Performance of Digital Nyquist-WDM

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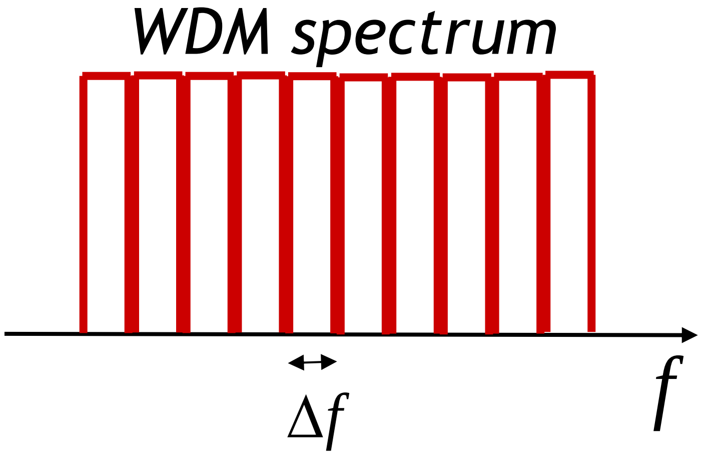
Nyquist-WDM

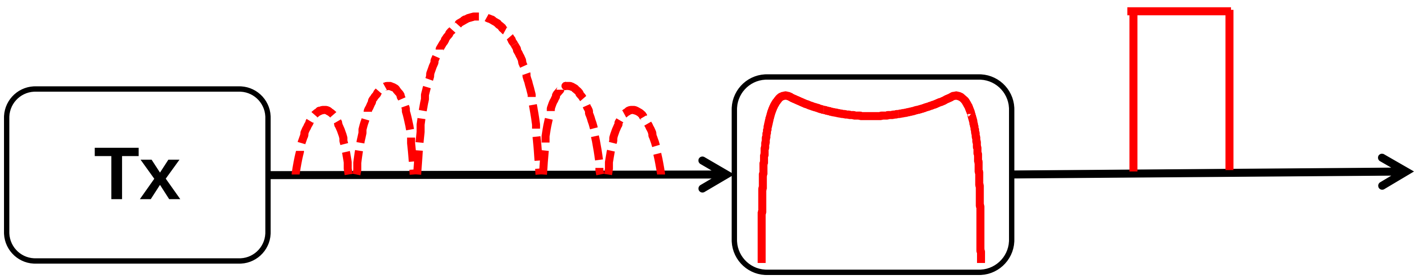
- "Nyquist-WDM" is a technique used to generate high spectral efficiency optical signals.
- It is based on the idea of limiting the crosstalk between adjacent sub-channels by means of tight filtering at the transmitter:



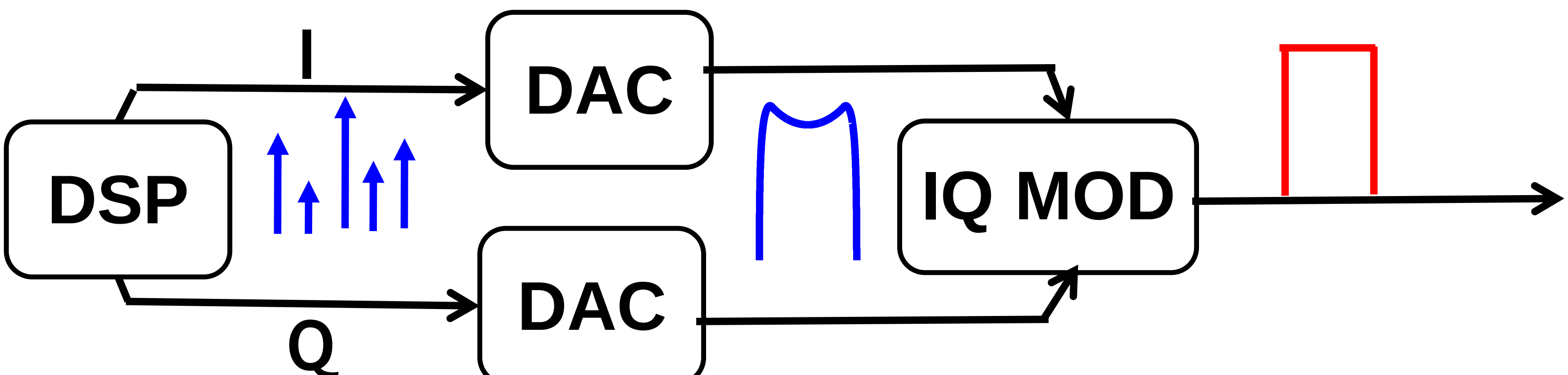
- The ideal "Nyquist pulse" is designed in order to satisfy the Nyquist criterion for the absence of ISI.

Spectral shaping: optical vs. digital

- Tight spectral shaping can be performed:
  - in the **optical domain**, through narrow transmitter (Tx) optical filtering



  - in the **digital/electrical domain**, combining digital signal processing (DSP) and digital-to-analog (D/A) conversion.



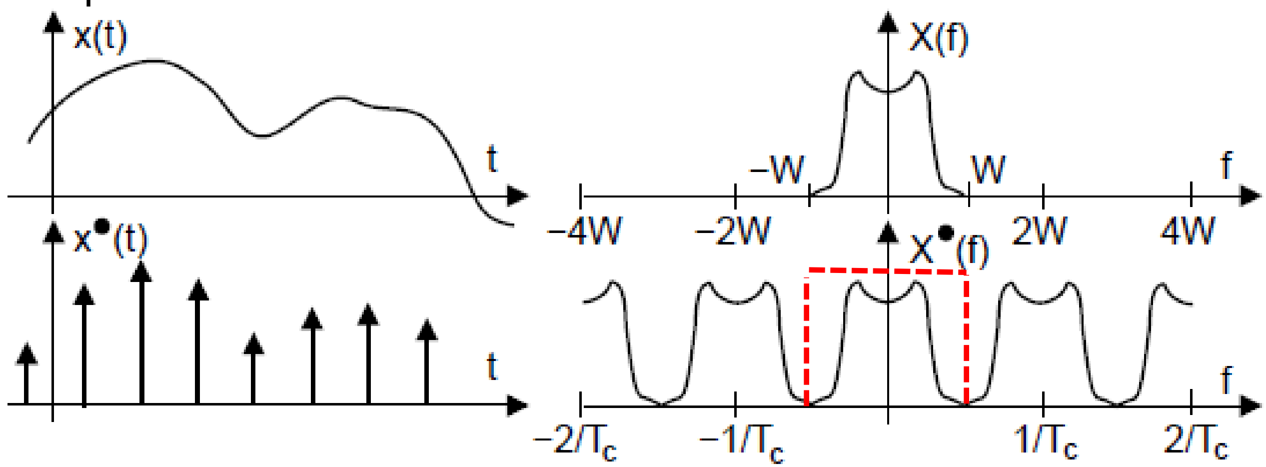
Motivations of this work

- Ideally, both techniques can achieve the same ultimate performance (with an optimum “matched filter” receiver).
- What limits the performance is the “practical” implementation of the transmitter, i.e. how well the spectral shaping can be performed [*].
- The goal of this work is to analyze the characteristics of Nyquist-WDM generated in the digital domain, taking into account the implementation characteristics of realistic D/A conversion:
  - Sampling speed
  - Bandwidth

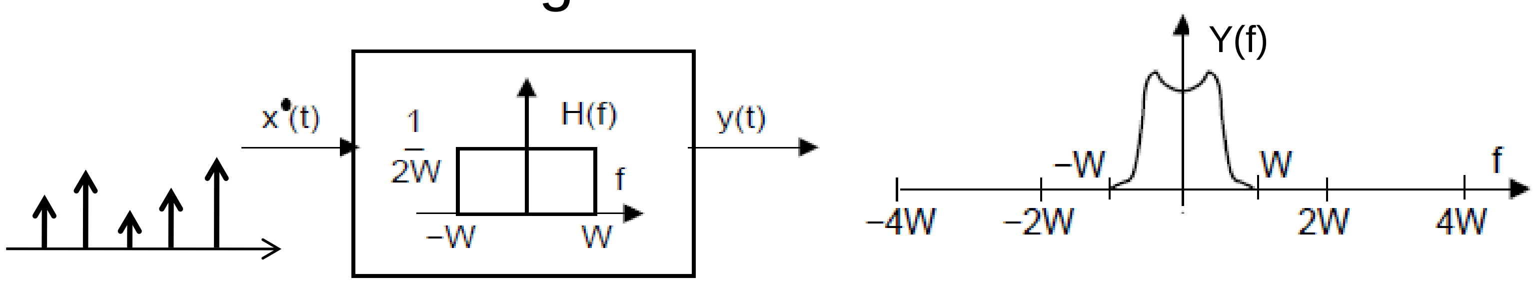
[*] G. Bosco et al., “Investigation on the Robustness of a Nyquist-WDM Terabit Superchannel to Transmitter and Receiver Non-Idealities”, ”, ECOC 2010, paper Tu.3.A.4, Torino, Sep. 2010.

Ideal D/A conversion

- The "Nyquist sampling theorem" states that any analog signal x(t), band-limited in [−W,W], can be perfectly reconstructed from its samples provided that the sampling frequency f_{samp} is greater than 2·W.

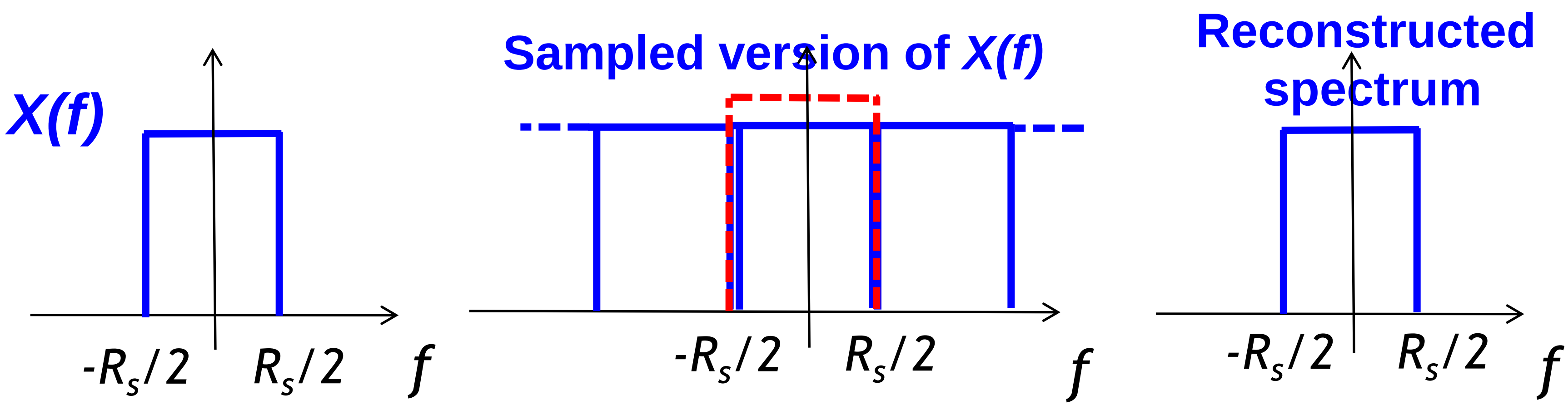


- Reconstruction of the signal:



From ideal to realistic …

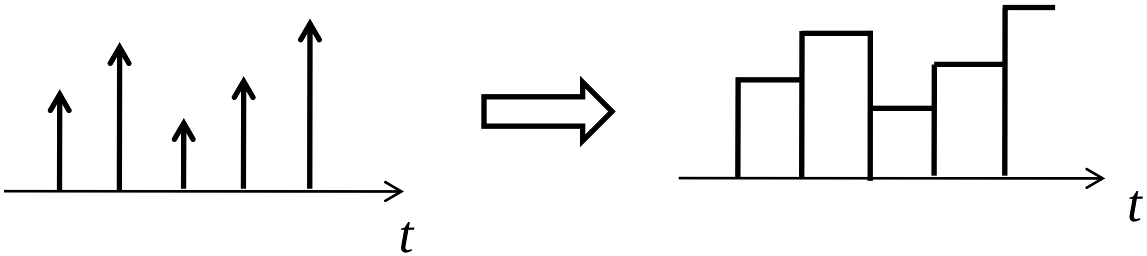
- To generate a perfectly rectangular Nyquist spectrum a DAC is needed operating at a speed equal to R_s samples/s (i.e. 1 sample/symbol) and with a perfectly rectangular transfer function with bandwidth $B_{DAC}=0.5 \cdot R_s$



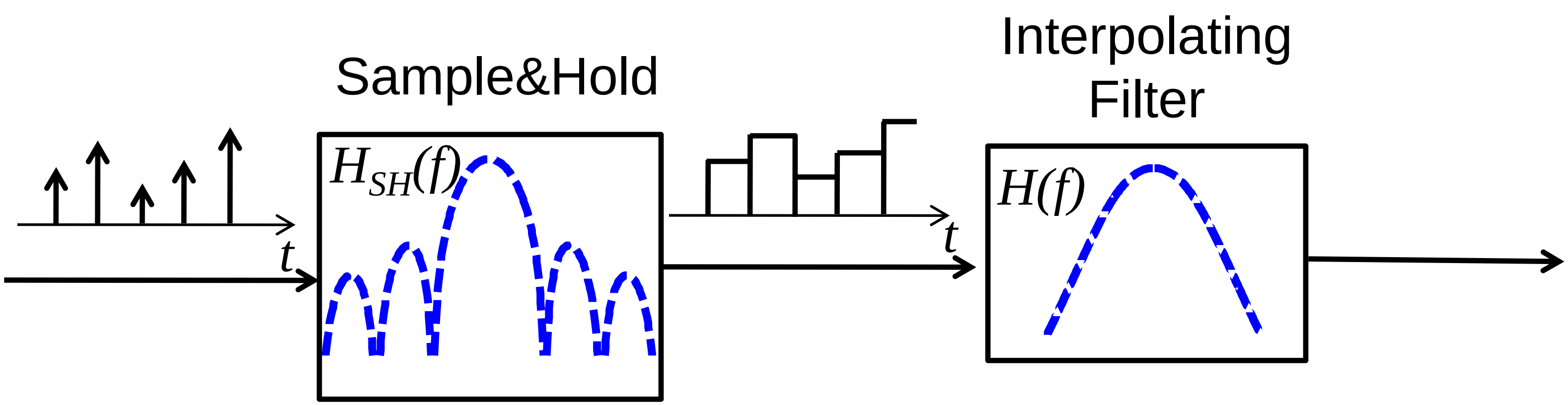
- Today commercial DACs are characterized by a maximum sampling speed f_{samp} around 24-30 Gsamples/s and a transfer function which is far from rectangular.

Realistic D/A conversion

- In “real” DACs, the “sampled” version of the signal is not composed of a sequence delta functions, but it is generated by “sample&hold” circuits

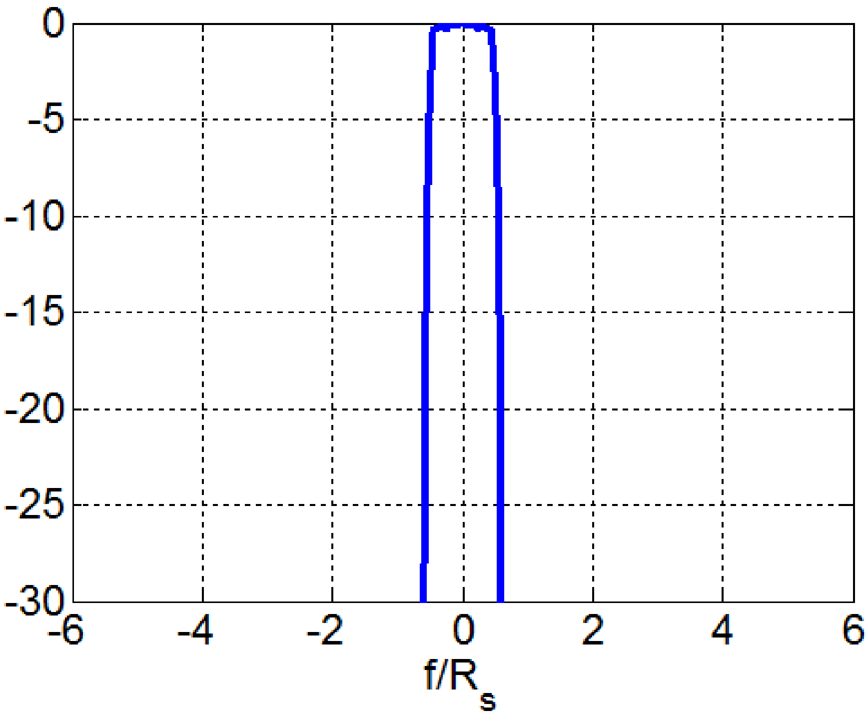


- Moreover, the interpolating filter is not an ideal low-pass filter, but a realistic one

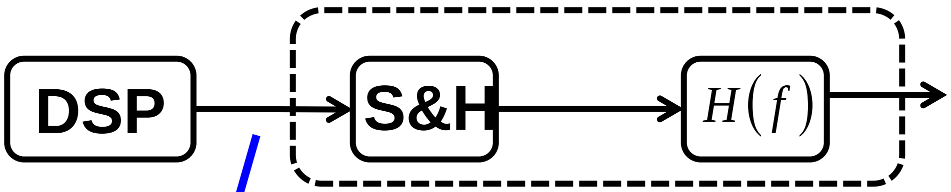


Spectra evolution in the D/A process

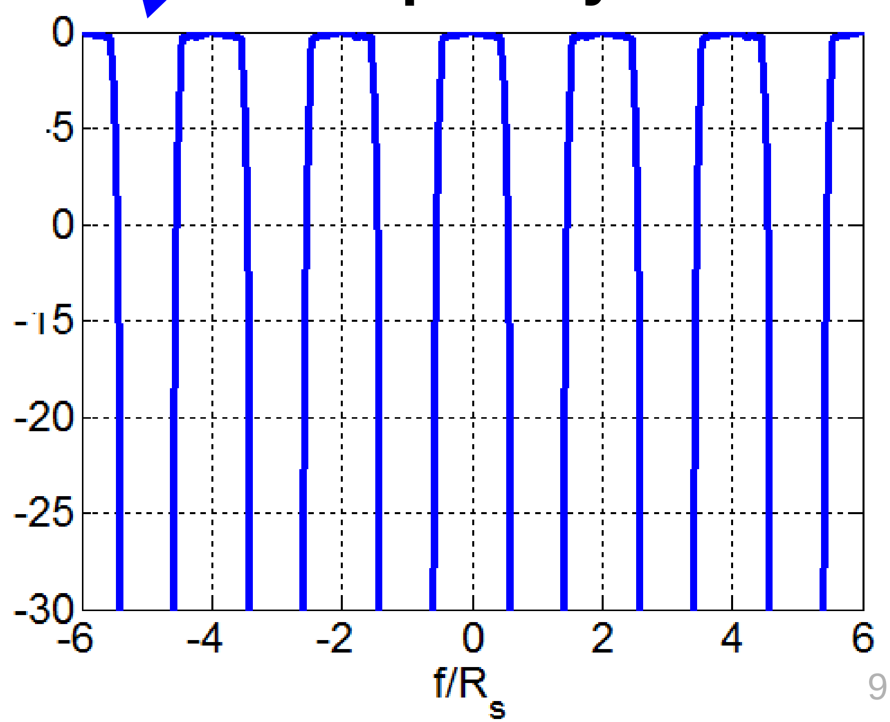
Ideal spectrum



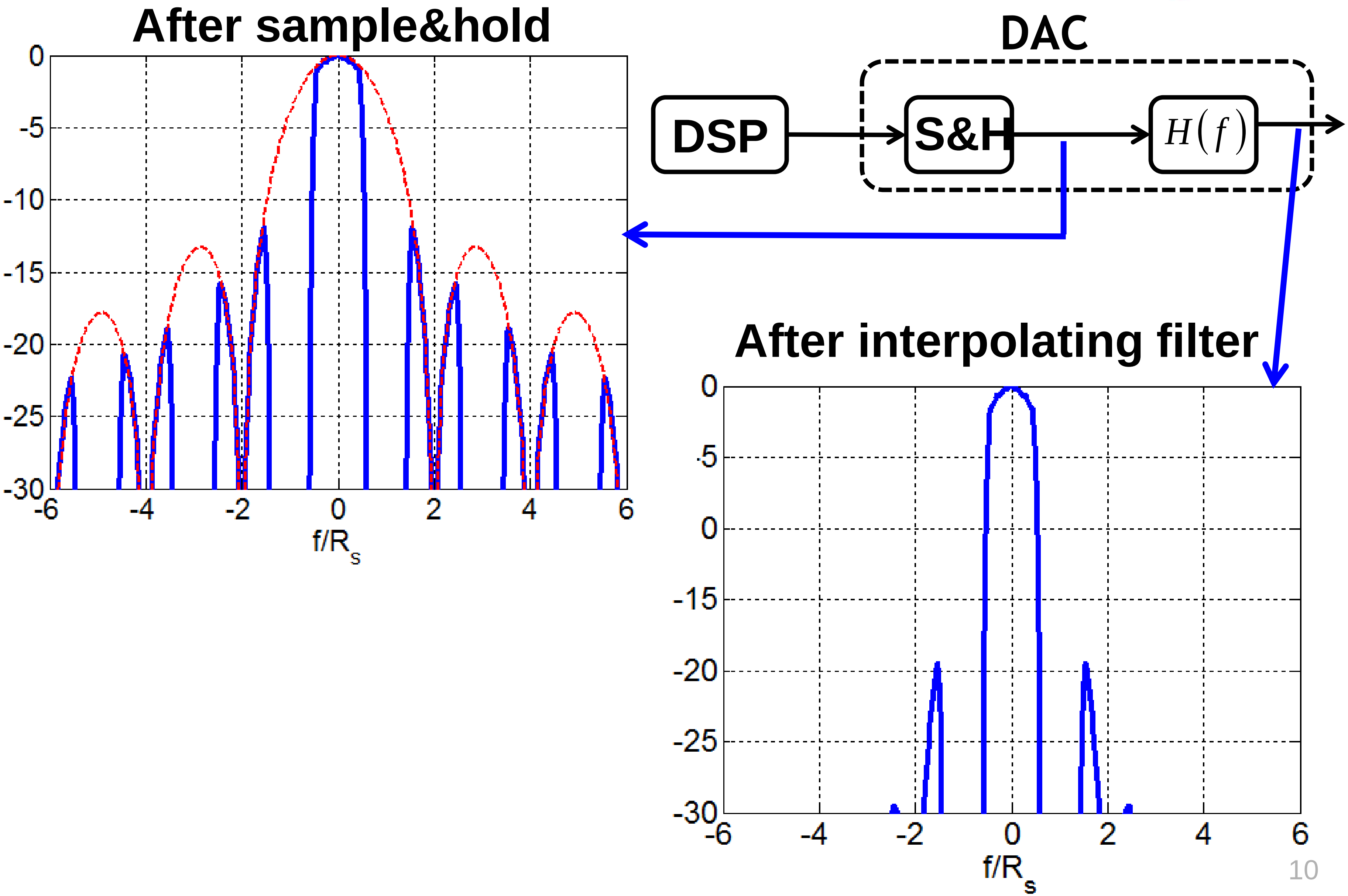
DAC



After sampling at 2 samples/symbol

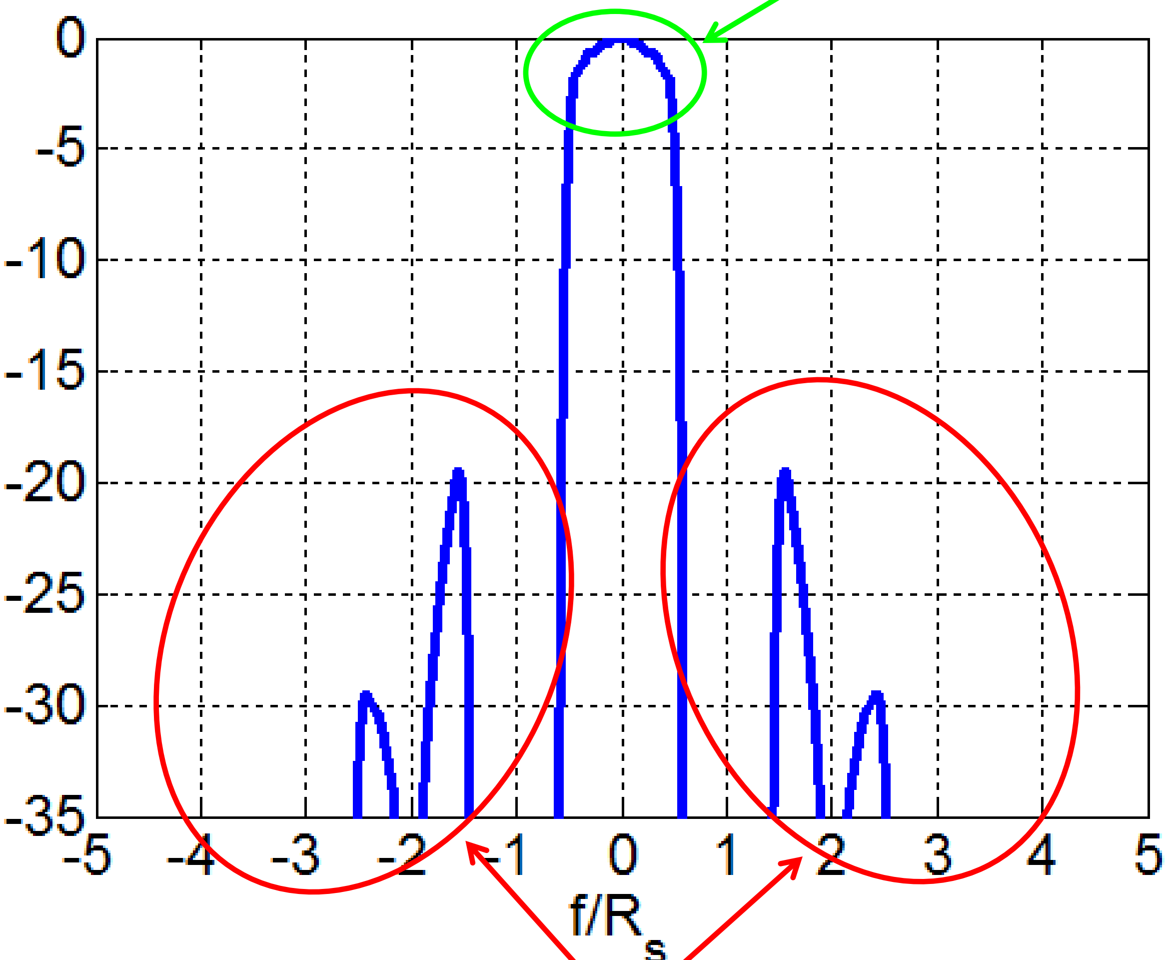


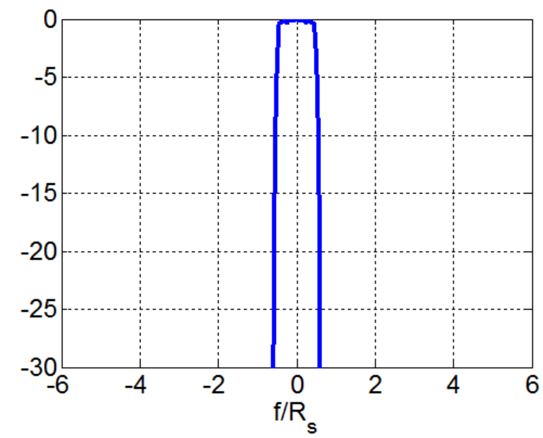
Spectra evolution in the D/A process



ISI and aliasing (2 samples/symbol)

Not flat → ISI





Spurious frequencies → WDM inter-channel cross-talk

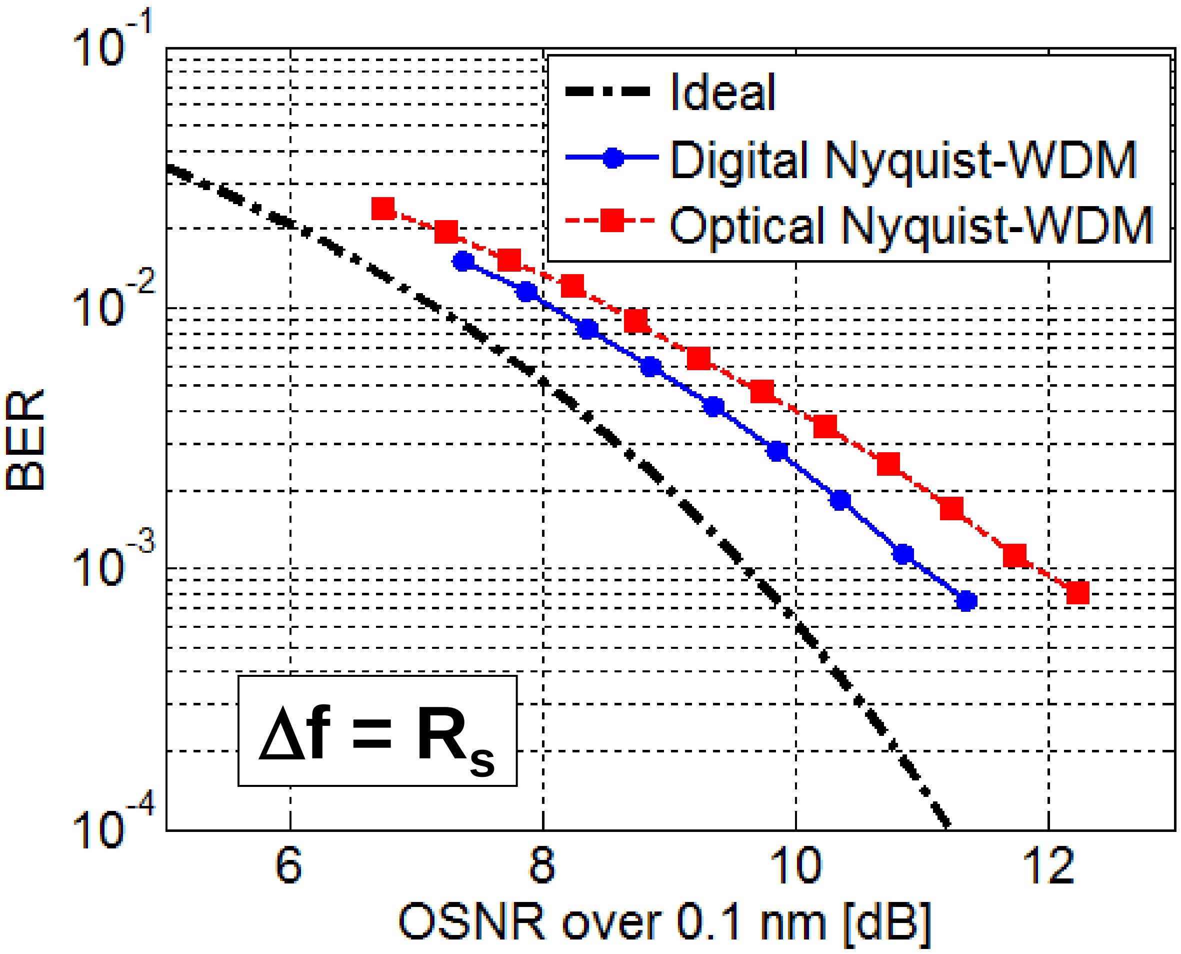
Analyzed system set-up

- 12-Gbaud PM-QPSK (or PM-16QAM) modulation format
- WDM signals with R_s (or 1.1 R_s) spacing

- DAC characteristics (Tektronix AWG 7000):
  - 24 Gsamples/s → 2 samples/symbol
  - bandwidth equal to 9.6 GHz (0.8 R_s)
  - 8 resolution bits

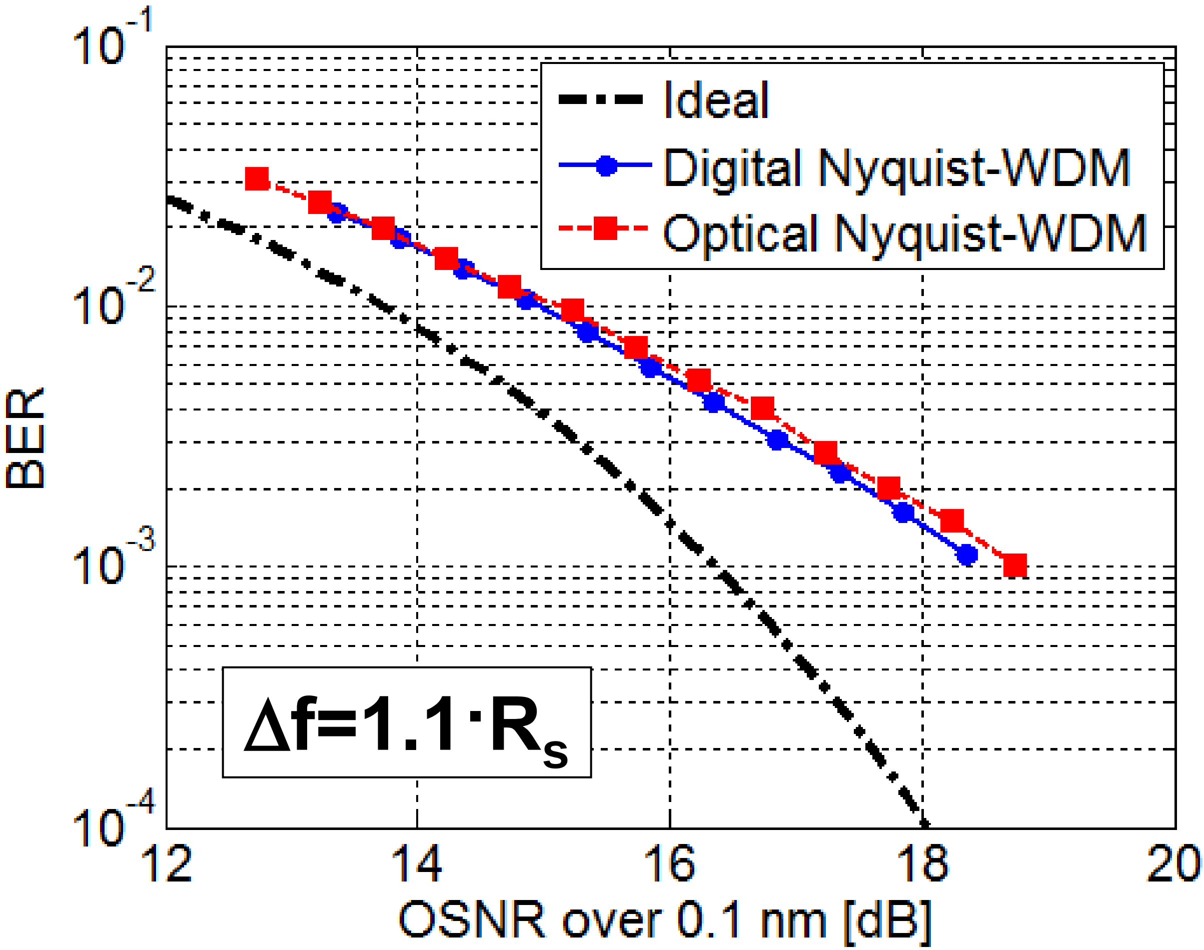
- The IQ modulator was biased in order to work in a quasi-linear regime and a proper pre-enhancement was applied to the digital samples in order to compensate for both the interpolating filter and the S&H process.

12-Gbaud PM-QPSK with $\Delta f = R_s$



- Optical filter: 4^{th} order Supergaussian with optimized bandwidth (12 GHz)
- Digital spectra: square-root raised-cosine with roll-off 0.15

12-Gbaud PM-16QAM with $\Delta f=1.1 \cdot R_s$



- Optical filter: 4^{th} order Supergaussian with optimized bandwidth (12 GHz)
- Digital spectra: square-root raised-cosine with roll-off 0.15

Conclusions

- The generation of Nyquist pulses in the digital domain through digital-to-analog conversion overcomes the need for a steep optical filter at the Tx side, which has been identified as one of the major drawbacks of "Optical Nyquist-WDM" technique.

- Preliminary results achieved using state-of-the-art DAC technology makes "Digital Nyquist-WDM" a promising technology for the generation of ultra-high spectral efficiency signals.

Thank you!

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