Digital, endless polarization control for polarization multiplexed fiber-optic communications

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Introduction

Higher Spectral Density can be achieved by Polarization Multiplexing.

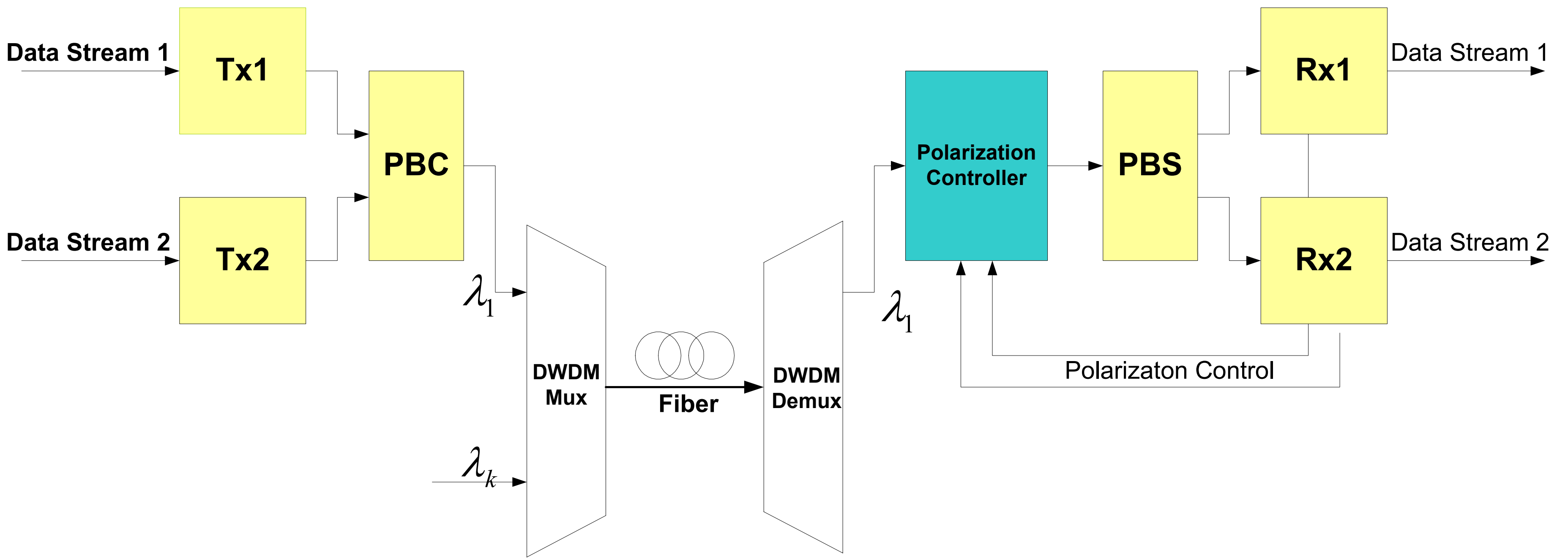
- Polarization Multiplexed On-Off Keyed Systems
- Polarization Multiplexed Coherent Systems (CeLight).

Polarization Control Requirements

- Endless/Reset-free
- Long term stability (low drift)
- Independent of input SOP (state of polarization)
- Fast response rate (order of 10^4 radians/s)
- Resolution much better than 1 degree
- Implementation of Polarization Control does not introduce extra degradation
- Low insertion loss

Conventional Implementation Diagram

- Optical Polarization Compensation Element
- Polarization Control Algorithm



Optical Polarization

Polarization Compensation Element

Type of Device	Disadvantages
Integrated-optic ($LiNb0_3$)	Non linear transfer matrix, dependency on input SOP
Optical Retardation Plates	Limited Control Range (Not endless/Require unwinding)
Fiber Squeezers	Bulky, Limited Control Range (Not endless/Require unwinding) High Input Voltage, Low duty cycle
Liquid Crystal	Slow for practical applications.

Polarization Control Algorithm

Practical Control Algorithms based on Optimization involving Dithering that introduces Implementation Noise

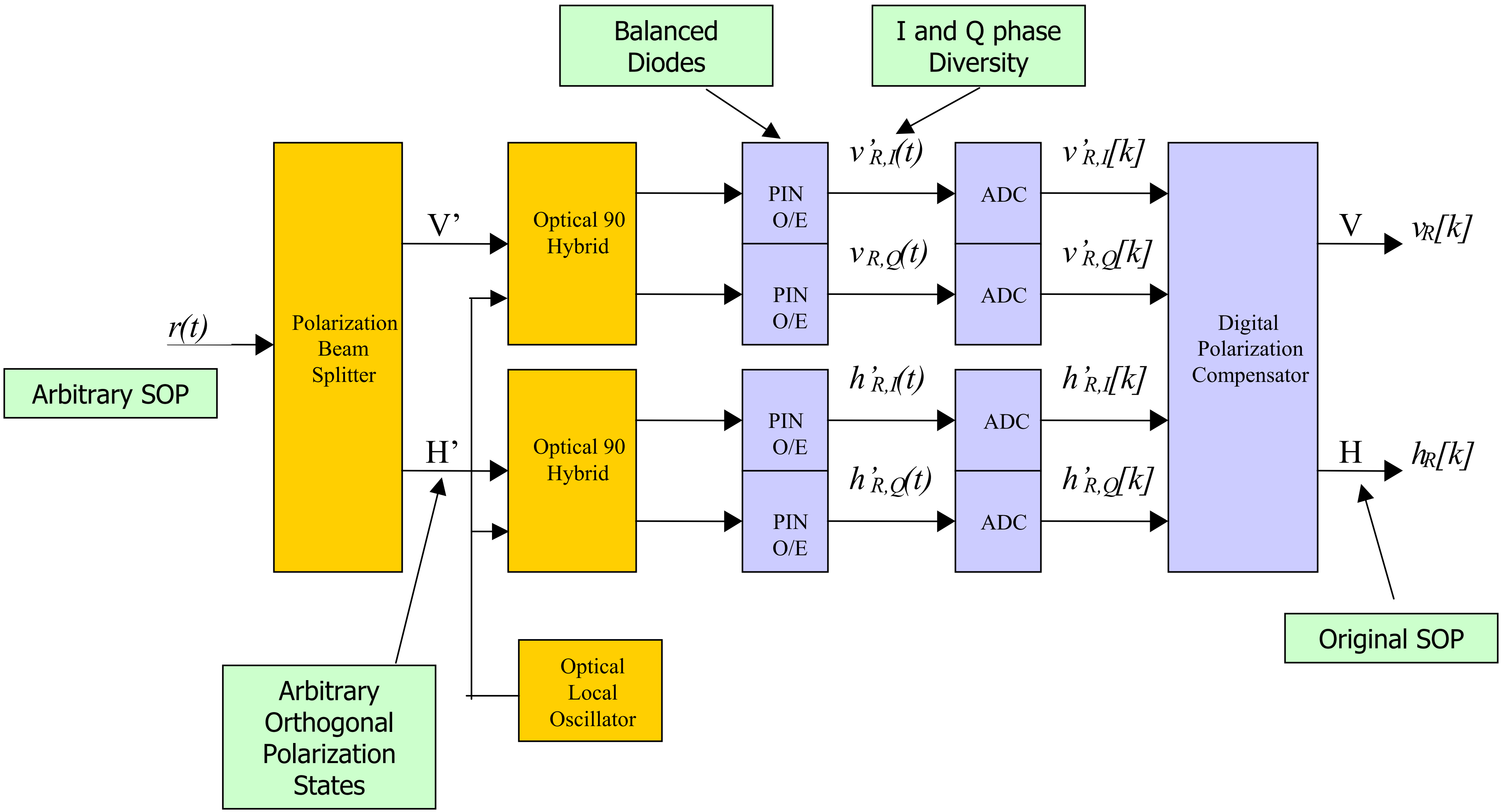
Digital Approach

Digital Polarization Compensation for Phase Diversity Receivers

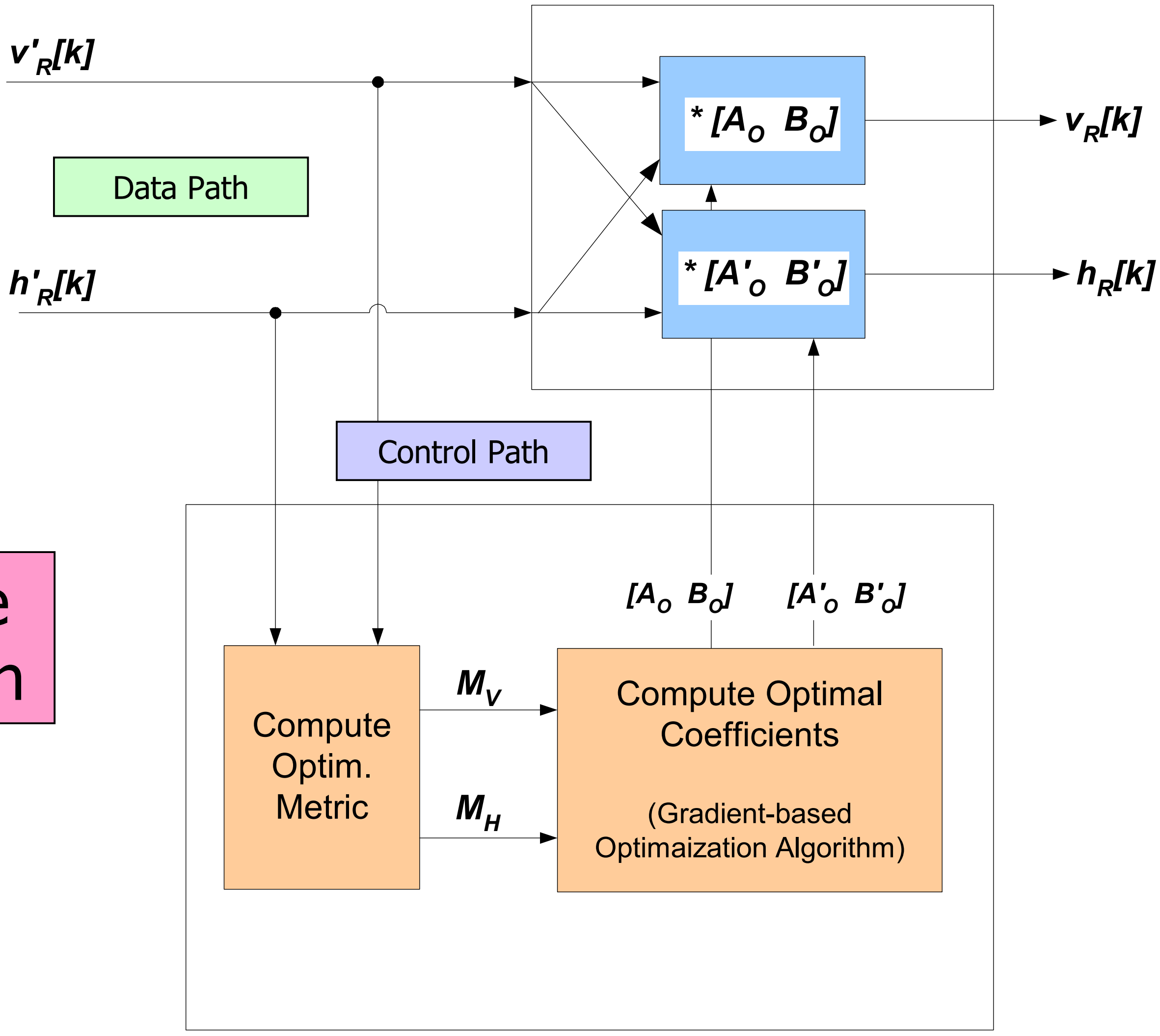
Advantages:

- Endless
- Stability is not an issue
- Performance is independent of input SOP
- Resolution is only limited by input SNR
- Optimization is performed using signal replica, therefore avoiding implementation noise
- Can compensate for PDL impairments
- Higher order PMD compensation is possible

Digital Architecture



Digital Polarization Compensator



Control is done out of data path

Polarization controller transformation

$$\begin{bmatrix} \mathrm{v}_R[k] \\ \mathrm{h}_R[k] \end{bmatrix} = T_{PC} \begin{bmatrix} \mathrm{v'}_R[k] \\ \mathrm{h'}_R[k] \end{bmatrix}$$

where $\boldsymbol{T}_{PC}$ *is a* general transformation matrix of the form :

$$T_{PC} = \begin{bmatrix} A_O & B_O \\ A'_O & B'_O \end{bmatrix} = \begin{bmatrix} \cos(\psi) + j\sin(\psi)\cos(\gamma) & -j\sin(\psi)\sin(\gamma)e^{j\mu} \\ -j\sin(\psi')\sin(\gamma')e^{-j\mu'} & \cos(\psi') - j\sin(\psi')\cos(\gamma') \end{bmatrix}$$

Angles (ψ, γ, μ) and (ψ', γ', μ') are computed as the optimal angles by the gradient-based algorithm that optimizes metrics Mv and Mh respectively.

Optimization metric

The choice of the criterion depends on the signal modulation scheme.

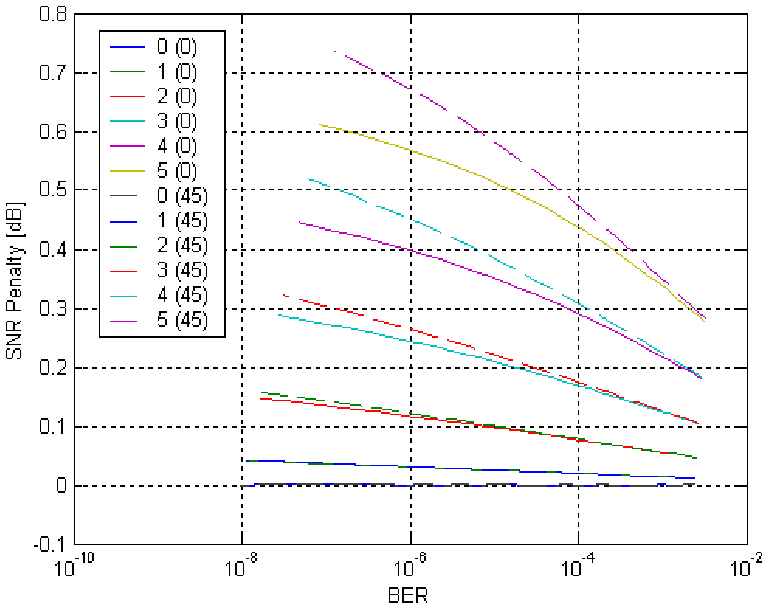
Possible criteria:

- Signal-to-Interference Ratio SIR
- Power Maximization/Minimization
- Envelope Based Metric
- Training Sequence (Unique Word) Correlation Based Metric

The metrics are separately optimized for each polarization to address PDL impairments.

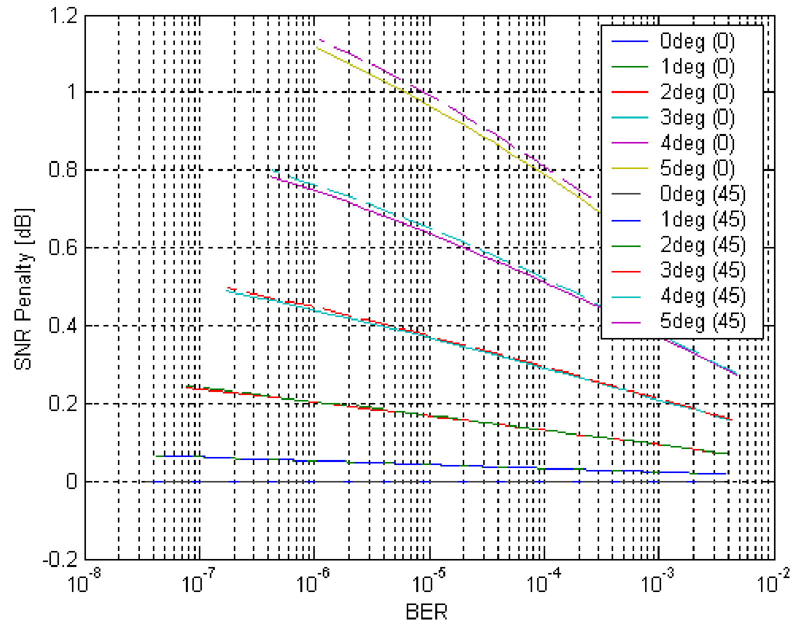
QPSK And DQPSK Penalties due to polarization tracking error

Polarization-Multiplexed QPSK



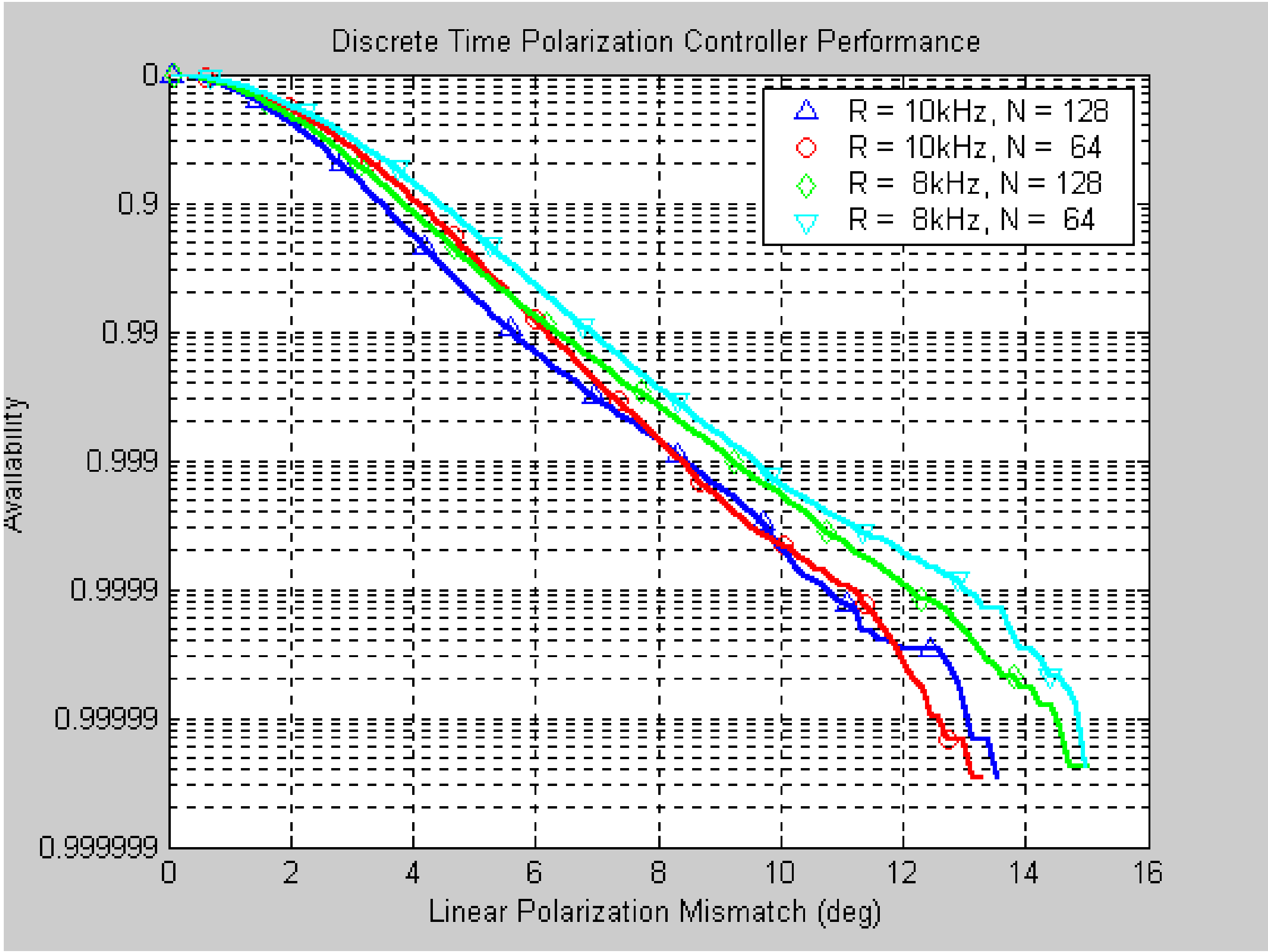
SNR penalty vs. BER for different values of polarization tracking error with θ =0 and θ =45°

Polarization-Multiplexed DQPSK

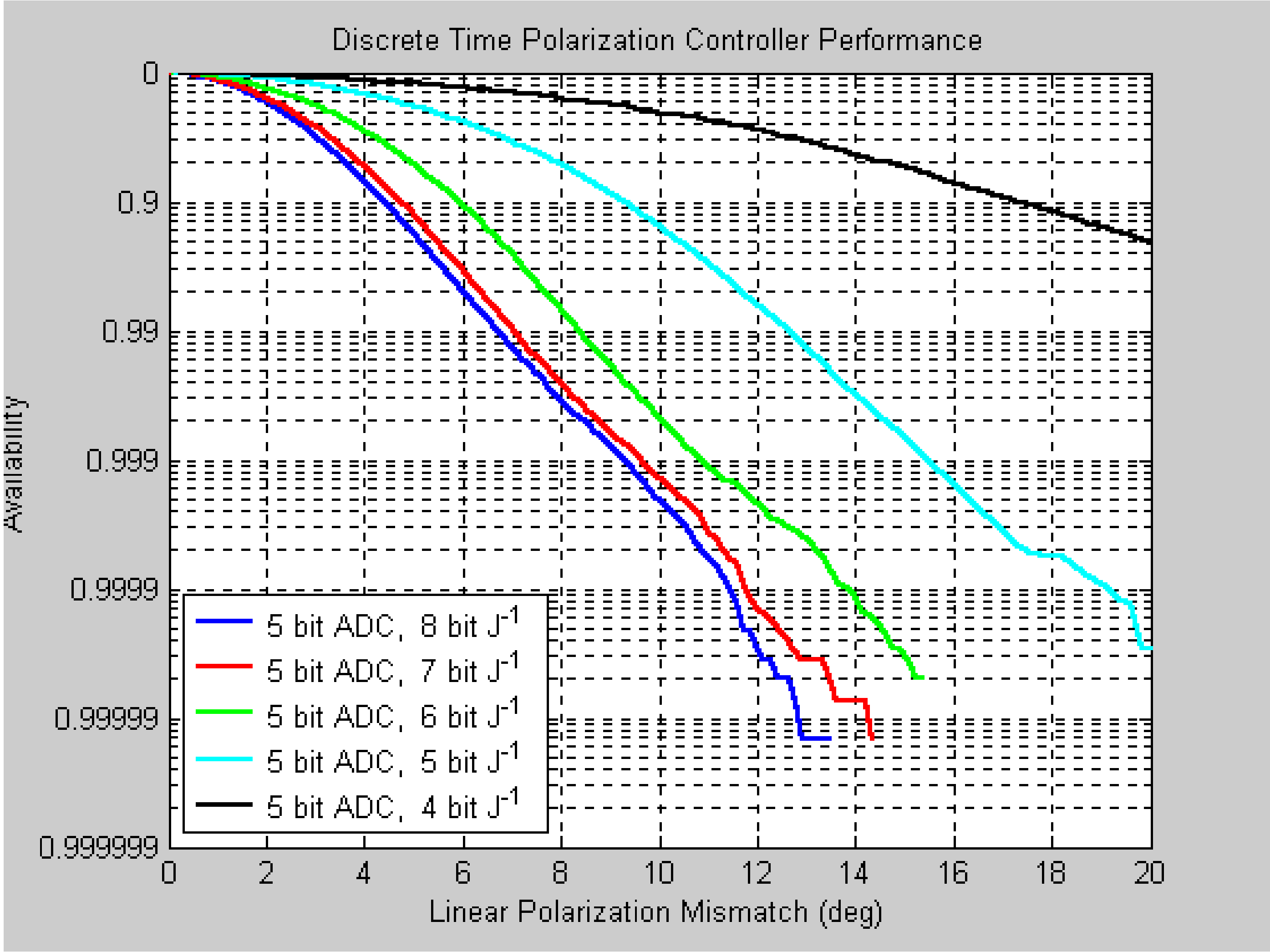


SNR penalty vs. BER for different values of polarization tracking error with θ =0 and θ =45°

Polarization Controller Performance



Finite Precision Algorithm Performance



Conclusions

- We proposed and numerically modeled a polarization compensator that digitally reconstructs the components of a polarization division multiplexed signal using a gradient-based optimization method
- The choice of the optimization criteria can be dynamically adjusted to the signal modulation scheme
- Applicable to any modulation format