UWB Channelized Digital Receiver

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UWB Characteristics

- Large bandwidth
  - Unlicensed band (3.1 – 10.6 GHz).
  - Bandwidth > 500MHz.
  - Large multipath diversity.

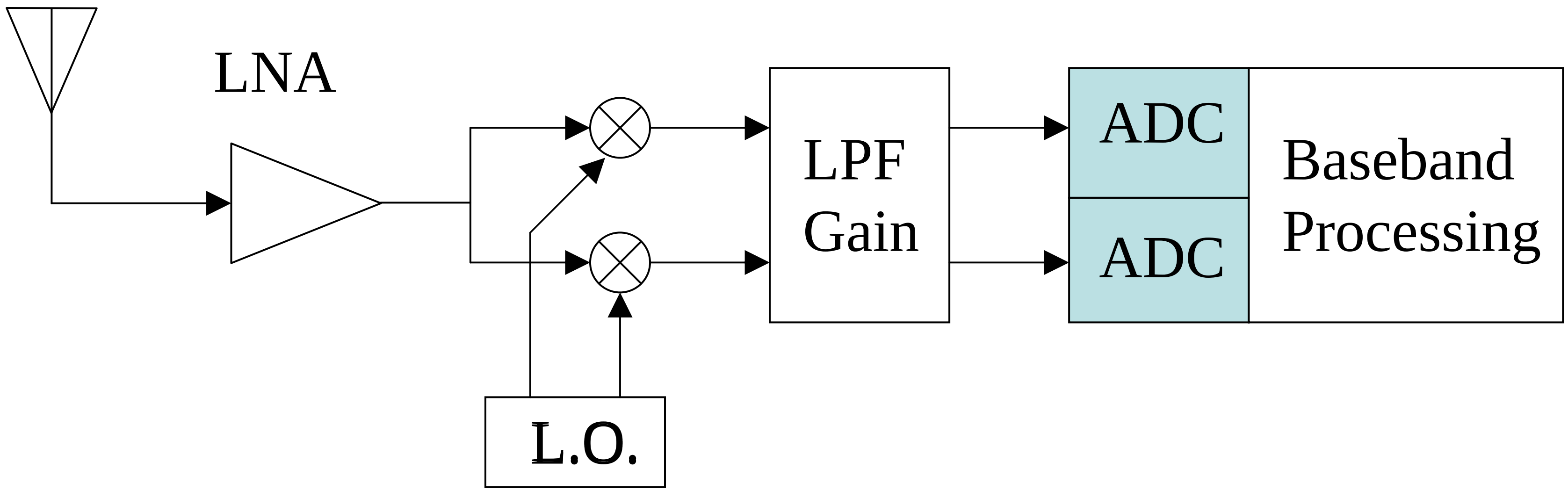
  → Effectively exploit large multipath diversity.
- Interferers.
  - In-band as well as out-of-band interferers.

  → Robust to interferers.

Why UWB Digital Receiver?

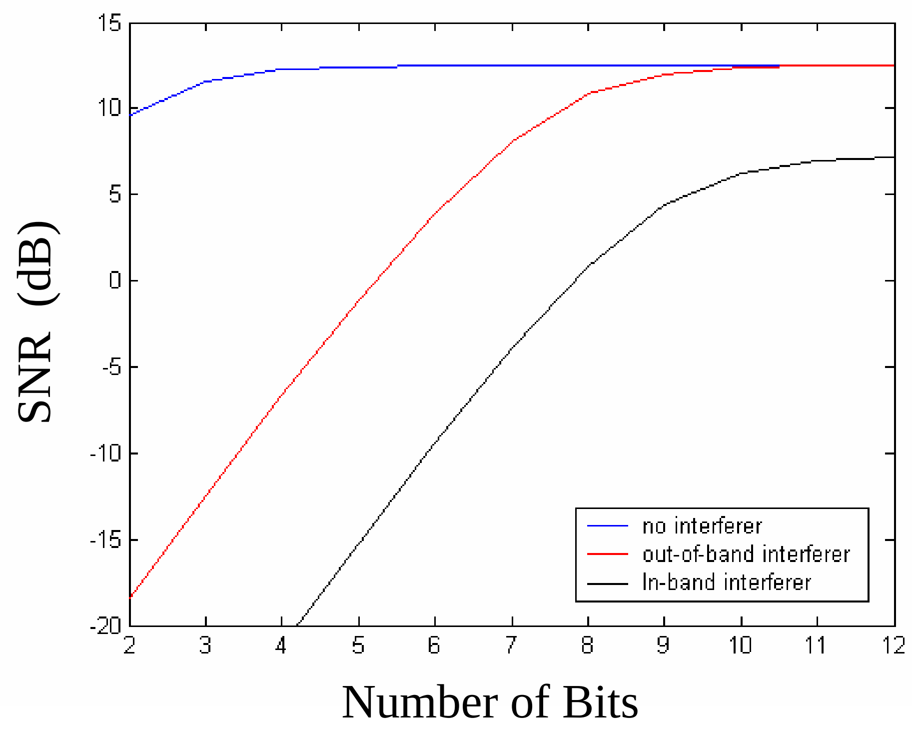
- Digital receivers perform receiver functions (e.g., correlation) digitally.
- High reception performance.
  - Many correlators needed to exploit multipath diversity.
  - Employ sophisticated interference suppression algorithms.
- Flexibility.
  - Support different modulation schemes.

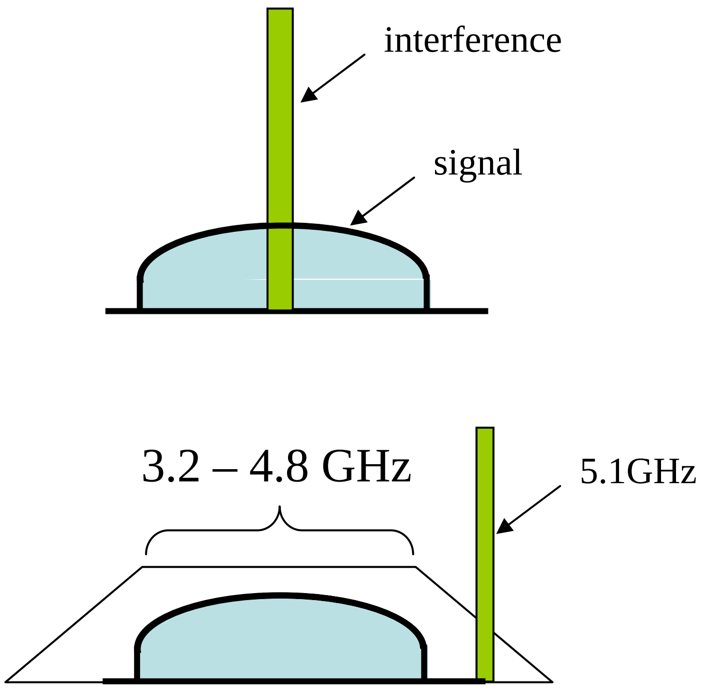
UWB Digital Receiver Architecture



- ADC is the primary implementation bottleneck.
  - High sampling frequency and dynamic range.
- Dominate overall power consumption.
  - Become even more dominant given current power scaling trends.

ADC Dynamic Range Requirement





- MMSE receiver SNR with knowledge of channel and noise statistics.
- Interference BW = 0.05 signal BW; Eb/I = -40dB.
- CM1 channel; 4th order LPF; 1GSymbol/sec; BPSK; 4GS/s ADC.

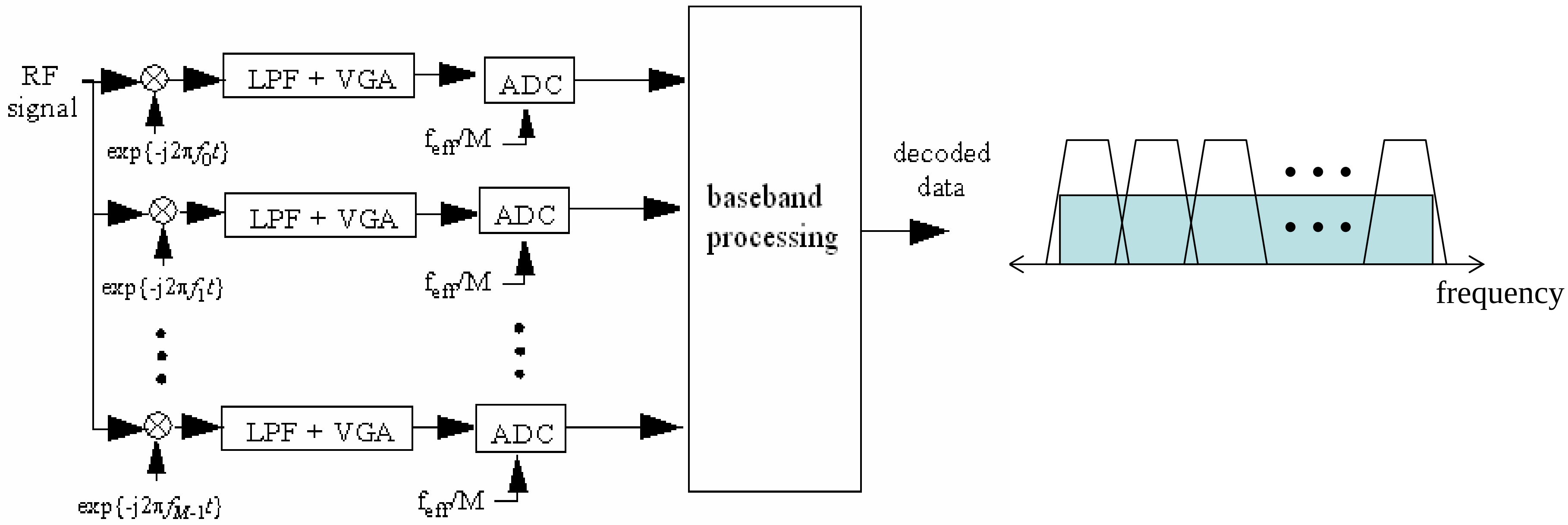
ADC Power Consumption Example

- Signal bandwidth is 2 GHz (e.g., 3-5 GHz).
- ADC requirements:
  - Sampling frequency > 2GS/s.
  - Resolution > 8-bits
- ADC figure of merit (*FOM*):

$$FOM = \frac{2^N \times f_{sample}}{Power}$$

- Using the best *FOM* of approx. 1e12, a 8-bit 2GS/s ADC consumes > 500mW.
  - **ADC power > 1 Watt !**

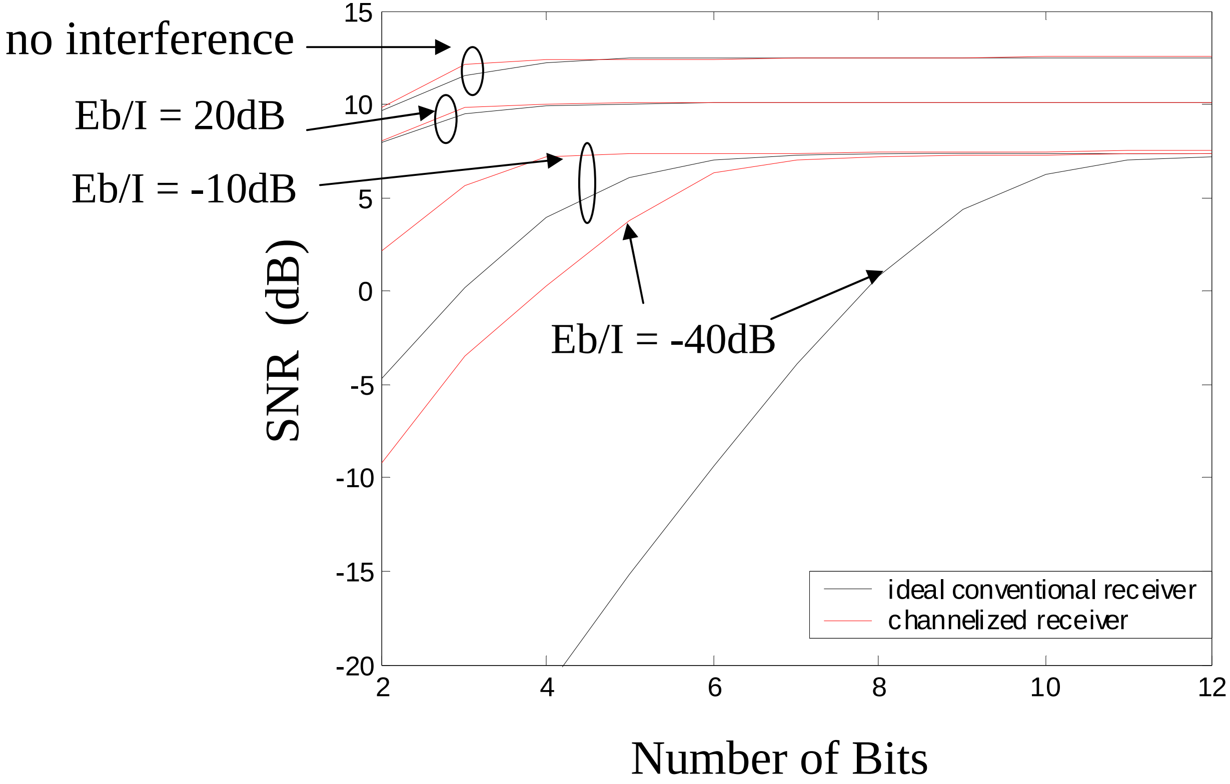
Frequency Channelized ADC



- Enables the use of a bank of simple, low-resolution, low-frequency ADCs.
  - Each ADC samples at approx. feff/M, where M is number of subbands.
- Isolates effects of large interferers → reduce ADC dynamic range.
  - ADC power decreases exponentially with number of bits.
- Implementation advantages valid regardless of technology improvements.

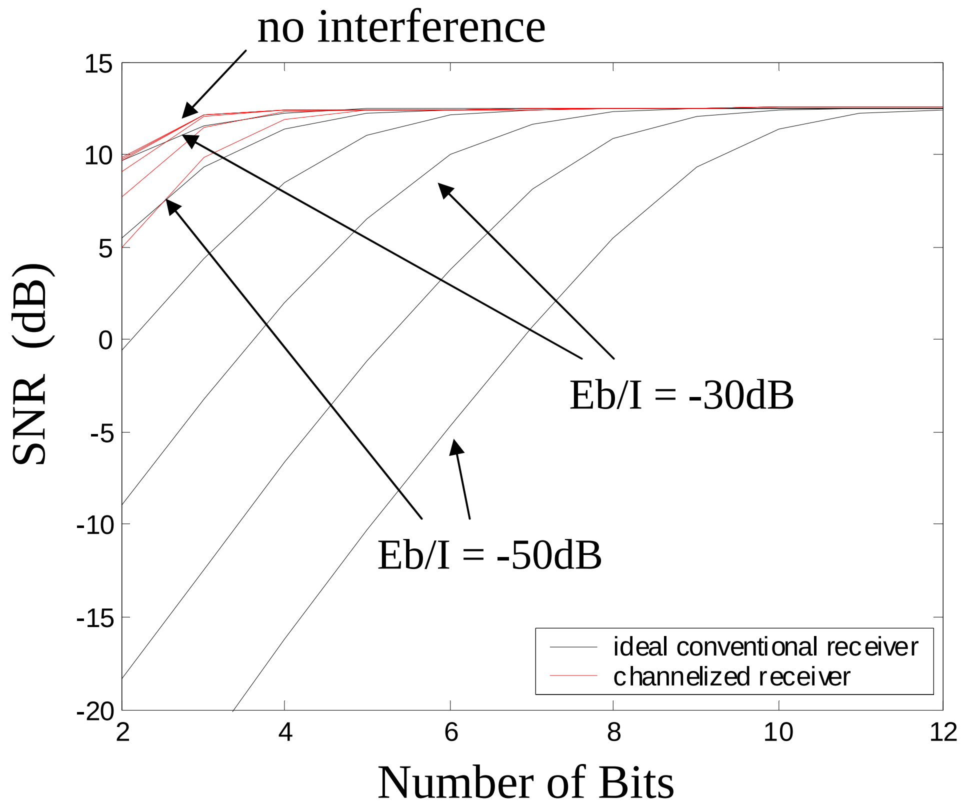
W. Namgoong, "A Channelized Digital Ultra-Wideband Receiver", IEEE Trans. on Wireless Communications, 2003.

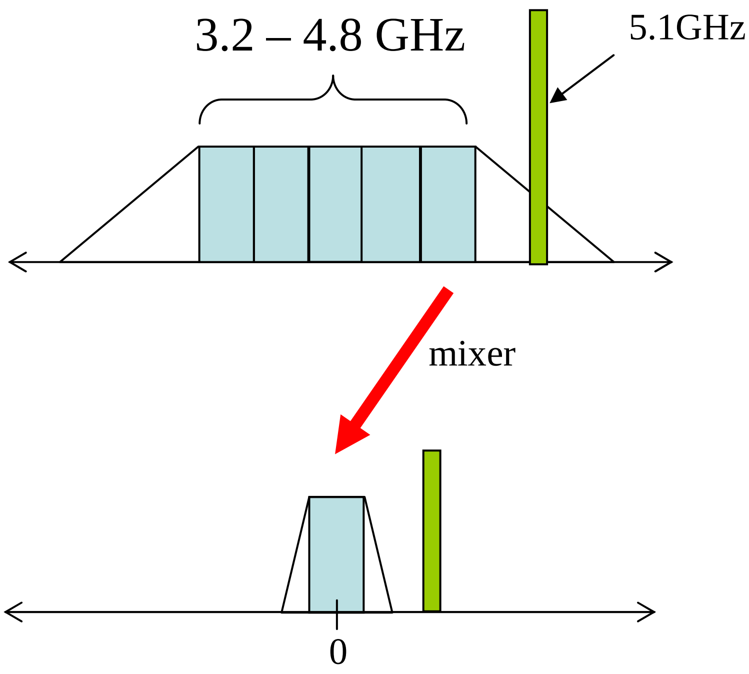
ADC Dynamic Range Comparison in the Presence of In-Band Interferer



- MMSE receiver SNR with knowledge of channel and noise statistics.
- Interference BW = 0.05 signal BW; worst center frequency.
- CM1 channel; 5 subbands; 4^{th} order LPF; BPSK; 1GSymbol/sec.

ADC Dynamic Range Comparison in the Presence of Out-of-Band Interferer





- MMSE receiver SNR with knowledge of channel and noise statistics.
- Interference BW = 0.05 signal BW; centered outside of signal spectrum.
- CM1 channel; 5 subbands; 4th order LPF; BPSK; 1GSymbol/sec.

Receiver Power Consumption Comparison

Full-band ADC

$$Power \approx \frac{2^{N_{FB}} \times f_{sample}}{FOM}$$

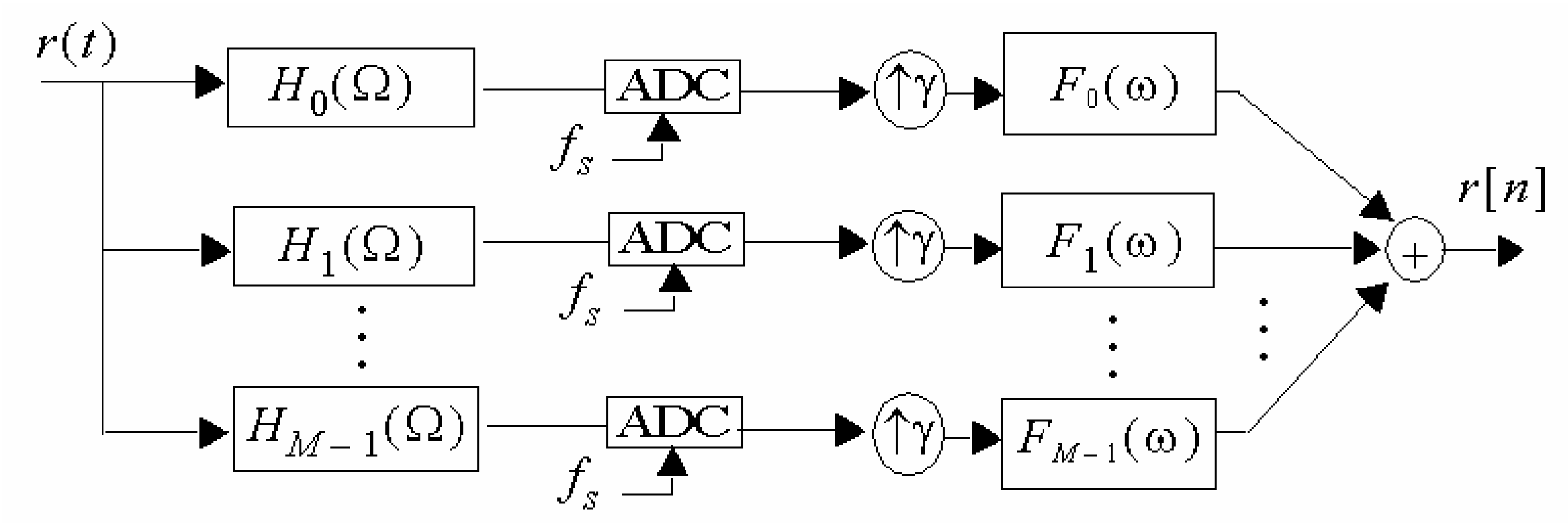
Frequency Channelized ADC

$$Power \approx M \times \frac{2^{N_{CH}} \times (f_{sample}/M)}{FOM}$$

- For the same performance, $N_{CH} \leq N_{FB} - 4$.
  →ADC power reduced by approx. 16X (= 2^4).
- Baseband amplifier power is comparable.
  - Overall gain-bandwidth product increases by approx. $\sqrt{M}$.
  - Linearity requirement relaxed.
- Additional mixer and synthesizer power can be made small.

→ Almost an order of magnitude reduction in receiver power possible!

Similar Digitization Approach …



- Hybrid filter banks (HFB) studied in 1990’s.
  - Continuous-time analysis and discrete-time synthesis filters.
- Integrated HFB has never been implemented.
  - Difficulty of designing accurate BPFs.
  - Requires accurate knowledge of BPF transfer functions.
  - Difficult due to process and temperature variations.

Estimation vs. Detection

- In existing HFB work, objective is perfect reconstruction.
  - Serve as analog-to-digital converter.
- Our objective is **data detection**, not reconstruction of received signal.
  - Much easier problem than signal estimation.
  - Can be readily made adaptive to uncertainties in analog filters.

→ HFB can be made practical.

Adaptive Channelized Receivers

- Adaptive digital filters converge slowly.
  - Many more parameters to estimate.
  - Estimate cross-filters that eliminate subband aliasing.
- Slow convergence problematic in time-varying UWB propagation channels.

  → Need fast convergence!
- Developed schemes that achieve convergence speed comparable to an ideal full-band receiver.
  - Low data rate transmitted reference systems.
  - High data rate cyclic prefixed systems.

Concluding Remarks on Frequency Channelized Receiver

- Channelized receiver not unique to UWB radio.
- Can be used in both narrowband and wideband receivers to relax implementation requirements.
  - ADC dynamic range, linearity, and sampling jitter.
  - Significant reduction in power.
- Frequency channelized serial-link ADC (ISSCC 2005).
  - First frequency channelized receiver implementation.
- Channelized receiver approach effective regardless of advances in ADC technology.