Functional and Partially-Functional Skewed-Load Tests

Irith Pomeranz
Purdue University
Sudhakar M. Reddy
University of Iowa

Overview

- Overtesting and Functional Broadside Tests
- The Need for Functional Skewed-Load Tests
- Definition of Functional and Partially-Functional Skewed-Load Tests
- Effect of Functional and Partially-Functional Skewed-Load Tests on Fault Coverage
- Conclusion

Overtesting

- Scan allows an arbitrary state to be scanned in. The state may not be reachable during functional operation.
- Detecting delay faults under non-functional operation conditions [Rearick 01, Saxena 03]:
  - May propagate signal-transitions along long functionally-unsensitizable paths.
  - Create higher-than-functional current demands.
- As a result a good chip may fail the test.

Functional Broadside Tests

- A broadside test <s_1a_1,s_2a_2> starts by scanning in s_1. Primary input vectors a_1 and a_2 are applied in functional mode. The state s_2 is the next-state of s_1a_1.
- In a functional broadside test s_1 is a reachable state. The circuit operates under functional operation conditions after s_1 is scanned in [Pomeranz 04,06].

The Need for Other Types of Tests

- The fault coverage achievable with functional broadside tests is lower than that achievable with unrestricted broadside tests.
- Solutions for improved fault coverage that do not consider overtesting:
  - DFT approaches.
  - Using skewed-load in addition to broadside tests.
    - Motivates the definition of functional skewed-load tests.

Existing Variations on Functional Broadside Tests

- Pseudo-functional broadside tests [Lin 05] –
  - The scan-in state is not guaranteed to be a reachable state.
- Partially-functional broadside tests [Pomeranz 09] –
  - A known Hamming distance between the scan-in state and a reachable state guarantees measurable deviation from functional operation conditions. Deviation exists for s_1 and s_2.

Functional Skewed-Load Tests

- A skewed-load test <s_1a_1,s_2a_2> starts by scanning in s_1. The state s_2 is obtained by a single shift of s_1.
- In a functional skewed-load test s_1 and s_2 are reachable state.
- The circuit operates under functional operation conditions under s_1a_1 and s_2a_2.
- However, s_2 is not the next-state of s_1a_1.

Partially-Functional Skewed-Load Tests

- A skewed-load test <s_1a_1,s_2a_2> is partially-functional if s_1 has a known Hamming distance from a reachable state, and s_2 is a reachable state.
- The circuit operates under functional operation conditions under s_2a_2.
- The deviation from functional operation under s_1a_1 is measurable.

Effect on Fault Coverage

- Measured by a fault simulation experiment.
- The ability to avoid overtesting is evaluated based on the switching activity during the capture cycles of the tests.

Fault Simulation Experiment

- Given a test set U of any type and a set of target faults F (transition faults):
- Set T=Φ and swa_max(T)=0.
- Consider the tests in U by order of increasing switching activity. For every test t:
- Perform fault simulation of F under t with fault dropping. If t detects any fault, add t to T and set swa_max(T)=swa(t).

Finite-State Machines Average

- U: Exhaustive functional broadside test set.
- Union of exhaustive functional broadside and functional skewed-load test sets.

type	T	f.c.	swa
func broad	98	92.99	117
+ func skew	121	97.07	109

U for ISCAS-89 Benchmarks

- A deterministic functional broadside test set.
- Union of a functional broadside test set and random partially-functional skewed-load test sets with Hamming distances i=0,1,….
- Switching activity is restricted not to exceed that of the functional broadside test set.
- Reachable and partially-reachable states are computed by a logic-simulation-based process.

Finding Reachable States

- Phase 1: Simulate the non-scan circuit under a random primary input sequence starting from the all-unspecified state. Stop with the first fully-specified state s. $S_{reach}=\{s\}$.
- Phase 2: For every s in S_{reach}, apply N random primary input vectors. Add the next-states to S_{reach}.

Phase 3

- For every s in S_{reach}, find the four shifted versions of s. For every shifted version s_{sh}:
- Check if s_{sh} is reachable from any state in S_{reach}. If so, add S_{sh} to S_{reach}. Otherwise, if s_{sh} is a left-shifted version of s, add the closest found reachable state p_{sh} to S_{reach}.
- The pairs s,s_{sh}, s_{sh},s and p_{sh},s can be used for defining functional or partially-functional skewed-load tests.

Results

circuit	type	i	T	f.c.	swa
s382	func broad	-	79	76.83	209
s382	+ func skew	0	103	84.29	209
s382	+func skew	3	149	90.97	209

circuit	type	i	T	f.c.	swa
s1196	func broad	-	343	99.92	615
s1196	+ func skew	0	566	99.96	615
s1196	+func skew	6	628	100	615

Results

circuit	type	i	T	f.c.	swa
s1423	func broad	-	325	86.51	737
s1423	+ func skew	2	351	87.46	737
s1423	+func skew	16	432	91.22	737

circuit	type	i	T	f.c.	swa
s5378	func broad	-	478	72.55	2757
s5378	+ func skew	45	561	73.40	2757
s5378	+func skew	64	600	73.78	2757

Results

circuit	type	i	T	f.c.	swa
b11	func broad	-	217	83.50	378
b11	+ func skew	1	250	85.57	378
b11	+func skew	2	281	87.98	404
b11	+func skew	3	319	90.00	415
b11	+func skew	5	346	90.60	378
b11	+func skew	6	337	90.71	379
b11	+func skew	7	339	90.82	399
b11	+func skew	9	338	91.04	381

max 459

Conclusion

- We defined functional and partially-functional skewed-load tests to improve the fault coverage of functional broadside tests.
- The fault coverage is improved without exceeding the switching activity of functional broadside tests.