Fault Diagnosis Aware ATE Assisted Test Response Compaction

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Outline

- Motivation and Objective of work
- ATE assisted test response compaction
- Diagnosis aware ATE test response compaction
- Experimental results
- Conclusion

Motivation

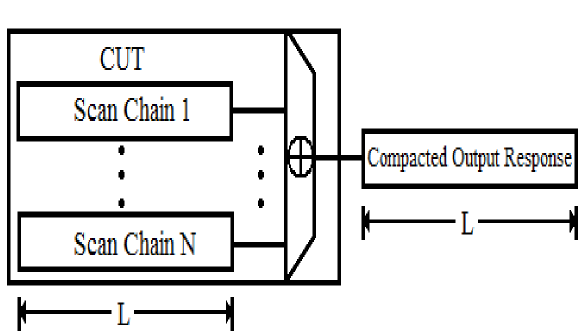
- Excessive test data volume is an issue in testing integrated circuits
  - Limited memory on ATE
  - Replacing ATEs is expensive
- Test data volumes are reduced by using test encoded tests and response compaction
- Reduced test data may still be higher than desired

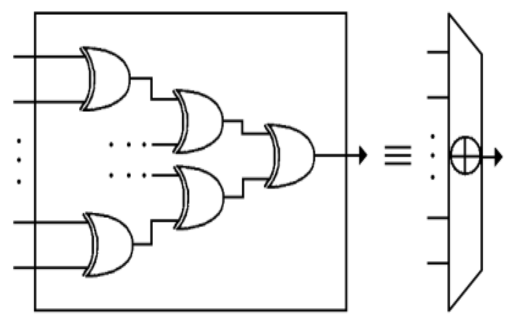
Objective

- Reduce test response data volume post-design-freeze
- Applicable to any design including legacy designs
- Independent of the test generation process

ATE Assisted Test Response Compaction

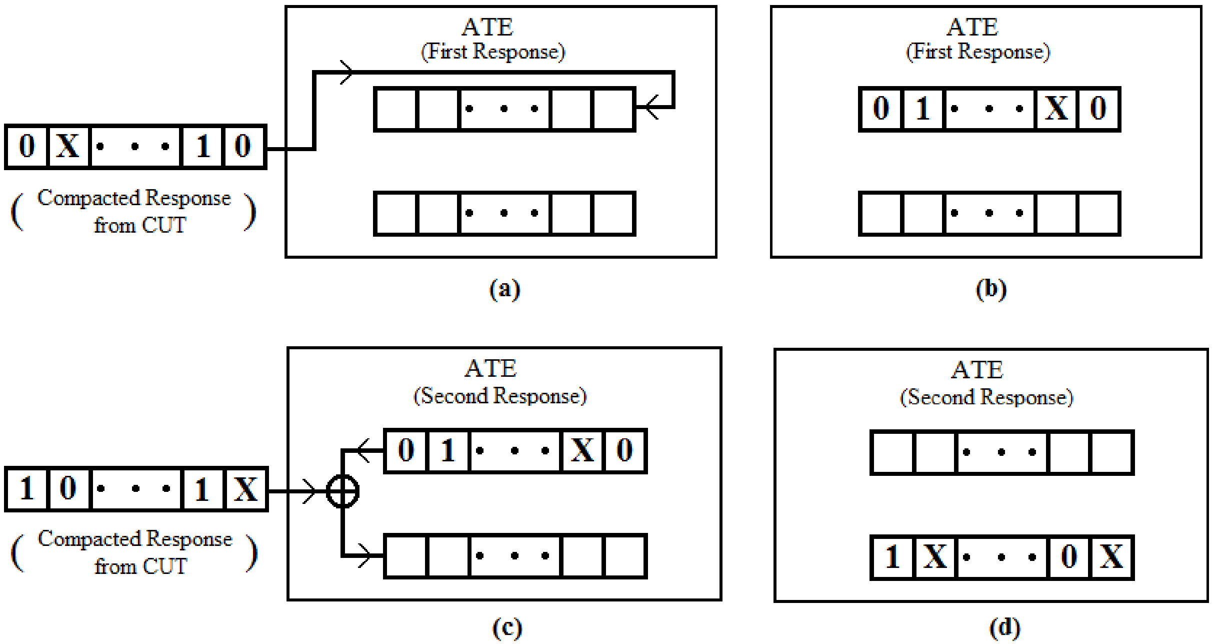
- Assumptions in this work – for simplicity of discussion
  - Single stuck-at faults
  - EOR trees used as compactors
- Technique
  - Store the linear sum (exclusive-OR) of the compacted responses of up to K consecutive tests [VLSI-DAT 2010]





ATE Assisted Test Response Compaction

- ATE Processing - Example



(a) First response of the pair from CUT

(b) First response stored in ATE

(c) Second response of the pair from CUT

(d) Linear sum of the pair of responses to be compared to the fault-free response

Features of ATE assisted compaction

- Up to an additional kX compaction. In this work we used k = 2.
- No additional on-chip logic
- Handles unknown (X) values
- No loss in fault coverage
- Can be used with space or finite memory compactors
- Can also be used with MISR time compactor if a signature is computed for each test

Fault Aware ATE Assisted Test Response Compaction

- Step 1 : {T, R, F, F1, F2}
  - T and R are the set of tests and responses
  - F is the set of detectable faults
  - F1 (F2) are faults detected only once (twice)
- Step 2 : {Rp}
  - Determine the set of pairs of responses not to be merged to avoid detection of faults in F_1 or F_2.

Fault Aware ATE Assisted Test Response Compaction

– Step 3 : Determine Responses to be Merged

- Let Rm be the set of pairs that are merged and Rc be the set of pairs in R but not in Rp
- Let NUM_BFE(ri, rj) be the number of blocked fault effects due to aliasing or masking for a pair (ri, rj) in Rc and MIN_BFE_PAIR(ri, rj) be the pair with minimum NUM_BFE
- Until Rc is empty repeat
- Include MIN_BFE_PAIR(ri, rj) in Rm and dropping faults in F detected by MIN_BFE_PAIR(ri,
- Remove MIN_NUM_BFE(ri, rj) from Rc and add to Rm and update Rc.

Fault Aware ATE Assisted Test Response Compaction

- Step 4
  - Fault simulate all faults in F with the merged responses in Rm and any responses which were not merged
  - Let Fu be the set of faults which are undetected due to merging
- Step 5
  - If Fu is not empty, unmerge pairs in Rm until Fu is empty
  - Let R2 (R1) be the set of merged (unmerged) responses
  - In R1 determine merge maximal number of pairs while maintaining empty Fu

Experimental Set Up

- To make the results on compaction and diagnosis realistic we inject unspecified values in to tests. The unspecified values are randomly set by leaving randomly selected unspecified values in test cubes prior to random filling of the remaining unspecified values.

Results on Compaction

	CR = 10						CR = 30					
	X = 1.0%			X = 2.0%			X = 1.0%			X = 2.0%		
Ckt	ACR1	ACR2	∆CR	ACR1	ACR2	∆CR	ACR1	ACR2	∆CR	ACR1	ACR2	∆CR
s5378	8.72	17.22	1.97	7.56	15.04	1.99	17.83	35.49	1.99	12.29	24.51	1.99
s9234	7.73	15.32	1.98	6.43	12.77	1.93	20.00	39.65	1.98	11.08	22.06	1.99
s13207	9.56	18.96	1.98	9.01	17.82	1.98	22.89	45.62	1.99	18.01	35.74	1.98
s15850	8.78	17.45	1.99	7.78	15.83	1.88	17.37	34.43	1.98	11.84	23.48	1.98
s35932	5.60	8.84	1.58	4.42	6.05	1.37	8.75	14.22	1.63	6.15	9.35	1.52
s38417	8.61	17.12	1.99	7.60	14.41	1.90	15.77	31.30	1.98	9.26	18.08	1.95
s38584	8.39	16.60	1.98	7.25	10.95	1.51	12.54	24.75	1.97	7.35	14.48	1.97

ACR1 – achieved compaction ratio without ATE assisted compaction
ACR2 – achieved compaction ratio with ATE assisted compaction

Results on Diagnosis

- Fault Diagnosis Results for Stuck-at Faults
  - The effectiveness of the technique is shown in a comparison between the size of the equivalence classes for single stuck-at faults
  - Comparisons are made between the on-chip compactor and the fault aware ATE assisted compaction technique

Results on single faults

	CR=10, X = 1.0%						CR=10, X = 2.0%					
	Comp		AAC		Δ		Comp		AAC		Δ	
Ckt	Mx	Av	Mx	Av	Mx	Av	Mx	Av	Mx	Av	Mx	Av
s5378	7	1.11	7	1.12	0	0.92%	7	1.11	7	1.13	0	2.33%
s9234	7	1.25	10	1.26	3	1.36%	9	1.25	10	1.27	1	1.45%
s13207	9	1.22	9	1.23	0	0.88%	18	1.22	18	1.23	0	1.16%
s15850	28	1.22	28	1.23	0	0.88%	28	1.22	28	1.23	0	1.10%
s35932	7	1.45	9	1.46	2	0.99%	6	1.46	10	1.48	4	1.48%
s38417	12	1.12	21	1.13	9	0.87%	13	1.12	16	1.13	3	0.69%
s38584	5	1.09	6	1.09	1	0.46%	6	1.09	7	1.09	1	0.41%

- Comp – On-chip compactor, AAC – Fault aware ATE assisted compaction
- △ - Difference between Comp and AAC
- Mx – Max class size, Av – Average class size

Results on single faults

	CR=30, X = 1.0%						CR=30, X = 2.0%					
	Comp		AAC		Δ		Comp		AAC		Δ	
Ckt	Mx	Av	Mx	Av	Mx	Av	Mx	Av	Mx	Av	Mx	Av
s5378	4	1.12	6	1.15	2	2.80%	4	1.11	5	1.14	1	3.03%
s9234	5	1.25	8	1.27	3	1.43%	7	1.25	10	1.28	3	2.42%
s13207	9	1.23	9	1.28	0	3.85%	13	1.23	19	1.26	6	2.47%
s15850	28	1.22	28	1.23	0	0.79%	28	1.22	28	1.24	0	1.11%
s35932	8	1.43	13	1.47	5	2.81%	11	1.44	25	1.50	14	4.09%
s38417	12	1.11	12	1.12	0	0.90%	17	1.11	17	1.11	0	0.80%
s38584	6	1.09	7	1.09	1	0.76%	5	1.08	7	1.10	2	1.18%

- Comp – On-chip compactor, AAC – Fault aware ATE assisted compaction
- △ - Difference between Comp and AAC
- Mx – Max class size, Av – Average class size

Double stuck-at Faults

- Double stuck-at Fault Diagnosis
  - 10,000 random double stuck-at faults
    - Correctly diagnosed (First_Hit)
    - Not diagnosed in the first three ranks (Not_Diag)
  - Compare diagnosis results for the on-chip compactor and the fault aware ATE assisted compaction technique

Results for Double Faults

	CR=10, X = 1.0%				CR=10, X = 2.0%			
	Not_Diag		First_Hit		Not_Diag		First_Hit	
Ckt	Comp	AAC	Comp	AAC	Comp	AAC	Comp	AAC
s5378	20	31	9937	9931	18	32	9935	9923
s9234	47	48	9929	9922	49	53	9924	9921
s13207	9	14	9971	9962	6	11	9978	9971
s15850	17	24	9959	9952	14	16	9977	9974
s35932	115	120	9875	9870	101	100	9887	9886
s38417	1	5	9988	9983	0	2	9992	9994
s38584	16	17	9982	9981	27	31	9969	9965
Ave	32	37	9949	9943	31	35	9952	9948

Results for Double Faults

	CR=30, X = 1.0%				CR=30, X = 2.0%			
	Not_Diag		First_Hit		Not_Diag		First_Hit	
Ckt	Comp	AAC	Comp	AAC	Comp	AAC	Comp	AAC
s5378	35	46	9885	9855	45	40	9880	9882
s9234	53	57	9915	9905	73	68	9897	9878
s13207	25	37	9940	9919	23	32	9957	9943
s15850	20	26	9948	9936	26	31	9948	9930
s35932	92	104	9889	9877	107	104	9865	9879
s38417	3	10	9985	9968	3	6	9991	9980
s38584	23	20	9971	9970	17	20	9971	9971
Ave	36	43	9933	9919	42	43	9930	9923

Run Times

- Obtaining both decreased test data volume through output response compaction and not impacting fault diagnosis resolution comes with the cost of additional CPU run-time to determine merged responses which minimally impact fault diagnosis resolution

Results on Run Times

	CR=10, X = 1.0%		CR=10, X = 2.0%	
Ckt	AAC (s)	FA-AAC (s)	AAC (s)	FA-AAC (s)
s5378	1.45	80.32	1.92	95.56
s9234	3.20	396.34	3.88	580.25
s13207	16.57	1602.44	18.02	1447.20
s15850	10.35	510.73	12.18	586.24
s35932	27.97	44.22	37.49	96.40
s38417	81.34	4734.72	89.34	3929.08
s38584	99.81	3138.72	119.30	12523.03

AAC – Time required for ATE Assisted Compaction

FA-AAC – Time required for Fault Aware ATE Assisted Compaction

Results on Run Times

	CR=30, X = 1.0%		CR=30, X = 2.0%	
Ckt	AAC (s)	FA-AAC (s)	AAC (s)	FA-AAC (s)
s5378	0.80	72.53	1.18	185.04
s9234	1.35	241.38	2.54	887.22
s13207	7.34	794.56	9.20	1261.38
s15850	5.64	401.92	8.38	1189.48
s35932	18.20	98.74	26.47	128.46
s38417	44.40	2493.73	72.65	7865.89
s38584	70.00	5494.52	112.53	23233.59

AAC – Time required for ATE Assisted Compaction

FA-AAC – Time required for Fault Aware ATE Assisted Compaction

Compaction – Uncollapsed Faults

	CR = 30					
	X = 1.0%			X = 2.0%		
Ckt	ACR1	ACR2	ΔCR	ACR1	ACR2	ΔCR
s5378	16.11	31.76	1.97	12.49	24.70	1.98
s9234	16.32	32.53	1.99	11.15	22.14	1.99
s13207	22.75	45.20	1.99	17.90	35.43	1.98
s15850	17.33	34.34	1.98	11.99	23.75	1.98
s35932	9.07	14.51	1.60	6.10	9.23	1.51
s38417	15.35	29.30	1.91	8.19	15.87	1.94
s38584	11.20	22.07	1.97	6.80	13.48	1.98

Single Fault Diagnosis – Uncollapsed Faults

	CR=30, X = 1.0%						CR=30, X = 2.0%					
	Comp		AAC		Δ		Comp		AAC		Δ	
Ckt	Mx	Av	Mx	Av	Mx	Av	Mx	Av	Mx	Av	Mx	Av
s5378	56	3.59	56	3.64	0	1.51%	56	3.59	56	3.66	0	1.69%
s9234	100	5.11	100	5.19	0	1.61%	100	5.10	100	5.21	0	2.08%
s13207	82	5.25	82	5.33	0	1.45%	82	5.23	82	5.32	0	1.71%
s15850	131	5.23	131	5.31	0	1.57%	131	5.23	131	5.31	0	1.42%
s35932	23	3.55	26	3.66	3	3.17%	25	3.57	25	3.73	0	4.34%
s38417	69	4.13	69	4.15	0	0.54%	69	4.13	69	4.16	0	0.84%
s38584	53	3.30	53	3.32	0	0.56%	53	3.29	53	3.33	0	1.07%

Conclusion

- Close to 2X additional compaction
- Does not require additional on-chip logic
- Does not compromise fault coverage
- Does not compromise fault diagnosis resolution compared to on-chip compaction
- Requires reordering of tests.