Sandia National Laboratories

National Nuclear Security Administration

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Power Spectrum Analysis (PSA) for Counterfeit and Aging Detection

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Validation and Failure Analysis
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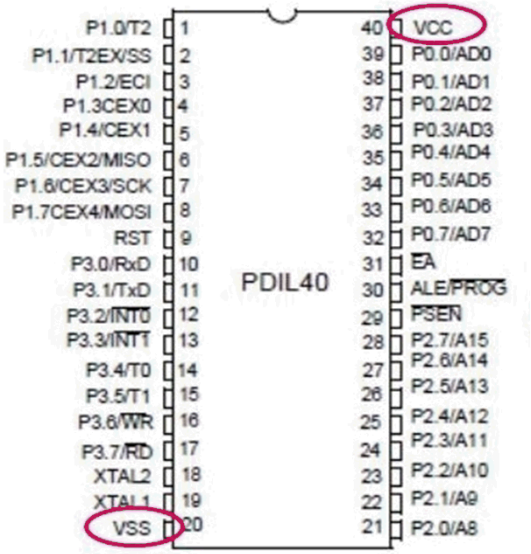
Purpose and Outline

- **Present a new non-intrusive electrical technique :**
  - **Power Spectrum Analysis (PSA)**
    - **Comparative technique**
      - **Standard or control sample**
    - **Off-normal biasing**
    - **Applied to a wide range of devices**
      - **Discrete, digital, analog, and mixed-signal devices**
- **Describe PSA applications**
  - **Counterfeit detection**
    - **Different manufacturers, different memory sizes and different date codes**
  - **Aging detection**
    - **Comparison with conventional test data**
    - **Correlation with physical analysis results**

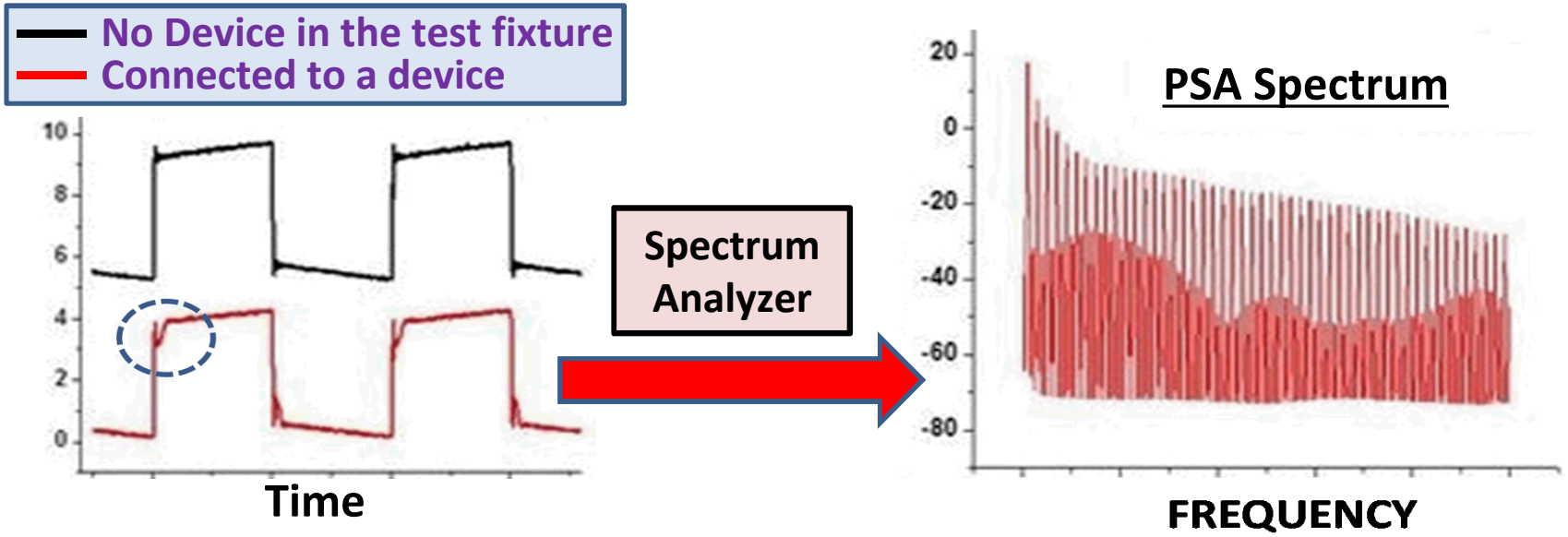
Off-normal Biasing

- Unconventional device biasing
- High difference detection sensitivity between devices
  - In many cases, not detectable with conventional testing
- Requires minimal electrical knowledge of a test device
  - Package pin layout and normal operating voltage
- Fast acquisition times (< 15 seconds)
- Pulse device with a periodic-waveform voltage
  - Sine, square, chirp
  - Stable frequency-domain signatures (PSA spectra)
  - Frequencies : 1 kHz to 1 MHz

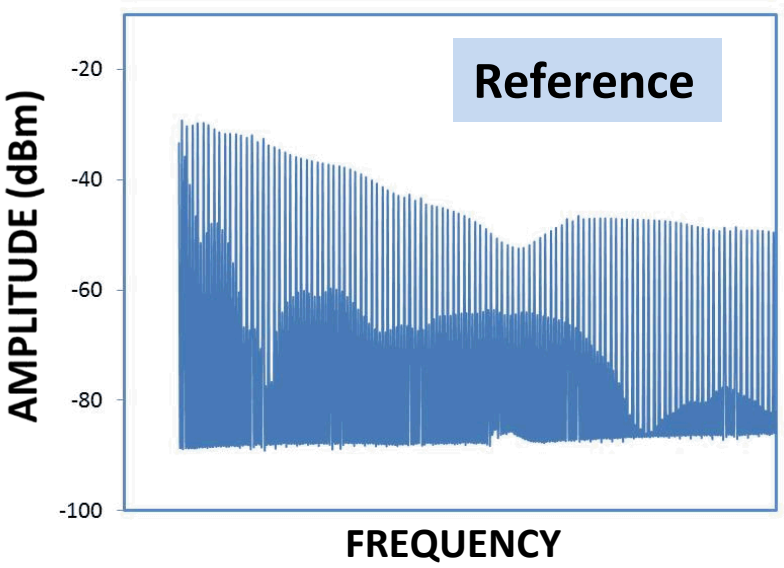
Example of Off-normal Biasing: Microcontroller

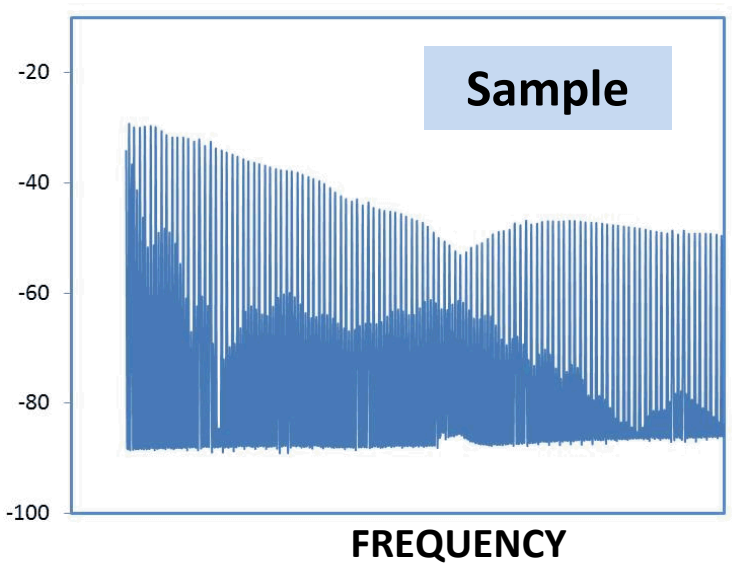


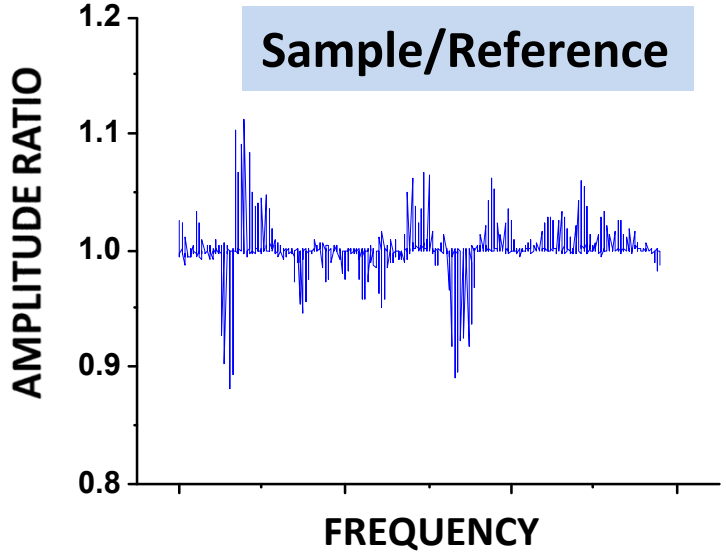
- Pulse device with a square-wave voltage
  - Between V_{CC} and V_{SS}
  - All other pins floating
  - Pulse amplitude : 0 to 4.5 V
  - Below the normal operating voltage of 5 V
- A slight distortion in the voltage waveform
  - When connected to the device
  - Distinct signatures in frequency-domain PSA spectrum (measured by a spectrum analyzer)



Normalized PSA Spectrum (Ratio Plot)



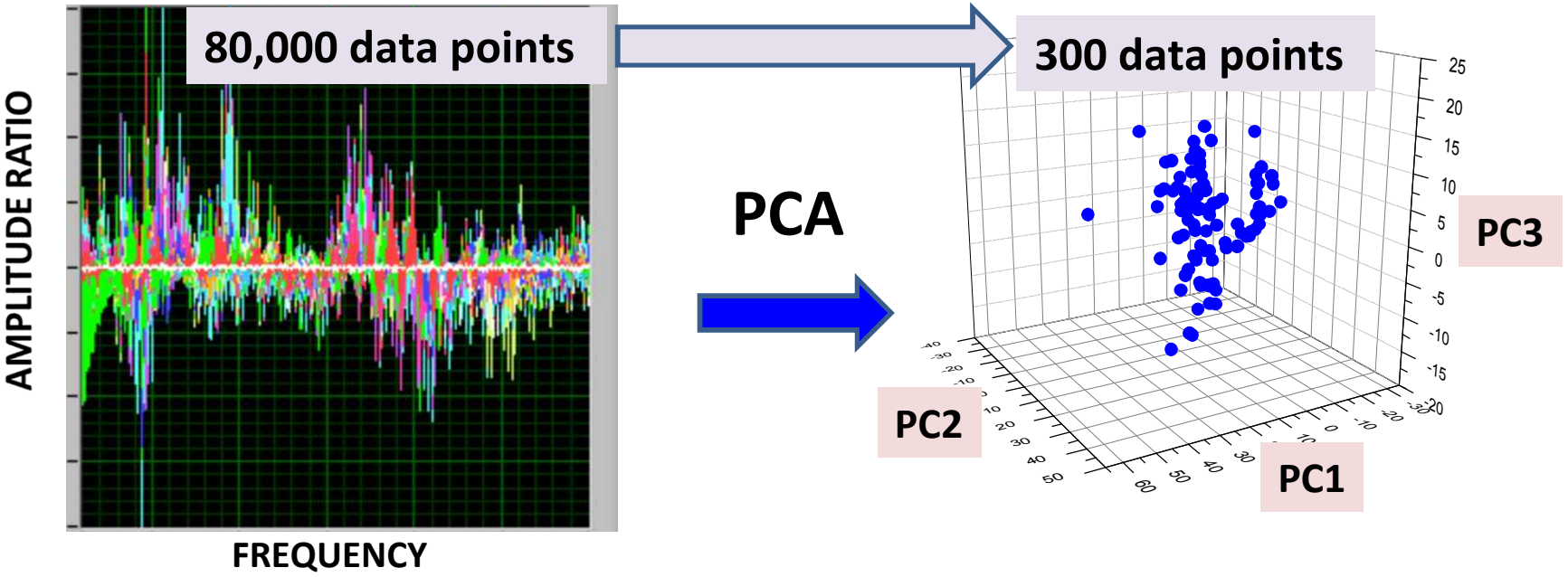




- Normalized spectra highlight differences
- Minimizes experimental variation effects
  - Allows comparison of data taken at different times

Principal Component Analysis (PCA)

- Statistical method of reorganizing information
  - A well-known technique used in spectroscopy
  - Find new variables, Principal Components (PCs)
  - Account for variability with a few Principal Components (PC1, PC2, PC3)
  - Facilitates visualization of variability in 3-D plots



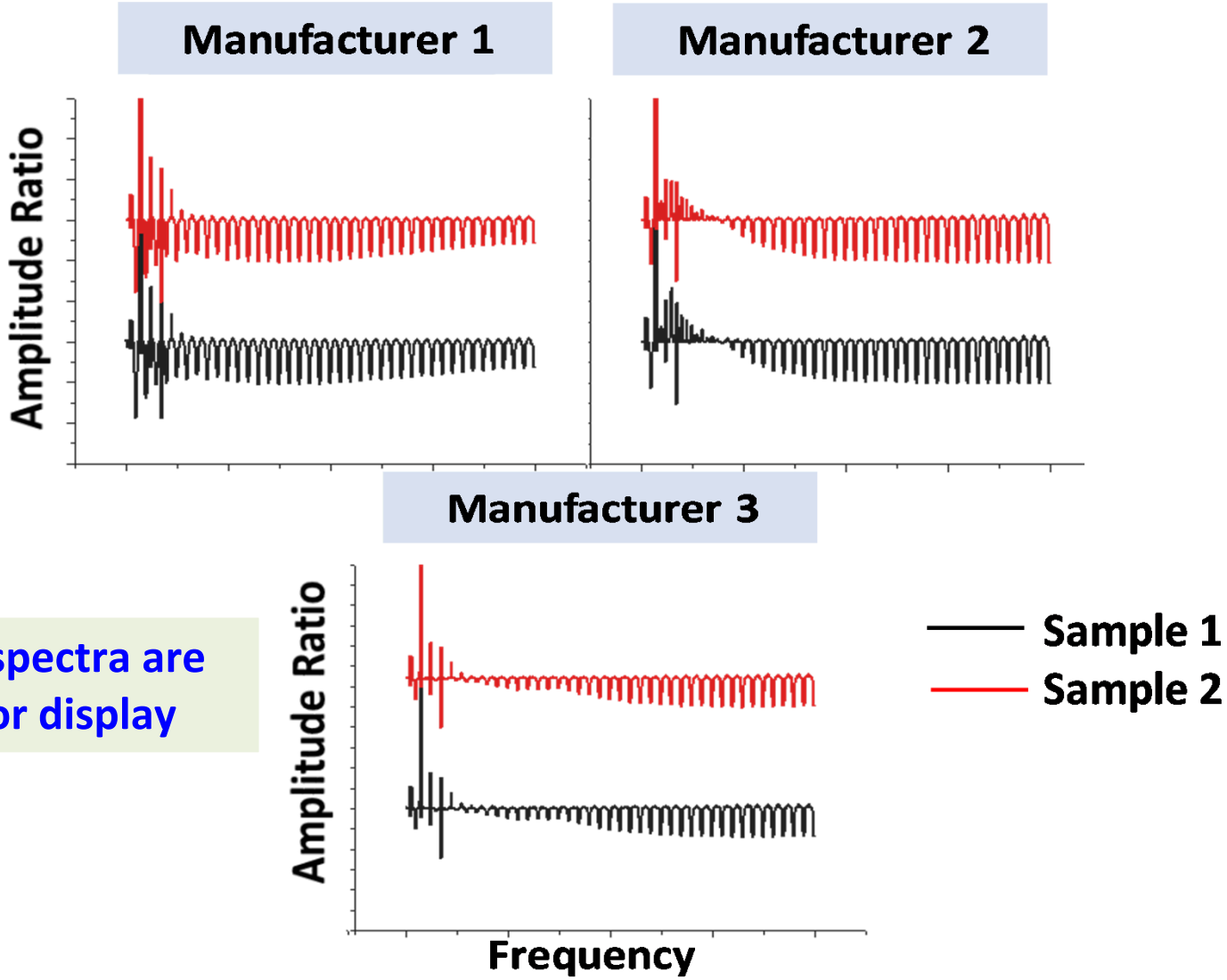
- Spectra from 100 samples superimposed
- 800 points (frequencies)/spectrum
- 80,000 data points total

- Each PC a linear frequency combination
- Each frequency weighted differently

Differences in Manufacturers (1)

Normalized PSA Spectra: LF351 Operational Amplifiers

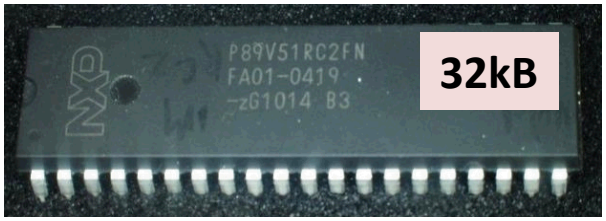
Normalized to the experimental setup (no device in the fixture)

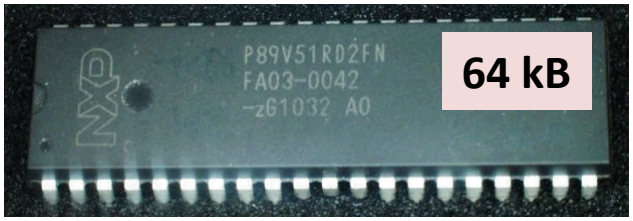


The PSA spectra are offset for display

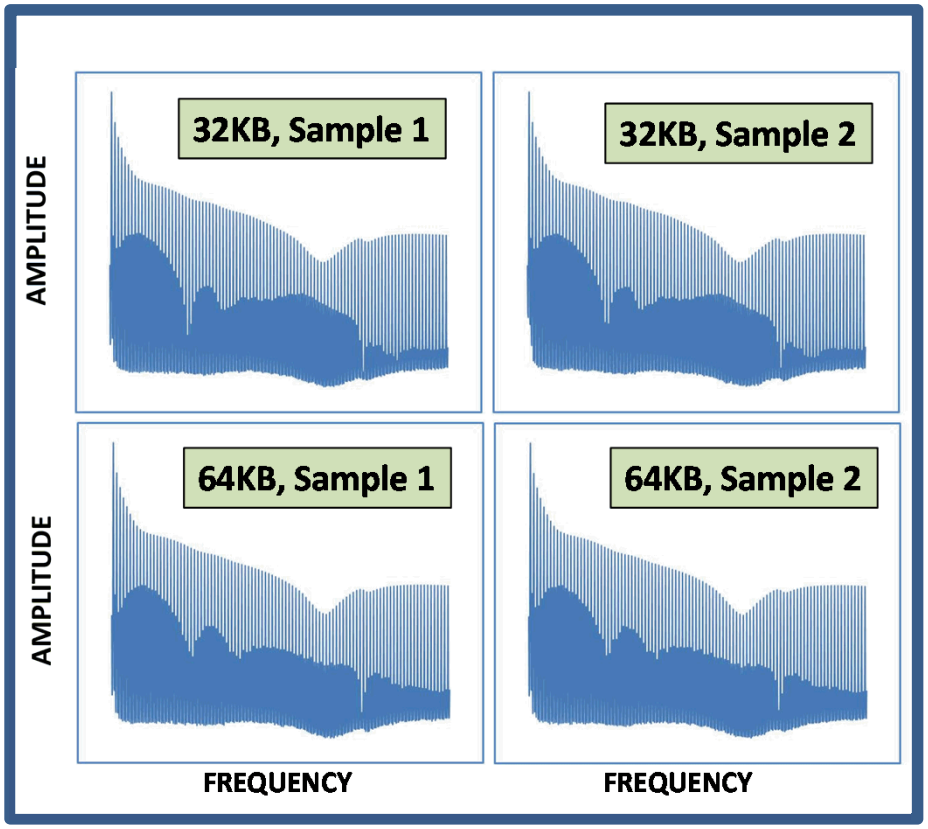
Different Memory Sizes

PSA Spectra: NXP Microcontrollers

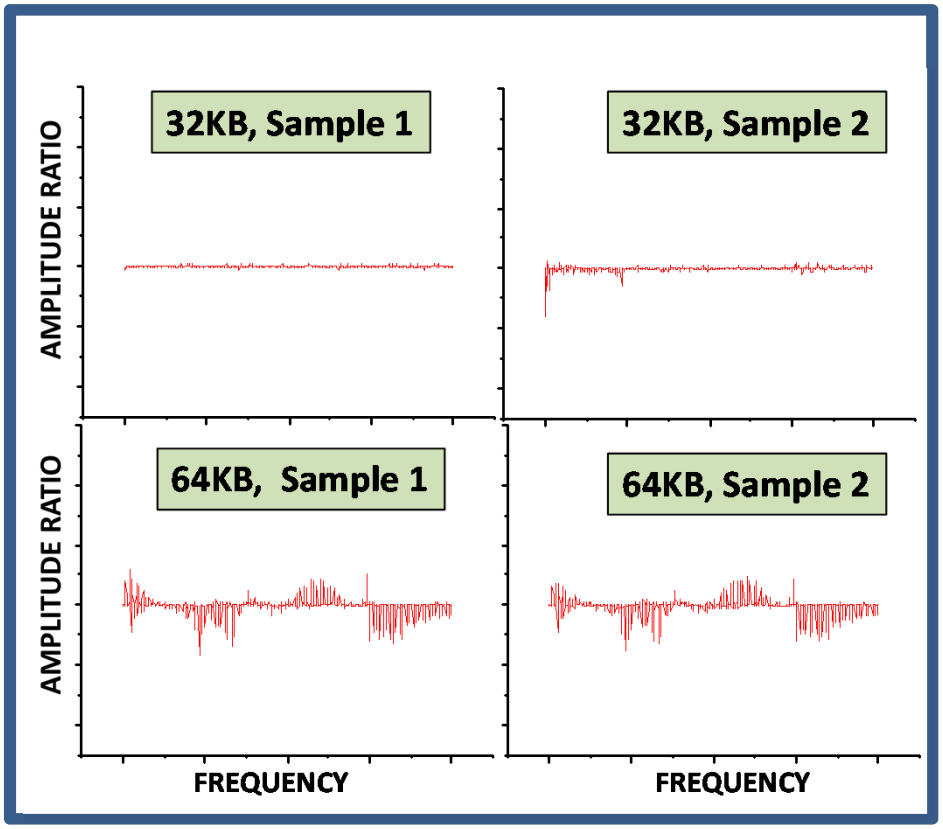




Raw PSA spectra

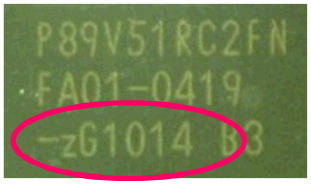


Normalized to the 32 kB sample 1

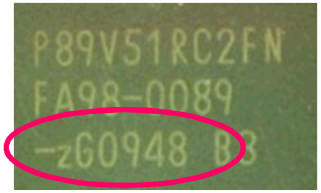


Different Date Codes

PSA Spectra: NXP 32 kB Microcontrollers

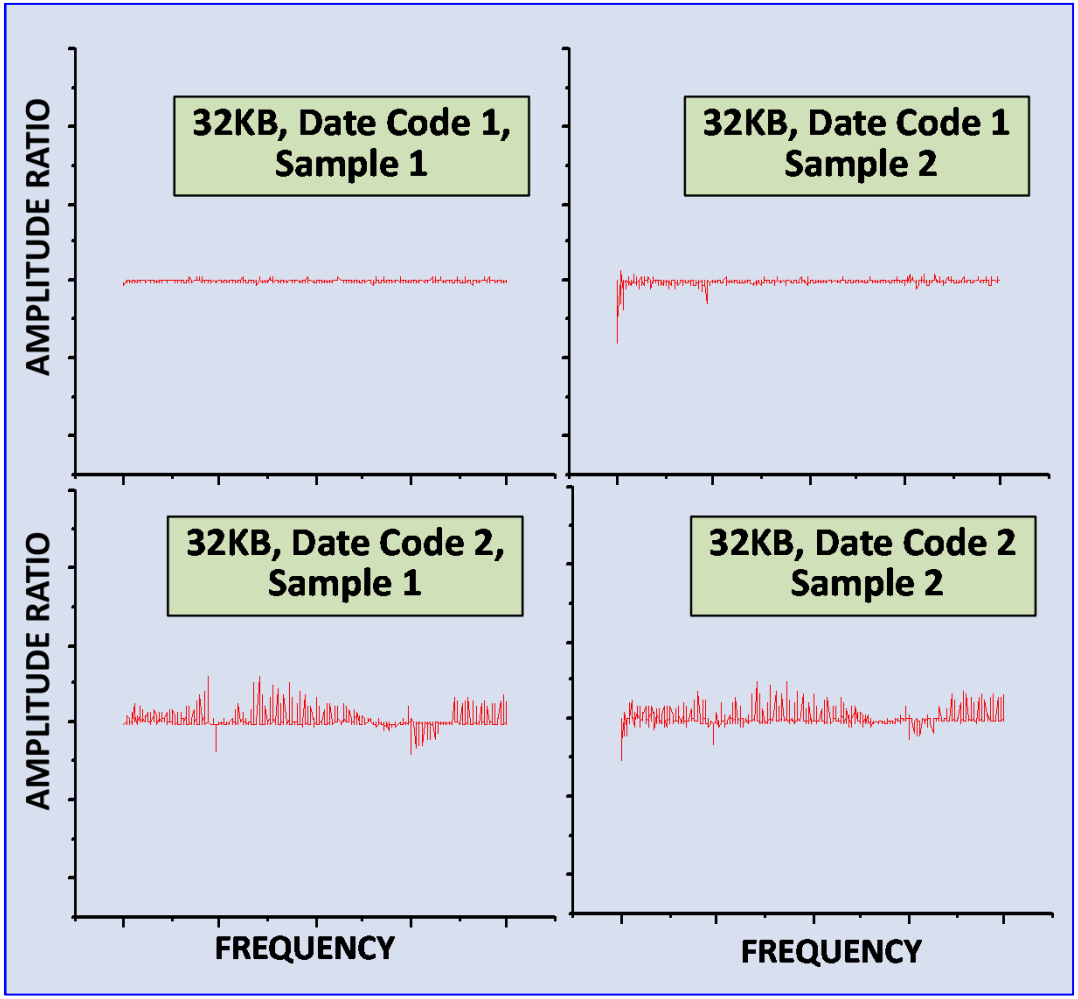


2010, Week 14



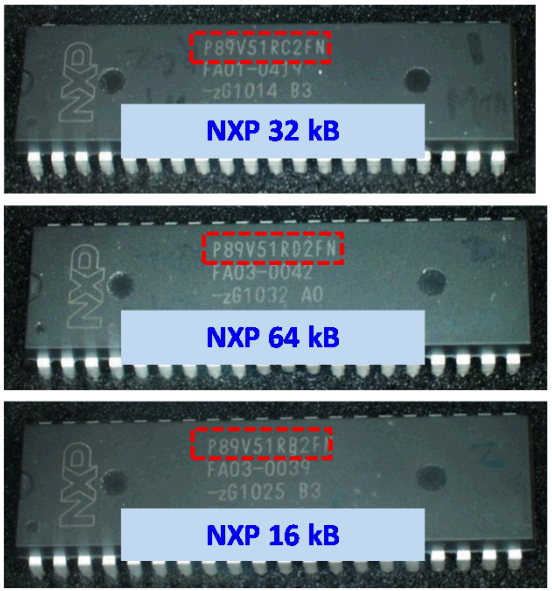
2009, Week 48

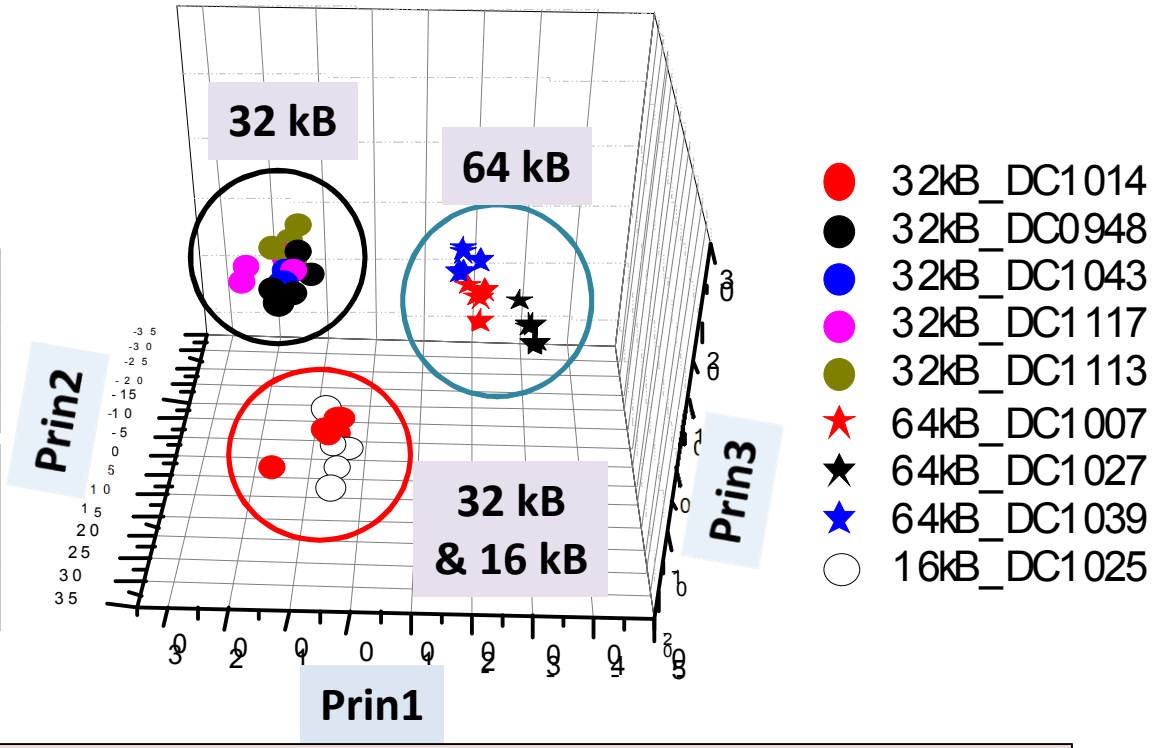
Normalized to the
32 kB, Date code1, sample 1



Different Memory Sizes and Date Codes

NXP Microcontroller PCA Analysis





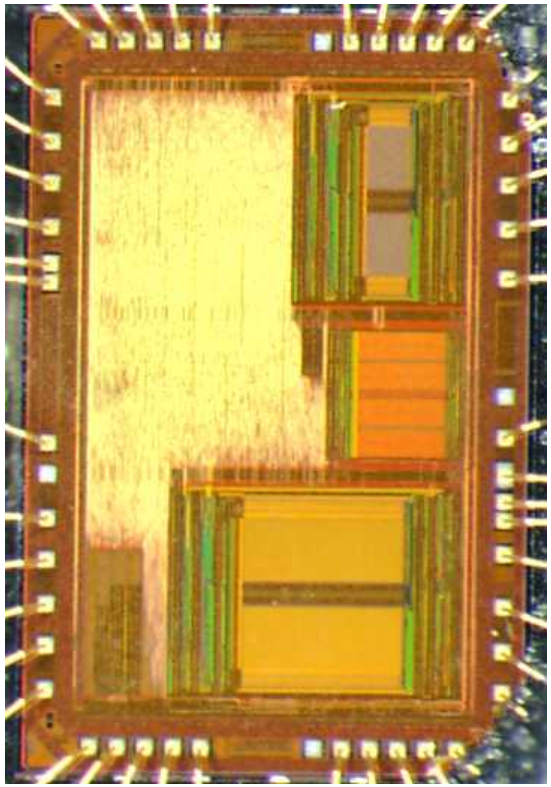
- 32 kB samples show a bi-modal distribution with samples from date code 1014 appearing in a separate cluster
- 16 kB samples lie in the same cluster as 32 kB samples with date code 1014

Different Memory Size (32 kB versus 16 kB)

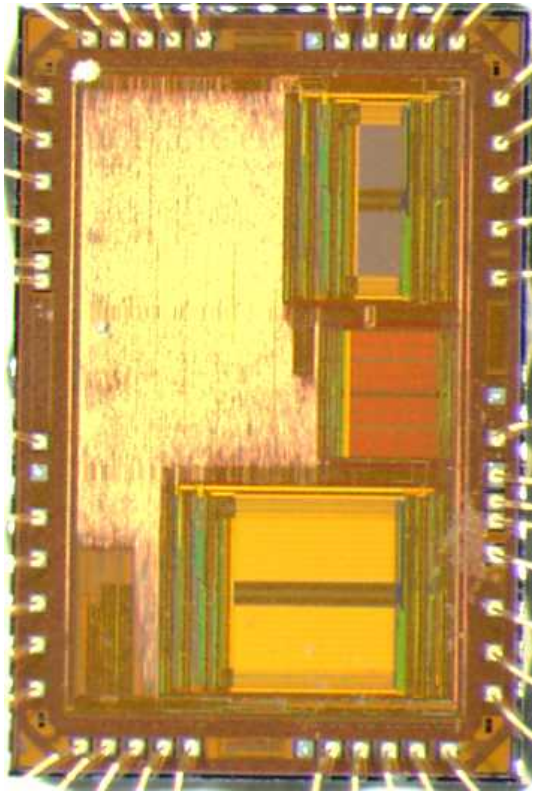
Optical Images of NXP Microcontrollers

- Same die type used for 32 kB and 16 kB
- Devices have different ID codes
- 16 kB devices can be used as 32 kB devices by ignoring the ID code

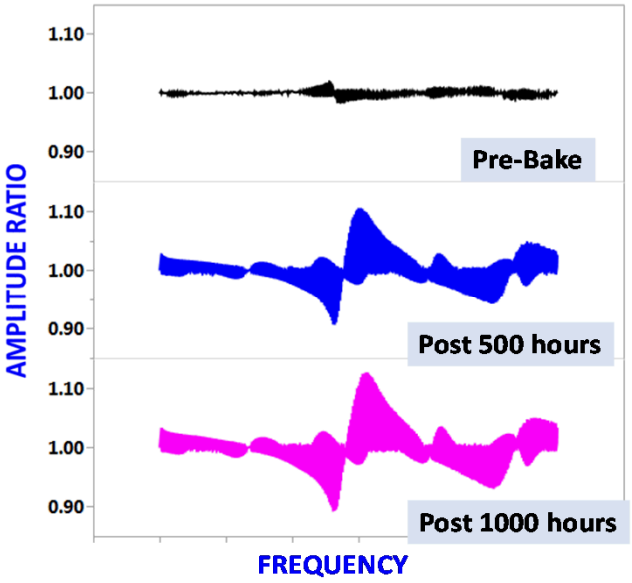
32 kB memory

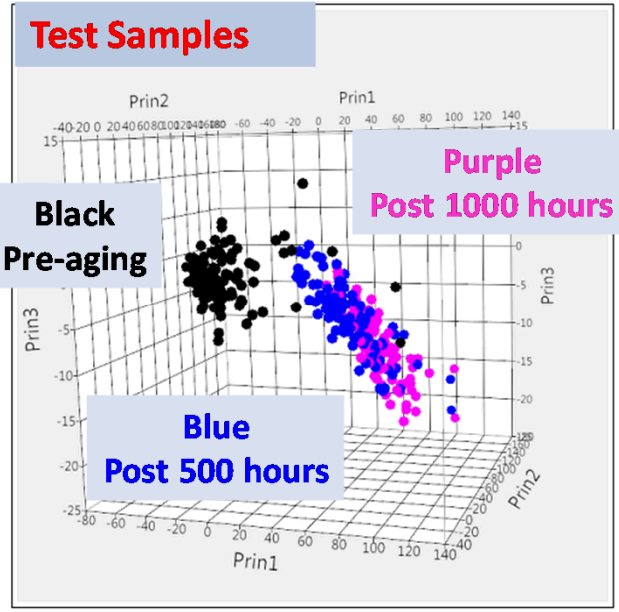


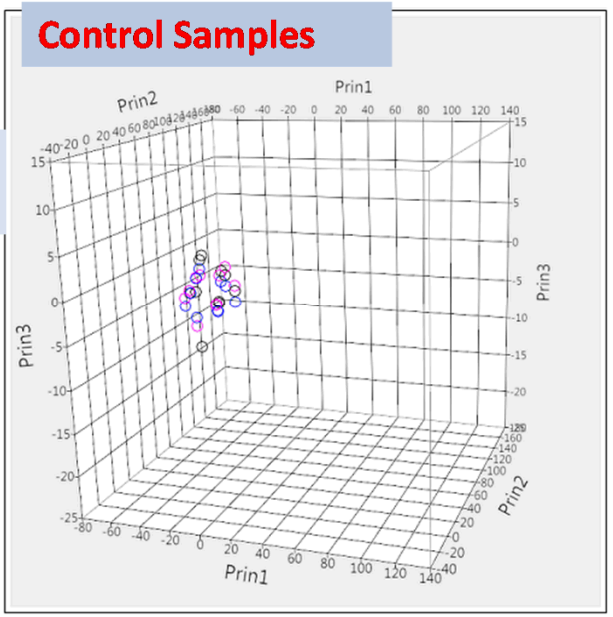
16 kB memory



Aging Effects : Zener Diodes
Normalized PSA Spectra and PCA Distributions
Before and After Aging





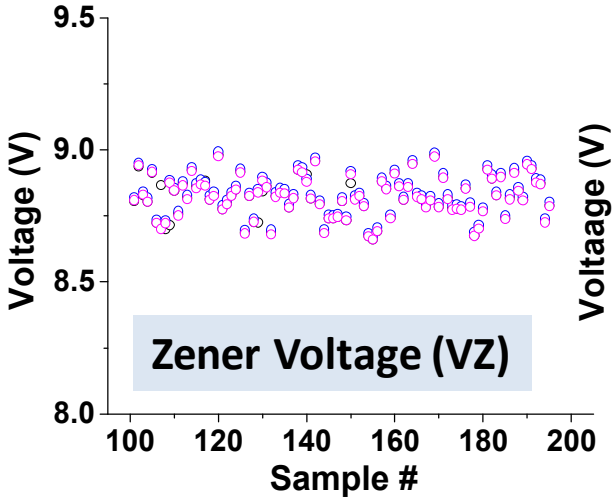


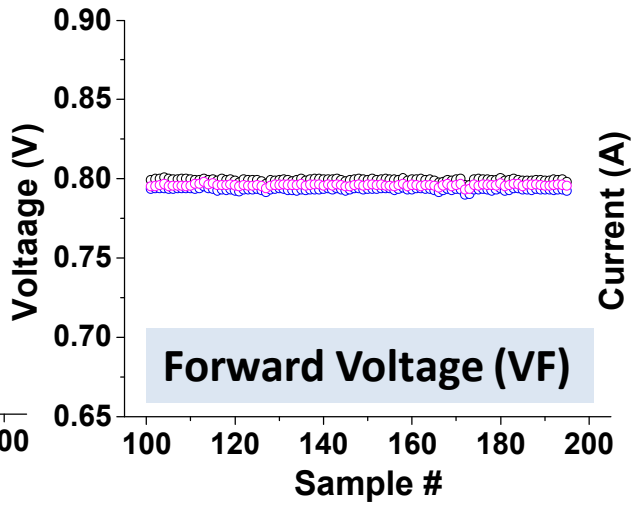
Black: Pre_Aging
Blue : Post 500 hours
Purple : Post 1000 hours
Filled Circles : Test Samples
Open Circles : Control Samples

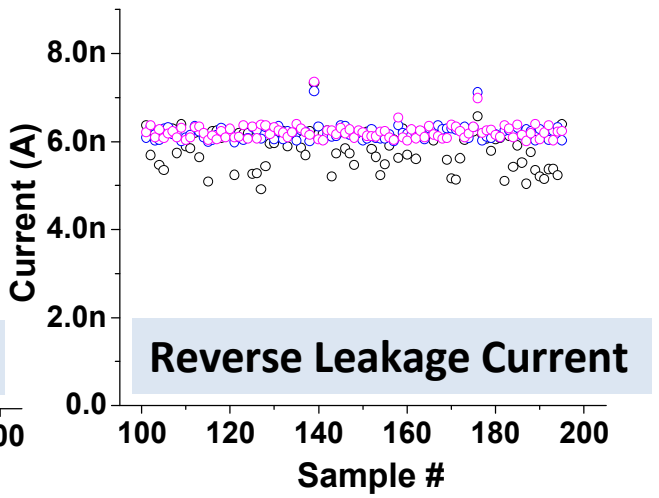
- Control samples not aged
- PSA spectra taken concurrently with the test samples before and after aging
- Demonstrates PSA system stability

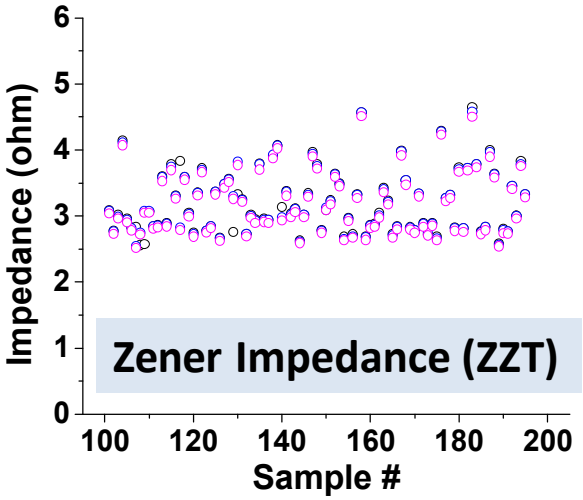
Zener Diode Electrical Test Data Before and After Aging

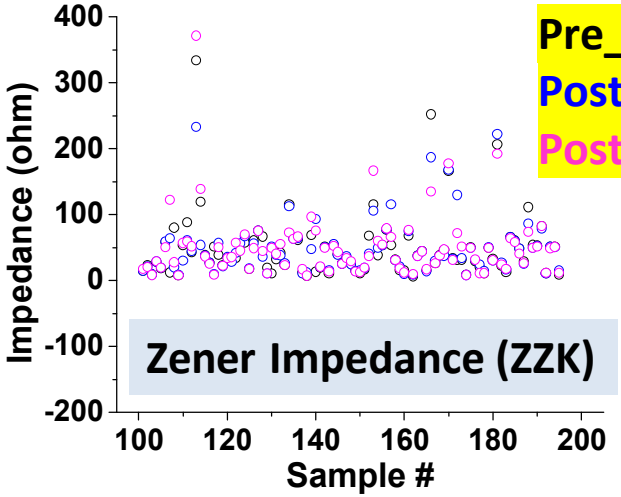
Essentially No Differences Observed







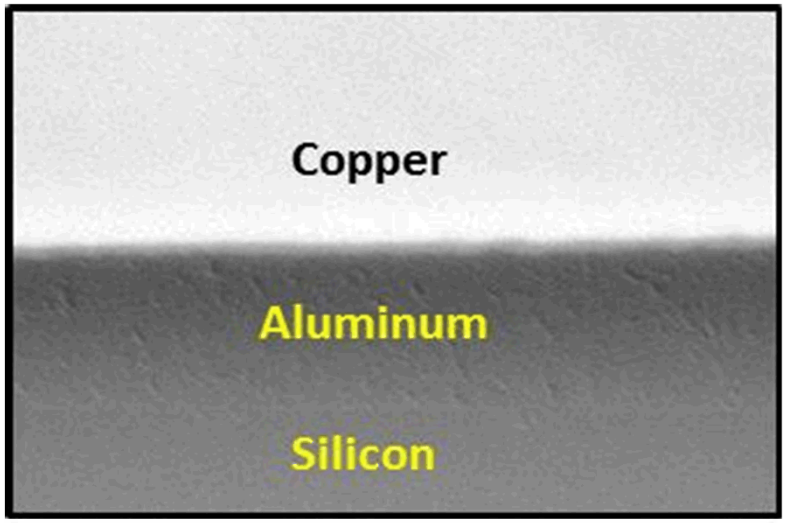




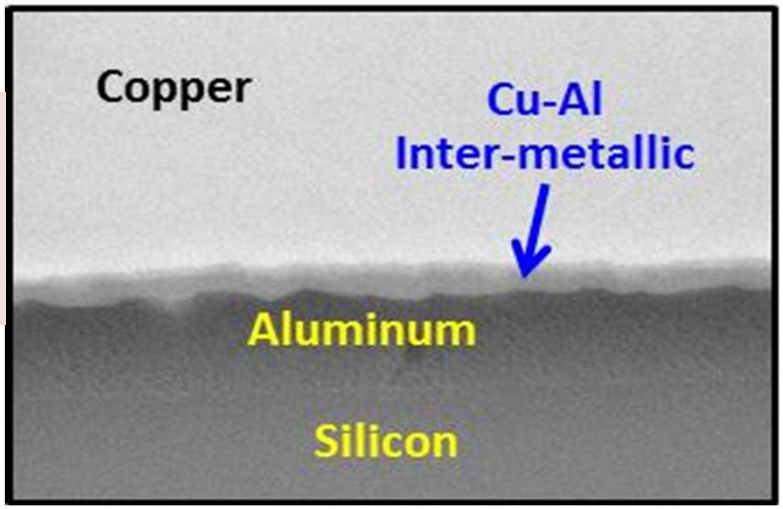
Pre_Aging (black)
Post 500 hours (blue)
Post 1000 hours (pink)

SEM Cross Sections of Bond-pad Areas
Zener Diodes

Growth of a Cu-Al Inter-metallic Layer at the bond pad after aging



Unaged



Post 1000-hour Bake

Good Correlation between PSA and physical analysis results

Summary

- PSA identifies subtle device differences
  - Not detectable with conventional testing in many cases
- PSA uses off-normal biasing
  - Requires minimal test device electrical knowledge
  - Fast acquisition times (< 15 sec)
- Applications related to counterfeit and aging detection presented
- Correlated PSA data with physical analysis results in Zener diodes