Diagnosis of Opens in FPGA Interconnects

Mehdi Baradaran Tahoori
Stanford CRC
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Outline

- Introduction
- Diagnosis
  - Stuck-open and resistive-open
    - Coarse grain diagnosis
    - Fine grain diagnosis
- Summary

Resistive Open

- Imperfect connection between two nodes
- Defect resistance
- Causes:
  - Imperfect Contact
  - Imperfect Via
  - Thin Wire

Modeling

- Delay of defective chain
  \[ \text{Delay} \approx [R_s (V_{DD}) + R_{dev}]C \]
- \( R_s (V_{DD}) \): Transistor turn-on resistance
- Function of \( V_{DD} \)

Terminology

- Delay Delta [Li ITC01]
  Defective Circuit Delay − Good Circuit Delay
- Delay Ratio
  \( \frac{\text{Defective Circuit Delay}}{\text{Good Circuit Delay}} \)
- Detectability metric for resistive open

Virtex FPGA Model
Diagnosis of Opens in FPGA Interconnects

Switch Matrix

<table>
<thead>
<tr>
<th>W1</th>
<th>W2</th>
<th>W3</th>
</tr>
</thead>
<tbody>
<tr>
<td>E1</td>
<td>E2</td>
<td>E3</td>
</tr>
<tr>
<td>S1</td>
<td>S2</td>
<td>S3</td>
</tr>
</tbody>
</table>

New Detection Technique

- Change load capacitance
- Additional fanout paths
- Higher delay ratio

Circuit Model

- One additional fanout
- Turning on one more PIP
- Maximum number of fanouts
- Number of PIPs connected to A

![Circuit Model Diagram]

Delay Ratio

![Delay Ratio Graph]

Diagnosis

- Two-step diagnosis flow
- Coarse-grain diagnosis
  - Defective net
- Fine-grain diagnosis
  - Inside defective net
  - Defective element inside net
  - PIP or line segment

Coarse-Grain Diagnosis

- Buffered WUTs [RATS Spr'01]
  - Wires Under Test
  - Going through FF every m CLBs
- Failing wire
  - Reading FFs contents
    - Scan out
    - Read-back
  - Reading content of all FFs at once
  - Much faster than regular scan-out
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Big Picture
Buffered at every 2 CLBs

Coarse-Grain Diagnosis
- No logic implemented (transparent logic)
  - The first failing clock
  - The first faulty FF
- The faulty WUT
- No extra effort for this diagnosis
  - As a part of test procedure

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Problem Statement
- Input
  - Failing WUT
    - FF + (PIP + Line segment) \(\Rightarrow\) + FF
- Output
  - Exact failing resource in that WUT
    - PIP or line segment

New Technique
- Remove & Reroute
  - Remove some resources from original WUT
  - Reroute the WUT without using those
- If new WUT fails
  - Fault in non-removed resources
- Else
  - Fault in removed resources

Basic Idea
- Original WUT
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**Basic Idea**
- After Removing

![Diagram](image)

**Configuration Generation**
- Removing
  - Remove the resources from configuration file
    - Partially routed net
- Rerouting
  - Let P&R tool complete the net
    - Without using specified resources
    - Marking those resources

**Solution**
- Removing
  - Remove incoming and outgoing PIPs
- Rerouting
  - Mark all PIPs connected to that line
    - Not to be used by P&R

**Automatic Config Generation**
- Problem statement
  - A systematic method to generate
  - A number of configuration
  - Some resources removed
    - Remove&Reroute method
  - Each pass or fail
  - Specify the faulty resource
  - Which resources to remove in each config?
  - How many configurations?
  - How many steps?
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Possible solutions
- Linear Search
  - Remove one element at a time
- Binary Search
  - Divide search space by two in each step

Linear Search
- For N elements
  - Number of steps: N - 1
  - Number of configurations: N - 1

New Technique
- Overlapped Search
  - For N elements
    - $\log_2 N$ configurations
    - $\log_2 N$ steps
  - No dynamic selection of next configuration
    - Unlike binary search

Overlapped Search
- In each configuration i
  - N/2 elements removed
    - Elements with bit i set
  - Failing configurations
  - Binary representation of faulty element

Diagnosis for Resistive Open
- Two-step method
  - Works best for stuck opens
  - Rerouting
    - Longer path
    - Lower delay ratio
New Technique

- Combines
  - Overlapped search
    - For faster diagnosis
    - Less configurations
  - Adding fanout branches
    - Instead of resource removing
    - Better delay ratio

New Technique (con’t)

- Overlapped search + fanouts

Summary

- Diagnosis
  - Two-step flow for stuck opens
    - Coarse-grain diagnosis
    - Fine-grain diagnosis
      - Remove & Reroute technique
        - Fewer configurations and steps
  - Diagnosis for resistive opens
    - Overlapped search + fanouts
      - Fewer number of configurations
      - Better resolution