A New Maximal Diagnosis Algorithm for Bus-structured Systems

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Abstract

Complex interconnects in highly integrated system chips are implemented with the bus structures. From a testing point of view, bus-structured systems require more complicated consideration than simple wiring networks since a bus line receives data from many drivers. Therefore, some faults are detected all the time and others are detected only at a particular time. We propose a new interconnect test algorithm for bus structures. The MD+ algorithm supports maximal diagnosis for the bus-structured system and its test period is shorter than the previous algorithms. Moreover, the MD+ algorithm is easy to apply since it is based on a complete diagnosis algorithm for wiring networks. The effectiveness of the MD+ algorithm is confirmed by comparing the test length with previous bus-based interconnect test algorithms.

1. Introduction

Deep submicron technology makes it possible to integrate a system into a single chip, called SOC (System on a Chip). The various modules are integrated in a chip and their complex interconnects are implemented with bus-structured systems. As a point of view for SOC testing, the defects on interconnects are shown as system defects because the current interconnect test is only done through the I/O pins of the SOC. As IEEE 1149.1[1] supports the testing environments for a board level test, IEEE P1500 specifies the same role for a SOC. The interconnect test procedure is executed by applying various interconnect test algorithms through a P1500 interface.

Considerable research [2]-[12] has been conducted concerning the diagnosis of interconnects. They assume stuck-at, stuck-open, and short fault models and the multiple fault models on a net, but it does not include a complete diagnosis of all the faults on the net. This occurs because complete diagnosis is physically impossible, so we focus on a maximal diagnosis. Most of the previous interconnect test algorithms focus on the wiring network. Even in a bus-structured system, each bus line is separately observed as a wiring network [11, 12].

The previous test algorithms are based on interconnect test algorithms for wiring networks such as the counting sequence, the maximal independent test set, and the walking one sequence. The counting sequence and the maximal independent test set are representative interconnect test algorithms with short test lengths. The test length of the counting sequence is only $log_2 n$ and the test length of the maximal independent test set is p, where $C^{p}_{p/2} \geq n$ when n is the number of nets. However, the counting sequence does not perform a full diagnosis because of the aliasing and confounding fault syndromes. The aliasing fault syndrome means that the response of a fault-free net is identical with that of a faulty net, so it is impossible to determine which nets are abnormal or fault-free. The confounding fault syndrome means that a response of a pair of shorted nets is the same as that of another pair of shorted nets, so it is impossible to determine which pairs of nets are shorted to each other. The enhanced counting sequence [3] which removes the aliasing fault syndrome was proposed with the $2log_2 n$ length and the maximal independent test set also removes the aliasing fault syndrome by applying the same number of binary values to each interconnect. However, a complete diagnosis is impossible for them to perform since the confounding fault syndrome still exists. The walking one sequence is a typical diagnosis algorithm. It diagnoses all the general faults along a given wiring network without aliasing and the confounding fault syndromes, but the test period of the walking one sequence is n where n is the entire number of nets, so the test length of the walking one sequence is too long to apply because the test pattern is serially applied.

The previous test algorithms for bus-structured systems are shown in [11] and [12]. In [11], various interconnect test algorithms for wiring networks are selectively used to detect the faults, but the diagnosis is not supported and decisively, the stuck-open fault is not included as a fault model. In [12], all the general faults are considered and the maximal diagnosis is supported. The fault models are categorized as three cases in [12], so the various algorithms are applied to each fault model tested, but the test length is too long and the test process is also complicated.

We propose a new maximal diagnosis algorithm for bus-structured systems. It is based on a complete diagnosis algorithm for wiring networks named GNS (Group Net Shifted) sequence. Using this algorithm, the diagnosis process becomes a simple one and the test length is shorter than the previously described diagnosis algorithms.

This paper is organized as follows. First, the GNS sequence is presented as a complete diagnosis algorithm for wiring networks. Its fault detection and diagnosis methods are also discussed. In chapter 3, fault models of the bus-structured system are described by observing the characteristics of bus-structured systems. In chapter 4, The MD+ algorithm and its diagnosis example are shown. Finally, the effectiveness of the MD+ algorithm is determined by comparing it with the previous algorithms.

2. GNS sequence

The GNS sequence is a complete diagnosis algorithm for wiring networks. The concept of the GNS sequence originates from the grouping of nets. Assume that there are n nets, $N_1, N_2, \cdots, N_n$. Let g be the number of groups and s the number of nets in each of the groups except for the last group. Let $G_1, G_2, \cdots, G_g$ be the groups. Groups $G_1, G_2, \cdots, G_{g-1}$ include s nets and G_g has less than or equal to s nets. The symbol s is determined as $\lceil \sqrt{n} \rceil$ and g is computed as $\lceil (n/s) \rceil$. Therefore N_{pq} represents the q-th net of the p-th group where $1 \le p \le g$ and $1 \le q \le s$.

The GNS sequence is composed of 3 sub-sequences called the group walking sequence (S_g), the net walking sequence (S_n) and the shifted net walking sequence (S_s). In S_g, the same values are applied to all nets within a group and the 1's are applied to g-th bit, so the test length of S_g is g. In S_n, walking sequence is applied to each group, so the test length of S_n is s. Finally, in S_s, walking sequences that have different initial values are applied to each group. Therefore the different serial test vectors(STV) are applied to each q-th net in all groups. The test length of S_s is s, so the total test length of GNS sequence is $g+2s$.

As an example, the GNS sequence for 15 nets is shown in Table 1. In S_g, a walking sequence is applied to G_1, G_2, G_3, and G_4 and the same values are applied to N_{p1}, N_{p2}, N_{p3}, and N_{p4}, where $1 \le p \le 4$. In S_n, since the same walking sequences are applied to each group, the values of N_{1q}, N_{2q}, N_{3q} and N_{4q}, where $1 \le q \le 4$, are the same. In S_s, the walking one sequences of G_1, G_2, G_3, and G_4 start from 0001, 0010, 0100, and 1000 respectively.

There is no STV composed of all 0's or 1's, since three 1's are applied to each net. Therefore all stuck-at faults are diagnosed by simply observing the associated serial response vectors (SRVs). Stuck-open faults are diagnosed by observing the number of 1's in SRVs. In order to fully diagnose short faults, aliasing and confounding fault syndromes should be removed. Since the 1's number of each STV is three, total number of 1's of the each SRV is three for fault-free interconnects. On the other hand, the SRV of a net with a wired-or short fault has a great number of 1's than three, so the 1's number of a fault-free SRV is always different with that of a defective net. As a result, the aliasing fault syndrome is completely eliminated.

Table 1. GNS sequence

Group	Net	S_g	S_n	S_s
G_1	N_{11}	0001	0001	0001
	N_{12}	0001	0010	0010
	N_{13}	0001	0100	0100
	N_{14}	0001	1000	1000
G_2	N_{21}	0010	0001	0010
	N_{22}	0010	0010	0100
	N_{23}	0010	0100	1000
	N_{24}	0010	1000	0001
G_3	N_{31}	0100	0001	0100
	N_{32}	0100	0010	1000
	N_{33}	0100	0100	0001
	N_{34}	0100	1000	0010
G_4	N_{41}	1000	0001	1000
	N_{42}	1000	0010	0001
	N_{43}	1000	0100	0010

Consider the elimination of the confounding fault syndrome. Assume that there are two short faults; one is between N_{pi} and N_{qj} and the other is N_{rk} and N_{sl}. Let SRV(A) and SRV(B) be the responses of the former and the latter, respectively.

Initially assume that $p=q$ which identifies a short fault within a group. In case of $r=s=p$(another short fault within the same group), since two short faults exist in a group, SRV(A) is distinguished from SRV(B) because of the walking sequence in S_n. In case of $r=s \neq p$(another short fault within different group), SRV(A) is different from SRV(B) according to S_g. In case of $r \neq s$(another short fault between two groups), SRV(A) is different from SRV(B) according to S_g, due to the walking sequence. Therefore when $p=q$, there is no confounding fault syndrome.

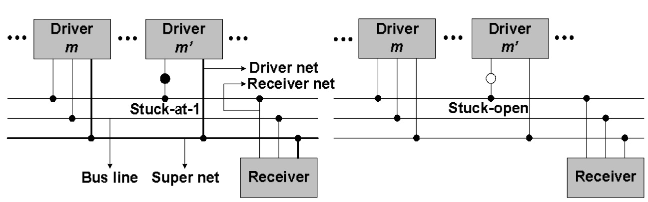
Table 2. Removal of the confounding fault syndrome

Short	Group relationship	S_g	S_n	S_s	Identifier
N_{11}, N_{12}	$p=q$	0001	0011	0011	
N_{13}, N_{14}	$r=s=p$	0001	1100	0110	S_n
N_{21}, N_{22}	$r=s\neq p$	0010	0011	0110	S_g
N_{31}, N_{42}	$r\neq s$	1100	0011	0101	S_n
N_{11}, N_{23}	$p\neq q$	0011	0101	1001	
N_{13}, N_{21}	$p=r,\ q=s$	0011	0101	0110	S_s
N_{11}, N_{43}	$p=r,\ q\neq s$	1001	0101	0011	S_g
N_{33}, N_{42}	$p\neq q\neq r\neq s$	1100	0110	0001	S_g

Now, assume that $p\neq q$ represents a short fault within two groups. There are three possible cases. Without a loss of generality, these possibilities are: 1) $p=r$ and $q=s$, 2) $p=r$ and $q\neq s$, and 3) $p\neq r\neq q\neq s$. In the case of 1), according to the assumption, i is different from k and j is different from l. If $i=l$ and $j=k$, the shorted sequences are the same in S_g and S_n, but SRV (A) is different from SRV (B) in S_s. Otherwise; SRV (A) is different from SRV (B) in S_n. In cases of 2) and 3), SRV (A) is different from SRV (B) in S_g, since different sequences are applied to different groups in S_g. Therefore, the confounding syndrome can be removed.

An example of the GNS sequence for 15 net is shown in Table 2. The shorted nets have unique SRVs and this is confirmed by eliminable factors. A complete diagnosis for the specified wiring network is achieved by applying the GNS sequence, since there are no aliasing and confounding fault syndromes

3. Fault models



(a) An example of a global fault (b) An example of a local fault

Figure 1. Global and local faults

A new fault model needs to be defined for the bus-structured system because the fault models for the simple wiring networks do not work in the same manner for the bus-structured system. They originate from the features of the bus structure shown in Figure 1. A bus line is functionally connected to various wires from the drivers to the receiver. The driver nets are the wires from a driver to the bus lines and receiver nets are the wires from the bus lines to the receiver, so if there are M drivers, a bus line is functionally connected to maximum M driver nets and a receiver net. These functionally connected nets are defined as a super net. To understand the fault character of the bus-structured system, key vocabulary is defined as follows [12]:

Definition 1 *(Global fault) A fault is global if it affects all of the points of a super net*

Definition 2 *(Local fault) A fault is local if it affects only some parts of a super net*

Figure 1 shows an example of both global and local faults. In Figure 1(a), the stuck-at fault can be detected at any point along the first super net, but in Figure 1(b), when driver 1 is driven, the first super net is regarded as a fault-free net even though there is a stuck-open fault on the first driver net of driver 2, so the stuck-open fault is not observed globally.

Consequently, the stuck-at fault is a global fault and the stuck-open fault is a local fault. The local fault creates constraints in detecting and diagnosing faults. However, in Figure 1(b), though the stuck-open fault on the first driver net of driver 2 is not diagnosed by applying the test vector to driver 1, it is diagnosed by applying the test vector to driver 2. In other words, all the global faults are simply diagnosed by applying the test vectors to the master driver, whose driver nets are respectively connected to all the bus lines. Unfortunately, these originate all from a single fault assumption which means a single fault exists on a super net, so the more complicated considerations are needed to deal with such general cases.

The general fault cases on bus-structured systems mean that various faults exist on a super net. All the cases are analyzed by considering the following properties. Let M be the number of drivers and N be the number of bus lines, so the number of wires on a super net except receiver net is maximally $M \cdot N$ driver nets and a bus line. Then we divide a bus line as M sub-bus lines; hence an m-th sub-bus line on the n-th super net is between the n-th driver net ends of the m-th driver and $(m+1)$-th driver. This is illustrated in Figure 2.

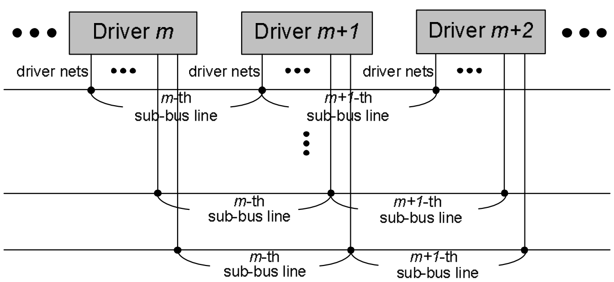


Figure 2. Partitioning of a bus line

Observation 1 *(Stuck-open fault) If a stuck-open fault is on the n-th driver net of the m-th driver and there is another fault – especially stuck-at fault - on the n-th super net, the stuck-open fault is not detected. In the case a short fault, the short fault and stuck open faults are all diagnosed.*

Observation 2 *(Stuck-open fault dominance) If a stuck-open fault is on the m-th sub-bus line on the n-th bus line and the n-th super net is fault-free on the n-th driver net of m+k-th driver and m+k-th sub-bus line, a stuck-open fault is always diagnosed* $(1 \le k \le M\text{-}m)$*. Furthermore if there is a short fault between the bus- lines or driver nets on the same super net, the stuck-open and the short faults are all detected.*

Observation 1 and 2 are shown in Figure 3. The bold lines represent the stuck-at dominance lines. In Figure 3(a), the stuck-at fault is the only one to be diagnosed, so only one fault can be detected and diagnosed in the dominant case. In Figure 3(b), the normal shorted pattern between the first and the third super net is shown at the receiver after driving driver 1, but if driving driver 2, the same pattern from the first driver net of driver 2 is observed from both the first and third receiver net. In this case the short fault and the stuck-open fault are diagnosed at the same time. In a like manner, Figures 3(c) to 3(f) show examples of *observation 2*. In Figure 3(e), the shorted pattern between the first and the third super net is observed at the first receiver net and a stuck-open fault is observed at the third receiver net after driving driver 1. When driver 2 is driven, a fault-free pattern is observed at the receiver nets. Similarly the stuck-at and the stuck-open faults are diagnosed in Figure 3(f). Consequently, the SRVs in Figure 3(b), (e) and (f) are different from simple wiring networks.

From *observations* 1 and 2, the stuck-open fault is treated as a nearest fault to the receiver. It is easily imagined that the stuck-at fault is always dominant when it is a closest fault to the receiver.

Observation 3 *(Short fault on a super net) If there is a short fault between the n-th driver net of the m-th driver and the n-th driver net of the m+k-th driver and no other fault exist on the super net, the super net is shown as a fault-free net* $(1 \le k \le M\text{-}m)$*.*

Observation 4 *(Short fault on a super net with stuck-at fault) If there is a stuck-at fault on the n-th super net under condition of observation 3, the stuck-at fault is diagnosed as if it is the only fault on the super net.*

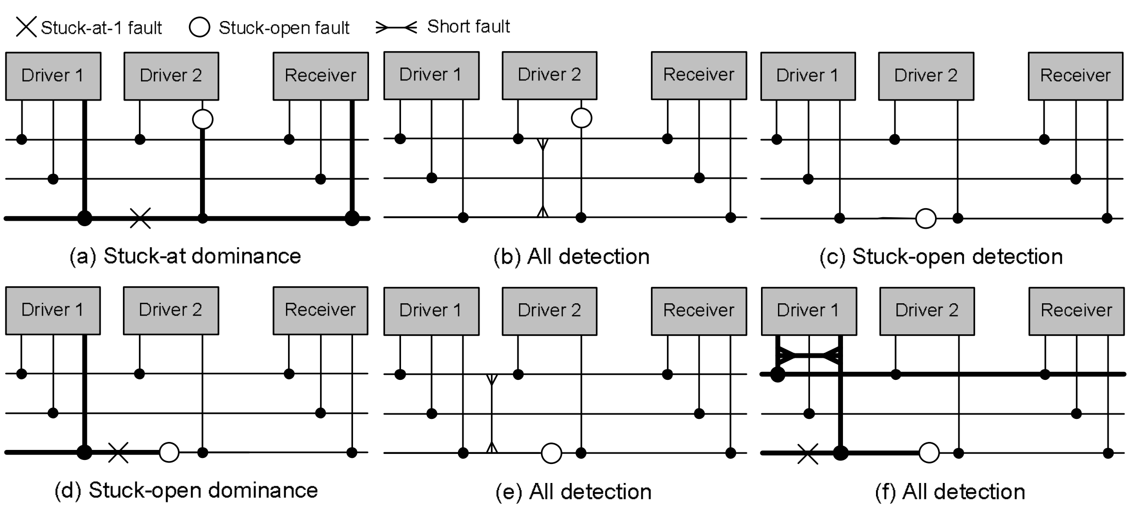
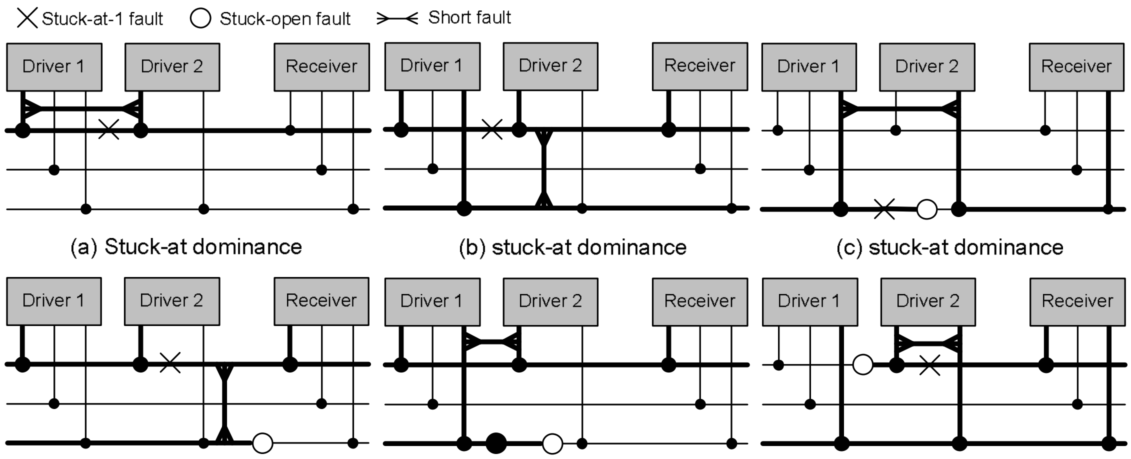


Figure 3. Fault analysis I



(a) Stuck-at dominance (b) stuck-at dominance (c) stuck-at dominance
(d) Stuck-open dominance (e) Stuck-open dominance (f) Stuck-at dominance

Figure 4. Fault analysis II

Observation 5 *(Short fault between different super nets) If there is a short fault between different super nets and no other fault is on the super nets, the short fault is the only fault to be diagnosed.*

Observation 6 *(Short fault between the different super nets with stuck-at fault) If there is a stuck-at fault on the n-th super net under condition of observation 5, the stuck-at fault is diagnosed as if it is the only fault on the super nets.*

Observations 3 to 6 show the dominant characteristics of stuck-at faults and the properties are easily understood by viewing Figures 4(a) and (b). On the basis of these properties, all the cases of the multiple faults are considered by inserting stuck-open faults like the one described in Figure 4(c), (d), (e) and (f).

In conclusion, various forms of fault analysis are available in bus-structured systems like figures 3 and 4, so the fault diagnosis process for bus-structured systems should be redefined.

4. MD+ (Maximal Diagnosis) algorithm

The proposed MD+ algorithm is shown in Figure 5. At first, the GNS sequence is applied to each driver net. Next, received responses are analyzed as shown in the flowchart. After applying all the patterns, we get an SRV list.

The total numbers of SRVs are divided into two groups. The first group is composed of SRVs in which each SRV is unique and the other group is composed of SRVs in which each SRV is not unique. If SRV_{mn} is not unique, there must be faults on the n-th super net. Conversely, if SRV_{mn} is unique and $SRV_{mn} = STV_{mn}$, there is no fault on the n-th driver net of the m-th driver and the m-th sub-bus line on the n-th super net, but this does not mean that the n-th super net is a fault-free net since a super net is composed of m driver nets and m sub-bus lines. Each SRV is analyzed as either a fault-free, stuck-at fault, stuck-open fault, or short fault net. The analytic process ends when all the SRVs are removed from the initial SRV list. Because a stuck-at fault is a global fault, there is no difficulty in diagnosing a stuck-at fault. However, short and stuck-open faults are not detected globally, so more close observation is needed to diagnose these kinds of faults. If there is a stuck-open fault on the m-th sub-bus line on the n-th super net, the stuck-open fault is detected from all the $SRV_{m'n}$ which is $m' \leq m$ and the fault-free response is observed from all the $SRV_{m'n}$ which is $m' \geq m$, so a fault exists on the boundary of the different response types. If SRV_{mn} for all m is the same type; that is either a stuck-at fault or the short fault, there is only a single kind of fault on the n-th super net. On the other hand, if there are various response types on a super net, there must be responses for a fault-free type, so the diagnosis is possible by observing these various fault types.

Figure 6 shows an example of the diagnosis. Stuck-open, stuck-at, and short faults are expressed separately. There are 6 faults on the bus-structured system which include: 4 stuck-open faults, a stuck-at fault and a short fault. All the faults are diagnosed as follows:

At first, the GNS sequence is applied to driver 1 and then the three faults are detected. The results are shown in Table 3. At driver 1, a short fault between super nets 1 and 3, stuck-at 1 fault on super net 2, and a stuck-open fault on super net 3 are detected. The short fault type is only detected on the first super net even though the short fault may be between the first and the third super nets. Therefore it is obvious that a stuck-open fault is not on the driver net but on the super net. These responses are exactly the same until the STVs are applied to driver *m-1*. The stuck-open fault on the second driver net of driver 1 is not detected because of the stuck-at fault dominance on the second driver net of driver *m+1*.

//STV_{mn} is the STV applied to *n*-th super net from *m*-th driver
//SRV_{mn} is the SRV of STVmn
//Apply GNS sequence to each driver set and analyze SRVs
//*M* is the number of drivers and *N* is the number of super nets
//List the whole SRVs Input SRV_{mn} and remove from whole SRV list

Input all SRV_{mn} and remove from whole SRV list

begin

If SRV_{mn} is unique

If SRV_{mn} = STV_{mn}

***n*-th super net is a fault free net**
Add to the diagnosed list

elseif SRV_{mn} is all 0 or all1

There is the stuck-at or the stuck-open fault on *n-th* super net
Add to the stuck-at and the stuck-open fault list

elseif STV_{mn} = $SRV_{mn'}$

here is the stuck-open fault on *n-th* super net or on *n'-th* super net with the short fault between *n-th* and *n'-th* super net
Add to the stuck-open and the short fault list

else

There is the stuck-open fault on *n-th* super net
Add to the stuck-open fault list

endif

Add diagnosed faults to diagnosed fault list

else

If SRV_{mn} is all 0 or all1

There is the stuck-at or the stuck-open fault on *n-th* super net
Add to the stuck-at or the stuck-open fault list

elseif SRV_{mn} = (STV_{mn} U $STV_{mn'}$)

There is the short fault between n-th and *n'-th* super net
Add to the short fault list

elseif STV_{mn}=SRV_{mn}=$SRV_{mn'}$

There is the stuck-open fault on *n'-th* super net and short fault between *n-th* and *n'-th* super net
Add to the stuck-open and the short fault list

else

There is stuck-open fault on *n-th* super net
Add to the stuck-open fault list

endif

endif

//Observe the stuck-open fault list
List the STV_{mn} for whole *m*

A stuck-open fault is on the *n*-th driver net of the *m*-th driver if the $SRV_{(m-k)n}$ is stuck-open fault pattern and $SRV_{(m+1)n}$ is fault-free pattern ($0<k<m$)
A stuck-open fault is on the n-th driver net of the m-th driver if all the SRVs except the SRV_{mn} are fault free pattern
If STV_{mn}=SRV_{mn}=$SRV_{mn'}$ and $SRV_{(m+1)n}$ is (STV_{mn} U $STV_{mn'}$), the stuck-at fault is on the *m*-th sub-bus line of the *n'*-th super net

end

Figure 5. MD+ algorithm

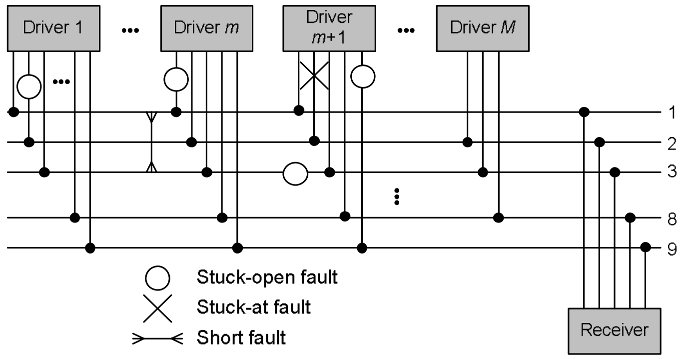


Figure 6. An example of faults on the bus-structured system

From the *m*-th driver, a short fault is no longer detected at the receiver net and the SRV_{m1} indicates a stuck-open fault. This means a stuck-open fault is on the first driver net of the *m*-th driver since the stuck-open fault on the *m*-th driver net is delivered to the receiver net only when a STV is applied to the *m*-th driver. This condition exists because of the local characteristic of the stuck-open fault.

Table 3. STVs and SRVs

Driver / Driver net		STVs			SRVs			Analysis
		S_g	S_n	S_s	S_g	S_n	S_s	
Driver 1	1	001	001	001	001	101	101	Short(1,3)
	2	001	010	010	111	111	111	Stuck-at 1
	3	001	100	100	100	111	101	Stuck-open
	4	010	001	010	010	001	010	Fault-free
	5	010	010	100	010	010	100	Fault-free
	6	010	100	001	010	100	001	Fault-free
	7	100	001	100	100	001	100	Fault-free
	8	100	010	001	100	010	001	Fault-free
	9	100	100	010	100	100	010	Fault-free
⋮		⋮			⋮			
Driver *m*	1	001	001	001	001	100	100	Stuck-open
	2	001	010	010	111	111	111	Stuck-at 1
	3	001	100	100	100	000	010	Stuck-open
	8	010	001	010	010	001	010	Fault-free
	9	010	010	100	010	010	100	Fault-free
Driver *m+1*	1	001	001	001	001	001	001	Fault-free
	2	001	010	010	111	111	111	Stuck-at 1
	3	001	100	100	001	100	100	Fault-free
	8	010	001	010	010	001	010	Fault-free
	9	010	010	100	110	001	111	Stuck-open
⋮		⋮			⋮			
Driver *M*	2	01	01	01	11	11	11	Stuck-at 1
	3	01	10	10	01	10	10	Fault-free
	8	10	01	10	10	01	10	Fault-free

After the test patterns are applied to driver *m+1*, all SRVs from the first and the third super nets are shown as fault-free nets, so the stuck-open faults lie on the first driver net of driver *m* and the *m*-th sub-bus line of the third super net. The short fault is located somewhere before driver *m*+1. The stuck-open fault on the ninth super net is newly detected. This also means that the stuck-open fault lies on the ninth driver net of driver *m+1*, so this fault is no longer detected as originating from another driver. This complete diagnosis process of a bus-structured system is presented in Figure 6.

In Table 3, the test length for driver 1 is 9 and the test length for driver *M* is 6. This condition is due to the various numbers of driven nets. Since the test length of each driver is maximally $3\lceil\sqrt{n}\,\rceil$, the test length of the MD+ algorithm is maximized as $3M\lceil\sqrt{n}\,\rceil$, where *M* is the number of drivers and *n* is the number of the super net.

5. Results

The MD+ algorithm makes diagnosis of any bus structure a simple process. [11] and [12] give the solutions for diagnosing a bus structure, but [11] is not a complete diagnosis algorithm and [12] is complicated and requires a lengthy testing period.

In [12], the maximal independent test set and the walking one sequence are used. It is well known that the maximal independent test set is not a diagnosis algorithm because there are the confounding fault syndromes, but the test length of the maximal independent test set is very short. On the other hand, the walking one sequence is a complete diagnosis algorithm, but the test length of the walking one sequence is too long to efficiently apply, so [12] uses the maximal independent test set first, and then the walking one sequence is used for diagnosing the remaining undetected faults. The net grouping process is also added to obtain a shorter test length. The test lengths of [11, 12] and MD+ algorithm are shown in Table 4. Each parameter is defined as follows:

$$R_s = \begin{cases} 2D & \text{if } n=2^D \\ 2D+\lambda_x & \text{otherwise} \end{cases}$$

where

$$\lambda_x = \begin{cases} n/2^D & \text{Walking one} \\ 2\lceil \log_2 n - D \rceil & \text{Counting + inverse} \\ C^{\lambda_x}_{\lambda_x/2} \geq n/2^D & \text{Maximal independent test set} \end{cases}$$

The symbol *p* is the minimal integer that satisfies $C^{p}_{p/2} \geq n$, and *D* and *M* is the number of the drivers. The symbol *G'* and *K'* are the number of additional PTVs for applying the walking one sequence. They are bounded by *n* where *n* is the number of the super net. The symbol *G'* depends on the probability that a net has a stuck-open or short fault and that we use the 10% which is determined as a realistic value in [12].

All the previous test algorithms categorize three kinds of fault models to be considered as follows:

Table 4. The comparison of test algorithms

Algorithms	Fault models	Fault Detected	Diagnosis	Test length
[11]	A	Yes	No	R_s
	B	Yes	No	R_s
	C	NA	NA	NA
[12]	A	Yes	Yes	$\log_2 n$
	B	Yes	Yes	$p+K'$
	C	Yes	Yes	$D(p+G'+2)$
MD+ algorithm	A	Yes	Yes	$3\lceil \sqrt{n} \rceil$
	B	Yes	Yes	$3\lceil \sqrt{n} \rceil$
	C	Yes	Yes	$3M\lceil \sqrt{n} \rceil$

(A: short, B: short and stuck-at, C: short, stuck-at, stuck-open, NA: Not Available)

Table 5. Test lengths for diagnosis

# of nets		100	200	300	400	500
[12]	All 0/1	2	2	2	2	2
	M. I.	9	10	11	11	12
	W. O.	20	48	73	100	125
	Sum	31	60	86	113	139
MD+ algorithm		30	45	54	60	66

(M. I.: Maximal Independent test set, W. O.: Walking One sequence)

1. Short fault only
2. Short and stuck-at fault
3. Short, stuck-at, and stuck-open fault

For the former two cases, short only, and short and stuck-at are not general cases, so even though the number of PTVs of [12] is relatively small for some cases, we focus on only the general case.

The real numbers of the test length for a single driver are shown in Table 5. Since the number of PTVs is based on a single driver, the number of the drivers should be multiplied to obtain the entire test length. As shown in Table 5, the difference of the test lengths increases as the number of nets grows.

6. Conclusion

The diagnosis for a bus-structured system is a hard and boring process because the diagnosis procedure is complicated and the test patterns are serially applied. In addition, the complete diagnosis of the bus-structured system is impossible because there are multiple fault cases that can not be detected, so maximal diagnosis is a pragmatic final target and it is accomplished by applying diagnosis test algorithms such as the MD+ algorithm.

The MD+ algorithm is a maximal diagnosis algorithm and its testing length is significantly less than the previous test algorithms, so the MD+ algorithm is an effective interconnect test algorithm for bus-structured systems.

7. References

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