Developing a Capacitor Model for Virtual Twin-Based Health Monitoring

COLLEGE OF ENGINEERING AND COMPUTING

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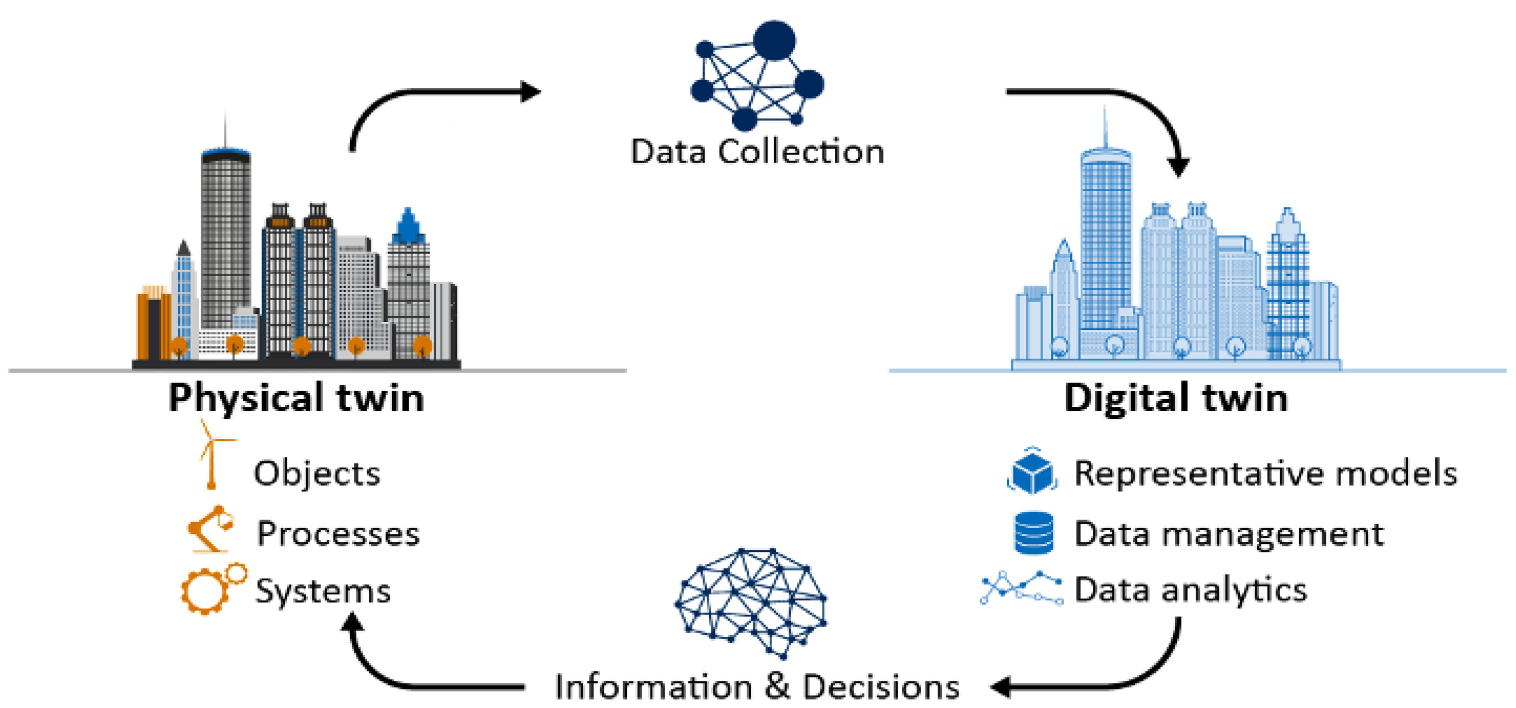
1. Motivation

<u>Predictive Health Monitoring Through Capacitor Modeling</u>

Building a simplified capacitor model in a lowpass filter. When used in virtual twinning, helps monitor component health and predict failures—saving time and resources.

Advantages:

- Planned maintenance
- Reduced system damage
- Increased productivity

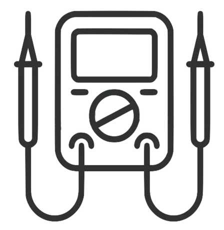


Sources: GAO; ladoga/stock.adobe.com. | GAO-23-106453

<u>Virtual Twinning</u>

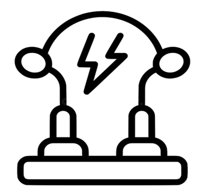
Digital replica → Track performance → Compare

2. Capacitor Artificial Aging Process



- Initial sample size: 40 capacitors
- Measurements taken initially and after each heating interval
- Capacitor impedance measured across a frequency sweep from 100 Hz to 8 MHz
- MATLAB used to calculate the capacitance and equivalent series resistance (ESR) at each frequency using measured impedance values

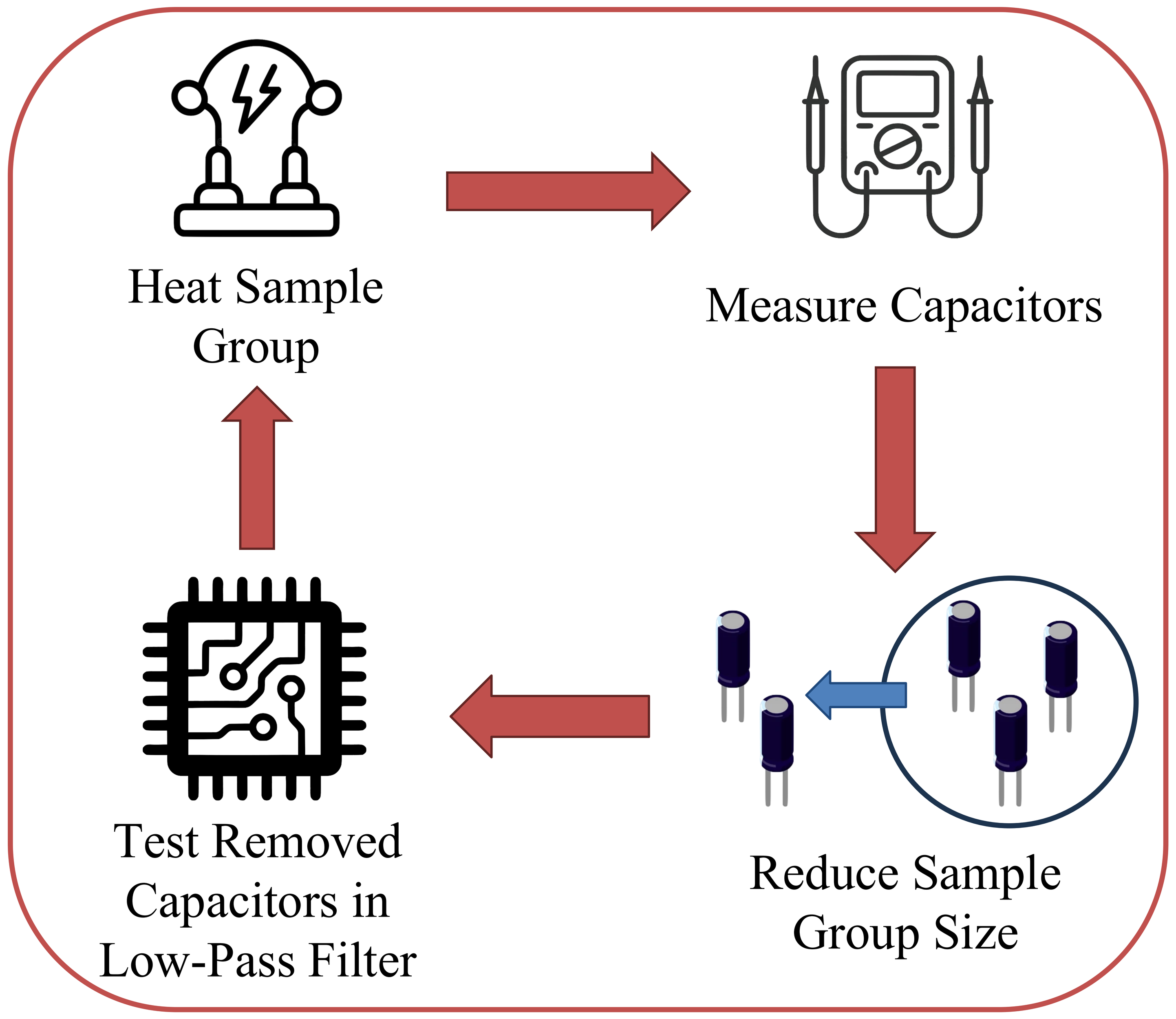
- Capacitor operating range: ≤ 85 °C for ≤ 2000 hours
- For every 10 °C above rated max temperature, expected capacitor lifetime decreased by half
- +40 degrees → Expected lifetime of 250 hours

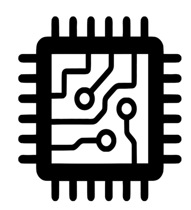


- Tube furnace used for heating
- 8 heating intervals of ~50 hours, constant 125 °C heat
- 5 capacitors removed from sample group after each heating interval

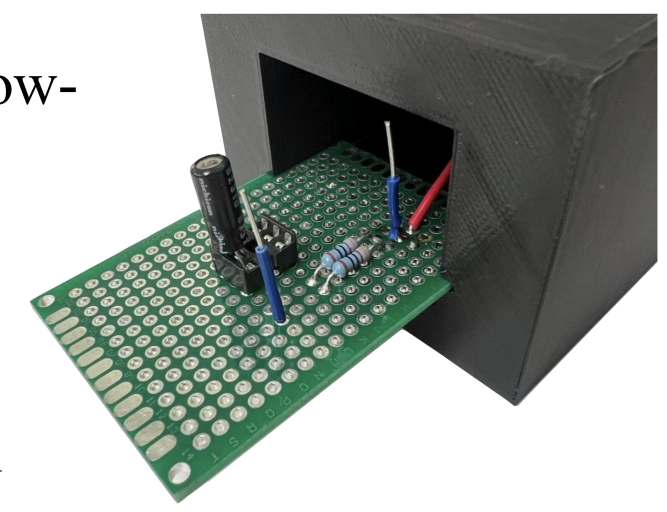
125 °C

400 hours total



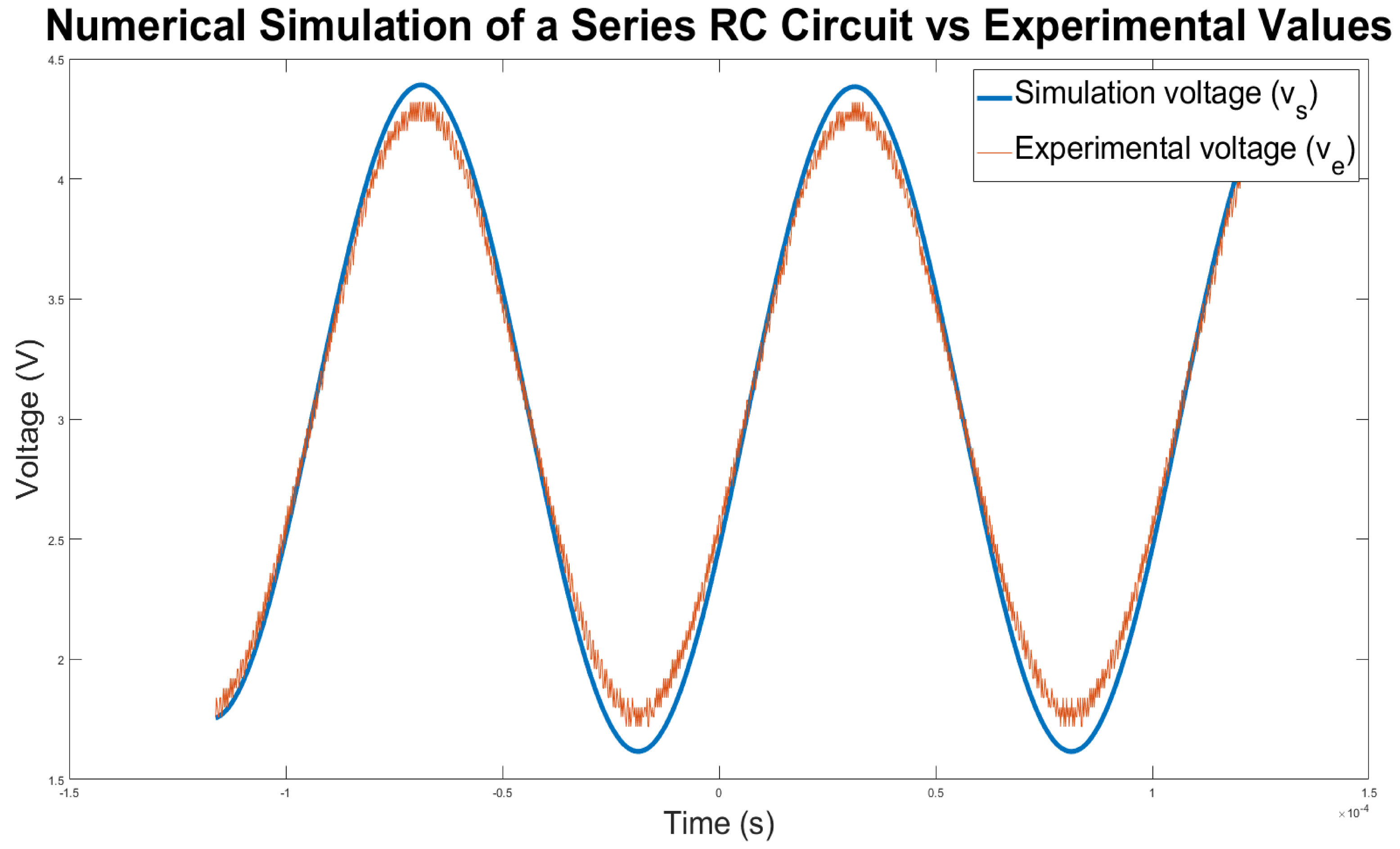


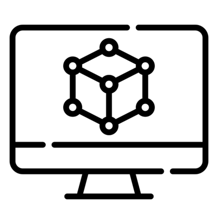
- Tested aged capacitors in a low-pass filter (LPF)
- Capacitor performance analysis against simulated model using MATLAB



3. Results

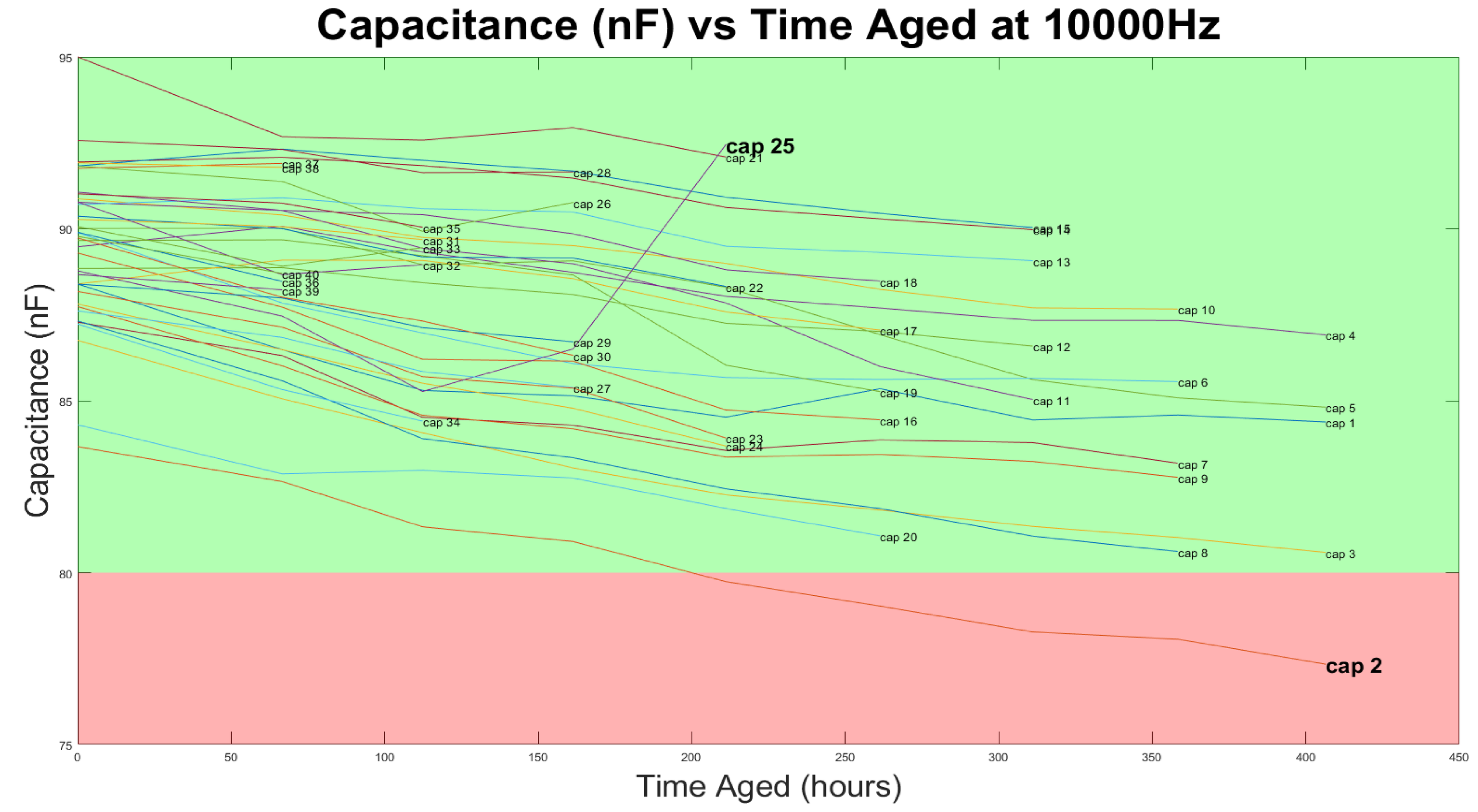
Numerical Simulation of a Series RC Circuit vs Experimental Values



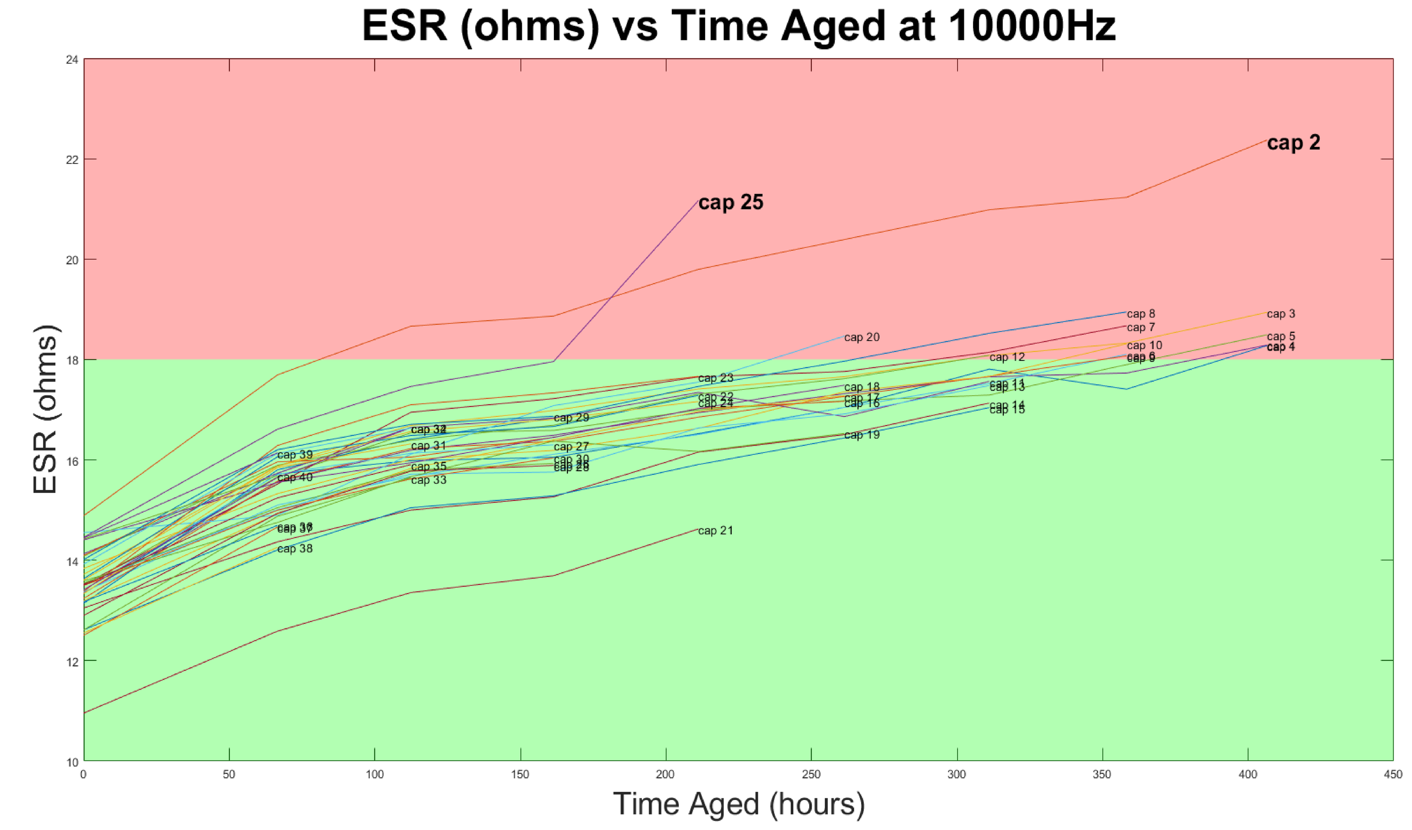


Using MATLAB, compared the developed model with measurements from an aged capacitor, incorporating aging data to improve model accuracy.

Capacitance (nF) vs Time Aged at 10000Hz



ESR (ohms) vs Time Aged at 10000Hz



- Capacitor 'failure' = 20% change from the nominal rated capacitance or extreme changes in ESR
- Graphs show Capacitor #2 reach fail state based on changes in both capacitance and ESR
- Other capacitors would have likely failed with further artificial aging time
- Results prove accelerated capacitor 'aging' process via heat

We would like to extend a word of thanks to Dr. Catherine Almquist of the Chemical, Paper, and Biomedical Engineering Department for use of some of her lab space and equipment needed to age the capacitors in this project.