Center for Reliable Computing

TECHNICAL NOTE

Some Faults Need an IDDQ Test

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Abstract:

Fault Simulation results of different implementations of 2-1 multiplexers and D-latches are presented. These results show that some faults can only be detected by I_{ddq} test. Simulation results also show that the "importance" of I_{ddq} as a test method can vary considerably with implementation.

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Introduction

IDDQ testing has been used in the last several years as a technique to improve quality of CMOS chips [Maxwell 92] [Wiscombe 93], and [Sawada 92]. In CMOS, there are some faults whose presence does not change the functionality of the circuit under test. Some of these cannot be detected (and thus are untestable or redundant). Others that cannot be detected by a Boolean voltage test (since the circuit functionality is correct) can, nevertheless, be discovered by a current test or a delay test [Ma 95] [Hawkins 94]. There are special difficulties in using IDDQ testing: determining the IDDQ threshold, ensuring that the design adheres to IDDQ design rules (so that IDDQ current of fault-free circuits is low enough to be differentiated from IDDQ of faulty circuits), and the increase in fault-free IDDQ values with the shrinking of circuit technology. In this work we examine different implementations of the same circuit to determine how "important" IDDQ is for each of the implementations. Importance of IDDQ for a circuit implementation is measured by the percentage of faults that are only detected by an IDDQ test. We show that regardless of the implementation, some faults can only be detected by an IDDQ test. However, some implementations have a smaller percentage of faults that can only be detected by an IDDQ test. In other words, if we cannot use an IDDQ test, then we will miss fewer faults with such implementations.

In this paper we analyze three different implementations of 2-to-1 multiplexers and three different implementations of D-latches. Multiplexers and D-latches are interesting because there are many different ways of implementing them, and are common in many designs. Our analysis shows that the percentage of faults that require IDDQ for detection vary considerably with different implementations.

In our analysis we perform fault simulation using the CrossCheck fault models, [Sucar 89] and [Chandra 93]. The fault models comprise shorted interconnects (STI), open interconnects (OPI), short-to-power (STP), short-to-ground (STG), transistor stuck-on (SON), and transistor stuck-open (SOP). In the simulations, faults are injected by modifying a copy of the circuit description. The faulty circuits are simulated using HSpice [Kielkowski 94].

The current limit for IDDQ testing is often determined experimentally, by plotting the values of many good and bad dies, and selecting an appropriate threshold that would detect as many faulty circuits as possible without discarding many good ones [Hawkins 89] and [Perry 92]. For our simulations, the current limit is determined by first measuring the maximum observed current for the fault-free circuit and for each faulty circuit (circuit with fault injected). An appropriate threshold is selected based on these numbers.

Multiplexer

A 2-to-1 multiplexer is shown in Fig. 1. Three different 2-to-1 multiplexer implementations were simulated. These are shown in Fig. 2. Two different tests were used in the simulations: an exhaustive test, which contains 8 patterns (EXH), and a test that applies all single bit transitions (STBET or Single Transition Bit Exhaustive Test), which contains 25 patterns. The tests are shown in Table 1. Each test was run twice, once with a cycle time (*cycle time* here is defined to be the time between the application of inputs) of 100 ns, and once with a cycle time of 10 ms. Outputs were measured just before applying the next input. The 100 ns cycle time is a typical test time for a boolean test, and the 10 ms cycle time is needed to allow IDD to settle to its quiescent value. The results of both tests are shown in Table 2 and 3. In these tables several numbers are reported: the total number of faults injected, the number of faults detected when both a boolean and an IDDQ test are done, the number of faults detected when only a boolean test is done, the number of faults detected when only an IDDQ test is done, and the number of faults detected by an IDDQ test but missed by a Boolean test. These tables show that a significant percentage of faults are missed if no IDDQ test is done. The AOI implementation with STBET test had the fewest faults detected by IDDQ missed by boolean test.

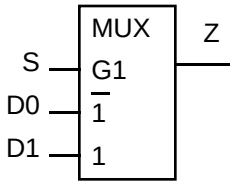

Figure 1 2-to-1 Multiplexer.

Table 1a Exhaustive Test For Multiplexer.

S	0	1	1	0	0	1	1	0
D0	0	0	1	1	0	0	1	1
D1	0	0	0	0	1	1	1	1
Z	0	0	0	1	1	1	1	0

Table 1b Single Transition Bit Exhaustive Test for Multiplexer.

S	0	1	1	0	0	1	1	0	0	0	0	0	1	1	1	1	1	1	0	0	0	0	1	1	0
D0	0	0	1	1	1	1	0	0	1	0	0	0	0	0	0	1	1	1	1	1	0	1	1	0	0
D1	0	0	0	0	1	1	1	1	1	1	0	1	1	0	1	1	0	1	1	0	0	0	0	0	0
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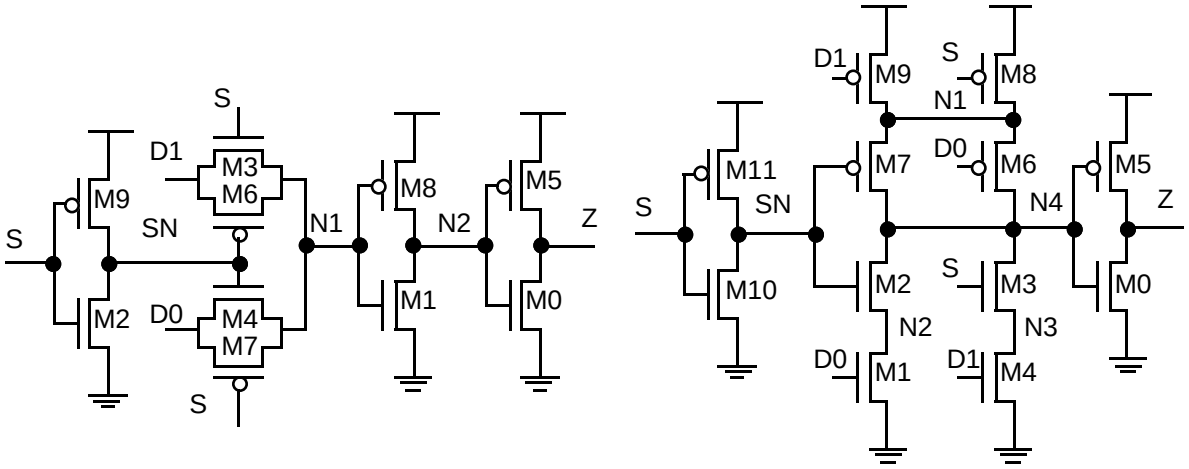
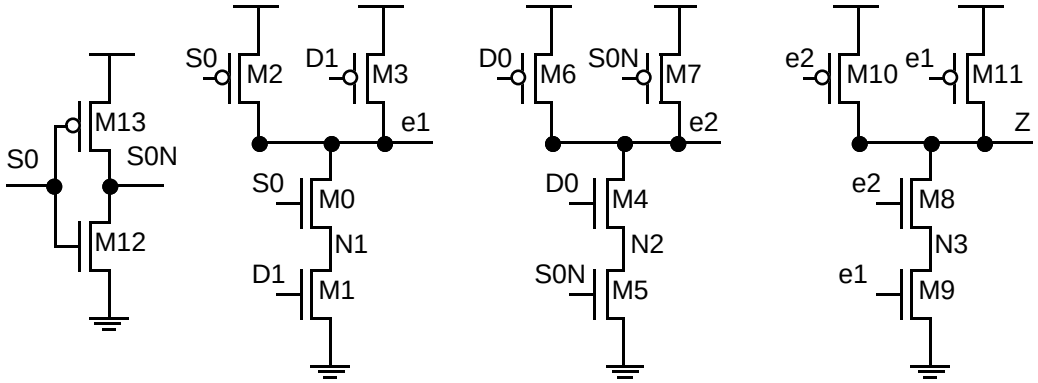


(a) Transmission Gate Implementation **(b) AOI Implementation**



(c) NAND/NAND Implementation

Figure 2 Multiplexer Implementations.

Table 2 Number of Faults for EXH Test on 2-1 Multiplexers.

Impl.	Total Injected	Detected by Boolean and IDDQ	Detected by Boolean Alone	Detected by IDDQ Alone	Undetectable	Detected by IDDQ not by Boolean
a	75	69	47	65	6	22 (31.9%)
b	102	102	78	98	0	24 (23.5%)
c	121	121	95	110	0	26 (21.4%)

Table 3 Number of Faults for STBET on 2-1 Multiplexers.

Impl.	Total Injected	Detected by Boolean and IDDQ	Detected by Boolean Alone	Detected by IDDQ Alone	Undetectable	Detected by IDDQ not by Boolean
a	75	69	47	65	6	22 (31.9%)
b	102	102	86	98	0	16 (15.7%)
c	121	121	100	115	0	21 (17.3%)

D-Latch

The D-latch circuit is shown in Fig. 3. Three different D-latch implementations were simulated. These are shown in Fig. 4. The test used here, shown in Table 4, is a checking experiment from [Makar 95]. A checking experiment guarantees the detection of all faults that do not increase the number of states in the circuit. In [Makar 95], we only presented and analyzed results for the first implementation, and showed that the test detects all detectable faults in the circuit. The other two implementations use the second and third multiplexer implementations

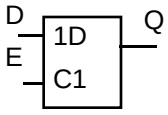
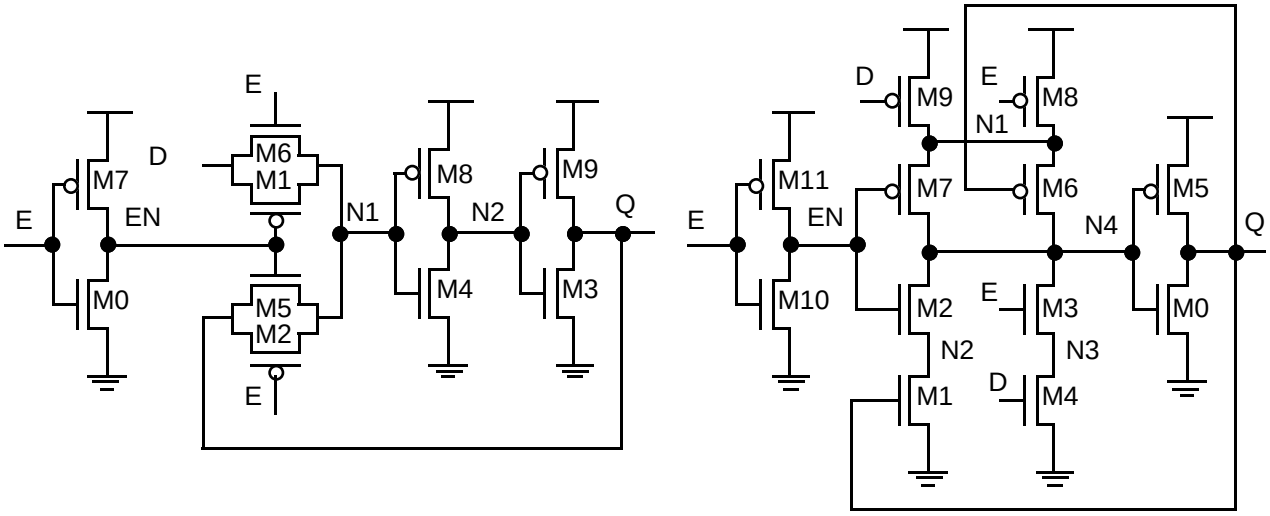
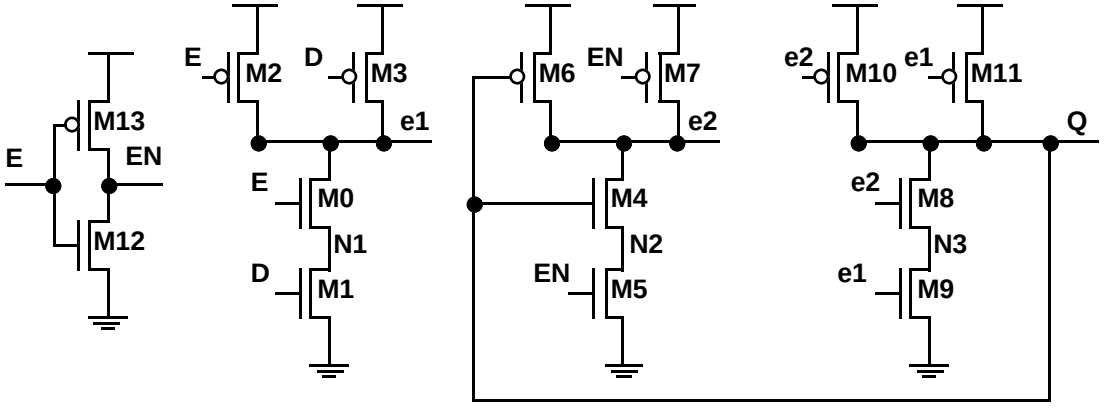


Figure 3 D-Latch Circuit.



(a) Transmission Gate Implementation **(b) AOI Implementation**



(c) NAND/NAND Implementation

Figure 4 D-Latch Implementations

described earlier. The output of the multiplexer is connected to the D0 input and renamed Q, the S input is renamed E (for enable), and the D1 input is renamed D. The results of the simulations are shown in Table 5. As with the multiplexers, Table 5 shows that a large number of faults are missed if no IDDQ test is done. The AOI implementation has the lowest percentage of faults that are detected only by IDDQ measurement.

Table 4 Checking Experiment for D-Latch.

E	1	0	1	0	1	0	0	1	0	1	0	0	1	0
D	0	0	0	0	0	0	1	1	1	1	1	0	0	0
Q	0	0	0	0	0	0	0	1	1	1	1	1	0	0

Table 5 Number of Faults for D-Latch Checking Experiment.

Impl.	Total Injected	Detected by Boolean and IDDQ	Detected by Boolean Alone	Detected by IDDQ Alone	Undetectable	Detected by IDDQ not by Boolean
a	67	66	47	61	1	19 (28.4%)
b	92	92	86	56	0	6 (6.5%)
c	110	110	100	72	0	10 (9.1%)

Conclusion

Simulation results presented in this technical note show that a large number of faults can be missed if no I_{ddq} test is performed. Even though these faults may not affect the functionality of the circuit, they may have an impact on the timing.

Acknowledgments

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