ASE-Noise Limit of Direct-Detection Receivers: Duobinary vs. IMDD

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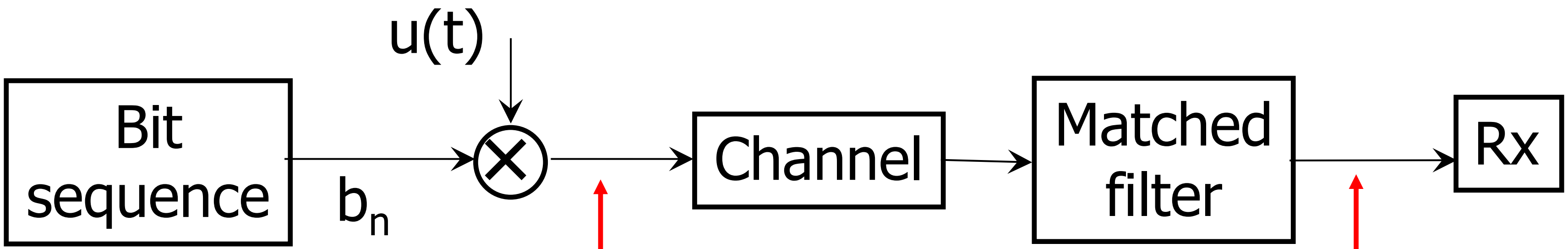
Introduction

- The optical duobinary data-coding is a promising technology for the implementation of ultra-dense WDM systems with spectral efficiency close to the Nyquist limit.
- The purpose of this work is to derive, for the first time to our knowledge, the back-to-back sensitivity of duobinary technique in ASE-noise-limited direct detected (DD) optical systems.

Summary

- Performance limit for Intensity Modulation
- The Duobinary modulation format
- Performance limit for Duobinary with a direct-detection receiver
- A practical implementation of optical Duobinary
- Conclusions

Intensity Modulation (IM)



$$s_{TX}(t) = \sum_n b_n u(t - nT)$$

$$s_{RX}(t) = \sum_n b_n x(t - nT) + n(t)$$

- **Coherent detection**

$$BER = \frac{1}{2}\operatorname{erfc}\left(\sqrt{OSNR}\right)$$

Average received signal power

$$OSNR = \frac{\overline{P}_S}{2 N_0 R_B}$$

Bit-rate

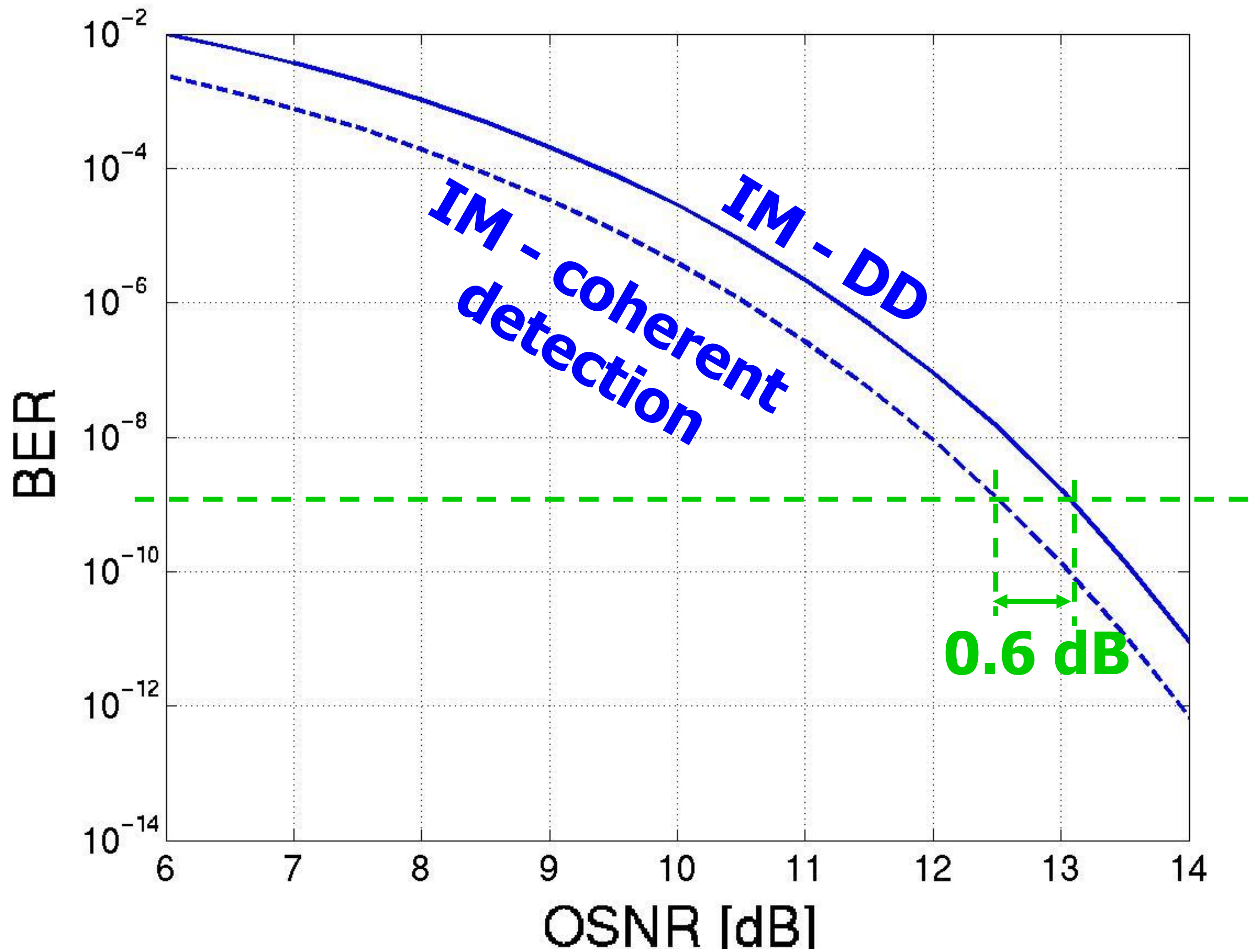
ASE noise power spectral density

- **Direct detection**

$$BER = \frac{1}{2}\left\{e^{-\phi}\left(1+\phi\right)+1-Q_2\left(\sqrt{8\,OSNR},\sqrt{2\phi}\right)\right\}$$

BER does not depend on the pulse shape

IM: coherent vs. direct detection



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IM vs. Duobinary

Intensity Modulation

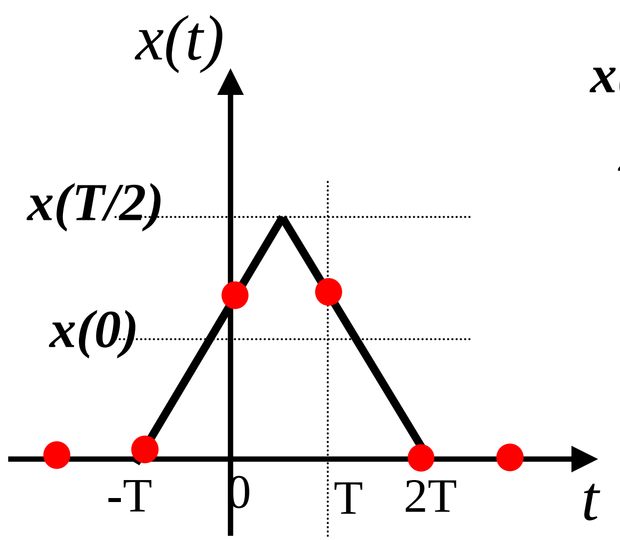
Absence of ISI:

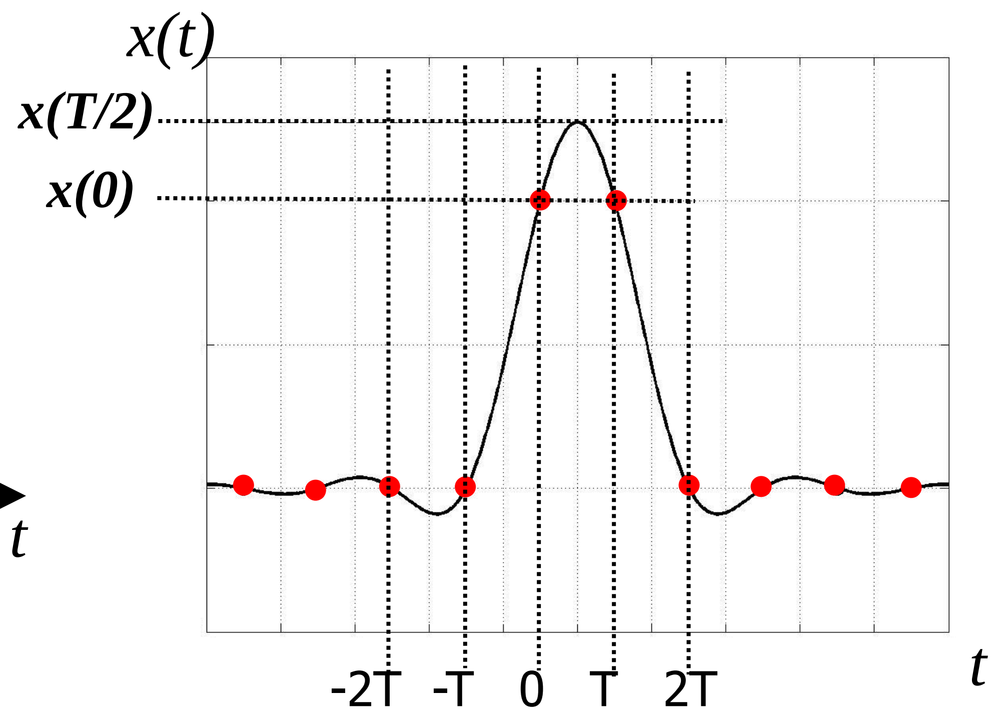
$$x(0) \neq 0, x(nT) = 0, \forall n \neq 0$$

Duobinary

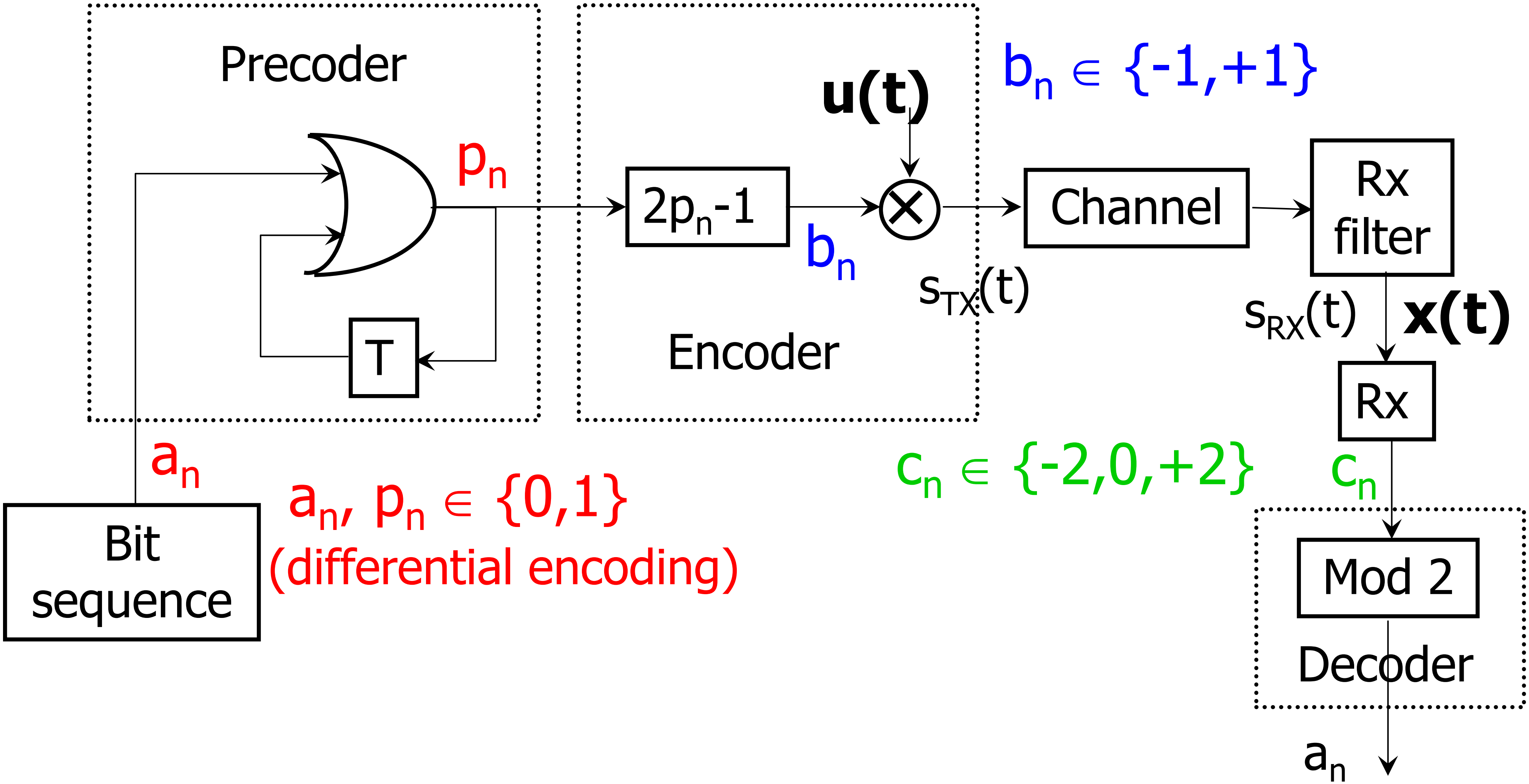
Controlled amount of ISI:

$$x(0) = x(T) \neq 0, x(nT) = 0, \forall n \neq 0,1$$

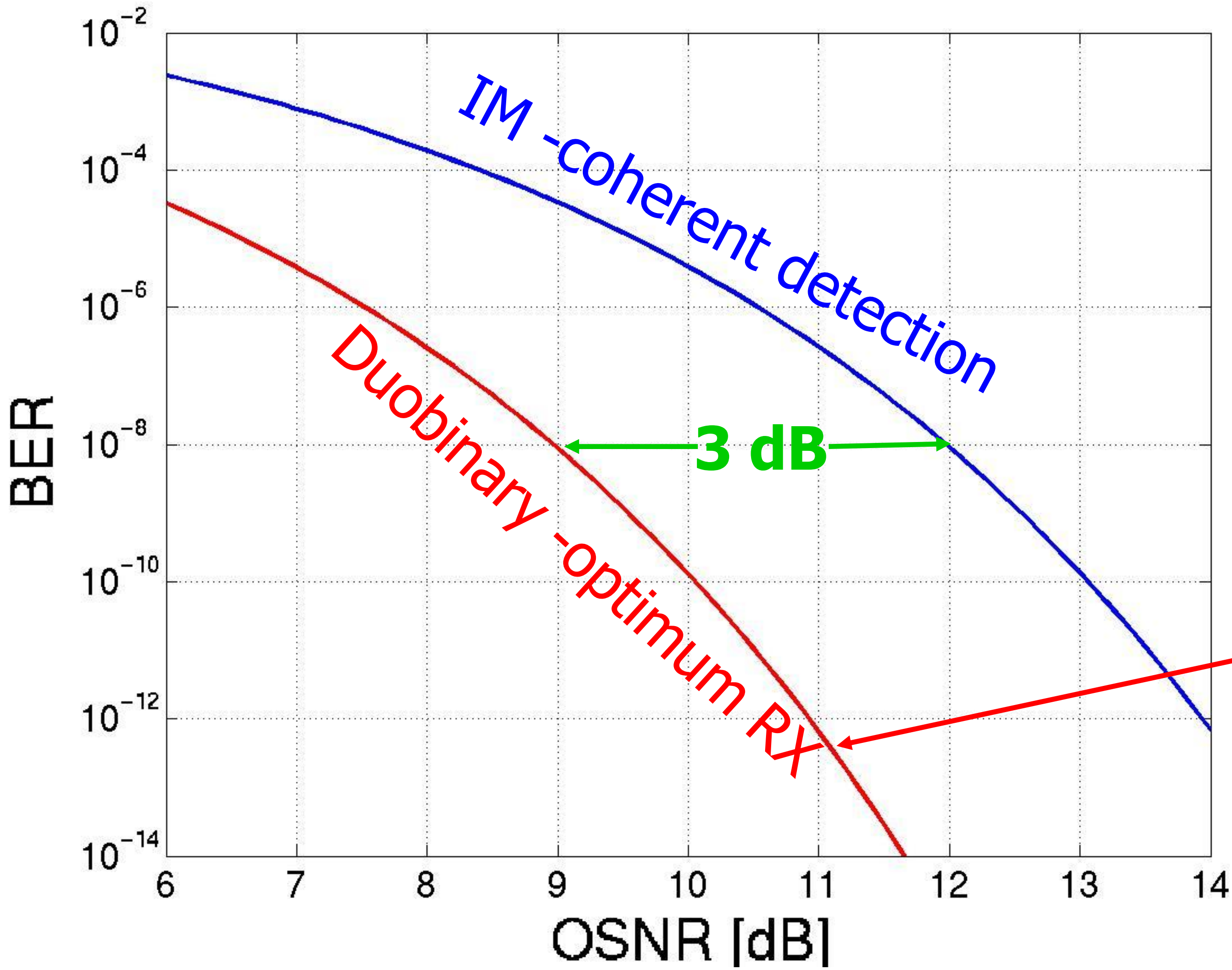




Duobinary system schematics



Duobinary vs. IM (optimum RX)



The optimum duobinary RX makes use of a Viterbi processor

(see J.G. Proakis, *Digital Communications*, New York, McGraw-Hill, 1989)

The BER is given by:

$$BER = \frac{1}{2}\,\mathrm{erfc}\left(\sqrt{2\,OSNR}\right)$$

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Duobinary received signal

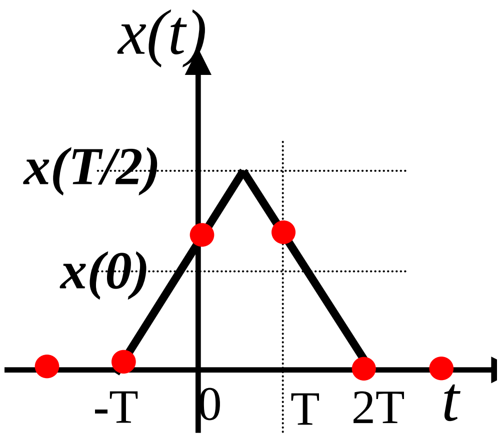
$$s_{RX}\left(t_{opt}+nT\right)=\left[c_n x(0)+n_r+j\,n_i\right]$$

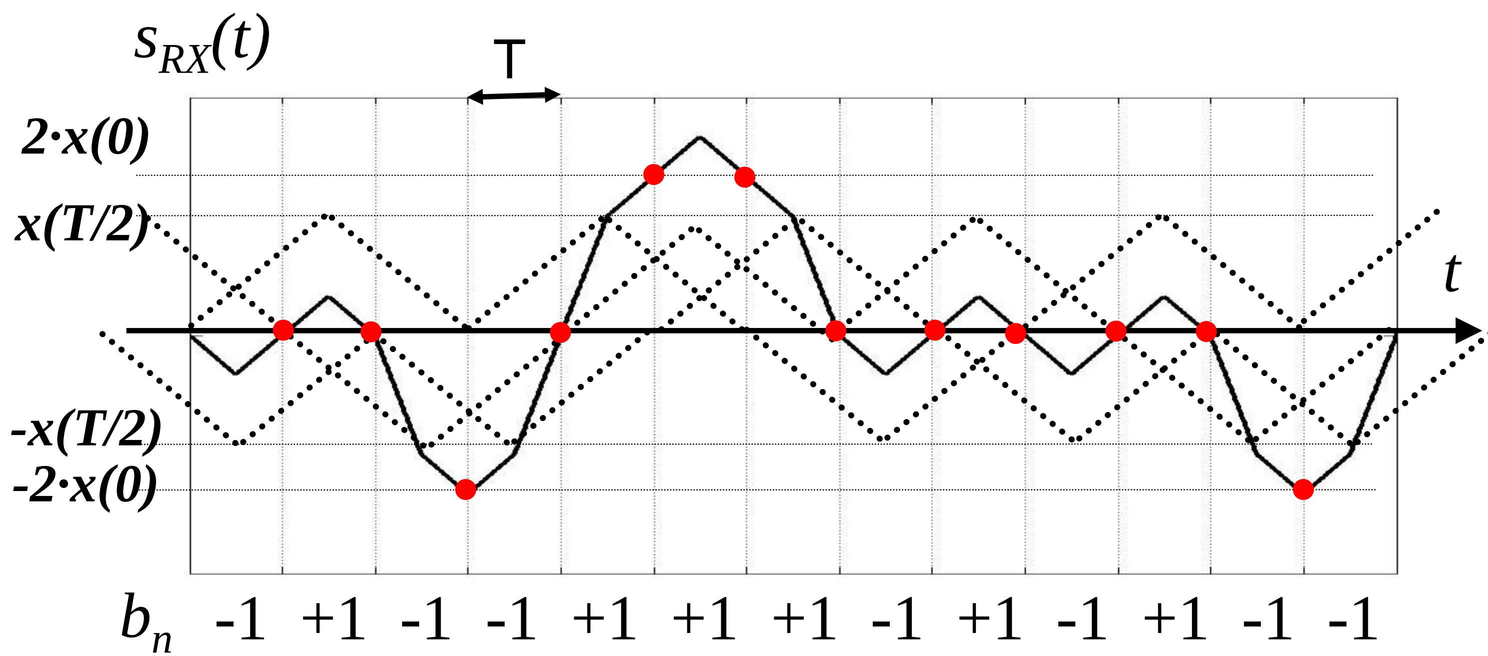
Gaussian r.v. with

$$\sigma^2 = x\left(T/2\right)\frac{N_0}{2}$$

$$c_n=\begin{cases}+2 & b_n=b_{n-1}=+1\\ 0 & b_n\neq b_{n-1}\\ -2 & b_n=b_{n-1}=-1\end{cases}$$

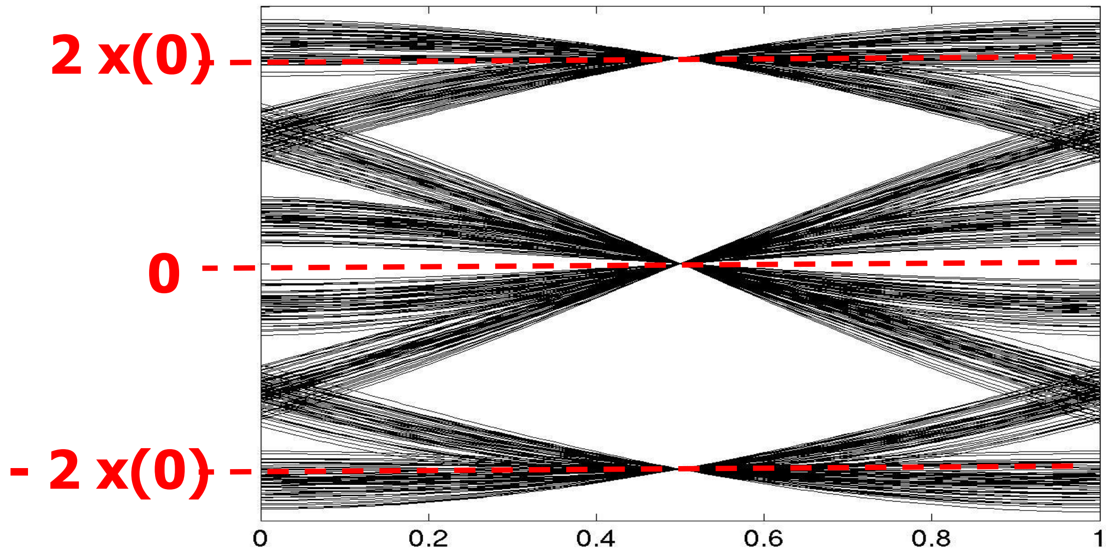
Three-level signal



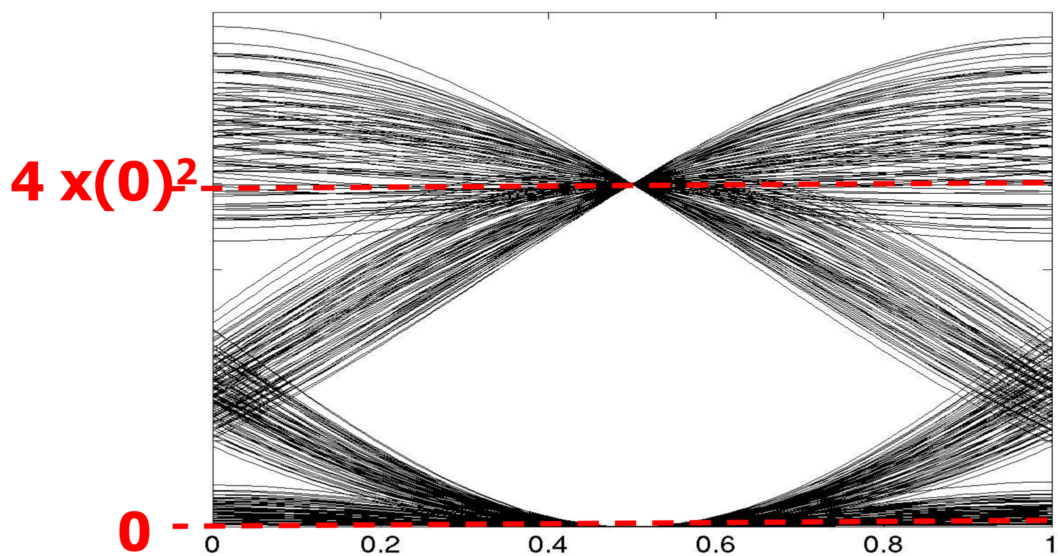


Noiseless eye diagrams

Before photodetection



After photodetection



Duobinary with direct-detection

- After photodetection:

$$v = \left| s_{RX}\left(t_{opt} + nT\right)\right|^2 = \left[c_n x(0) + n_r\right]^2 + n_i^2$$

Gaussian r.v. with

$$\sigma^2 = x\left(T/2\right)\frac{N_0}{2}$$

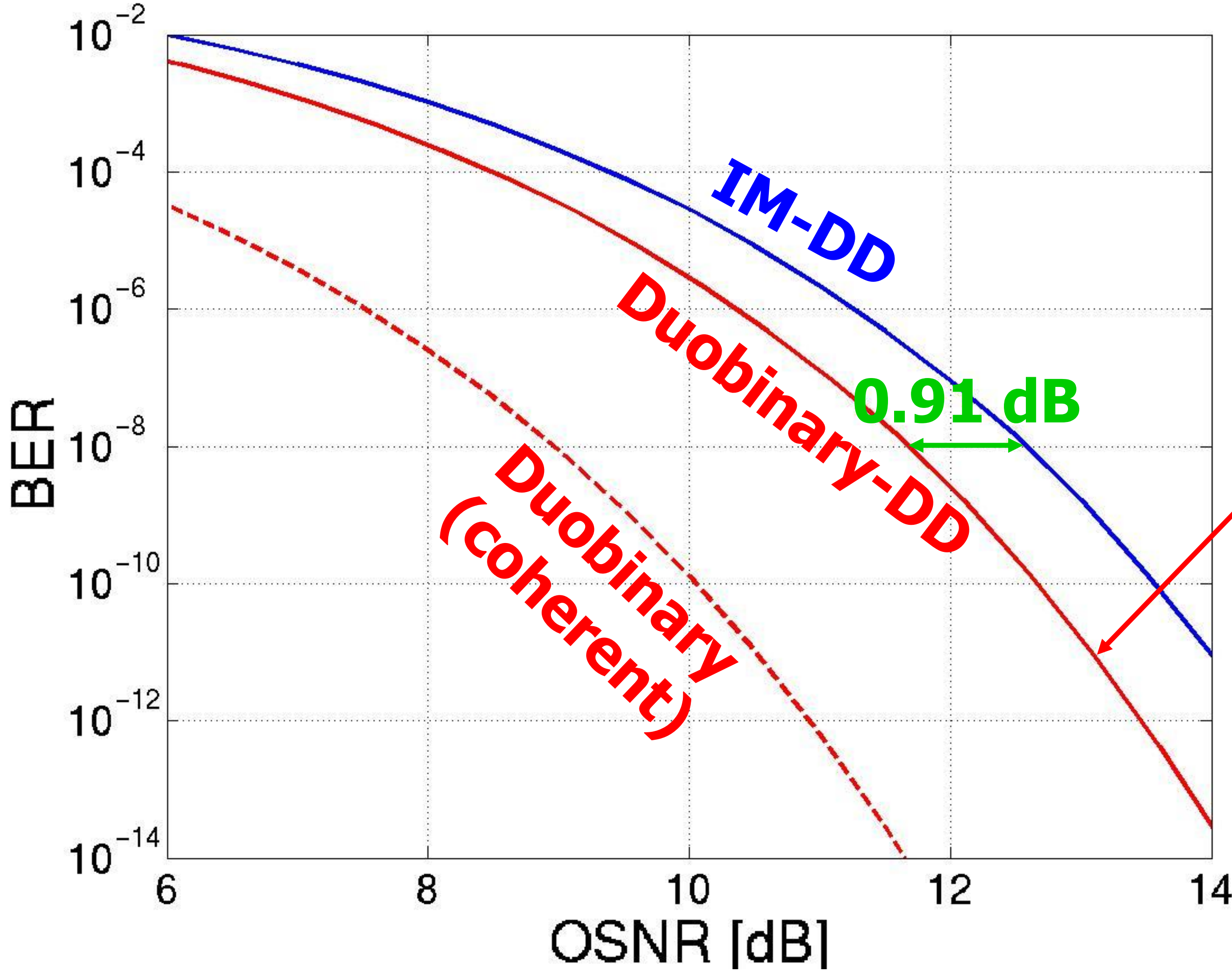
- v is a Chi-square distributed r.v. with variance parameter σ^2 and centrality parameter $s = c_n x(0)$.

- The BER can be analytically written as:

$$BER = \frac{1}{2}\left\{ e^{-\phi}\left(1+\phi\right) + 1 - Q_2\left(\frac{x(0)}{x(T/2)}\sqrt{16\,OSNR}, \sqrt{2\phi}\right)\right\}$$

The BER depends on the pulse shape !!!!

Direct detection: IM vs. Duobinary

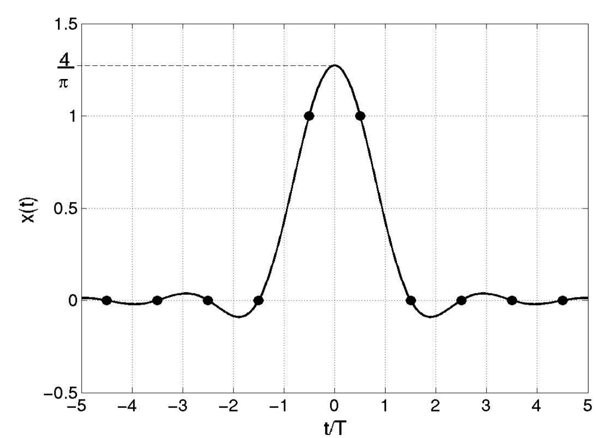


Obtained with the minimum-bandwidth pulse:

$$X(f) = 2T\cos(\pi fT)$$

$$\text{for } f \in \left[-\frac{1}{2T}, \frac{1}{2T}\right]$$

$$X(f) = 0 \text{ otherwise}$$



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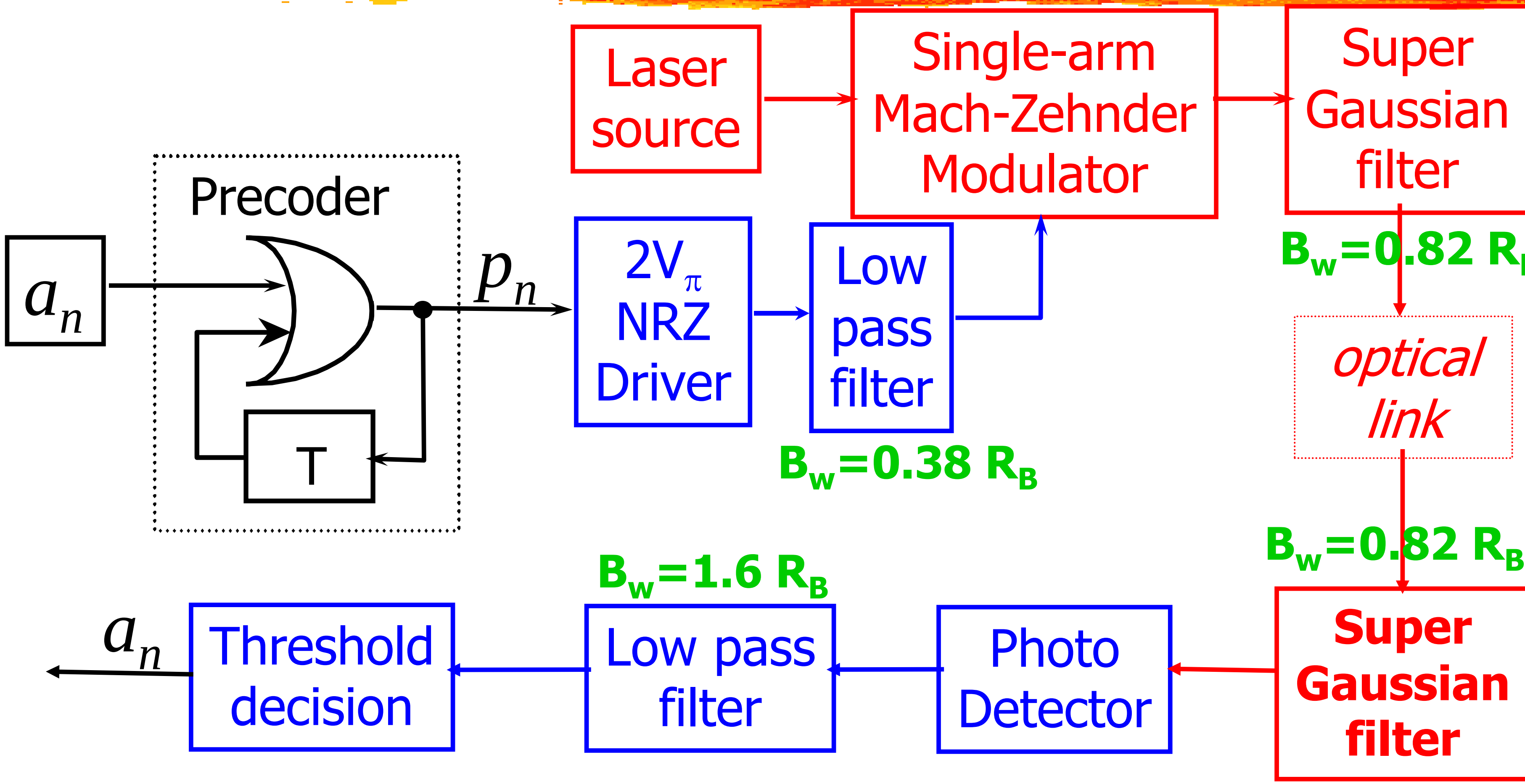
Practical implementation of optical duobinary



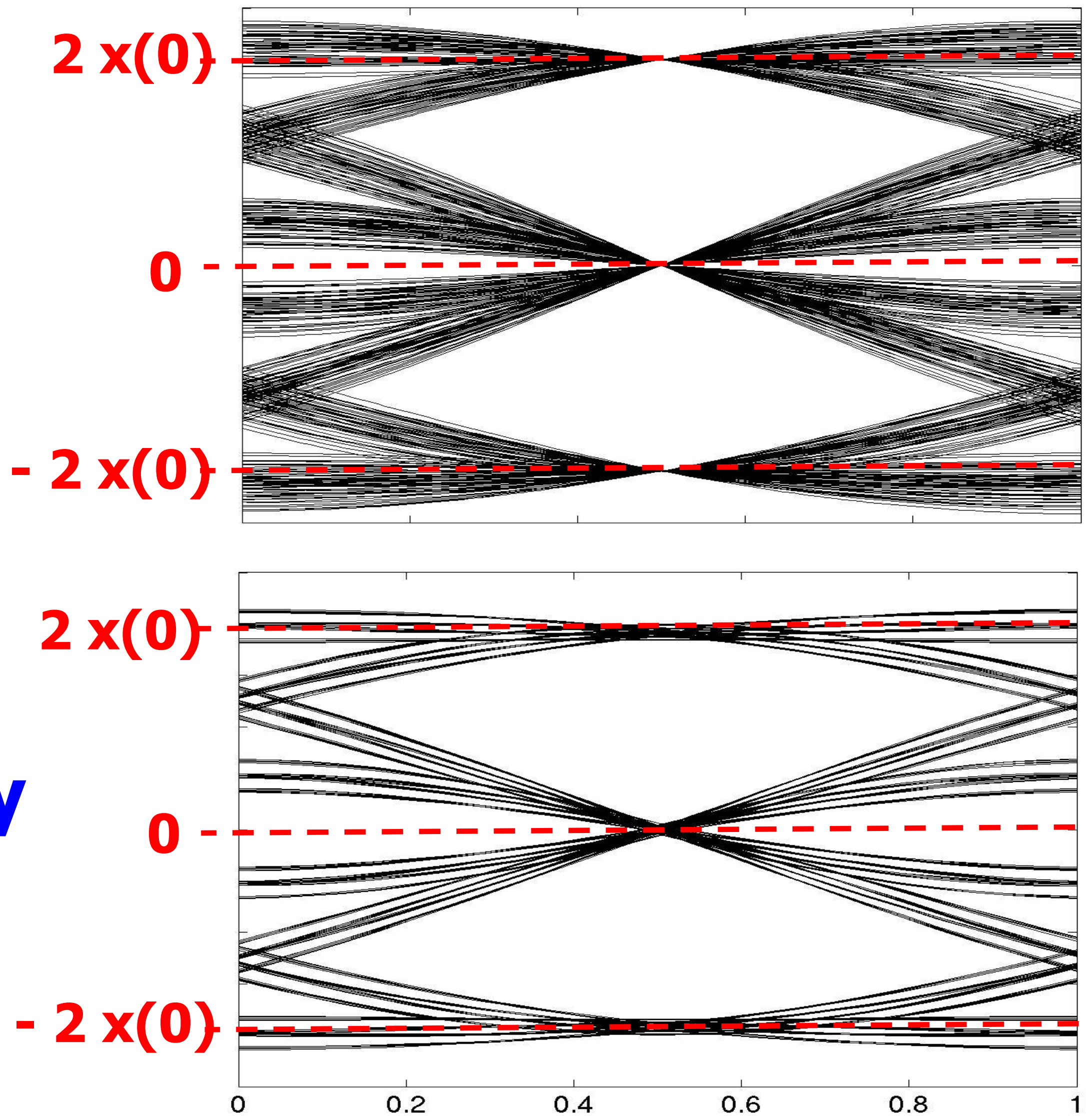
D. Penninckx et al., "The Phase-Shaped Binary Transmission (PSBT)": a new technique to transmit far beyond the chromatic dispersion limit", *IEEE Photon. Technol. Lett.*, vol. 9, no. 2, Feb. 1997.

Noiseless eye diagrams

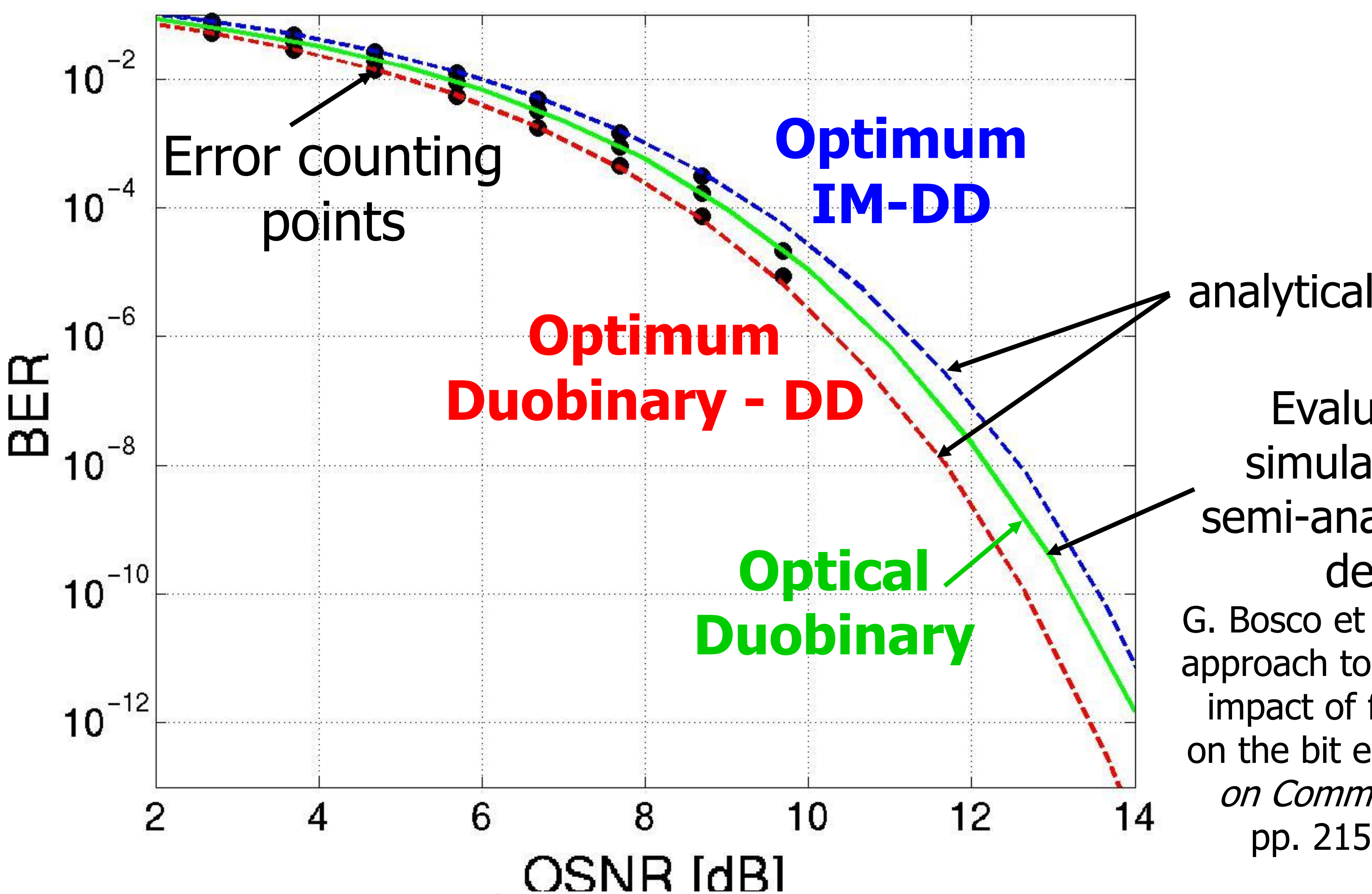
Matched filter with minimum bandwidth pulse

(before photodetection)

Optical duobinary



Performance comparison



Evaluated through simulation using the semi-analytical technique described in:

G. Bosco et al., "A novel analytical approach to the evaluation of the impact of fiber parametric gain on the bit error rate", *IEEE Trans. on Commun.*, vol. 49, no.12, pp. 2154-2163,Nov. 2001

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Conclusions

- An expression of the BER in a back-to-back ASE noise limited optical system emplying the duobinary modulation format has been derived.
- The expression of the BER for the matched-filter duobinary depends on the pulse shape.
- The back-to-back sensitivity of direct-detection duobinary is at least 0.91 dB better than the one of intensity modulation.
- Practical implementations of optical duobinary have the potential of exceeding the quantum limit of IMDD.