Best optical filtering for duobinary transmission

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speaker

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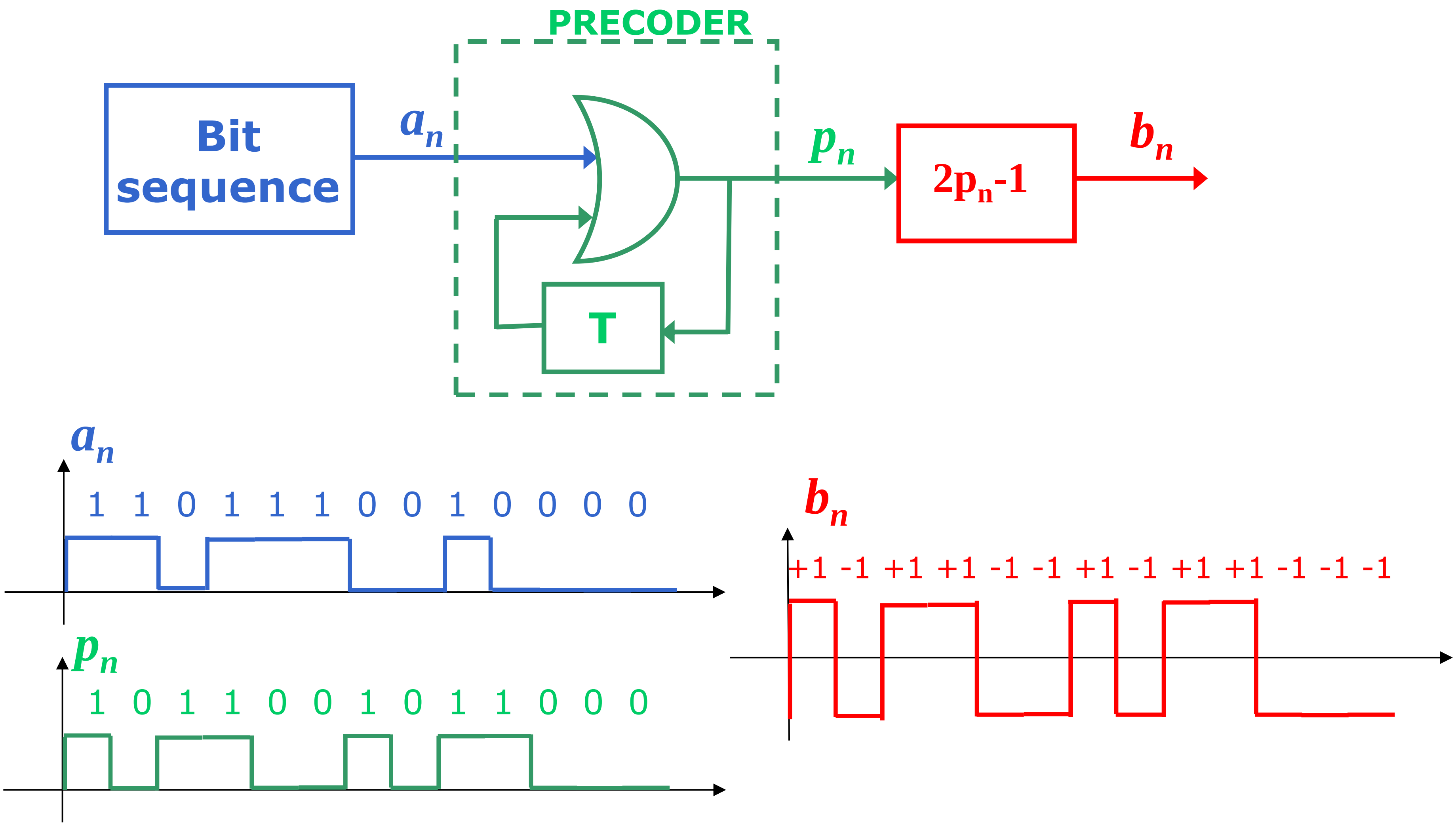
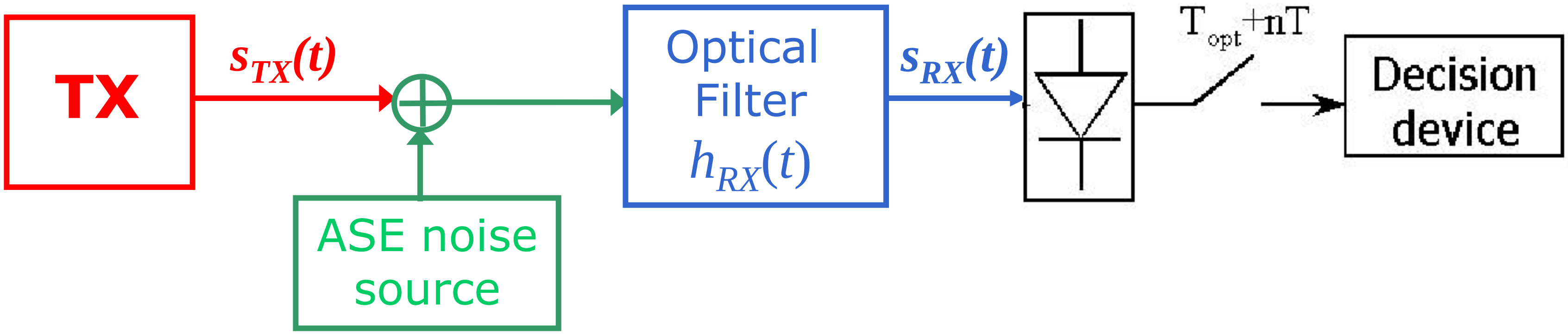
Introduction

- The purpose of this work is to demonstrate that, while in standard IMDD systems the optimum receiver is based on the optical filter matched to the pulse shape, for duobinary transmission systems this is not valid in general.
- 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 and high dispersion resilience.

Duobinary signal generation



Transmission system configuration



$$s_{TX}(t)=\sqrt{P_S}\left[\sum_n b_n u(t-nT)\right]e^{j2\pi f_0 t}\widehat{v}_{\parallel}$$

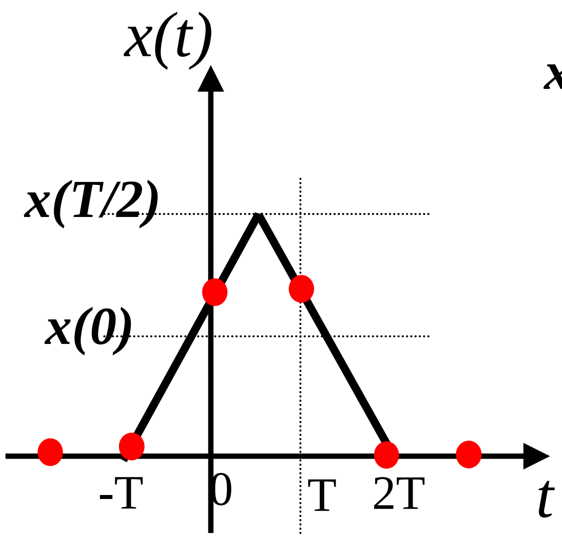
$$x(t)=u(t)*h_{RX}(t)$$

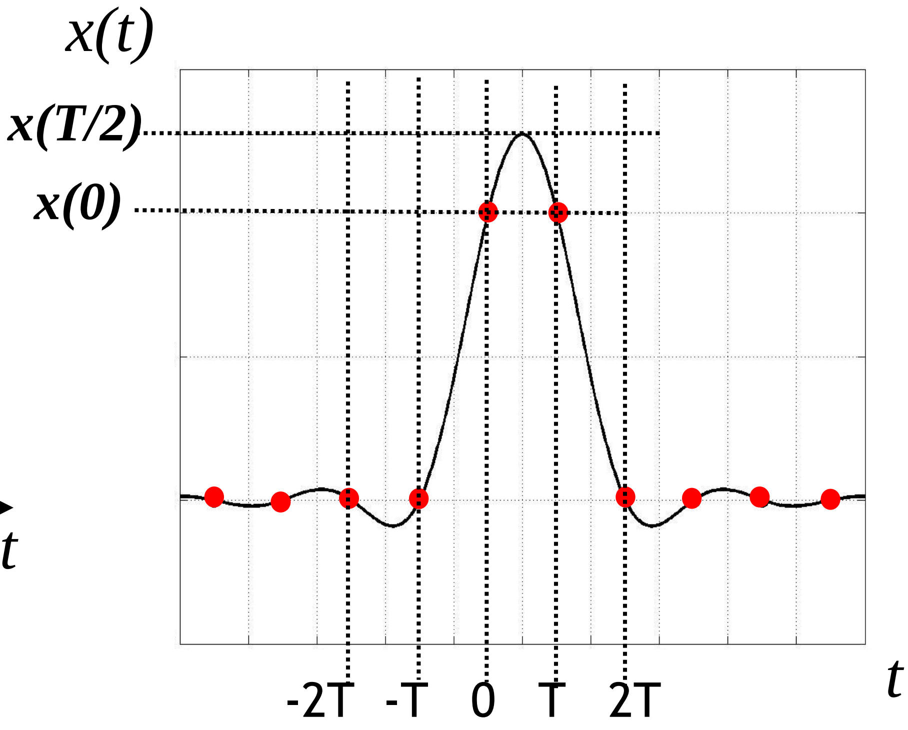
$$s_{RX}(t)=\left\{\sqrt{P_S}\left[\sum_n b_n x(t-nT)+n_{\parallel F}(t)\right]\widehat{v}_{\parallel}+n_{\perp F}(t)\widehat{v}_{\perp}\right\}e^{j2\pi f_0 t}$$

Duobinary constraints

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

Controlled amount of ISI





Duobinary received signal

- If the received pulse satisfies the duobinary constraints, the filtered optical signal at the optimum sampling instant can be written as:

$$s_{RX}(t_{opt}) = \left\{ \sqrt{\overline{P}_S}\, c_n x(0) + n_r + j n_i \right\}$$

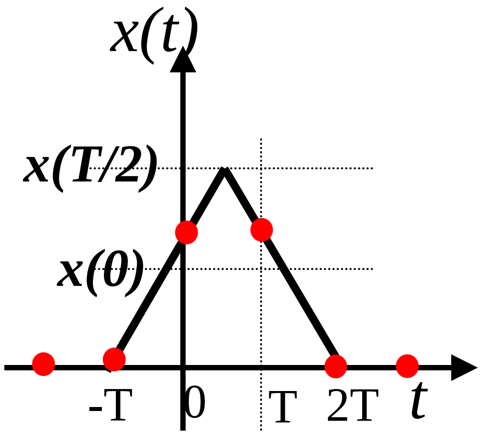
Gaussian r.v. with

$$\sigma^2 = \frac{N_0}{2} B_{eq,RX}$$

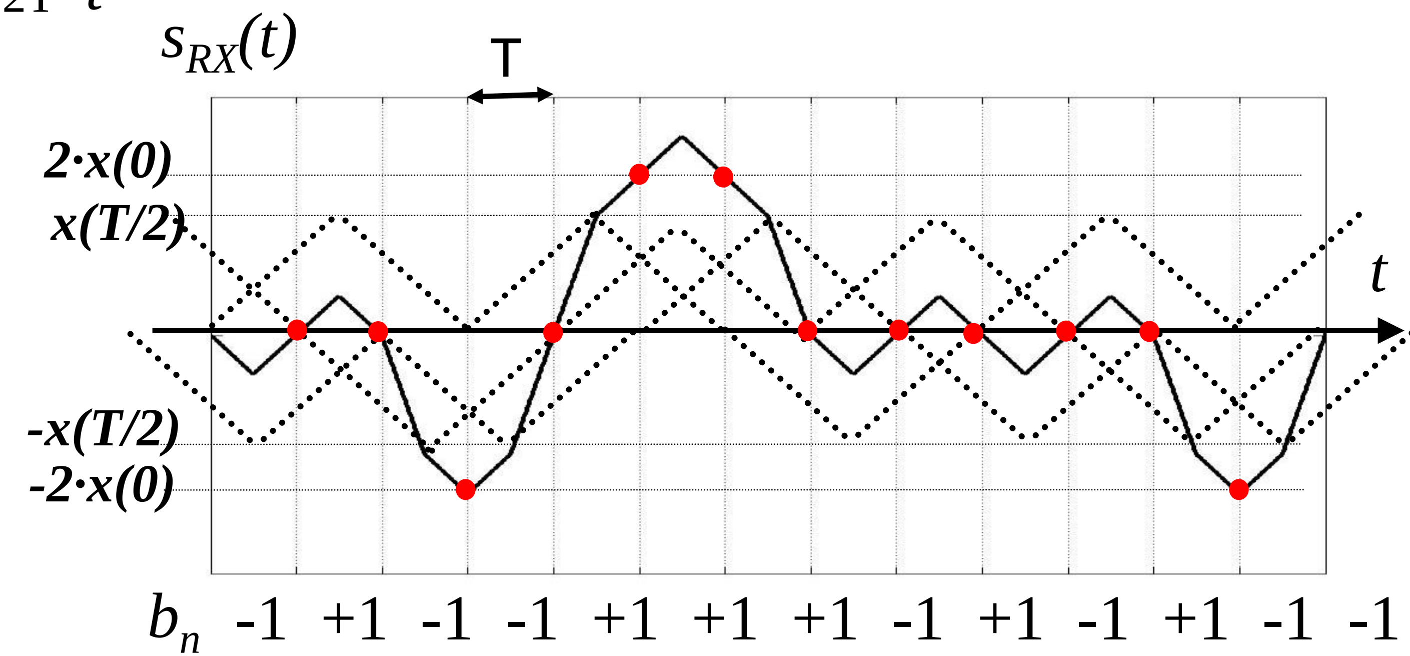
$$c_n = \begin{cases} +2 & b_n = b_{n-1} = +1 \\ 0 & b_n \neq b_{n-1} \\ -2 & b_n = b_{n-1} = -1 \end{cases}$$

Three-level signal

Duobinary received signal

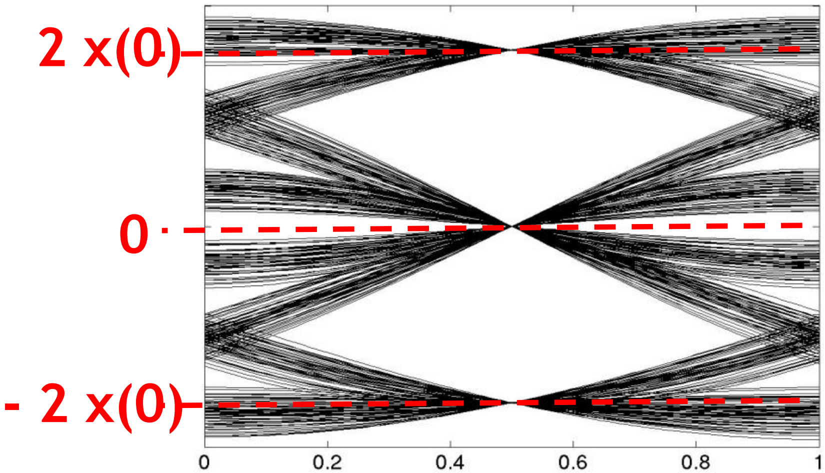


$$s_{RX}\left(t_{opt}\right) = \left\{\sqrt{P_S}\, c_n x(0) + n_r + j\, n_i\right\}$$

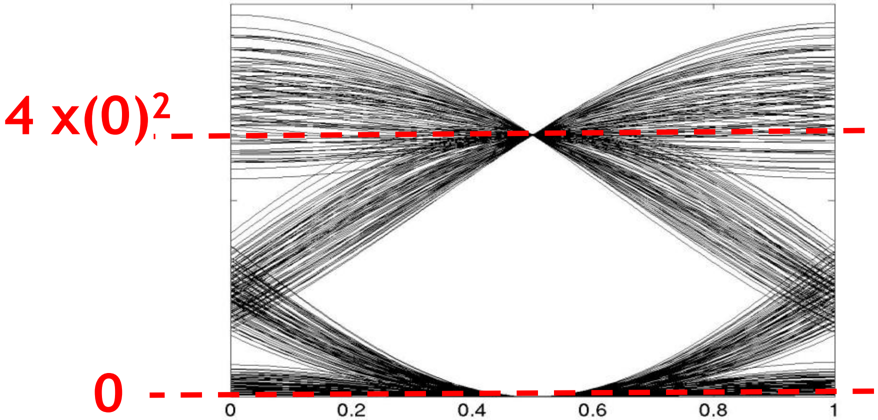


Noiseless eye diagrams

Before photodetection



After photodetection



Duobinary with direct-detection

- After photodetection:

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

Gaussian r.v. with

$$\sigma^2 = \frac{N_0}{2} B_{eq,RX}$$

  - v is a Chi-square distributed r.v. with variance parameter σ^2 and centrality parameter $s = \sqrt{\overline{P}_S}\, c_n x(0)$

- The BER can be analytically written as [1]:

$$BER = \frac{1}{2}\left\{ e^{-\phi}(1+\phi) + 1 - Q_2\left(\sqrt{\frac{4\overline{P}_S x^2(0)}{\sigma^2}}, \sqrt{2\phi} \right) \right\}$$

The BER depends on both the transmitted pulse and the receiver filter shape !!!!

[1] G.Bosco et al, "Quantum limit of direct detection optically preamplified receivers using duobinary transmission", *IEEE Photon. Technol. Lett.*, vol.15, no.1, pp.102-104, Jan. 2003.

Duobinary with direct-detection

$$BER = \frac{1}{2}\left\{ e^{-\phi}(1+\phi) + 1 - Q_2\left(\sqrt{\frac{4\overline{P}_S x^2(0)}{\sigma^2}}, \sqrt{2\phi} \right) \right\}$$

The BER depends on both the transmitted pulse and the receiver filter shape:

$$x(0) = u(t) * h_{RX}(t)\Big|_{t=0} =$$

$$= \int u(t) h_{RX}(T/2 - t)\,\mathrm{d}t$$

$$\sigma^2 = \frac{N_0}{2}\int \left| h_{RX}(t) \right|^2 \mathrm{d}t$$

Optimum duobinary system

- Being: $$\frac{4\overline{P}_S x^2(0)}{\sigma^2} = 16\,\mathrm{OSNR}\,\frac{x^2(0)/T}{\int |h_{RX}(t)|^2 dt}$$

  we must optimize (maximize):

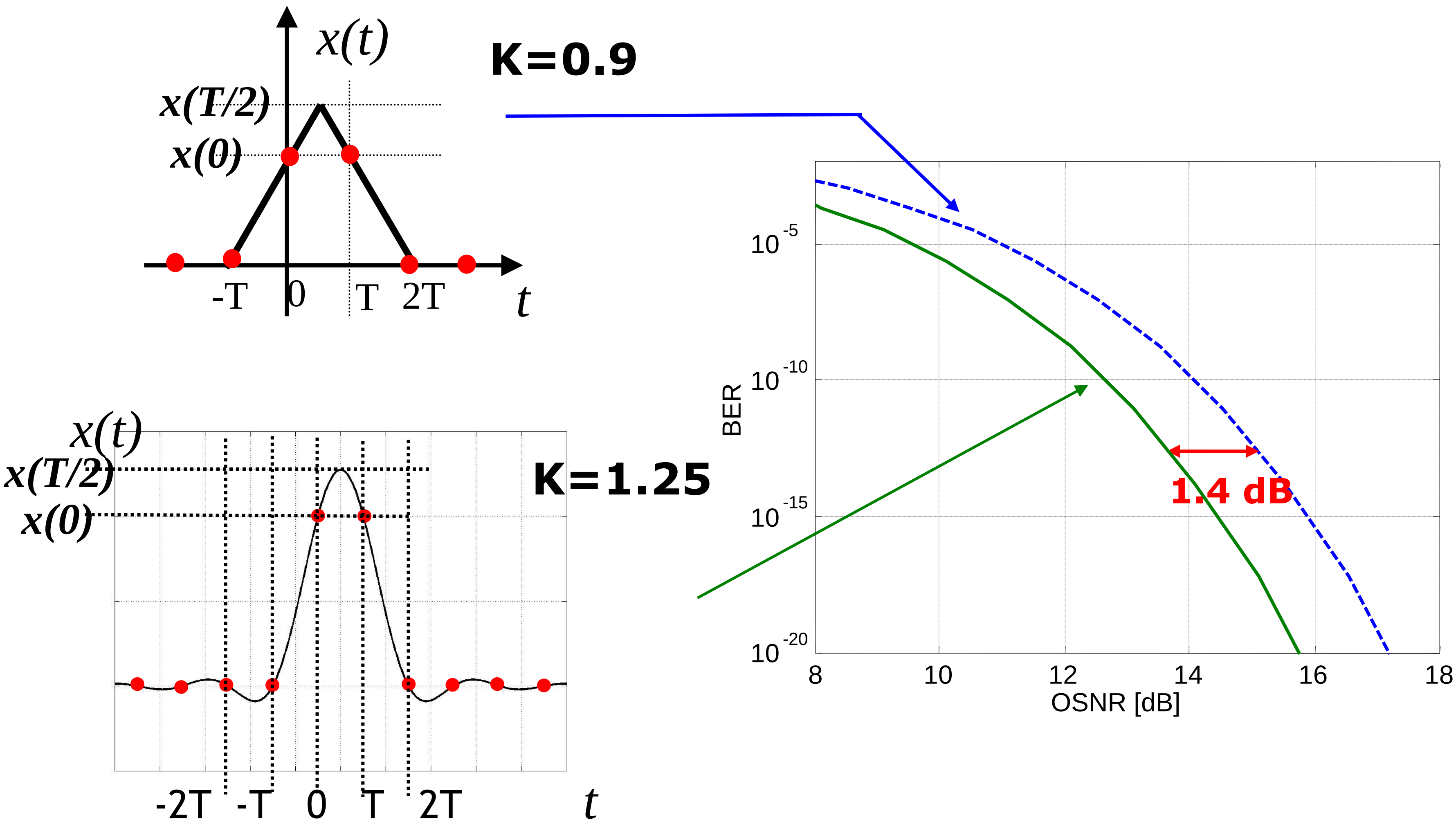
$$K = \frac{2\,x^2(0)/T}{\int |h_{RX}(t)|^2 dt} = \frac{\frac{2}{T}\left(\int u(t) h_{RX}(T/2-t)dt\right)^2}{\int |h_{RX}(t)|^2 dt}$$

  with the constraints:

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

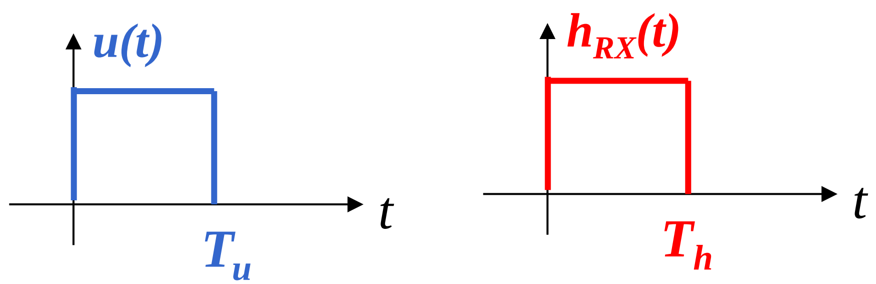
- The optimum duobinary system configuration is based on pulse-filter pair that maximizes the parameter K.

Examples of K in "matched" systems



Simplifying hypothesis

- We assume that both the transmitted pulse and the receiver optical filter impulse response have a rectangular shape with duration respectively T_u and T_h.



- We can evaluate K for each couple (T_u,T_h) finding the optimum filter for each pulse, showing that the best filter is not in general the matched filter $(T_u=T_h)$.

Duobinary constraints

- In order to comply with the duobinary constraints:

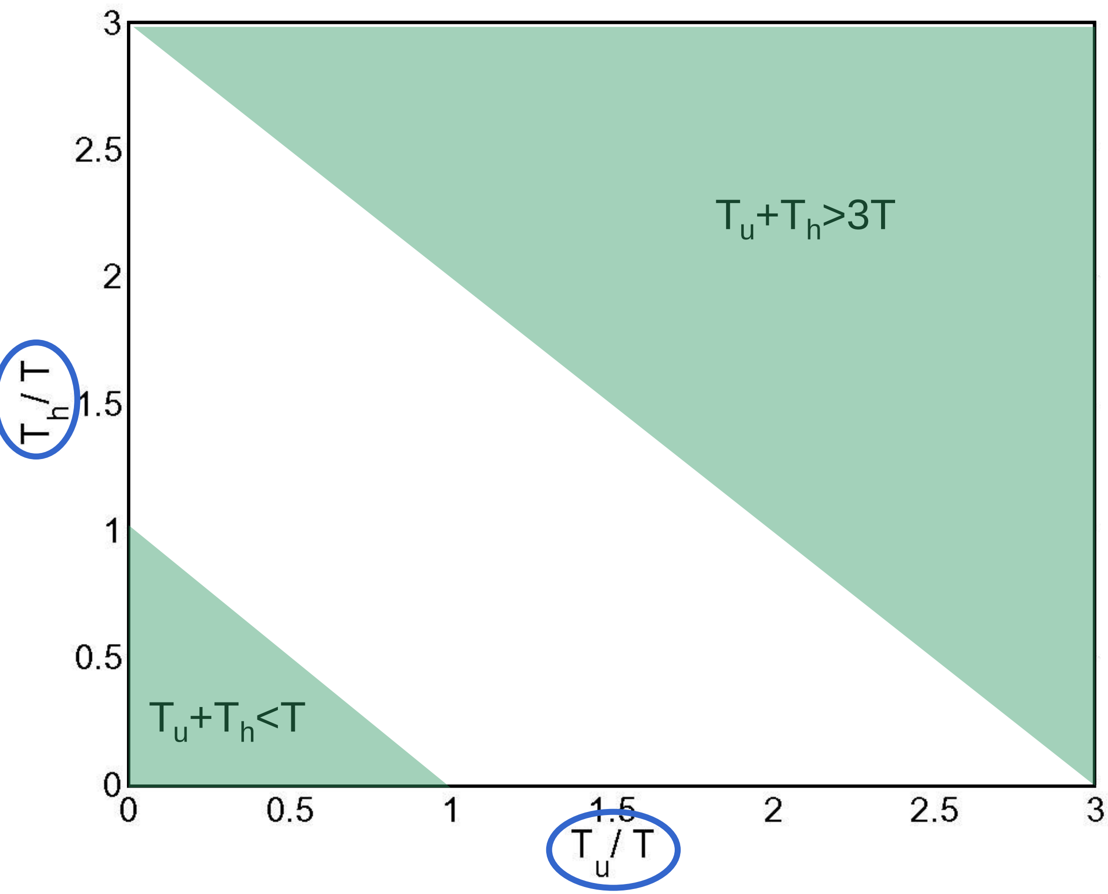
$$x(0) = x(T) \neq 0, \; x(nT) = 0, \forall n \neq 0,1$$

T_u and T_h must satisfy the following constraints:

$$T_u + T_h > T \qquad\qquad T_u + T_h < 3T$$

Contour plot of parameter K

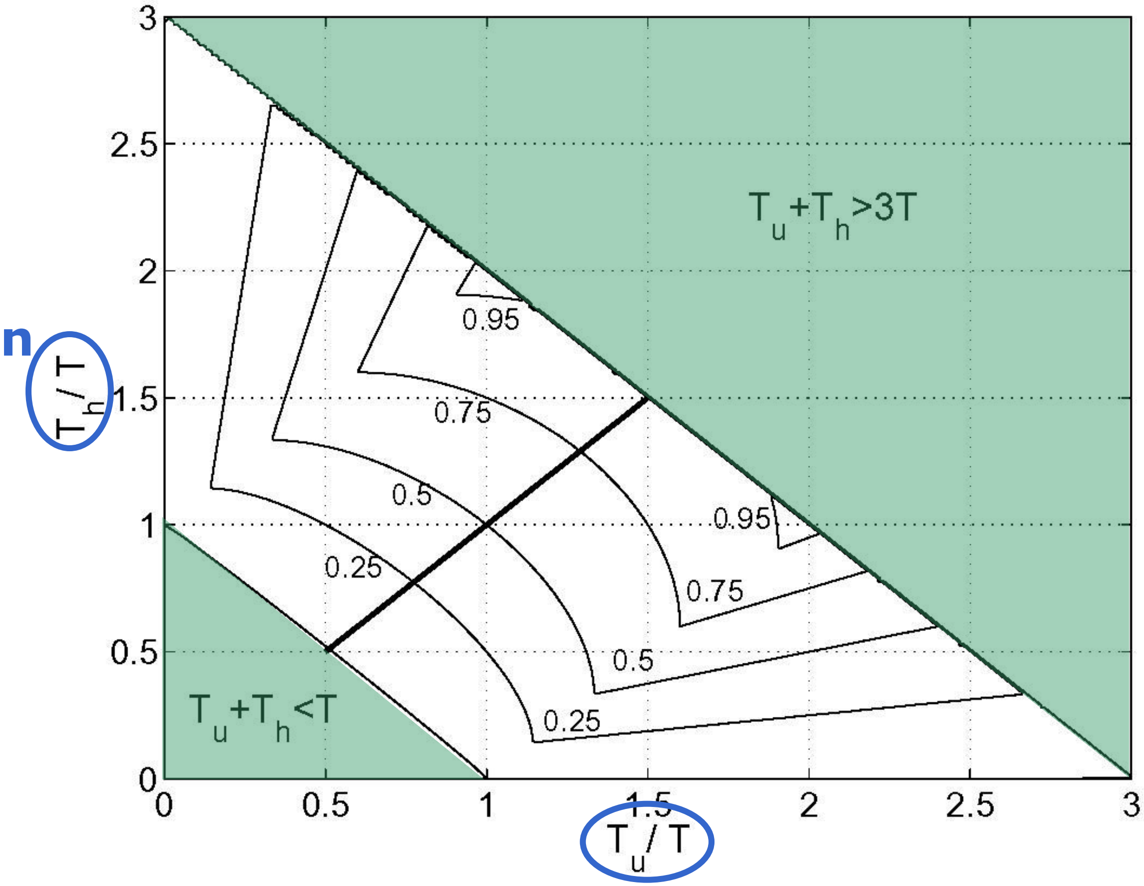
Normalized duration of the RX filter impulse response



Normalized duration of the transmitted pulse

Contour plot of parameter K

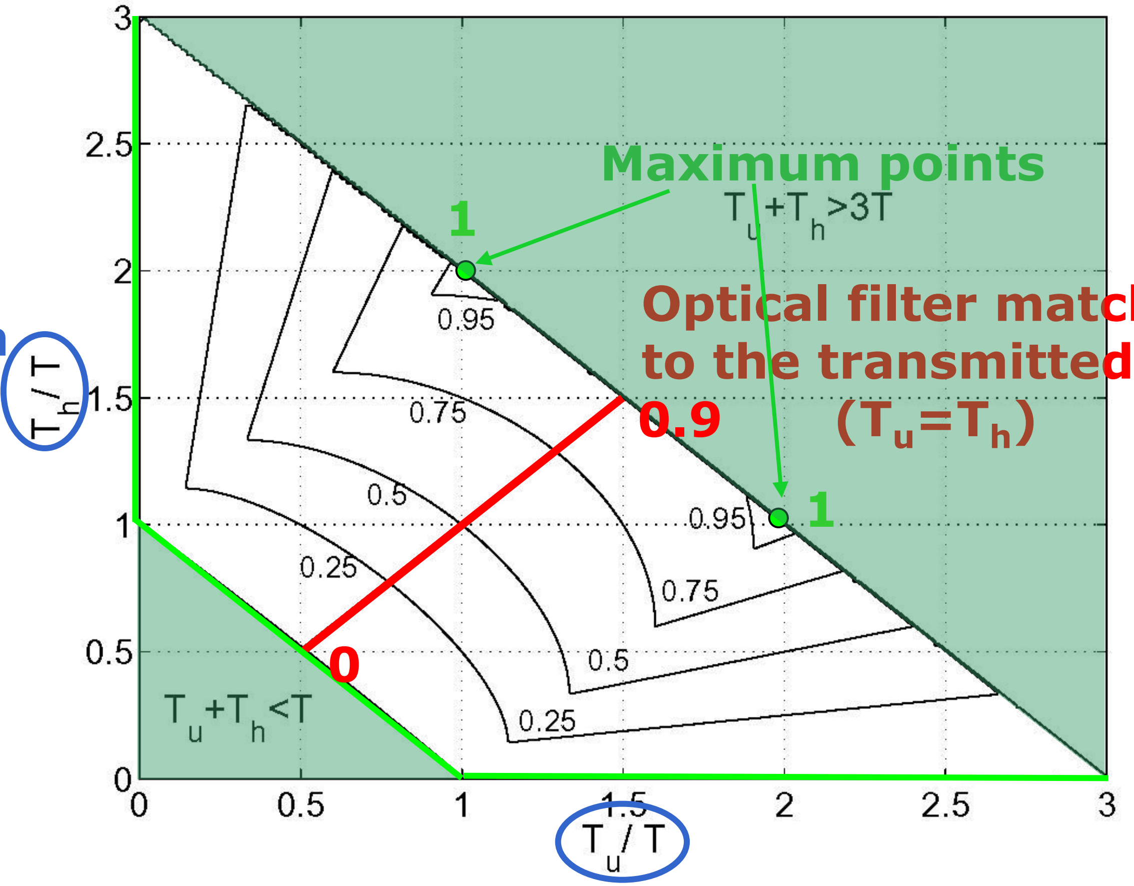
Normalized duration of the RX filter impulse response



Normalized duration of the transmitted pulse

Contour plot of parameter K

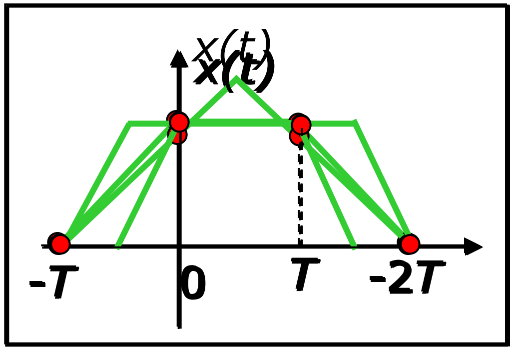
Normalized duration of the RX filter impulse response

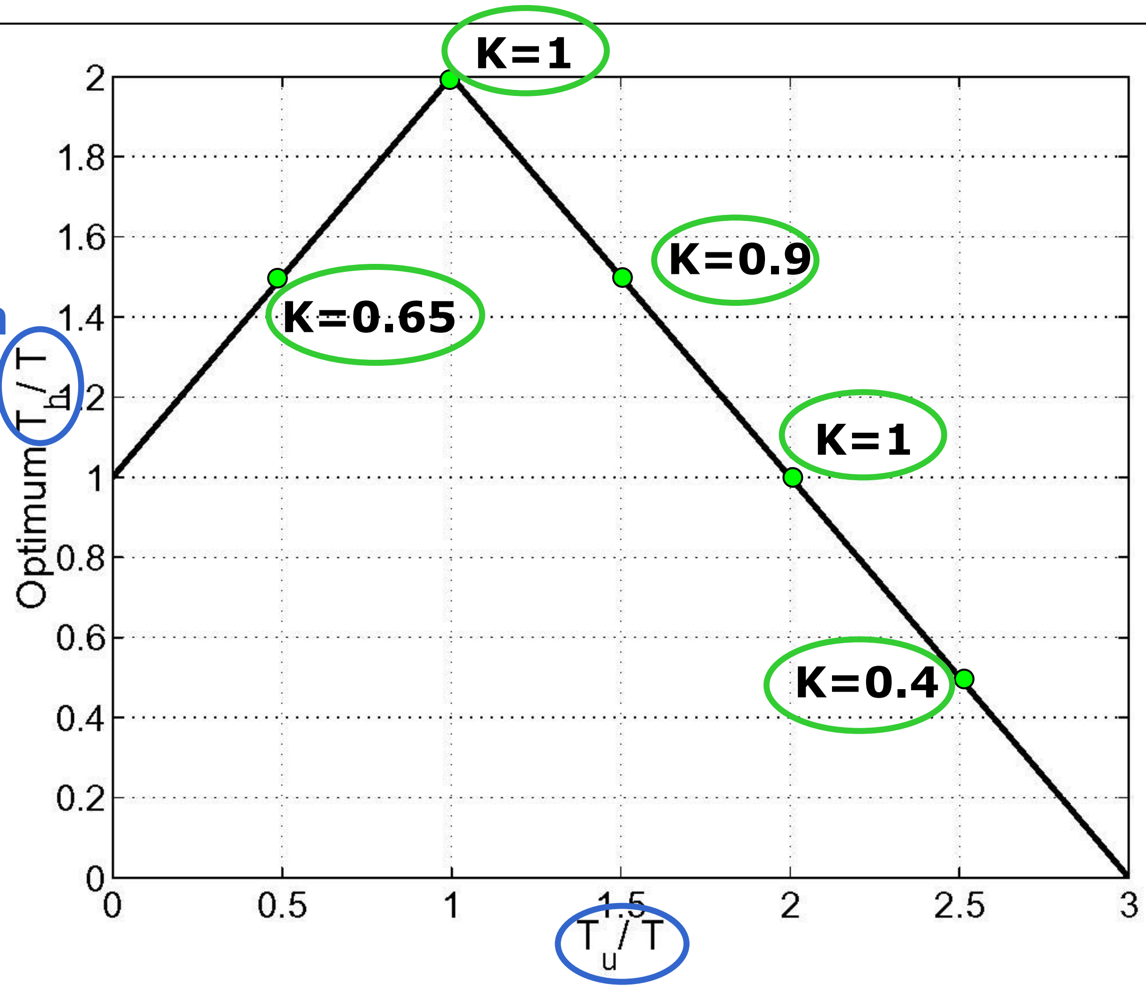


Normalized duration of the transmitted pulse

Optimum (T_u,T_h) couples

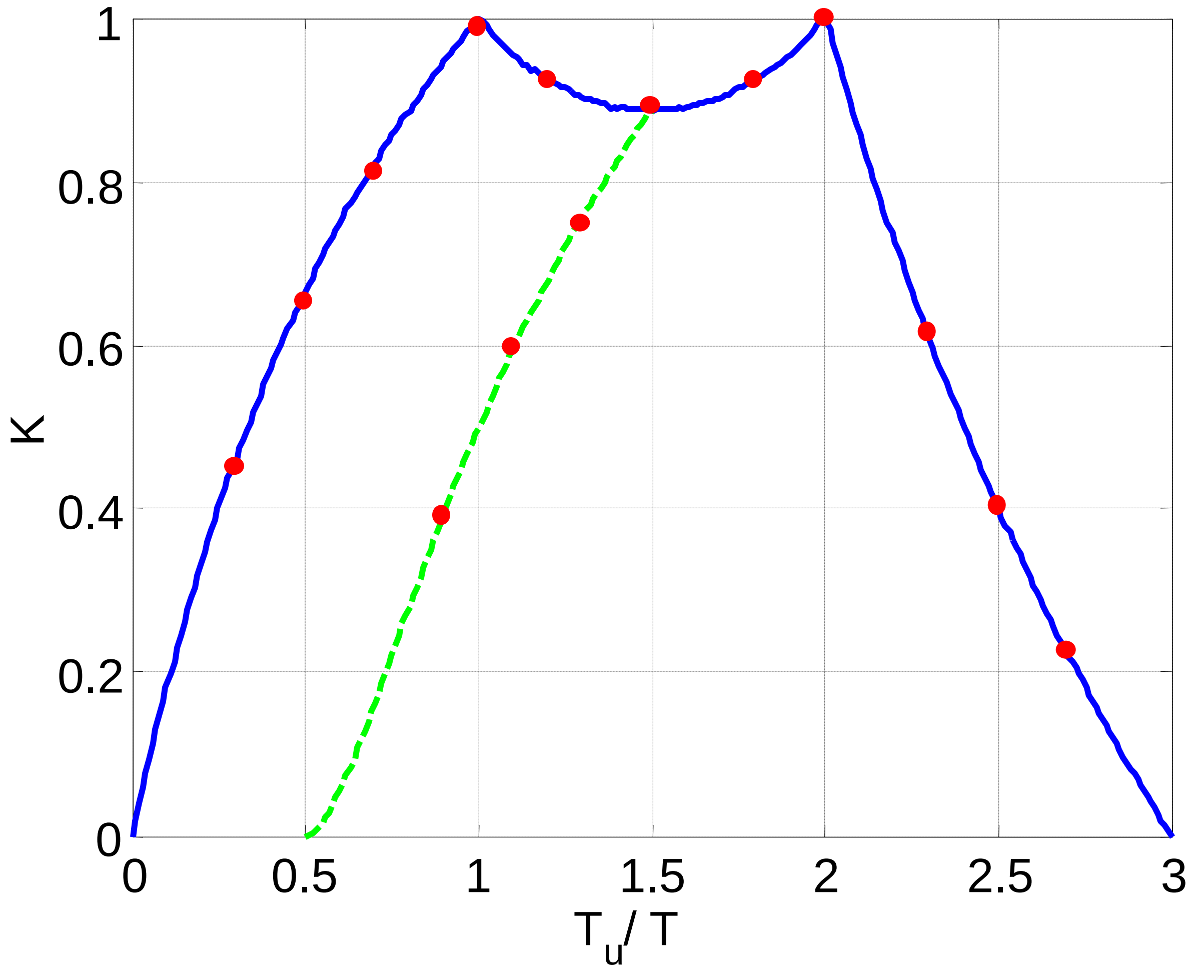
Normalized duration of the RX filter impulse response





Normalized duration of the transmitted pulse

Optimum K vs. transmitted pulse duration



Dashed line refers to the matched filter (sub-optimal) scenario.

Red dots are obtained through numerical simulations based on error counting.

Conclusions

- If both the transmitted pulse and the receiver optical filter impulse response have a rectangular shape with duration respectively T_u and T_h, the optimum performance are obtained when: $T_u=T$, $T_h=2T$ or $T_u=2T$, $T_h=T$.
- When using a **matched filter**, the best achievable performance, which is obtained for $T_u=T_h=1.5\ T$, has an OSNR loss of about 0.45 dB with respect to the optimum performance.
- This results show that, for duobinary transmission, the optimum receiver is not in general based on the optical filter matched to the transmitted pulse.
- We are currently working on a mixed analytical/numerical solution of the general maximization problem in order to find the absolute optimum of the transmitted pulse/receiver filter couple.