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Hardware & Software for Deep Brain Stimulation

Early-Stage Assessment

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Presentation Outline

Background on Deep Brain Stimulation

1 – Background, Challenges & Research Objectives

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Deep Brain Stimulation (DBS)

- Specific areas of the brain are stimulated using implanted electrodes
- Approved treatment for Parkinson's disease [1], epilepsy [2] and other neurological disorders
- Current Implementations are Open – Loop [3]
    - Stimulation waveforms are varied by trial and error using patient feedback

Adaptive Neuromodulation

- Local field potentials (LFP) represent aggregate activity of local neurons
- Power Spectral Density (PSD) of LFP (0.5Hz to 330Hz) contains relevant biomarkers [4]
- Aim: Record LFPs while area is stimulated, then adjust stimulation adaptively
    - Challenge 1: Stimulation artefacts contaminate recordings
    - Challenge 2: Transmit Data to Processing Unit
    - Challenge 3: Determine the biomarker-to-parameter relationship

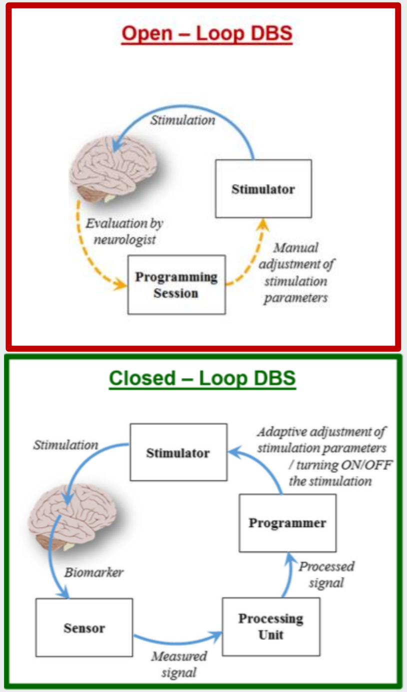

Figure 1 – Overview of open – loop vs closed – loop DBS adapted from [5]

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Challenges & Research Objectives

- Design instrument for neural recordings
  - Versatile & Tunable
  - High – Precision
  - Low – Power & Handheld
  - Can suppress stimulation artefacts

- Integrate modalities for real-time symptom monitoring
- Investigate biomarkers that can be extracted using the designed instrument
- Develop algorithms for closed – loop DBS using extracted biomarkers

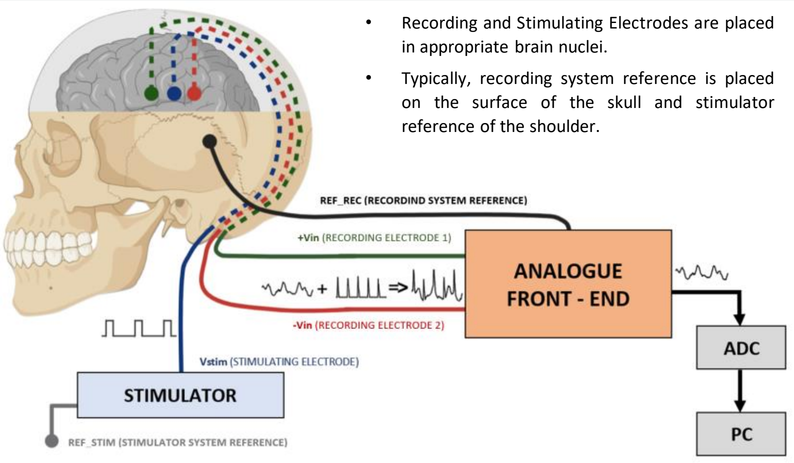

Figure 2 – Set – up for recording during DBS

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System Overview

2 – Instrument Design

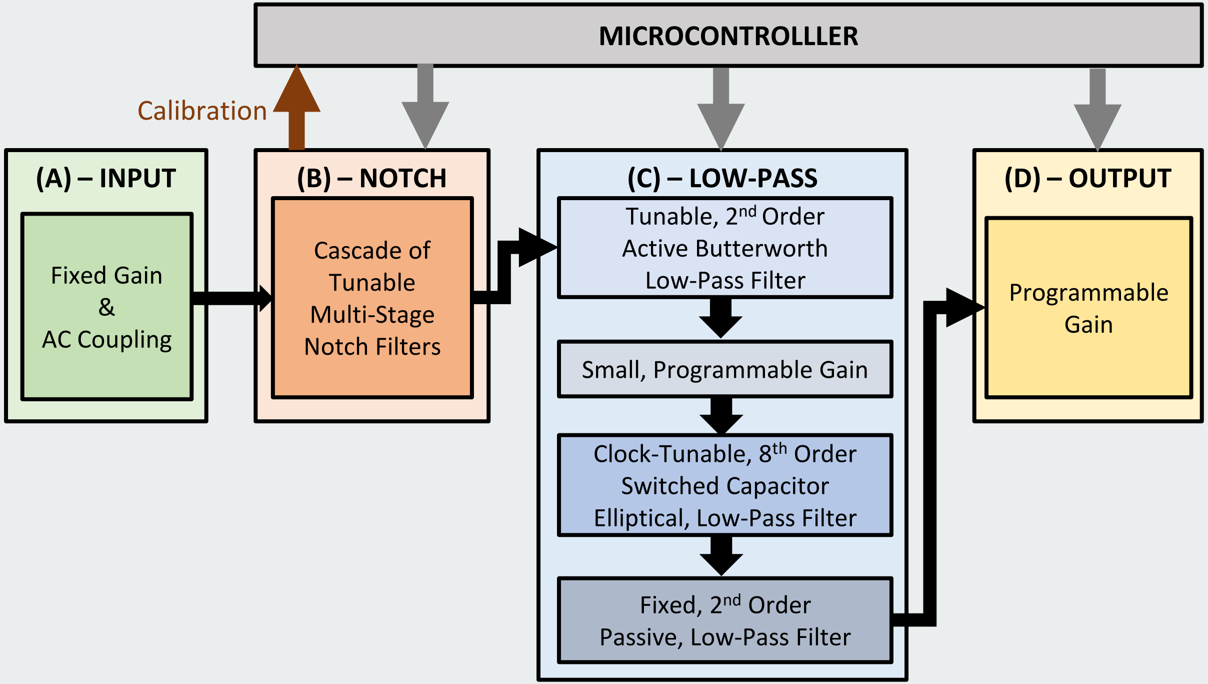

Figure 3 – Overview of System Architecture

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Input Stage

2 – Instrument Design

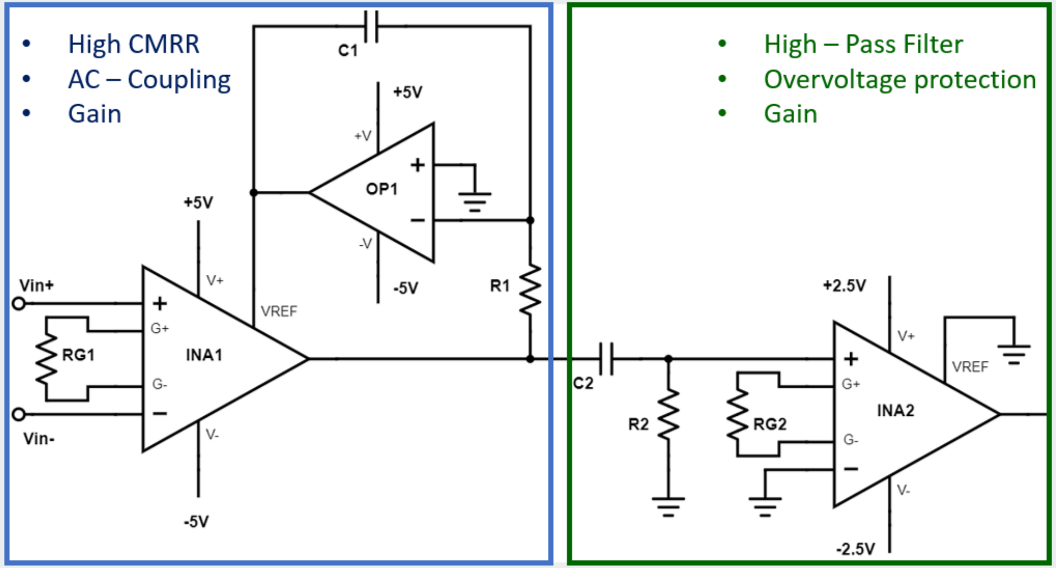

Figure 4 – Input Stage Schematics

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Notch Filter Stage

2 – Instrument Design

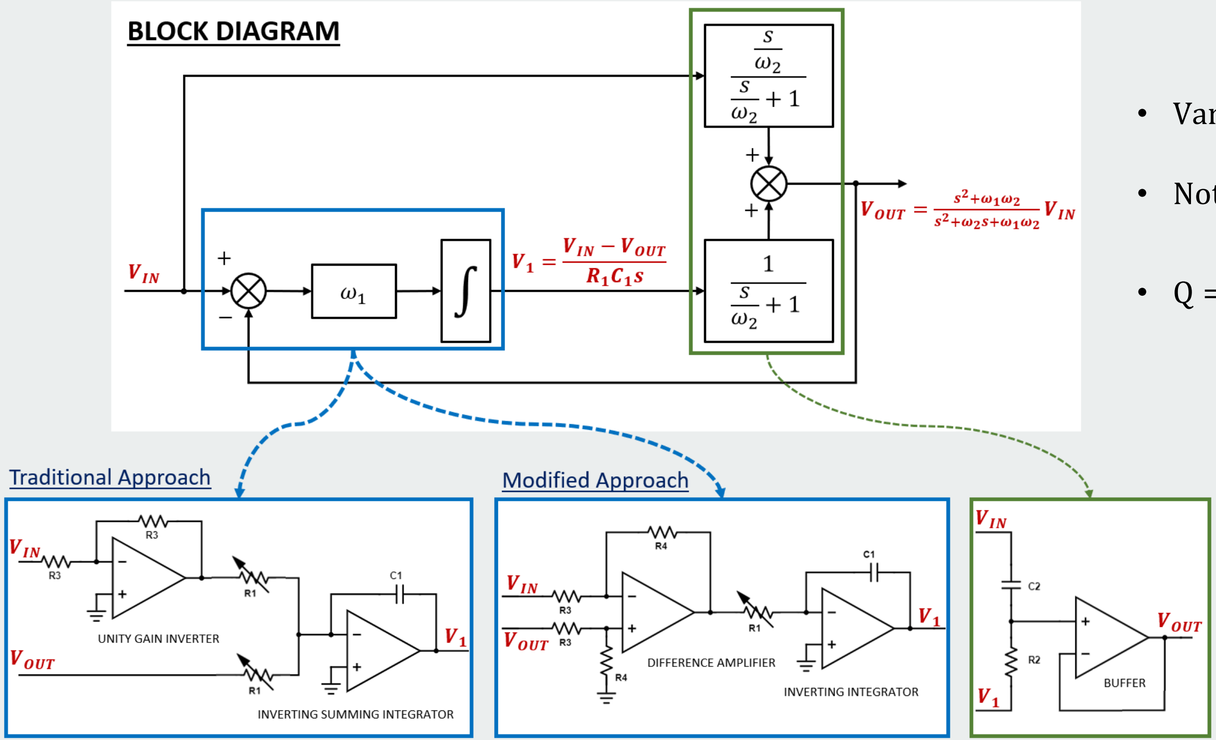

Figure 5 - Bainter Notch Filter: Traditional and Modified Realisation

- Variable R_1 tunes f_{notch}
- Notch Width Δf=constant
- $Q = \frac{f_{notch}}{\Delta f}$

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Tuning the Notch Filter

2 – Instrument Design

- Calibration $\longrightarrow$ Tuning error only from resistor resolution
- Range of resistor values determines tuning range $\left(\frac{f_{MAX}}{f_{MIN}} = \sqrt{\frac{R_{MAX}}{R_{MIN}}}\right)$.
- The gain at the target frequency is approximately: $\frac{\frac{1}{2} \cdot f_{notch}^{3} \cdot \delta R}{f_{MIN}^{2} \cdot R_{MAX} \cdot \Delta f}$
- Strategy: Ensure sufficient resistor range and resolution

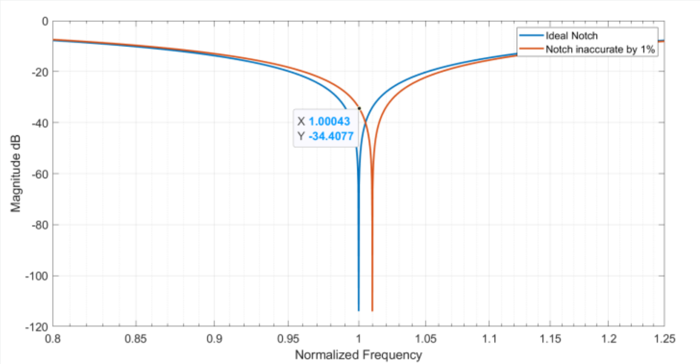

Figure 6 – Example of tuning Error (Q=1). Gain at the target frequency is -34dB

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Notch Filter Depth

2 – Instrument Design

- Parasitic Poles or Zeros limit the Notch depth.
  - Gain at the $f_{notch} \rightarrow Q \cdot \frac{f_{notch}}{f_{pz\,(dominant)}} = \frac{f_{notch}^2}{\Delta f \cdot f_{pz\,(dominant)}}$
- Sources of parasitic poles/zeros:
  - Parasitic Capacitance/Inductance
    - Negligible
  - Opamp Bandwidth
    - Non – Negligible for ultra low-power opamps
  - Variable Resistor Bandwidth
    - Non – Negligible for Digital Potentiometers
    - Can be mitigated by different Ladder architecture

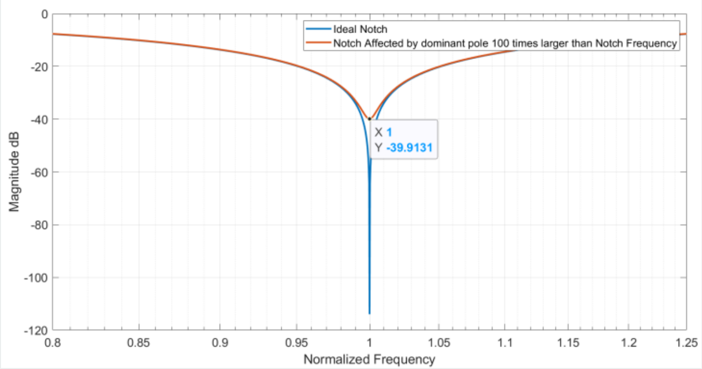

Figure 7 – Example of Limited Notch depth due to parasitic pole (Q=1). Notch Depth is -39dB.

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Variable Resistor Architecture

2 – Instrument Design

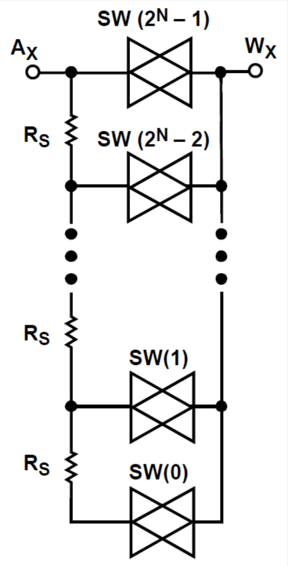

Figure 8 – String DAC

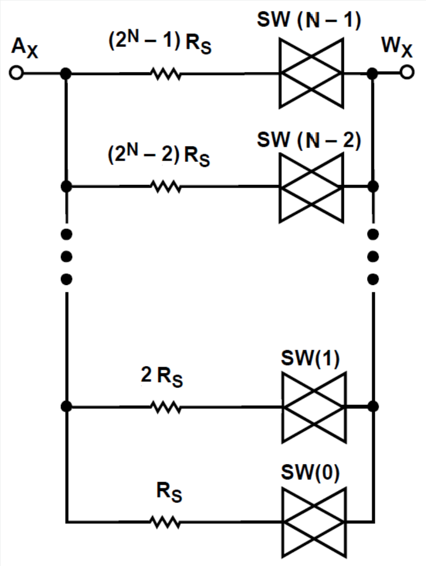

Figure 9 – Binary DAC

- Digital Potentiometers are String DACs
  - Convenient & Space-saving
  - Guaranteed Monotonic
  - Increments in Resistance
  - Limited Bandwidth:
    - 2^N Switches | Cannot utilize virtual ground
- Custom Current-Mode Binary-Weighted DAC
  - Space-Consuming
  - Difficult to Guarantee Monotonicity
  - Increments in Conductance
  - Increased Bandwidth
    - N Switches | Can fully utilize virtual ground

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Low – Pass Filter and Output Stage

2 – Instrument Design

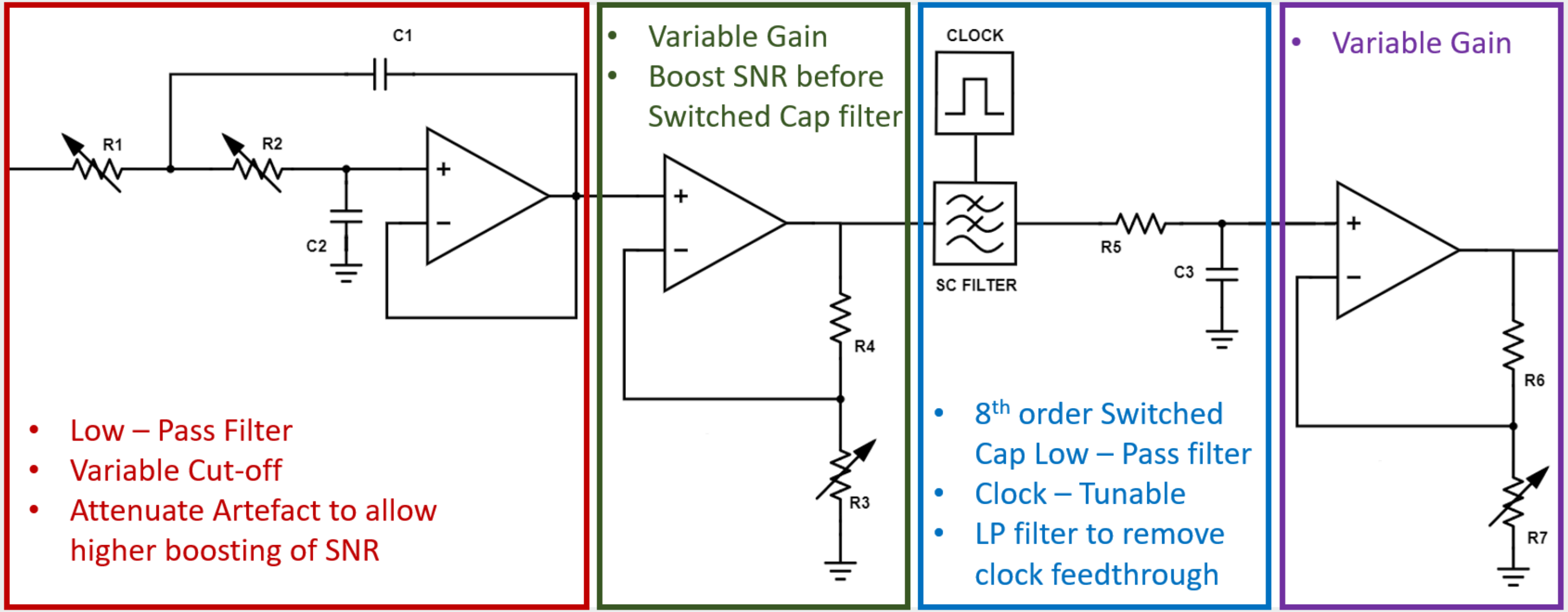

Figure 10 – Low – Pass and Output Stage Schematics

Presentation Outline

1. Background, Challenges & Research Objectives
2. Instrument Design
3. **Preliminary Results**
4. Improved Instrument Design
5. Contributions so far and Future Work
6. References

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First Device Implementation

3 – Preliminary Results

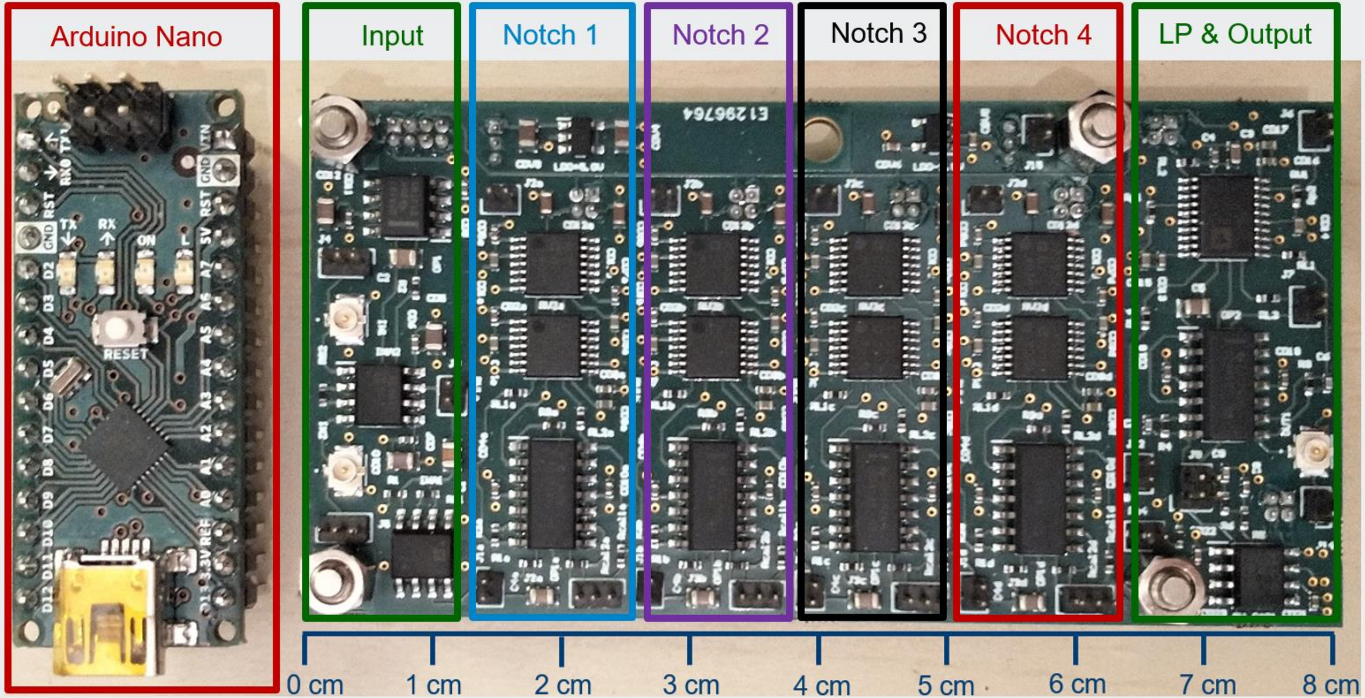

Figure 11 – Digital Potentiometer based implementation on PCB

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Measured Results

3 – Preliminary Results

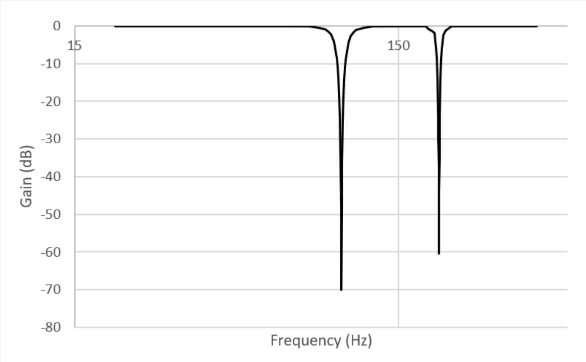

Figure 12 – 2 stages tuned to 100Hz, and 2 stages tuned to 200Hz

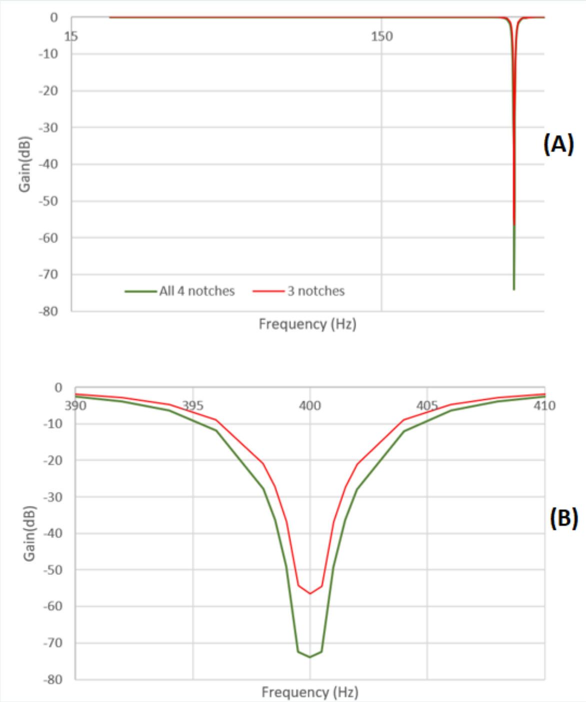

Figure 13 – (A) three (red) and four (green) stages tuned to 400Hz, (B) Zoomed – in to illustrate notch depth and width

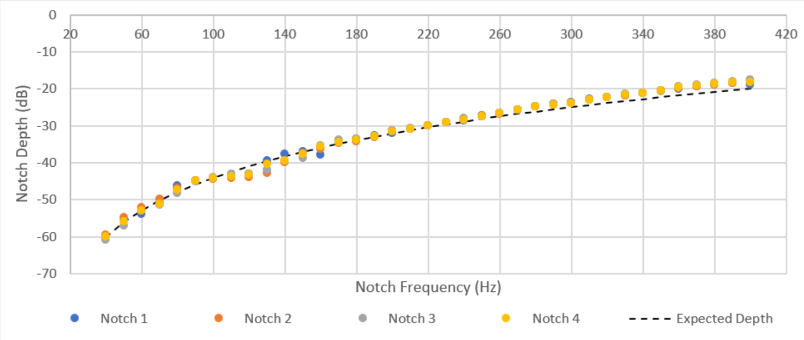

Figure 14 – Experimental Notch Depth

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Second Device Implementation

4 – Improved Instrument Design

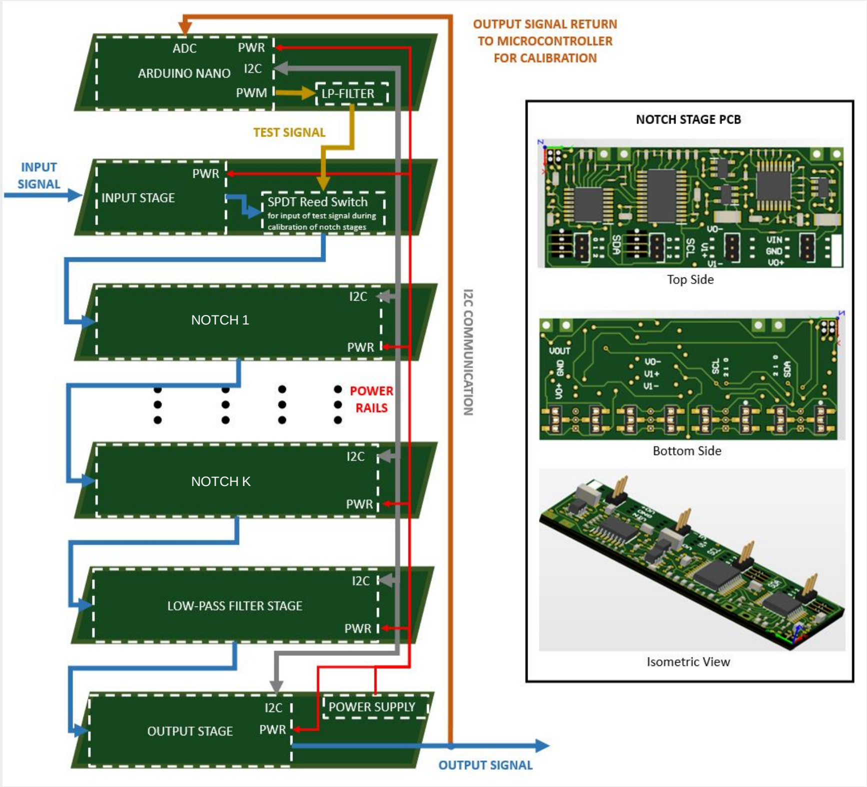

Figure 15 – Stackable Design is versatile and improves on Notch Depth

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Contributions so far and Future Work

Contributions so far

- Modified Bainter topology
- 1st Iteration designed, laid out and manufactured
- Measured Cascade of Tunable Notch filters with more than 60dB attenuation
- Proposed versatile stackable design with predicted >60dB *per* Notch stage

Future Work

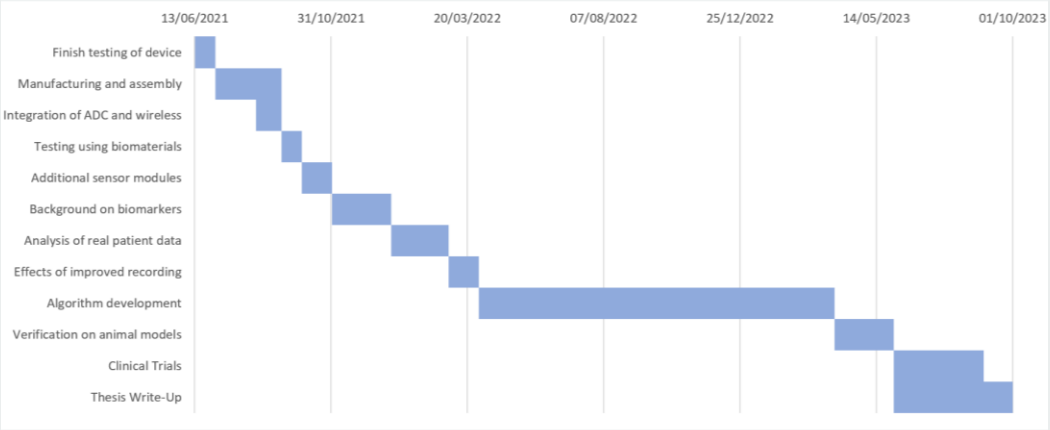

Figure 16 – Gantt Chart

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References

[1] “*Treatment, Parkinson's disease*” Apr. 30, 2019. Accessed on: June 1, 2021. [Online]. Available: www.nhs.uk/conditions/parkinsons-disease/treatment/

[2] “*Treatment, Epilepsy*,” Sept. 4, 2017. Accessed on: June 1, 2021. [Online]. Available: www.nhs.uk/conditions/epilepsy/treatment/

[3] F. Hell, C. Palleis, J. H. Mehrkens, and K. Bötzel, "Deep brain stimulation programming 2.0: Future perspectives for target identification and adaptive closed loop stimulation," Frontiers in Neurology, vol. 10, no. APR, 2019.

[4] A. c. Yang, D. w. Meng, H. g. Liu, L. Shi, K. Zhang, H. Qiao, L. c. Yang, H. w. Hao, L. m. Li and J. g. Zhang, "The ability of anterior thalamic signals to predict seizures in temporal lobe epilepsy in kainate-treated rats," Epilepsia, vol. 57, no. 9, pp. 1369-1376, 1 9 2016.

[5] M. Parastarfeizabadi and A. Z. Kouzani, “Advances in closed-loop deep brain stimulation devices,” *Journal of neuroengineering and rehabilitation*, vol. 14, no. 1. p. 79, Aug. 11, 2017. doi: 10.1186/s12984-017-0295-1.