Complexity of Test for Ferroic Components and Systems

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Summary

- Ferroic components, including ferroelectric capacitors, piezoelectric actuators and sensors, pyroelectric sensors, and electrocaloric elements, will require an extremely complex test environment in order to reach the market and operate reliability.

- Characterization of Ferroic materials and components may become the largest cost in bringing Ferroic products to market.

Goal

Develop the tools for the Materials Engineer, Process Engineer and Reliability Engineer to enable the Product Engineer to predict the lifetime performance and time-to-failure of his or her products.

- Radiant Technologies has made some progress with models for its thin PZT film capacitors and pMEMS components.
- *Complexity of Test* is the *core principle* in the architecture and operation of Radiant's Precision family of testers.

Objectives

The objectives of this presentation are to

1. Explore the origin of behavioral complexity in Ferroic components.

2. Provide examples of unexpected outcomes caused by non-linear devices with memory.

3. Identify test architectures that capture complex behaviors of Ferroic components over their lifetimes.

4. Propose a hierarchy of tests, analyses, and logical decisions for evaluating the complexity of any component.

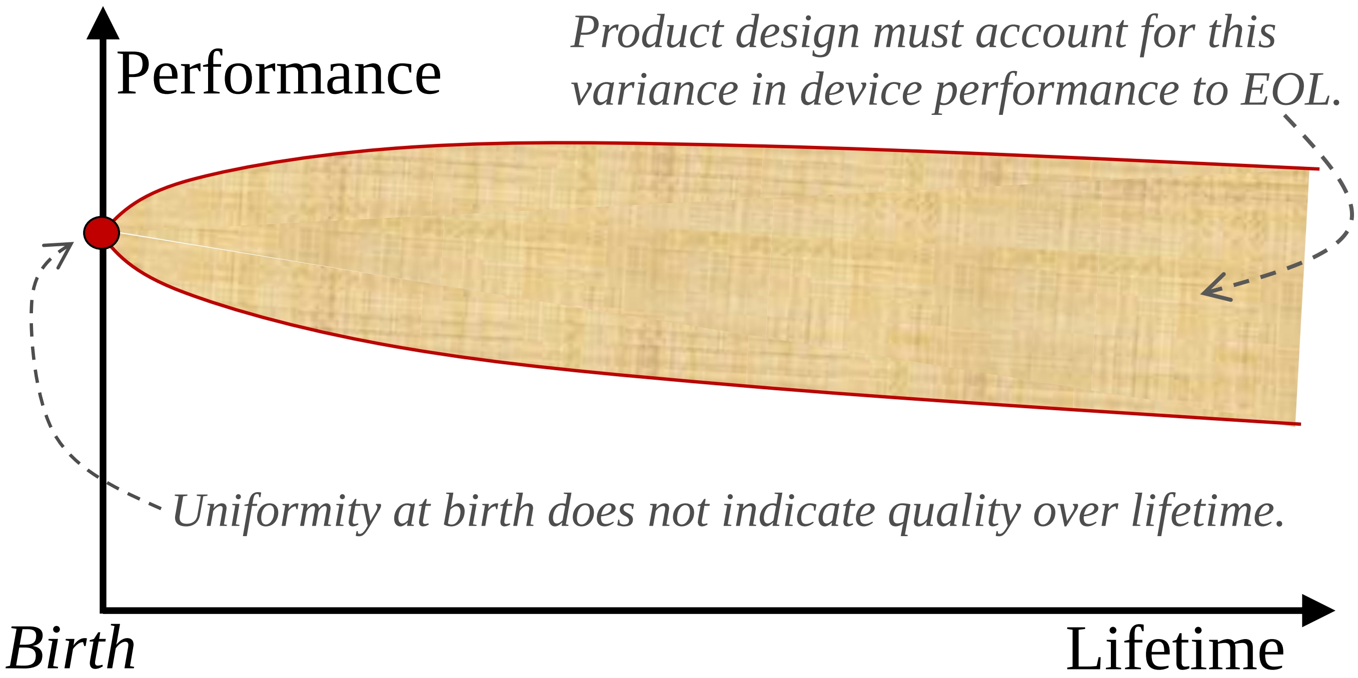
Origins of Complexity

- Anyone who has worked with Ferroic materials knows that they change their performance with constant use.
  I. Change their rest state in time whether in use or not.
  II. Change *how they change* based on external conditions.
  III. Have memory: i.e. each change depends upon the starting position set by earlier changes.

- No two devices *ever* see the same history so no two devices ever exhibit the same performance or follow the same exact path in their lifetimes.

Results from Complexity

- Think of the performance or response of a single devices as the Y-axis on a plot versus lifetime.



- The *reliability engineer* must find the *outer boundaries* of this performance envelope. The *product engineer* must *design* to it.

Examples

The following examples of the complexity of ferroelectric capacitor performance and reliability will be presented on the next few pages.

1. FRAM 2T2C Memory Bit – divergence of capacitor properties.

2. Piezoelectric actuator – properties versus temperature

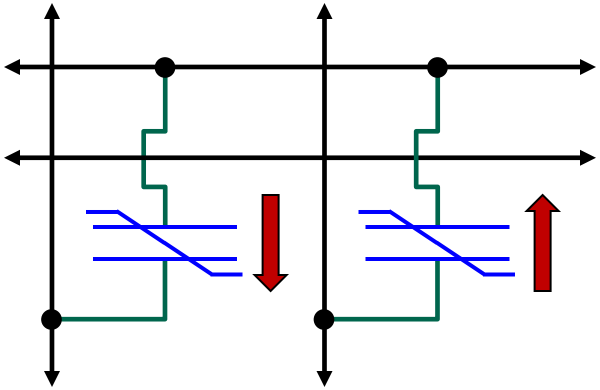
3. Simple capacitor – fatigue and imprint vs temperature and composition.

4. Magneto-electric piezoMEMS

FRAM

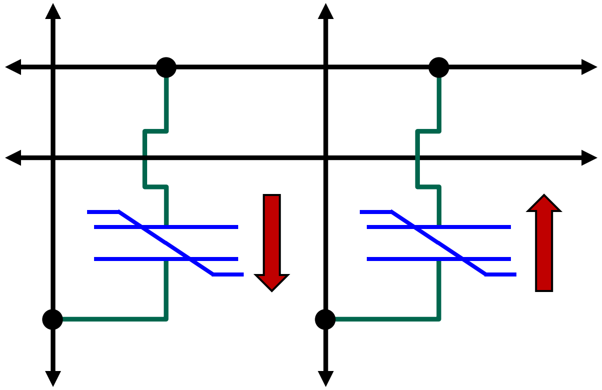
- The now-commercial FRAM architecture is perfect for visualizing the complexity that arises in a relatively simple Ferroic circuit.

- Each 2T2C FRAM memory cell has two ferroelectric capacitors, always oriented in opposite directions.



- Geometry dictates that these two capacitors will always be different.

Performance Evolution

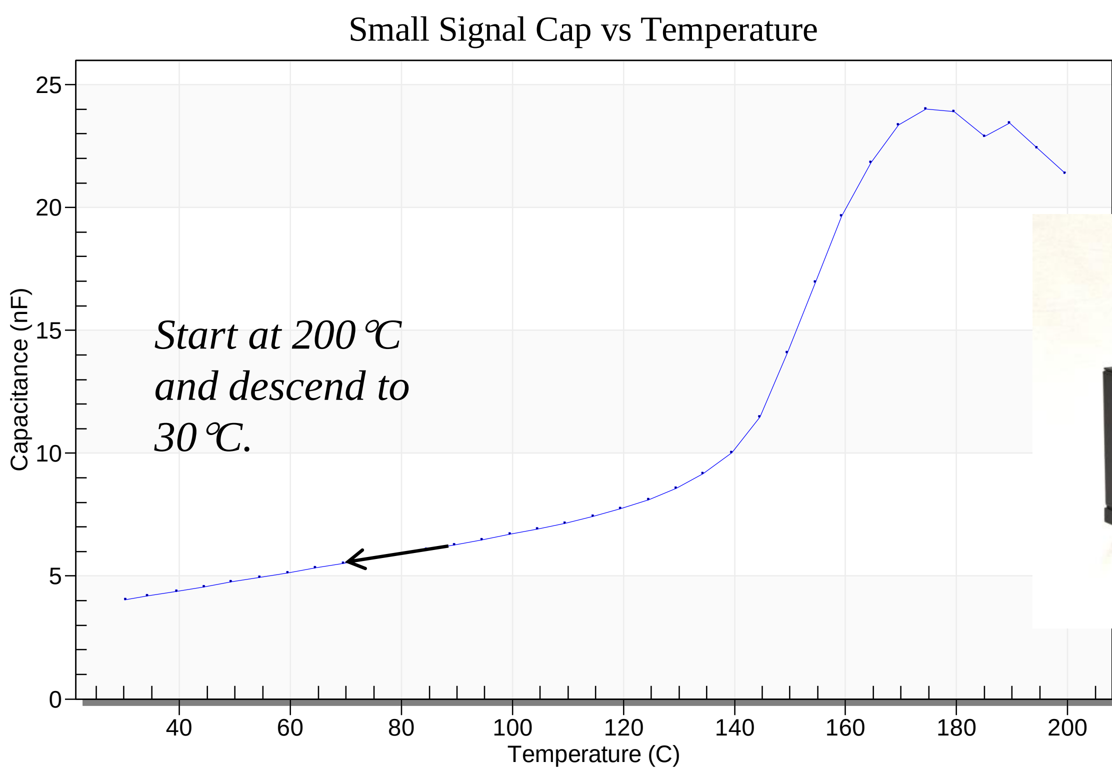


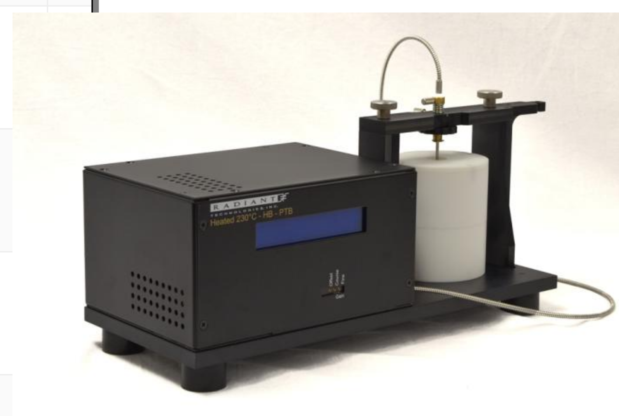
Operation	DOWN Capacitor	UP Capacitor
WR Once- Wait 10 years -RD Once	+Imprint	-Imprint
WR Same Value Continuously	+Imprint Slower	-Imprint Slower
WR Alternating Values Continuously	Fatigue	Fatigue
RD Continuously	Fatigue	-Imprint

- Imagine FRAM in a car that winters in Alaska but summers in Arizona!
- FRAM from Texas Instruments and Fujitsu can meet these requirements!

Piezoelectric Actuator

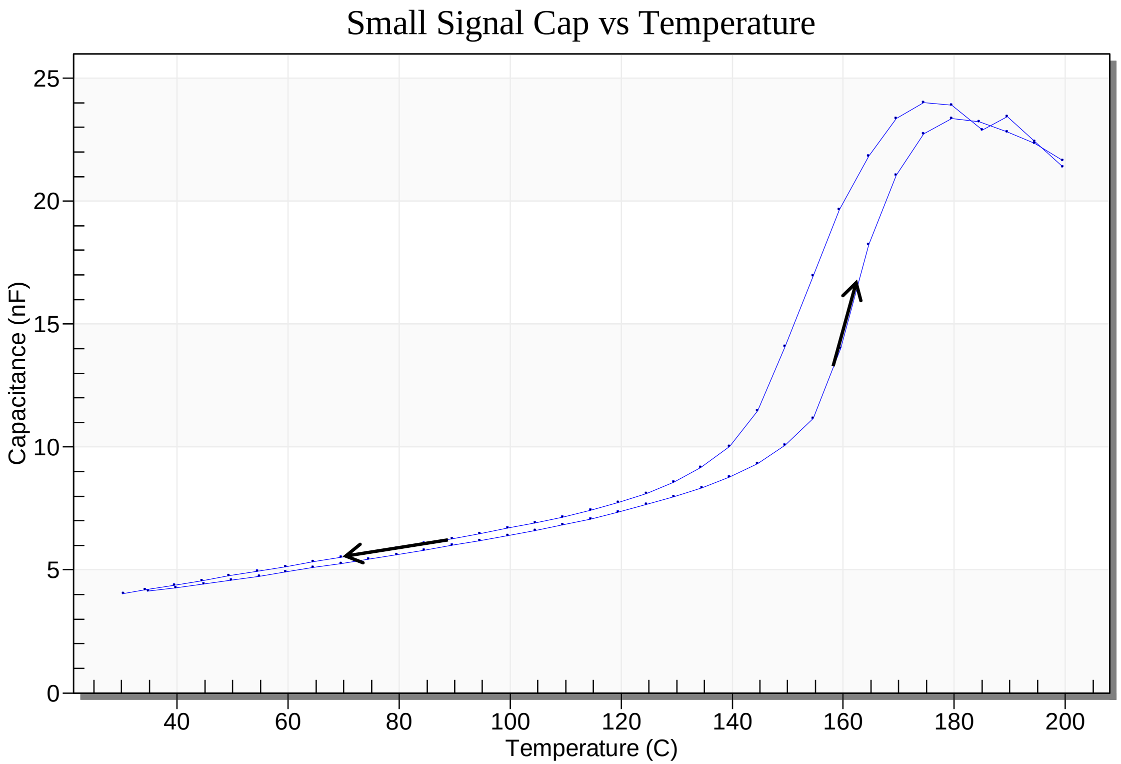
- Commercial PZT piezoelectric disk 100µm thick.
- Measure small signal capacitance versus temperature in thermal chamber controlled from tester.





Is there Temperature Hysteresis?

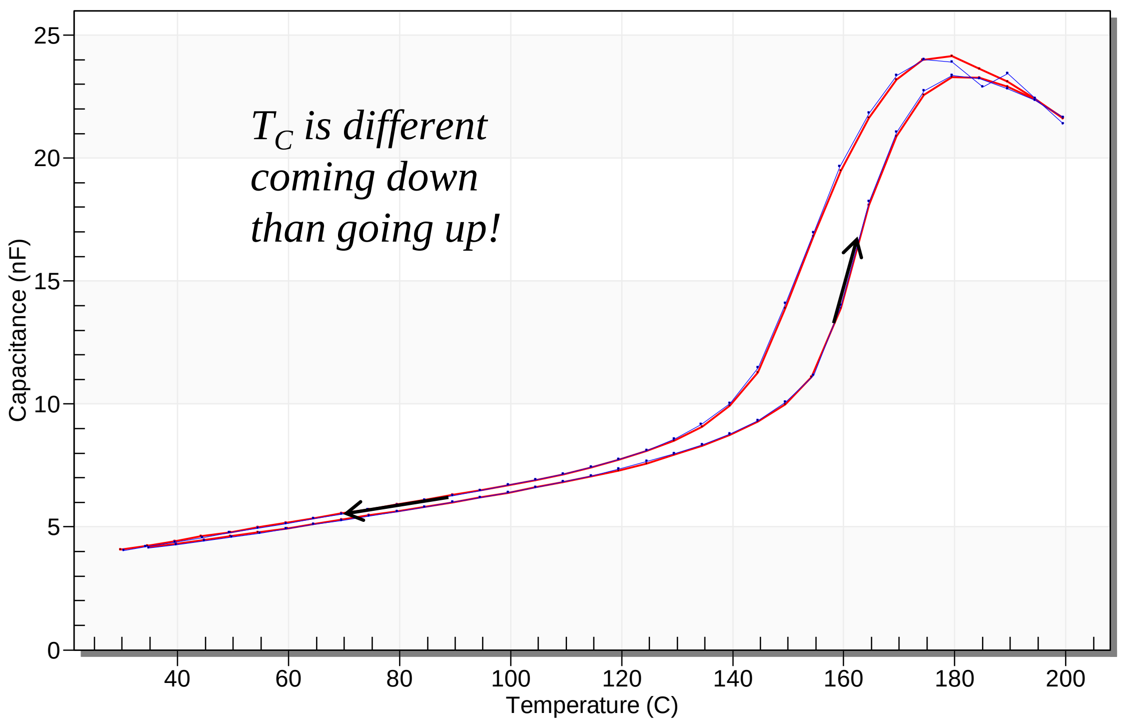
- Start at 200°C and descend to 30°C.
- Go back to 200°C.
- There is hysteresis.



Does the Hysteresis Repeat?

- Execute a second cycle around the temperature loop.
- 200°C → 30°C → 200°C → 30°C → 200°C.
- The temperature hysteresis overlays each time but there are two T_C values!

Small Signal Cap vs Temperature

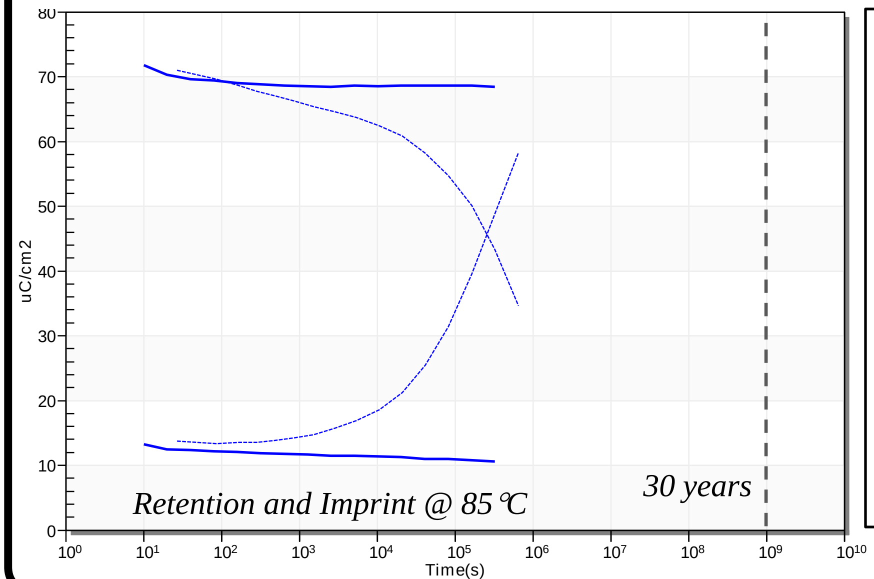


How uniform is this property? That questions requires many more tests.

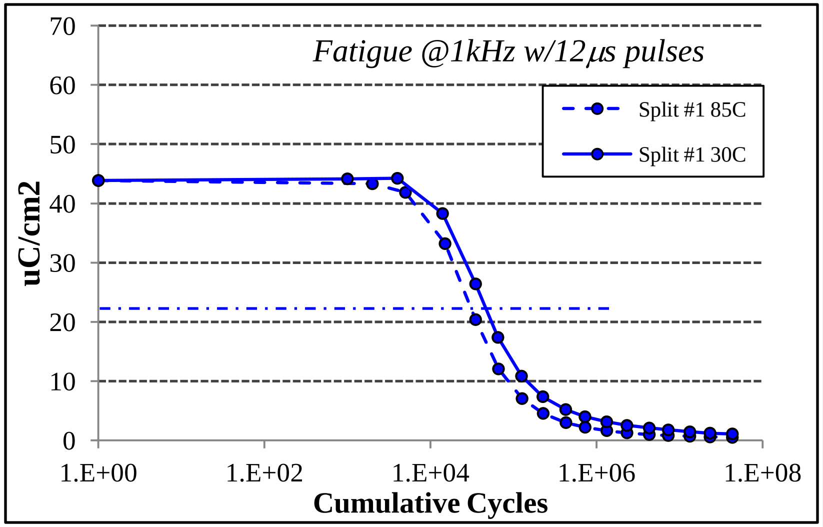
Thin PZT Film Reliability

- Insert PCB into thermal chamber.
- Imprint identical capacitors in opposite directions during 85°C retention.
- Fatigue of one @ 85°C then fatigue of the other @ 30°C.
- 0.26µm 20/80 PZT with platinum electrodes.

Solid line – Retention
Dashed Line - Imprint



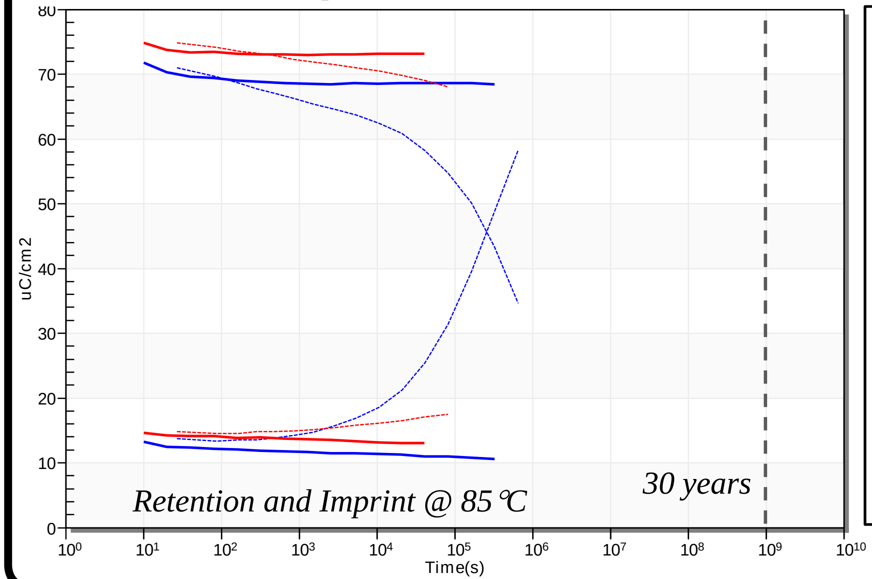
Solid line – 30C Fatigue
Dashed Line – 85C Fatigue



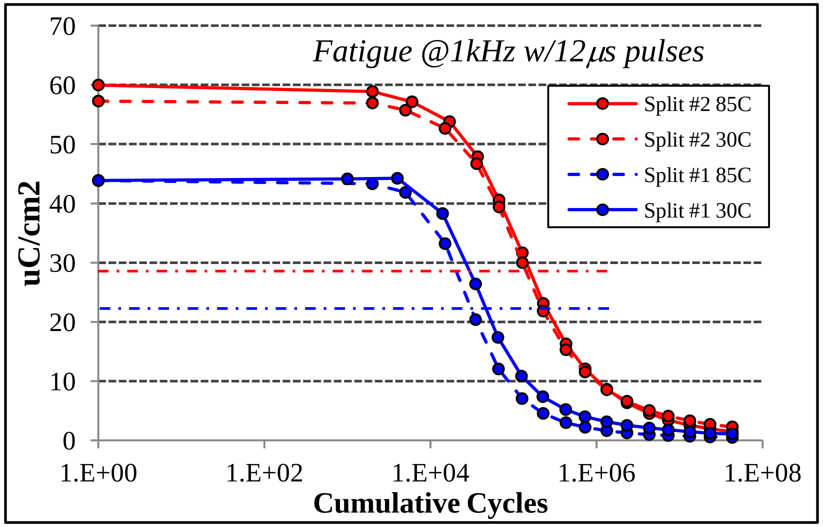
Process Split

- Execute a *process split* to determine the effect on fatigue and imprint.
- Result: Fatigue to the 50% point can be modified for platinum-electroded capacitors without oxide electrodes.

Solid line – Retention
Dashed Line - Imprint



Solid line – 30C Fatigue
Dashed Line – 85C Fatigue



ME pMEMS

- The NSF-funded Translational Applications of Nanoscale Systems (TANMS) at UCLA wants to build composite magneto-electric devices as point-source antennas.

- Such a device combines PZT capacitors with MEMS technology with ferromagnetism.

- The issues facing the test engineer:
  - Each technology must be tested separately
  - All three technologies must be tested integrated together.
  - The performance of the finished device over its lifetime must be predicted.

Test Architecture

- A high level of automation is needed:
  - The test **hardware** must be capable of replicating any *stimulus* and any *measurement* in any *environment* in any *order* undisturbed and unmonitored by the researcher.
  - The test **software** must
    I. Sequenced these four functions in any order.
    II. Adjust the test sequence as the test progresses based on sample response.
    III. Collect, save, and process the data automatically.
    IV. Provide tools to recall and analyze the results.
- Radiant labels this *Autonomous ATE*.

Levels of Complexity

- The complexity of test for Ferroic components directly impacts
  a. the Cost of the Test
  b. Time to Market
  c. Cost of Product Development
- Radiant Technologies is attempting to identify the test elements necessary to accommodate this complexity of non-linear materials and establish a hierarchical priority of those elements.
- The ultimate goal is to 1) enable successful product introduction and 2) keep cost of test as low as possible.

Proposed Hierarchy

Productivity	**Description**
Complexity	
Level 0	Manual Execution of Any Test
Level 1	Rate of Test Execution *(relative to 3min. manual hysteresis test with export and plot)*
Level 2	Environmental Control
Level 3	Long Duration Tests
Level 4	Automatic Test List Execution
Level 5	Environment Adjustable during Test List Execution
Level 6	Arbitrary Data Operations during Execution
Level 7	Conditional Logic Controlling Execution
Level 8	Adjustable Test Parameters during Execution
Level 9	Autonomous Operation *(full custom test generation in-house, data management, and data distribution)*
Level 10	Production Reliability *(>1 week unattended)*
Library	Tasks Available in Library for Test List

Conclusion

- Ferroic components will require an extremely complex test environment in order to reach the market and operate with high reliability.
- A specialized architecture for test system hardware is an absolute necessity to fully enable Ferroic test.
- Complexity of Test for Ferroic devices demands a hierarchy of test sequence elements on software to enable autonomous test execution under automatic control.
- Characterization of Ferroic materials and components may become the largest cost in bringing Ferroic products to market.