Introduction to Brain Computer Interface(BCI)

Bishal Paudel

PhD 2nd Year
NeuRonICS lab, DESE
Indian Institute of Science, Bangalore
Under the guidance of **Chetan Singh Thakur**

Department of Electronic Systems Engineering

Table of Contents

Three Building Blocks of BCI

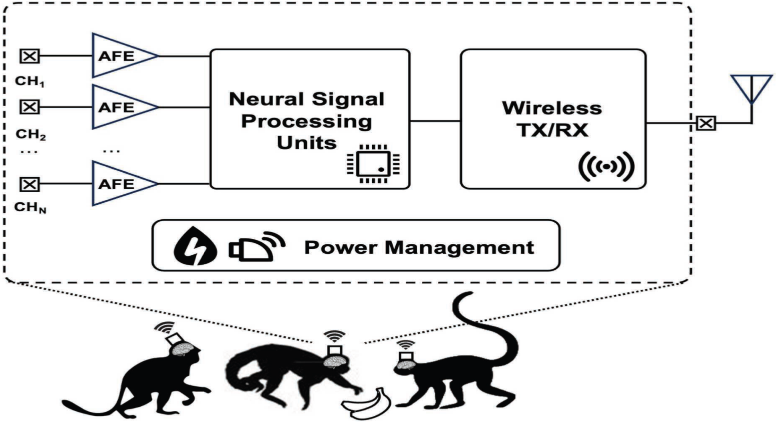
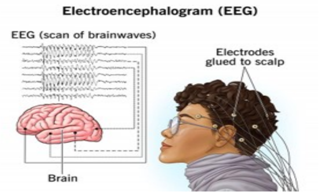


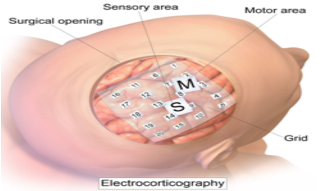
Figure: A block diagram of a wireless compact neural interface.

Amplitude & Freq. Characteristics

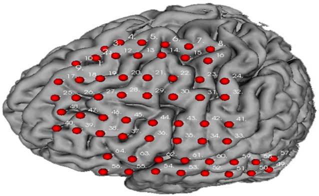
Parameter	EEG	LFP	NeuralSpikes
Frequency(Hz)	0.1-100	0.1-100's	100-1,000's
Amplitude(μV)	1-10	10-100	100-1,000
IRN(μV_{rms})	$\approx$1	$\approx$2	$>$10
Bandwidth(Hz)	100	400-800	10000



(a) EEG



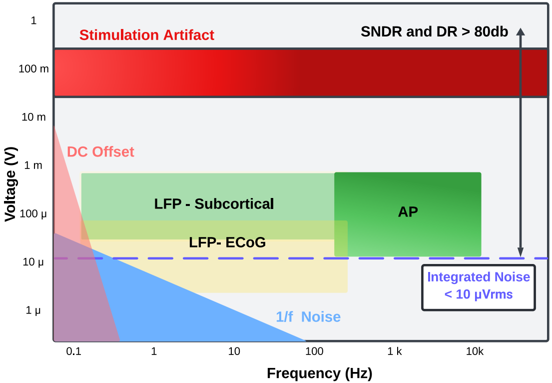
(b) Electrocorticography

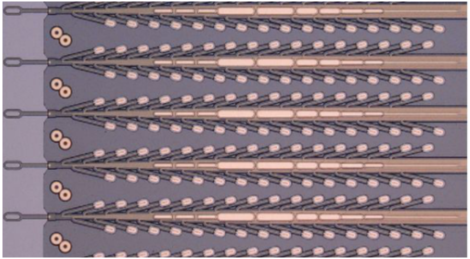


(c) Intracranial EEG (iEEG)

***Note:** Whereas LFPS Amplitude of iEEG will be of range 100-1000 μV

Amplitude & Freq. Characteristics



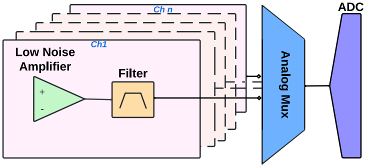


..."***Therefore, we designed the Neuralink ASIC to be capable of electrical stimulation on every channel, although we have not demonstrated these capabilities here.***"...

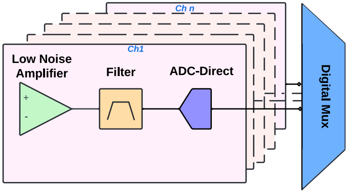
(Source: Neuralink, Elon Musk)[4]

Note:Stimulation artifact can go as high as 100 mV, that extend DR to 80 dB [1]

AFE Architectures



Scheme 1: Good till 10s of electrode 👍

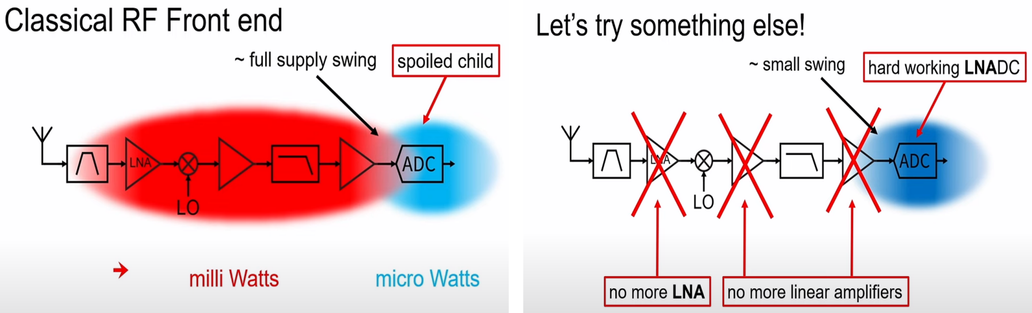


Scheme 2: Good till 100s of electrode 👍

- Epilepsy ->More electrode ->Impact on silicon area, the wireless throughput and battery life.
- Perspective: 5KHz signal ->15KS/s (Nyquist rate): Sampled at 15KS/s at 10bit precision, 100 electrodes ->15Mbps

Scheme 3: Good till 1000s of electrode 🤔

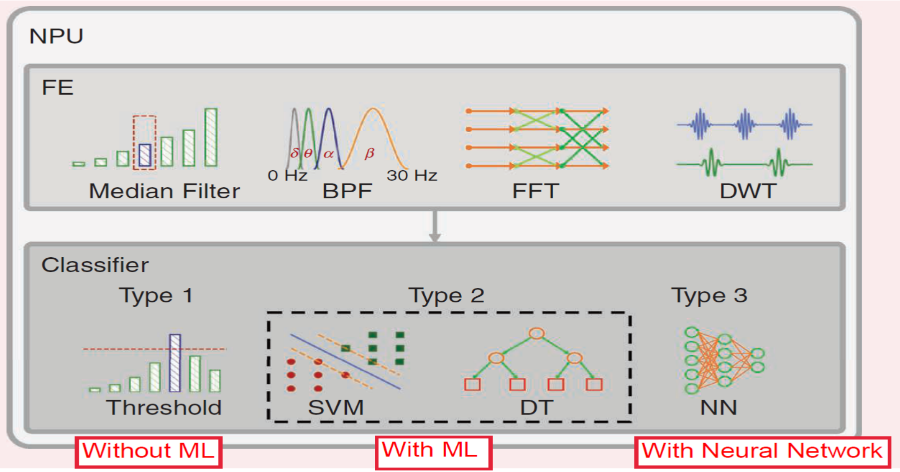
Proposed Solution



This is just a IDEA !!

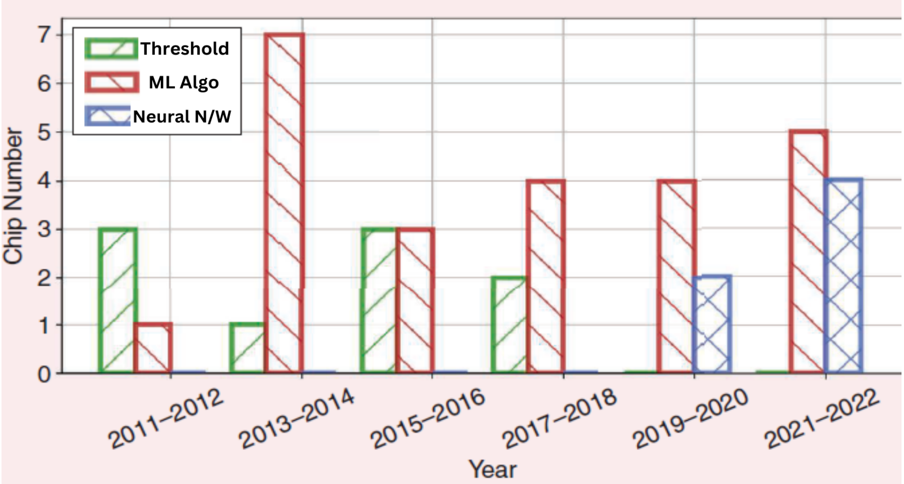
Source : Nauta, B. (2024). 1.2 Racing Down the Slopes of Moore's Law. Digest of Technical Papers - IEEE ISSCC [5]

On-Chip Neural Signal Processing Unit(NPU)



*It could be **highlighted** that the combination of the **spectral band energy feature** with an **SVM classifier** seems the most popular selection. [7]

Which path to be taken?



*From the existing research results, the end-to-end NN-based NPU with optimized low computational load is promising to be a competitive solution in the future. [7]

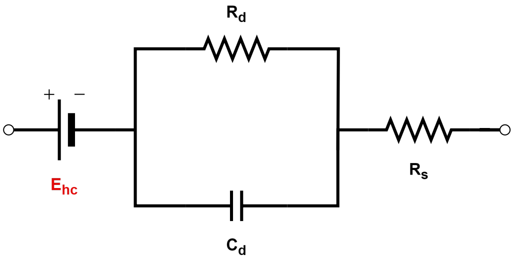
Low-Power Wireless Transceiver and Transfer

- The data rate of the uplink can be several Mb/s for EEG, ECoG, and LFP signals, while the data rate of the downlink is far less since only control commands are needed. As a result, the uplink data transmission is more essential.
- IPT(Inductive power transfer) and UPT (Ultrasonic power transfer) are commonly employed due to their compact volume size, high power delivery density, and safety

Inductive Power Transfer (IPT)	**Ultrasonic Power Transfer(UPT)**
RF signal is more attenuated by human tissues	Less attenuated by the human tissues $(0.5 - 1.0 dB.cm^{-1}.MHz^{-1})$
The maximum power intensity for RF is $10mW/cm^2$	Maximum power intensity for UPT is $720mW/cm^2$

*According to Food & Drug Administration regulations [3]

Modelling of Electrode

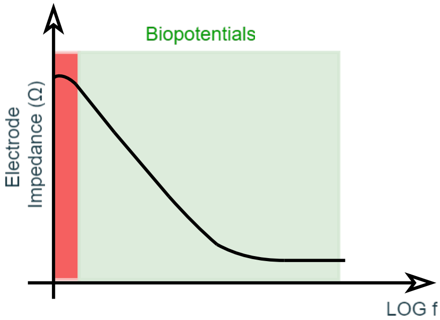


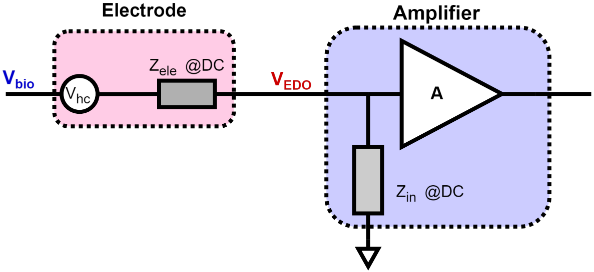
- R_d & C_d: intrinsic properties
- R_s: Extrinsic property
- E_{hc}: Half Cell Potential

Electrode	Half cell potential
Zinc	-0.760
Tin	-0.140
Lead	-0.126
Hydrogen	0.000
Silver	0.799
Platinum	1.200
Gold	1.420
Ag/AgCl	0.233

(Source: Vaughan1999)[6]

Input Impedance for small Electrode DC offset

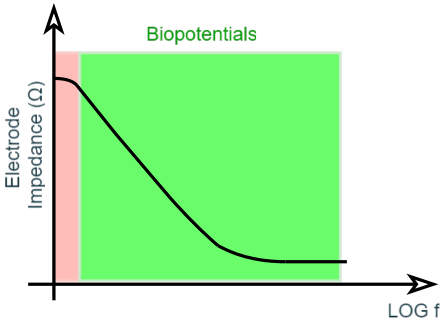


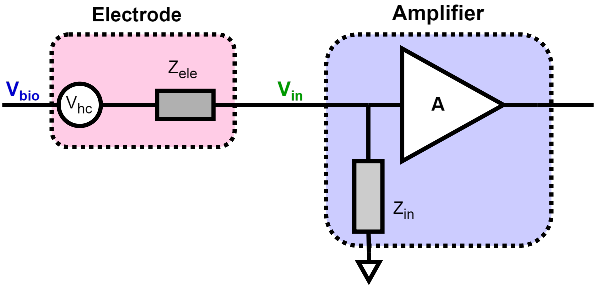


$$V_{EDO} = \frac{Z_{in}(DC)}{Z_{in}(DC) + Z_{ele}(DC)} V_{hc}$$

$$Small \;\; V_{EDO} = Low \;\; Z_{in} \;\; @DC$$

Input Impedance for AC signal

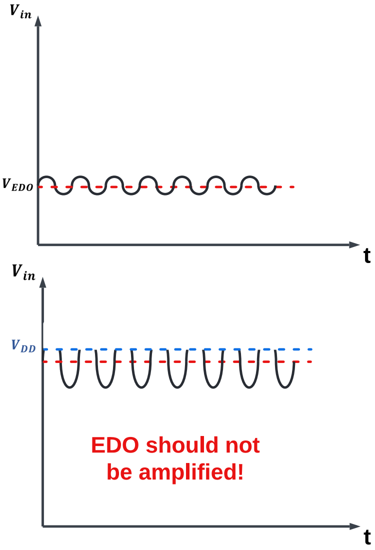


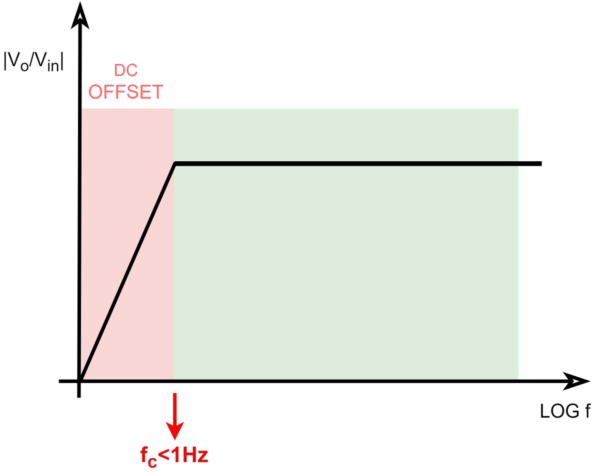


$$V_{in} = \frac{Z_{in}}{Z_{in} + Z_{ele}} V_{bio}$$

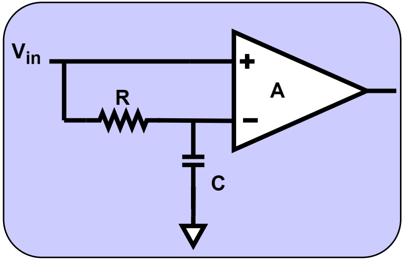
$$Z_{in} > 10 \times Z_{ele}$$

Problem with electrode DC offset

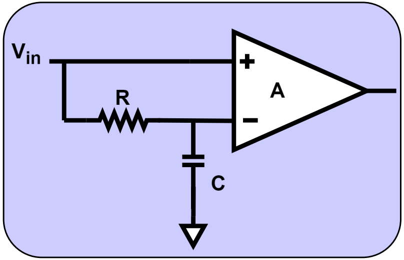


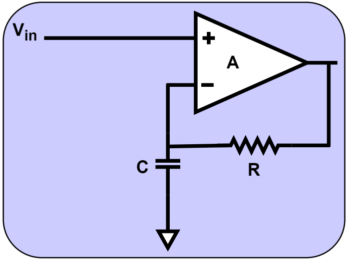


How to remove EDO

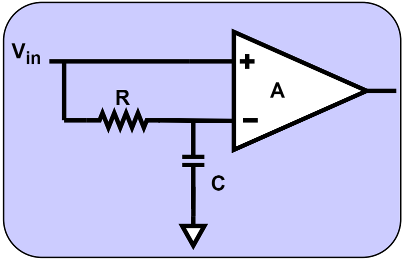


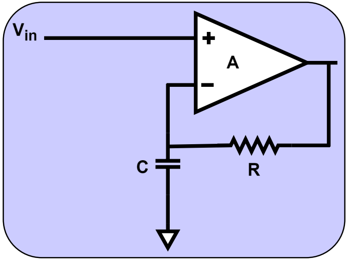
How to remove EDO

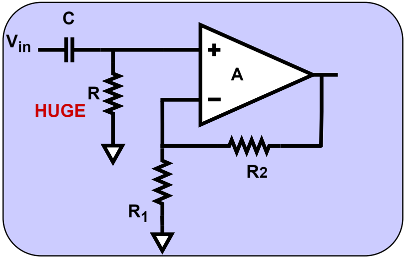




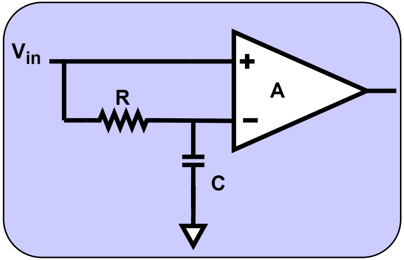
How to remove EDO

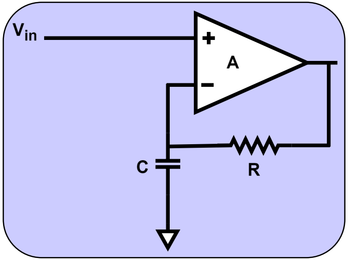


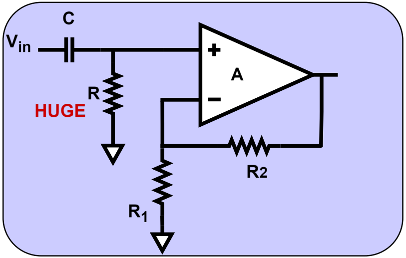


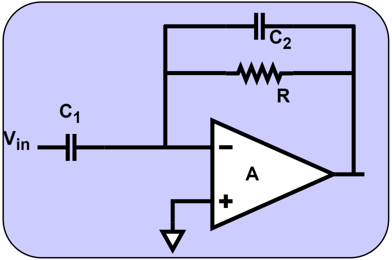


How to remove EDO



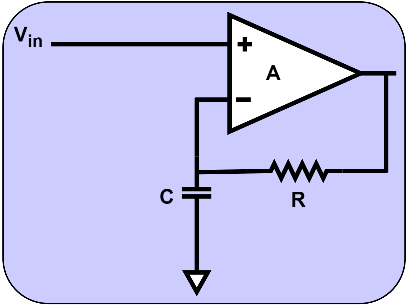




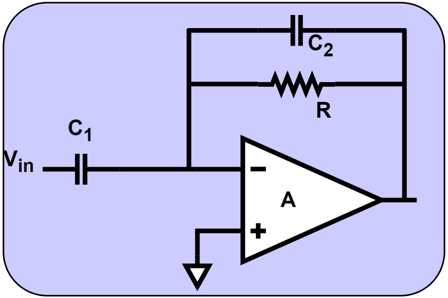


How to achieve High Impedance

Large C_1 : High Gain ; Low noise
Small C_1 : High Z_{in} ; Small Area

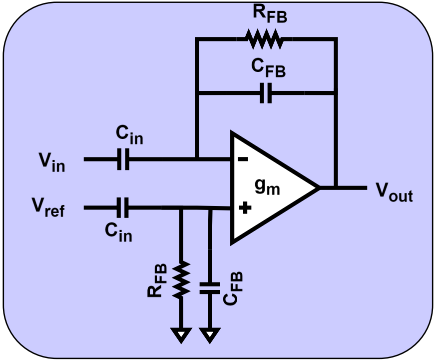


- Highest input impedance
- Amplifier input range have to cover V_{EDO} too



- Input Impedance $= \frac{1}{2\pi fC}$
- High input impedance requires small C

Neural Amplifier

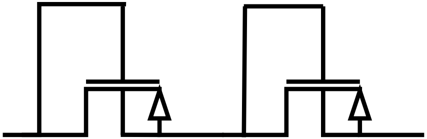


- AC Coupled
- High input impedance
- Low Power
- How to implement R_{FB}?

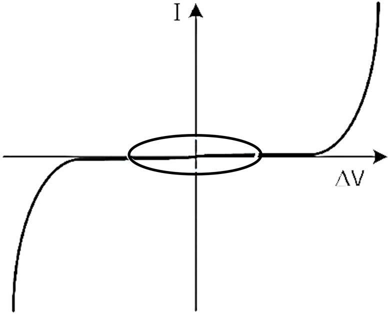
For low cut-off frequency, $\sim 100\,G\Omega$ resistance required for ~pF capacitance.

But the area required for $100\,G\Omega$ resistance is HUGE!

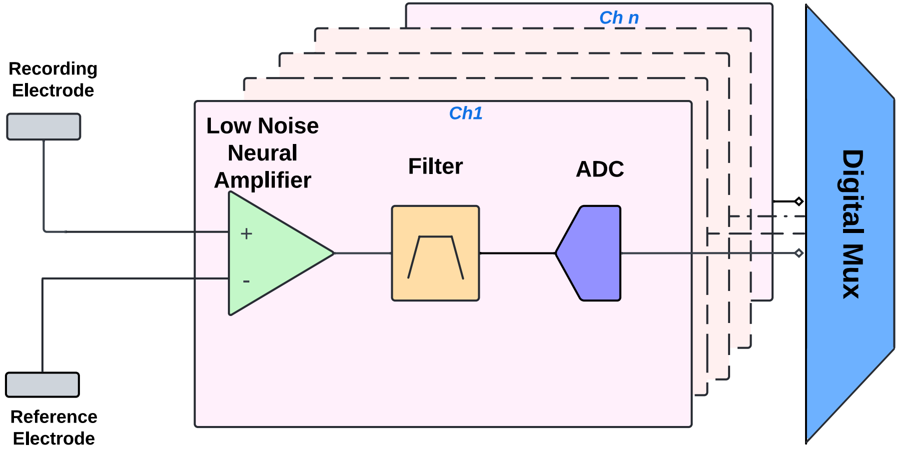
Pseudo Resistor [2]



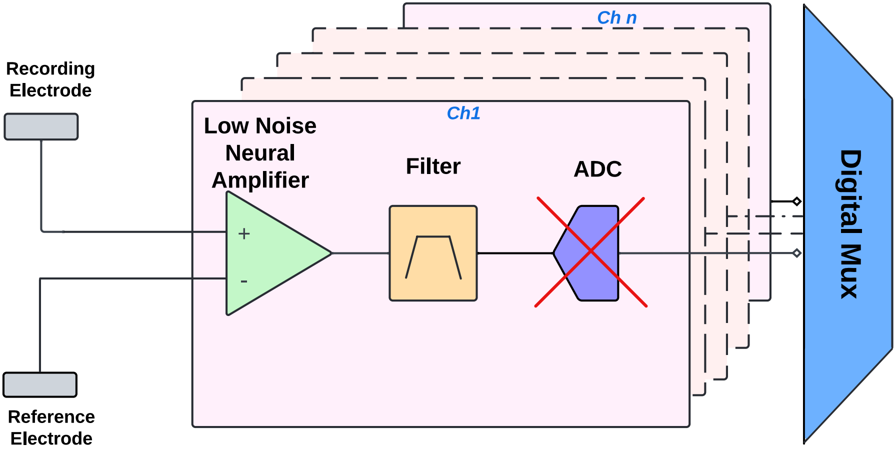
- Diode connected MOS in weak inversion region
- dV/dI in $G\Omega$ for $\Delta V < 0.2V$
- Small Area, low power consumption
- Very non-linear!



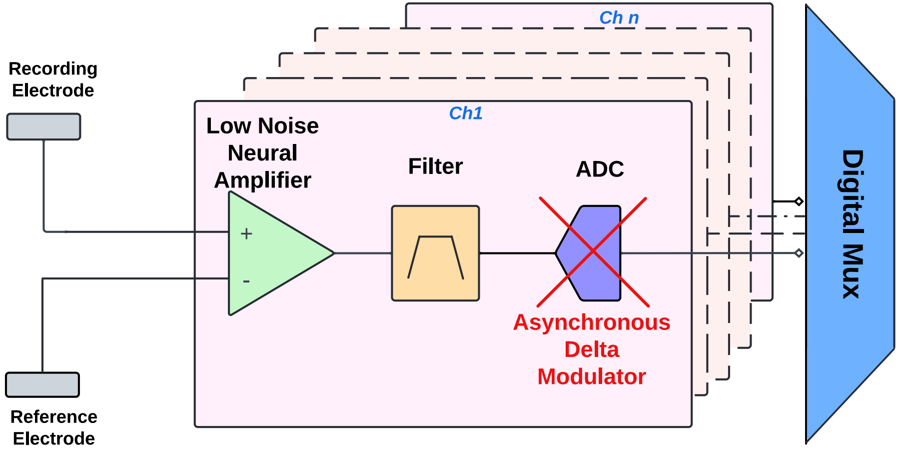
Complete Biopotential Readout



Complete Biopotential Readout



Complete Biopotential Readout



Future Scope

Challenges/Future Avenues

1. Handle Large Stimulation Artifacts.[1]
2. Dynamics-aware ML model.
3. Integration of bi-directional wireless data and power transmission method.
4. Potential Brain-inspired neuromorphic models e.g., SNN

Questions to Ponder about

1. What type of signal should be recorded from brain
2. How reliable the signal should be
3. What new neuromorphic compression technique could be implemented
4. How the resulting new specifications will affect the iBCI neural interface design

References

[1] Wenlong Jiang et al. "A ±50-mV Linear-Input-Range VCO-Based Neural-Recording Front-End With Digital Nonlinearity Correction". In: *IEEE Journal of Solid-State Circuits* 52.1 (Jan. 2017), pp. 173–184. ISSN: 0018-9200. DOI: 10.1109/JSSC.2016.2624989.

[2] Hossein Kassiri, Karim Abdelhalim, and Roman Genov. "Low-distortion super-GOhm subthreshold-MOS resistors for CMOS neural amplifiers". In: *2013 IEEE Biomedical Circuits and Systems Conference (BioCAS)*. IEEE, Oct. 2013, pp. 270–273. ISBN: 978-1-4799-1471-5. DOI: 10.1109/BioCAS.2013.6679691. URL: http://ieeexplore.ieee.org/document/6679691/.

[3] *Marketing Clearance of Diagnostic Ultrasound Systems and Transducers | FDA*. 2023.

[4] Elon Musk. "An integrated brain-machine interface platform with thousands of channels". In: *Journal of Medical Internet Research* 21.10 (Oct. 2019), e16194. ISSN: 14388871. DOI: 10.2196/16194.

[5] Bram Nauta. "1.2 Racing Down the Slopes of Moore's Law". In: *Digest of Technical Papers - IEEE International Solid-State Circuits Conference* (2024), pp. 16–23. ISSN: 01936530. DOI: 10.1109/ISSCC49657.2024.10454417.

[6] Christopher L. Vaughan, Brian L. Davis, and Jeremy C. O'Connor. "Dynamics of human gait". In: (1992), p. 137.

[7] Milin Zhang et al. "Wireless Compact Neural Interface for Freely Moving Animal Subjects: A Review on Wireless Neural Interface SoC Designs". In: *IEEE Solid-State Circuits Magazine* 15.4 (Sept. 2023), pp. 20–29. ISSN: 19430590. DOI: 10.1109/MSSC.2023.3312227.

Thank You!