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A comparative study on march tests for SRAMS

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Abstract: - SRAMs are widely used in cache memories due to its infinite and very fast read/write operations. The ever increasing density of embedded memories on SoC's (System on Chips) gives rise to many defects and faults which cannot be identified during the fabrication process. The advantages of March tests for fault detection which make it acceptable for industries includes simplicity, high fault coverage and the linearity of test time with memory size.. High reliability is a major concern for memories if they are a part of control units implemented in hazardous environments. Even the occurrence of a single fault may lead to disasters.This emphasizes the importance of comparing and evaluating existing March tests considering all types of faults. All the traditional tests concentrates on the probability of occurrence of a fault rather than its mere occurrence This paper analysis the various types of faults in SRAMs(Static Random Access Memories), evaluates various dedicated March tests considering the percentage of fault detection.

Index Terms: - *SRAMs, static dynamic coupled, March tests.*

I. INTRODUCTION

A Comparative research on different existing march tests concentrating on faults in SRAMs is introduced in this paper. Advanced scaling techniques and shrinking dimensions in embedded memories cause new faults to appear in the core memory and its associated circuits. Due to the area, cost and time constraints for BIST(Built-in-Self Test) schemes in SoC's, the existing march tests concentrate on a particular classification of faults only. This paper compares the efficiency of different march tests to detect different fault models. March tests like SS [3] can detect different types of static single cell and double cell faults with a test length of 22N.March RAW and March RAW1 has a test length of 13N and 26N respectively. The former one detects dynamic single cell and later covers dynamic double cell faults. March AB , an improved version of March RAW detects whole set of dynamic faults detected by AB.It is also able to cover all static faults detected by March SS.March test BDN ,which is an extended modified version of March AB improves the fault coverage of AB, but maintains the same test complexity.

This paper is organized as follows: Section 2 deals with the basics and background. The classification of faults in SRAM's,definitions and notations, functional fault models and fault primitives are presented in Section 3..Section 4 deals with the results obtained after the comparative analysis of different well known march tests.

II. BASICS AND BACKGROUND

A.SRAM CELL

A 6T SRAM cell array is shown in figure [1]. This cell comprises of two inverters connected back to back, two access transistors, bit lines, word lines and associated circuitry. Defects and hence faults can occur either in the memory array or in the associated peripheral circuits.Faults differ according to the type of defect, their location in the memory structure and also due to the way of performing read/ write operations. We can perform read/ write operations in SRAM cells with the activation of word lines and read/ write logic.

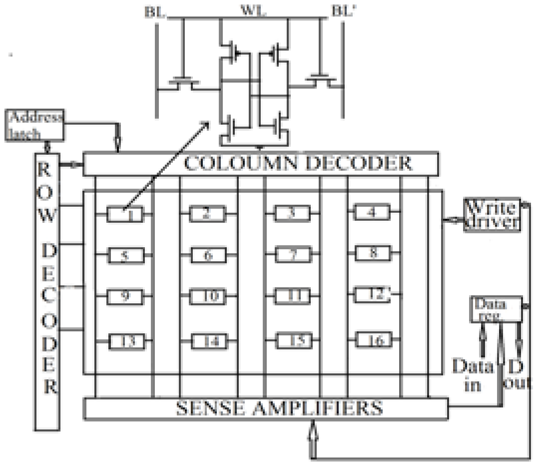

Fig1. SRAM Cell'

B.MARCH TESTS

As explained in [9], a March test is a test algorithm composed of a sequence of March elements which is usually denoted by a ' {...} ' bracket. Each March element [ME] is a sequence of operations applied sequentially on certain memory cell before proceeding to the next one, denoted by using ' (…) 'bracket.The ith operation can be defined as op_i where op_i ε {rd, wd}, 'rd' means read the contents of the memory cell and verify whether it is equal to 'd'.'wd' denotes write 'd'in a particular cell location, where 'd' ε {0, 1}.

C.FAULT NOTATIONS

The concept of functional fault primitives(FP),the compact notation used helps us to precisely define various functional fault models(FFM).For a given memory failure, a combination of S,F,R denoted as <S/F/R> (or <S/F/Rv>) represents FP for a single cell . <S_a; Sv/F/R> (S_a; Sv/F/$R_{a,\ v}$) represents the FP for two cells. ' S ' denotes the operation/value sensitizing the fault. S ϵ {0,1,0r0,0r1,1r0,1r1,0w0,0w1,1w0,1w1}.In the case of two cell FP's, S_a represents the operation (state) of the aggressor cell and S_v represents the operation(state) of the victim cell.' F' denotes the value of the faulty cell due to some sensitizing operation, where F Є{0,1 ↑,↓,?} whereby ↑(↓) represents an up(down) transition..R represents the logical value that appears at the output of the SRAM cell if the sensitizing operation is a read operation where .RЄ{0,1,?,-}.Here,'?' represents random or undefined logical value.A '-' in R represents that the output is not applicable in that case and the sensitizing operation does not contain a read operation.

III. FAULT CLASSIFICATION

Faults can be classified as simple static faults, static coupled faults, dynamic faults, dynamic coupled faults and faults associated with peripheral circuitry. Peripheral circuits of SRAMs includes address decoders, read/write control logic, sense amplifiers etc.

1) Simple static faults: Faults which cannot influence each other come under simple static faults.Static fauls are those FP's which can be sensitized by performing at most one operation. ***Case 1:***If the state of a cell is stuck at one, no operation is needed to sensitize the fault.***Case2:***If a read operation causes a cell to flip, one operation will be required to detect the fault.These faults can be classified as static faults.

a) State fault (SF): A cell is said to have a state fault, even if no operation is being performed on the cell, its logic value flips before it is accessed. No operation is needed for the sensitation of the fault.
b) Stuck at fault(SAF): A cell suffers from a stuck –at fault,if the contents of the cell remains stuck at a particular logical value irrespective of the operation performed on it.
*c) No-Access Fault(NF):*A cell suffers from a no access fault if the cell cannot be accessed.
d) Transition fault(TF): A cell suffers from a transition fault if the cell fails to undergo a transition while performing a write operation on the cell.

e) *Write destructive fault(WDF):* A cell is said to have write destructive fault if a non-transition write operation performed in a particular cell causes a transition of its contents.

TABLE 1 FAULT PRIMITIVES OF SINGLE CELL STATIC FAULTS x€ {0, 1}

Type of fault	FFM		FP's
Simple static faults	**State fault**	**SF**	**<0/1/->,<1/0/->**
	Stuck-at-fault	**SAF**	**<∀/1/->,<∀/0/->**
	No access fault	**NAF**	**{<0w1/0/->,<1w0/1/->,<rx/x/?>}**
	Transition fault	**TF**	**<0w1/0/->,<1w0/1/->**
	Write destructive fault	**WDF**	**<0w0/↑/->,<1w1/↓/->**
	Read destructive fault	**RDF**	**<r0/↑/1>,<r1/↓/0>**
	Deceptive read destructive fault	**DRDF**	**<r0/↑/1>,<r1/↓/1>**
	Random read destructive fault	**RRDF**	**<r0/↑/?>,<r1/↓/?>**
	Incorrect read fault	**IRF**	**<r0/0/1>,<r1/1/0>**
	Random read fault	**RRF**	**<r0/0/?>,<r1/1/?>**
	Data retention fault	**DRF**	**{<1T/↓/->,<0T/↑/>,<xT/?/->}**
	Undefined state fault	**USF**	**<1/?/->,<0/?/->**
	Undefined read fault	**URF**	**<rx/?/0>,<rx/?/1>,<rx/?/?>**
	Undefined write fault	**UWF**	**<0w0/?/->,<0w1/?/->, <1w0/?/->, <1w1/?/->**

f) *Read destructive fault(RDF*): A cell has a read destructive fault if a read operation performed in a particular cell changes the logical value stored in the cell and returns an incorrect value at the output.

g) *Decepive read destructive fault:(DRDF*): A cell suffers from a deceptive read destructive fault if a read operation performed on the cell returns a correct value at the output but changes the data in the cell.

h) *Random read destructive fault(RRDF);* A cell has a random read destructive fault if a read operation performed on the memory cell changes the logical value stored in the cell and returns a random value as output.

i) *Incorrect read fault(IRF):* A cell is said to have an incorrect read fault if a read operation performed on the cell does not change the contents of the cell but returns a incorrect logical value at the output.

j) *Random read fault(RRF):*A cell suffers from a random read fault if a read operation performed on the cell retuns a random value at the output while keeping the correct value within the cell.

k) *Undefined State Fault(USF):*A cell suffers from an undefined state fault, if even if we are not performing any operation on the memory cell ,the contents of the cell flips to an undefined value ,before being accessed.

l) *Undefined Write Fault(UWF***):** A cell has a undefined write fault,if a write operation perforrmed on the cell brings the cell to an undefined state.

m) *Undefined Read Fault(URF):*A cell is said to have an undefined read fault if a read operation performed on the memory cell brings the cell to an undefined state.

n) *Data retention fault(DRF):* A cell has a data retention fault if the contents of the cell changes after a certain time T,before it is being accessed.

*2) Static coupled faults:*Faults related to two cell operations come under static coupled faults.The classification of static coupled faults are as under.

a) State coupling fault(CFst):: Two cells suffers from a state coupling fault if we are not performing any operation on the victim cell or aggressor cell,.the victim cell is forced into a given logic state , only if the aggressor cell is in a logic state.

*b) Undefined State Coupling Fault(CFus):*Two cells are said to have an undefined state coupled fault if we are not performing any operation on the victim cell or aggressor cell,.the victim cell is forced into a given logic state , only if the aggressor cell is in a logic state.

c) Disturb coupling fault(CFds): Two cells are said to have a disturb coupling fault if the the contents of the victim cell flips on application of an operation(read,non-transition write,transition write) performed on the aggressor cell.

TABLE II TABLE OF DOUBLE CELL STATIC FAULTS

Type of fault	FFM		FP's
Static coupled faults	**State coupling fault**	**CFst**	**<0;0/1/->,<1;0/1/->,<;0;1/0/->, <1;1/0/->**
	Undefined state coupling fault	**CFus**	**<0;0/?/->,<0;1/?/->,<1;0/?/->, <1;1/?/->**
	Disturb coupling fault	**CFds**	**<0w0;0/↑/->,<0w1;0/↑/->,<1w0;0/↑/>, <1w1;0/↑/>,<0w0;1/↓/->,<0w1;1/↓/->,<1w0;1/↓/->, <1w1;1/↓/->,<r0;0/↑/->, <r1;0/↑/->,<r0;1/↓/->,<r1;1/↓/->,**
	Undefined Disturb coupling fault	**CFud**	**<0w0;0/?/->,<0w1;0/?/->,<1w0;0/?/->,<1w1;0/?/->, <0w0;1/?/->,<0w1;1/?/->,<1w0;1/?/->,<1w1;1/?/->, <r0;0/?/->,<r1;0/?/->, <r0;1/?/->,<r1;1/?/->**
	Idempotent coupling fault	**CFid**	**<0w1;0/↑/->,<1w0;0/↑/->, <0w1;1/↓/->,<<1w0;1/↓/->**
	Inversion coupling fault	**CFin**	**{<0w1;0/↑/->,<0w1;1/↓/->}, {<1w0;0/↑/->,<1w0;1/↓/->}**
	Transition coupling fault	**CFtr**	**<0;0w1/0/->,<1;0w1/0/->, <0;1w0/1/->,<1;1w0/1/->**
	Write disturb coupling fault	**CFwd**	**<0;0w0/↑/->,<1;0w0/↑/->, <0;1w1/↓/->,<1;1w1/↓/->**
	Read disturb coupling fault	**CFrd**	**<0;r0/↑/1>,<1;r0/↑/1>, <0;r1/↓/0>,<1;r1/↓/0>**
	Deceptive Read disturb coupling fault	**CFdrd**	**<0;r0/↑/0>,<1;r0/↑/0>, <0;r1/↓/1>,<1;r1/↓/1>**
	Random read destructive coupling fault	**CFrrd**	**<0;r0/↑/?>,<1;r0/↑/?>, <0;r1/↓/?>,<1;r1/↓/?>**
	Incorrect read disturb coupling fault	**CFir**	**<0;r0/0/1>,<1;r0/0/1>, <0;r1/1/0>,<1;r1/1/0>**
	Random Read coupling fault	**CFrr**	**<0;r0/0/?>,<1;r0/0/?>, <0;r1/1/?>,<1;r1/1/?>**
	Undefined Read coupling fault	**CFur**	**<0;r0/?/0>,<1;r0/?/0>,<0;r0/?/1>,<1;r0/?/1>,<0;r0/?/?>, <1;r0/?/?>,<0;r1/?/0>,<1;r1/?/0>,<0;r1/?/1>, <1;r1/?/1>,<0;r1/?/?>,<1;r1/?/?>**
	Undefined Write coupling fault	**CFuw**	**<0;0w0/?/->,<1;0w0/?/->,<0;0w1/0/->,<1;0w1/0/->, <0;1w0/?/->,<1;1w0/?/->,<0;1w1/?/->, <1;1w1/?/->**

*d) Undefined Disturb Coupling Fault(CFud):*Two cells are said to have an undefined disturb coupling fault if the victim cell is forced into an undefined state on application of an operation(read,non-transition write,transition write) performed on the aggressor cell.

e) Idempotent coupling fault(CFid): Two cells are said to have an iodempotent coupling fault if the contents of the victim cell flips on application of a transition write operation on the aggressor cell.

f) Inversion coupling fault(CFin): Two cells are said to have an inversion coupling fault if the contents of the victim cell gets inverted on application of a transition write operation on the aggressor cell.

g) Transition coupling fault(CFtr): Two cells are said to have a transition coupling fault if a logic value in the aggressor cell prevents a transition write operation on the victim cell.

h) h) Write destructive coupling fault(CFwd): Two cells are said to have a write distructive coupling fault, if the aggressor cell in a certain logic state ,a non-transition write operation performed on the victim cell results in a transition of the contents of the victim cell.

i) Read destructive coupling fault(CFrd):: Two cells are said to have a read destructive coupling fault, if the aggressor cell in a certain logic state,a read operation performed on the victim cell changes the contents of the victim cell and returns an incorrect value at the output.

j) Deceptive read disturb coupling fault(CFdrd):: Two cells are said to have a deceptive read destructive fault, if the aggressor cell in a certain logic state,a read operation performed on the victim cell changes the contents of the victim cell and returns a correct value at the output.

*k) Random Read Disturb Coupling Fault(CFrrd):*Two cells are said to have a random read disturb coupling fault if the aggressor cell in a certain logic state, a read operation performed on the victim cell changes the contents of the victim cell and returns a random value at the output

l) Incorrect read disturb coupling fault(CFir): Two cells are said to have an incorrect read disturb coupling fault if the aggressor cell in a certain logic state , a read operation performed on the victim cell does not changes the contents of the victim cell, but returns an incorrect value at the output.

m) Random read coupling fault:(CFrr): Two cells are said to have a random read coupling fault if the aggressor cell in a certain logic state, a read operation performed on the victim cell does not changes the contents of the victim cell and returns a random value at the output.

*n) Undefined Read Coupling Fault(CFur):*Two cells are said to have an undefined read coupling fault if the aggressor cell in a certain logic state, a read operation performed on the victim cell brings the victim cell to a undefined state.

o) Undefined Write Coupling Fault(CFuw): Two cells are said to have an undefined write coupling fault if the aggressor cell in a certain logic state, a write operation performed on the victim cell changes the victim cell to a undefined state.

3) Dynamic faults**:** Dynamic faults are those faults that can be sensitized by at least two sequential operations.For example,a dynamic read operation(i.e,a write operation immediately followed by a read operation) changes the logical value stored in the memory cell and returns an incorrect output .Then in this case we need two read operations to sensitize the fault.

a) Dynamic read disturb fault(dRDF): In the case of this fault, a write operation immediately followed by a read operation returns an incorrect output value and changes the data stored in the memory cell.

b) Dynamic deceptive read destructive fault(dDRDF): In the case of this fault, a write operation immediately followed by a read returns a correct output but changes the data stored in the memory cell.

c) Dynamic incorrect fault (dIRF): In the case of this fault, a write operation immediately followed by a read operation, returns an incorrect output but does not change the data stored in the memory cell.

TABLE III FAULT PRIMITIVES OF SINGLE CELL DYNAMIC FAULTS

Type of fault	**FFM**		**FP's**
Simple, dynamic fault	**Dynamic read disturb fault**	**dRDF**	**<0w0r0/1/1>,<1w1r1/0/0>, <0w1r1/0/0>,<1w0r0/1/1>**
	Dynamic Deceptive read disturb fault	**dDRDF**	**<0w0r0/1/0>,<1w1r1/0/1>, <0w1r1/0/1>,<1w0r0/1/0>**
	Dynamic incorrect read fault	**dIRF**	**<0w0r0/0/1>,<1w1r1/1/0>, <0w1r1/1/0>,<1w0r0/0/1>**

*3) Dynamic coupling faults:*The FP's of dynamic faults includes operations performed on the aggressor and victim cell.The classification of dynamic coupling faults are as under:

a) Dynamic Disturb Coupling Fault(dCFds): In the case of this fault,a write operation immediately followed by a read operation on the aggressor cell, causes the victim cell to flip.

*b) Dynamic Read Disturb Coupling Fault(dCFrd):*Two cells are said to have a dynamic read disturb coupling fault if the aggressor cell is in a given state, a write operation immediately followed by a read operation performed on the victim cell returns an incorrect output but changes the logical value stored in the memory .

*c) Dynamic Deceptive Read Disturb Coupling Fault(dCFdrd):*Two cells are said to have a dynamic deceptive read disturb coupling fault if the aggressor cell is in a given state, a write operation immediately followed by a read operation performed on the victim cell returns an correct output but changes the logical value stored in the memory

*d) Dynamic Incorrect Read Disturb Coupling Fault(dCFir):*Two cells are said to have a dynamic incorrect read disturb coupling fault if the aggressor cell is in a given state, a write operation immediately followed by a read operation performed on the victim cell returns an incorrect output but does not affect the logical value stored in the memory.

TABLE IV FAULT PRIMITIVES OF DOUBLE CELL DYNAMIC FAULTS

Dynamic coupled faults	**Dynamic disturb coupling fault**	**dCFds**	**<0w0r0,0/1/->,0w0r0,1/0/->,<1w1r1,1/0/->, <1w1r1,0/1/->,<0w1r1,0/1/->,<1w0r0,1/0/->, <0w1r1,1/0/->,<1w0r0,0/1/->,**
	Dynamic read disturb coupling fault	**dCFrd**	**<0,0w0r0/1/1/>,<1,0w0r0/1/1/>,<1,1w1r1/0/0/>, <0,1w1r1/0/0/>,<0,0w1r1/0/0/>,<1,0w1r1/0/1/>, <1,1w0r0/1/0/>,<0,1w0r0/1/0/>,**
	Dynamic deceptive read disturb coupling fault	**dCFdrd**	**<0,0w0r0/1/0>,<1,0w0r0/1/0>,<1,1w1r1/0/1>, <0,1w1r1/0/1>,<0,0w1r1/0/1>,<1,0w1r1/0/1>, <1,1w0r0/1/0>,<0,1w0r0/1/0>**
	Dynamic incorrect read disturb coupling fault	**dCFir**	**<0,0w0r0/0/1>,<1,0w0r0/0/1>,<1,1w1r1/1/0>, <0,1w1r1/1/0>,<0,0w1r1/1/0>,<1,0w1r1/1/0>, <1,1w0r0/0/1>,<0,1w0r0/0/1>**

IV. RESULTS AND DISCUSSIONS

TABLE V SIMPLE STATIC FAULT DETECTION OF VARIOUS MARCH TESTS

FFM's	**A**	**Q**	**SS**	**C-**	**OP.C -**	**SR**	**iC**	**RAW**	**AB**	**BDN**	**Cd**
SAF	*	*		*	*	*	*				
SOF											
SF			*						*	*	
TF	*	*	*	*	*	*	*		*	*	
RRF		*-			*-	*-					
RDF		*	*	*	*	*	*		*	*	
WDF			*						*	*	
DRF		*			*						
DRDF		*	*		*	*			*	*	
USF											
UWF											
URF											
NAF											
IRF		*	*	*	*	*	*		*	*	

The table V comprises fourteen different types of simple static faults. March Q is an efficient test which can detect nearly 50% of simple static faults.March SS ,AB and BDN detects 42.8% of simple static faults.March RAW concentrates on dynamic faults.iC detects the same set of faults detected by C-.OP.C- detects data retention faults, deceptive read destructive faults and a fraction of the random read faults, in addition to the faults detected by C-.Considering the complete set of fault models March Q and March OP.C- has the highest percentage of fault detection in the case of simple static faults.

TABLE VI STATIC COPLED FAULT DETECTION OF VARIOUS MARCH TESTS

FFM's	A	Q	SS	C-	OP.C-	SR	iC	RAW	AB	BDN	Cd
CFst	*	*	*	*	*	*	*		*	*	*
CFus											
CFin	*										*
Cfid	*										*
Cfds		*	*	*	*	*	*		*	*	
CFud											
CFwd			*						*	*	
CFtr		*	* -	*	*	*	*		*	*	
CFrd		*	*	*	*	*	*		*	*	
CFdrd			*						*	*	
CFir		*	*	*	*	*	*		*	*	
CFuw											
CFur											
CFrr											
CFrrd											

March A can detect SF, TF and a fraction of CFs.In the case of coupling faults, March Q detects 33.3 % of static coupled faults .(state coupling fault, disturb coupling fault,transition coupling fault, read disturb coupling fault,incorrect read disturb coupling fault.)March C-, March OP. C-, March SR and March iC- covers the same set of static coupled faults as detected by March Q.March SS has a better % (~ 46.66%) of fault detection when compared to the above mentioned tests. In addition to the faults detected by March C- it detects deceptive read disturb coupling fault and a fraction of write destructive coupling faults. Compared to all the tests mentioned in this paper, March AB and March BDN have the same percentage of fault coverage as March SS. (46.66%).

TABLE VII SIMPLE DYNAMIC FAULT DETECTION OF VARIOUS MARCH TESTS

FFM's	A	Q	SS	C-	OP.C-	SR	iC	RAW	AB	BDN	Cd
dRDF								*	*	*	
dDRF								*	*	*	
dIRF								*	*	*	
dDRF										*	

In the case of single cell dynamic faults, only March AB, March RAW, and March BDN can detect dynamic faults. All the other tests proposed in this paper either concentrates on simple static faults or double cell static faults. March AB and March RAW detects (75%) of single cell dynamic faults considered in this paper. They detects dynamic read destructive fault, dynamic deceptive read destructive fault and dynamic incorrect read fault.Refering to the different march tests considered, March BDN has the highest fault coverage(100%).

TABLE VIII DYNAMIC COUPLED FAULT DETECTION OF VARIOUS MARCH TESTS

FFMs	A	Q	SS	C-	OP.C-	SR	iC	RAW	AB	BDN	Cd
dCFrd								*	*	*	
dCFdrd								*	*	*	
dCFir								*	*	*	
dCFds								*	*	*	

Among the different March tests considered, only March AB, March RAW, and March BDN can detect dynamic coupled faults. These tests have the same set of fault coverage(100 %).They are capable of detecting dynamic disturb coupling fault , dynamic read disturb coupling fault, dynamic deceptive read disturb coupling fault, dynamic incorrect read disturb fault.

Peripheral faults can occur anywhere in the associated circuits of SRAMs.They can occur in read/write logic,sense amplifier or in address decoder circuits.Another type of fault associated with memory is linked faults. These types of faults do influence each other. In this case, masking occurs i.e. the behavior of a particular fault can change the behavior of another one. Assume that we are performing an operation in cell $c_1$and let it changes the contents of the cell c_v. Now, an operation performed in cell c_2 causes a fault in the same cell but the effect of the fault is just opposite to that caused by c1.In other words, masking will occur in c_v, if we perform an operation in c1 followed by an operation in c_2. No fault will be visible since the fault effect in c1 is masked by that in. c_2.

TABLE IX PERIPHERAL FAULT DETECTION OF VARIOUS MARCH TESTS

FFMs	A	Q	SS	C-	OP.C-	SR	iC	RAW	AB	BDN	Cd
LRF											
ADOF	*			*	*		*			*	
R-AODF	*			*			*			*	
Slow WDF										*	
Bridging fault											
NPSF											
Sense amplifier recovery fault											
Write recovery fault											
Disturb fault											

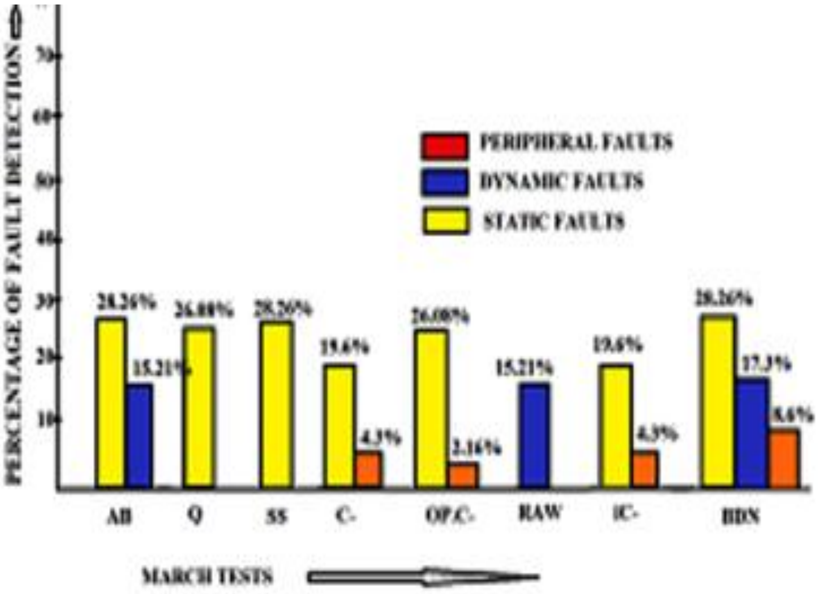

Fig2 PERCENTAGE OF FAULT DETECTION OF VARIOUS MARCH TESTS

V. CONCLUSION

Various March tests have been analyzed and evaluated in this paper. In the case of simple static faults, March Q has the higher percentage of simple static fault coverage. For static coupled faults, March SS, March AB, March BDN have the highest fault coverage when compared to other tests. In the case of simple dynamic faults, March BDN detects the maximum number of faults. When compared to other tests, March RAW, March AB and March BDN have the highest percentage of fault detection for dynamic coupled faults. It is seen that March BDN has the overall highest percentage of fault coverage when compared to all tests.

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