Neural Interfaces

NX-422

Digitization

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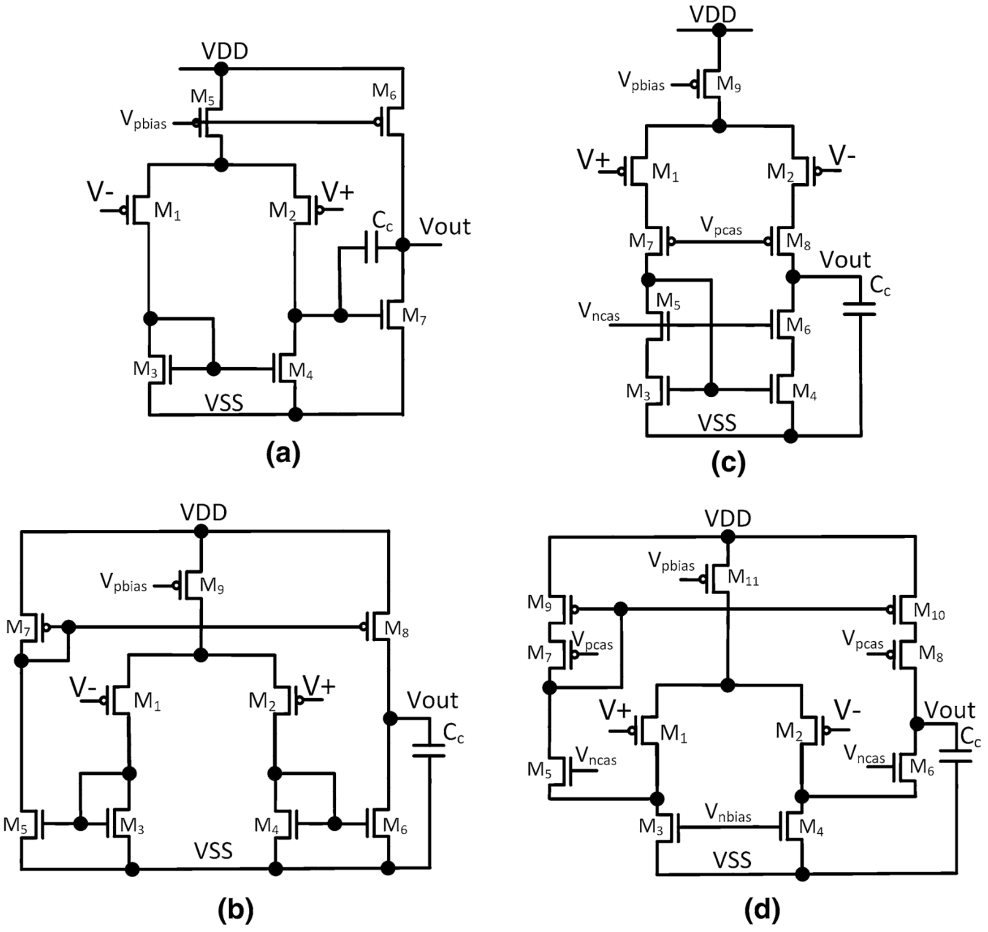
IEM and Neuro-X Institutes

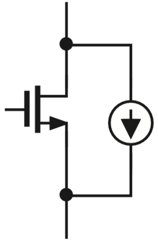
Recap: Neural Amplifier: OTA architecture

a) 2-stage
b) Current mirror
c) Telescopic cascode
d) Folded cascode



Recap: Noise basics

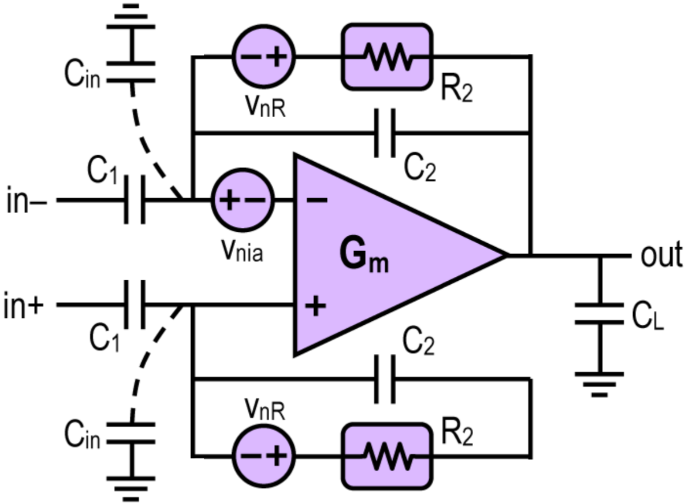
Thermal noise:

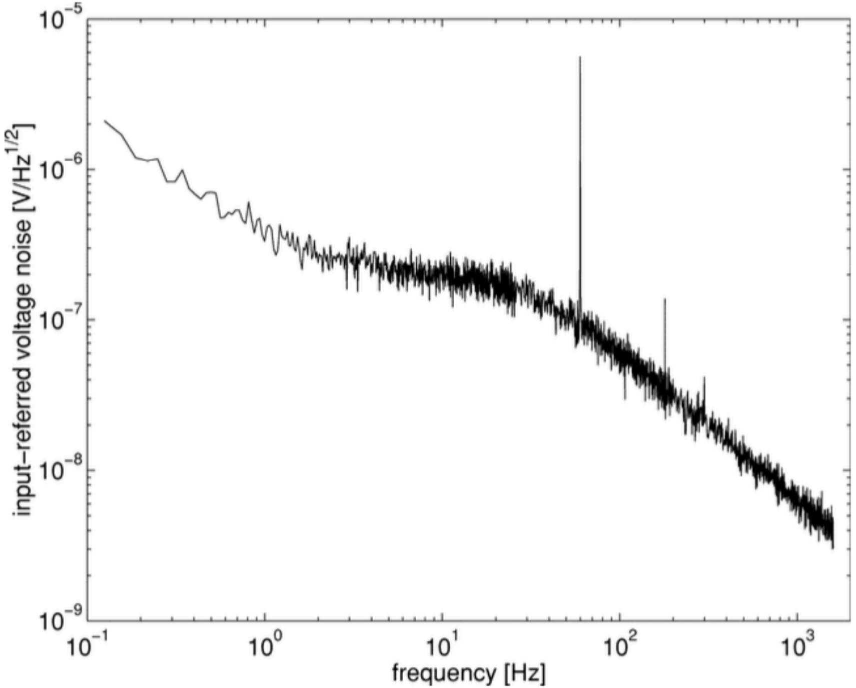


$$\overline{I_n^2} = 4kT\gamma g_m$$

Flicker (1/f) noise:

$$\overline{v_i^2} = \left(\frac{K_f}{WLC_{ox}f}\right)$$

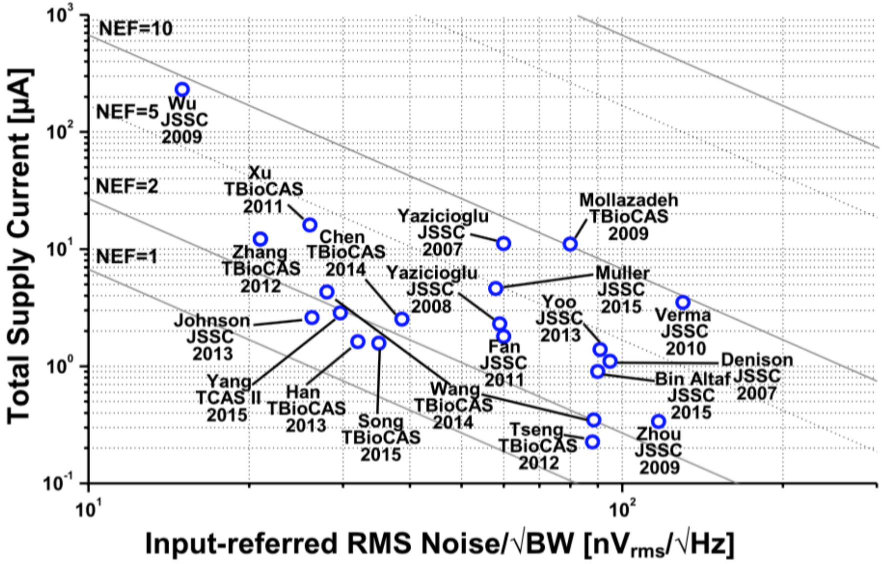




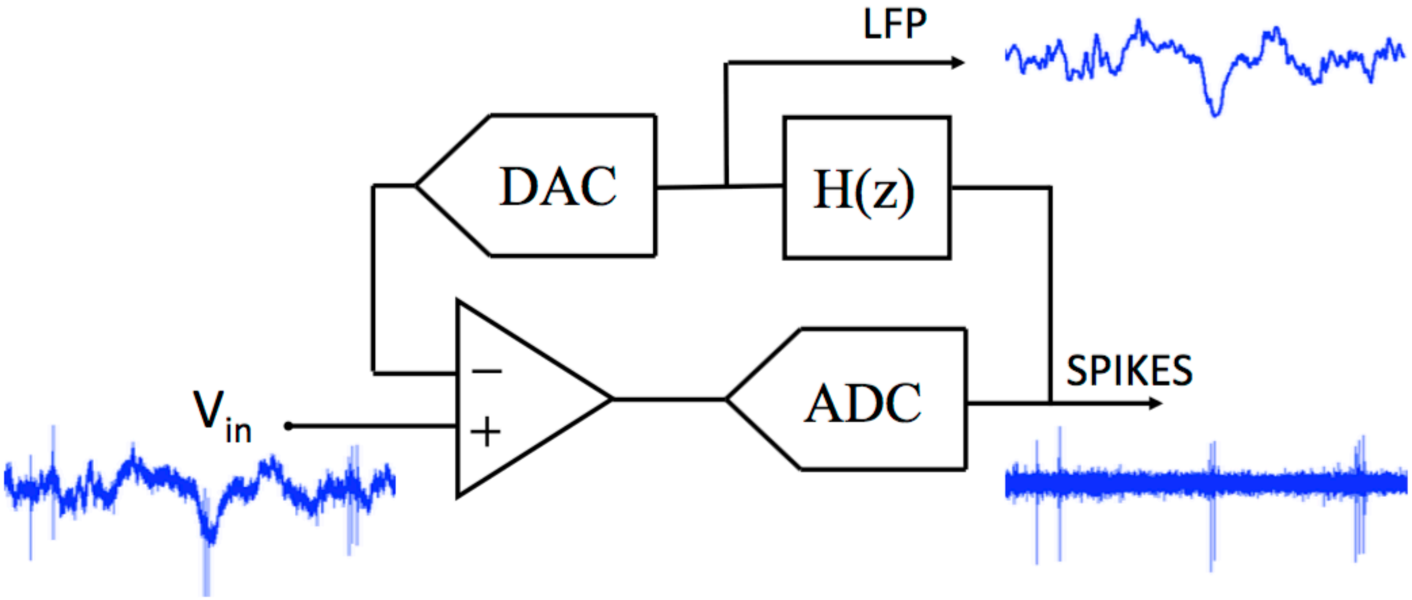
Noise Efficiency Factor (NEF)

- $V_{rms,in}$: The total input-referred noise
- I_{tot}: The total current drain
- V_t: The thermal voltage
- BW: The 3-dB bandwidth of the system

$$\mathrm{NEF} = V_{\mathrm{rms,in}} \sqrt{\frac{2I_{\mathrm{tot}}}{\pi V_t \cdot 4kT \cdot BW}}$$

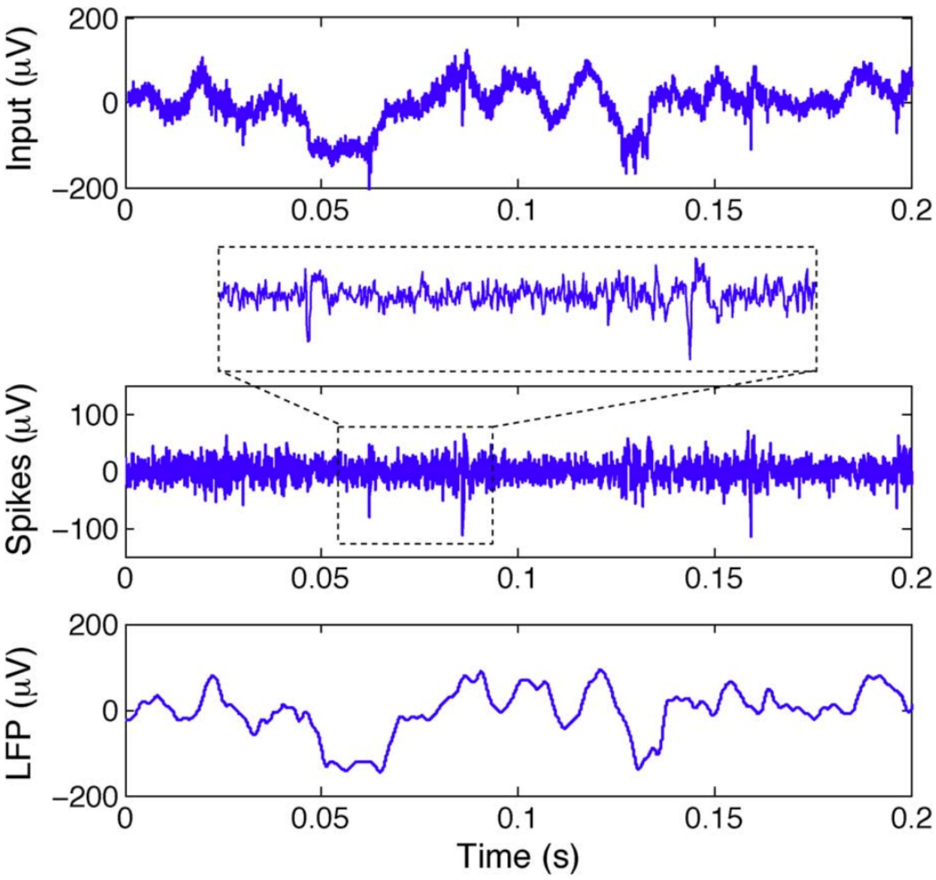


DC Offset Cancellation with DC-Coupled Amplifier



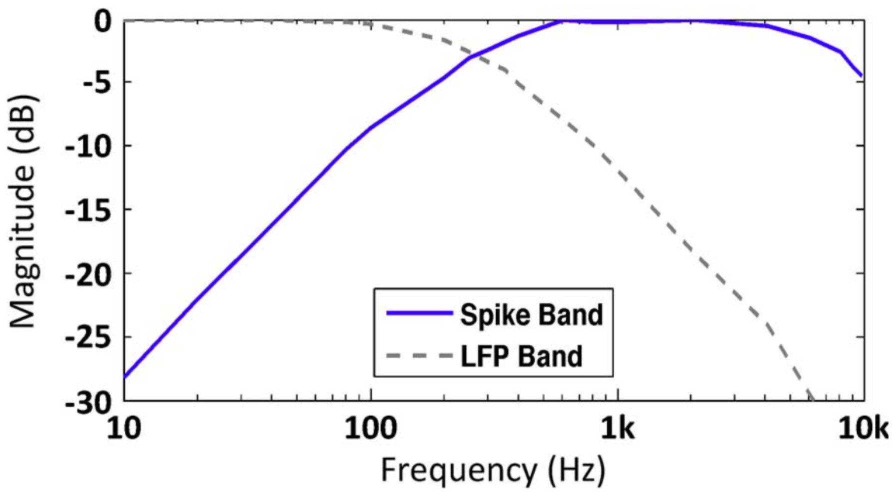
R. Muller et al., JSSC 2012

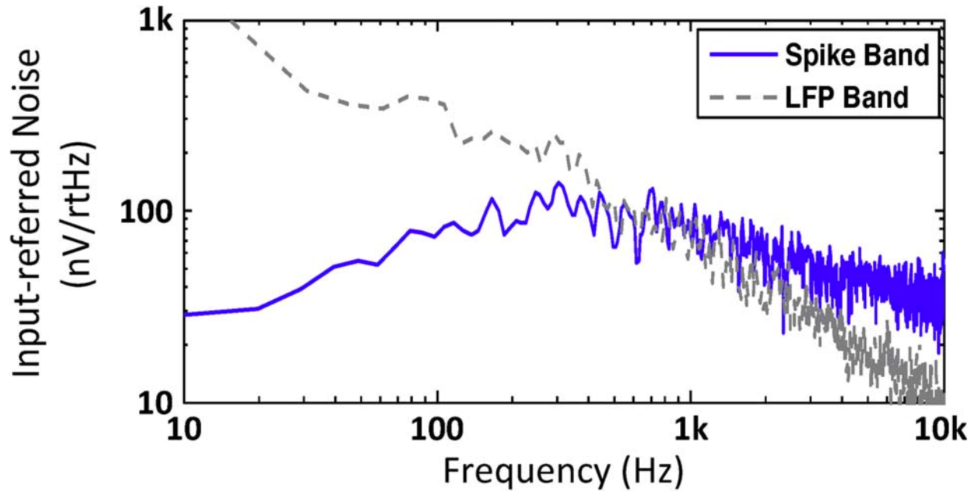
Spike and LFP Measurements



R. Muller et al., JSSC 2012

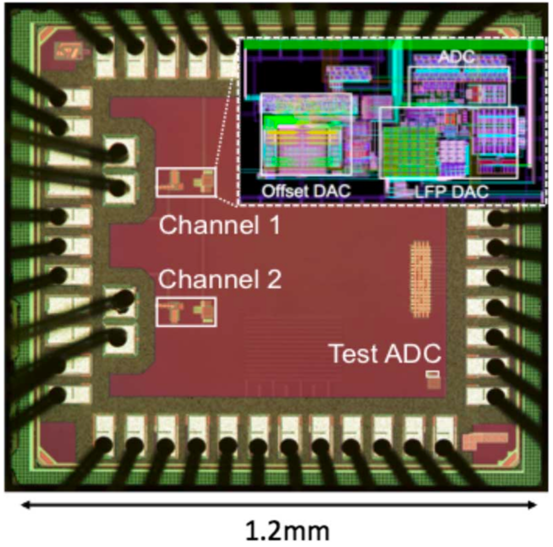
Amplifier gain and input-referred noise





R. Muller et al., JSSC 2012

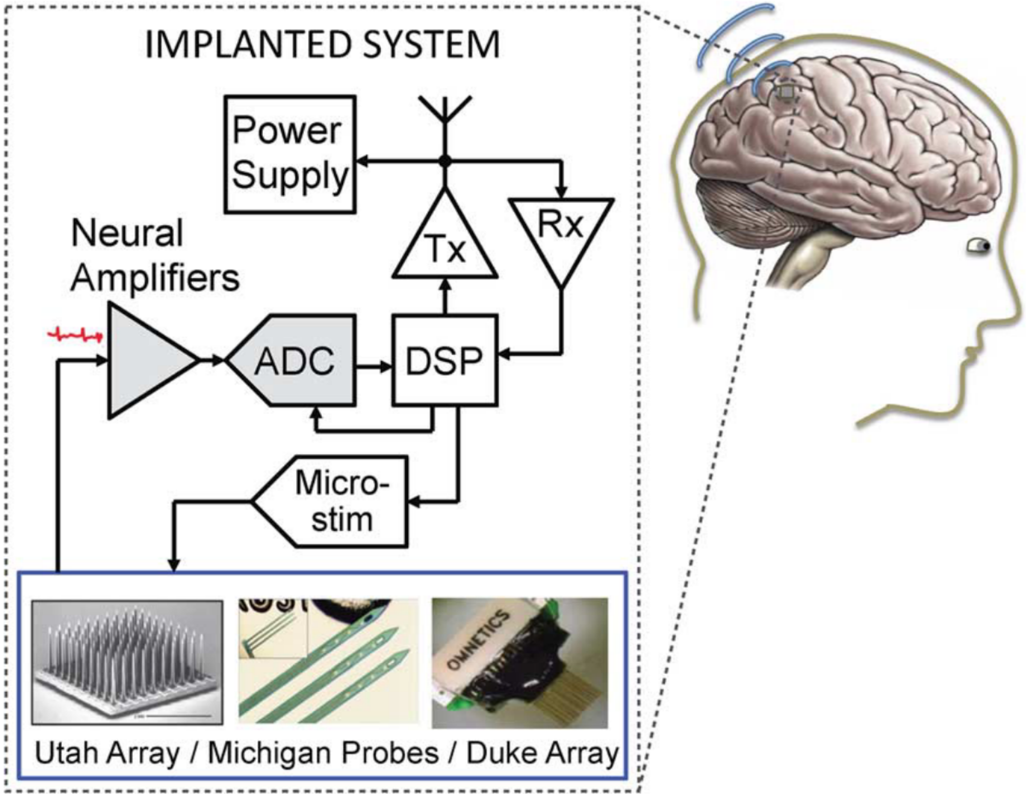
Die photo and performance smmary



	Power	Area
Merged Amplifier-DAC	4.13µW	0.0037mm^2
Summing Amplifier & DAC	0.66µW	0.0045mm^2
ADC	0.24µW	0.0018mm^2
Digital Filters	0.1µW*	0.0017mm^2

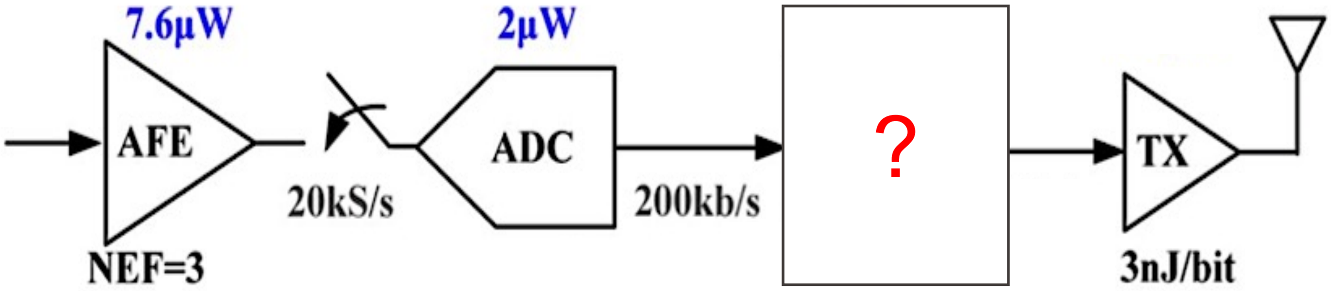
	[3] JSSC '09	[4] JSSC '07	[6] BioCAS '07	[7] ISSCC '10	[24] VLSI '11	This Work
Power (µW)	15	42.2	7.56	0.64	43	**5.04**
IRNoise (µV), Spike	7.0	5.1	3.06	14	2.2	**4.9**
Spike Bandwidth	5kHz	5kHz	5.3kHz	6.2kHz	10kHz	**10kHz**
NEF	4.6	9.8	2.67	6.5	5	**5.99**
$NEF^2 \cdot V_{DD}$	63.48	316.9	20	33.8	30	**17.96**
IRNoise (µV), LFP	-	-	1.66*	-	14	**4.3**
LFP Bandwidth	-	-	300Hz*	-	100Hz	**300Hz**
CMRR (dB)	-	-	66	59	-	**75**
PSRR (dB)	-	-	75	71	-	**64**
V_{DD} (V)	3	3.3	2.8	0.8	1.2	**0.5**
Area (mm^2)	0.04	0.16	0.16	0.4**	0.2**	**0.013**
Technology	0.35µm	0.5µm	0.5µm	0.13µm	0.13µm	**65nm**
Blocks included in comparison	LNA, BPF	LNA, BPF	LNA, BPF	LNA, BPF	LNA, BPF, ADC	**LNA, BPF, ADC**

Circuit Block Diagram of a Neural Interface: ADC



Neural Interface: ADC and Compression

- The typical circuit blocks used in sensors for medical monitoring and their associated energy cost and power consumption



F. Chen et al, *JSSC'12*

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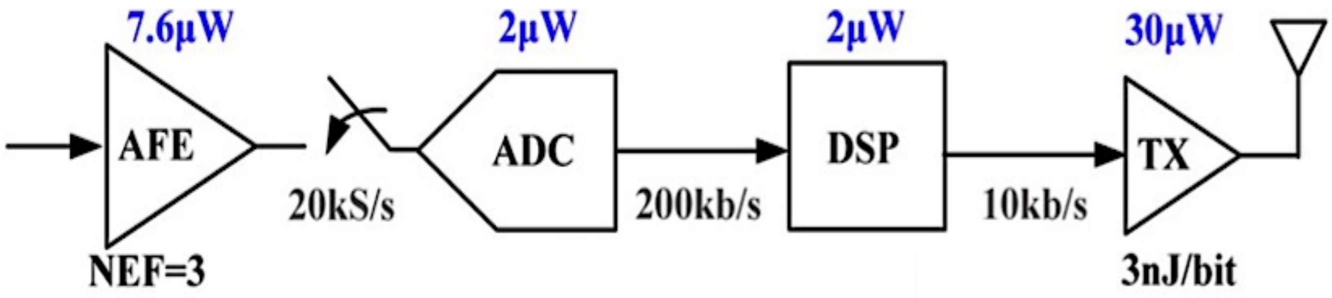

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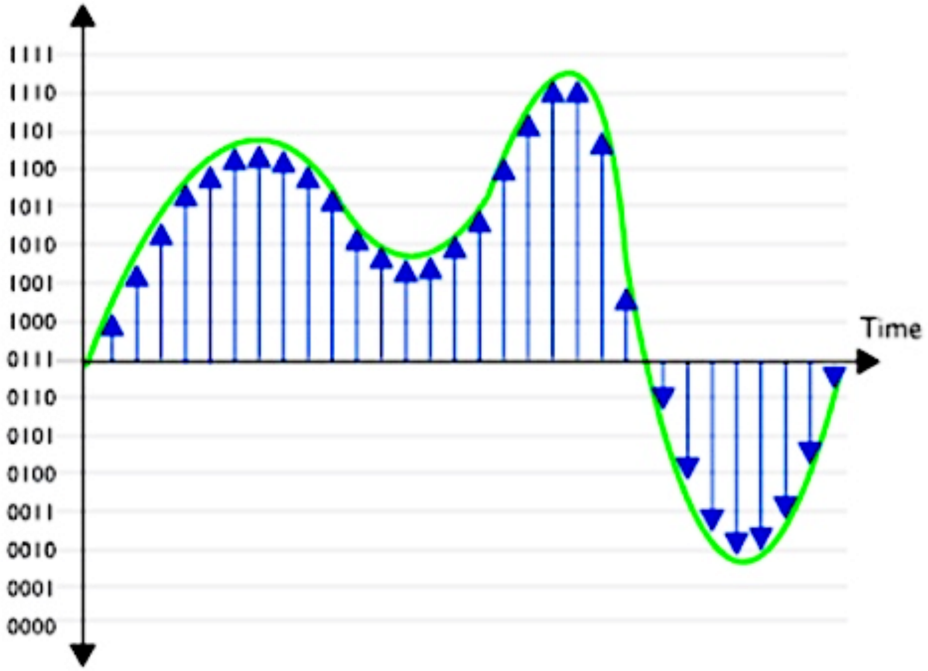
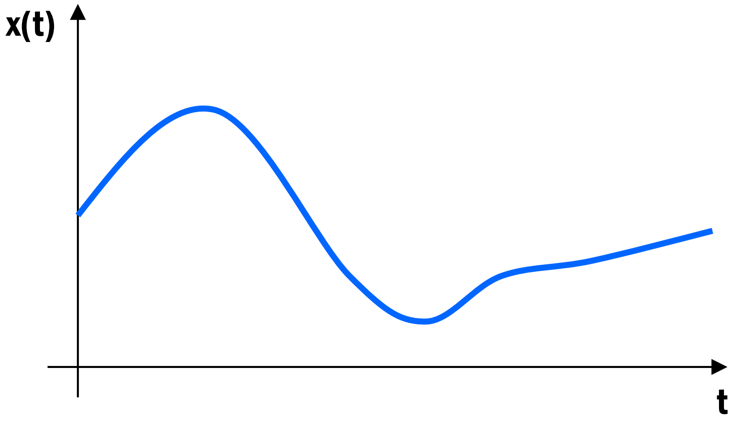
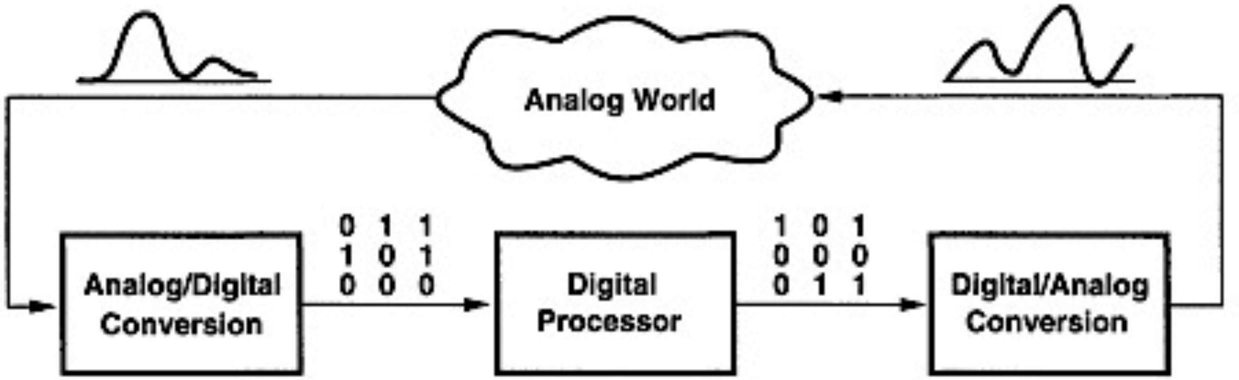
Analog to Digital Conversion

- After amplification and filtering, signal is digitized (sampled at a fixed rate)



Analog and Digital Signals





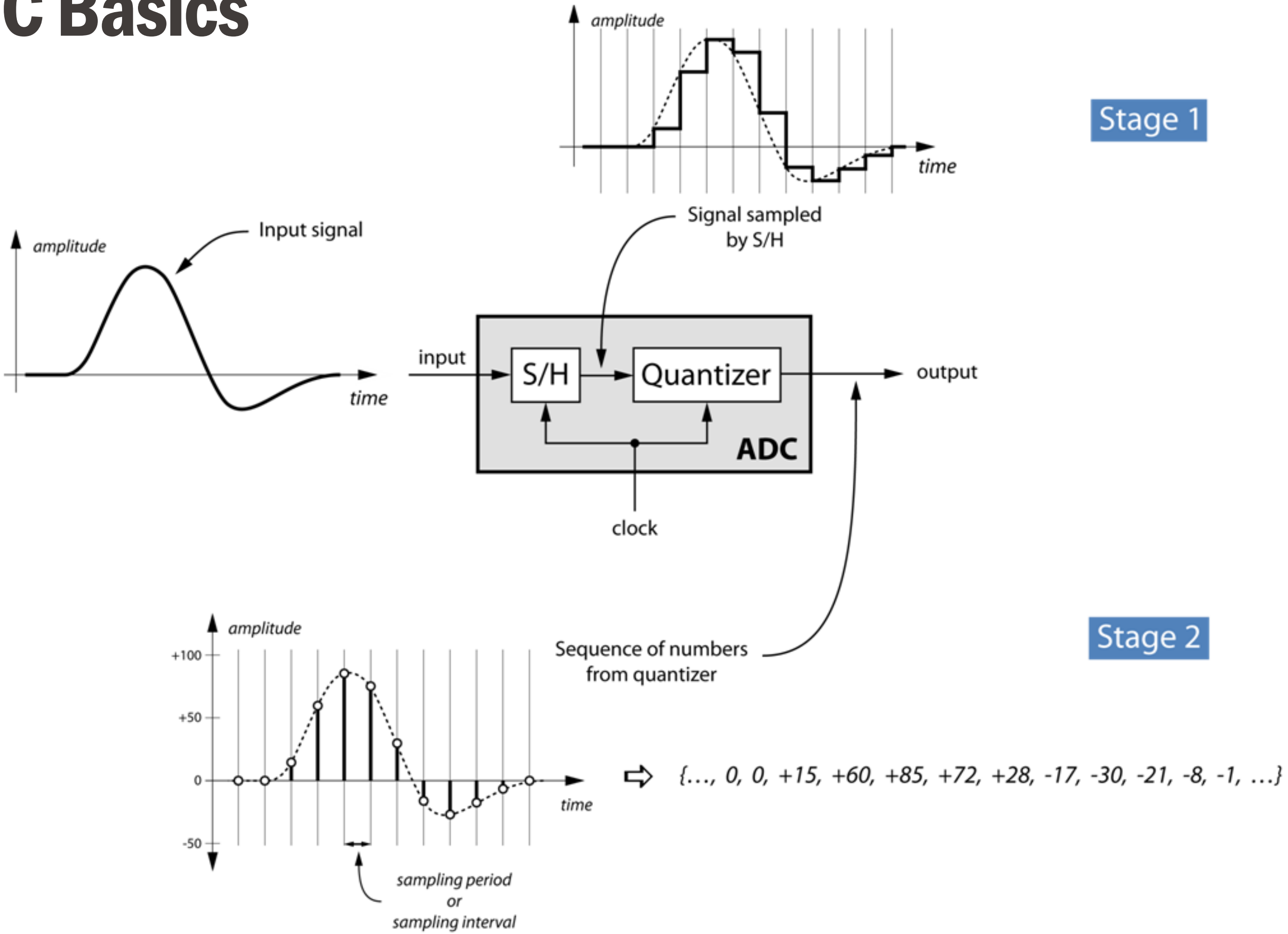
Digital Data Acquisition

Foundation: *Shannon/Nyquist sampling theorem*

"if you sample densely enough (at the Nyquist rate), you can perfectly reconstruct the original analog data"

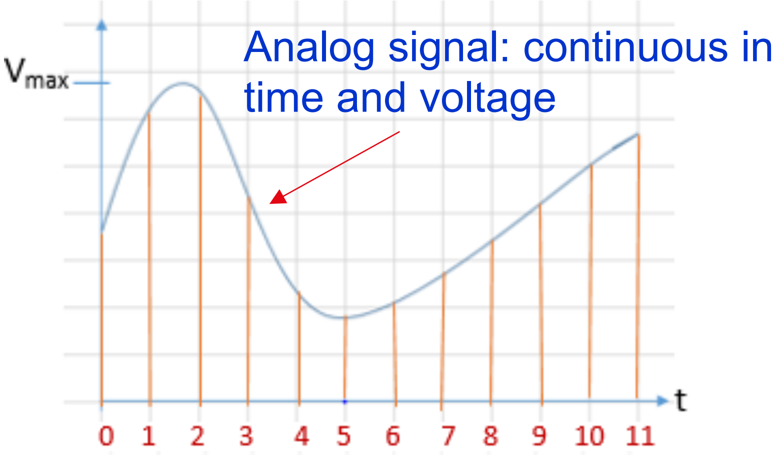
- A bandlimited analog signal can be perfectly reconstructed from a sequence of samples if the sampling rate **fs** exceeds $\mathbf{2f_{max}}$ samples per second, where f_{max} is the **highest frequency** in the original signal.

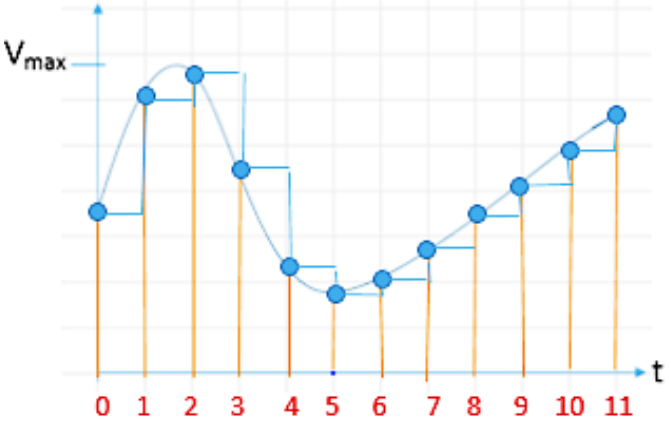
ADC Basics


amplitude
time
Stage 1
Signal sampled
by S/H
amplitude
Input signal
time
input
S/H
Quantizer
ADC
output
clock
amplitude
+100
+50
0
-50
time
sampling period
or
sampling interval
Sequence of numbers
from quantizer
Stage 2
{..., 0, 0, +15, +60, +85, +72, +28, -17, -30, -21, -8, -1, ...}

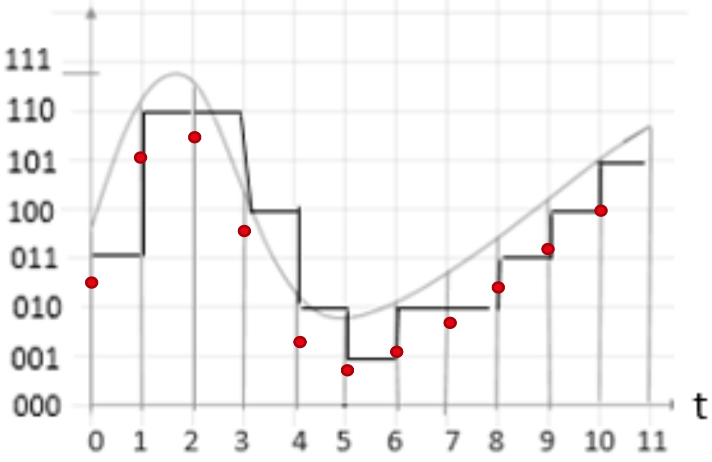
ADC Operation

Sampling and Holding



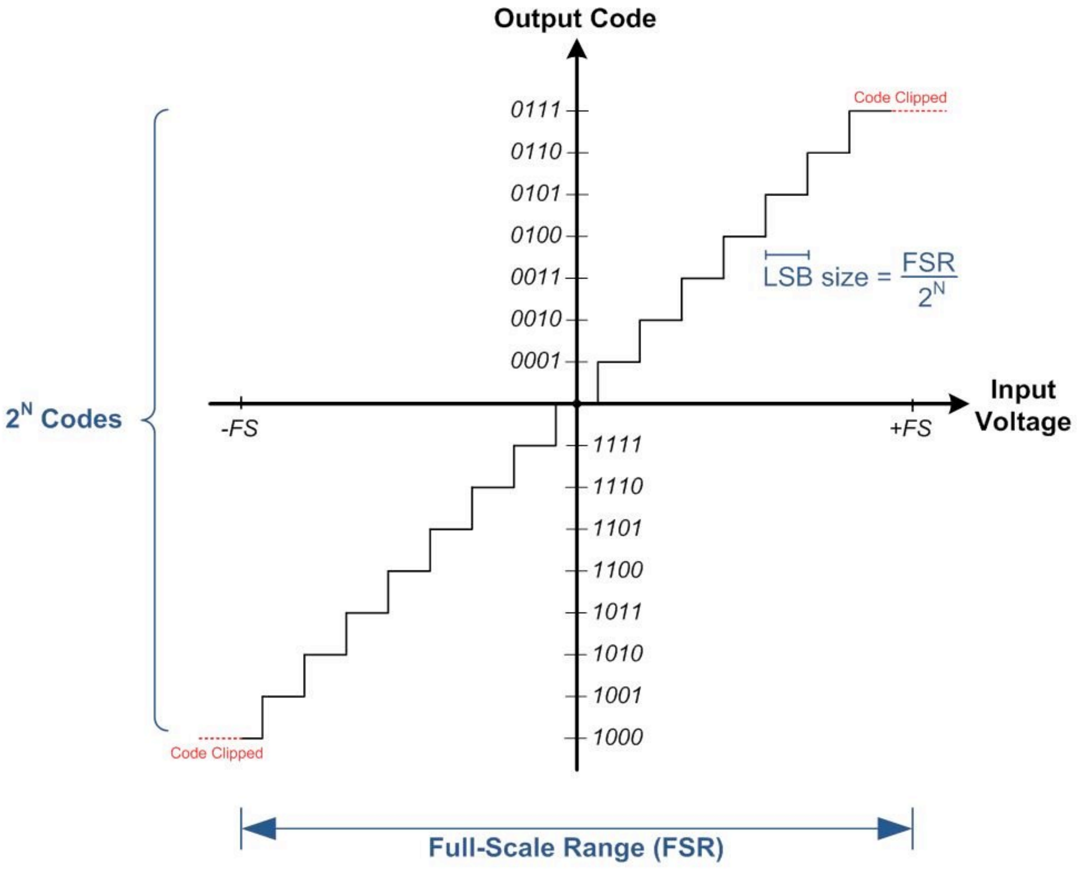


Quantization and Encoding

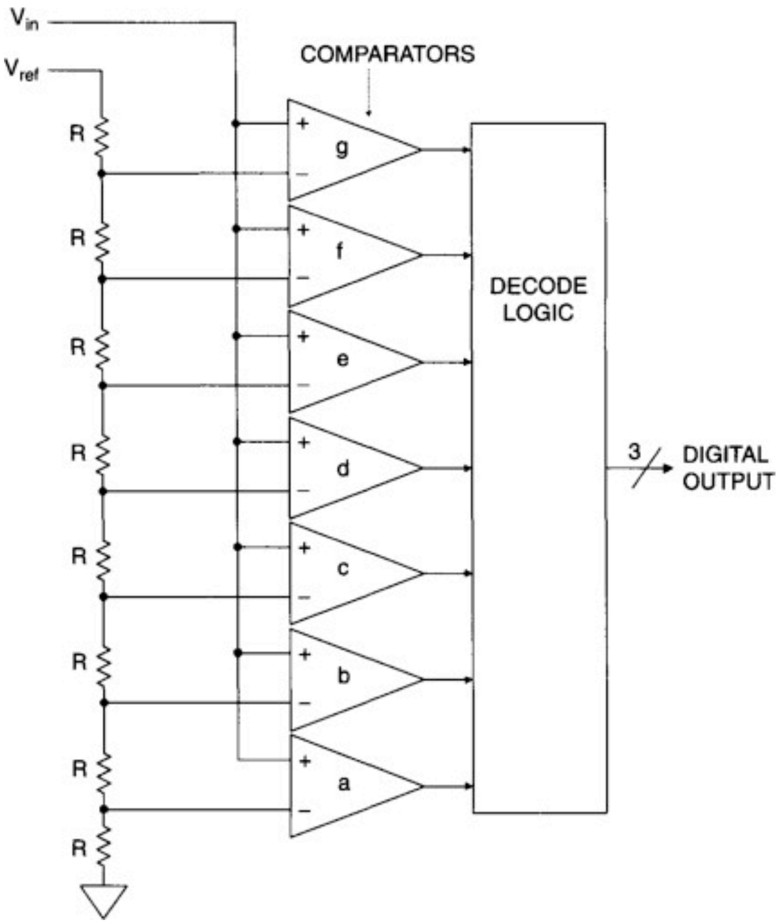


Sequence of digital codes:
011, 110, 110, 100, 010, 001, 010, 010, 011, 100, 101, …

The least significant bit (LSB)



3-bit flash (parallel) ADC



- An n-bit flash ADC uses 2^n-1 comparators, 2^n resistors and a decode logic.

- Pros: the fastest type of ADC.
- Cons: limited resolution, expensive, large power consumption and low accuracy

- Applications: Data acquisition, sampling oscilloscope and high-density disk drives.

Successive-approximation-register (SAR) ADC