Investigation on the Robustness of a Nyquist-WDM Terabit Superchannel to Transmitter and Receiver Non-Idealities

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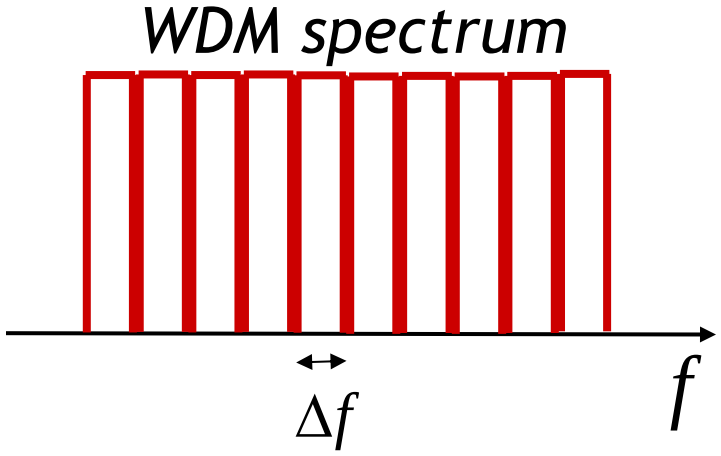
Outline

- Nyquist-WDM technique
  - Description of the technique
  - Motivations of the work
- Description of the system set-up
  - Generation of a PM-QPSK Terabit superchannel
- Simulation results
  - Impact of transmitter and receiver non idealities to system performance
- Conclusions

What is “Nyquist WDM”?

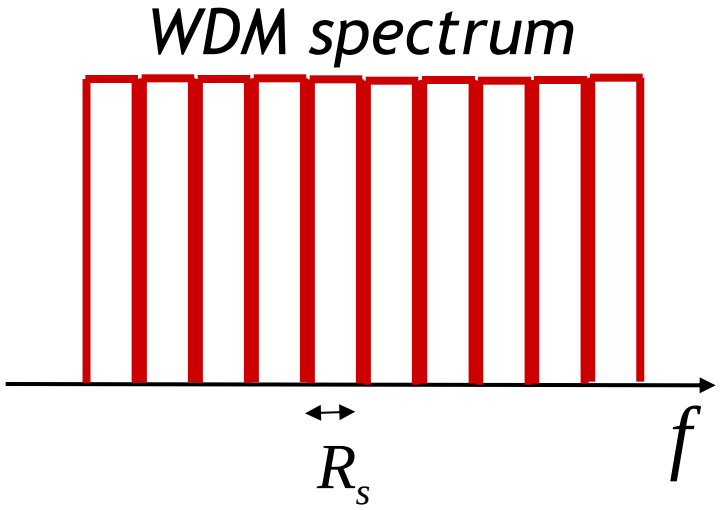
- "Nyquist WDM" is a technique used to generate high spectral efficiency optical signals.

- It is based on the idea of limiting the crosstalk between adjacent sub-carriers in a Terabit superchannel by means of tight filtering at the transmitter:



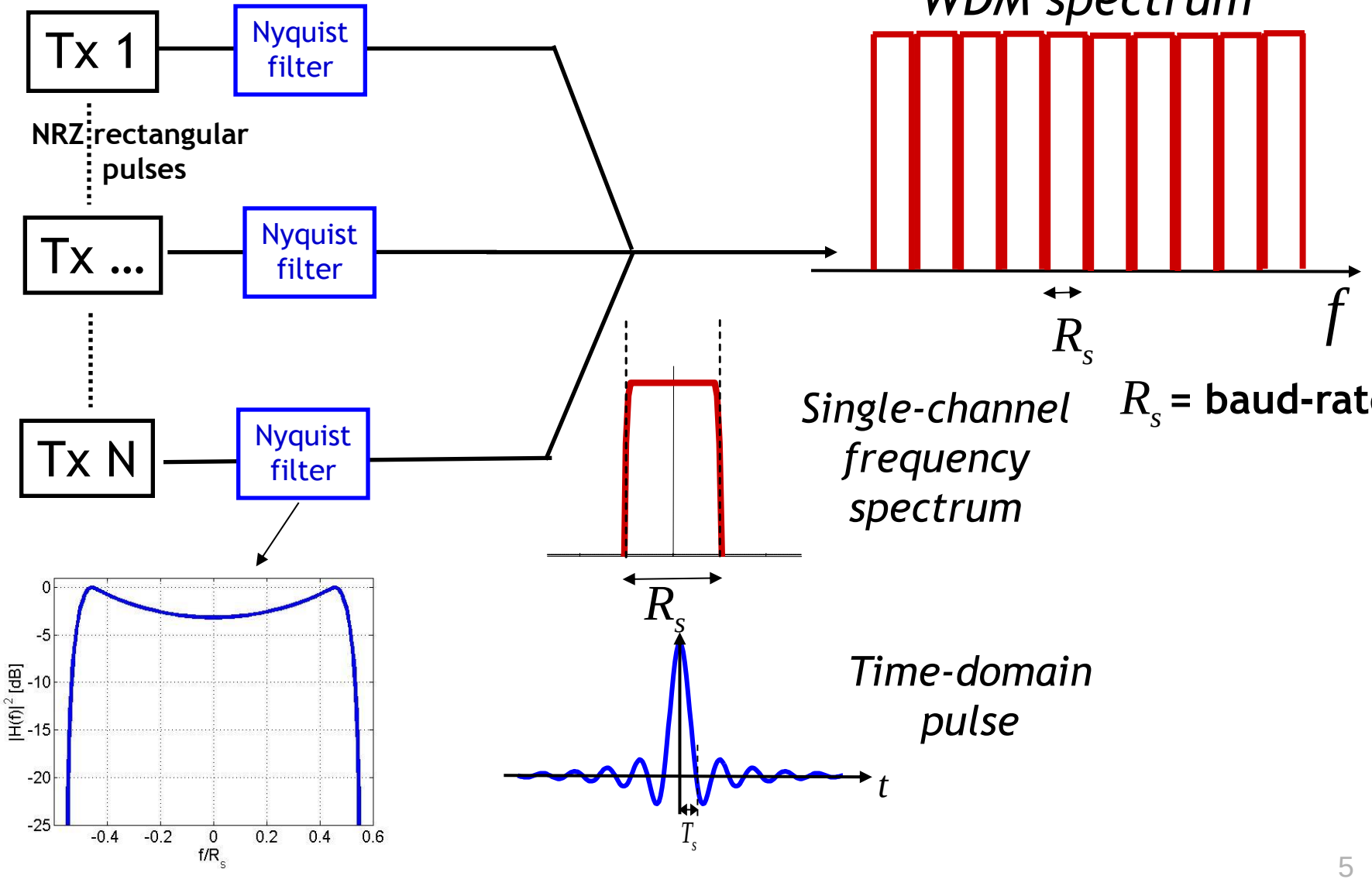
The “Nyquist filter”

- The ideal “Nyquist filter” is designed in order to satisfy the Nyquist criterion for the absence of ISI
  - Rectangular or raised-cosine are examples of spectra satisfying the Nyquist criterion
- The minimum channel spacing with potentially no penalty with respect to the ideal matched filter case is equal to the baud-rate R_s:



Ideal Nyquist-WDM transmitter

111 Gb/s PM-QPSK



Single-channel frequency spectrum

R_s = **baud-rate**

Time-domain pulse

Why Nyquist-WDM?

- The effectiveness of Nyquist-WDM has been successfully demonstrated in several ultra long-haul high-speed experiments:
  - *Cai, J.-X. et Al., "Transmission of 96×100G pre-filtered PDM-RZ-QPSK channels with 300% spectral efficiency over 10,608km and 400% spectral efficiency over 4,368km", OFC 2010, San Diego, paper PDPB10.*
  - *E. Torrengo et al., "Transoceanic PM-QPSK Terabit Superchannel Transmission Experiments at Baud-Rate Subcarrier Spacing", **ECOC 2010, Torino, paper We.7.C.2***
- Nyquist WDM Superchannels can ideally achieve optimum matched-filter performance
  - *G. Bosco, A. Carena, V. Curri, P.Poggiolini, F. Forghieri, "Performance Limits of Nyquist-WDM and CO-OFDM in High-Speed PM-QPSK Systems", IEEE Phot. Technol. Lett., vol.22, no.15,* pp. 1129-1131, Aug. 2010.
- Performance can be strongly degraded by implementation non idealities.

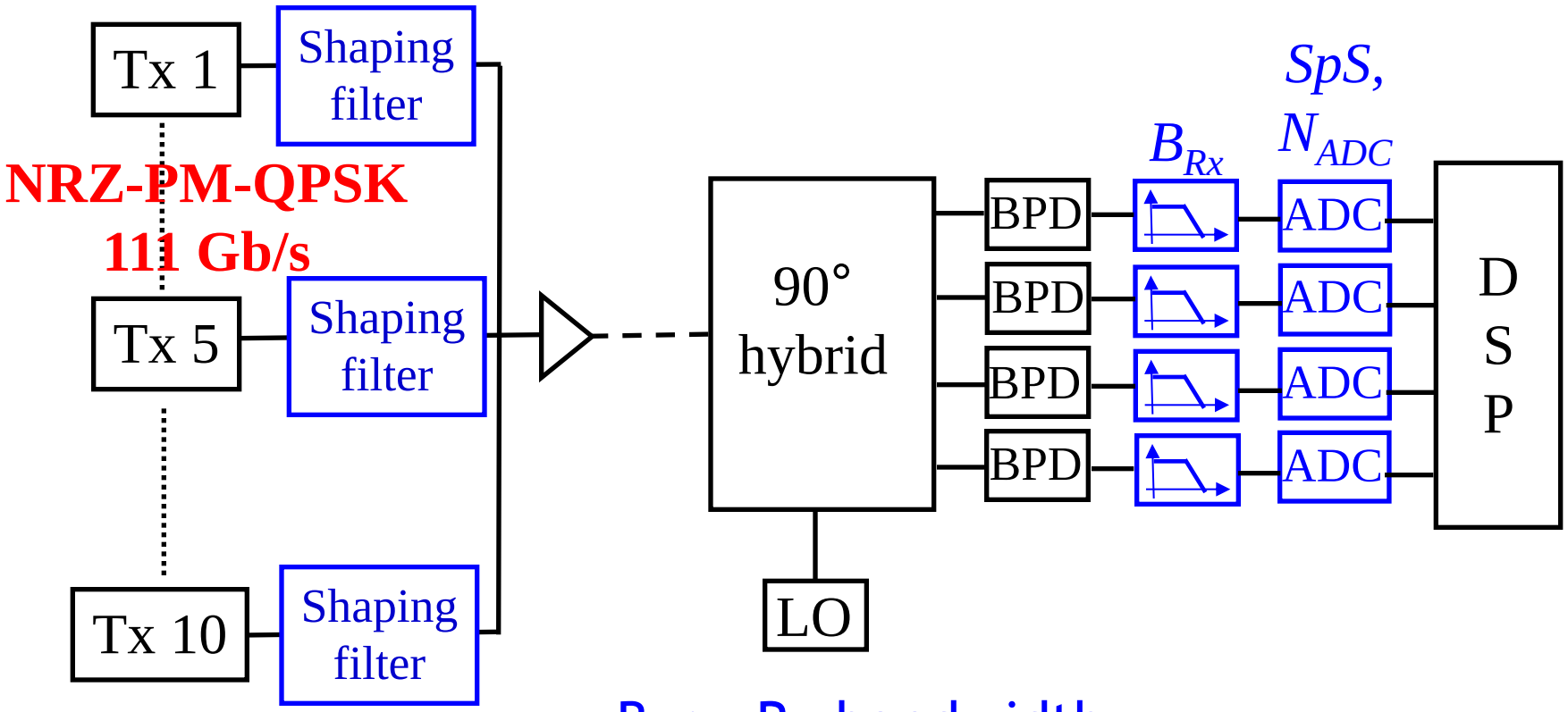
This work

- We analyzed by simulation the robustness of an optical Nyquist-WDM Terabit Superchannel to transmitter and receiver non-idealities.

- We focus in particular on:
  - use of a realistic optical shaping filter
  - ADC finite resolution
  - ADC speed (limited number of samples per symbol available at the receiver)
  - limited electrical bandwidth of the receiver

Layout of the simulated system

- Target BER: $4 \cdot 10^{-3}$, OSNR defined over 0.1 nm



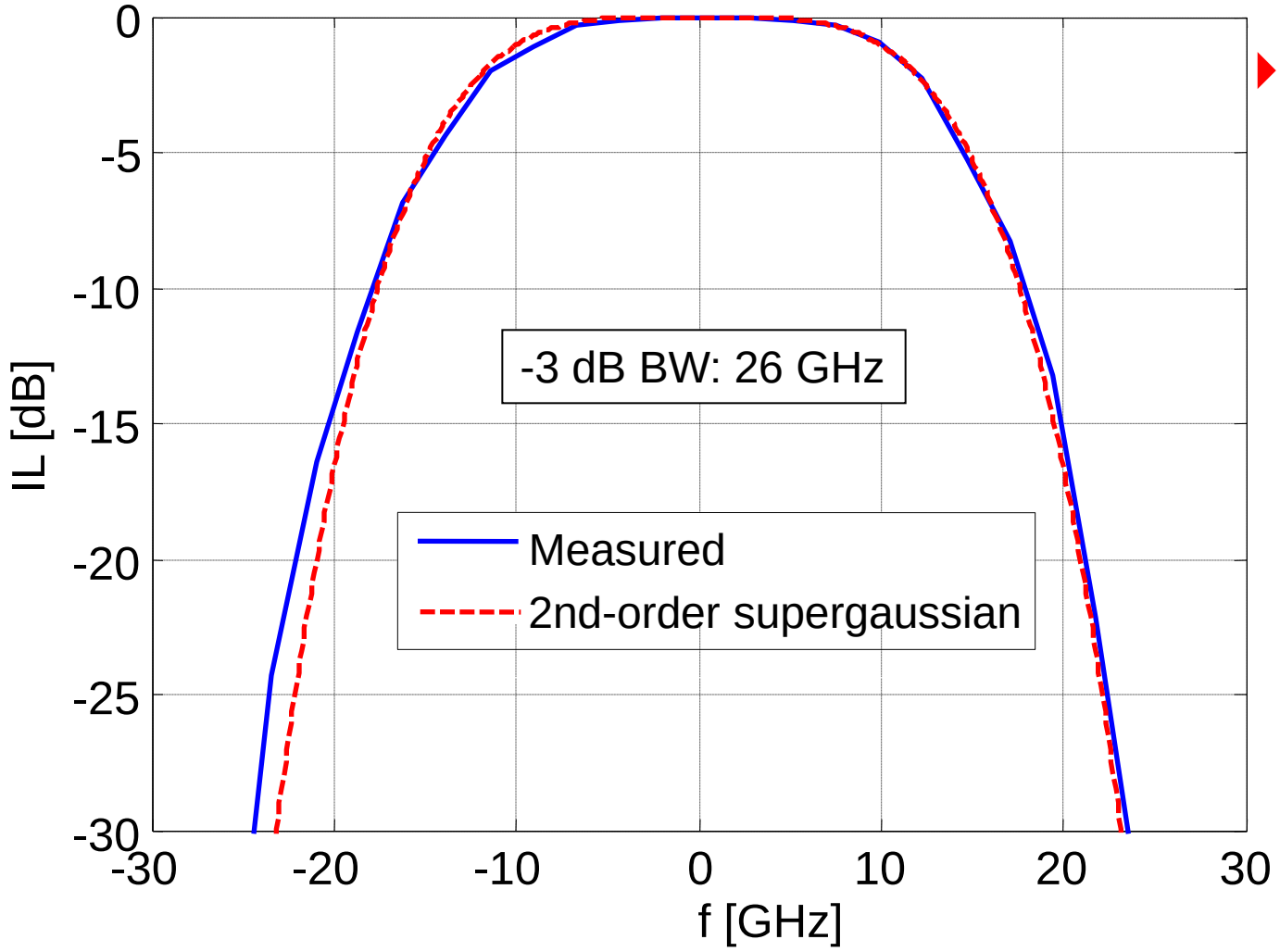
B_{rx}: Rx bandwidth

SpS: Number of samples per symbol

N_{ADC}: Number of resolution bits of ADC

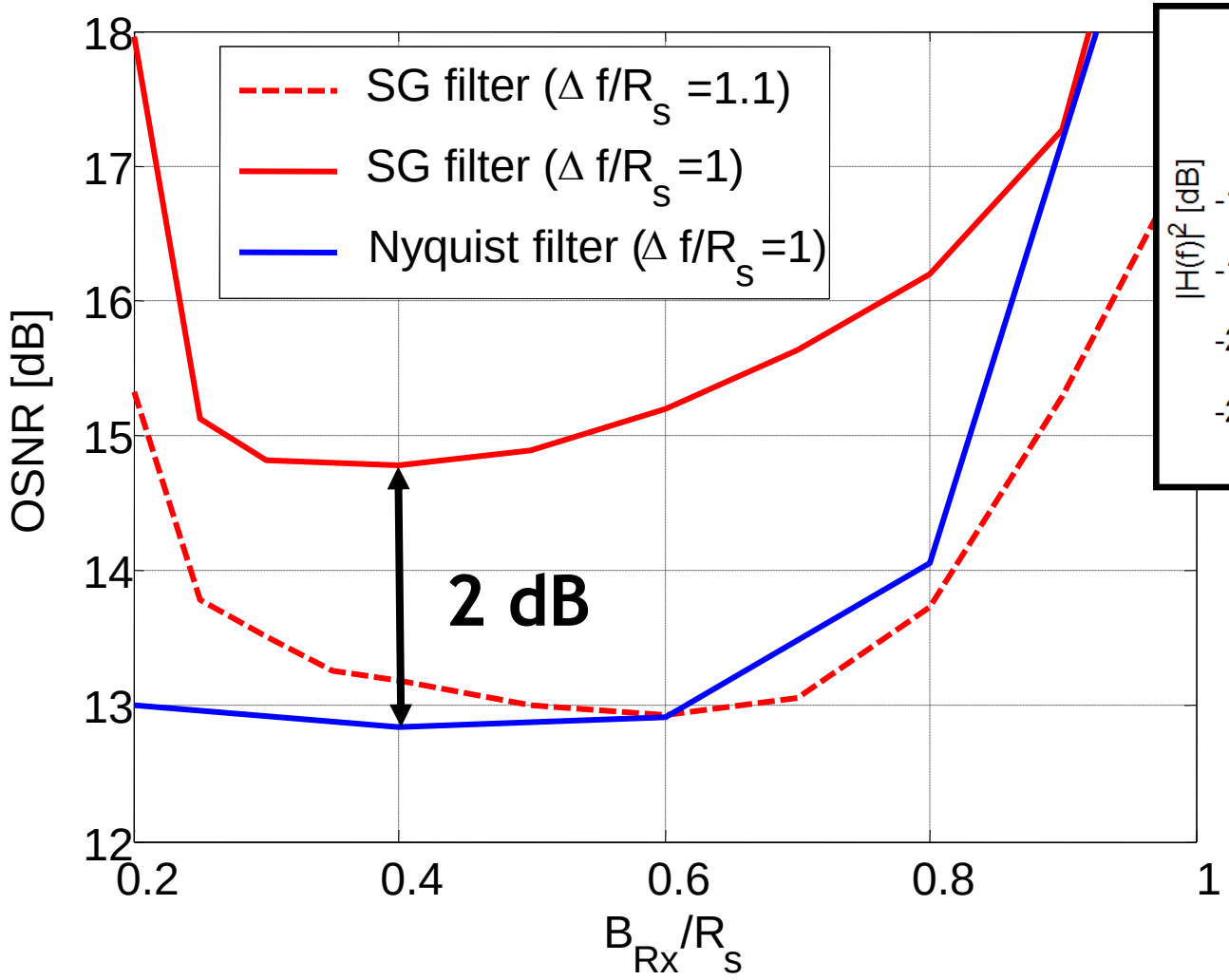
Optical pre-filter shape

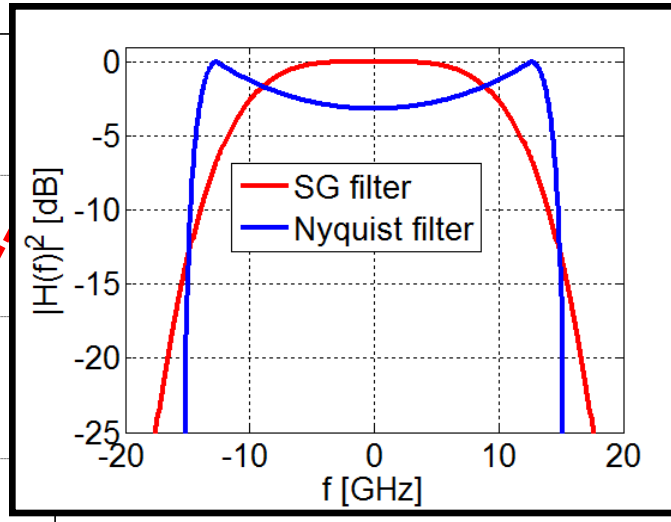
Fitting of Finisar Waveshaper™ with analytical functions



- Note that this a sort of "worst case" since state-of-the-art AWGs and interleavers have steeper transfer functions (up to 4th order Supergaussian)

Ideal vs. realistic optical filter in btb



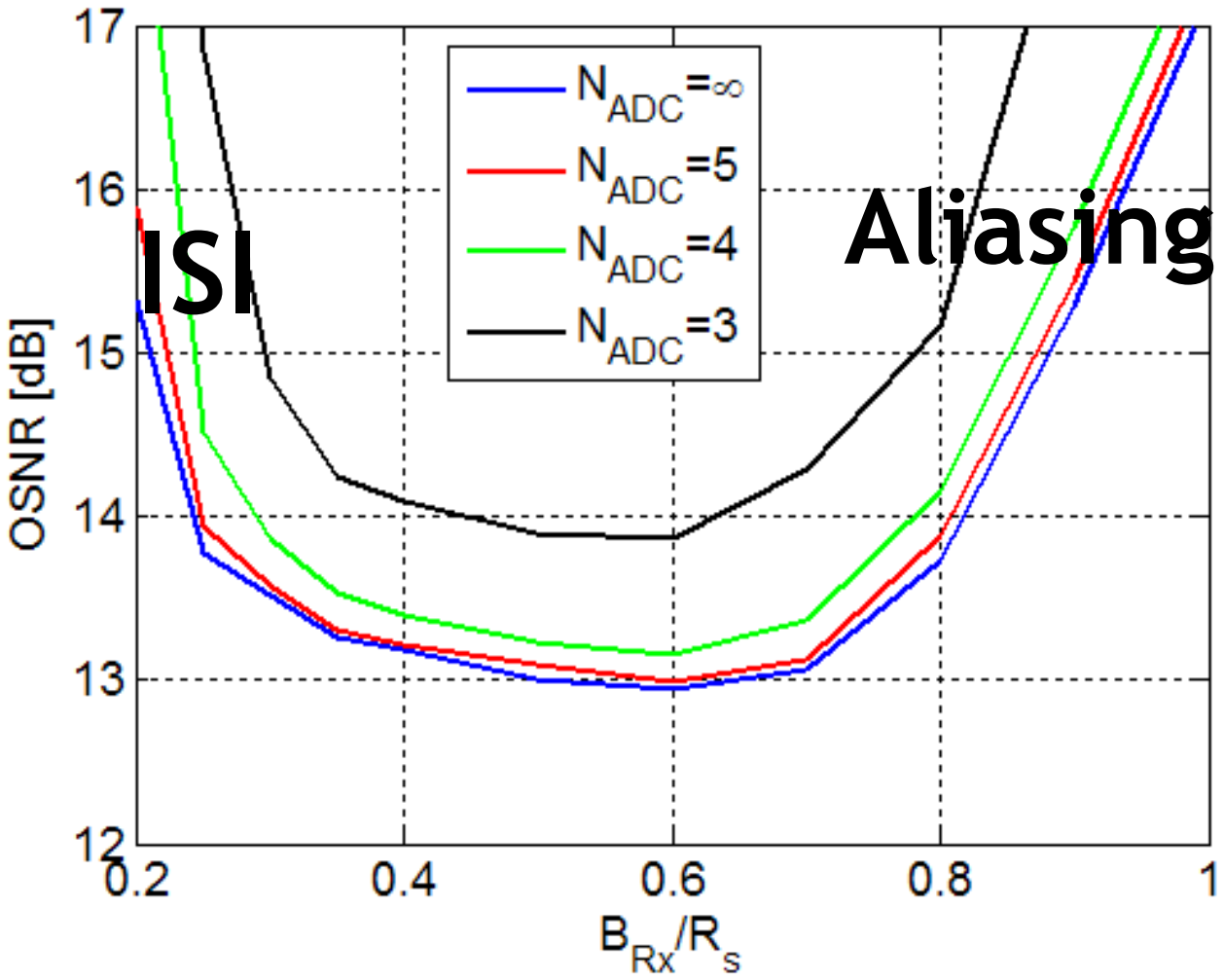


- Increasing the spacing to 1.1 R_s this penalty is almost canceled

- ADC with ideal resolution and 2 SpS

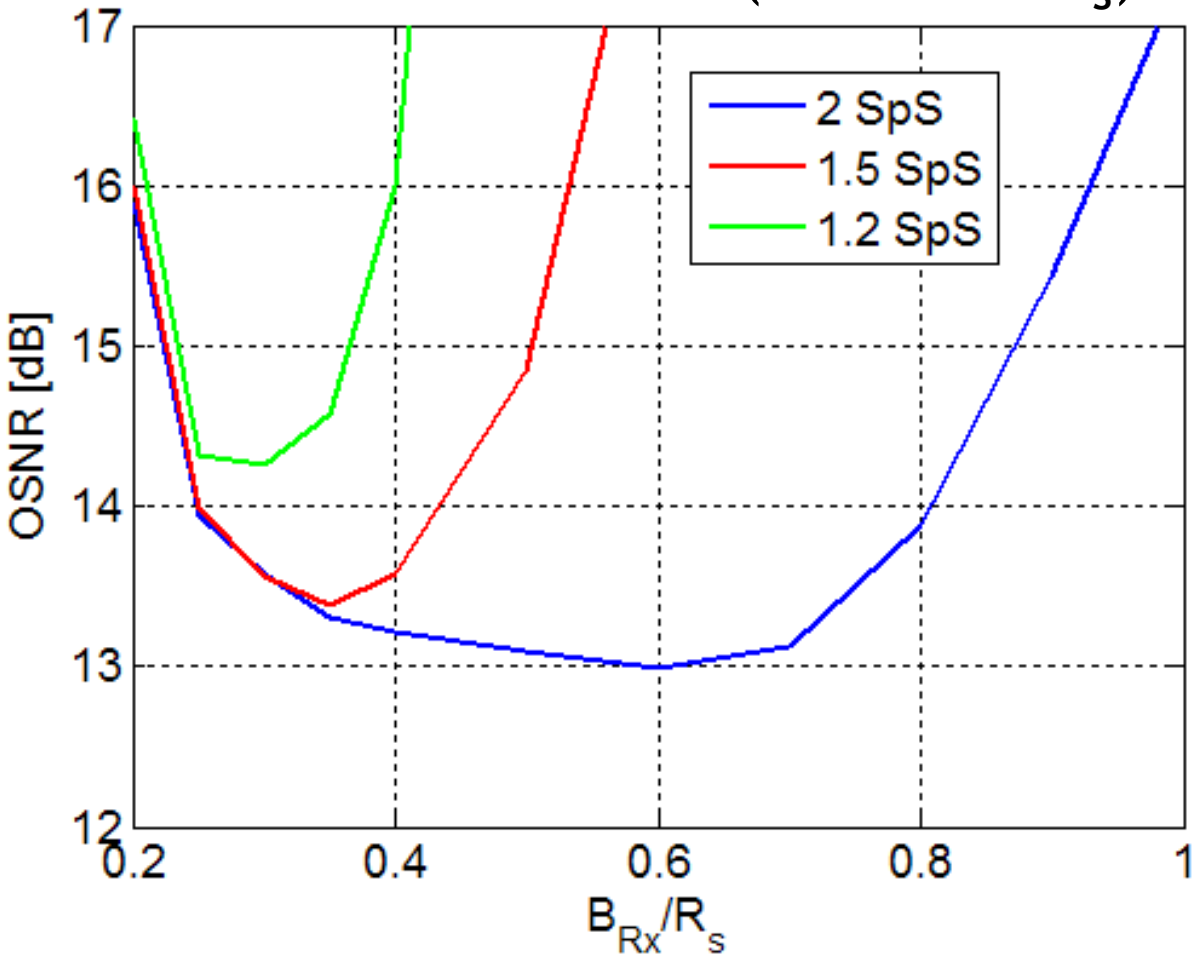
ADC finite resolution

Finisar-like filter ($\Delta f = 1.1\ R_s$)



- The quantizer is assumed to be uniform with 1% of overload.
- The penalty in using a finite number of resolution bits is almost negligible down to 4 bits, but even at 3 bits the penalty is limited (lower than 1 dB).

ADC sampling speed



- The resolution of ADC is assumed to be 5 bits.
- The OSNR penalty with respect to the 2 SpS case is equal to 0.4 dB and 1.3 dB when using 1.5 and 1.2 SpS, respectively.

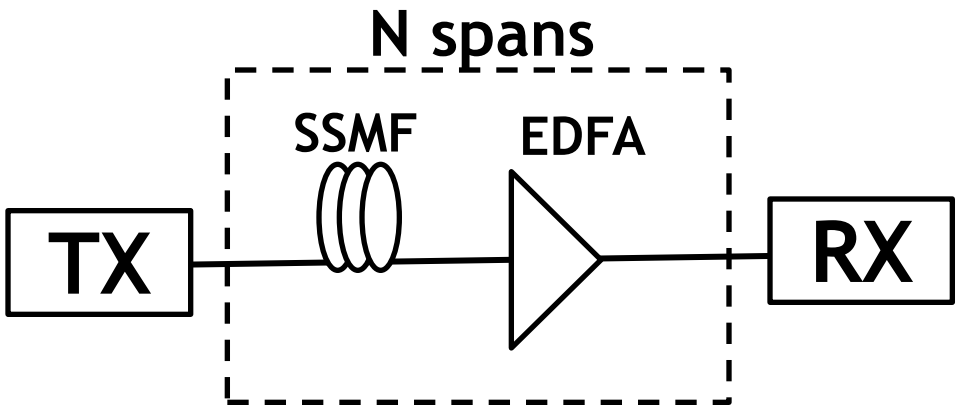
Comments

- One peculiarity of Nyquist-WDM is its good performance even at very low values of the receiver electrical bandwidth B_{Rx}, a circumstance that may have significant practical impact.

- As an example, at 27.75 Gbaud the optimum receiver bandwidth as a function of the number of samples per symbol (SpS) is:

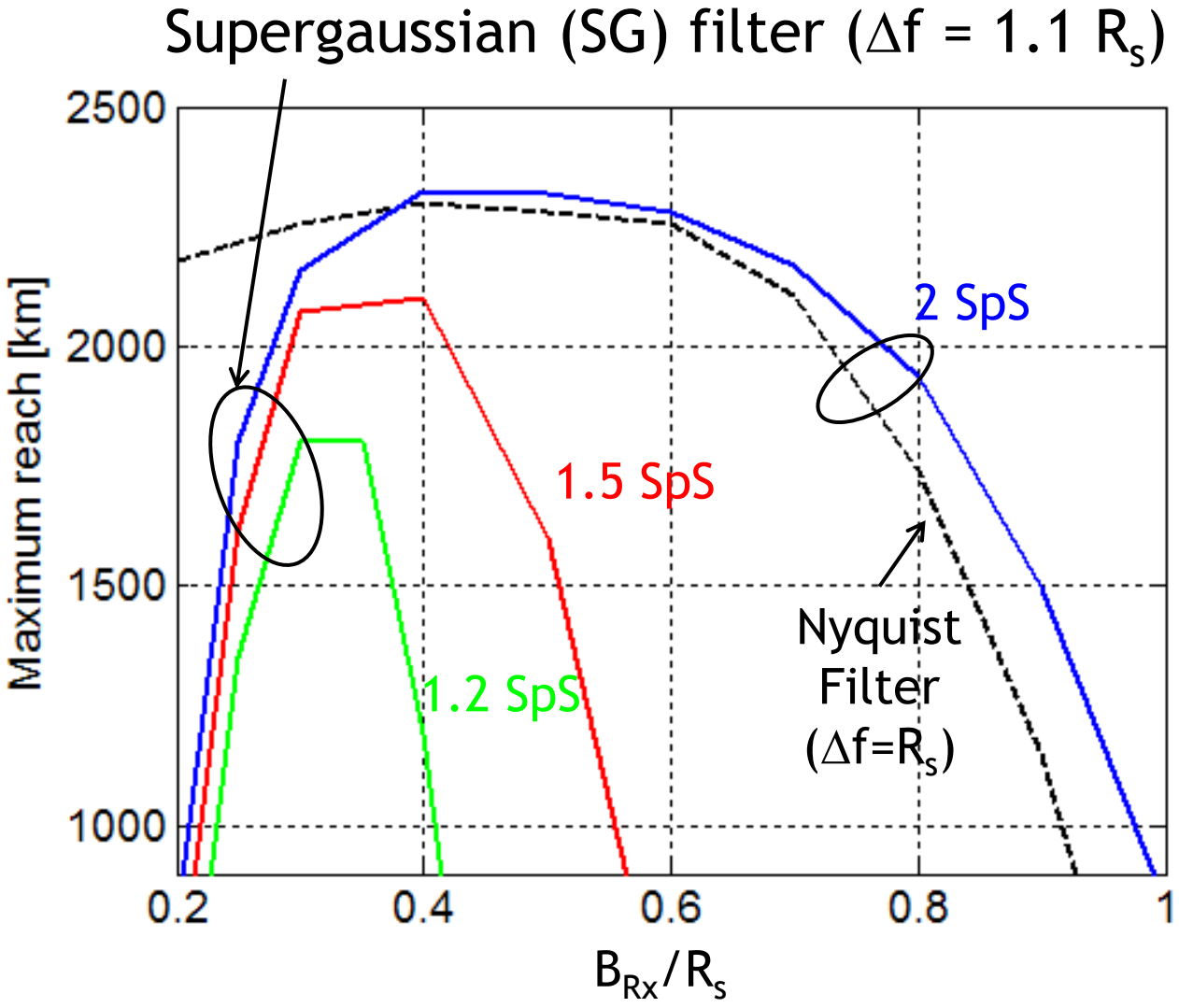
SpS	B_{RX}
2.0	16 GHz
1.5	10 GHz
1.2	8 GHz

Nonlinear propagation



- Span length: 90 km
- SSMF fiber
  - D = 16.7 ps/nm/km
  - α = 0.22 dB/km
  - γ = 1.3 1/w/km
- EDFAs noise figure: 5 dB
- No in-line dispersion compensation
- Total span loss (fiber attenuation + extra-losses + margin) = 25 dB
- Reference BER: 4e-3

Maximum reach



- The same maximum distance of 2300 km can be achieved with both
  - Nyquist filter at $\Delta f = R_s$
  - SG filter at $\Delta f = 1.1\ R_s$

  when using 2 SpS and 5 bits of ADC resolution.

Conclusions

- We have analyzed the impact of some key transmitter and receiver non idealities on the performance of a Terabit superchannel system, composed of 10x111 Gbit/s PM-QPSK subchannels, based on (or approaching) the ‘Nyquist’ WDM condition.

- The obtained results suggests that ‘Nyquist’ WDM Terabit superchannels are quite robust to implementation non-idealities and could be a promising technology for future high-spectral efficiency Tb/s per channel systems.

Acknowledgments

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