Hybrid Opto-Electronic WDM ADC

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Abstract: The design of a WDM ADC system and associated DSP is described. The hybrid system behaves as an analog mixer.

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Optical wavelength division de-multiplexing (WDM) analog-to-digital conversion (ADC) has been suggested for high-speed sampling of signals [1]. Multi-wavelength time-interleaved optical pulses [2] are used to sample a RF signal as shown schematically in Fig. 1. After modulation, the pulses of different center wavelength are spatially separated in an array wave-guide grating (AWG). Pulses of different center wavelength have a repetition rate reduced by a factor of *n* (where *n* is the number of different wavelengths). Each optical signal is detected, low-pass filtered, and electronically quantized. Digital signal processing (DSP) is then used to reconstruct the original signal by time-interleaving the sample from each ADC.

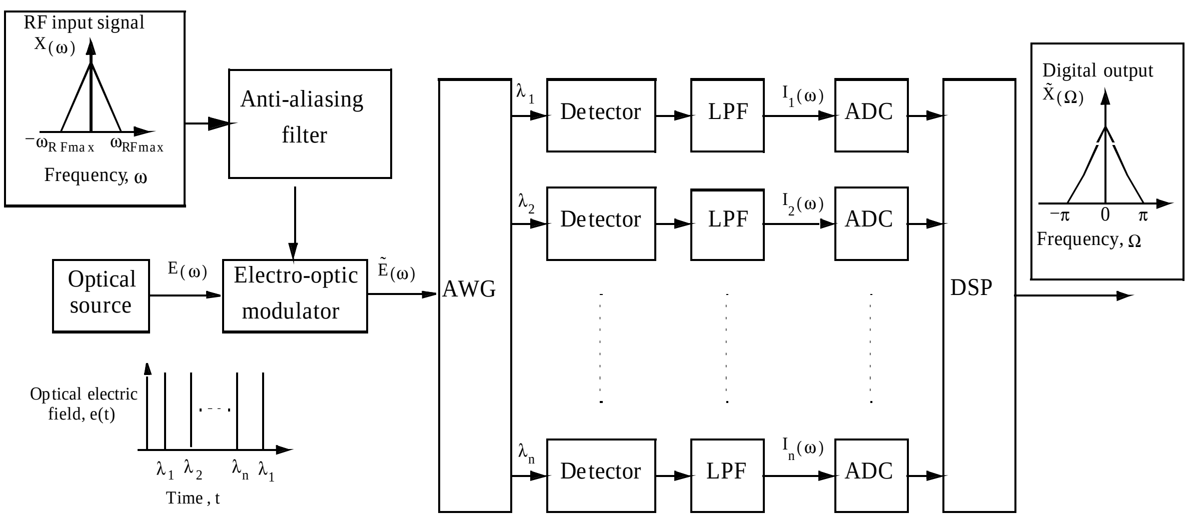

Fig. 1 - Schematic diagram of the hybrid opto-electronic WDM ADC system architecture. The optical multi-wavelength source is RF modulated and demultiplexed using an AWG. The output of the AWG is detected, low-pass filtered, and quantized. DSP reconstructs the original signal.

The frequency of pulses for a single center-wavelength is *n* times smaller than the sampling frequency. This means that in the frequency domain the detector current is an aliased signal. Fig. 2 shows schematically the detected signal spectrum of one channel. Here, ω_C is the frequency of mode-locked laser, $X(\omega_{RF})$ is the signal spectrum and $H(\omega_{RF})$ is the low-pass filter (LPF) transfer function (assumed to be ideal). Since the input signal has higher bandwidth compared to the mode spacing of mode locked laser the resulting detector current has high-frequency components of the signal aliased (or mixed) with low-frequency components.

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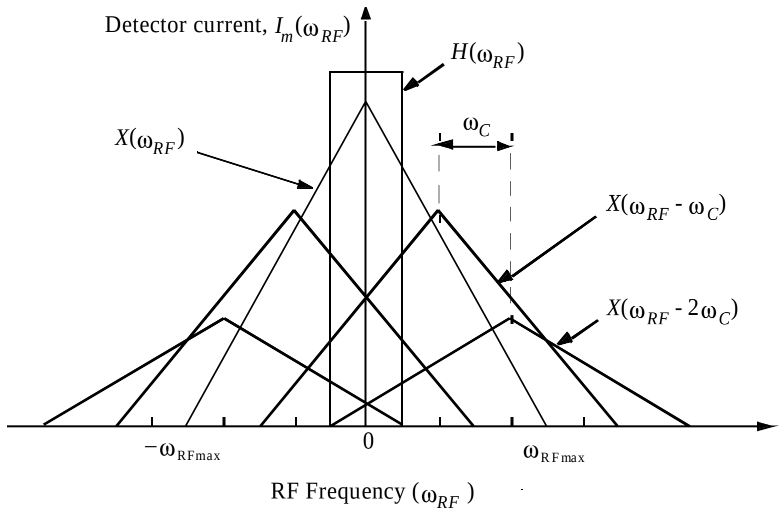

Fig. 2 - Schematic diagram of signal mixing in each detector. The high frequency components are mixed with low frequency components because of the mode spacing ω_C is small compared to the RF bandwidth ω_{RFmax}.

The complete system can be interpreted as an analog transfer function,

$$T(w_{RF}) = \sum_{k=-(n-1)/2}^{(n-1)/2} (N - |k|) H(w_{RF} - kw_C) \,,$$

and an effective sampling rate equal to n times the individual ADC sampling rate [3]. Here, N is the number of locked modes. Fig. 3 shows the system transfer function for a 4-pole Chebyshev filter with different –3 dB bandwidths. The sampling rate is 8 GS/s, n = 5, N = 4, and the system transfer function bandwidth is 5 times the LPF bandwidth.

A n-channel system requires at least $(n+1)/2$ optical modes locked together so that all high-frequency components are mixed with low-frequency components. This determines the minimum optical pulse width

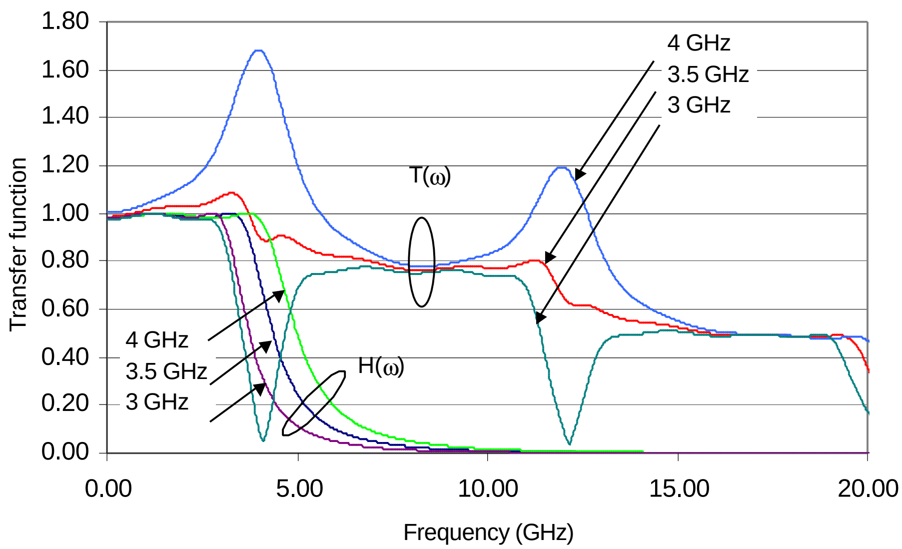

Fig. 3 - Transfer function $H(w_{RF})$ of the LPF and corresponding 5-channel system transfer functions $T(w_{RF})$ for different LPF –3 dB bandwidths for four-pole Chebyshev filters.

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for each individual center wavelength. The minimum bandwidth for each ADC (LPF bandwidth) must be chosen to obtain a smooth transfer function. If we have 8 GS/s ADCs and require a system sampling rate of 40 GS/s, 5 channels are needed with a minimum of 3 optical modes locked together spaced by 8 GHz and an input LPF of near 4 GHz bandwidth. The mode-locked laser frequency must be the same as sampling rate frequency.

Simulation results show that to achieve 6-bit resolution for sampling rates up to 40 GS/s in an $n = 5$ system we need less than 100 fs of jitter and an input optical power to each detector greater than 1 mW. Simulations assuming 10 fs jitter and 10 mW received optical power per channel predict 10-bit resolution is acheivable in a $n = 5$, 40 GS/s system.

References:
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