Fault Isolation Using Tests for Non-Isolated Blocks

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Design methodologies for large designs produce circuits that consist of interconnections of functional blocks. If the blocks are large, as in core-based designs, they may be isolated for testing purposes (e.g., by test wrappers) such that different blocks can be tested independently. However, even if a test wrapper exists, it is advantageous to test functional paths that go through two or more blocks by using test vectors that propagate fault effects through several blocks. This contributes to testing of defects that cannot be detected if each block is tested separately. One of the issues that arises when several blocks are tested by the same test is that of fault isolation. If a test that propagates fault effects through blocks C_1 and C_2 produces a faulty response on the outputs of C_2, the goal of fault isolation is to identify which one of C_1 and C_2 is faulty. Fault isolation is perfect if every faulty response on the outputs of the circuit can be uniquely attributed to a single block. This happens when every pair of faults belonging to different blocks is distinguishable. If faults of different blocks remain indistinguished, fault isolation is not possible when responses equal to the responses produced by these faults are produced by the circuit-under-test.

It may appear that tests for several non-isolated blocks will not be able to isolate faults. In this work, we study this issue and demonstrate that perfect or close-to-perfect fault isolation is possible with tests that propagate fault effects through several blocks.

We use a circuit model where pairs of blocks C_1 and C_2 are connected in series such that C_1 drives C_2. Tests are applied to the inputs of C_1, and faults are detected on the outputs of C_2. For C_1, this means that tests must propagate fault effects from the outputs of C_1 to the outputs of C_2. We study blocks having small numbers of inputs so that we can use exhaustive test sets for the interconnection. In this way, we eliminate effects of test selection and incomplete fault coverage on the ability to isolate faults. We obtained similar results for pairs of circuits with large numbers of inputs. We use single stuck-at faults as the target fault model.

The results of fault isolation are shown in Table 1. Under column *circuit 1* we show the name of C_1, followed by its number of faults and the number of faults of C_1 that are detected on the outputs of C_2. Under column *circuit 2* we show the same information for C_2. Under column *fault pairs* we show the total number of faults pairs, where the first fault of a pair is a detectable fault of C_1 and the second fault is a detectable fault of C_2. We then show the number of fault pairs distinguished, and the percentage of distinguished fault pairs.

From Table 1 it can be seen that for many of the circuit pairs, all the fault pairs are distinguished. This implies perfect fault isolation. In a majority of the remaining cases, the percentage of distinguished fault pairs is larger than 99.80%. This implies that in a vast majority of cases, it will be possible to uniquely attribute a faulty response to one of the blocks. This contradicts the intuitive notion that fault isolation will be poor for interconnected circuits that are tested by propagating fault effects through several blocks.

Next, we attempt to provide an explanation to the high fault isolation ability demonstrated in Table 1. We counted for every detectable fault of each circuit the number of bits where the output response of the faulty circuit is different from the output response of the fault free circuit. For a fault f, we denote this number by $n_{diff}(f)$. We captured the minimum, maximum and average values of $n_{diff}(f)$ computed over all the detectable faults of C_1, and the same parameters for C_2.

In Table 2, we show for each one of the circuit pairs of Table 1 the values of the parameters above. From Table 2 it can be seen that the parameter values are significantly different for the two circuits. This indicates that the faults of C_1 affect the outputs of C_2 in a way that is different from the way the faults of C_2 affect its outputs for the same set of input vectors. This explains the high fault isolation cability.

By adding a small number of observation points on the border between the blocks it is possible to distinguish all the faults and obtain perfect fault isolation. We demonstrate this in Table 3. We show the numbers of faults of C_1 and C_2 that are not distinguished from all the faults of the other circuit. We then show the number of outputs of C_1, and the number of observation points required to distinguish all the remaining fault pairs. It can be seen that in the majority of cases, observation points are required on a small number of outputs to ensure perfect fault isolation.

Table 1: Distinguished fault pairs

circuit 1			circuit 2			fault pairs		
name	flts	det	name	flts	det	total	dist	%dist
add6	260	260	z4	130	130	33800	33800	100.00
alu1	103	103	adr4	146	119	12257	12255	99.98
alu2	213	213	radd	122	120	25560	25560	100.00
dk17	192	107	Z9sym	443	99	10593	10536	99.46
dk17	192	165	adr4	146	103	16995	16995	100.00
dk17	192	190	dk17	172	150	28500	28498	99.99
dk17	192	165	radd	122	105	17325	17325	100.00
dk48	233	193	add6	236	159	30687	30687	100.00
dk48	233	169	adr4	146	88	14872	14871	99.99
dk48	233	217	dk48	233	196	42532	42529	99.99
radd	138	138	rd53	138	138	19044	19044	100.00

Table 2: Numbers of differences

circuit 1				circuit 2			
name	min	max	ave	name	min	max	ave
add6	118	5772	1848.62	z4	40	3852	1020.85
alu1	256	9342	1675.02	adr4	12	7466	1189.73
alu2	2	1820	375.95	radd	4	1259	328.48
dk17	1	29	6.42	Z9sym	1	1020	47.63
dk17	2	1046	116.55	adr4	1	1047	239.72
dk17	1	5836	619.89	dk17	1	4941	416.77
dk17	2	1043	116.67	radd	1	1033	254.76
dk48	2	32785	2704.73	add6	1	32769	9274.64
dk48	2	32778	2274.04	adr4	1	32792	8937.62
dk48	1	359903	27032.73	dk48	1	294505	22056.75
radd	10	389	117.56	rd53	1	225	44.91

Table 3: Adding observation points

		indist flts		circ1 out	
circ1	circ2	circ1	circ2	tot	obs
alu1	adr4	1	2	8	1
dk17	Z9sym	19	32	11	5
dk17	dk17	2	1	11	1
dk48	adr4	1	1	17	1
dk48	dk48	3	3	17	2

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