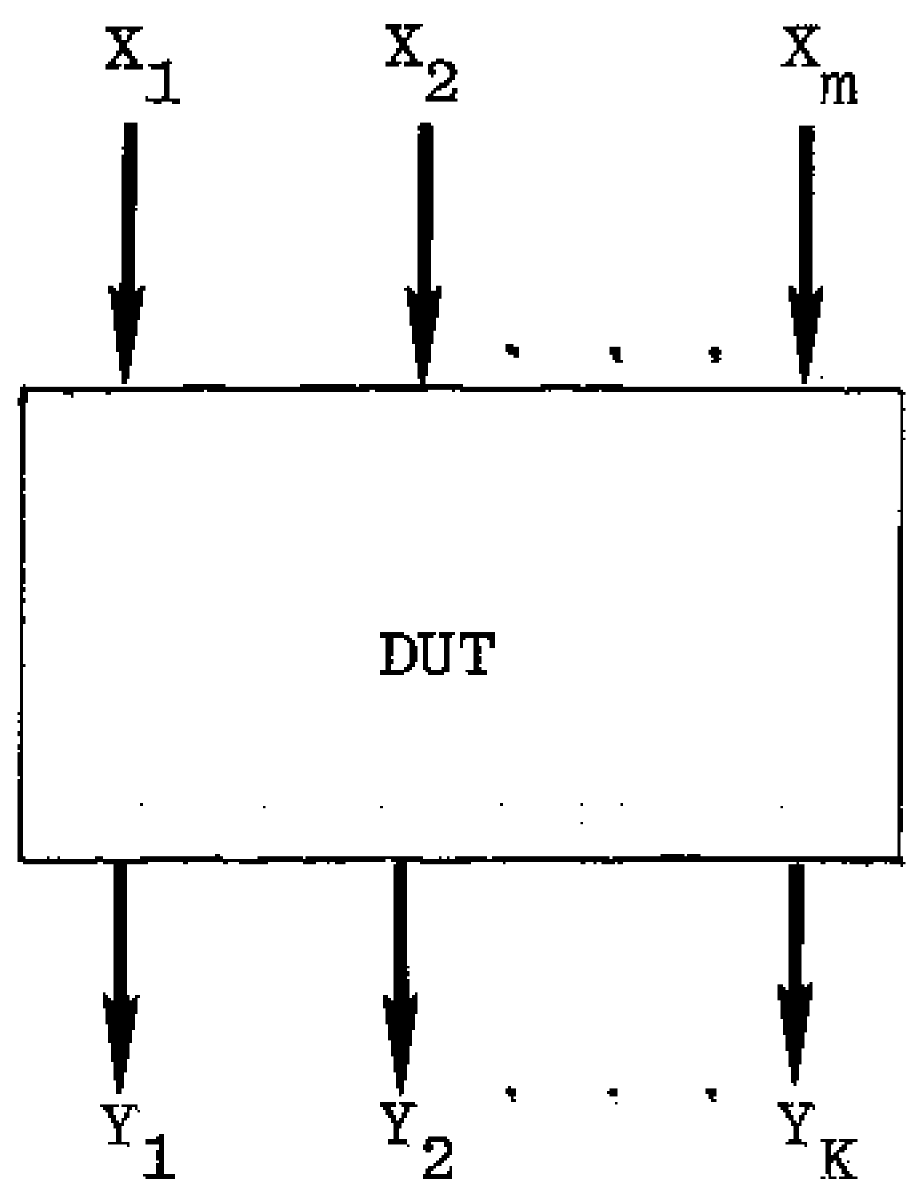
COVER

UNIVERSAL TESTS DETECTING INPUT/OUTPUT FAULTS IN ALMOST ALL DEVICES

M. KARPOVSKY

Computer Science Department
State University of New York
Binghamton, New York 13901

DEVICE - UNDER - TEST



$m \rightarrow \infty$

∴ Combinational networks

∴ Sequential networks with LSSD

∴ Sequential networks, internal states for every test pattern randomly chosen.

FAULT-MODEL

1. Input stuck-at faults
2. Output stuck-at faults

} Single and multiple

3. Input bridgings
4. Output bridgings
5. Feedback bridgings

} (AND and OR-type)

6. Any single input/out fault

DETECTION OF SINGLE INPUT STUCK-AT FAULTS

$N_{IS}^{(1)}(m,K)$ - minimal number of test patterns for detection of all single stuck-at faults in almost all (m,K) - devices.

T1 (i) For any K

$$1 + \left\lceil \frac{\log_2 m}{K} \right\rceil \leq N_{IS}^{(1)}(m,K) \lesssim 2\left\lceil \frac{\log_2 m}{K} \right\rceil .$$

<u>T1</u>. (ii) Test

$$T_{0-1}^{i} = \overbrace{\begin{bmatrix} 0 & 0 & \cdots & 0 & 0 & \cdots & 0 \\ 1 & 0 & \cdots & 0 & 0 & \cdots & 0 \\ 0 & 1 & \cdots & 0 & 0 & \cdots & 0 \\ \vdots & & \cdots & & & \cdots & \vdots \\ 0 & 0 & \cdots & 1 & 0 & \cdots & 0 \\ 1 & 1 & \cdots & 1 & 1 & \cdots & 1 \\ 0 & 1 & \cdots & 1 & 1 & \cdots & 1 \\ 1 & 0 & \cdots & 1 & 1 & \cdots & 1 \\ \vdots & & \cdots & & & \cdots & \vdots \\ \underbrace{1 \;\; 1 \;\; \cdots \;\; 0}_{i} & & & & 1 & \cdots & 1 \end{bmatrix}}^{m}$$

$$i \approx \left\lceil \frac{\log_2 m}{K} \right\rceil - 1$$

is the universal optimal test for single input stuck-at faults

Corollary 1 . If $K > \log_2 m$

$$N_{IS}^{(1)}(m,K) = 2,$$

$$T=T_{0-1}^{0} = \underbrace{\begin{bmatrix} 0 & 0 & \ldots & 0 \\ 1 & 1 & \ldots & 1 \end{bmatrix}}_{m}$$

Example 1 . n-bit combinational adder

$m=2n$, $K=n+1$.

T_{0-1}^{0} detects all single input stuck-at faults

DETECTION OF MULTIPLE INPUT STUCK-AT-FAULTS

$N_{IS}^{(\ell)}(m,K)$ - minimal number of test patterns for detection of all input stuck-at faults with multiplicity up to ℓ in almost all (m,K)-devices .

T2 . (i) $$N_{IS}^{(\ell)}(m,K) \lesssim \left\lceil \frac{2\ell \log_2 m}{K} \right\rceil .$$

delete "i"
add "m"

(ii) Test

$$T_{0-1}^{\,i} = \left.\overbrace{\left[\begin{array}{cccc|c}
0 & 0 & \cdots & 0 & \\
1 & & & 0 & \\
 & 1 & & & \\
 & & \ddots & & 0 \\
0 & & & 1 & \\
\hline
1 & 1 & \cdots & 1 & \\
0 & & & 1 & 1 \\
 & 0 & & & \\
 & & \ddots & & \\
1 & & & 0 & \\
\multicolumn{4}{c}{\underbrace{\hphantom{0\;0\;\cdots\;0}}_{i}} &
\end{array}\right]}^{m}\right\} 2\,(i+1)$$

is the universal optimal test for input stuck-at faults with multiplicity ℓ ,

$$i \simeq \left\lceil \frac{\log_2 \sum_{i=1}^{\ell} \binom{m}{i}}{K} \right\rceil - 1$$

DETECTION OF OUTPUT STUCK-AT FAULTS WITH ANY MULTIPLICITY

N_{OS} (m,K) - minimal number of test patterns.

T3. For randomly chosen test, $K \to \infty$

$$N_{OS}\ (m,K) \simeq \lceil \log_2 K \rceil$$

for any m.

T4. If $m > K$, then

$$N_{OS}(m,K) = 2.$$

Corollary 2. If $m > K > \log_2 m$, then for detection input/output stuck-at faults

$$N_S(m,K) = 3.$$

Example 2. n-bit subtractor

$$Y = X-Z, \quad X>Z, \quad m=2n, \; K=n.$$

Test: $(X = 0\ldots0 \,,\ Z = 0\ldots0)$

$(X = 1\ldots1 \,,\ Z = 0\ldots0)$

$(X = 1\ldots1 \,,\ Z = 1\ldots1)$

DETECTION OF SINGLE INPUT BRIDGINGS

$N_{IB}(m,K)$ - minimal number of test patterns for detection of all single input bridgings in almost all (m,K) - devices.

T5. (i) If $K \to \infty$, then

$$N_{IB}(m,K) \simeq \lceil \log_2 m \rceil .$$

(ii) Universal optimal test is

$$T = T_C = \begin{bmatrix} t_{11} & \cdots & t_{im} \\ \vdots & & \vdots \\ t_{N1} & \cdots & t_{Nm} \end{bmatrix} \qquad N \simeq \lceil \log_2 m \rceil \quad ;$$

Columns of T_C are codewords of an error-correcting code C with the Hamming distance $d \simeq \left\lceil 2 \frac{\log_2 m}{K} \right\rceil$.

<u>Corollary 3.</u> If $K > 2 \log_2 m$, then

(i) $$N_{IB}\ (m,K) = \lceil \log_2 m \rceil ,$$

(ii) the universal optimal test is

$$T = T_1 = \left.\underbrace{\begin{bmatrix} 0 & 0 & 0 & 0 & . & . & . & 1 & 1 \\ 0 & 0 & 0 & 0 & . & . & . & 1 & 1 \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ . & . & . & . & . & . & . & . & . \\ 0 & 0 & 1 & 1 & . & . & . & 1 & 1 \\ 0 & 1 & 0 & 1 & . & . & . & 0 & 1 \end{bmatrix}}_{m}\right\} \lceil \log_2 m \rceil$$

<u>Example 3.</u> n - bit multiplier

$Y = X \cdot Z$, $m = 2n$, $K = 2n$.

T_1 detects all single input bridgings

DETECTION OF OUTPUT BRIDGINGS

WITH ANY MULTIPLICITY

$N_{OB}(m,K)$ - minimal number of test patterns.

T6. For randomly chosen test and any m , if $K \to \infty$, then

$$\lceil \log_2 K \rceil \leq N_{OB}(m,K) \lesssim \lceil 2 \log_2 K \rceil .$$

DETECTION OF SINGLE FEEDBACK BRIDGINGS

$N_{FB}(m,K)$ – minimal number of test patterns

T7. If $m \geq \log_2 K$, then

(i) $N_{FB}(m,K) \sim \lceil \log_2 K \rceil$,

(ii) the universal optimal test is

$$T = T_0^{\,i} = \overbrace{\underbrace{\begin{bmatrix} 0 & 0 & \dots & 0 & 0 & \dots & 0 \\ 1 & 0 & \dots & 0 & 0 & \dots & 0 \\ 0 & 1 & \dots & 0 & 0 & \dots & 0 \\ \dots & \dots & \dots & \dots & \dots & \dots & \dots \\ 0 & 0 & \dots & 1 & 0 & \dots & 0 \end{bmatrix}}_{i}}^{m}$$

$i \simeq \lceil \log_2 K \rceil - 1$.

DETECTION OF ALL INPUT, OUTPUT AND FEEDBACK BRIDGINGS

$N_B\ (m,K)$ - minimal number of test patterns.

T8. If $m > \log_2 K$, $K \to \infty$, then

(i) $\max(\log_2 m, \log_2 K) \lesssim N_B\ (m,K) \lesssim \log_2 K + \max(\log_2 m, \log_2 K)$.

delete
add $\frac{\quad}{k}$ bottom

__T8.__ (ii) The universal optimal test for bridgings is $T = T_0^{\,i} \cup T_C$, where

$$T_0^{\,i} = \begin{array}{c} \overbrace{\qquad\qquad\qquad\qquad\qquad}^{m} \\ \left.\begin{bmatrix} 0\,0 & . & . & . & 0\,0 & . & . & . & 0 \\ 1\,0 & . & . & . & 0\,0 & . & . & . & 0 \\ 0\,1 & . & . & . & 0\,0 & . & . & . & 0 \\ . & . & . & . & . & . & . & . & 0 \\ 0\,0 & . & . & . & 1\,0 & . & . & . & 0 \end{bmatrix}\right\} i+1 \\ \underbrace{\qquad\qquad}_{i} \end{array}$$

$$i \simeq \lceil \log_2 K \rceil - 1$$

$$T_C = \begin{bmatrix} t_{11} & \cdots & t_{1m} \\ \vdots & \cdots & \vdots \\ t_{N1} & \cdots & t_{Nm} \end{bmatrix} \qquad N \simeq \max(\log_2 m,\ \log_2 K),$$

Columns of T_C are codewords of an error-correcting code C

with distance $d \simeq \left\lceil 2\dfrac{\log_2 m}{k} \right\rceil$.

DETECTION OF ALL SINGLE INPUT/OUTPUT STUCK-AT AND BRIDGING FAULTS

$N(m,K)$ - minimal number of test patterns.

T9. If $m > \log_2 K$, then

(i) $\max(\log_2 m, \log_2 K) \lesssim N(m,K) \lesssim \log_2 K + \max(\log_2 m, \log_2 K)$,

(ii) the optimal universal test is $T_0^i \cup T_C$ (the same as for bridgings).

Corollary 4. If $K = rm$ (r = Const), then

$$\log_2 m \lesssim N(m,K) \leq 2 \log_2 m .$$

Examples. Shifters, counters, adders, subtractors, multipliers, dividers, etc. $0.5 \lesssim r \lesssim 1$.

k \ m	30	62	126	254	510
1	54	58	65	73	75
2	37	42	43	50	52
4	30	32	33	37	38
8	28	29	30	31	32
16	26	27	28	29	30
32	26	27	28	29	30
64	27	28	29	30	31
128	29	30	31	32	33
256	30	31	32	33	34
512	31	32	33	34	35

Table I. Minimal numbers of test patterns for detection of all input/output stuck-at and bridging faults with a probability at least $1-2^{-10}$.