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Automated Algorithms for Screening Electronic Parts for Aging using Power Spectra Analysis (PSA) Data

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To be covered

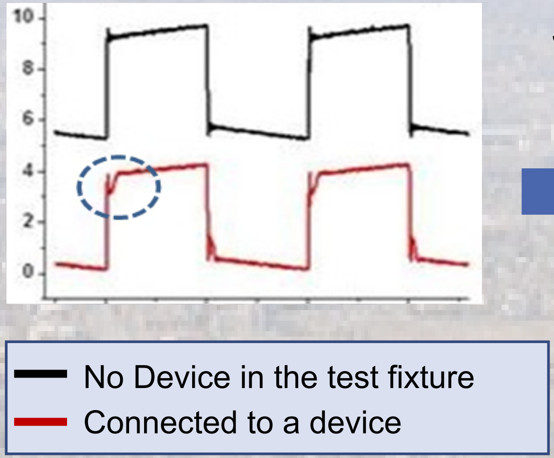
- Analysis objective
- Power Spectral Analysis (PSA)
- Multivariate analysis as a tool for building screening algorithms
- Data used in the analysis
- Algorithm results
  - High Humidity Zener Diode PSA Algorithms
  - MOSFET PSA Algorithms
  - Zener Diode Conventional IV Algorithms
- Conclusions & Next Steps

Analysis objective

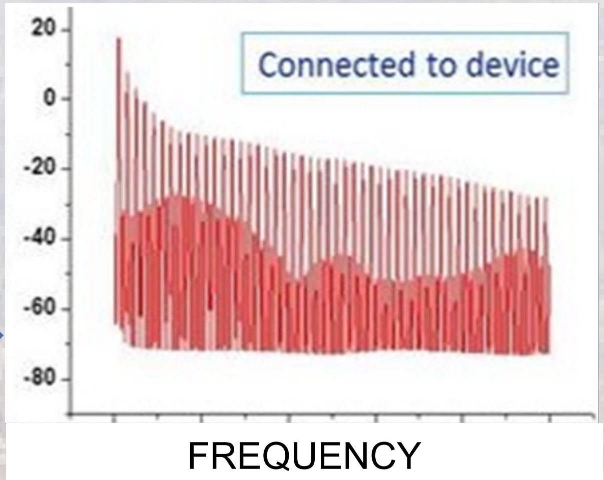
- Understanding the use age of semiconductor parts is of interest to manufacturers using semiconductor parts and to semi-conductor part manufacturers for quality control.
- Power spectrum analysis (PSA) is a fast, non-destructive, sensitive method for examining semiconductor parts.
- The objective of this analysis is to investigate the use of multivariate analysis on PSA data and conventional IV data collected to create algorithms that can be automated to screen semiconductor parts for aging.
- The automated algorithms could then be used in manufacturing facilities to
  - screen incoming parts for use aging in manufacturing facilities using semiconductor parts
  - evaluate and predict the performance of semiconductor parts through reliability stressing in semiconductor manufacturing facilities for the purpose of quality control

Power Spectral Analysis (PSA)

- PSA uses a unique off-normal biasing scheme to detect differences between electronic devices.
  - the testing board is pulsed with a periodic-waveform voltage
  - this waveform is modified when a test device is connected due to dynamic loading of the device
  - this time-domain signal is then transformed via Fourier transform to a frequency signal that is characteristic of the device
  - PSA is a comparative technique, so this frequency is normalized to a reference spectrum prior to analysis.
    - accounts for changes in the signal related to changes in instrument set-up or other changes in measurement environment over time
- PSA non-intrusive and fast
  - typically taking only ~10 seconds to collect data on any given device.

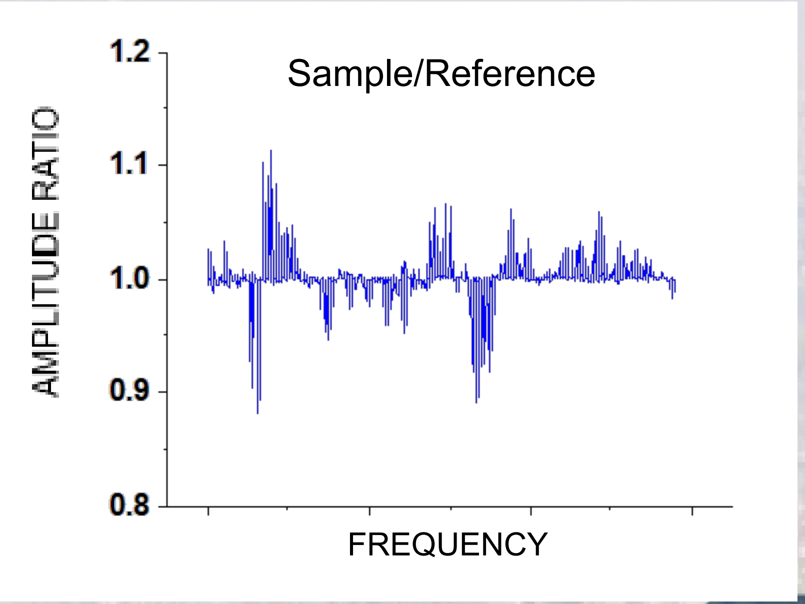


Spectrum Analyzer



PSA Spectrum

Normalize Spectrum

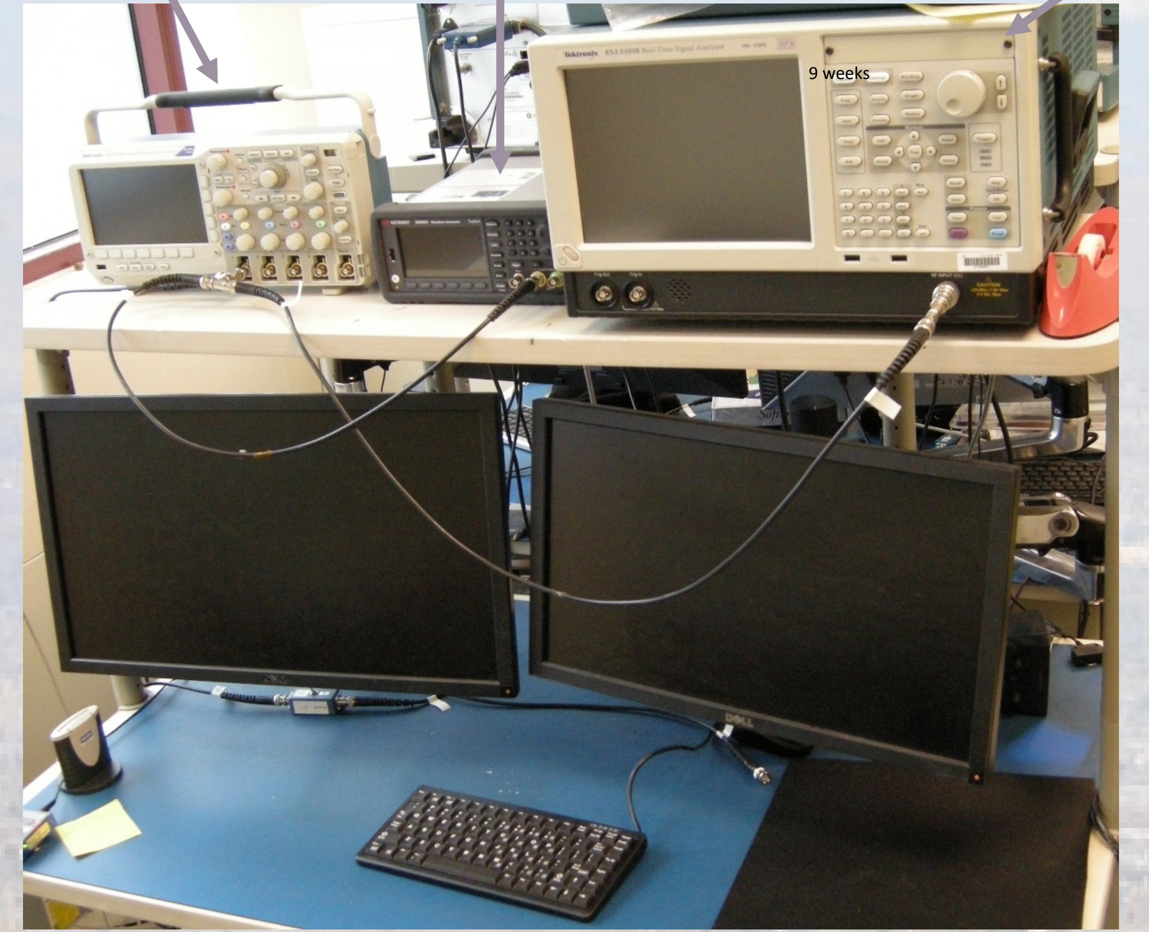


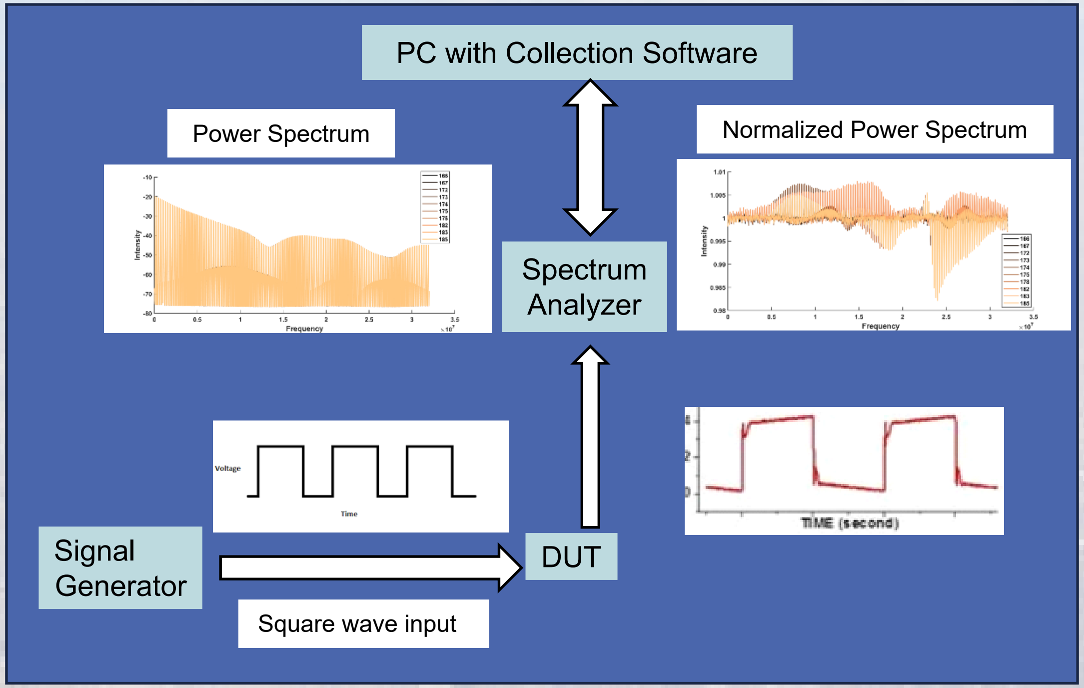
PSA Data Collection

Oscilloscope

Signal Generator

Spectrum Analyzer





Multivariate Analysis

Modeling method that assumes a relationship exists between a set of measured variables (observations) and the properties of interest

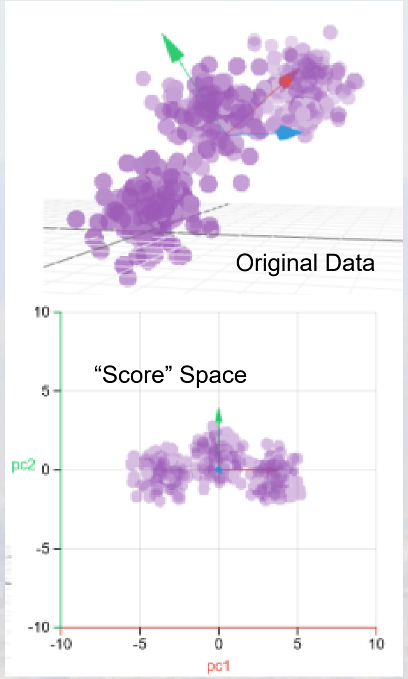
- Observation = Structure + Noise
  - Variables X (set of observations)
  - Response Y = F(X) (set of possible responses)

Modeling extracts the structure in the data that correlates to the observed responses.

Successive transformations are used for the analysis in which the data is projected onto axes or "Principal Components" (PC's) representing the direction of maximum variation of the data.

- PC's are centered on the mean of the data, aligned to the direction of the maximum variation of the data, and orthogonal to each other

With each successive transformation to a new PC, more of the variance in the data is explained and a smaller portion of the variance remains unexplained.



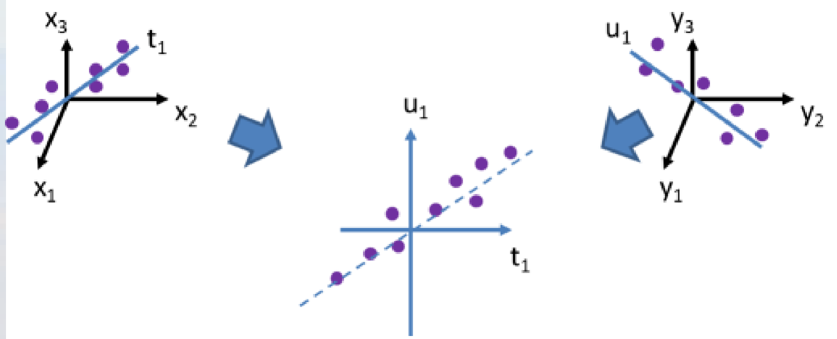
Projection of original data onto PC1 & PC2

Partial Least Square Regression (PLSR)

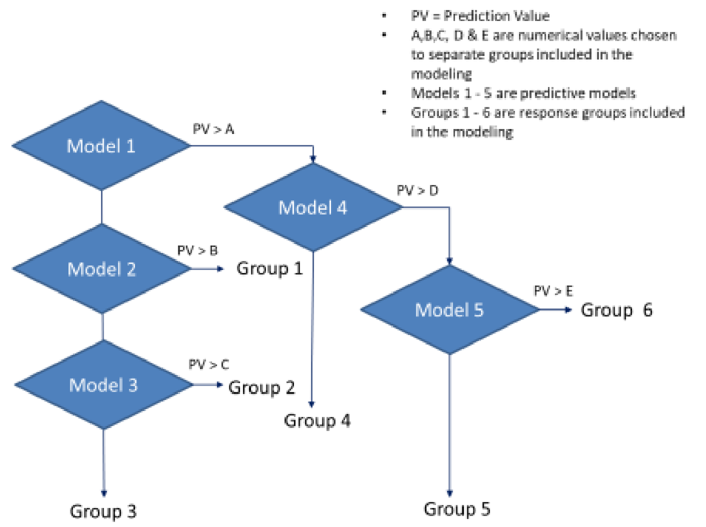
- Data is arranged in a 1Xn matrix for modeling.
- PC's are calculated by modeling both the X and Y matrices (variables and responses) simultaneously using known data.
  - Uses PCA on the variables (X^TY)
  - Uses PCA on the responses (Y)
  - Creates a transformation designed to maximize the covariance between X & Y
- Each interactively calculated PC has a characteristic linear equation for the relationship of the response to the variables:

  $$Y = b0 + b1x1 + b2x2 + b3x3 + \ldots.$$

  - The loadings indicate the contribution of each variable to the PC calculation
- Using an optimal number of PC's, a "Prediction Value" (PV) is calculated by the PLS prediction model that indicates how well matched new input data is to one of the response groups in the modeling.
- Multiple models can be combined to create a programmed flow to differentiate new data based on PV's for input data.



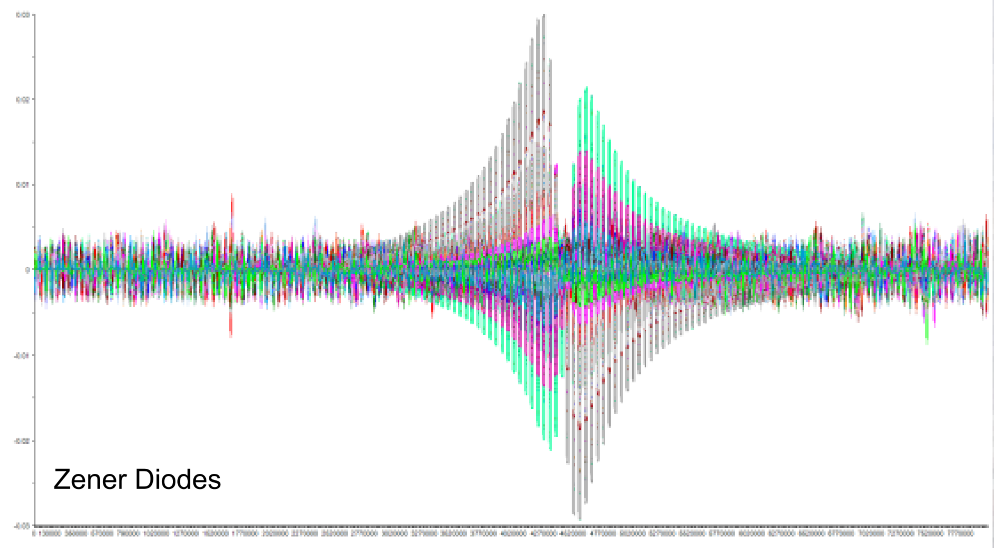
Y data structure influences the decomposition of the structure in the data

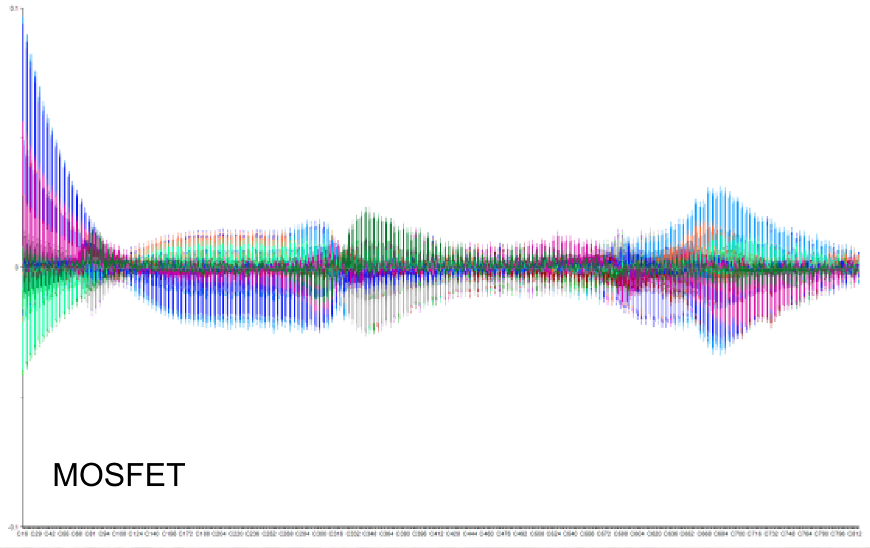


Analysis "Fingerprints"

Multivariate analysis can be done on any data set provided.

- 1 X n data structure can be created to represent each unit/test being evaluated
- Columns in the vector must be the same for all measurements in the data set
  - All columns must have the same information
  - No missing data

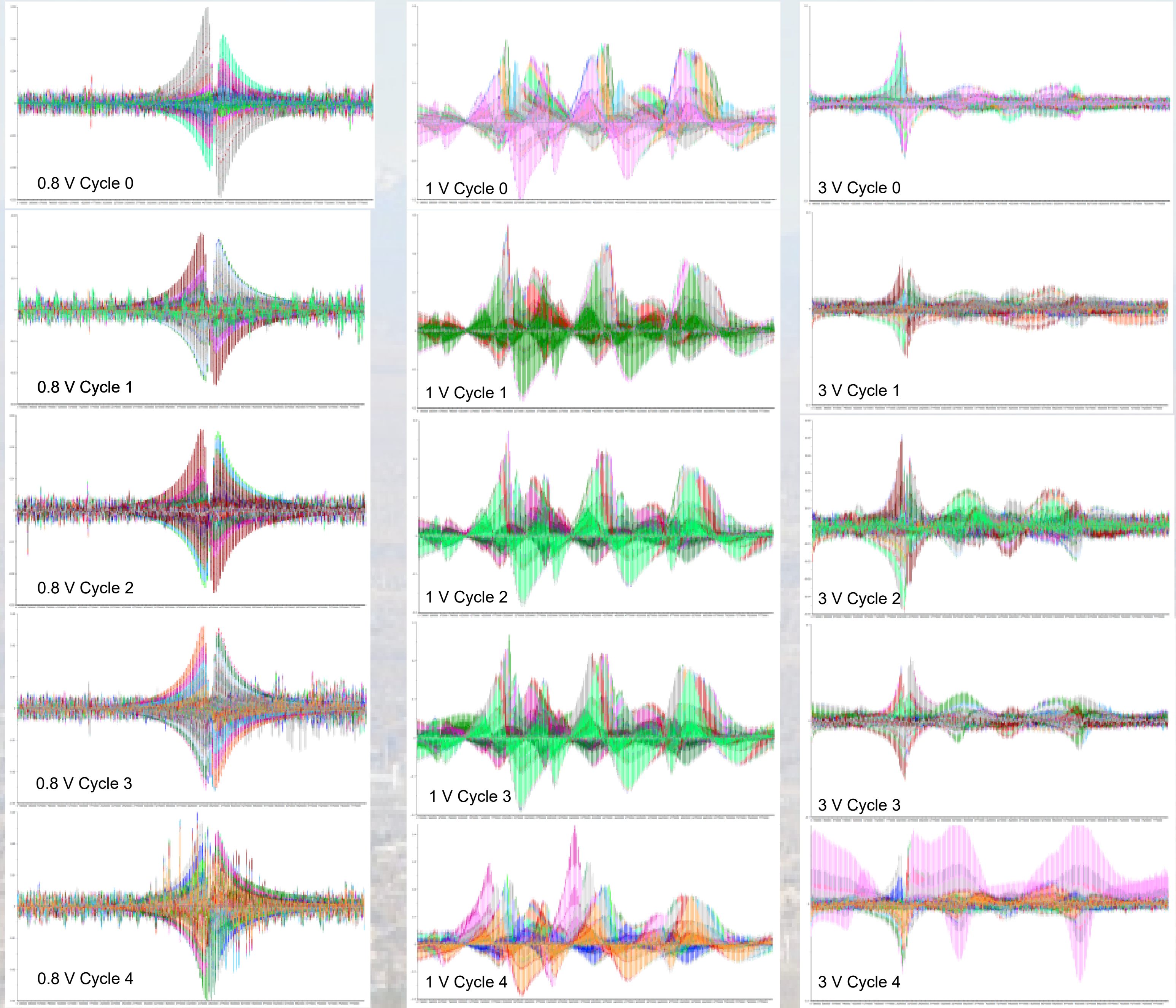




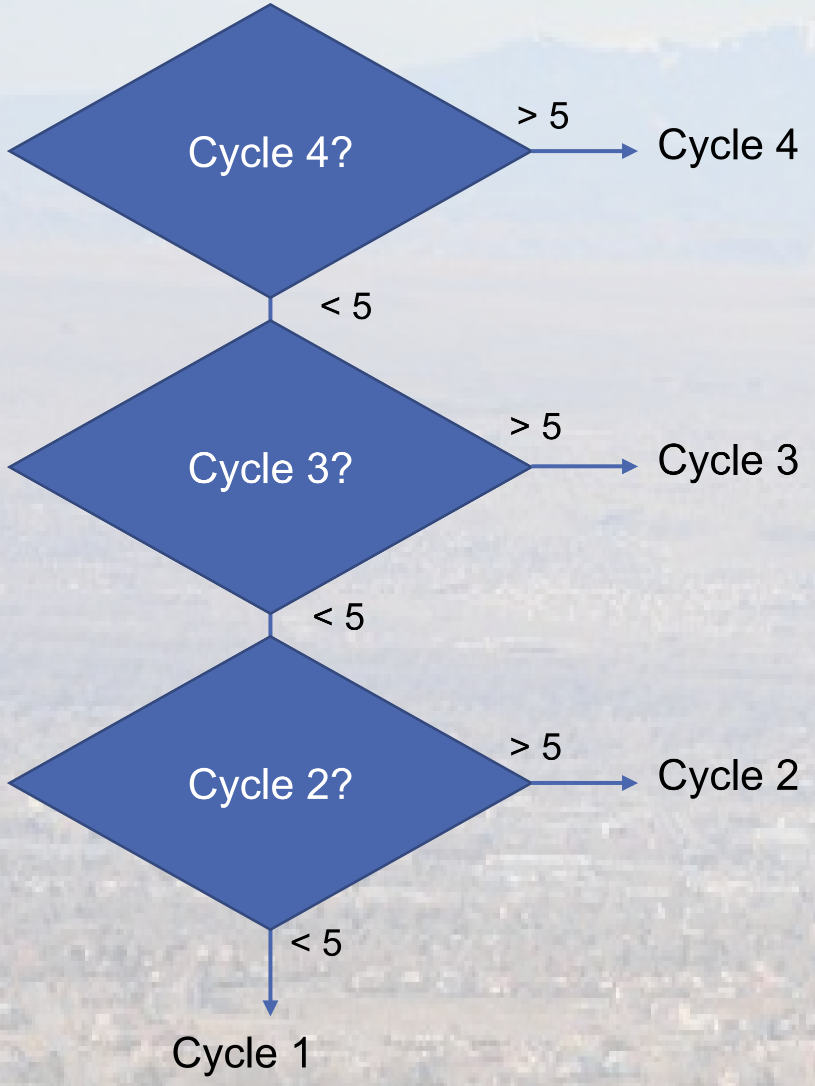
Data used in the PSA analyses

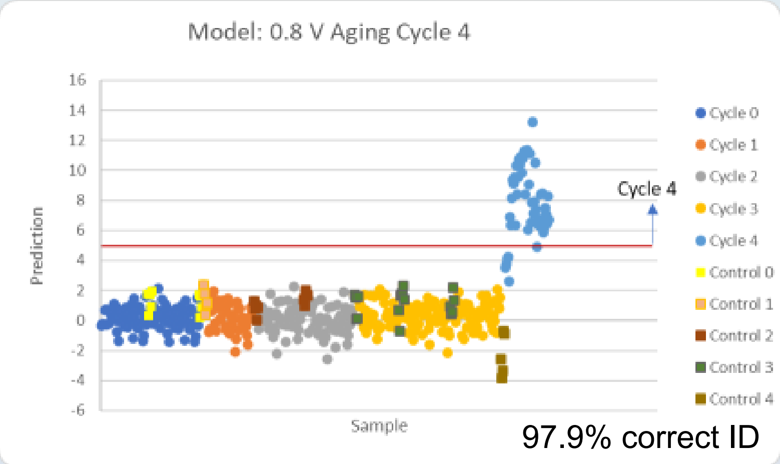
- Zener Diode
  - 3 different bias voltages: 0.8 V, 1 V, & 3V
  - 4 Stress cycles: 110 ^{o}C, 85% Relative Humidity
  - Controls: No aging stresses applied
- MOSFETS
  - 2 different vendors
  - 2 different bias voltages
  - 6 stress conditions: none, conditioned, 24 hrs., 48 hrs., & 96 hrs.
  - Controls: No aging stresses applied
- Data was centered by mean of controls and divided into a modeling and test set prior to analysis.

Zener Diode PSA Data



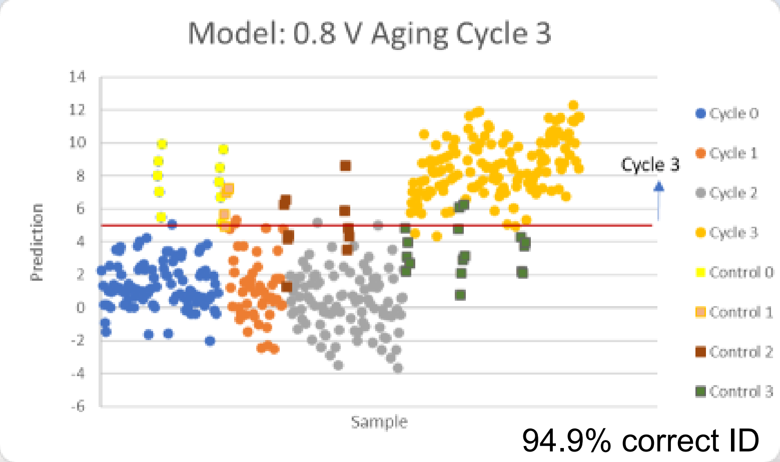
Zener Diode
0.8 V Algorithm





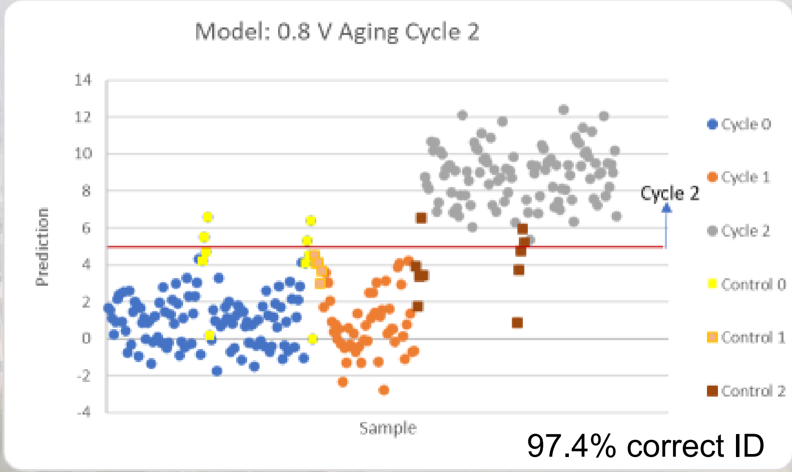
97.9% correct ID

- Modeled on 484 measurements
- Tested on 483 measurements



94.9% correct ID

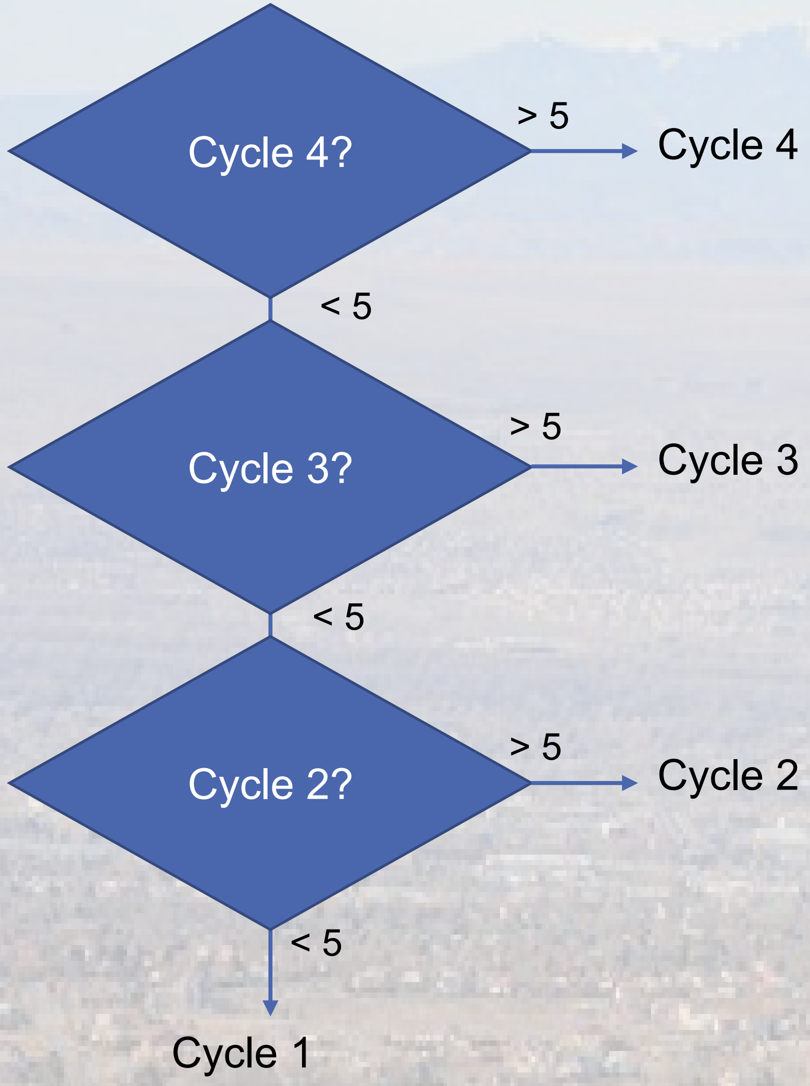
- Modeled on 431 measurements
- Tested on 430 measurements

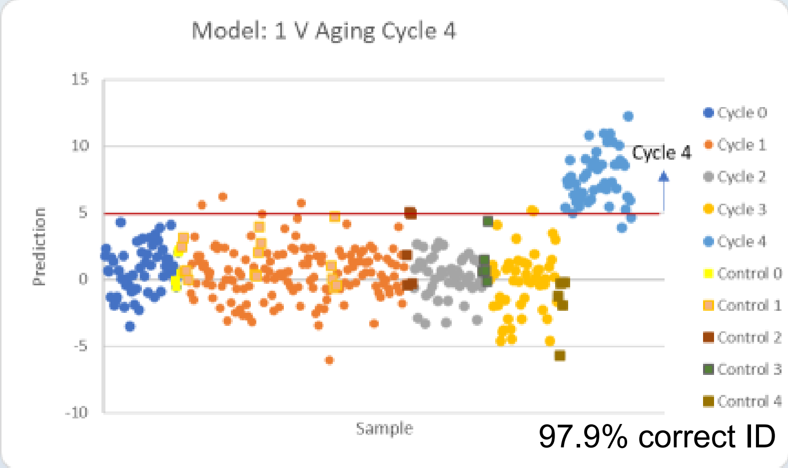


97.4% correct ID

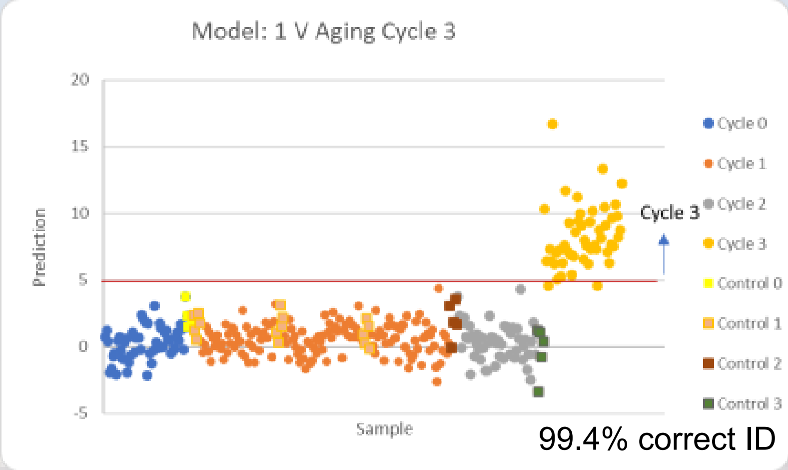
- Modeled on 272 measurements
- Tested on 272 measurements

Zener Diode
1 V Algorithm

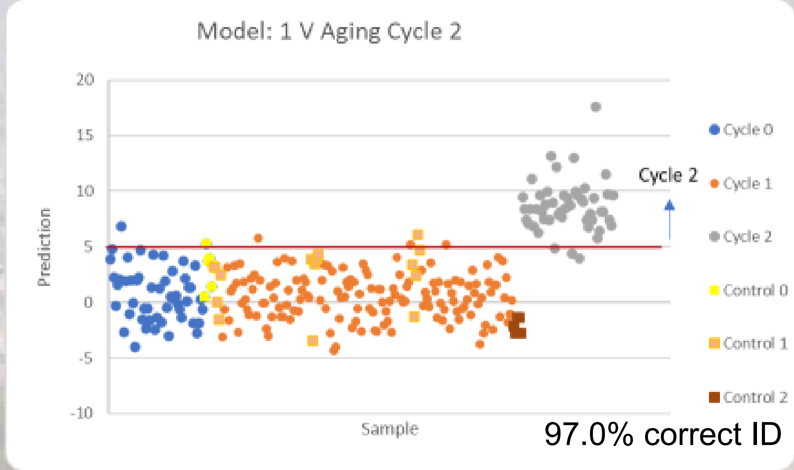




- Modeled on 377 measurements
- Tested on 376 measurements

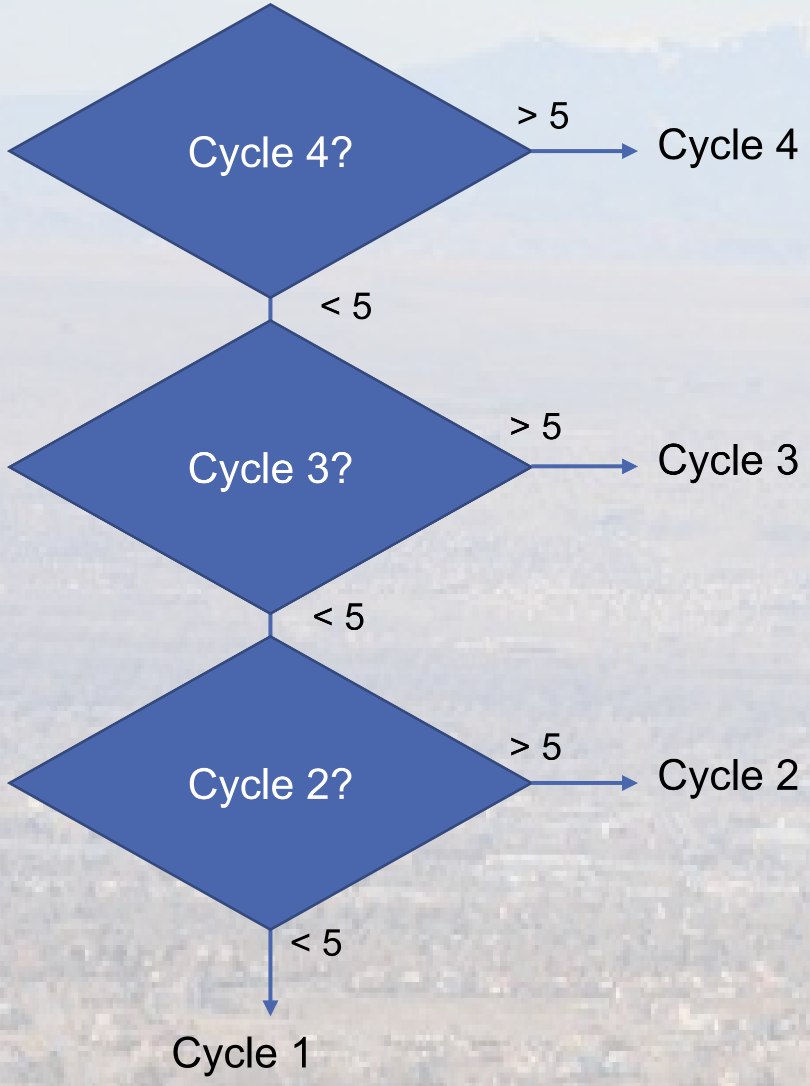


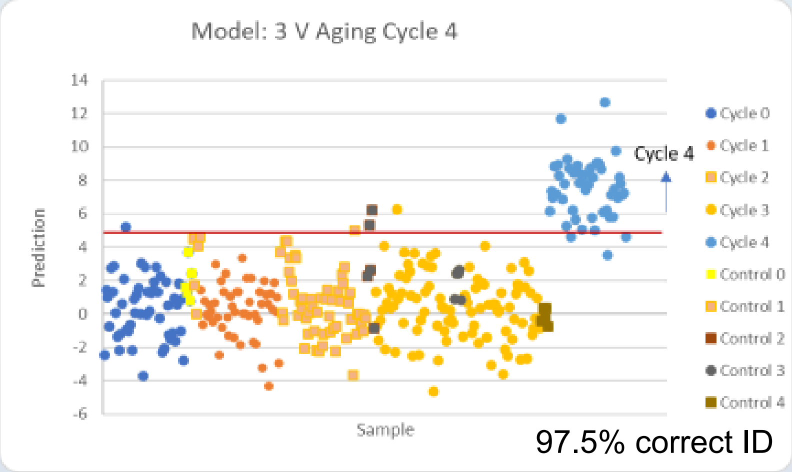
- Modeled on 324 measurements
- Tested on 323 measurements



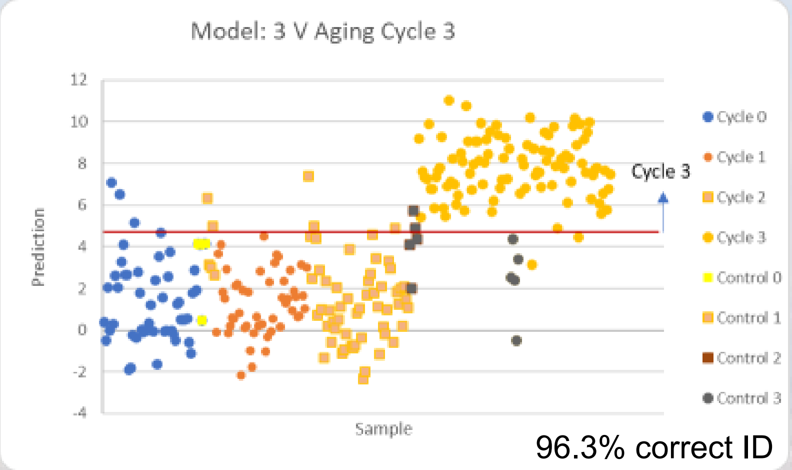
- Modeled on 270 measurements
- Tested on 269 measurements

Zener Diode
3 V Algorithm

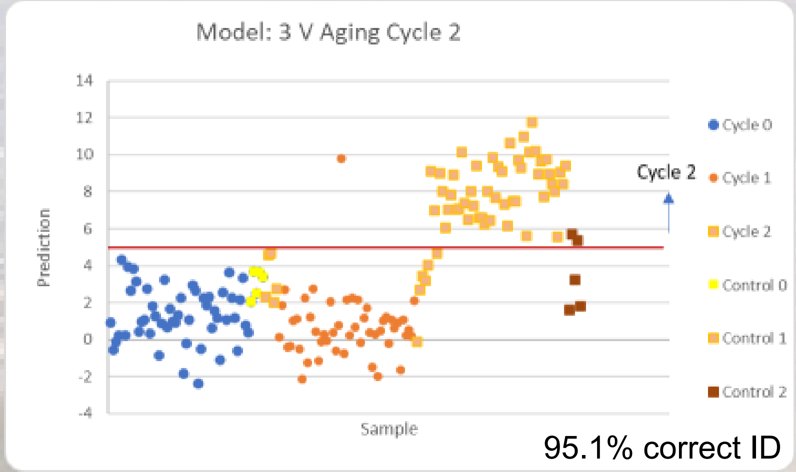




- Modeled on 324 measurements
- Tested on 324 measurements



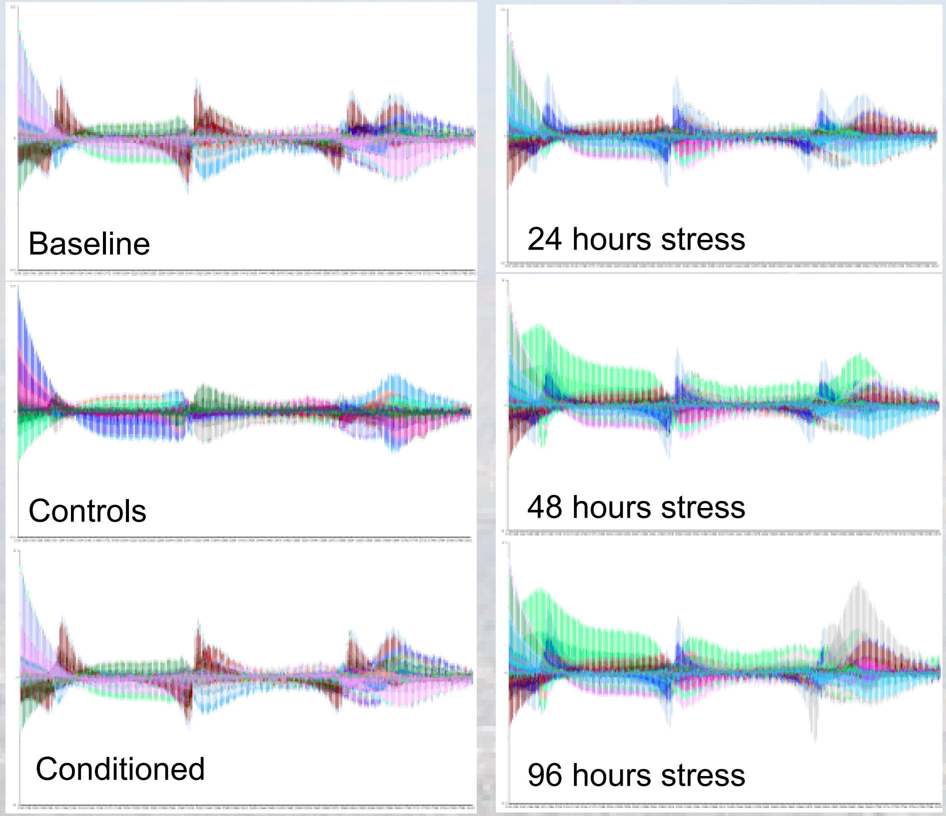
- Modeled on 271 measurements
- Tested on 271 measurements



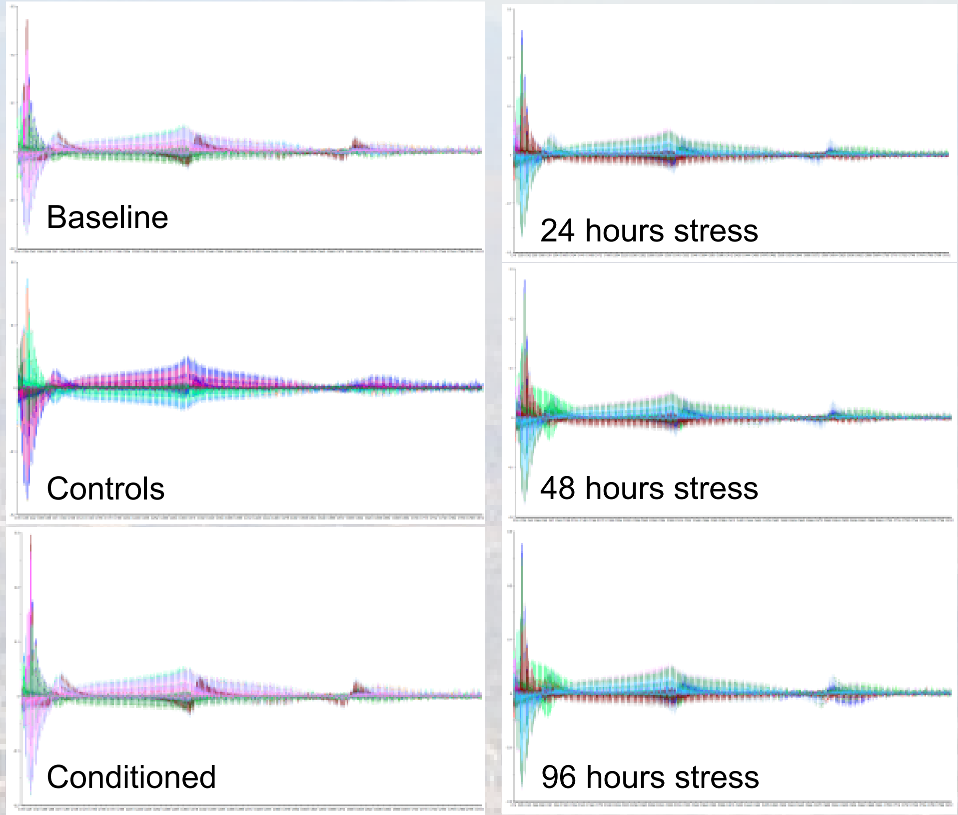
- Modeled on 163 measurements
- Tested on 163 measurements

MOSFET PSA Data

Bias 1



Bias 2

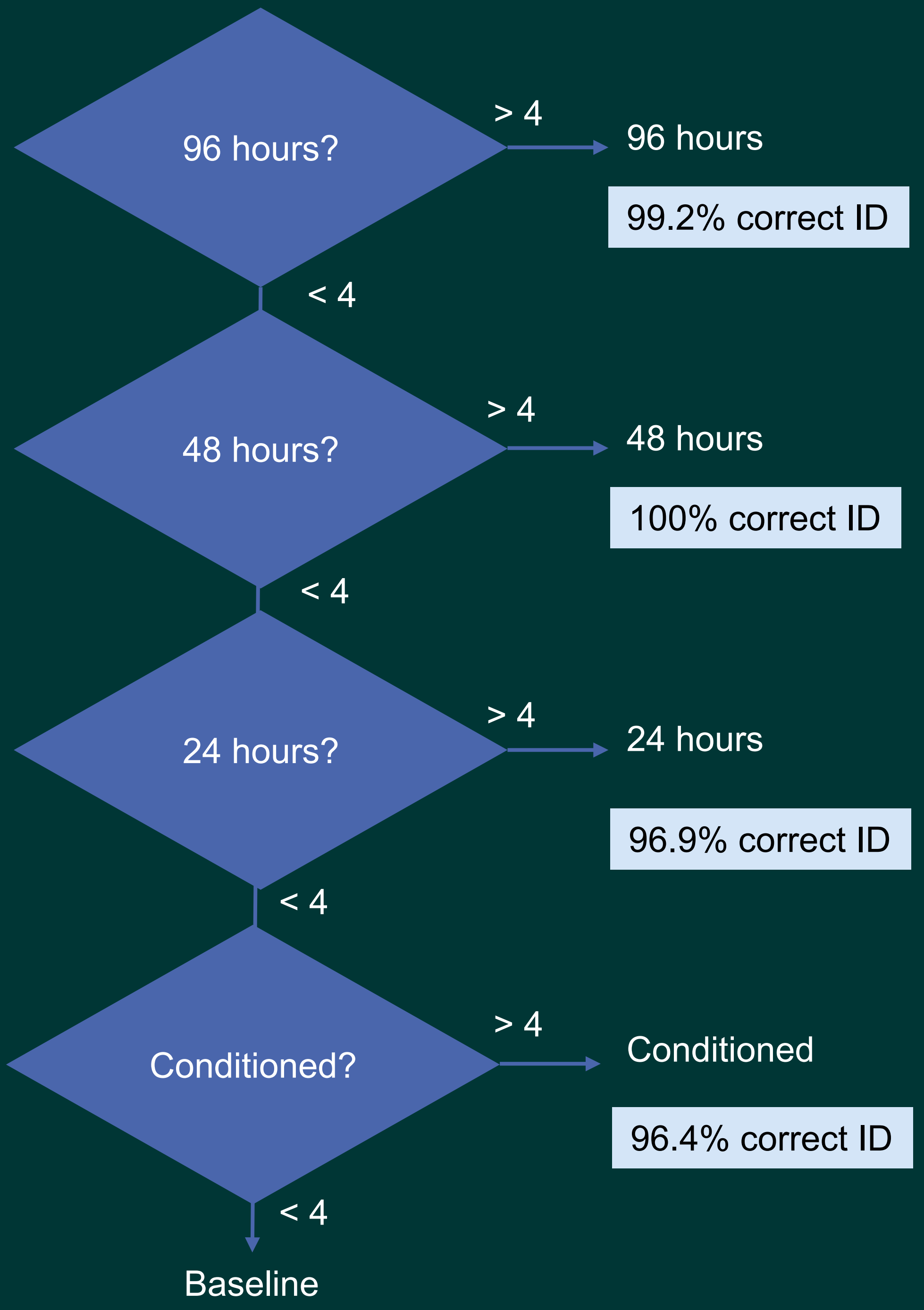


MOSFET
Bias 1 Algorithm

96.8% Correct ID

96.4% Correct ID

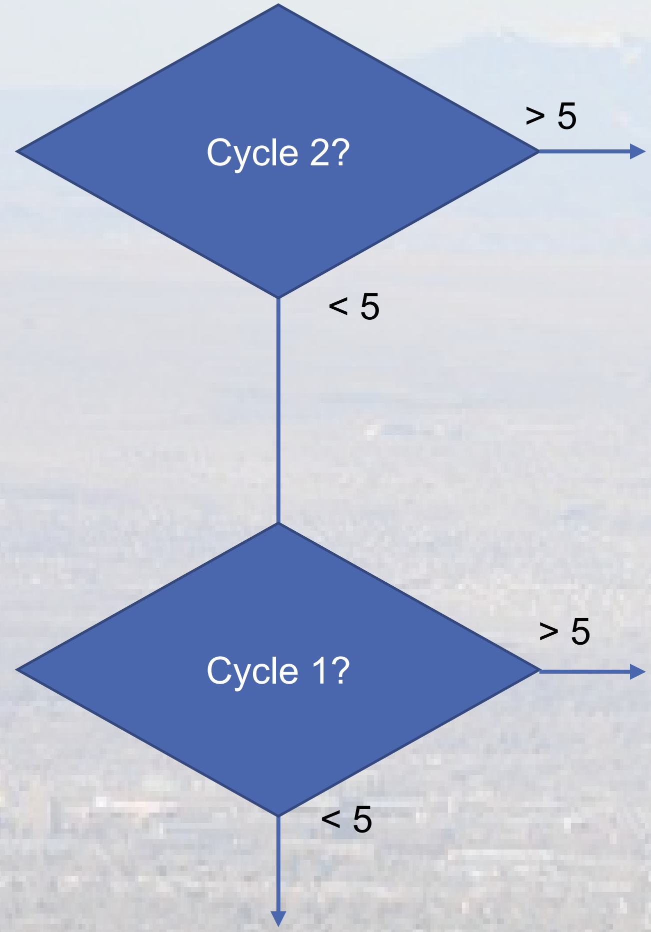
MOSFET Bias 2 Algorithm



Zener Diode
Conventional IV Algorithm

For Algorithm:
- Modeled on 111/79 measurements
- Tested on 1476 measurements

Cycle 0 – no stressing
Cycles 1 & 2 stressing at 150 °C, 65% Relative Humidity



Cycle 2

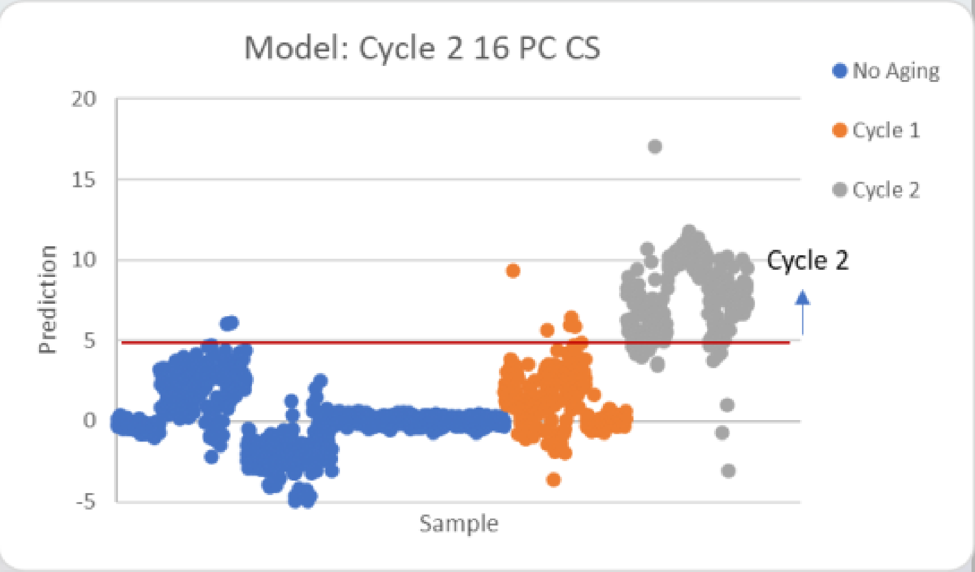
91.7% Correct ID (289/315)
8.3% mis-ID (26/315)

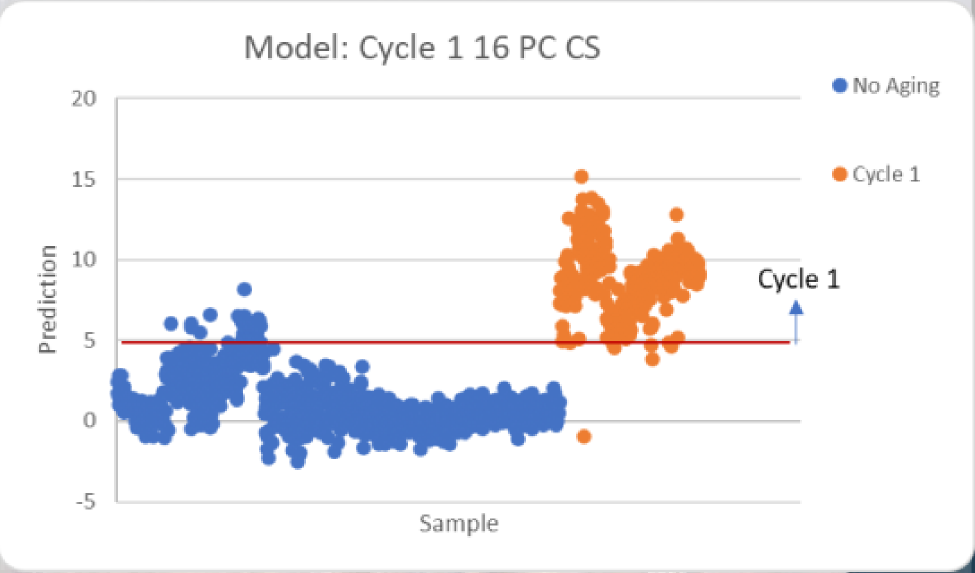
Cycle 1

96.5% Correct ID (307/318)
3.5% mis-ID (11/318)

Cycle 0

97.5% Correct ID (930/954)
2.5% mis-ID (24/954)





Conclusions & Next Steps

- Multivariate analysis of PSA data and conventional IV data can be used to create algorithms that could be automated to screen semiconductor parts for aging.
- The ability to screen semiconductor parts for aging is useful for:
  - Manufacturers using electronic parts in the systems they are making
  - Semiconductor manufacturers interested in the quality and reliability of the parts being made
  - Anyone interested in assess the age related performance of a semiconductor device
- The next steps in this research are to investigate another semiconductor components (GaN HEMT) and other kinds of data that can be included in the analysis fingerprint (ex. combine PSA and IV data into one fingerprint for analysis).

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