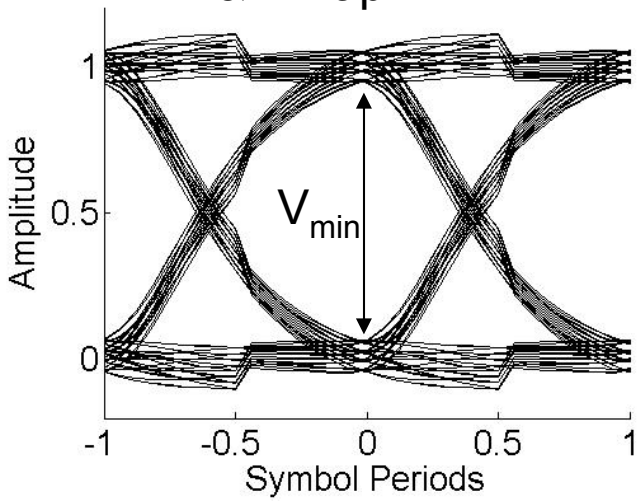
System-Level Analysis

- DFEs with varying number of taps were simulated over a range of γ and $\Delta\tau$
- For each (γ, $\Delta\tau$) pair, the ISI penalty was calculated for the minimum eye opening

Unequalized



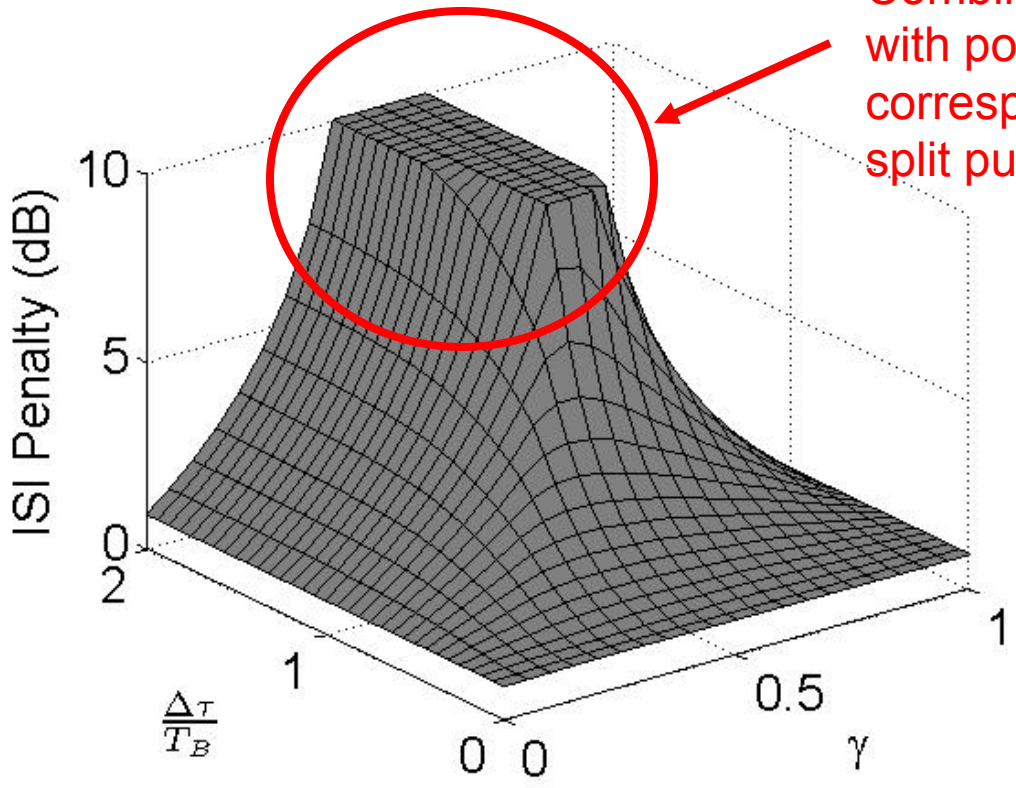
Equalized with 3-Tap FFE & 1-Tap FBE



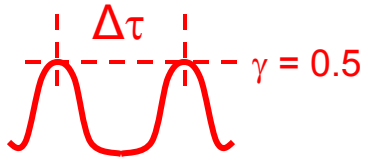
System-Level Analysis

- ISI penalty over all (γ, $\Delta\tau$) pairs forms surface

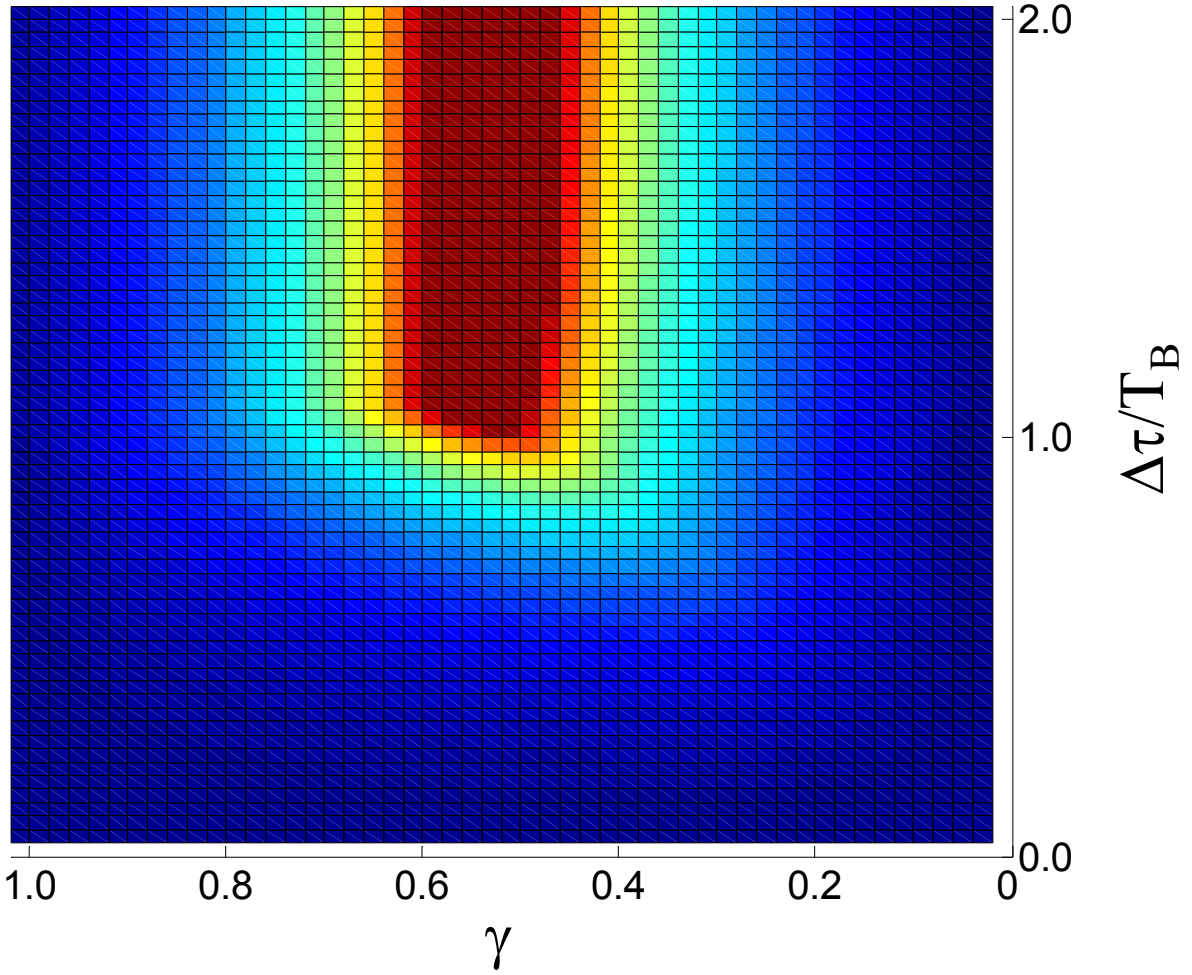
  e.g. unequalized case:



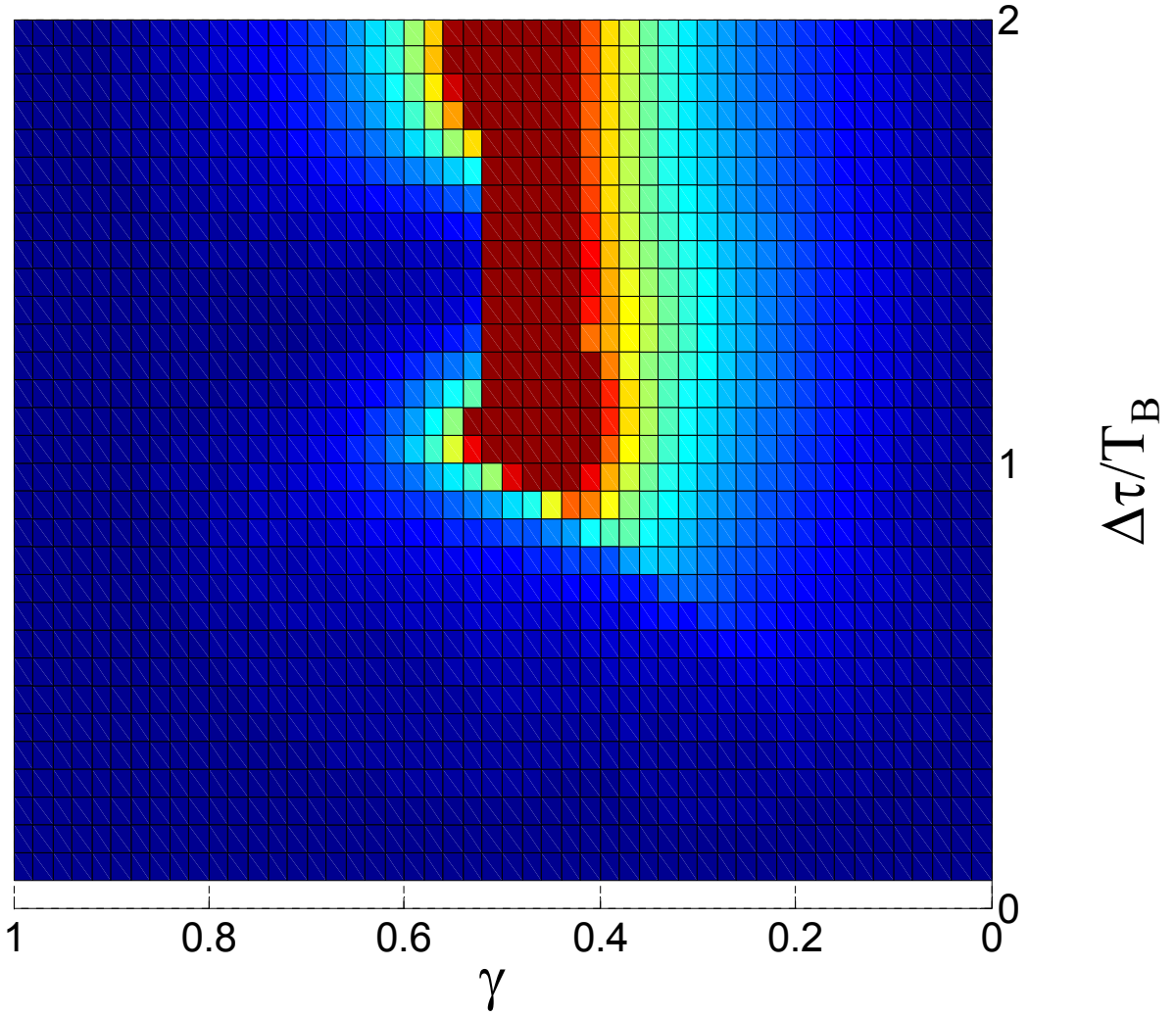
Combinations of (γ, $\Delta\tau$) with poor performance correspond to 2 equally split pulses:



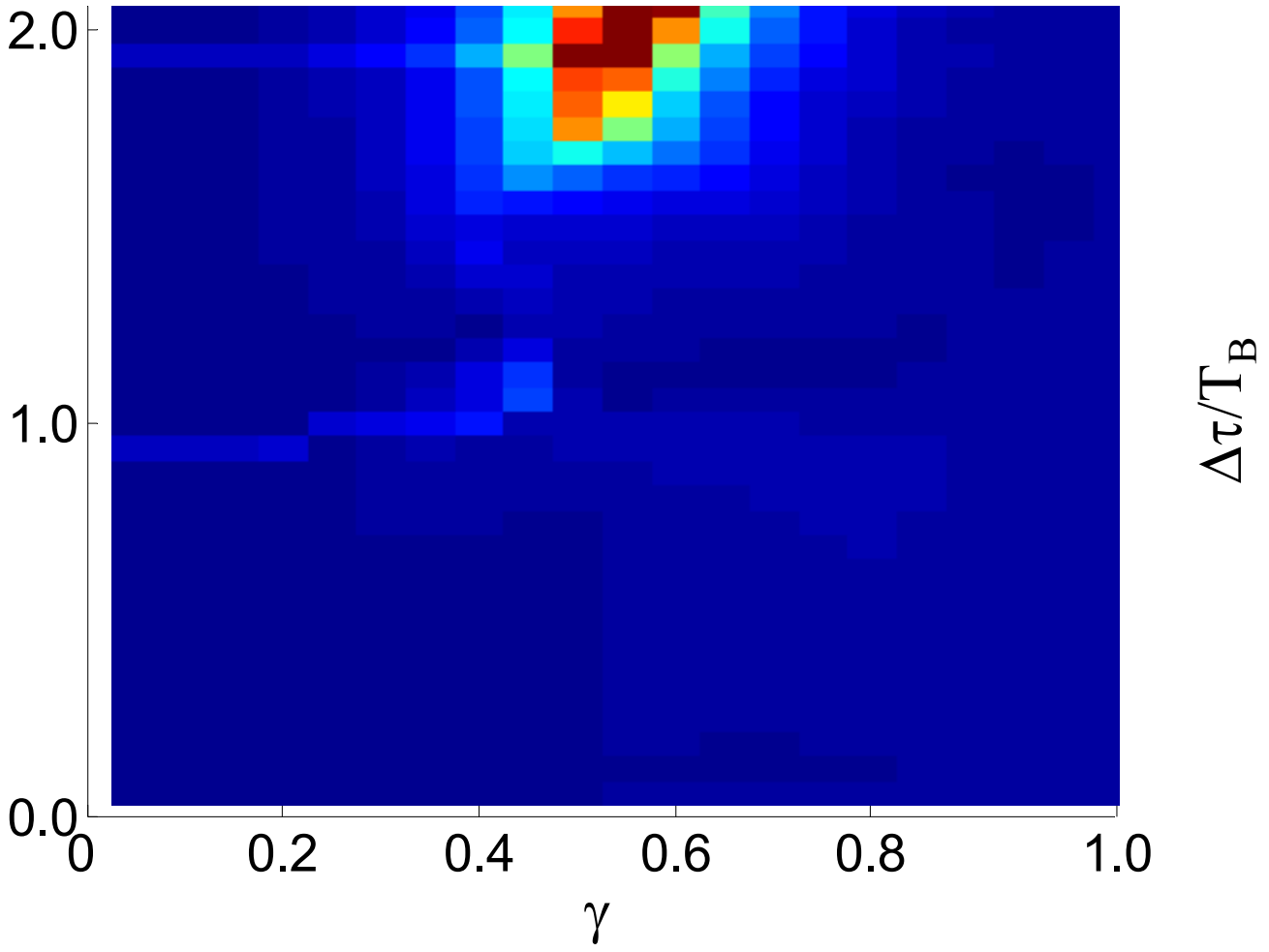
No equalization



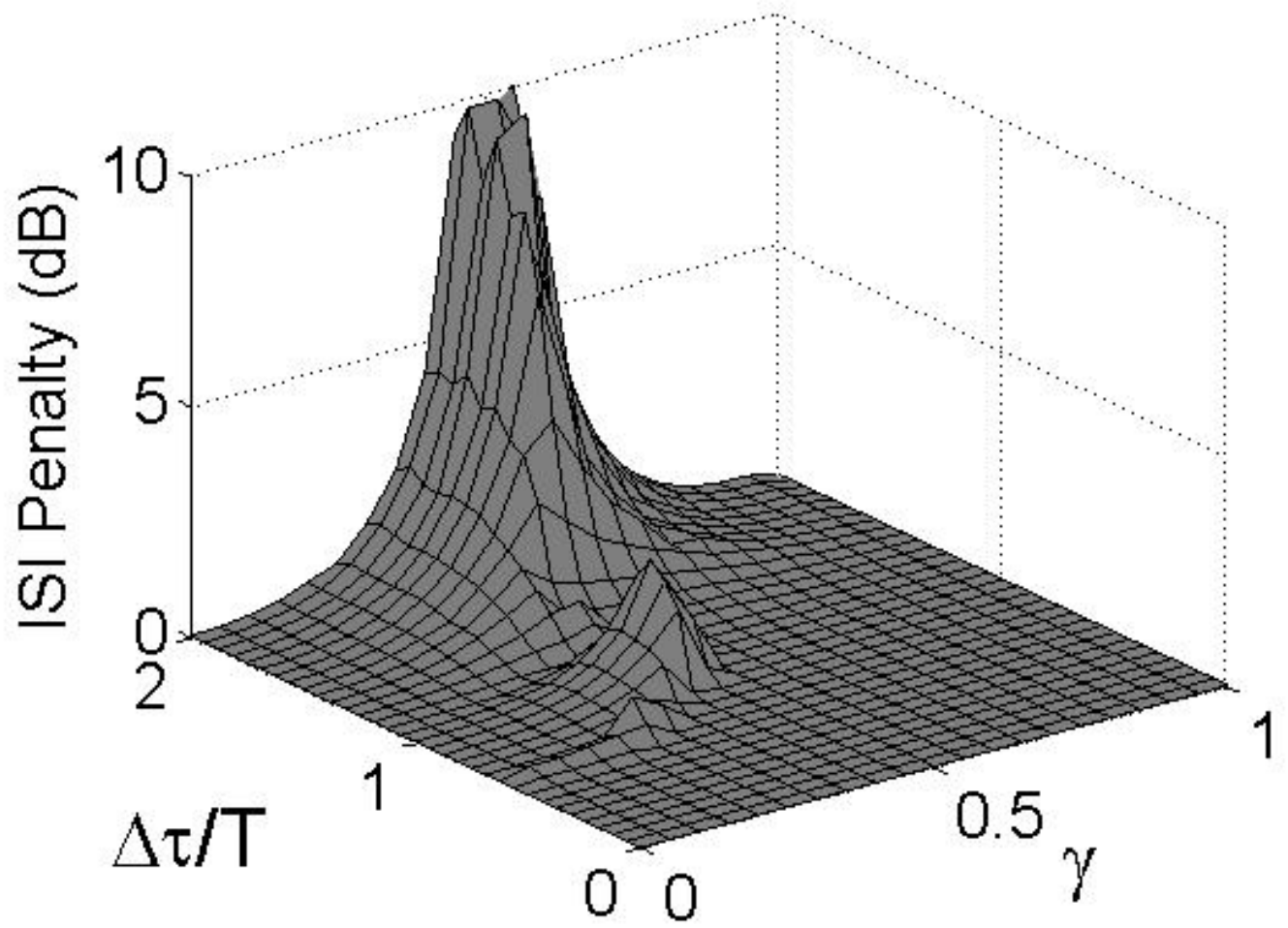
3-Tap Linear Eq. (No Feedback)



3-Tap Linear & 1-Tap Feedback Eq.

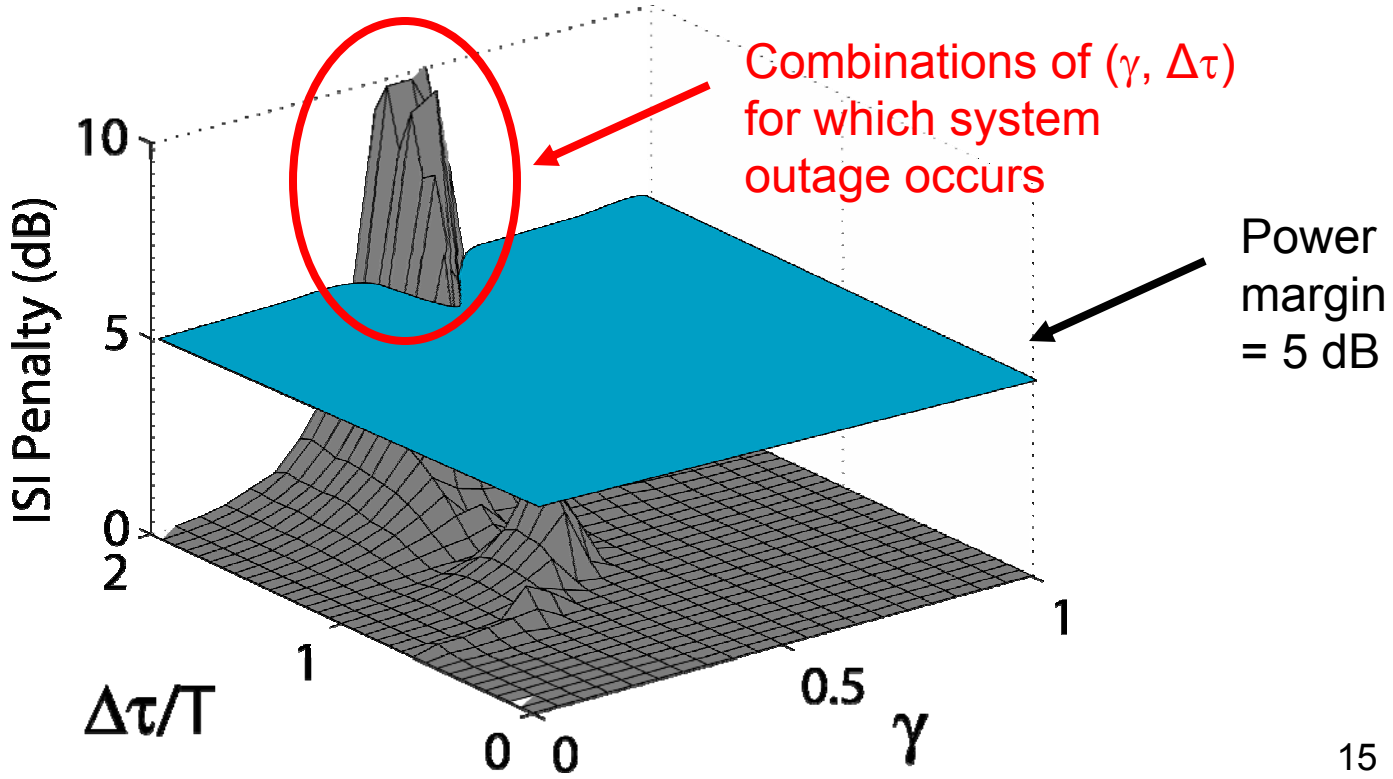


3-Tap Linear & 1-Tap Feedback Eq.



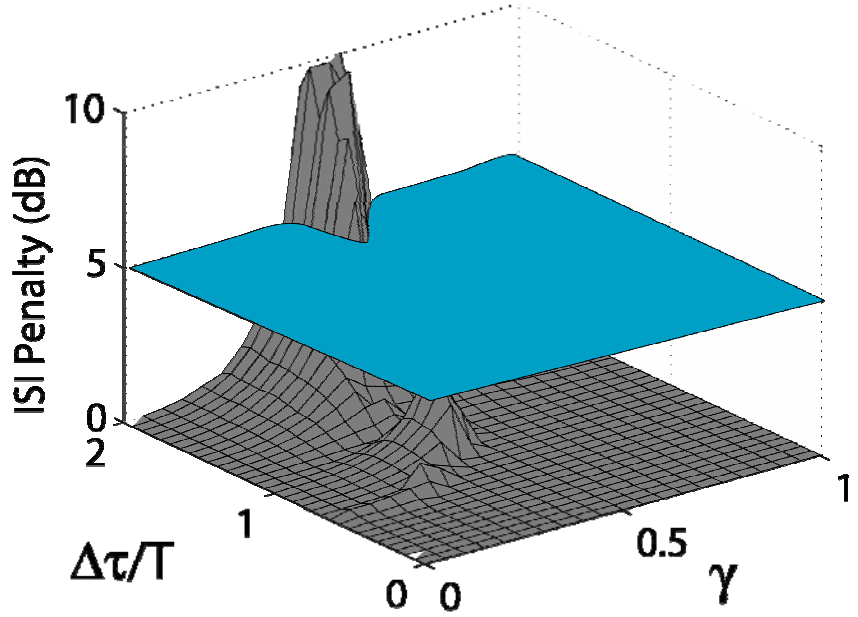
System-Level Analysis

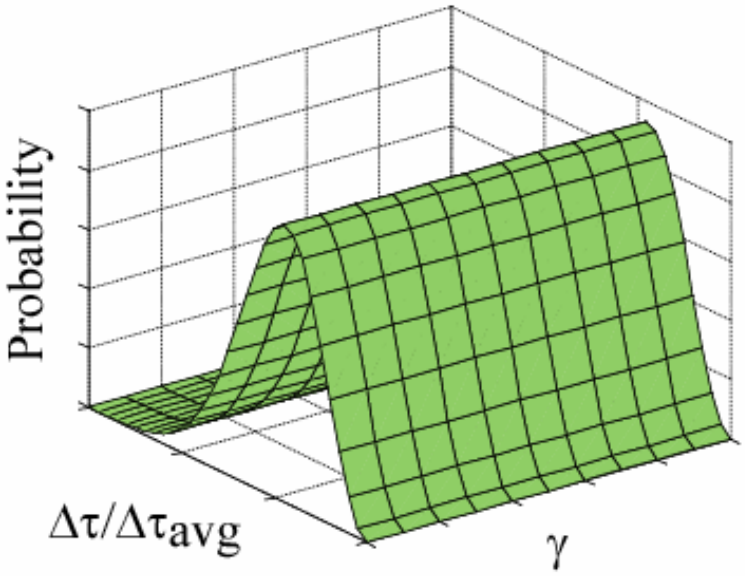
- A fixed power margin is used to include all non-idealities including offset, noise, etc.



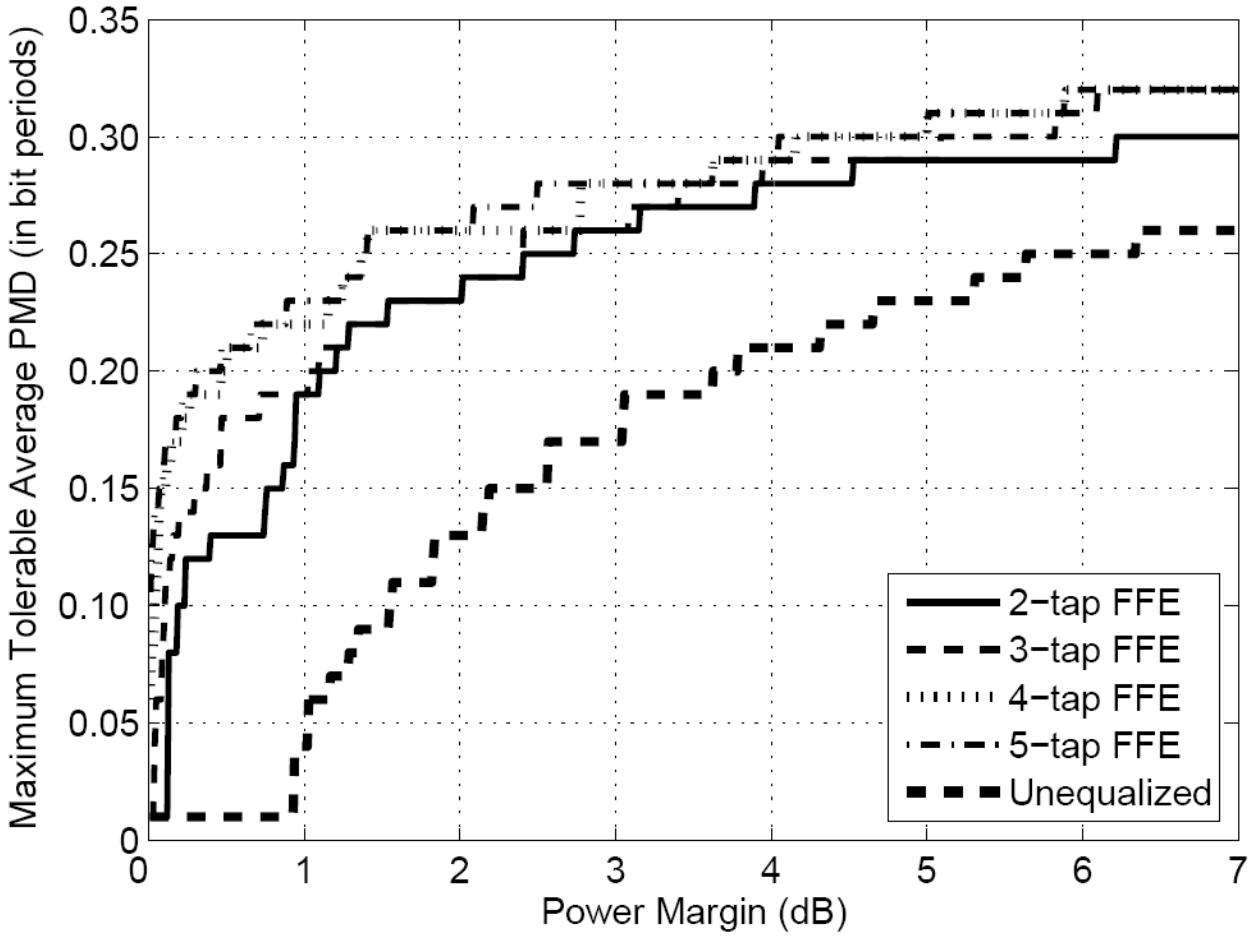
System-Level Analysis

- Combine with probability distribution of fibres to calculate outage probabilities for a given power margin and average DGD
- Outages of less than thirty seconds per year are sought (corresponding to a probability of 10^{-6})

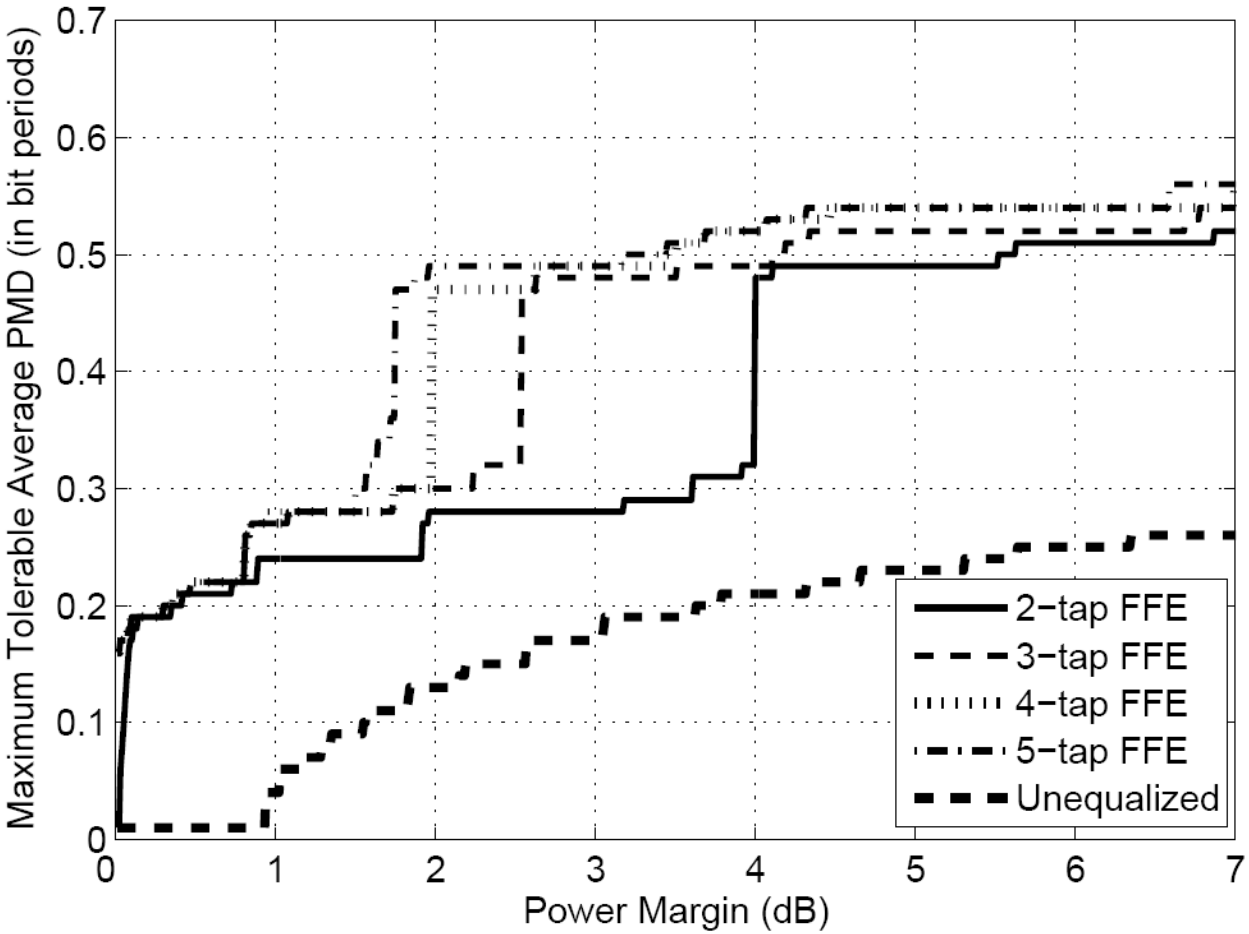




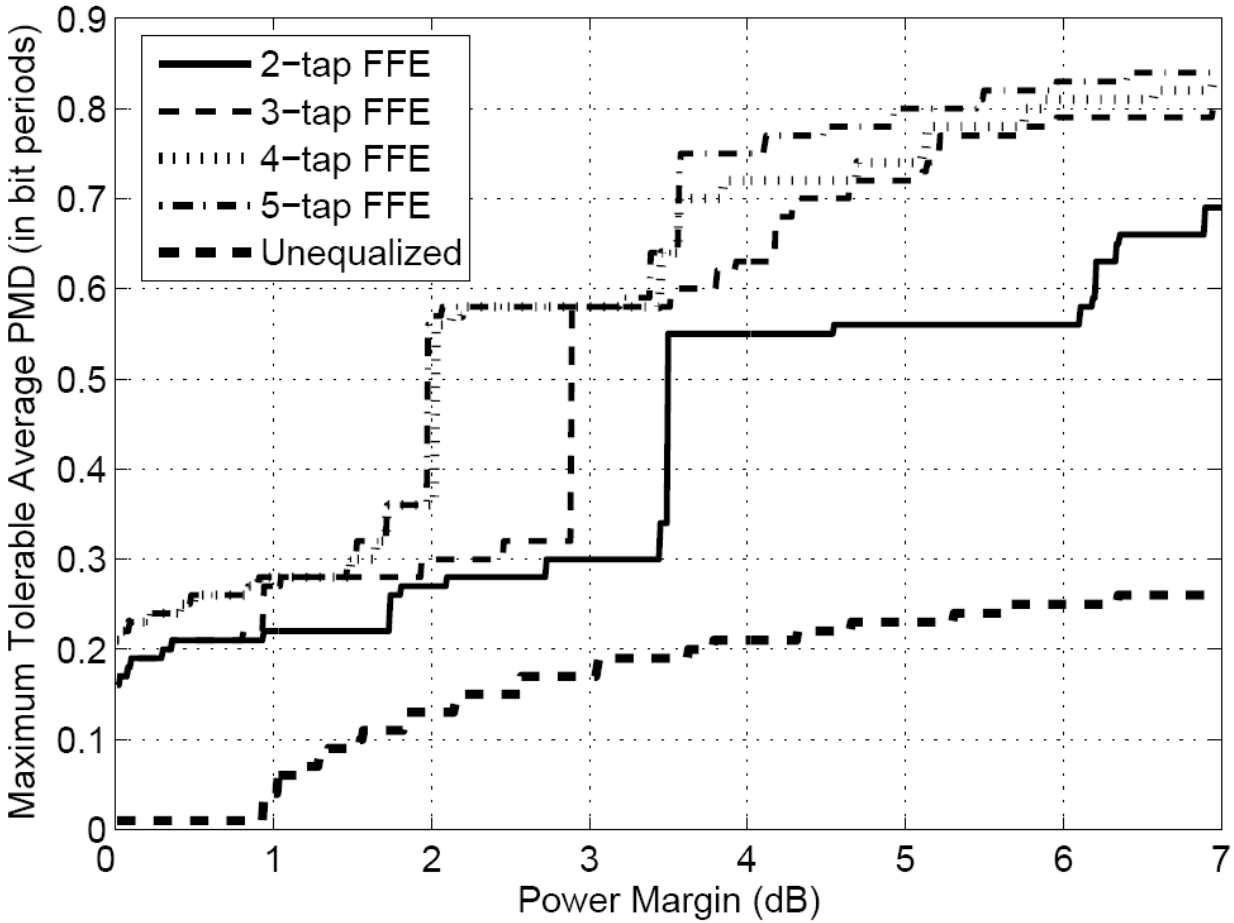
Results: FFE only



Results: 1-Tap FBE

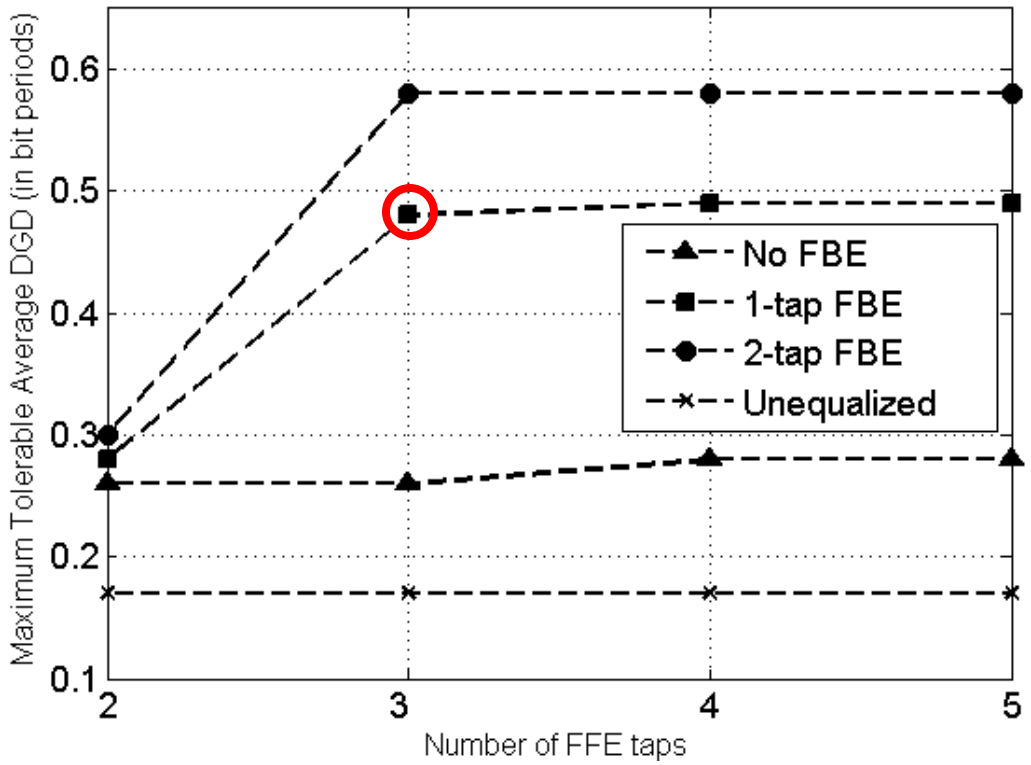


Results: 2-Tap FBE



System-Level Analysis

- Maximum tolerable average DGD vs. number of FFE taps for different FBEs and 3-dB power margin



3-tap FFE provides performance equal to 4- and 5-tap FFEs

Most of the improvement from the DFE comes from the 1st tap

Conclusions

- DFE with 3-tap FFE and 1-tap FBE offers a good balance between performance and complexity
- Using such a DFE allows an increase in system length of almost 9x

  (assuming that PMD is the dominant limitation)
- e.g. for a fiber with PMD of 1 ps/km^{½}, system reach can be extended from 18 km to 150 km
- DFE with a few taps eliminates PMD as dominant length limitation