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At-Speed Defect Localization by Combining Laser Scanning Microscopy and Power Spectrum Analysis

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Purpose

- Describe a new method for localizing at-speed defects
- Combine local thermal stimulation and Power Spectrum Analysis (PSA)
  - Leverages PSA sensitivity and frequency selection
- Big data, high-speed problem into a DC signature

Outline

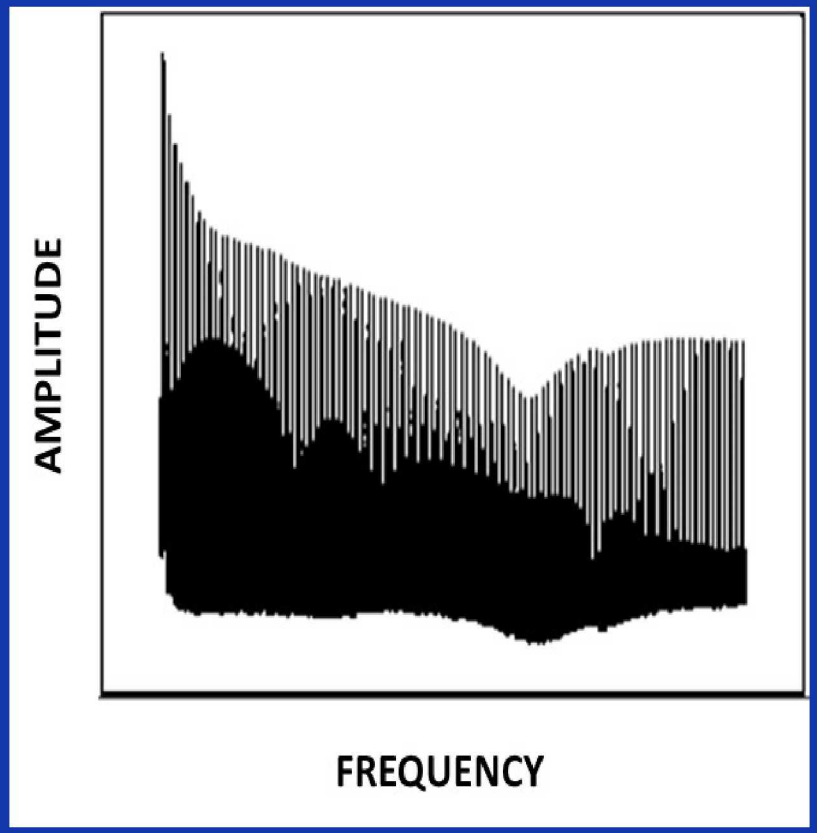
- Motivation for development
- Failure description and experimental approach
- Imaging results
- Conclusions

Need for a New Method

- At-speed defect localization is difficult
  - Simultaneous GHz operation and detection
- SDL (Soft Defect Localization) and LADA (Laser-Assisted Defect Analysis) effective
  - Pass/fail detection can be difficult at speed
- General detection method has inherent advantages
- Need for detection scheme encountered on a particular functional failure
  - Heat sensitive, intermittent failure
    - Real-time pass/fail detection difficult
  - PSA an attractive alternative to existing FA methods

PSA (Power Spectrum Analysis)

- Displays device frequency components under dynamic stimulus
  - Can be a very complex tapestry
- Leverages advancements in spectrum analyzers
- Extremely sensitive to changes in target sample properties
  - Highlighted by normalization
- Multiple applications
  - Counterfeit detection, attribution, aging, defect detection, etc.[1]



Example PSA spectrum

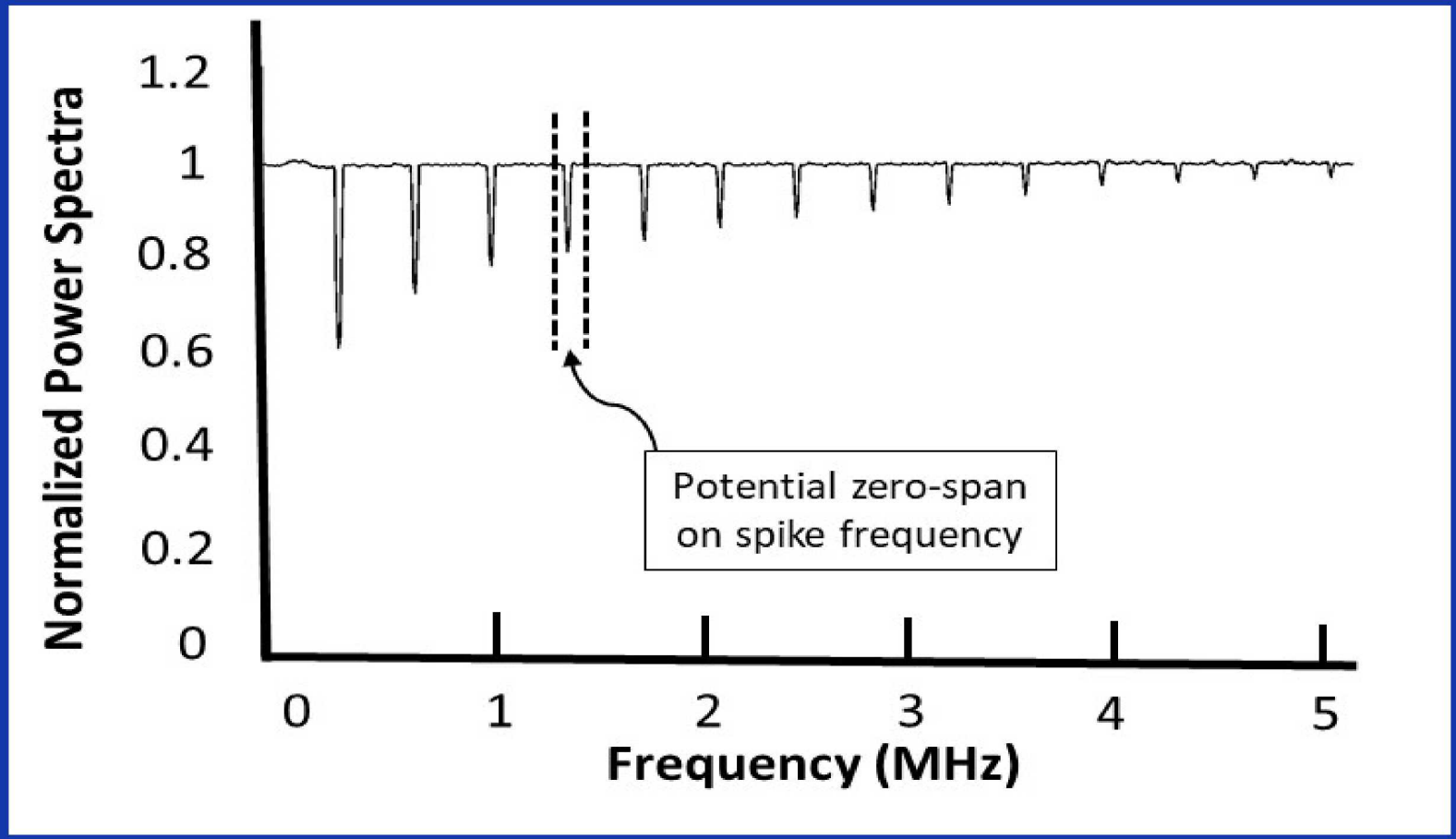
1. P. Tangyunyong, E.I. Cole, Jr., G.M. Loubriel, J. Beutler, D.M. Udoni, B.S. Paskaleva, and T.E. Buchheit, "Power Spectrum Analysis (PSA)," in *Proc. From the 43rd International Symposium for Testing and Failure Analysis*, 2017, pp. 73-78.

PSA and Local Laser Stimulus

- Failure condition has a unique PSA signature
  - Normalization emphasized difference spikes with heating
- Individual frequency(ies) isolated and “zero-spanned”
  - Zero-spanning: power only at a given frequency
- Zero-span power used to modulate image contrast
- PSA power amplitude map formed with local laser scanning
  - Similar to SDL/LADA/LIVA, etc.
  - At-speed digital pass/fail detection ***NOT*** required

Normalized PSA Spectrum

- Normalized data highlights differences in conditions
- Zero-spanning of power at a given frequency only

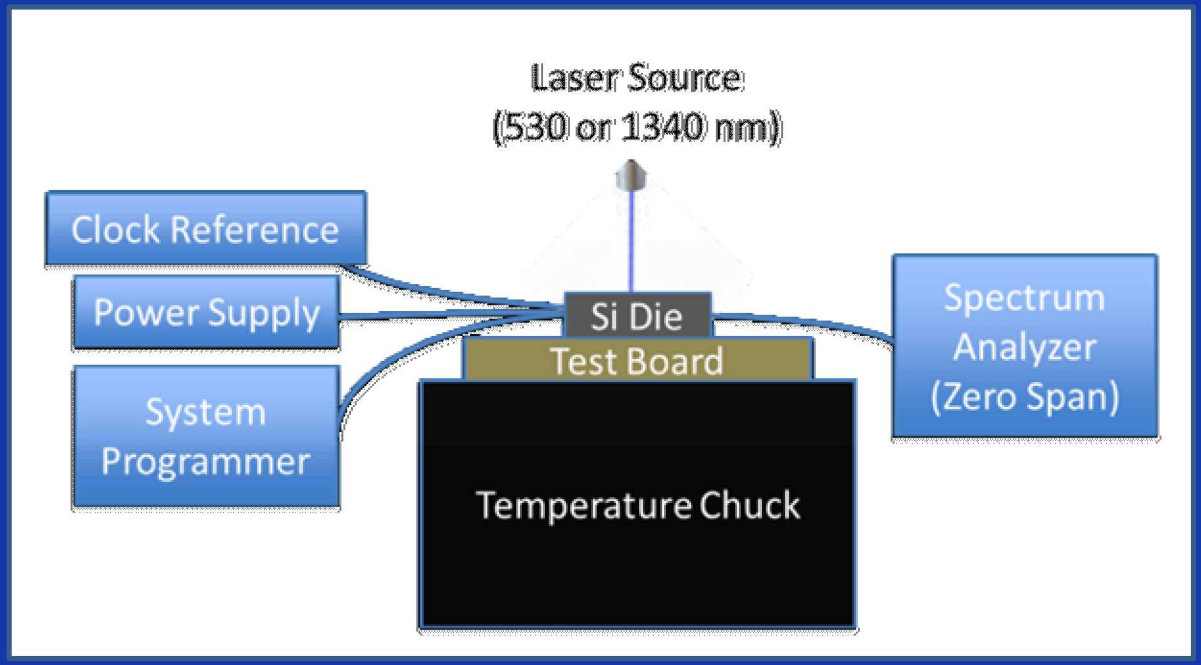


Failure Description and FA Approach

- Si PLL (phase-locked loop) missed counts at elevated temp
  - Well within operating specs
  - Multiple devices displayed failure
- No LIVA/TIVA faults detected, although multiple signals appeared in maps
- SDL considered
  - Pass/fail instrumentation difficulties
- PSA spectra collected during PLL counting
  - Observed different signatures under passing and failing conditions
  - Zero-spanned on a pass/fail frequency
  - Analog output of spectrum analyzer utilized

Failure Description and FA Approach

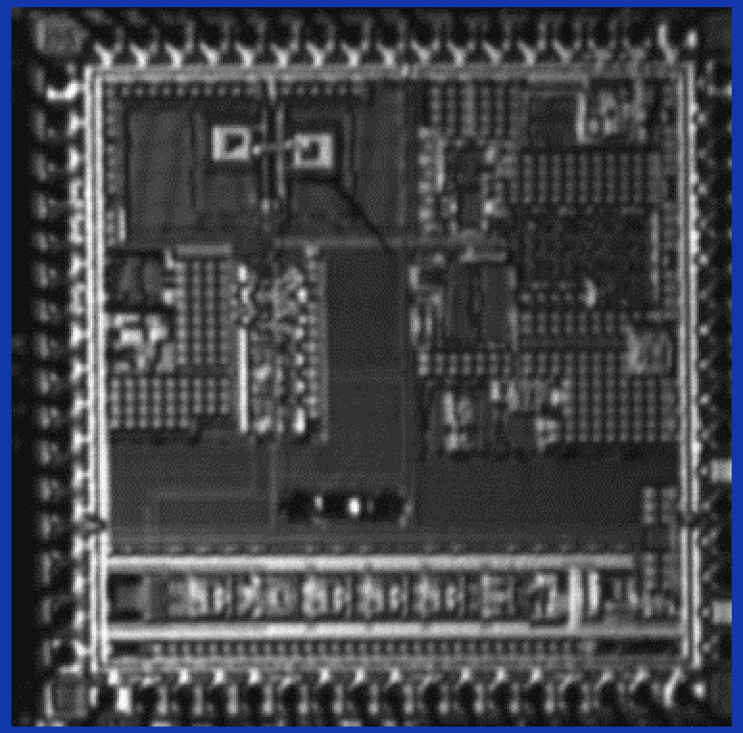
- Device powered and heated to just below failure (44.8°C)
- Zero-spanning on a specific frequency generates F_i power amplitude maps
  - Acquired in 1-2 minutes with averaging
  - Laser stimulus at wavelengths above and below Si indirect bandgap



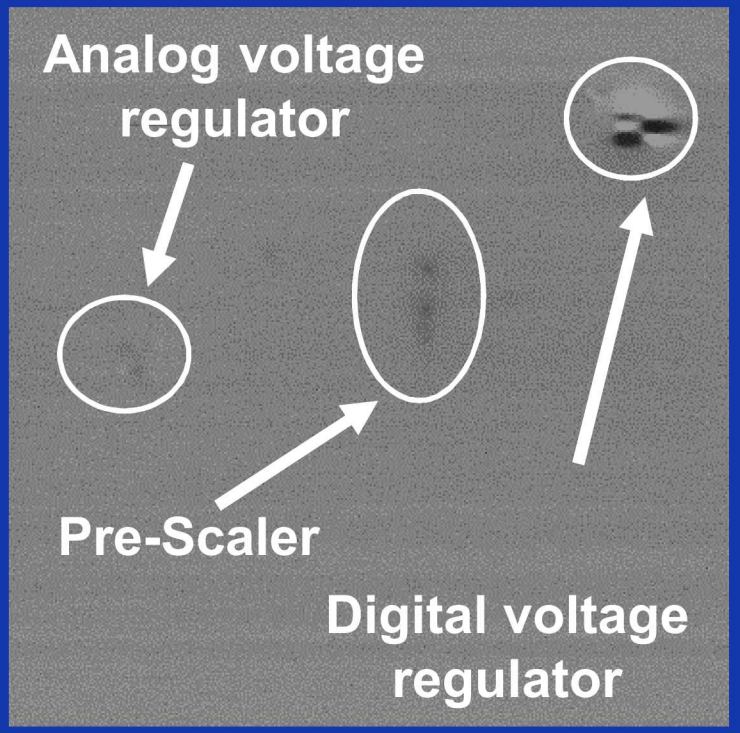
Experimental Results

***F_0 Amplitude Map*:**
Image contrast generated at frequency F_0

- **Identified by PSA with global heating**
- **1340 nm used for local heating**
- **Dark contrast indicated increased failure**
  - **Lower F_0 peak power**



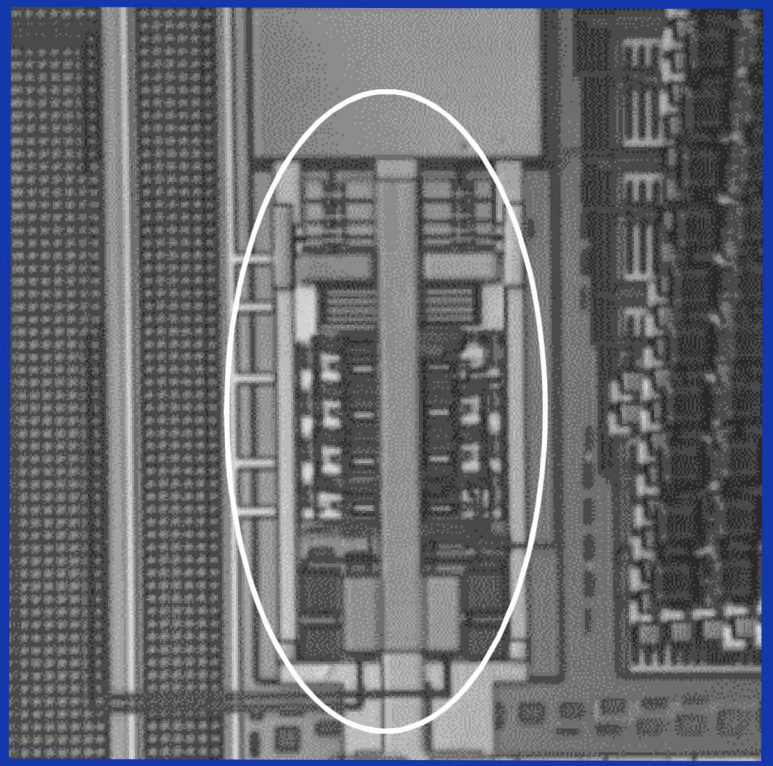
1340 nm Reflected Light Image



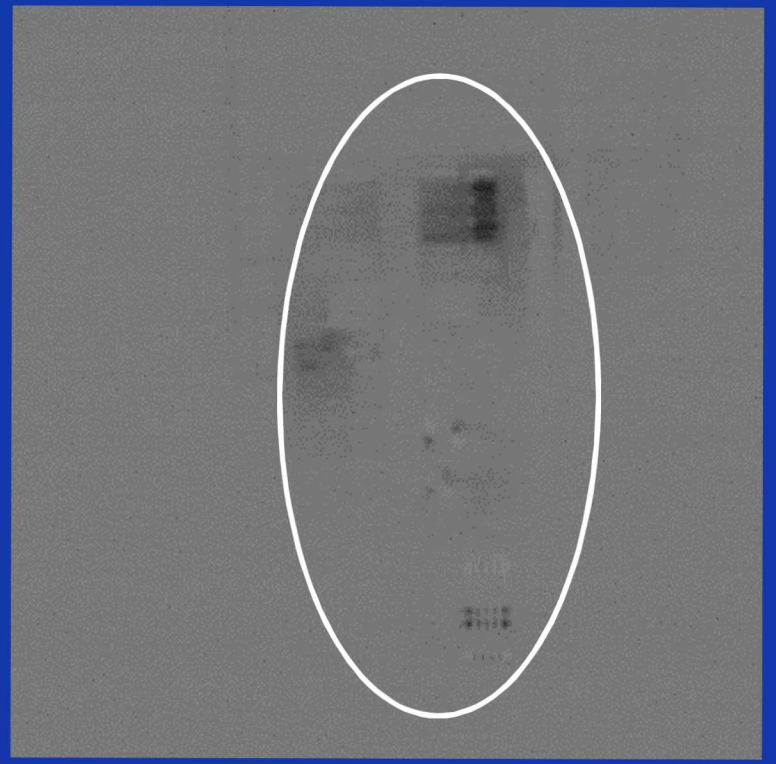
F_0 Amplitude Map

Pre-Scaler Area

- Imbalance between sides not expected
  - Should be matched pairs
  - Not clear if symptom or cause
- Regulator signals not of interest
  - Expected variations with exposure



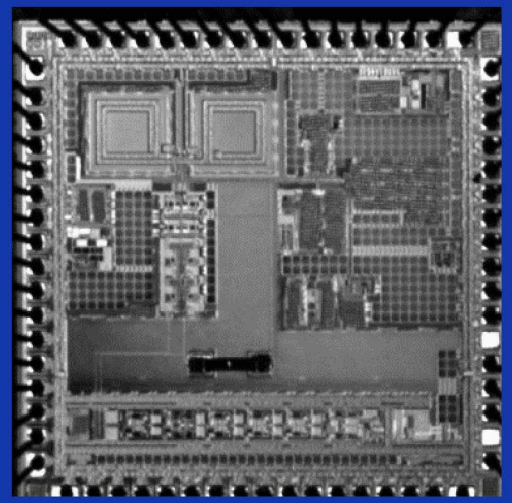
1340 nm
Reflected Light Image

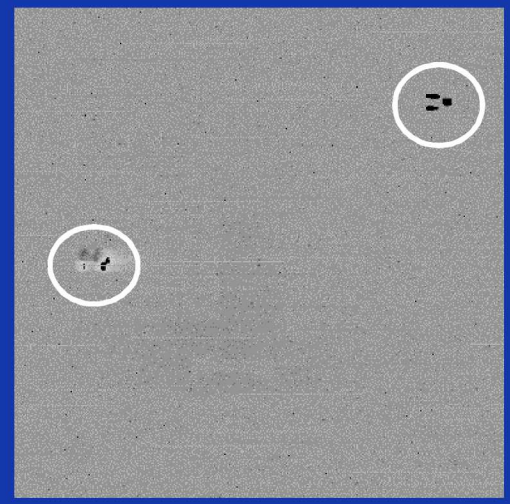


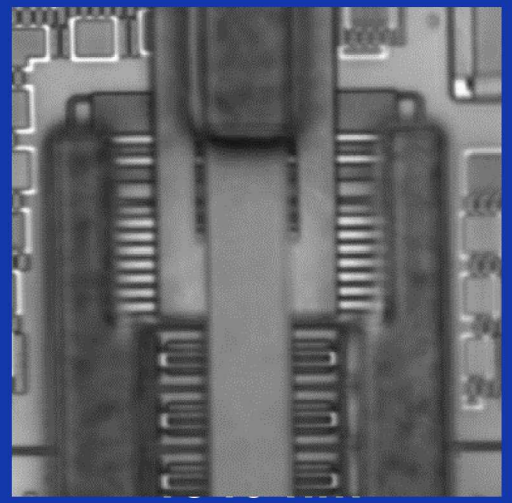
F_0 Amplitude Map

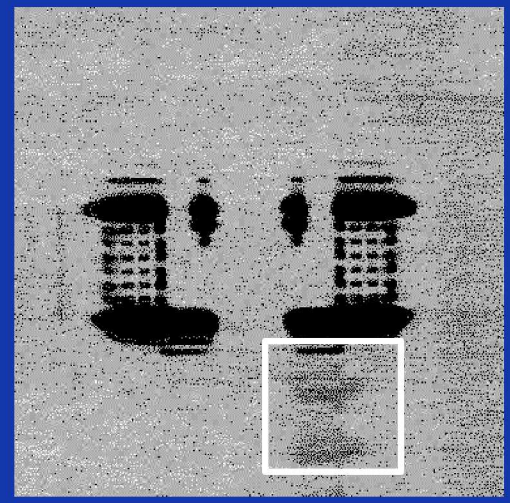
F_0 Amplitude Image at 532 nm

- Only regulators seen
- Higher mag of analog regulator shows varactor
  - Photocurrents dominate
  - Weak signal from heating?
  - Consistent asymmetry
    - Not failure cause









Reflected Light Images

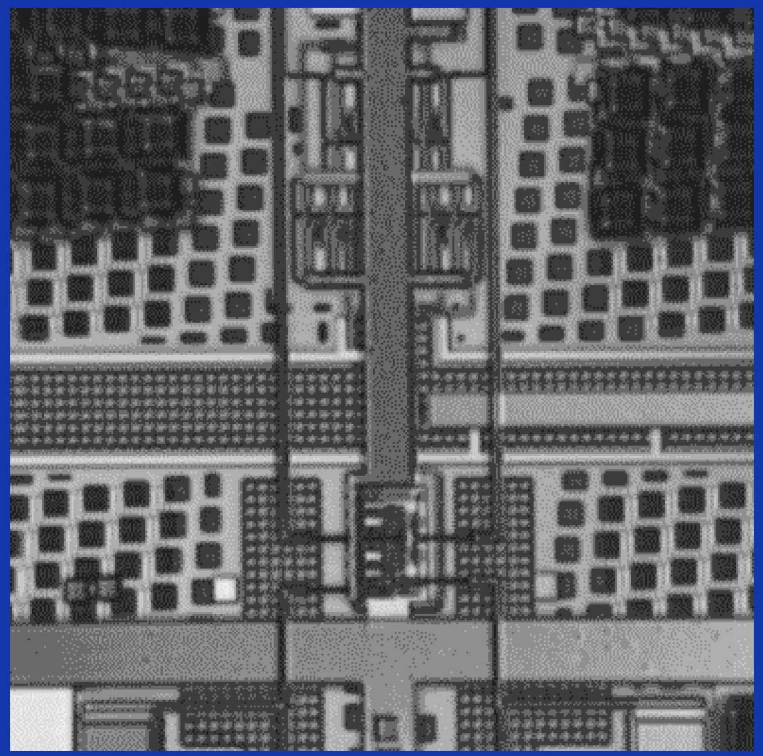
F_0 Amplitude Maps

Moving to a Different PSA Frequency

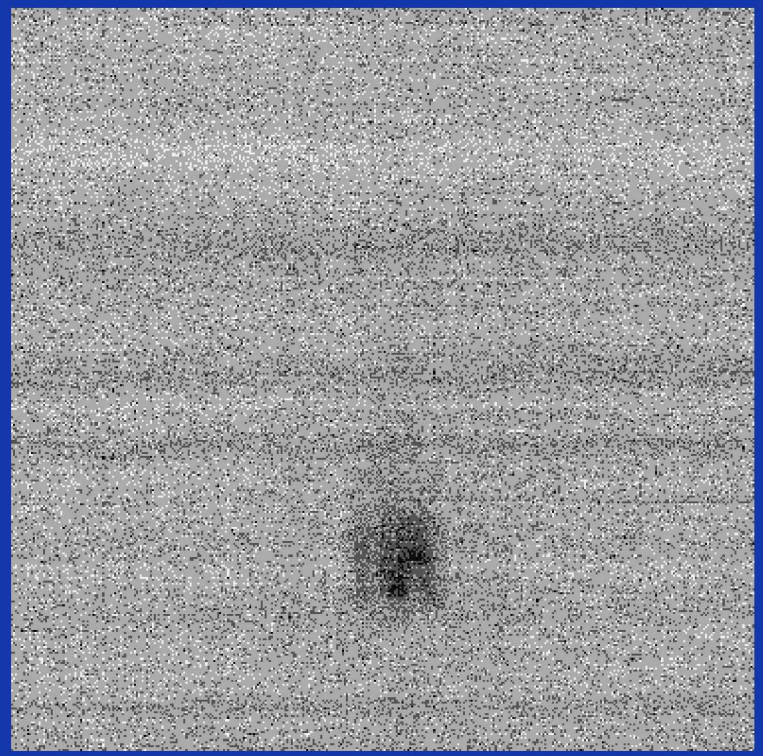
- Initial F_0 selected from global heating
- Refined frequencies determined by local heating
  - Laser spotted in F_0 amplitude maps
  - New spectra collected and new zero-spanned frequencies identified
  - Zero-spanned images collected at the identified frequency, F_1
- Goal to identify/differentiate global and local heating effects

F_1 Amplitude Map Identified Divide-by-2 Counter

- **Potential failure source**
  - Not seen in F_0 amplitude maps



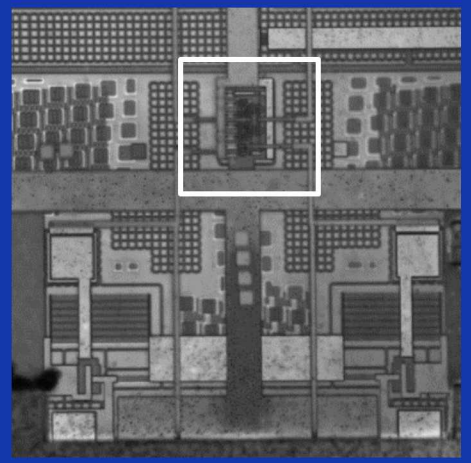
1340 nm Reflected Image

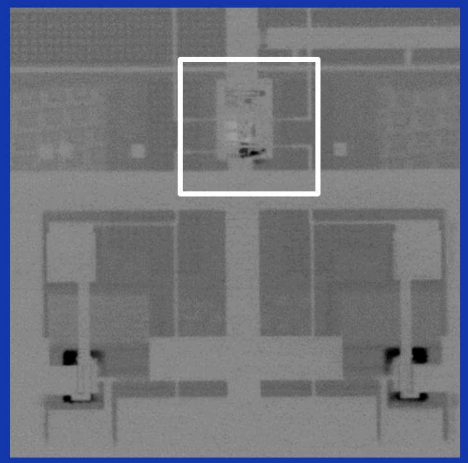


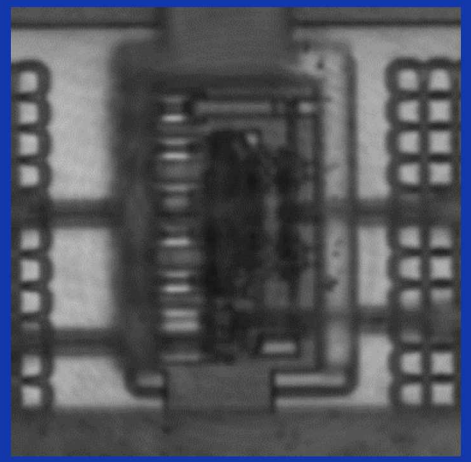
F_1 Amplitude Map

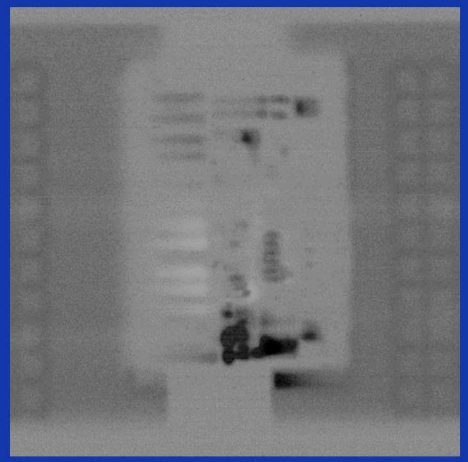
F_1 Amplitude Images at 532 nm: Analog Amp and Divide-by-2 Circuitry

- New areas not seen in F_0 maps
- Better spatial resolution in divide-by-2 area
  - Shorter λ









Reflected Images

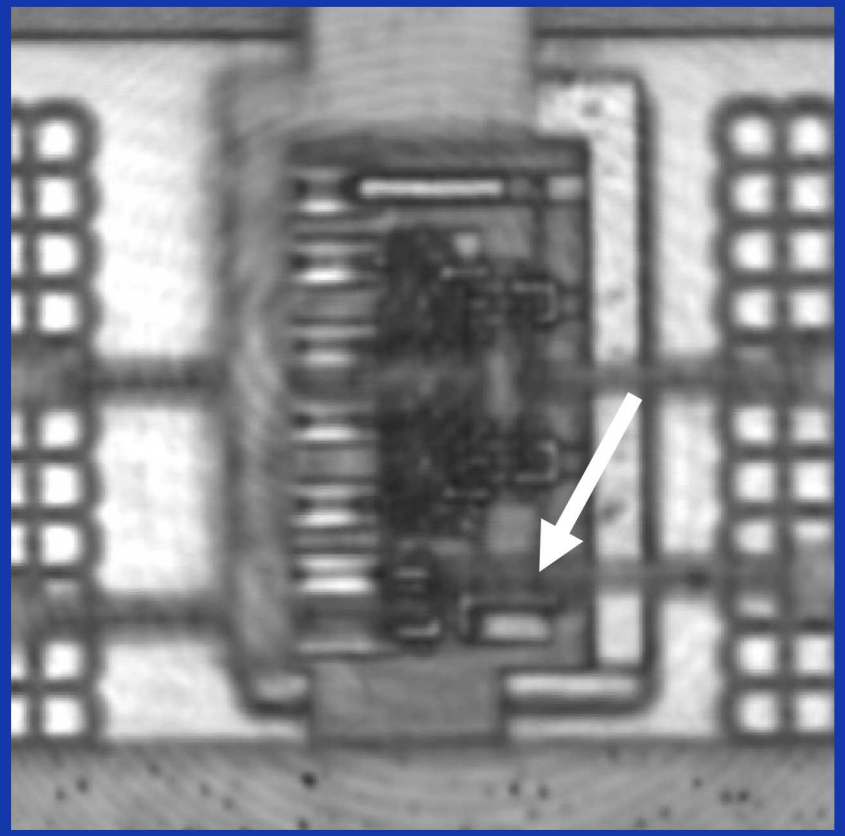
F_1 Amplitude Maps

Selecting Another Zero-Span Frequency

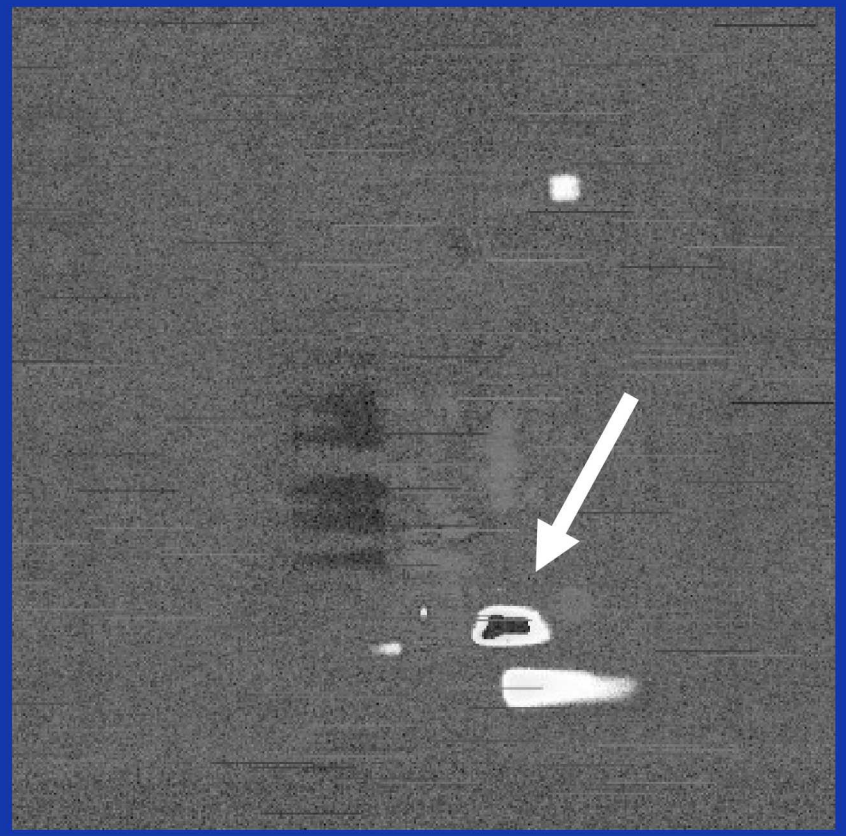
- Methodology to select F_1 from F_0 images used to select a new F_2
  - Generated from F_1 images
- F_2 zero-span images further indicated the divide-by-2 counter circuitry
  - Additional F_2 frequencies also highlighted the divide-by-2 counter

F_2 532 nm Amplitude Map of Divide-by-2 Circuitry

- Arrow indicates most thermally sensitive area



Reflected Light Image



F_2 Amplitude Map

Divide-by-2 Circuitry Identified as Failure Site

- Multiple frequency iterative process showed same site
- Failure site validated with circuit simulation
- Imbalance seen earlier was NOT the cause of failure
  - Result of imbalanced output loading
- Divide-by-2 localization satisfied customer needs

Conclusions

- New methodology described to localize at-speed failures
- Approach based on combining two techniques:
  1) PSA for frequency detection sensitivity
  2) Local laser stimulus
- Selection of zero-span frequency initially from global effects
- Subsequent chosen frequencies from localized effects
  - Iteratively selecting new frequencies facilitated localization
- Combined approach filters a big data problem into a single frequency
  - High speed failure into a DC signature