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AI-NET-PROTECT

Phase-Predistortion to Mitigate Chromatic Dispersion Effects in Direct Detection Systems

24. VDE ITG Fachtagung Photonische Netze

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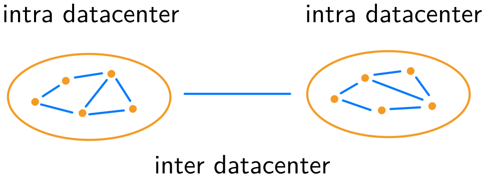
Overview

Short-Reach Fiber-Optic Communication System



keep system costs down:

- no amplifiers
  - ⇒ nonlinear effects negligible
- direct detection (DD) receiver

EM wave $E(t)$ ⟶ [DD] ⟶ current $\sim |E(t)|^2$

Impact of Chromatic Dispersion

propagation of baseband signal $s(z,t)$ over purely dispersive optical fiber channel:

$$\left(\frac{\partial}{\partial z} - \mathrm{j}\beta_2/2 \cdot \frac{\partial^2}{\partial t^2}\right) \cdot s(z,t) = 0$$

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- expressing $s(z,t)$ by its magnitude and phase, i.e., $s(z,t) = |s(z,t)| \cdot \exp\left(\mathrm{j}\varphi(z,t)\right)$:

$$\frac{\partial|s(z,t)|}{\partial z} + \beta_2 \cdot \frac{\partial|s(z,t)|}{\partial t} \cdot \frac{\partial\varphi(z,t)}{\partial t} + \frac{\beta_2}{2} \cdot |s(z,t)| \cdot \frac{\partial^2\varphi(z,t)}{\partial t^2}$$
$$+\,\mathrm{j}\left(|s(z,t)| \cdot \frac{\partial\varphi(z,t)}{\partial z} - \frac{\beta_2}{2} \cdot \frac{\partial^2|s(z,t)|}{\partial t^2} + \frac{\beta_2}{2} \cdot |s(z,t)| \cdot \left(\frac{\partial\varphi(z,t)}{\partial t}\right)^2\right) = 0$$

- separate into real and imaginary part:

$$\Longrightarrow \ \frac{\partial |s(z,t)|}{\partial z} = -\beta_2 \cdot \left(\frac{\partial |s(z,t)|}{\partial t} \cdot \frac{\partial \varphi(z,t)}{\partial t} + \frac{|s(z,t)|}{2} \cdot \frac{\partial^2 \varphi(z,t)}{\partial t^2} \right),$$

$$\Longrightarrow \ \frac{\partial \varphi(z,t)}{\partial z} = \frac{\beta_2}{2} \cdot \left(|s(z,t)|^{-1} \cdot \frac{\partial^2 |s(z,t)|}{\partial t^2} - \left(\frac{\partial \varphi(z,t)}{\partial t} \right)^2 \right)$$

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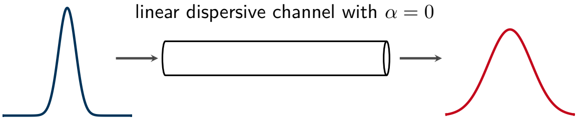


$|s(z=0,t)|$ with $s(z=0,t) \in \mathbb{R}$ $\quad$ $|s(z=L,t)|$ with $s(z=L,t) \in \mathbb{C}$

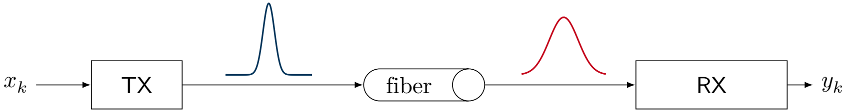
Impact of Chromatic Dispersion (CD)

$\Longrightarrow$ CD causes time-varying phase $\triangleq$ time-variant frequency deviation, i.e., $\partial\omega(z,t) = \frac{\partial\varphi(z,t)}{\partial t}$

$\Longrightarrow$ different frequency contributions propagate at different speeds

$\Longrightarrow$ pulse gets distorted in magnitude and phase

Non-Optical Chromatic Dispersion Compensation



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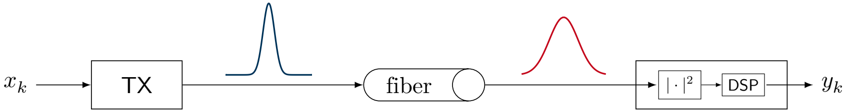
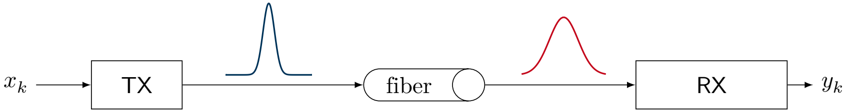


equalization at the receiver:

- nonlinear equalization due to square law detector

⇒ complex receiver design

Non-Optical Chromatic Dispersion Compensation



predistortion at the transmitter:

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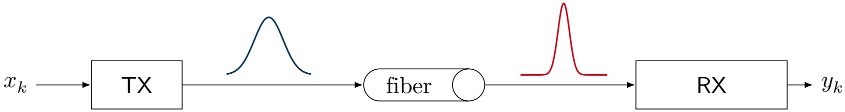

predistortion at the transmitter:

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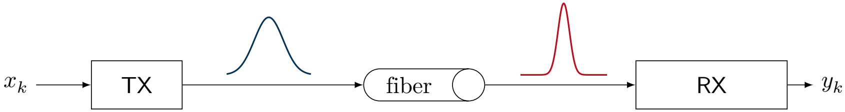


predistortion at the transmitter:

- predistortion of phase and magnitude
    - using IQ-Mach-Zehnder modulator[1]
    - or direct modulation with amplitude modulator[2]

equalization at the receiver:

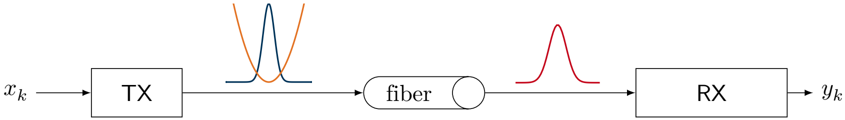
- nonlinear equalization due to square law detector

$\Rightarrow$ complex receiver design

[1] Killey et al., Electronic dispersion Compensation by Signal Predistortion, 2006.

[2] Koch et al., Dispersion Compensation by Active Predistorted Signal Synthesis, 1985.

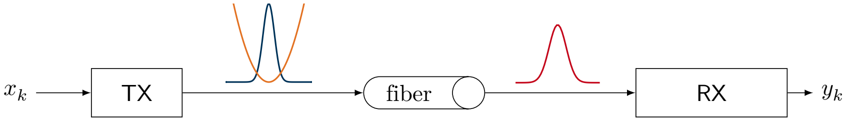
Non-Optical Chromatic Dispersion Compensation



predistortion at the transmitter:

- phase predistortion on symbol-per-symbol basis

Non-Optical Chromatic Dispersion Compensation



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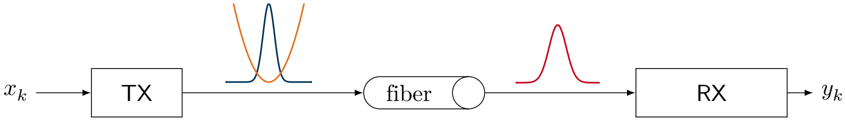

predistortion at the transmitter:

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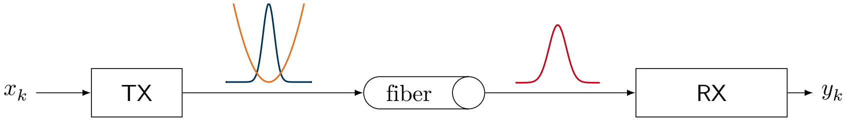
$\Rightarrow$ imperfectly predistorted signal

  - chromatic dispersion cannot be reduced/compensated for arbitrarily large distances
  - phase predistortion limited to single symbol duration

Non-Optical Chromatic Dispersion Compensation



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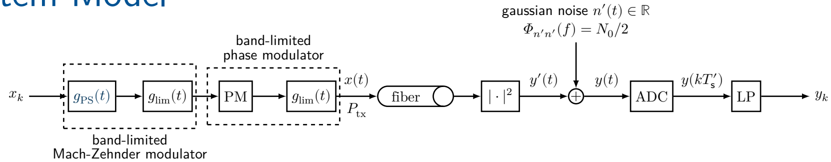
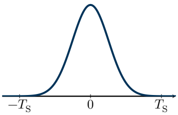
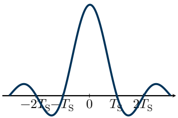
$\Rightarrow$goal: performance enhancement in cost effective simple manner

System Model

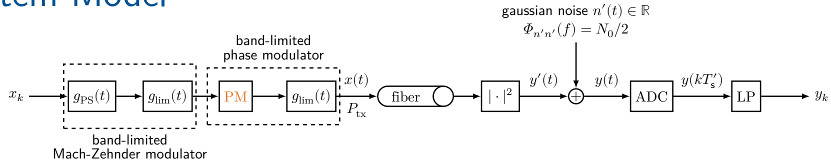


- symbols uniformly drawn from on-off keying (OOK) alphabet $\mathcal{A}$, i.e., $x_k \in \mathcal{A}$
- considering two pulse shapes $g_{PS}(t)$ (Gaussian and sinc) with $B = 1/T_S = 33\,\text{GHz}$:

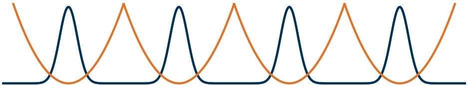




System Model

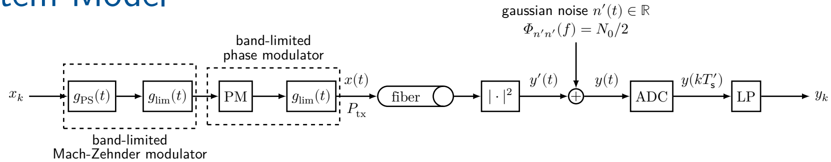


- phase is applied symbol-wise by phase modulator:



- Kerr non-linearity neglected ⇒ linear channel (distortions: attenuation and CD)

System Model



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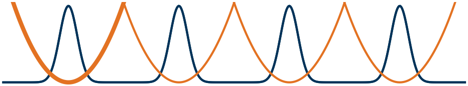
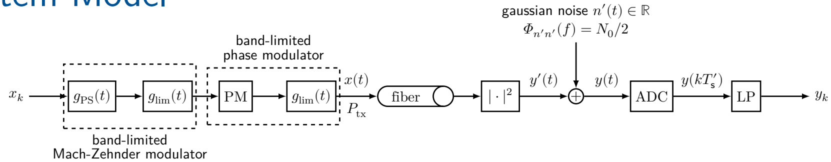


$$\Rightarrow \partial\omega(t) = \frac{\partial\varphi(t)}{\partial t} = -\mathrm{sgn}(\beta_2) \cdot C \cdot t$$

- Kerr non-linearity neglected $\Rightarrow$ linear channel (distortions: attenuation and CD)

System Model

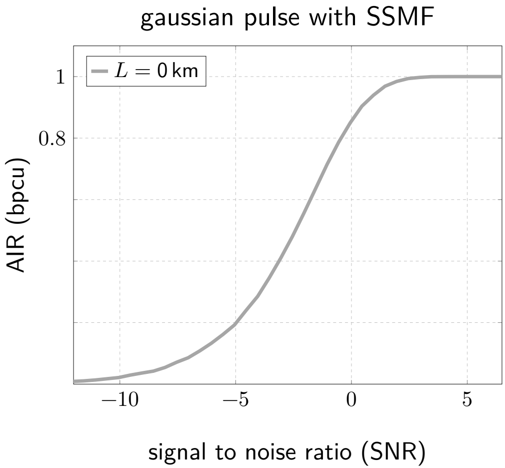


- analog-to-digital converter (ADC) is a bandlimited sampling device with $N_{\mathrm{OS}} = 3$
- in case signal bandwidth is smaller than ADC bandwidth, the noise power is further reduced by the LP filter

Numerical Results

- C-band at $\lambda_c = 1550\,\text{nm}$
- performance metric: achievable information rate (AIR)
- SNR definition: $\text{SNR} = P_{\text{tx}}/\sigma_n^2$, where noise variance after the ADC is set to $\sigma_n^2 = 1$

Saving Input Power



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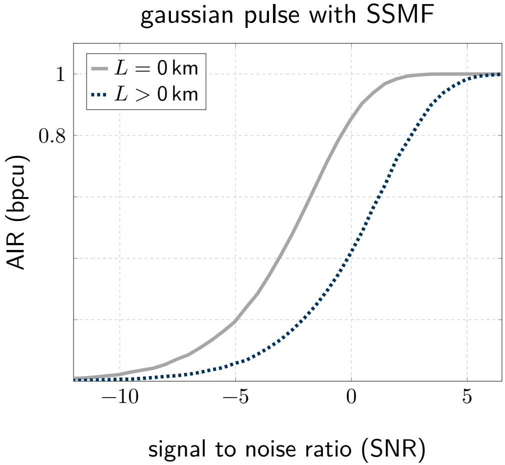

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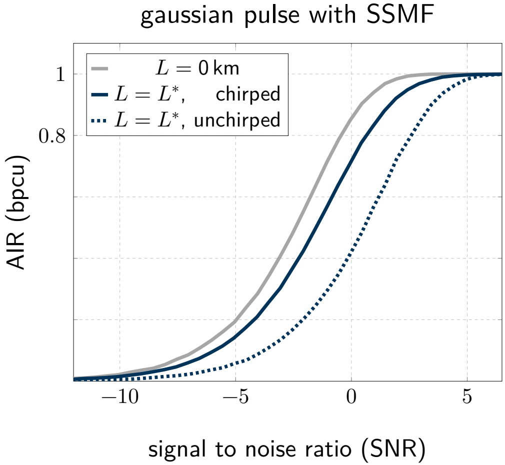
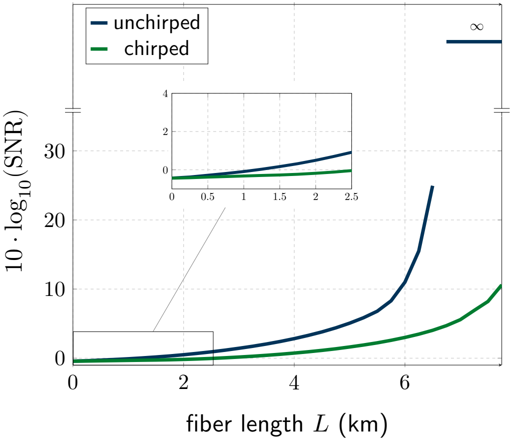


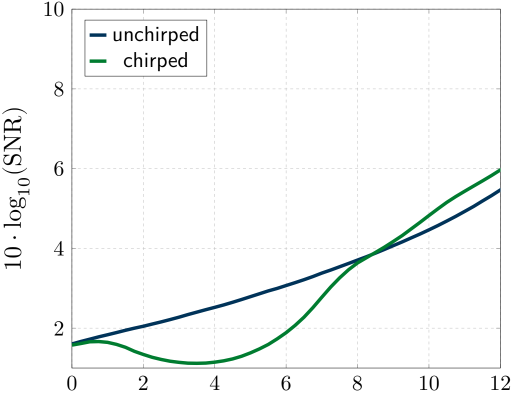
by chirping: system operating point is achieved for less input power

Required SNR over Length: Gaussian Pulse Shaping



by chirping: absolute reach increase

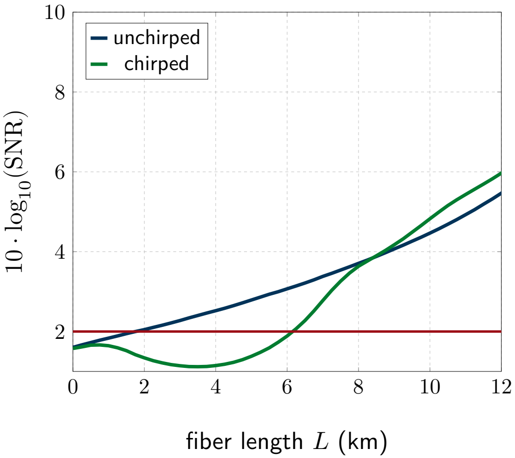
Required SNR over Length: Sinc Pulse Shaping



fiber length L (km)

by chirping: no absolute reach increase

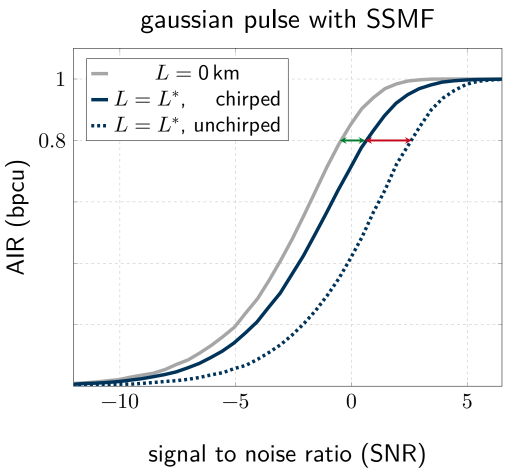
Required SNR over Length: Sinc Pulse Shaping



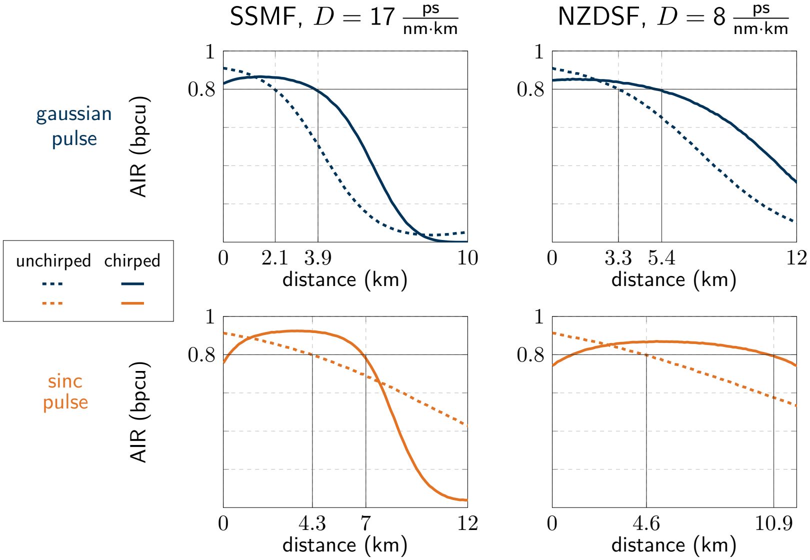
by chirping: no absolute reach increase

⇒ reach increase under input power constraint

1 dB Power Constraint



- allow power penalty of 1 dB (green arrow)
- find C^* for certain reach L^* while satisfying power constraint


SSMF, $D = 17 \frac{\text{ps}}{\text{nm}\cdot\text{km}}$
NZDSF, $D = 8 \frac{\text{ps}}{\text{nm}\cdot\text{km}}$
gaussian pulse
sinc pulse
AIR (bpcu)
1
0.8
0
2.1
3.9
10
3.3
5.4
12
4.3
7
4.6
10.9
distance (km)
unchirped
chirped

Ongoing Work

- C-band + O-band
- interaction of chirp with nonlinear fiber channel
- different pulse shapes: time-limited vs. band-limited
- optimized chirp shape