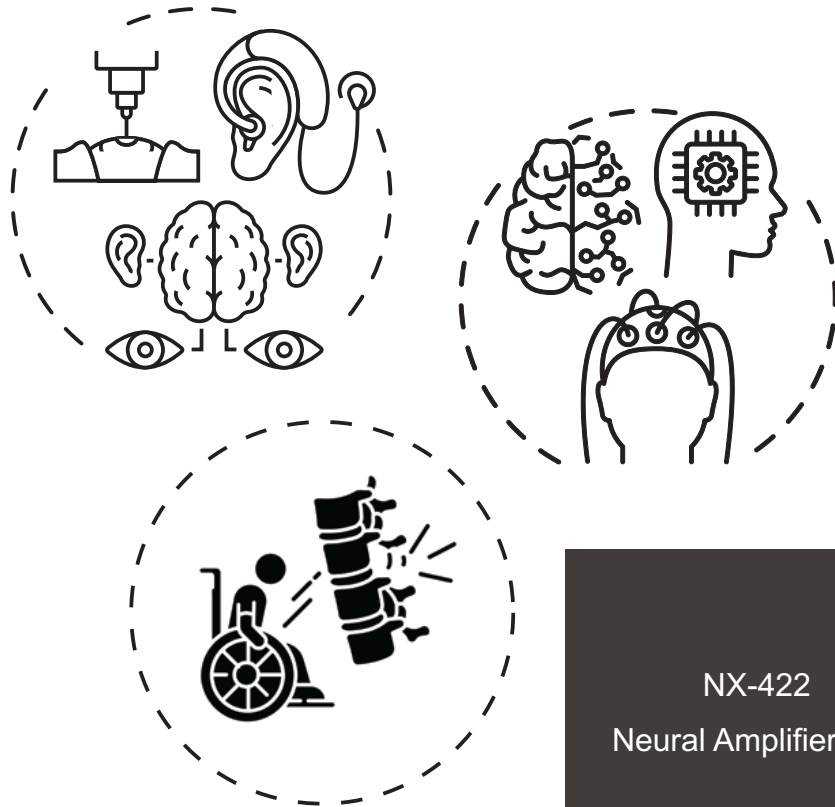


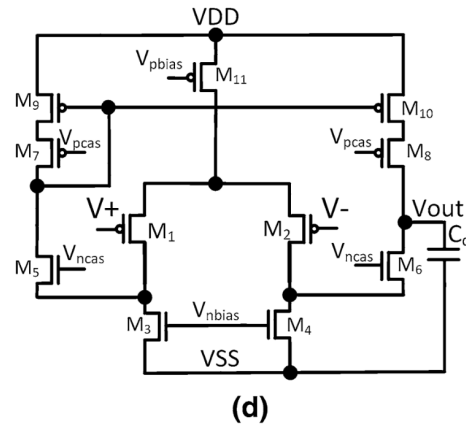
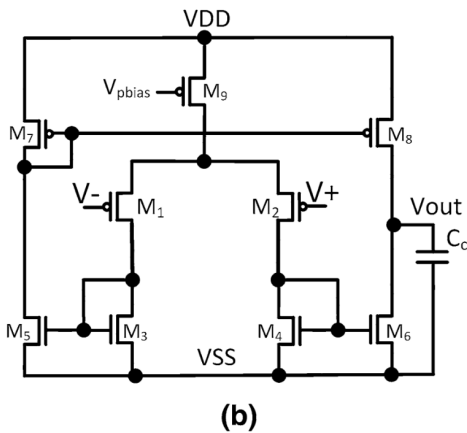
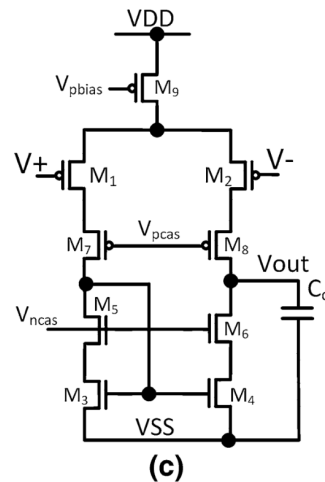
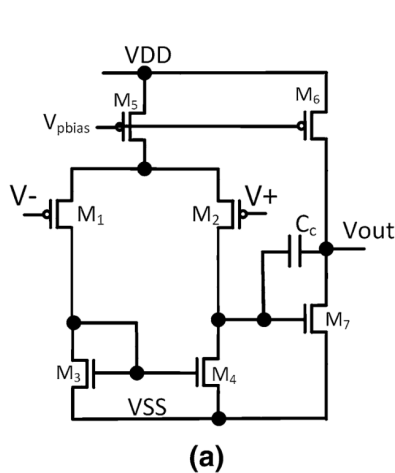


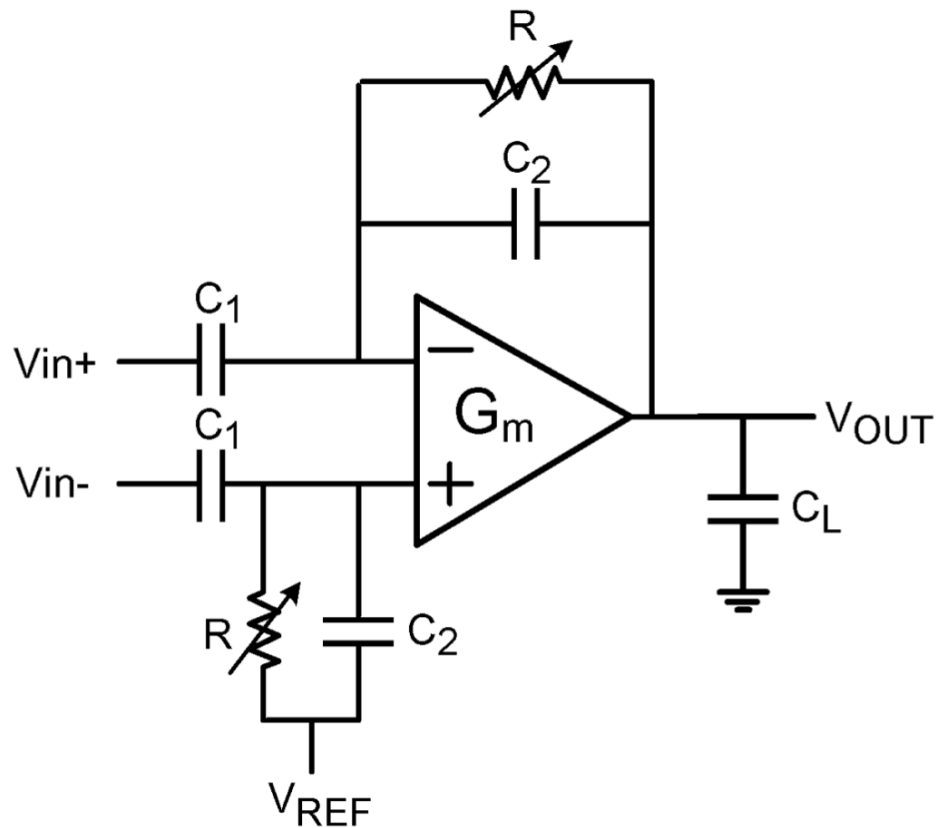
Neural Interfaces

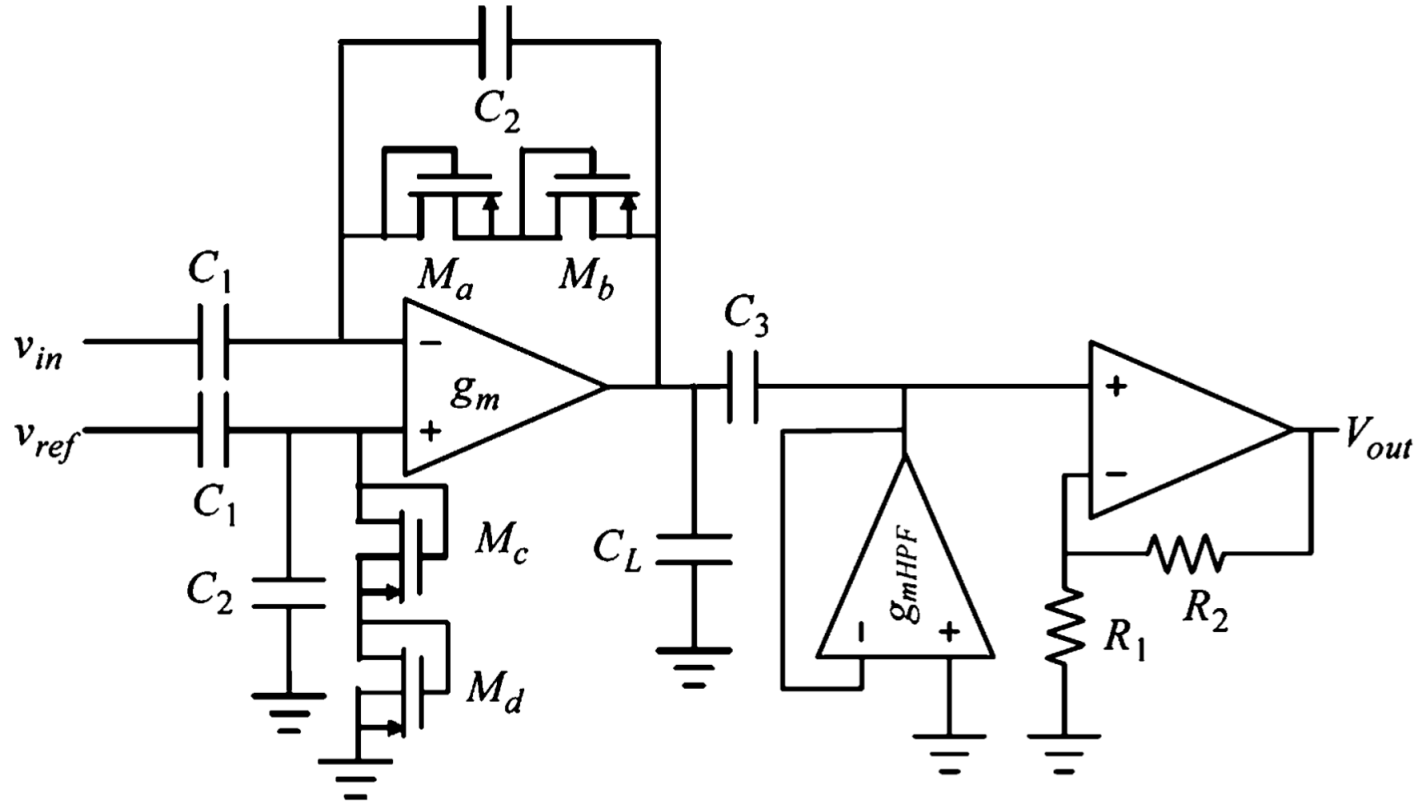
NX-422
Neural Amplifiers (3)

Mahsa Shoaran
IEM and Neuro-X Institutes

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



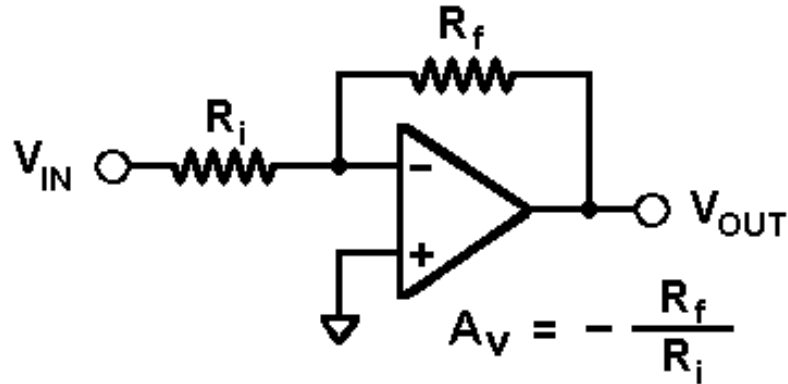




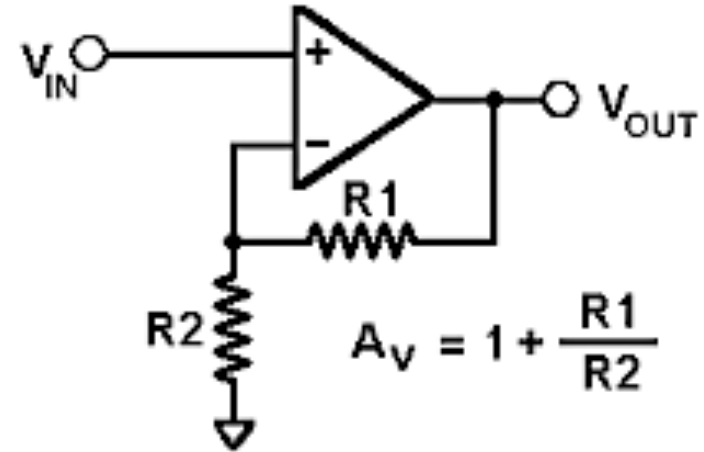
EPFL Recall: Inverting and non-inverting amplifiers

31

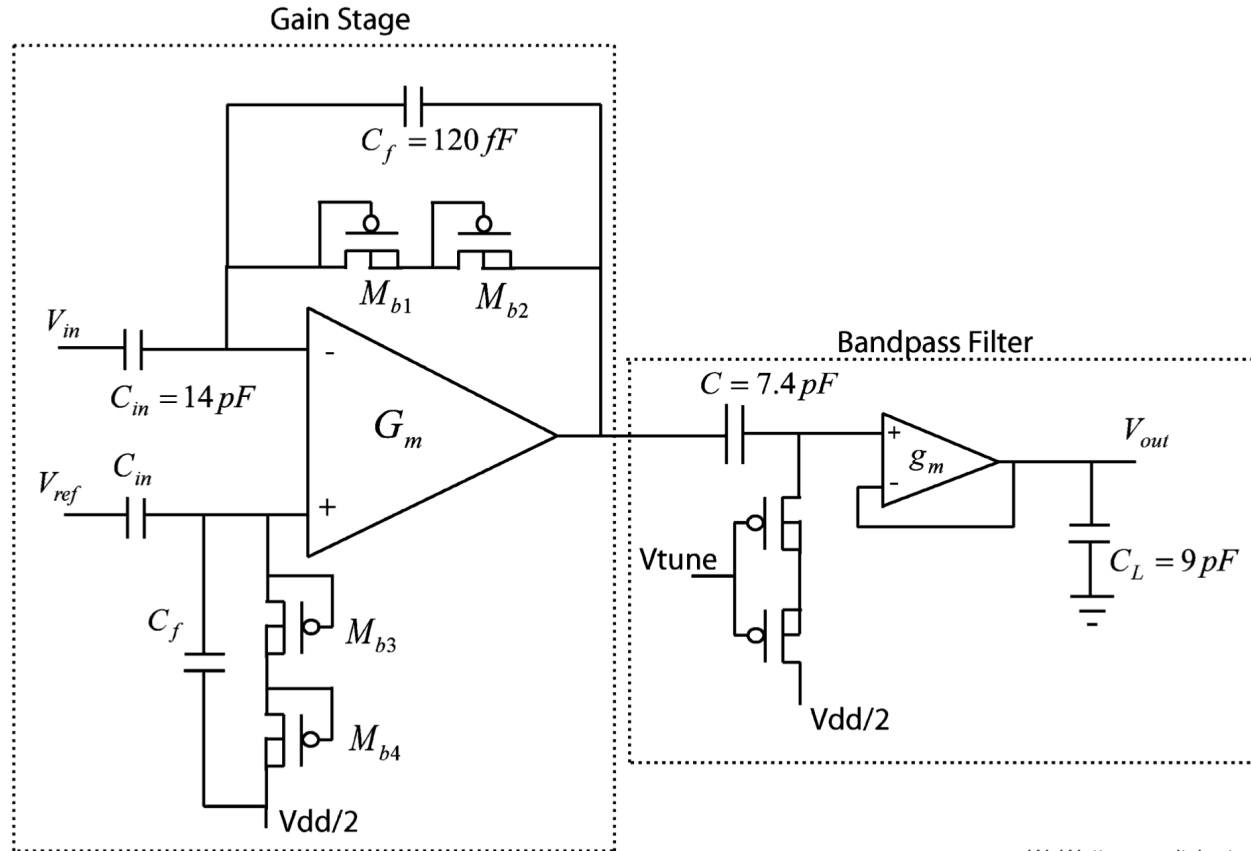
Inverting Amplifier



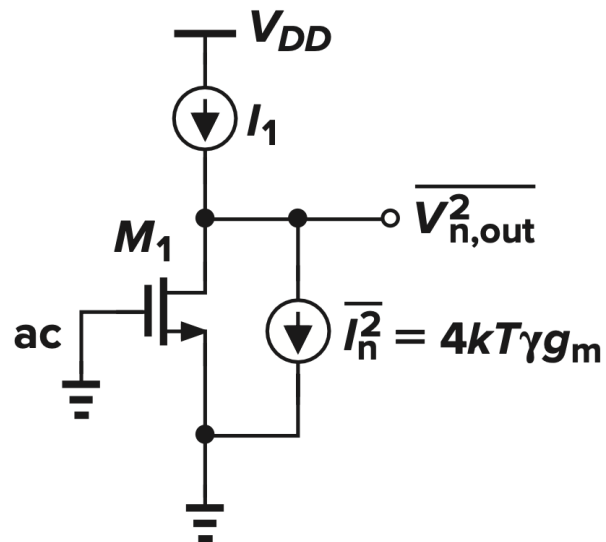
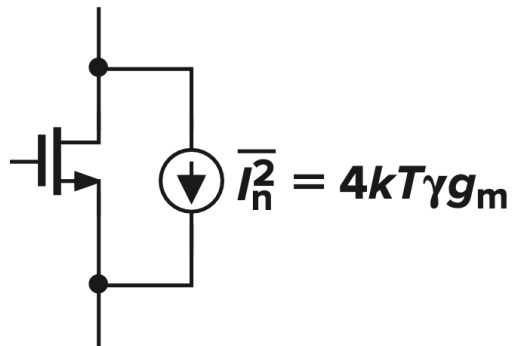
Non-Inverting Amplifier



Neural amplifier, bandpass filter



Thermal noise:



Flicker (1/f) noise:

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

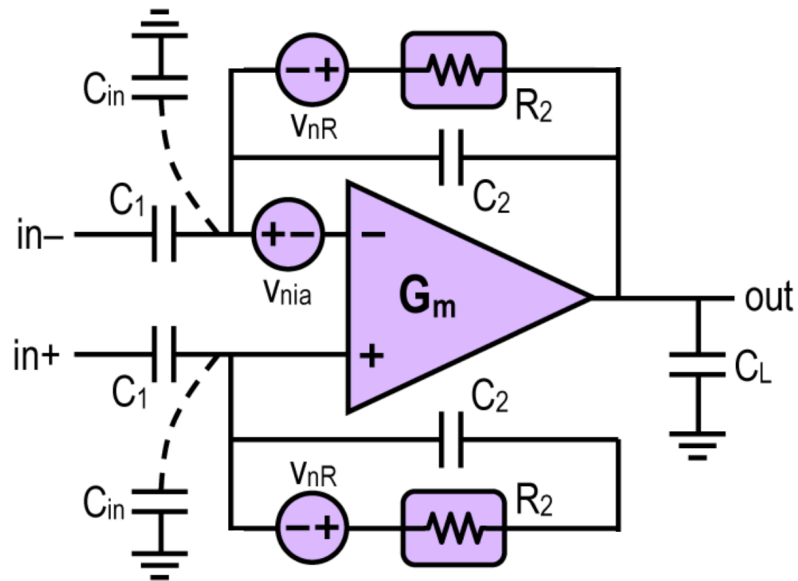
$$\begin{aligned} \overline{V_n^2} &= \overline{I_n^2} r_O^2 \\ &= (4kT\gamma g_m) r_O^2 \end{aligned}$$

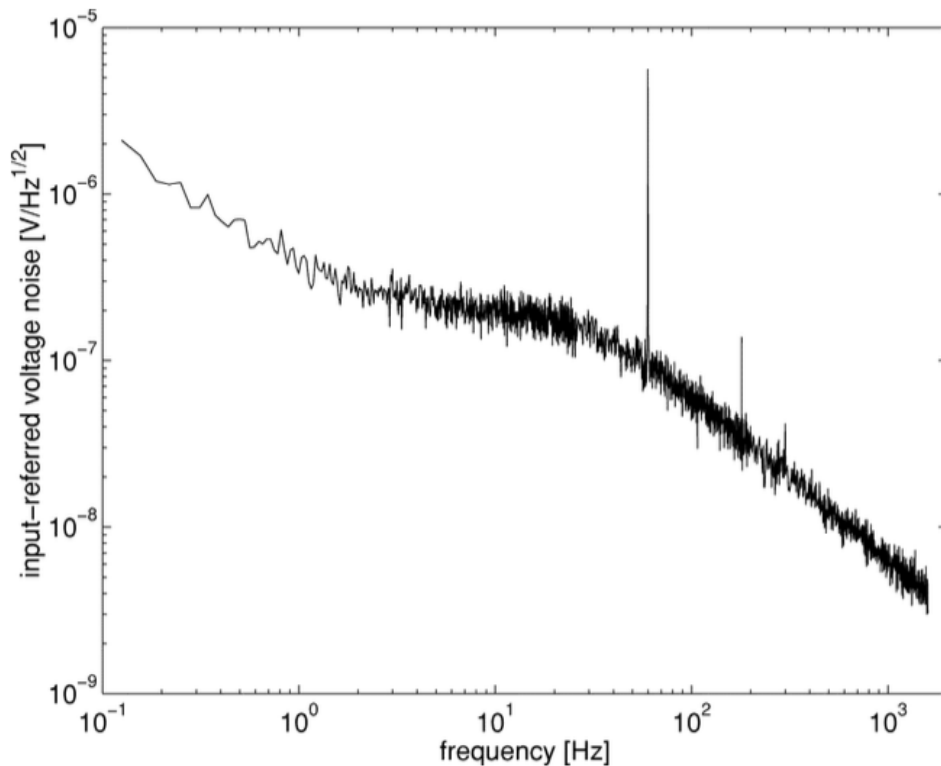
$$\overline{v_{ni, \text{amp}}^2} = \left(\frac{C_1 + C_2 + C_{in}}{C_1} \right)^2 \cdot \overline{v_{ni}^2}$$

Depends on the OTA topology

Noise Efficiency Factor (NEF):

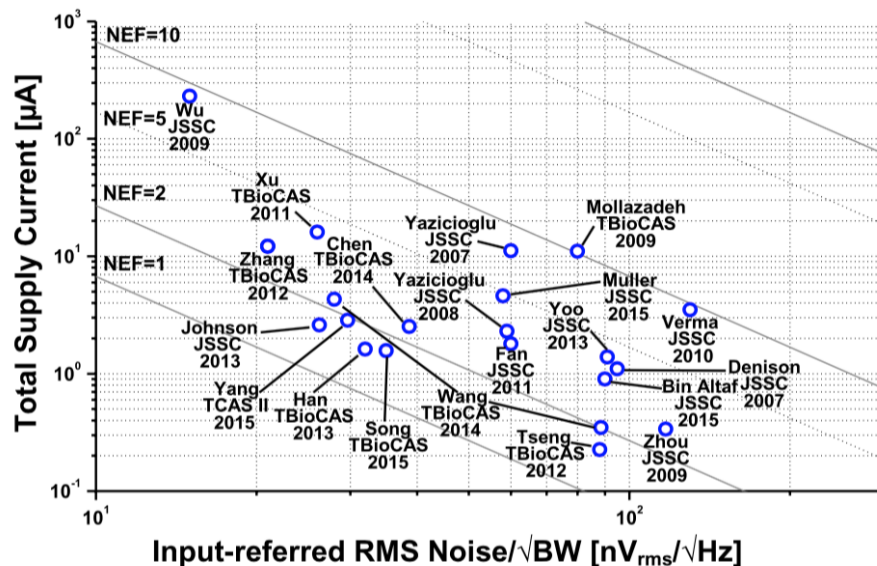
$$\text{NEF} = V_{\text{rms}, \text{in}} \sqrt{\frac{2I_{\text{tot}}}{\pi V_t \cdot 4kT \cdot BW}}$$



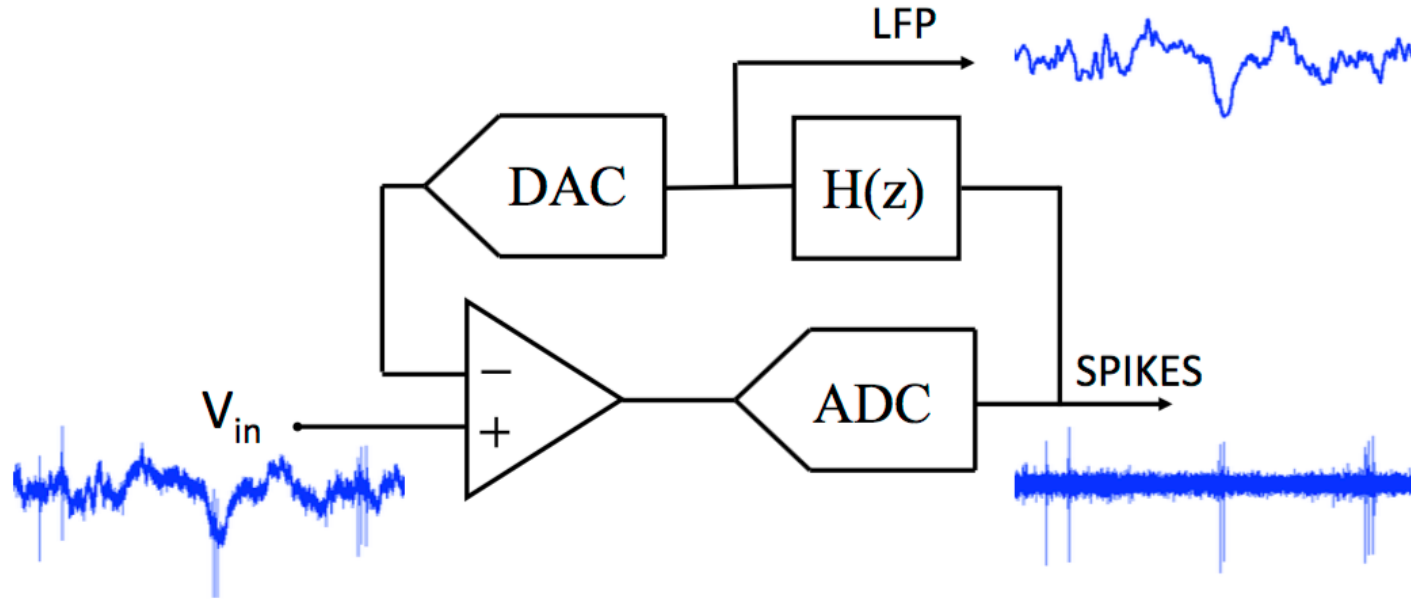


- $V_{\text{rms,in}}$: The total input-referred noise
- I_{tot} : The total current drain
- V_t : The thermal voltage
- BW: The 3-dB bandwidth of the system

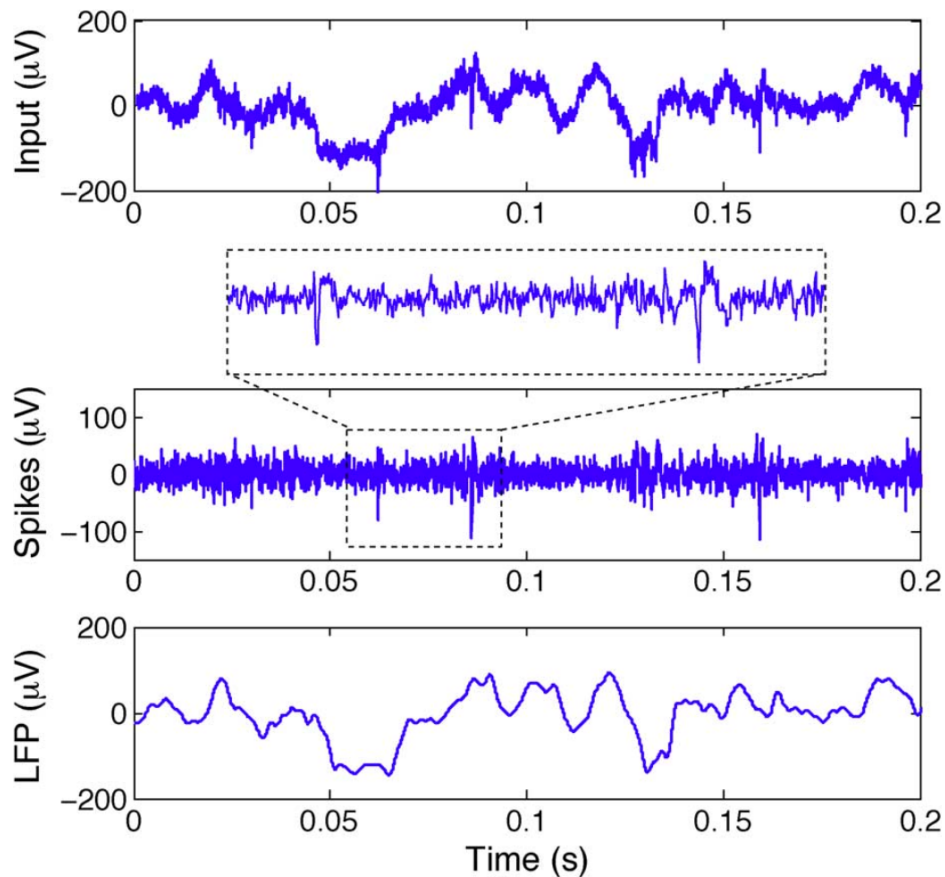
$$\text{NEF} = V_{\text{rms,in}} \sqrt{\frac{2I_{\text{tot}}}{\pi V_t \cdot 4kT \cdot BW}}$$



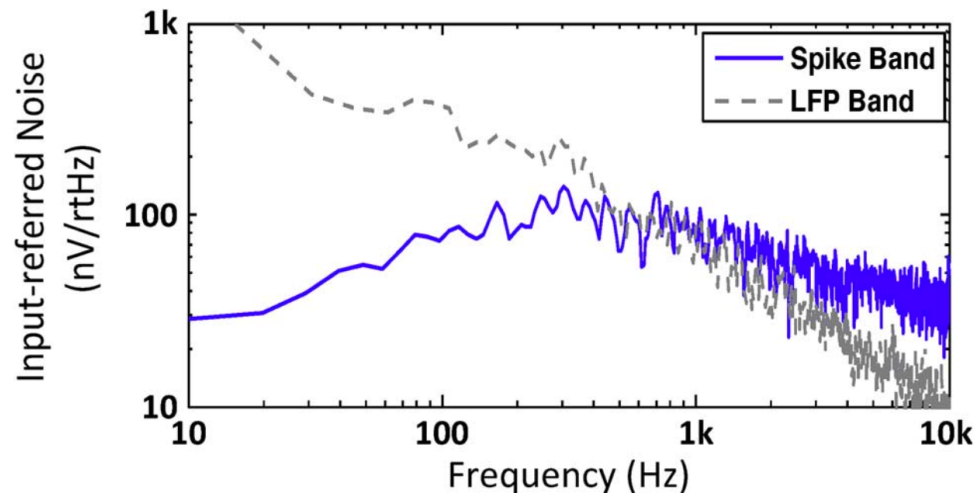
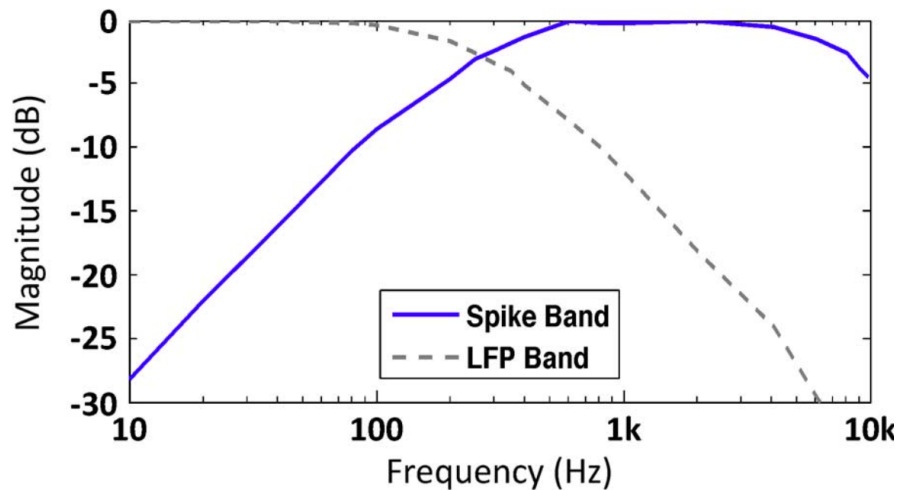
DC Offset Cancellation with DC-Coupled Amplifier



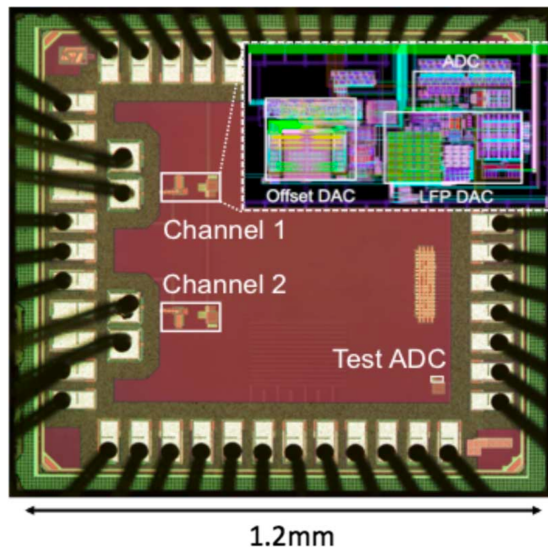
Spike and LFP Measurements



Amplifier gain and input-referred noise



Die photo and performance summary



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

	[3] JSSC '09	[4] JSSC '07	[6] BioCAS '07	[7] ISSCC '10	[24] VLSI '11	This Work
Power (μ W)	15	42.2	7.56	0.64	43	5.04
IRNoise (μ V), 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 ·V _{DD}	63.48	316.9	20	33.8	30	17.96
IRNoise (μ V), 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	0.35 μ m	0.5 μ m	0.5 μ m	0.13 μ m	0.13 μ m	65nm
Blocks included in comparison	LNA, BPF	LNA, BPF	LNA, BPF	LNA, BPF	LNA, BPF, ADC	LNA, BPF, ADC