Innovations In Capacitor Technology, High Frequency Electrochemical Capacitors

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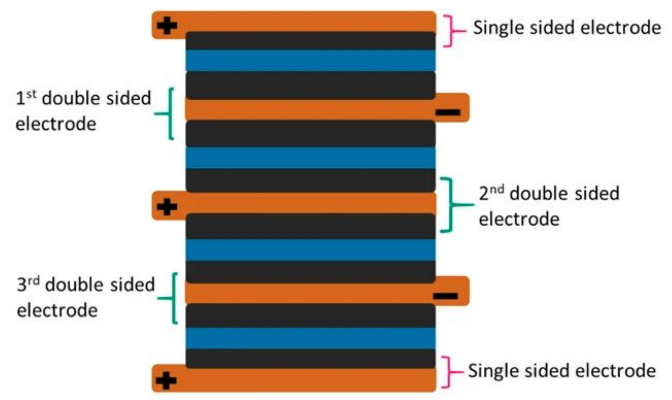
Introduction

What is a High-Frequency Electrochemical Capacitor (HF-EC)?

A High-Frequency Electrochemical Capacitor (HF-EC) is a type of supercapacitor designed to operate at higher frequencies while maintaining high energy and power density. It stores energy through electrochemical charge separation, similar to traditional supercapacitors.

HF-ECs operate different from traditional supercapacitors in that their performance is mainly at line frequencies (60 & 120Hz) and higher when supercapacitors operate better at DC frequencies.

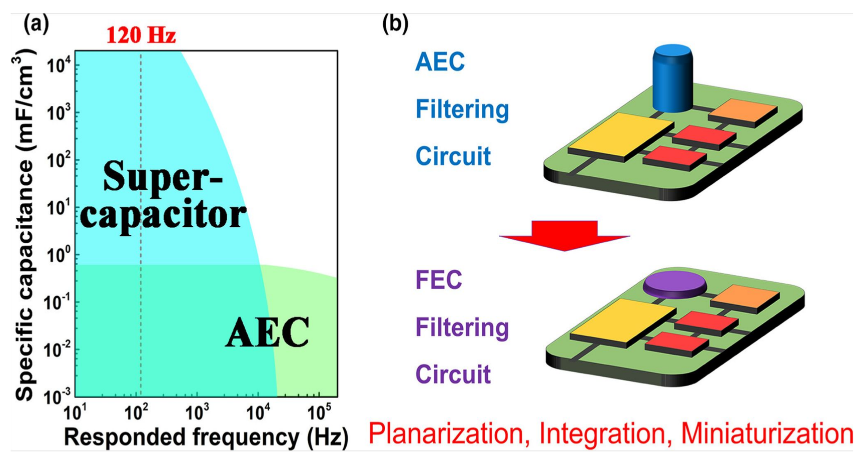


Source: S. L. Chiam et al., (2018)

Motivation for the Project:

Current Aluminum Electrolytic Capacitors have much lower capacitance for their given size, and have poor high frequency performance.

New technologies require smaller, surface mountable capacitors without sacrificing high frequency performance.



Source: Tang et al., (2022)

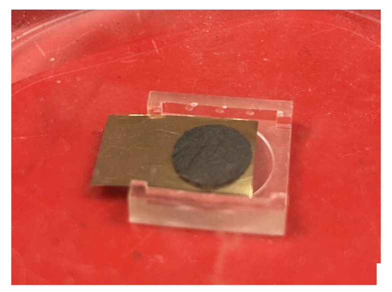
Project Objective:

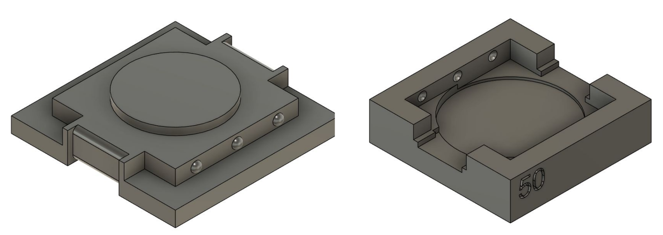
Develop a surface-mount HF-EC housed inside a compact package to support high-frequency operation and promote circuit miniaturization.

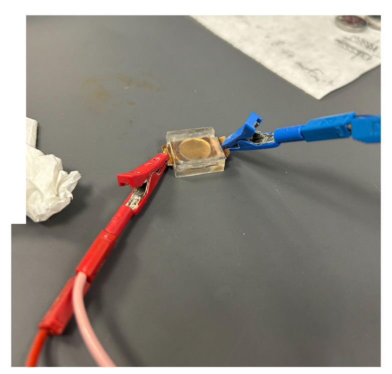
Methodology

Material Research

- Evaluated materials compatible with corrosive electrolytes:
  - 6M Potassium Hydroxide (KOH)
  - **1M Lithium bis(trifluoromethanesulfonyl)imide (LiTFSI)**
- Current collector materials evaluated:
  - **Gold-plated copper**
  - Nickel-plated copper





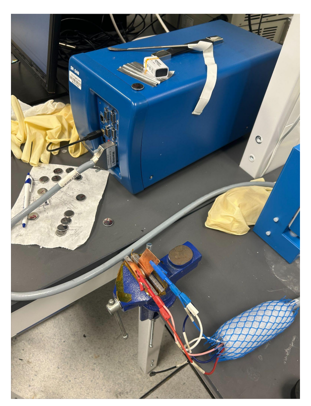


Custom Enclosure Fabrication

- Designed and 3D-printed using UV-curable resin
- Created multiple height variants to compress internal layers

Performance Characterization

- Conducted **Electrochemical Impedance Spectroscopy (EIS)**
  - Frequency from **1 MHz to 1 mHz**
  - Measured complex impedance, phase, current response

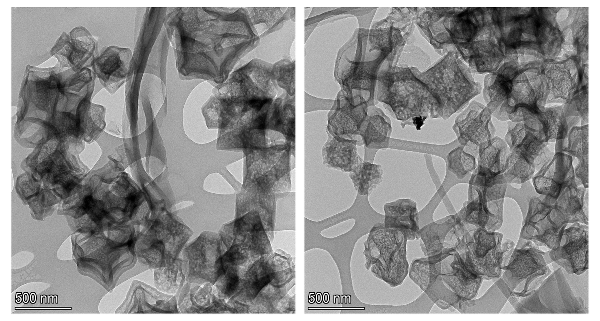


Results

Materials used for the HF-EC package are stated below:

- Current Collector: **Gold-coated copper**
- Electrodes: **25µm Carbon**
- Separators: **25µm polyethylene-coated (PE) paper**
- Organic Electrolyte: **LiTFSI**

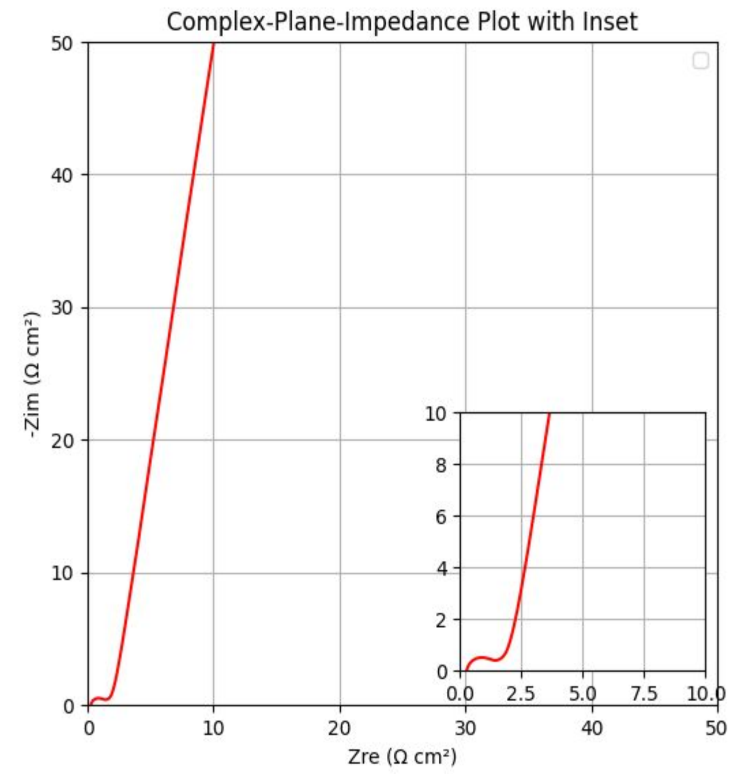
$$C = \frac{1}{2\pi f \cdot |Im(z)| \cdot Area}$$

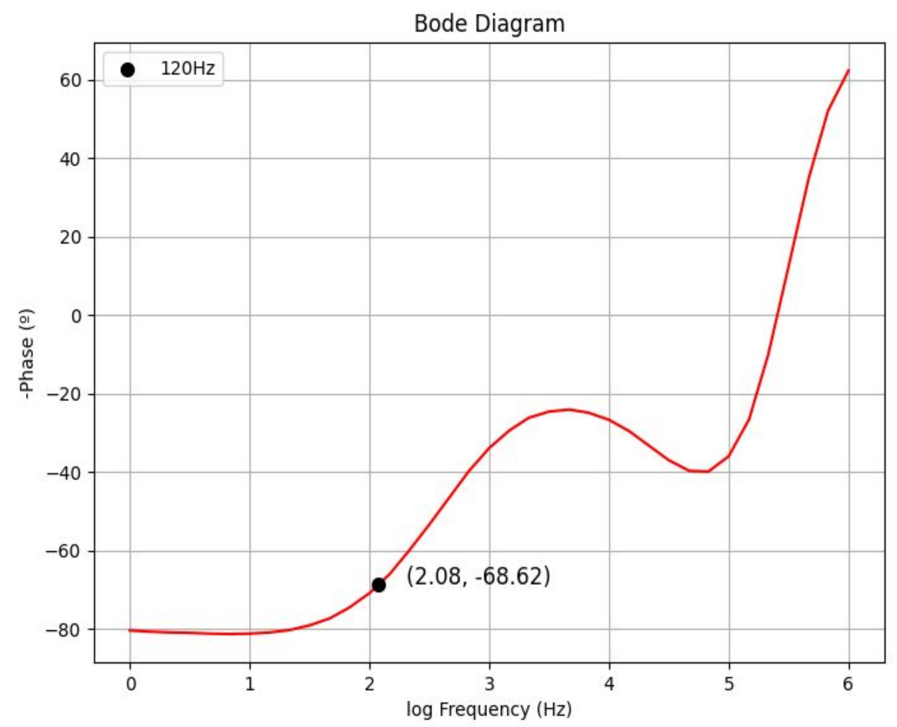


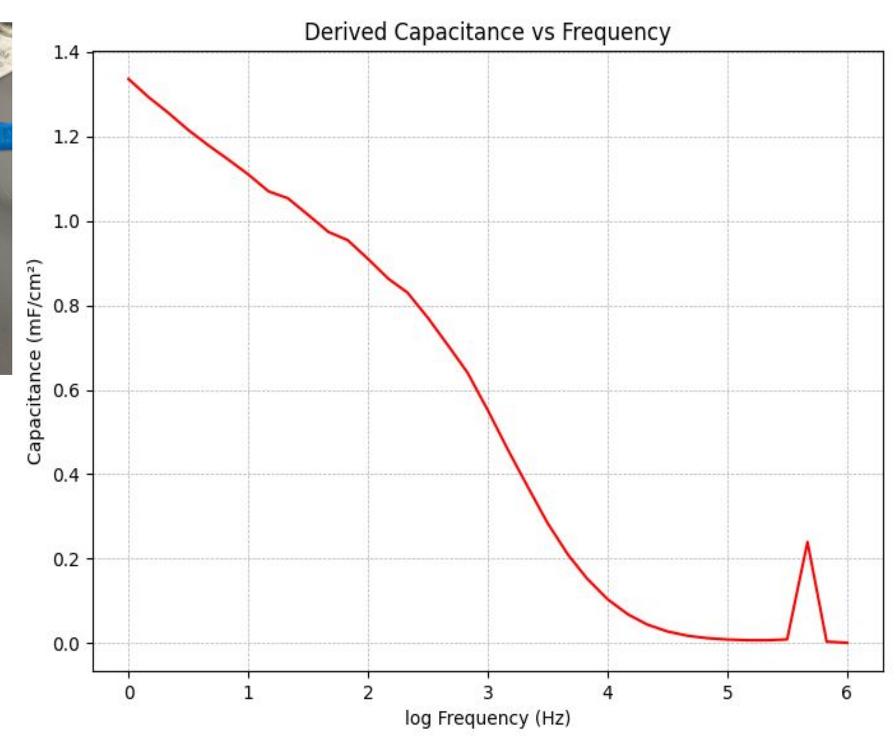
Carbon electrodes: nanodoped ZIF on Kimwipe, thickness = 25µm

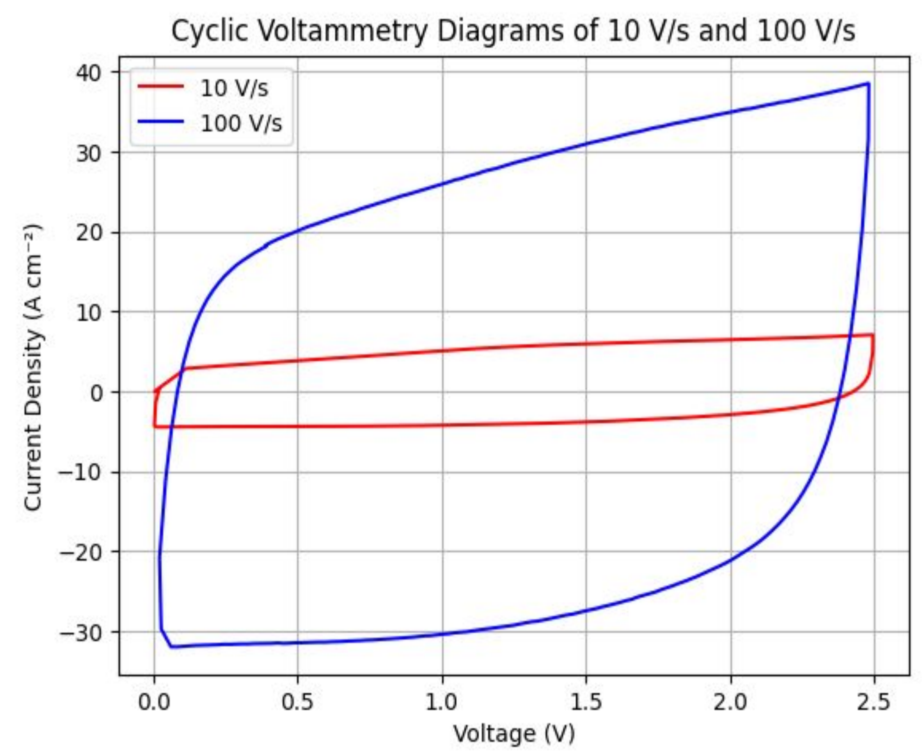
Performance Summary:

- **Complex-Plane Impedance Plot (Nyquist Plot):** Low ESR indicates efficient charge transport.
- **Bode Plot:** Phase angle near −70° at 120 Hz, showing capacitive behavior at line frequencies.
- **Capacitance Derivation Plot:** Shows frequency-dependent capacitance from impedance data.
- **Cyclic Voltammetry (CV):** Exhibits near-rectangular CV curve, validating ideal capacitor response.
- **Capacitance vs Frequency Comparison:** HFEC maintains high capacitance and outperforms the AEC at 120 Hz.





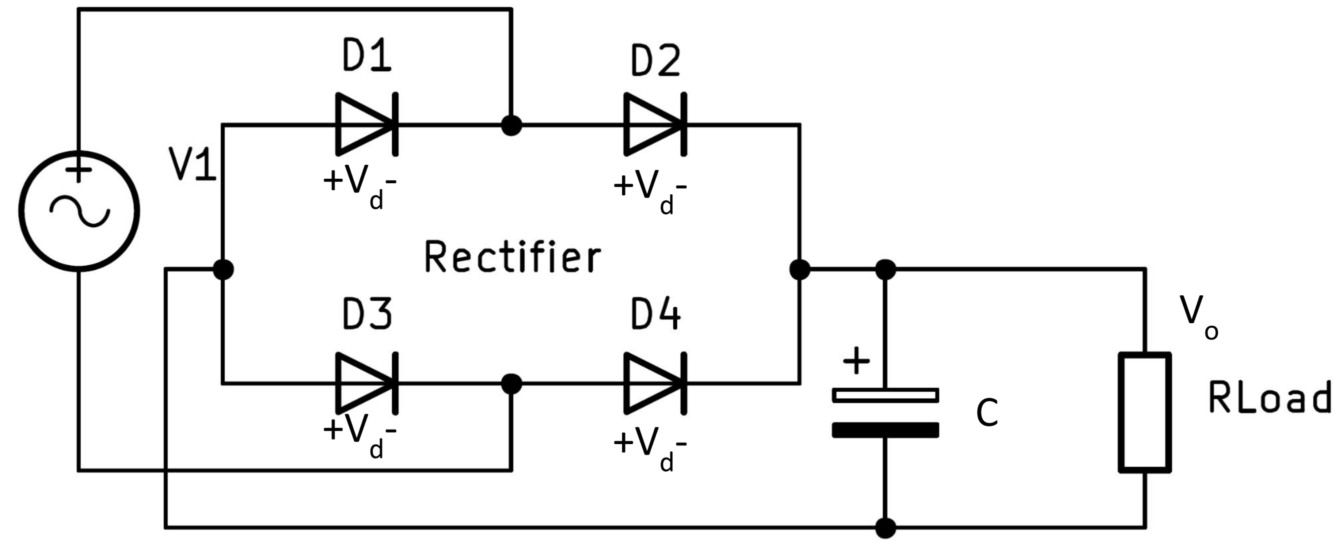




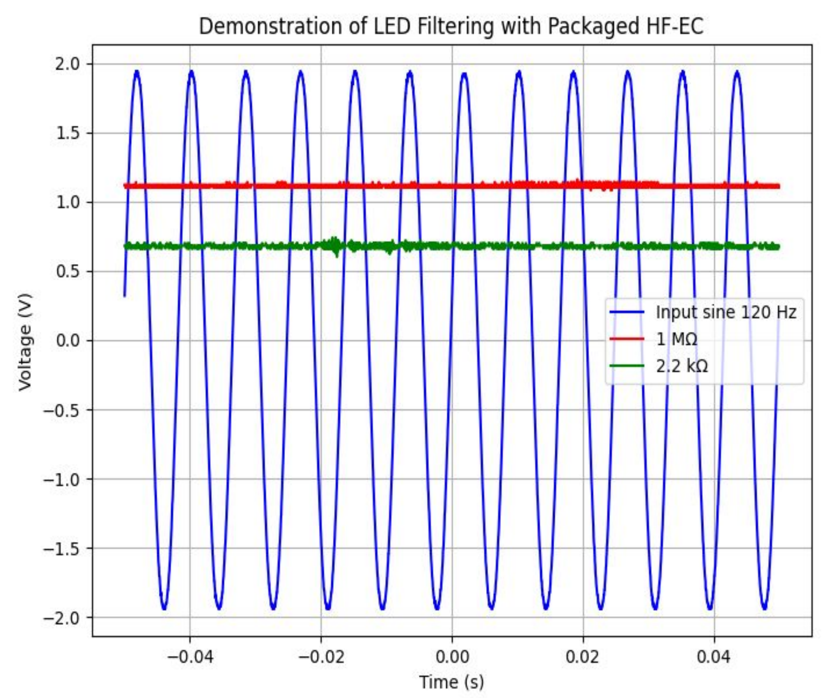
Application

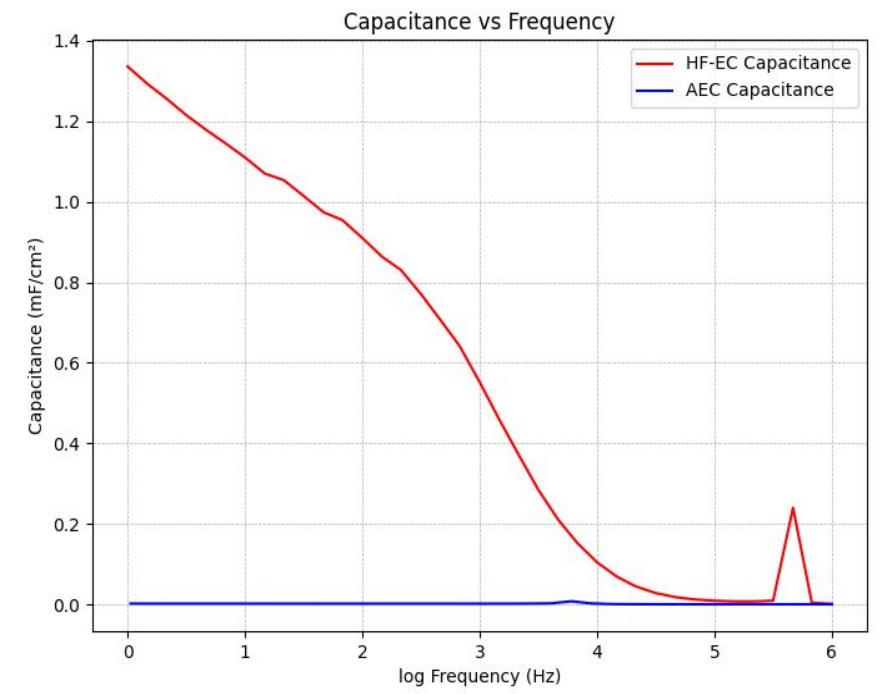
Some applications for HF-ECs:

- **Line-frequency ripple current filtering** in power electronics and rectifier circuits
- **Energy harvesting systems** for capturing ambient energy (vibration, RF, thermal) and delivering fast discharge
- **Replacement of AECs** in applications where size reduction and longevity are of utmost importance



$$V_r \approx \frac{V_o - 2V_d}{2fCR}$$





Conclusion & Future Work

Key Achievements

- Custom Enclosure Fabrication: 3D-printed packages designed for optimal compression of internal layers
- Demonstrated the potential of HF-ECs as high-frequency alternatives to AECs.
- Surface-mount package supports miniaturization of circuits.

Impact and Future Potential

- HF-ECs present a **compact, efficient, and scalable** energy storage solution
- A promising step toward reducing dependency on bulkier capacitors and improving lifespan of batteries in electronics