WCOMP: Waveform Comparison Tool for Mixed-signal Validation Regression in Memory Design

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- Time-shift comparison
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Motivation

- One of the bottlenecks in memory design is mixed-signal full-chip validation and performance validation, because
  - Some errors are hard to predict and capture, such as glitch.
  - Simulation results have to be manually checked today. Existing tools are limited to digital design
  - Corner analysis with variations of process parameters, supply voltages and temperatures (PVT) is time consuming.
- Regression run of above validations multiplies the efforts
  - Validation regression in digital designs is well developed(test-bench, formal verification and assertion.)
  - Whereas, one in mixed-signal area is still relied on manual inspection
- Validation takes up to 70% of development effort.
  - Thus, important to have a tool to assist the mixed-signal validation in regression tests

Waveform Comparison Methodology

- Tools such as ModelSim, SPICE-explorer and WaveFormer support wave comparisons, but
  - Their support in analog signal is very limited.
- Traditional wave comparison is directly waveform comparison and purely based on graphical differences.
  - It recognizes the waveform differences
  - Many of those differences are not truly functional errors. They are false alarms.
- Therefore, we propose WCOMP
  - Compare waveform based on their functional nature
  - Remove all false alarms introduced by directly waveform comparison
  - Flags only real errors.

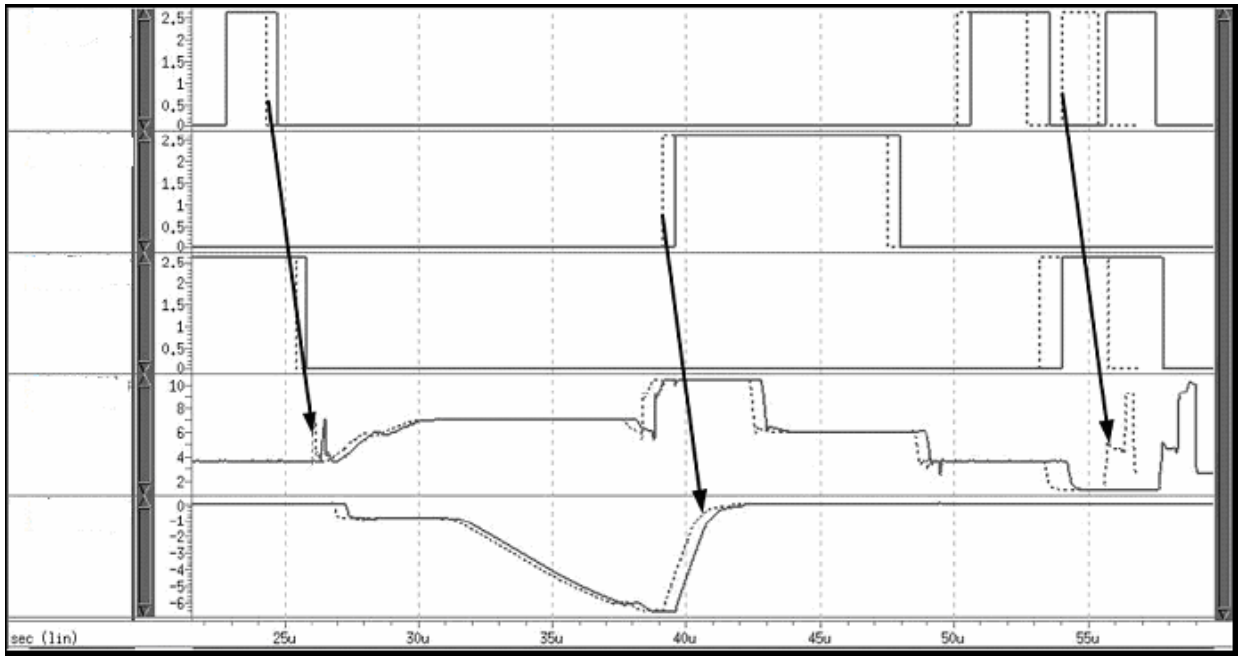
False Alarms in Flash Memory Design

- The tool aims to alarm designers for all the functional errors when a waveform under test is inconsistent with the golden waveform.
- False alarms in consideration (ordered by difficulty)
  - Case 1: Differences of gate loading, transistor size.
  - Case 2: Delay differences of clock synchronized events. For instance, inserted “no-op” instructions in MCU control code btw two simulation runs.
  - Case 3: Simulations under different PVT corners, in which shapes of waveforms are distorted.

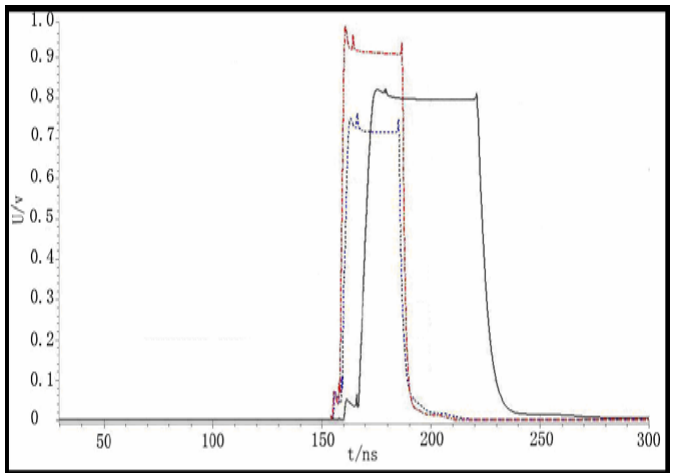
Case 1 and Case 2

Digital control signals

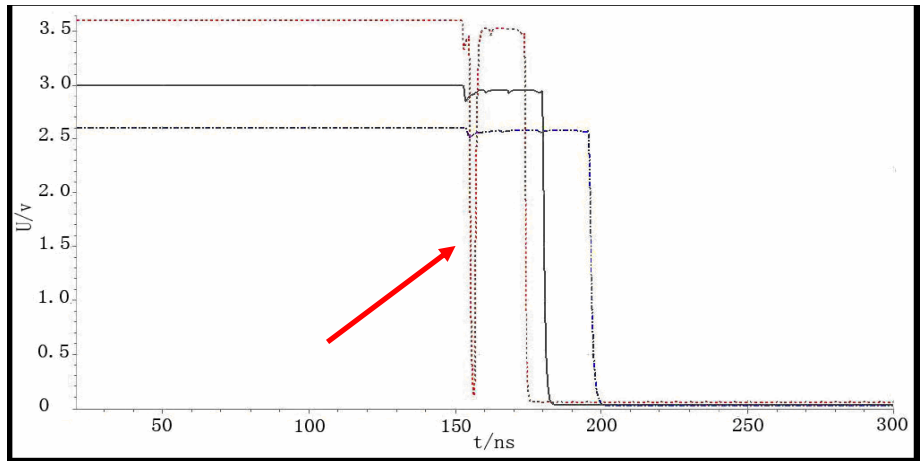
Analog signals



Case 3



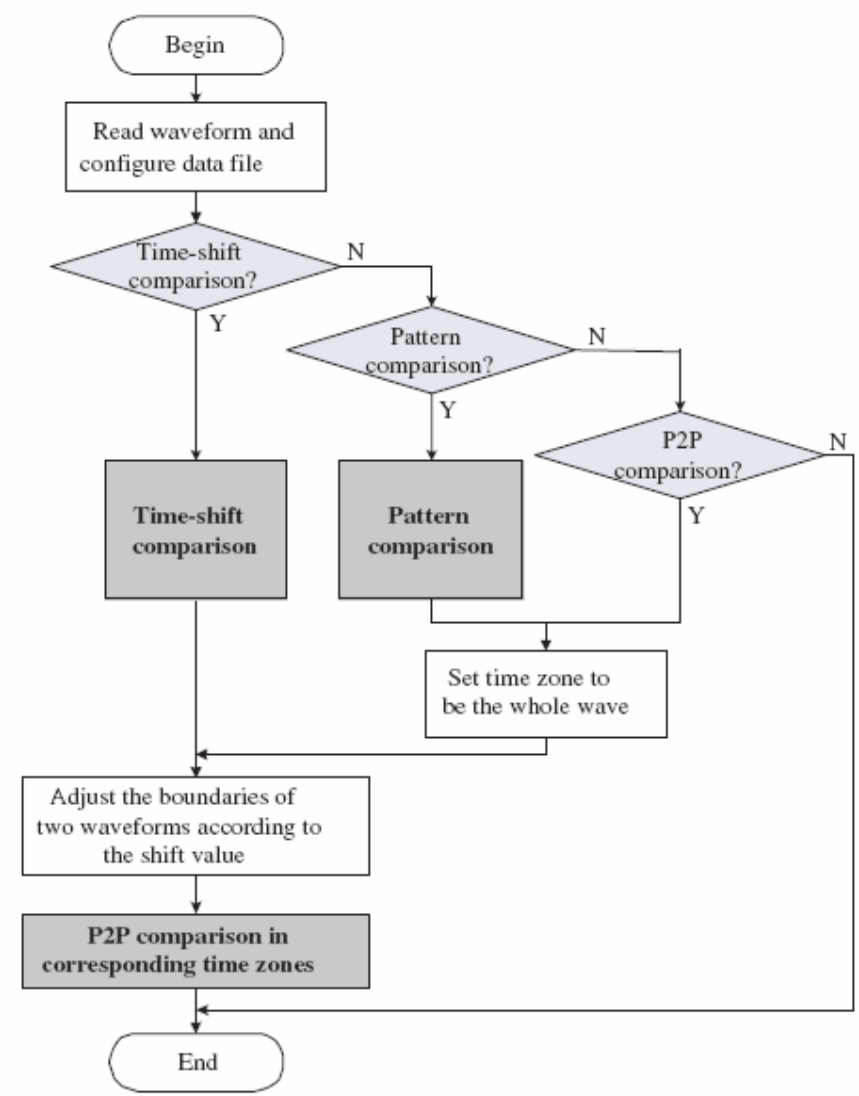
(a) Same signal under different PVT corners.



(b) An error case with one signal has an unexpected glitch.

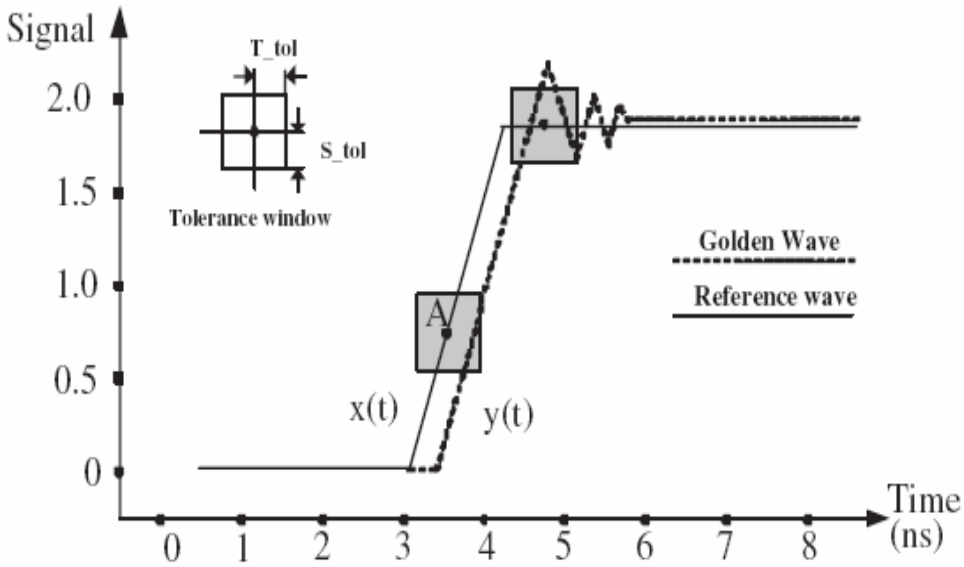
WCOMP Tool

- According to the above 3 cases, WCOMP consists of three main functionalities:
  - Point-to-point comparison
  - Time-shift comparison
  - Pattern comparison



Basic Idea of Point-to-point Comparison

- Time tolerance window is defined by voltage tolerance and time tolerance. To remove false alarm in Case I.

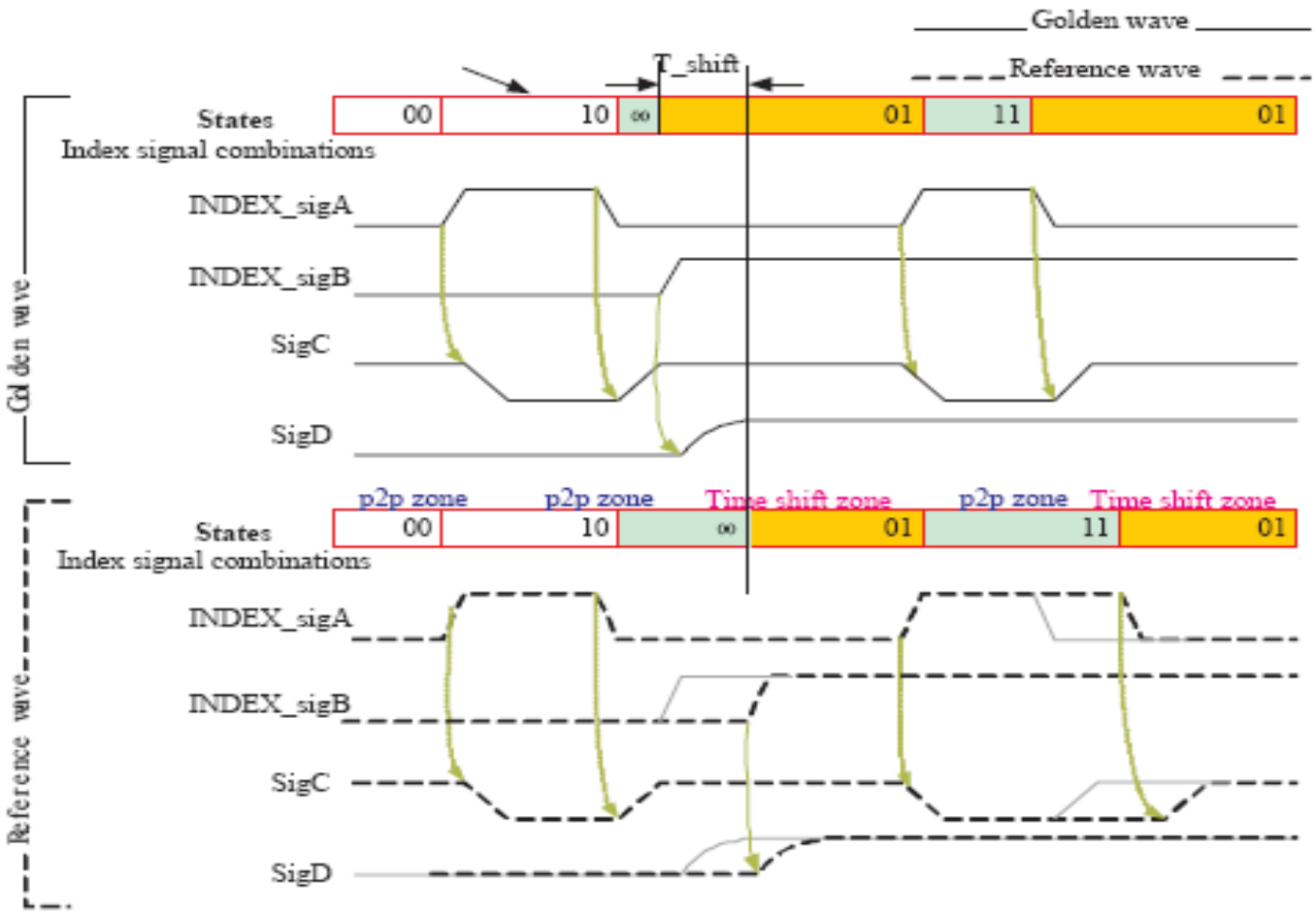


- x(t) is said to be “matched” at point A if the corresponding tolerance window intersects with any line segments of y(t)

Basic Idea of Time-shift Comparison

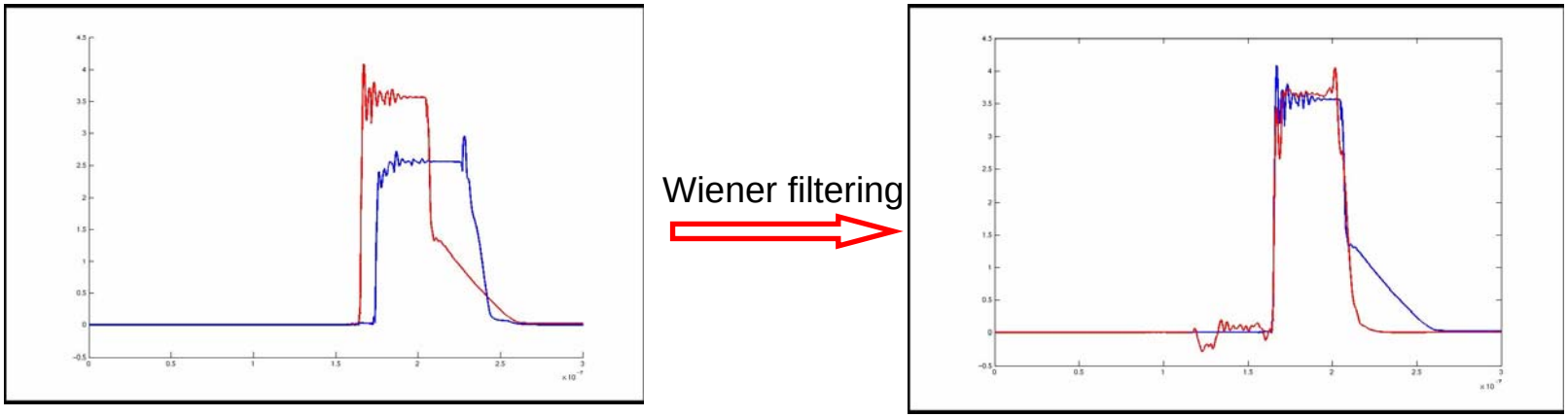
- To remove false alarms introduced by Case 2.
  - Digital control/Index signals are first identified.
  - State is defined as the a vector of a set of index signals
- Waveforms are divided into different time zones according to the state change of Index signals.
- Two waveforms are “matched” only if their states are in same sequences.
- If states are in same sequences, then
  - Each state time zones is aligned by time shifting.
  - Then, point-to-point comparison is applied.

Time-shift Comparison



Basic Idea of Pattern Comparison

- To remove false alarms of Case 3.
- Compare waveforms under different PVT corners.
- Firstly, Wiener filtering technique is employed to align two waveforms.



(a) Original waveforms. (b) after the Wiener filtering.

- Then point-to-point comparison is applied.

Wiener Filter

- Finite duration impulse response (FIR) filter.
- Let *y*(*t*) and *x*(*t*) be the reference waveform and the golden waveform respectively. Wiener filter function is given by:

$$x'(t) = \sum_{k=0}^{P-1} w_k \cdot y(m-k) = w^T y$$

- where
  - w_k's are coefficients of Wiener filter, solved by CGNR (Conjugate gradient normal residue)
  - *P* is the order of the filter
  - *x*'(*m*) is the transformed signal at time *m*

Experimental Results

Comparison between two regression runs and two densities of memory design

Waveform name	#signals	Data points /signal	Run time (sec)	Errors detected	Real Errors
RevTest1	1760	9672	26.41	0	0
RevTest2	1699	17822	59.23	0	0
RevTest3	1699	7944	15.69	0	0
RevTest4	1699	9388	23.94	0	0
DensTest1	1760	9672	28.11	0	0
DensTest2	1699	17822	50.87	1	1
DensTest3	1699	7944	18.85	3	3
DensTest4	1699	9388	19.91	2	2

Comparison of False Alarms

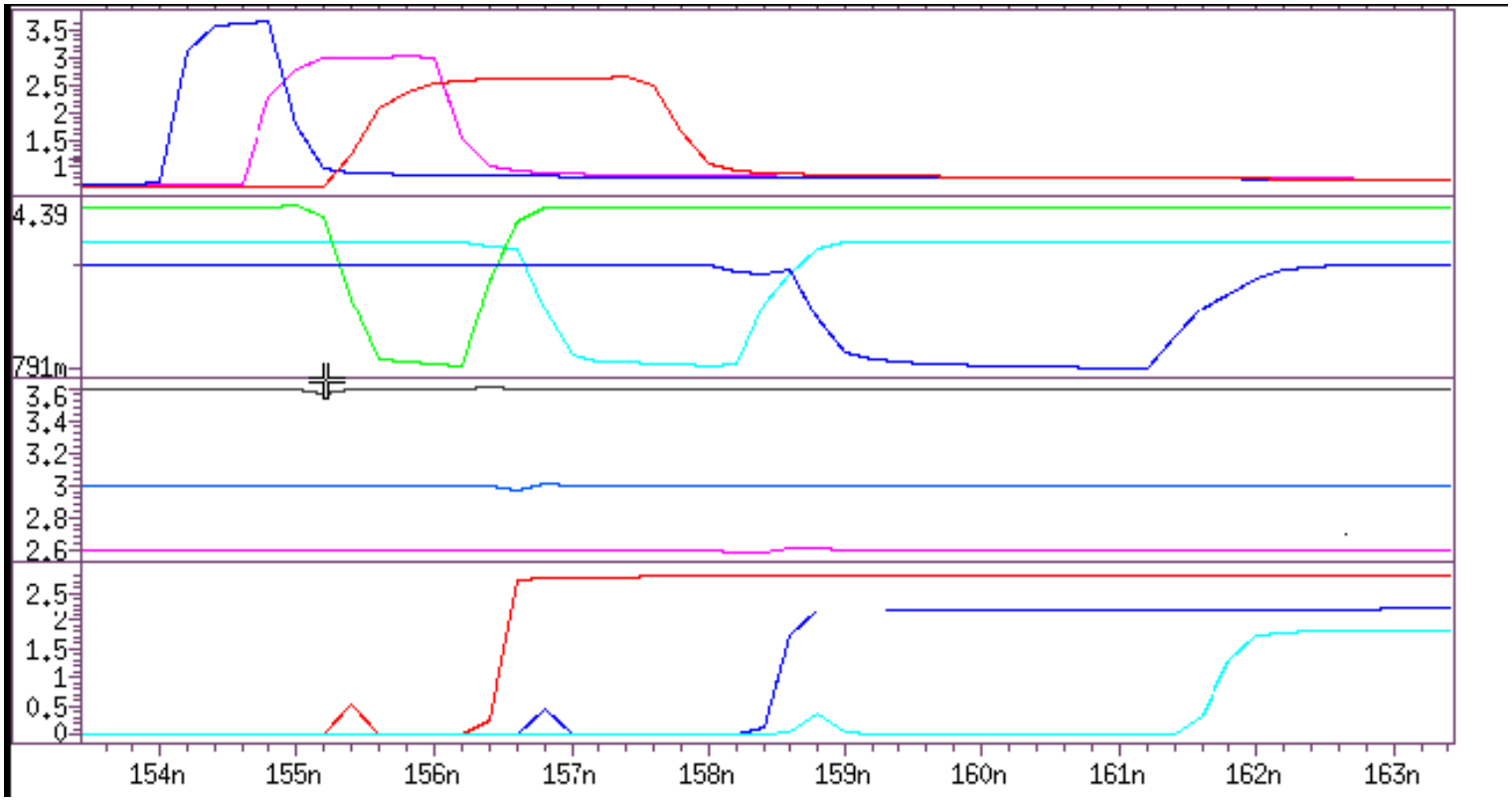
Waveform name	Wave differences by differences algo.			
	w/o time tolerance.	w/o time-shift	WCOMP tool	Manual check
TolTest1	17	800	17	17
TolTest2	30	1153	30	30
TolTest3	6	635	3	3
TolTest4	16	1	1	1
TolTest5	55	6	6	6
TolTest6	22	0	0	0

Pattern Comparisons Results

Each test compares nine corners at the same time.

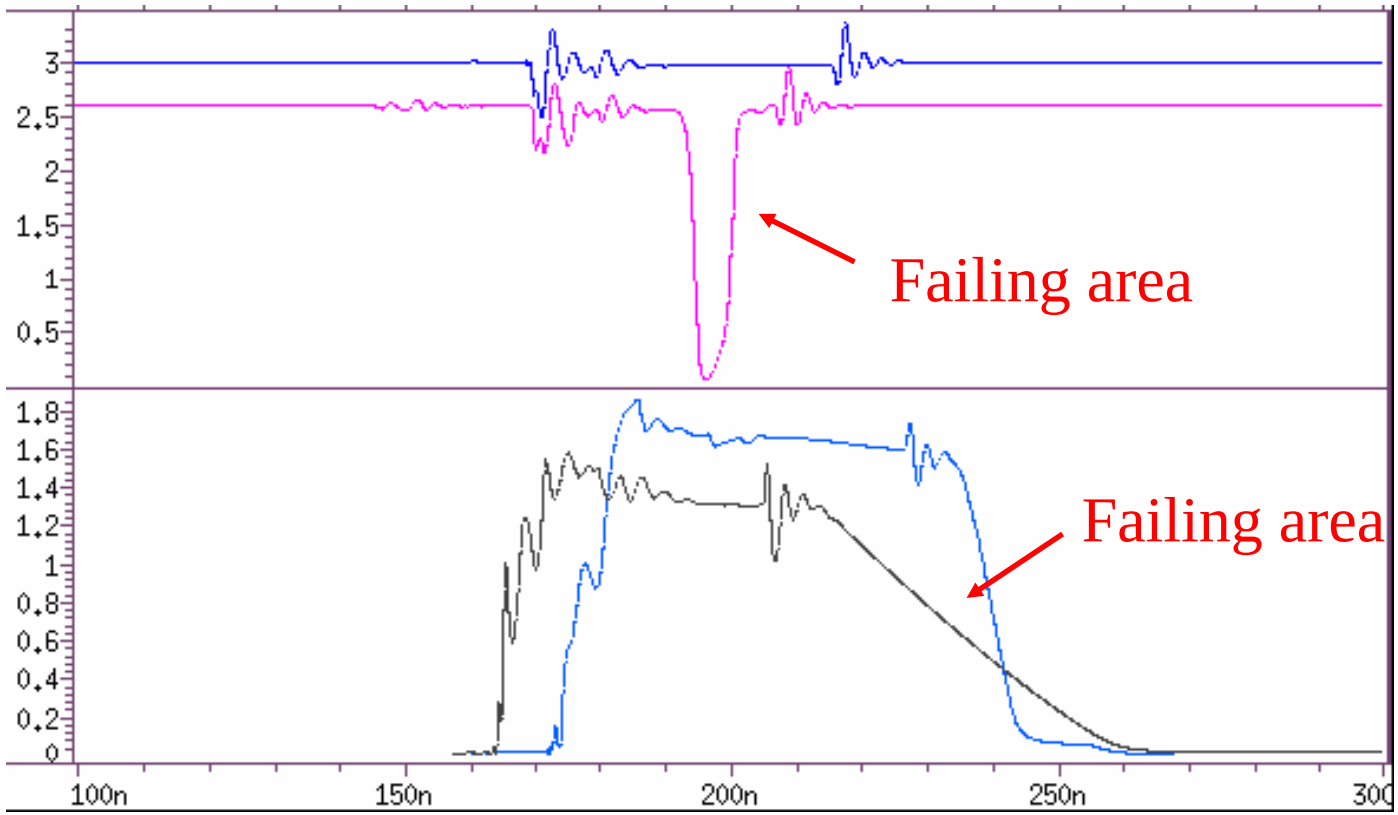
Test name	Total signal	#Iter. of CGNR	Max. run time (sec)	Errors detected	Real errors
PatTest1	12	140	173	1	1
PatTest2	12	50	78	0	0
PatTest3	12	55	153	1	1
PatTest4	5	12	1	0	0

Pattern Compare Results



No error reported

Pattern Comparison Results



Summary

- WCOMP compares waveform regarding to functional differences.
  - Can screen out many false alarms and identifies real errors effectively.
- WCOMP has been applied to a flash memory design flow to compare simulations
  - Among different regression runs
  - Among different densities
  - Among different PVT corners
  - Expect its usage to compare pre-silicon simulation waveforms with post-silicon test waveforms.