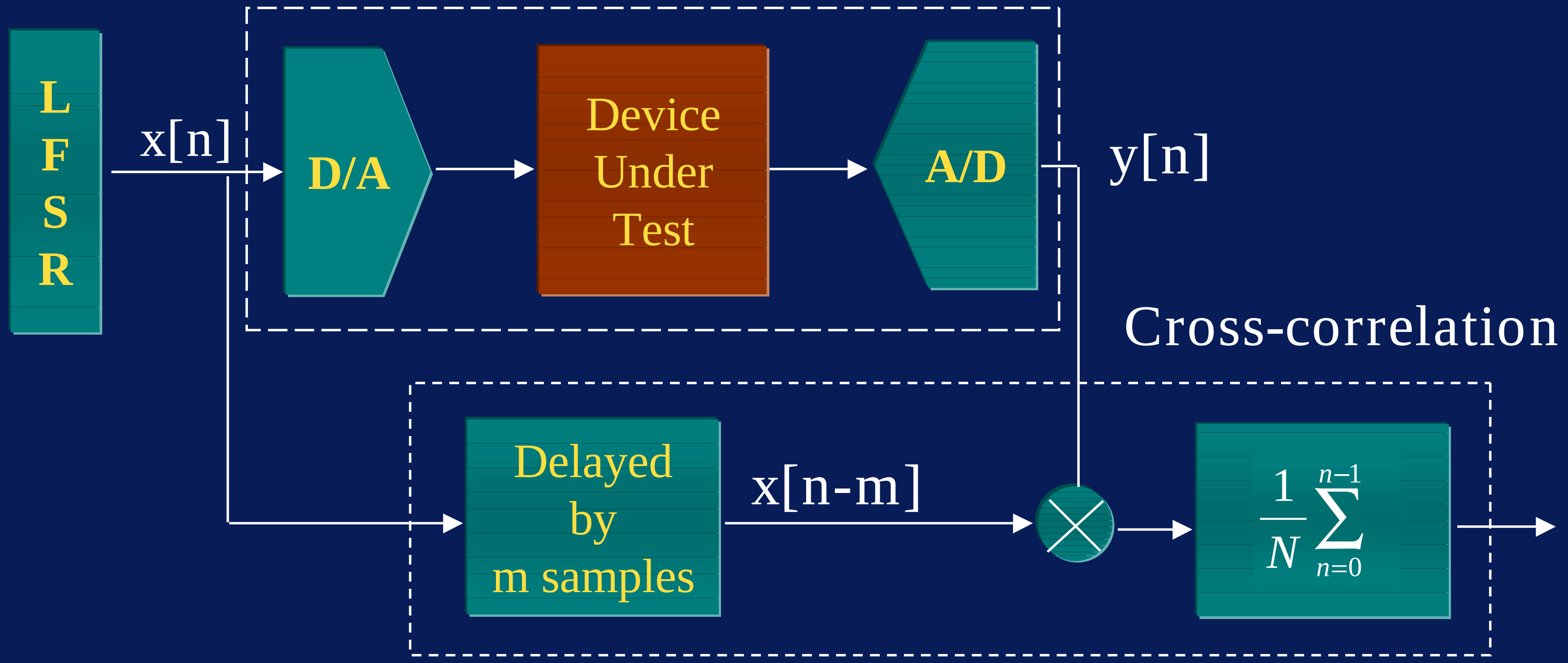
Characterization of a Pseudo–Random Testing Technique for Analog and Mixed–Signal Built–In–Self–Test

Jan Arild Tofte, Chee–Kian Ong[2], Jiun–Lang Huang[2], and Kwang–Ting (Tim) Cheng[2]
The work was done when the first author was with Univ. of California at Santa Barbara.

[1]Mentor Graphics Corporation, 8005 SW Boeckman Road, Wilsonville, OR, US
[2]Department of Electrical and Computer Engineering, Univ. of California, Santa Barbara, CA, US

Pseudo–Random Structure



L F S R

x[n]

D/A

Device Under Test

A/D

y[n]

Cross-correlation

Delayed by m samples

x[n-m]

$$\frac{1}{N}\sum_{n=0}^{n-1}$$

$$\overline{\phi}_{xy}[m] = E\{x[n-m]\cdot y[n]\}$$

Ref: Pan & Cheng, ICCAD95

Cross–Correlation Signature

Cross–Correlation is Proportional to the Impulse Response:

$$\phi_{xy}[m] = h[m] \cdot \sigma_x^2 + \mu_x^2 \cdot \sum_{k=0}^{\infty} h[k]$$

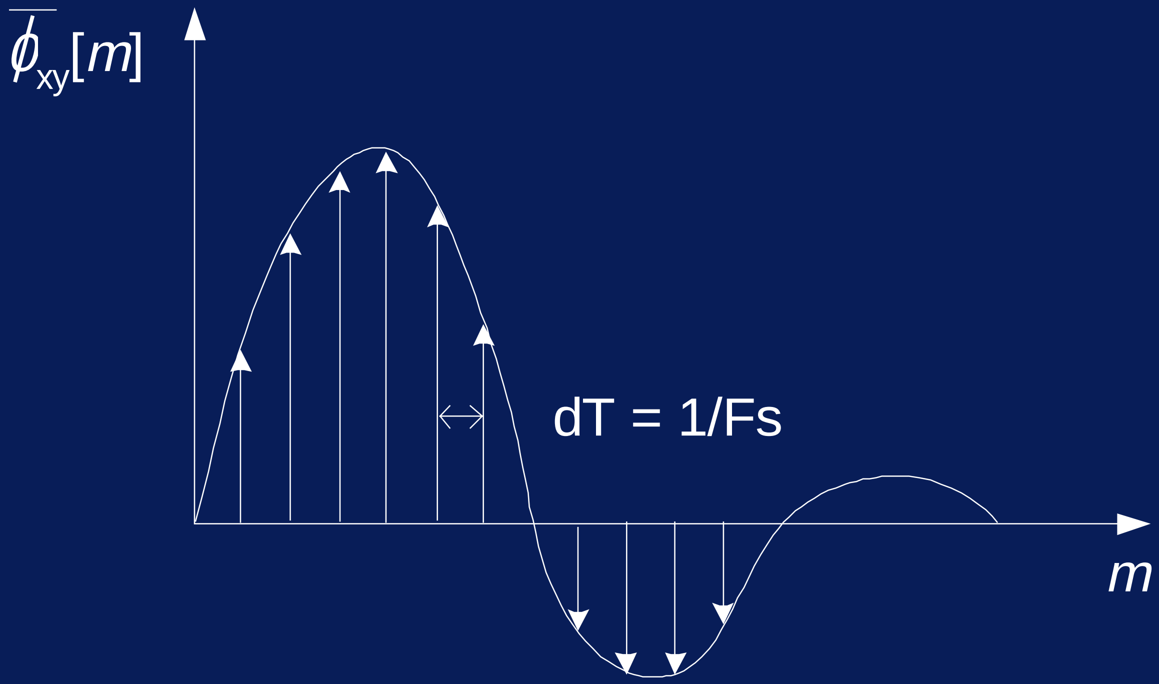
Estimated Cross–Correlation Signature Samples:

$$\overline{\phi}_{xy}[m] = \frac{1}{N} \sum_{n=0}^{n-1} x[n-m] \cdot y[n]$$

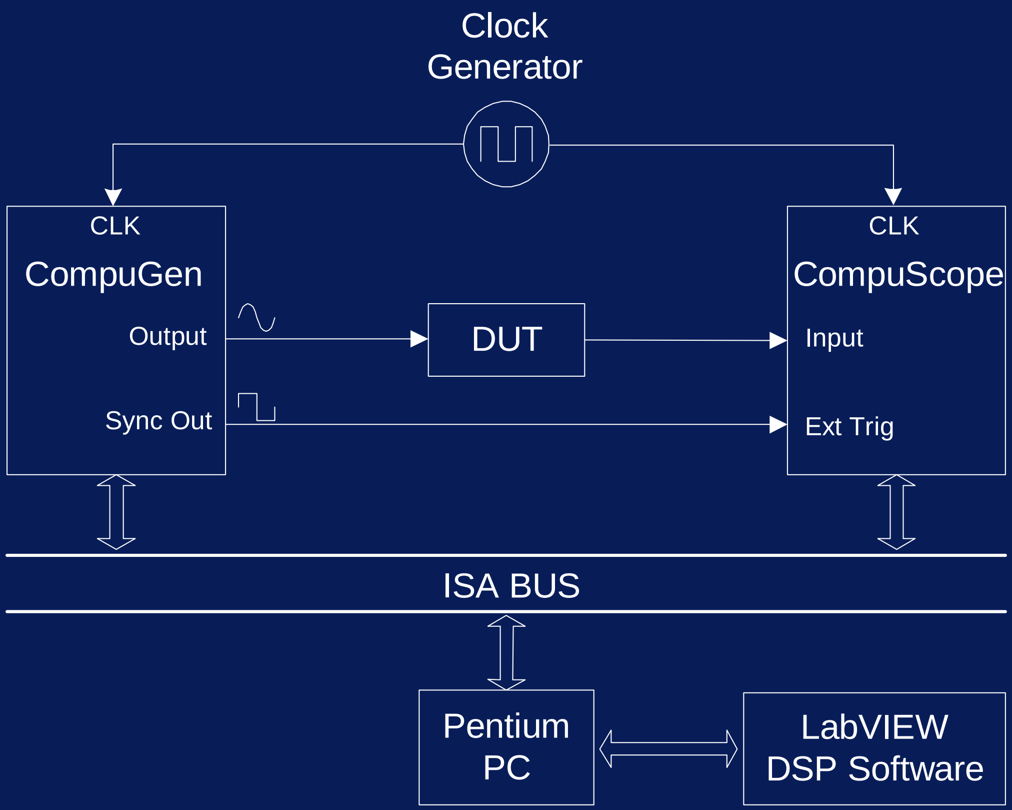
Complete Signature Set:

$$\phi = \{\overline{\phi}_{xy}[0], \overline{\phi}_{xy}[1], \overline{\phi}_{xy}[2], \overline{\phi}_{xy}, \ldots, [K-1]\}$$

Cross–Correlation Response



Testbed Implementation


Clock
Generator

CLK
CompuGen
Output
Sync Out

DUT

CLK
CompuScope
Input
Ext Trig

ISA BUS

Pentium
PC

LabVIEW
DSP Software

Overview of Experimental Procedure

- Each circuit instance is generated using the Monte Carlo method.

- Pseudo–random patterns are applied to the DUT, and the cross–correlation signature samples are computed.

- A signature set is marked fault–free (faulty) if the circuit instance is within (outside) the performance boundaries.

Test–Session Procedure

1) Load the pseudo–random patterns into CompuGen’s memory–buffer.

2) Instruct CompuGen to start continuous delivery of test–sessions.

3) Arm CompuScope to hardware trigger on CompuGen’s *Sync Out* signal.

4) When a trigger is detected, mark the starting point of the test–session.

5) When the current test–session has been successfully captured, transfer the response samples from CompuScope’s memory–buffer to the application software.

Software Procedure

1) Adjust the values of the external resistors.

2) Obtain the DC offset and gain spectrum by applying a series of frequency–sweep test–sessions.

3) Perform a test–session based on the pseudo–random test patterns to obtain the phase spectrum and cross–correlation.

4) Check if the circuit instance of the DUT satisfies/violates the performance parameters

5) mark the cross–correlation signature set fault–free/faulty, and log the results to file.

Classification of Circuit Instances

- Generate circuit instances collectively called a *training set*
- Carefully select 2 cross–correlation signatures
- Derive a polygon based on the convex hull function that encloses all fault–free circuit instances
- Generate circuit instances collectively called an *evaluation set*
- An instance in the *evaluation set* is classified as fault–free (faulty) if it falls within (outside) the boundaries established by the polygon.

Classification Accuracy

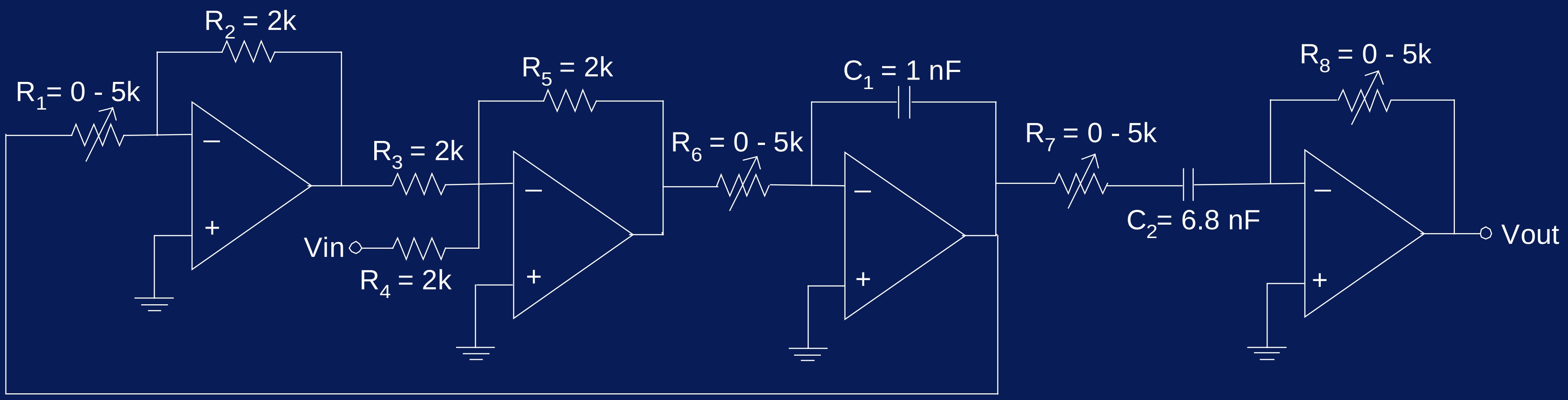
- Yield Coverage (Y):

  The number of instances correctly classified as fault–free divided by the total number of known fault–free instances.

- Fault Coverage (F):

  The number of instances correctly classified as faulty divided by the total number of known faulty instances in.

Experiment: Bandpass Filter

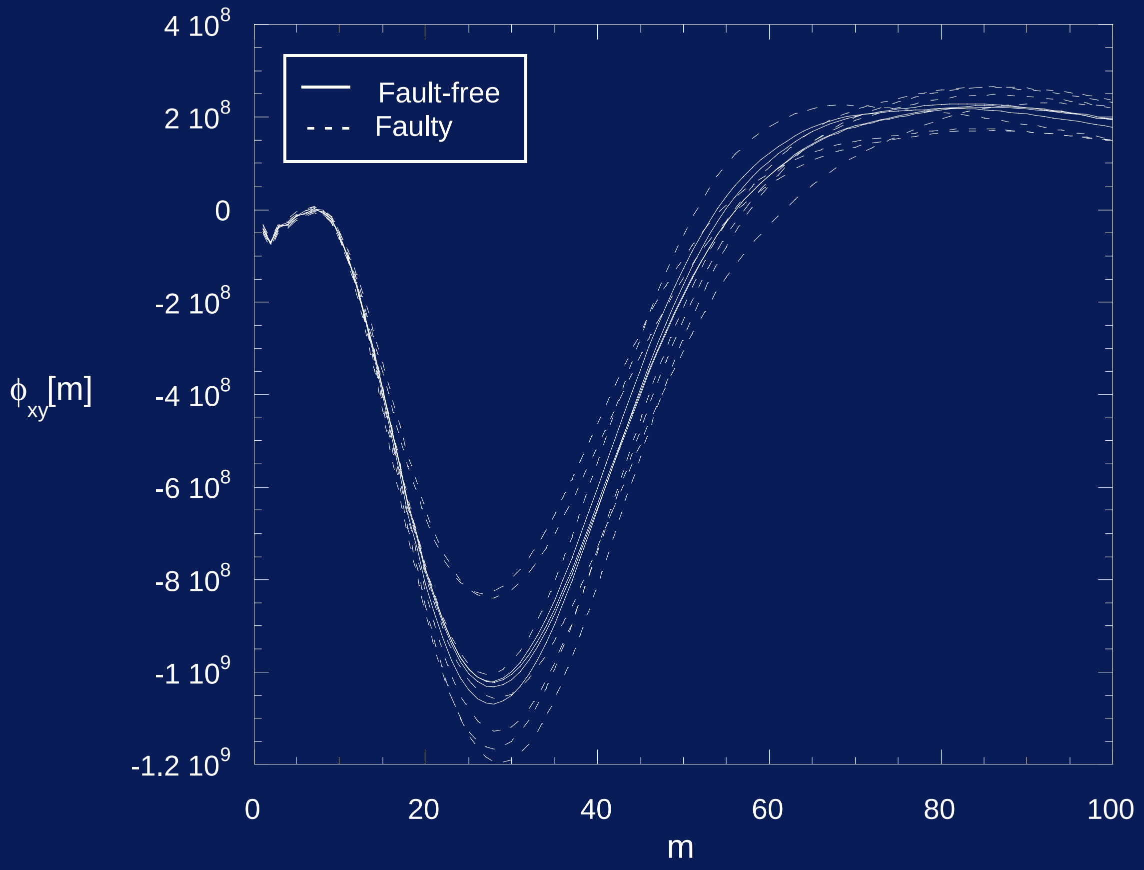


Performance parameter constraints:

- Pass–band gain (50 kHz – 200 kHz): $-1.5\text{ dB} \leq A_0 \leq 1.5\text{ dB}$.
- Stop–band attenuation: $A_0 \leq -8$ dB at10 kHz and 200 kHz.
- Pass–band phase margin: $\phi \leq 5°$.
- DC offset in pass–band: $V_{os} \leq 2.4$ mV.

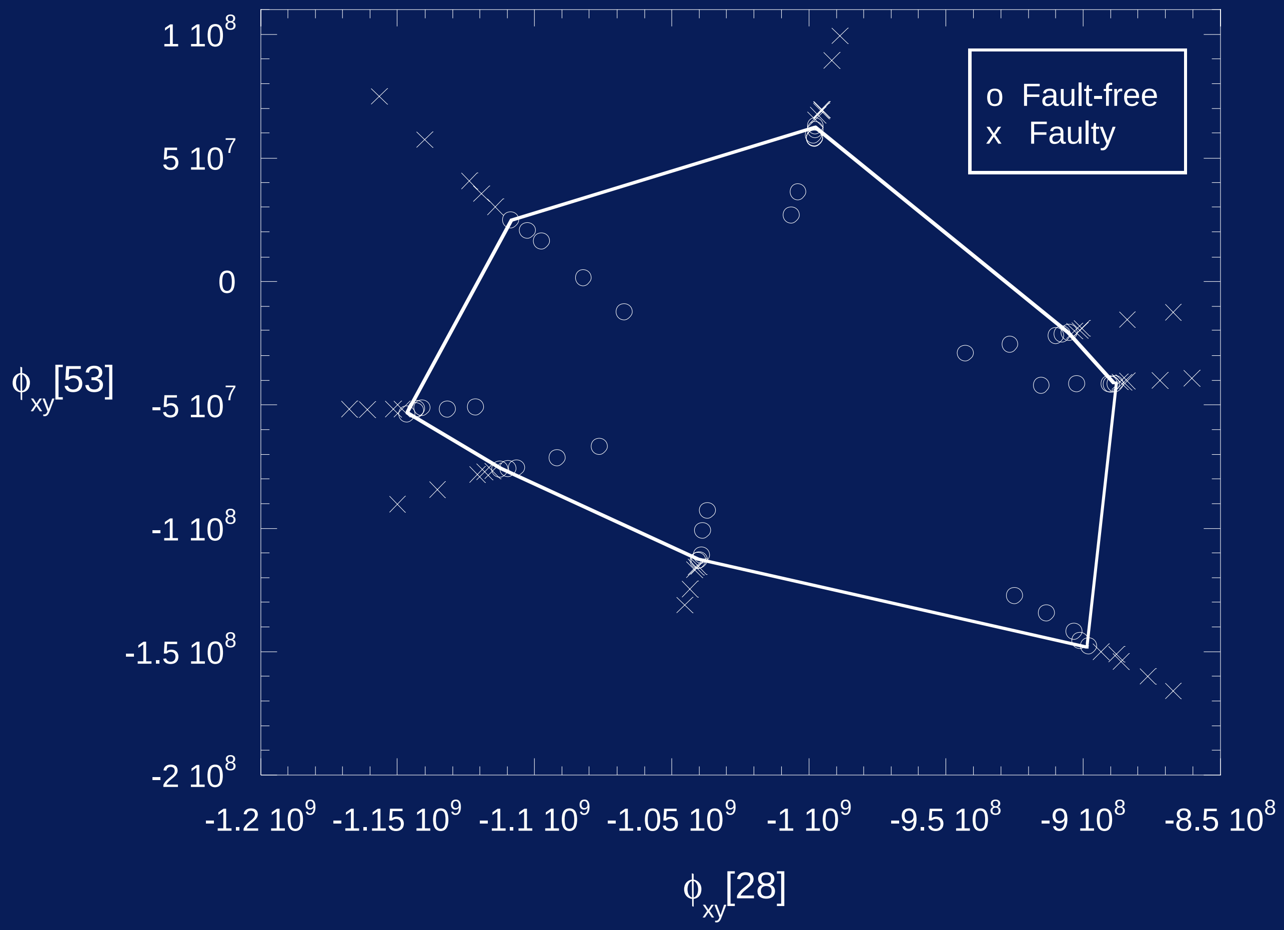
Cross–Correlation Response Curves

Select 2 cross–correlation samples (signature–pair)



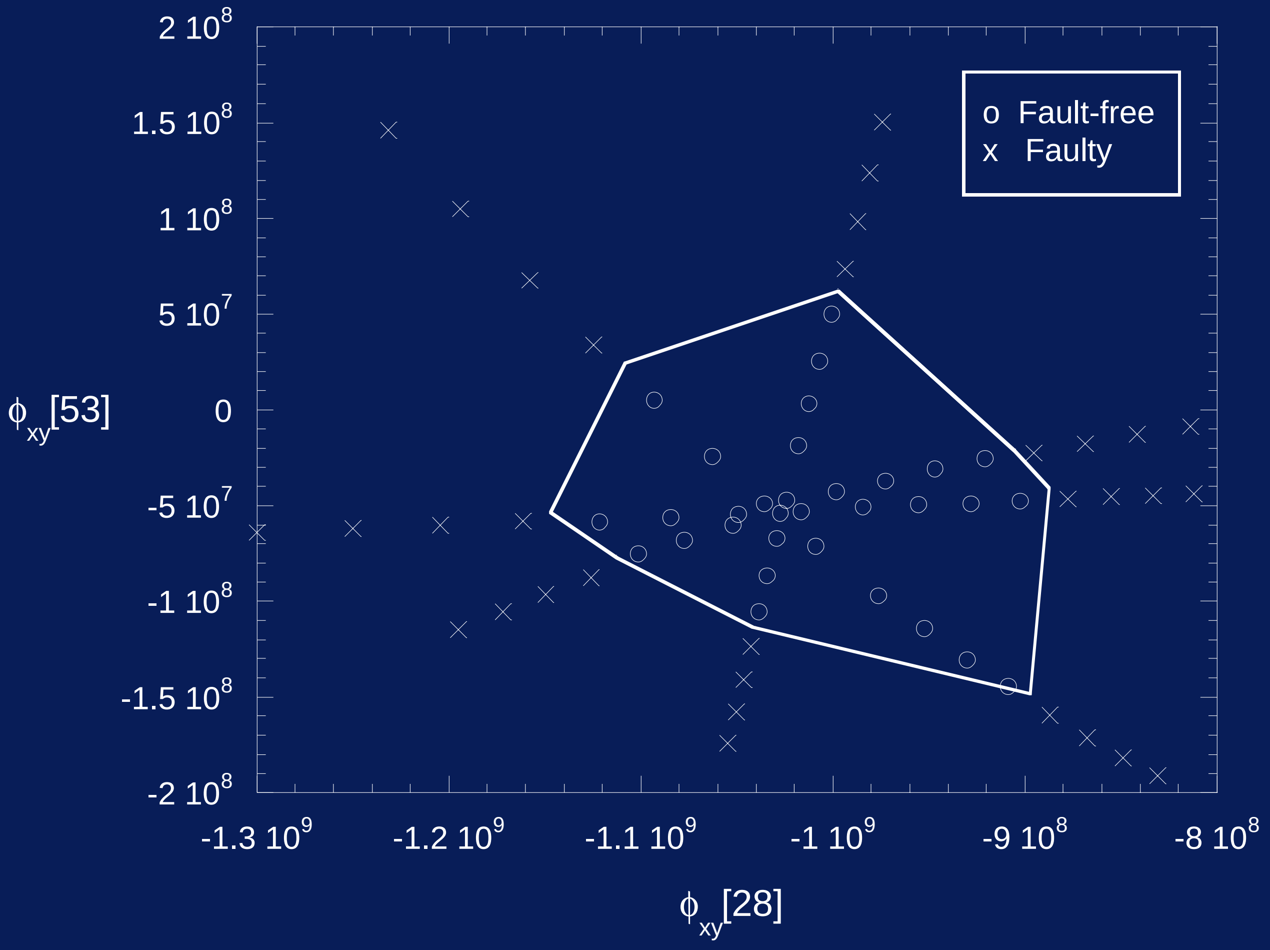
Training Set

Derive classification boundaries to enclose all fault–free instances



Evaluation Set

Apply classification boundaries to the evaluation set



Results: Bandpass and Lowpass Filters

- Noise does not seem to affect the classification accuracy
- Several Signature–pairs give 100% yield and fault coverage

	Bandpass Filter		Lowpass Filter	
n	Noise (%)	Signature–pairs (%)	Noise (%)	Signature–pairs (%)
1	0.070	7.2	0.137	1.4
4	0.026	7.2	0.048	1.5
9	0.017	6.6	0.029	1.7
16	0.015	5.7	0.022	1.7
25	0.013	6.6	0.019	1.8

Practical BIST Implications

- Digital on–chip test stimulus and signal analysis covering the complete frequency spectrum
- Area efficient if D/A and A/D converters are available in the design
- Cross–correlation signatures are captured into a cross–correlation signature register (CCSR) and scanned out using only one I/O pin
- ATE verifies that the 2–dimensional representation of the signatures falls within the classification boundaries of the polygon

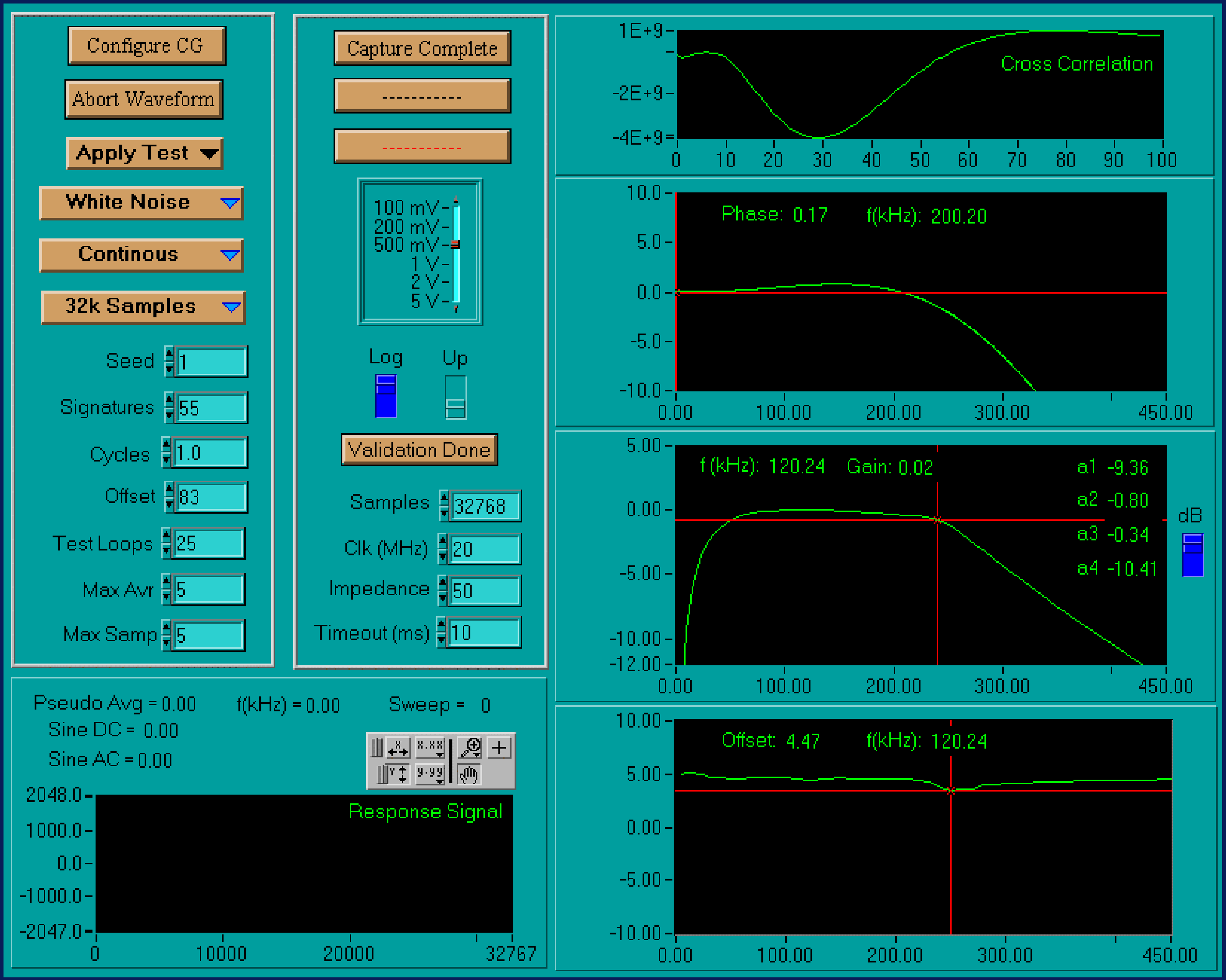
Future Work

- Need to generate a larger number of circuit instances for the training and evaluation set

- Need to evaluate more complex circuits with a larger number of parametric fault sites

- Complex circuits might require more than 2 cross–correlation signatures for classification

Application Software — User Interface



White Noise

Continous

32k Samples

Seed 1

Signatures 55

Cycles 1.0

Offset 83

Test Loops 25

Max Avr 5

Max Samp 5

Samples 32768

Clk (MHz) 20

Impedance 50

Timeout (ms) 10

Pseudo Avg = 0.00

f(kHz) = 0.00

Sweep = 0

Sine DC = 0.00

Sine AC = 0.00

Phase: 0.17 f(kHz): 200.20

f (kHz): 120.24 Gain: 0.02

a1 -9.36

a2 -0.80

a3 -0.34

a4 -10.41

Offset: 4.47 f(kHz): 120.24