Mixed-Signal BIST - Organization

- Testing Analog Circuits
- BIST Architectures
  - ❖TPGs
  - ❖ORAs
- BIST Operation
- Analysis
  - ❖Fault Simulations
- Benefits and Limitations

Testing Analog Circuits

Testing analog circuits very different from digital circuits

- Testing requires determination of output signal quality
  - ❖ not just a simple logic 0 or 1 value
- Variations are expected in output waveforms
  - ❖ due to acceptable component parameter variation
  - ❖ due to environmental variations (temperature, voltage, etc.)
- Analog fault models not well defined for DFT
  - ❖ Catastrophic (hard) faults
    - ➢ components missing or disconnected (open terminals)
    - ➢ components shorted out
  - ❖ Parametric (soft) faults
    - ➢ components out of acceptable tolerance range

Historical Aspects & Trends

- Analog DFT is about 20 years behind digital DFT
  - Similarly analog fault simulation is new as well
- First approaches applied digital DFT approaches to analog
  - Ad-hoc techniques have good applicability to analog
  - Scan design has no direct analogy in analog circuits
    - attempts have been made but produce inefficient results
  - BIST approaches have been successful in mixed-signal
- New analog DFT approaches are typically BIST based
  - Are usually specific to a given type of analog circuit
    - PLLs, ADC/DACs, filters, amplifiers
  - A few are generally applicable

Ad-hoc Techniques

Improving controllability & observability works for analog

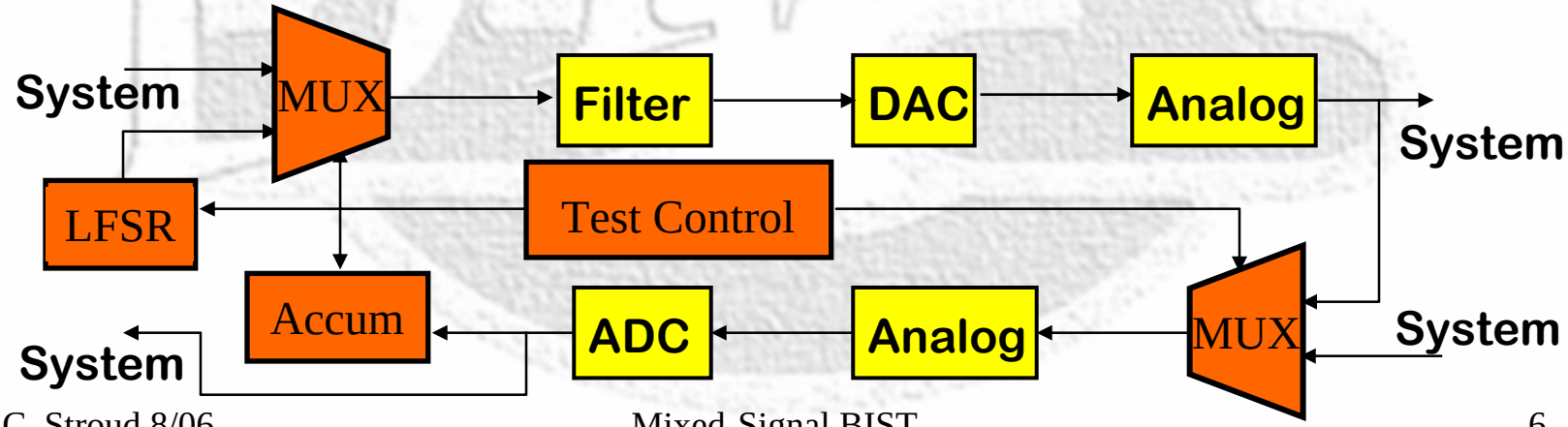
- Good results in most cases
  - Additional I/O pins for test points
  - Multiplexing with existing I/O pins more difficult
- Same advantages/disadvantages as digital
  - Have to determine where is best places to incorporate
  - Minimum impact to performance of analog circuit
    - Extra capacitance/resistance for added DFT circuitry
- Analog fault simulation needed
  - To determine test quality
  - To determine where to put ad-hoc DFT circuitry

BIST for Analog & Mixed Signal Circuits

- LFSR sufficient for digital pseudorandom TPG
  - But analog circuits require different test signals
- Traditional signature and syndrome analysis work for digital BIST since results are exact
  - Analog circuit output response expected to vary which can prevent reproducible results
    - Quantization noise in DACs and ADCs
    - Tolerances in analog component parameters
    - Environmental variations (temp., voltage, noise)
  - Expect range of good circuit signature values for analog and mixed-signal test approaches

Mixed Signal BIST

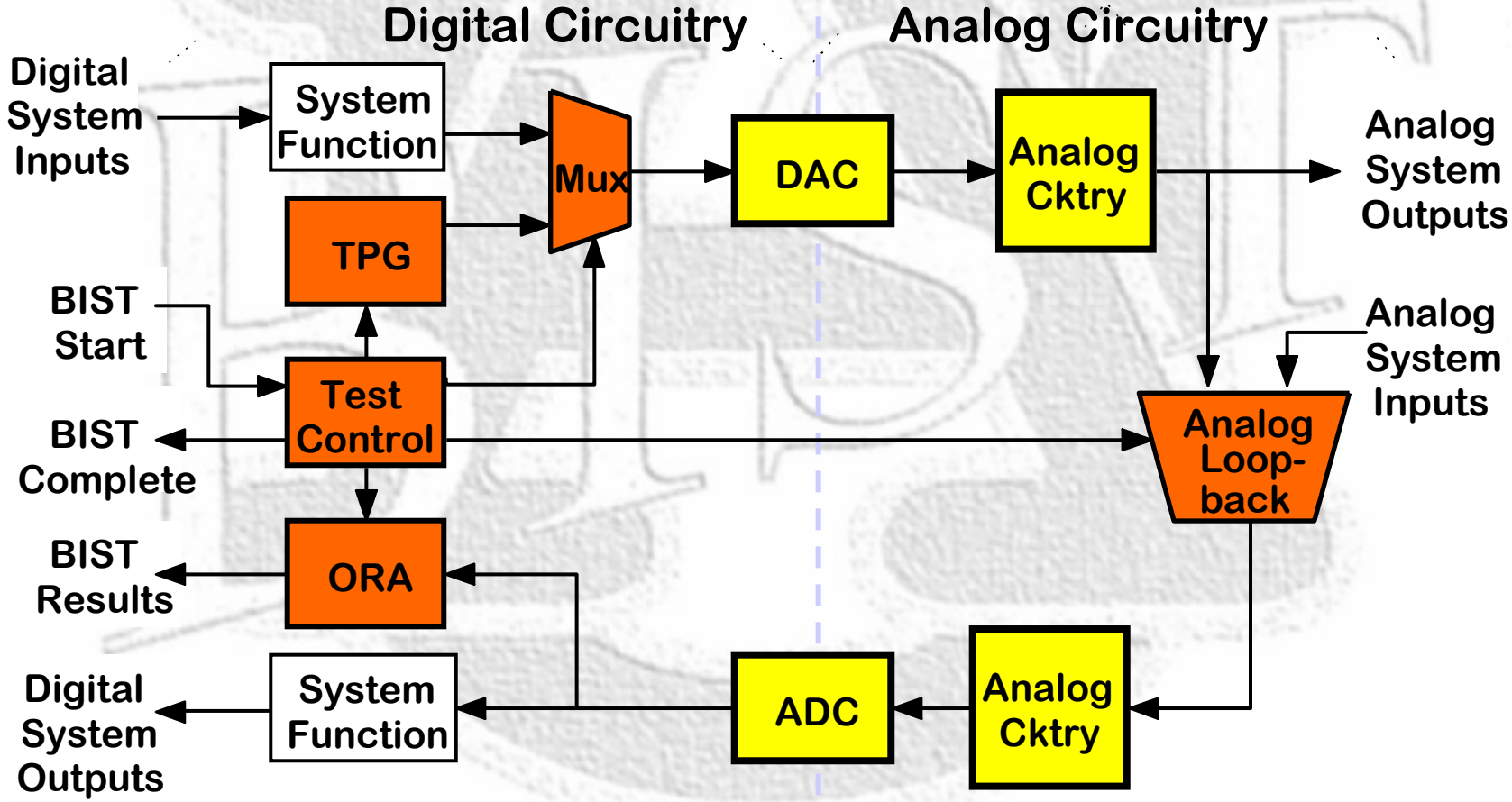
- Bell Labs (Stroud - 1987)
  - **Shared test resource used to test analog lines & circuits**
    - Long test/diagnostic run time due to wait for test resources
  - **Designed BIST in a mixed-signal ASIC cost reduction**
    - BIST used in conjunction with shared test resource
    - BIST performed intended function but never analyzed
    - Accumulator used for ORA since output sequences will vary
- Ohletz – 1991
  - Similar architecture but used SAR/MISR for ORA
    - Theoretically possible but not practical to map all good circuit signaturees



Mixed Signal BIST (cont.)

Redesigned & improved at Univ. of KY and UNC-Charlotte (Stroud - 1996-2003)

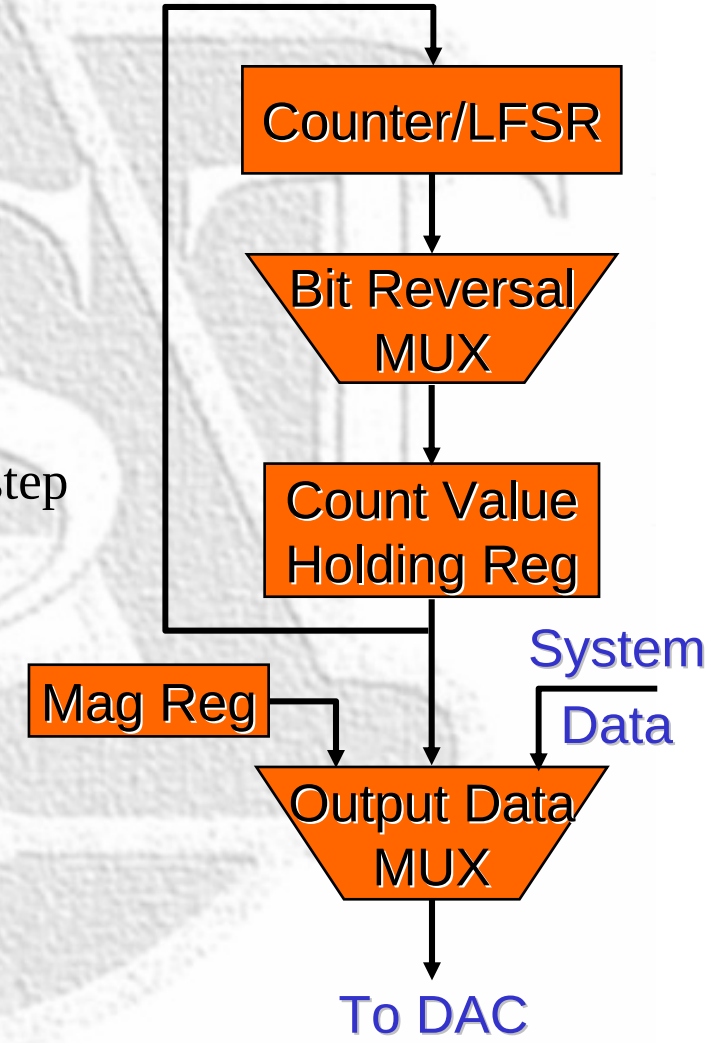
- Better TPG & ORA capabilities
  - ❖ Achieved > 95% FC of hard & soft faults



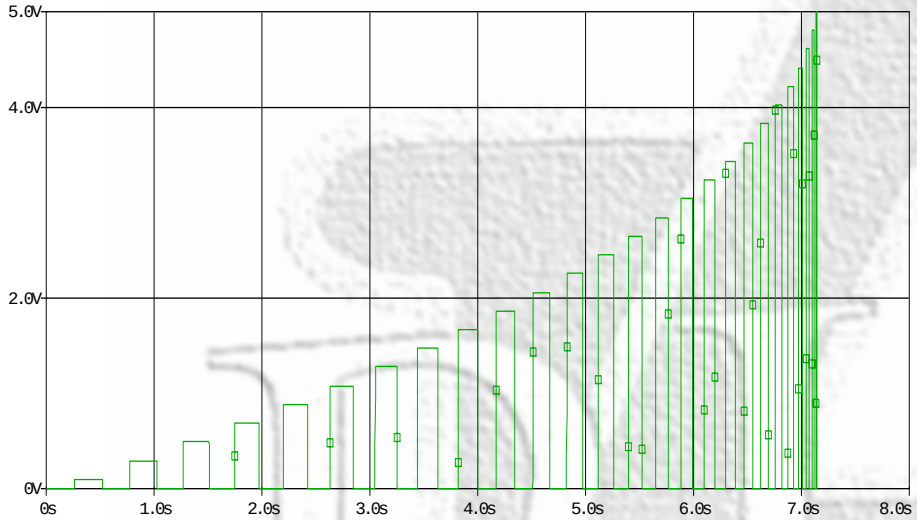
Mixed Signal BIST: Test Pattern Generation

TPG generates 16 test waveforms:

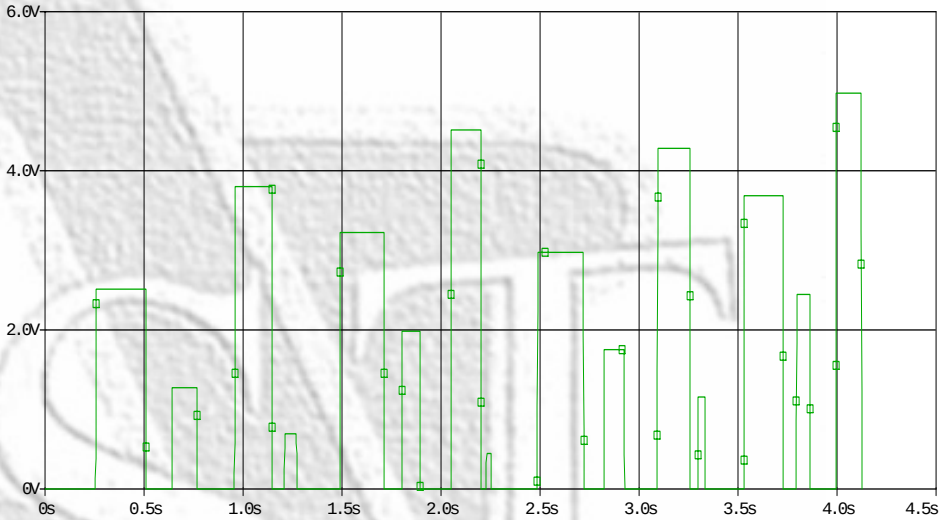
- Counter (up, down, & up/down)
  - ramp, sawtooth & triangle waveforms
- LFSR (pseudo-random patterns)
  - white-noise-like waveforms
- Magnitude register
  - programmable amplitude DC, impulse, & step response tests
- Frequency sweep
  - varying & programmable amplitudes
- Bit reversal (for most waveforms)
  - noise & random frequencies/amplitudes



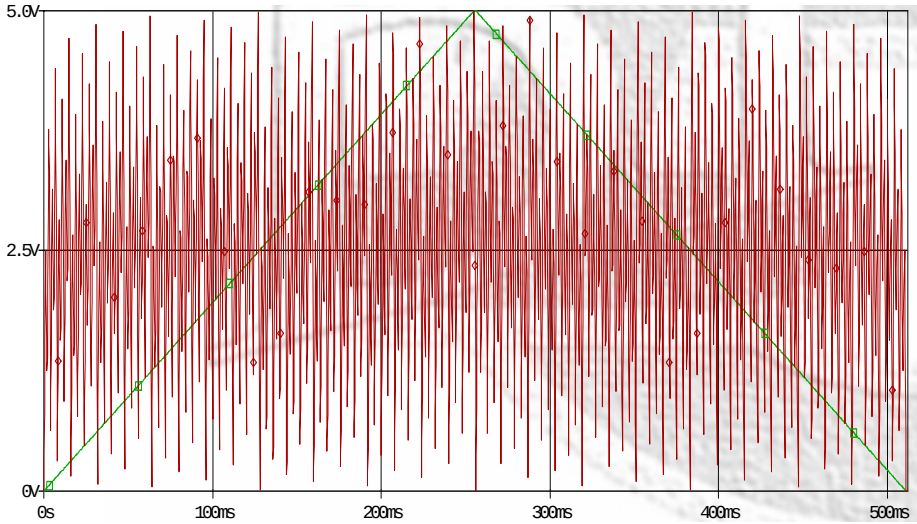
Sample Test Waveforms



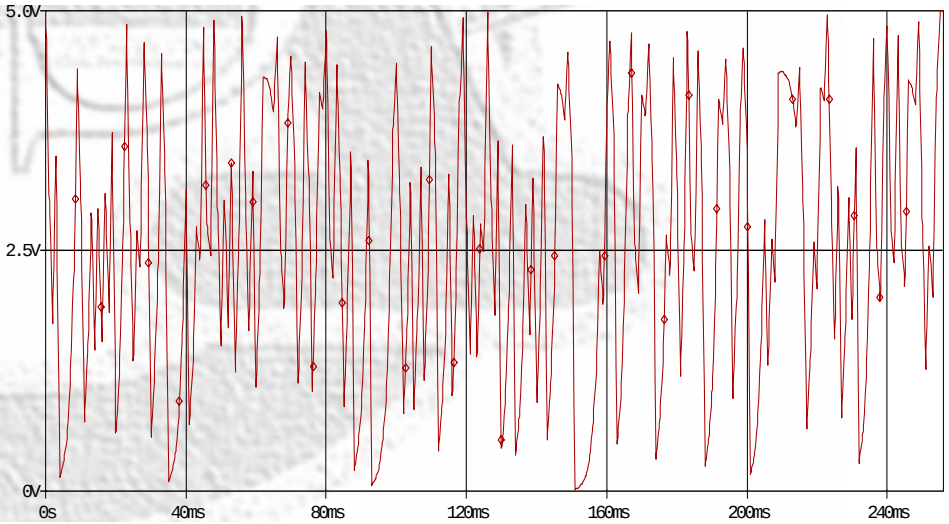
Freq. Sweep Varying Amplitude



Freq. Sweep w/ Bit Reversal



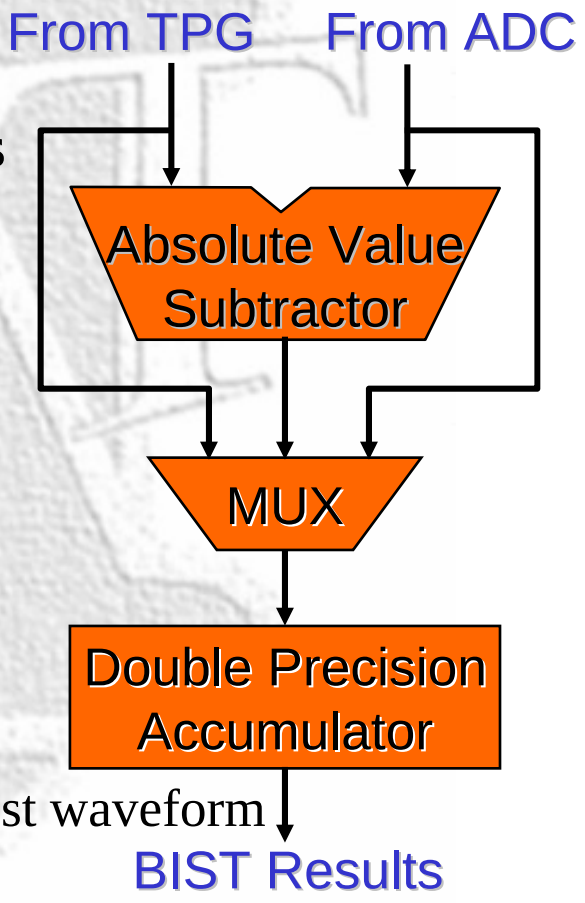
Triangular Wave & Bit Reversal



Pseudo-Random Patterns

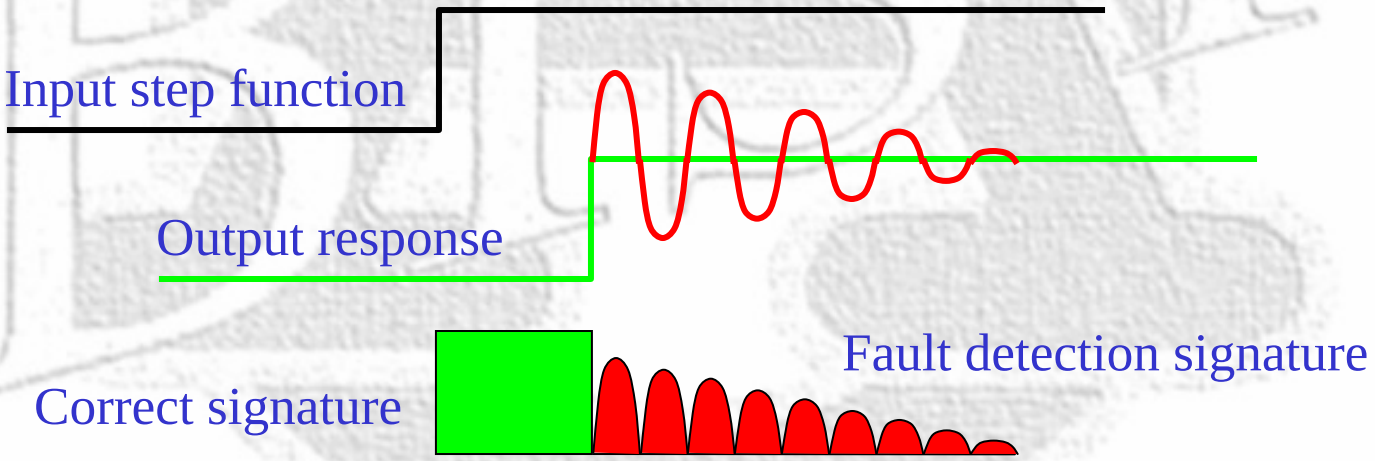
Mixed Signal BIST: Output Response Analyzer

- Traditional signature and syndrome analysis
  - ❖ Good for digital circuit since results are exact
  - ❖ Quantization noise in DAC/ADC prevents reproducible results
    - ➢ also parameter & environmental variation
- Accumulators allow range of BIST results
  - ❖ Accounts for variation in analog output responses
  - ❖ Accumulators investigated include:
    - ➢ Single Precision - modulo 2^N addition
    - ➢ Residue - end-around carry addition
    - ➢ Double Precision - modulo 2^{2N} addition
      - ▪ double precision found to be best overall
  - ❖ Two accumulator modes used:
    - ➢ Sum the magnitudes of the output response
      - ▪ TPG output tests BIST circuitry
        - ❑ Look for exact signature
    - ➢ Sum absolute value of difference in response & test waveform
      - ▪ detects faults causing noise and phase shifts



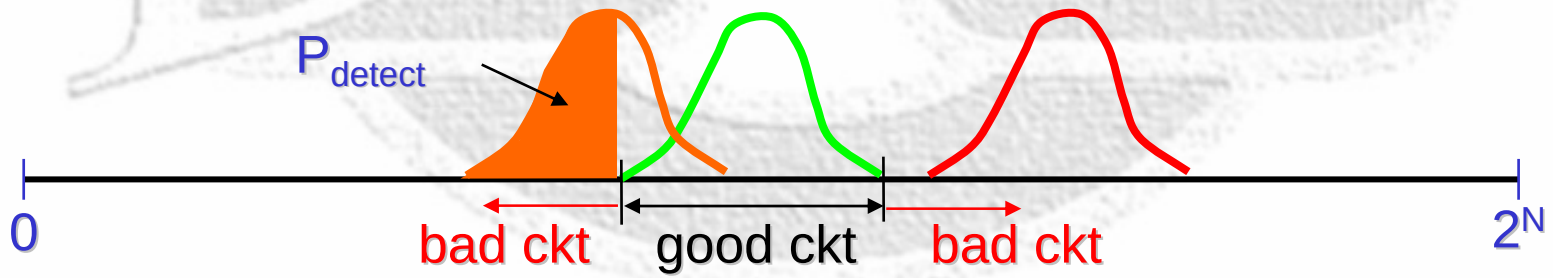
Absolute Value Difference

- Detects faults causing:
  - ❖ Noise riding on an otherwise good waveform
  - ❖ Phase shift
  - ❖ Overshoot/ringing



Analog Fault Detection with BIST

- Fault simulation very time consuming
  - ❖ Must simulate every fault multiple times with acceptable variation of fault-free components
  - ❖ Normal & uniform distributions have been used
    - ➢ ***Observation:*** all variations produce normal distribution of signatures
- Detected vs. undetected faults
  - ❖ Potentially detected faults
    - ➢ P_{detect} = #detects/#simulations
  - ❖ Fault Coverage = (#detect + ΣP_{detect})/#faults



Other Approaches in Analog BIST

Oscillator BIST

- During test mode, circuit is converted to oscillator
  - Measure frequency of oscillation to detect faults
- Works for most analog circuits
  - Automated synthesis for many analog circuits
    - Developed by ***OpMaxx*** (now part of ***Fluence***)
- Has been attempted in digital circuits
  - Results have been promising
- Effect on system performance is not well known
  - Extra capacitive & resistive loading on original circuit

Histogram-based Analog BIST (HABIST) (***Fluence***)

- Known good & CUT histograms are normalized
- Adjustments made for offset & gain variations
- The two are subtracted to obtain difference histogram
  - Used to determine detection of faults