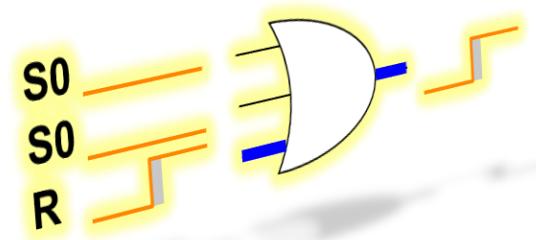


Delay Test

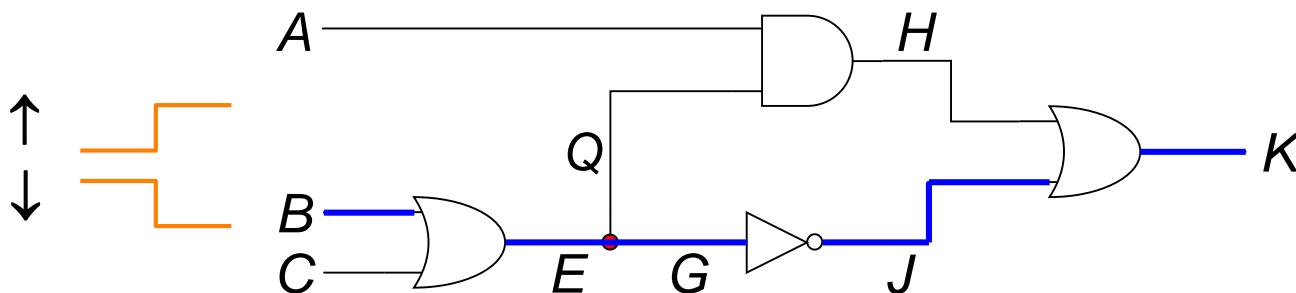
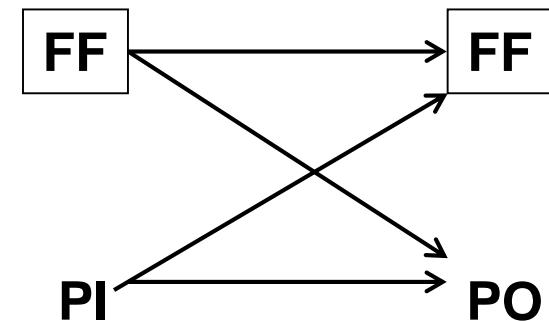
- Introduction and delay fault models
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 - * Nonrobust
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↓
loose
stringent



Path / Path Delay Fault

- What is a **path**?
 - ◆ A serial connection of combinational gates
 - * Begins from a primary input or FF/latch
 - * Ends at a primary output or FF/latch
- Two **path delay faults** for each path
 - ◆ Rising (notation \uparrow)
 - ◆ Falling (notation \downarrow)
- Example: BEGJK is a path
 - ◆ 2 PDF: \downarrow BEGJK, \uparrow BEGJK

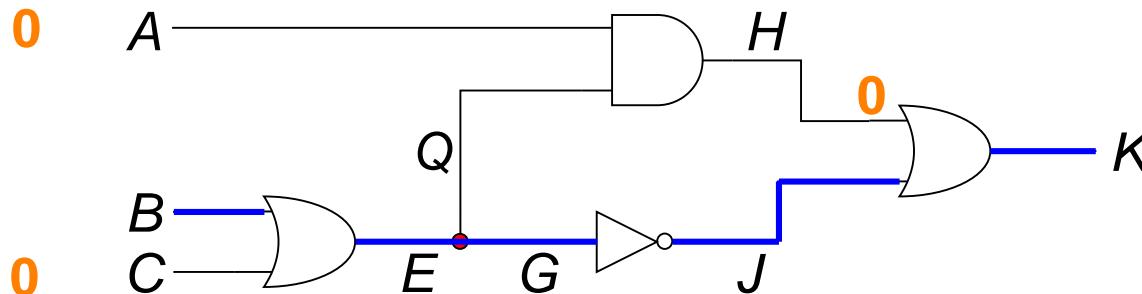


Testable Path

- A path is **testable** if a transition can propagate from input to output along the path under certain **sensitization criteria (condition)**
 - ◆ testable path is also called a **true path**
- If such a test pattern does not exist, the path is **untestable**
 - ◆ Also known as (aka.) **false path**
- Note: there are many different **sensitization criteria**
 - ◆ untestable under criterion A may be testable under criterion B

Static Sensitization Criterion

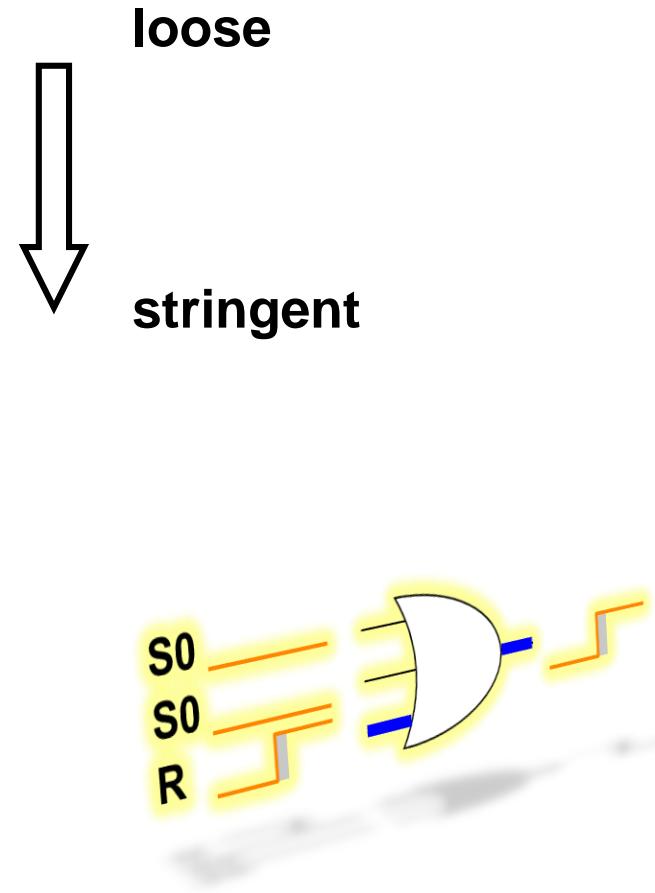
- For a given *target path*
 - ◆ **On-path** signals: on target path (aka. *on-input* to the gate)
 - ◆ **Off-path** signals: not on target path but feed gates on target path (aka. *side-input*, *off-input* to the gate)
- A path is *statically sensitized* if
 - ◆ All off-path signals assume *non-controlling* values
 - ◆ Any signal change on a statically sensitized path is observed
- Example: target path BEGJK is statically sensitized
 - ◆ BEGJK: on-path signals
 - ◆ C, H: off-path signals. They are non-controlling



- NOTE: static sensitization is for one single test pattern only

Delay Test

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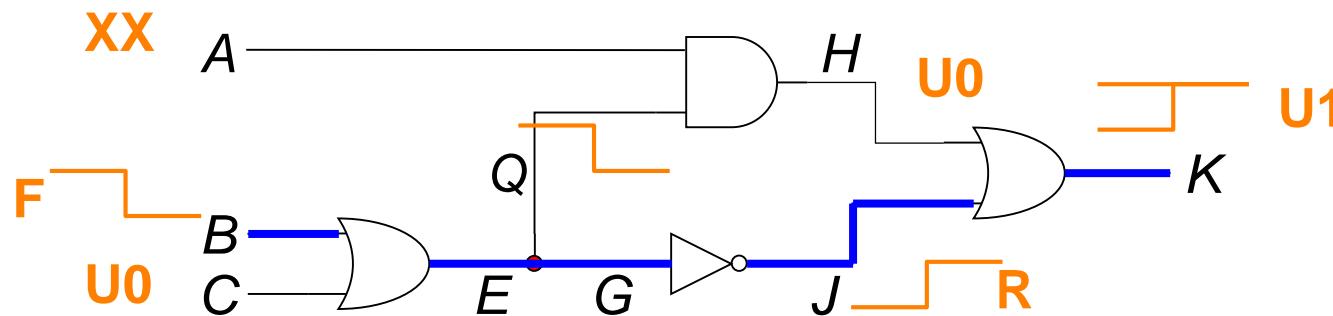


9-valued Logic

- **9-valued logic** for two-pattern test
 - ◆ R: rising $0 \rightarrow 1$
 - ◆ F: falling $1 \rightarrow 0$
 - ◆ U0: $X \rightarrow 0$
 - ◆ U1: $X \rightarrow 1$
 - ◆ S0: static zero , $0 \rightarrow 0$
 - ◆ S1: static one, $1 \rightarrow 1$
 - ◆ 0*: static 0-hazard , $0 \rightarrow 1 \rightarrow 0$
 - ◆ 1*: static 1-hazard, $1 \rightarrow 0 \rightarrow 1$
 - ◆ XX: unknown for both patterns $X \rightarrow X$
- NOTE: there are many different logic systems
 - ◆ More logic values, handles timing more accurately
 - ◆ But more difficult for ATPG

How to Sensitize Path by 2 Patterns?

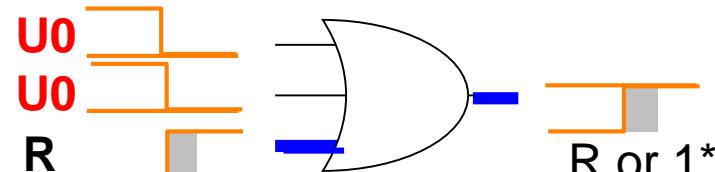
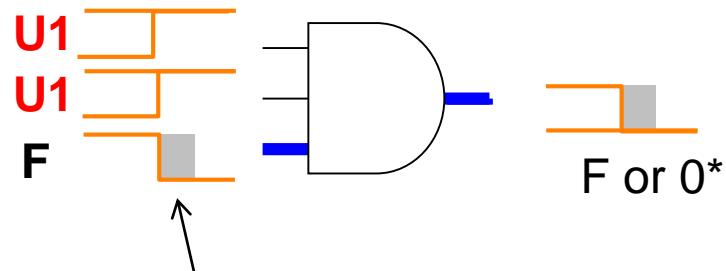
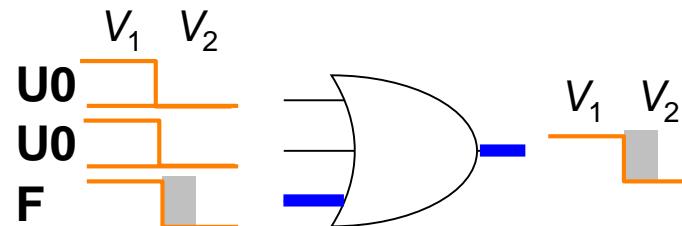
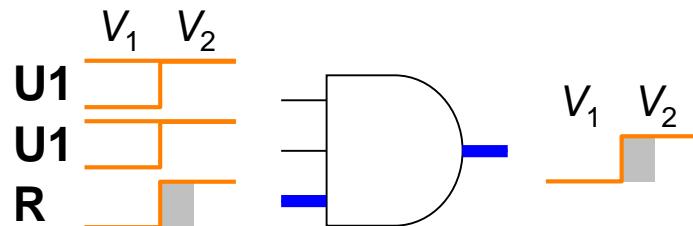
- PDF requires 2-pattern test
- How to sensitize target path in 2-pattern test?
 - ◆ Simple idea: all off-input hold non-controlling (NC) in 2nd pattern
- Example: PDF \downarrow BEGJK
 - ◆ C is U0; H is U0



- Q: K may not have transition?
 - ◆ ANS: a non-robust test may NOT cause gate output transition
 - ◆ When A=0X, K =rising. This is called a *strong* non-robust test.
 - ◆ When A=1X, K =static-1 hazard. This is called a *weak* non-robust test. (not in exam)

Non-Robust Sensitization Criterion

- Non-robust sensitization Criterion: all off-inputs are $x \rightarrow nc$
- Example: target path in blue

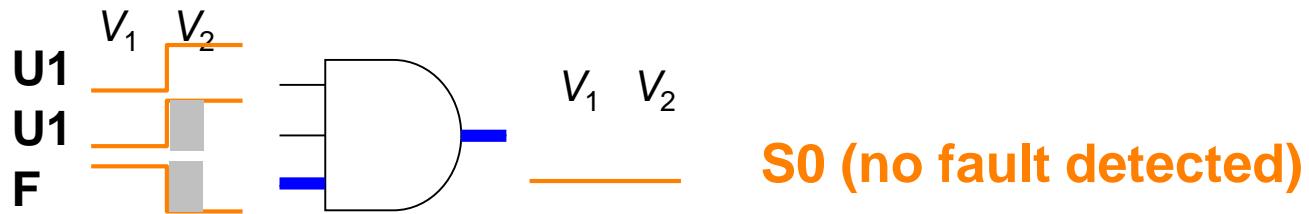


Gray area represents delay fault effect

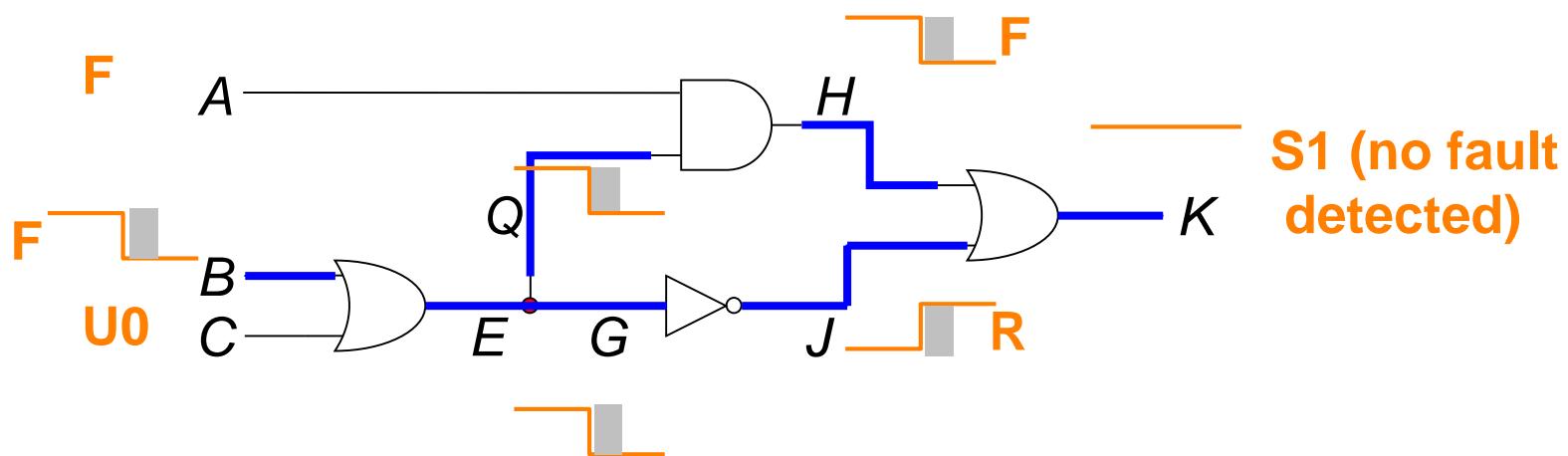
NR Sensitization: off-input is NC in 2nd pat.

Why Non-Robust?

- Non-robust path delay test **CANNOT** guarantee to detect target PDF
 - ◆ test effectiveness depends on other path delay
 - ◆ Test escape when **multiple PDF** exist simultaneously
 - Example: if off-input also has delay fault, NR test is *invalidated*



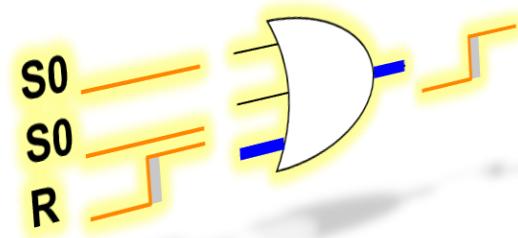
- Example 2: ↓ BEQHK can invalidate NR test for ↓BEGJK



Delay Test

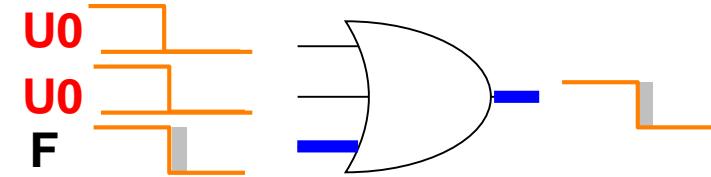
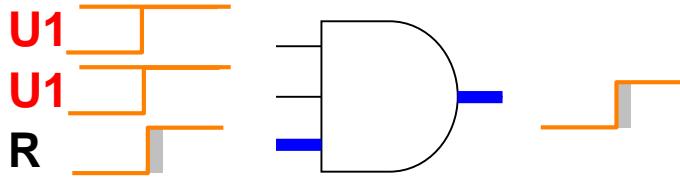
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Need more stringent sensitization criterion than NR!

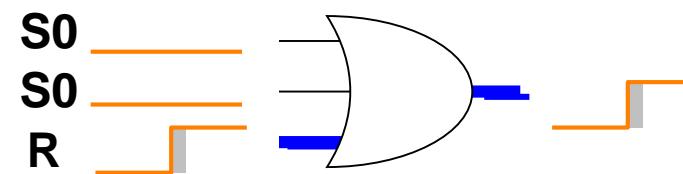
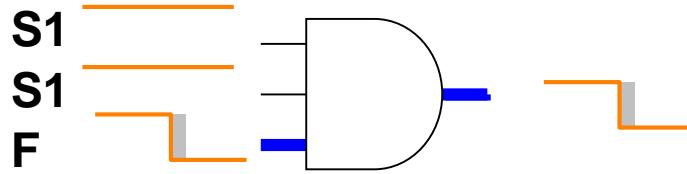


Robust Sensitization Criterion

- Idea
 - ◆ Output *cannot change before the on-input change*
- Robust Sensitization Criterion: (**NC=non-controlling, C = controlling**)
 - ◆ (1) when on-input is $C \rightarrow NC$, off-inputs $X \rightarrow NC$ (same before)



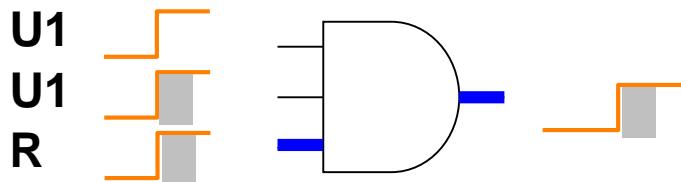
- ◆ (2) when on-input is **NC** \rightarrow **C**, off-inputs **MUST remain NC** \rightarrow **NC**



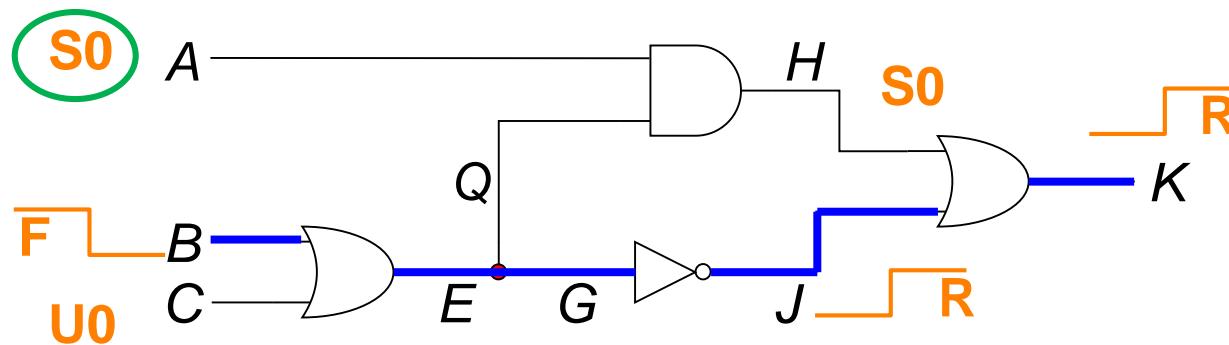
Robust: on-input NC \rightarrow C, off-input keep NC

Why Robust?

- A robust path delay test **guarantees** to detect target PDF,
 - ◆ regardless of other path delay
 - ◆ Because output cannot change before on-input change
- Example: even if both inputs have delay faults, still a valid test



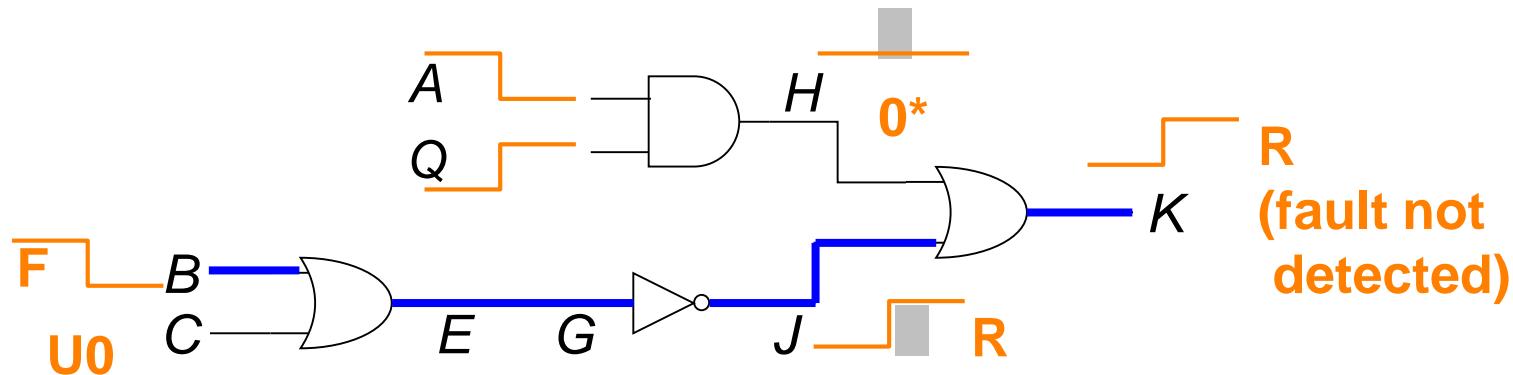
- Example 2: PDF \downarrow BEQHK now can't invalidate robust test for \downarrow BEGJK
 - ◆ A is now S0, instead of XX



Robust test has better quality than NR test

Robust Test Still not Perfect ...

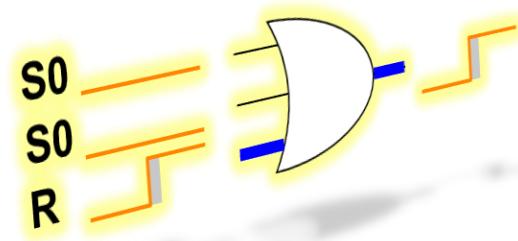
- **Hazard** can still invalidate a robust test
- Example: robust test for PDF ↓BEGJK
 - ◆ But target PDF not detected due to hazard



Delay Test

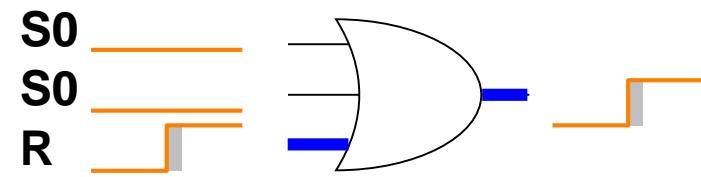
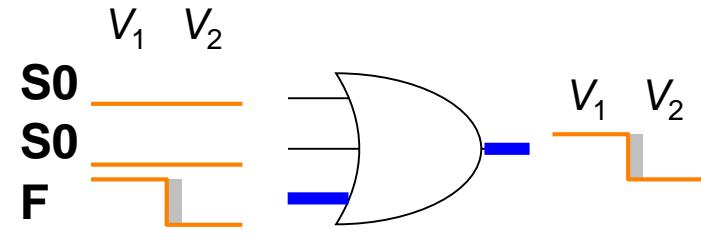
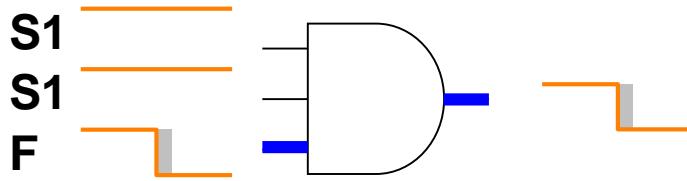
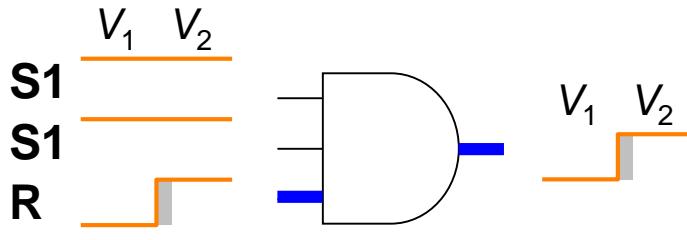
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Need more stringent sensitization criterion than robust!



Hazard-free Sensitization Criterion

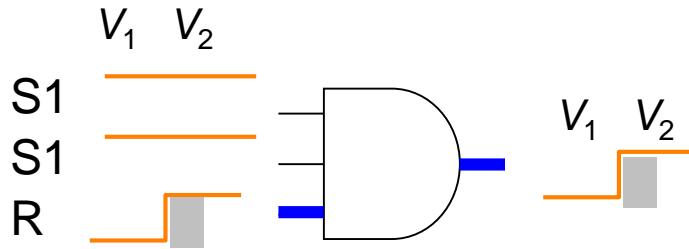
- Criterion: off-inputs are *stable non-controlling* NC \rightarrow NC
 - Regardless on-input values
- Example: target path is blue



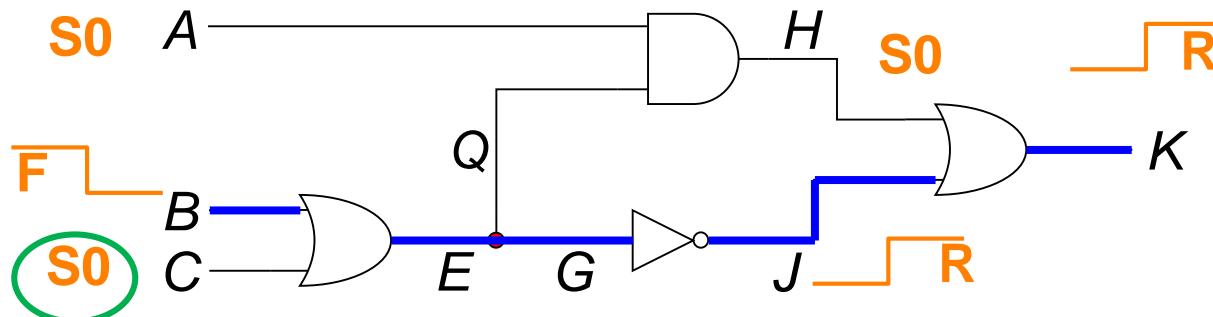
HF test requires off-inputs are stable NC

Hazard-free Path Delay Test

- A hazard-free path delay test guarantees to detect target PDF
 - ◆ regardless of other PDF and hazard
- Example:

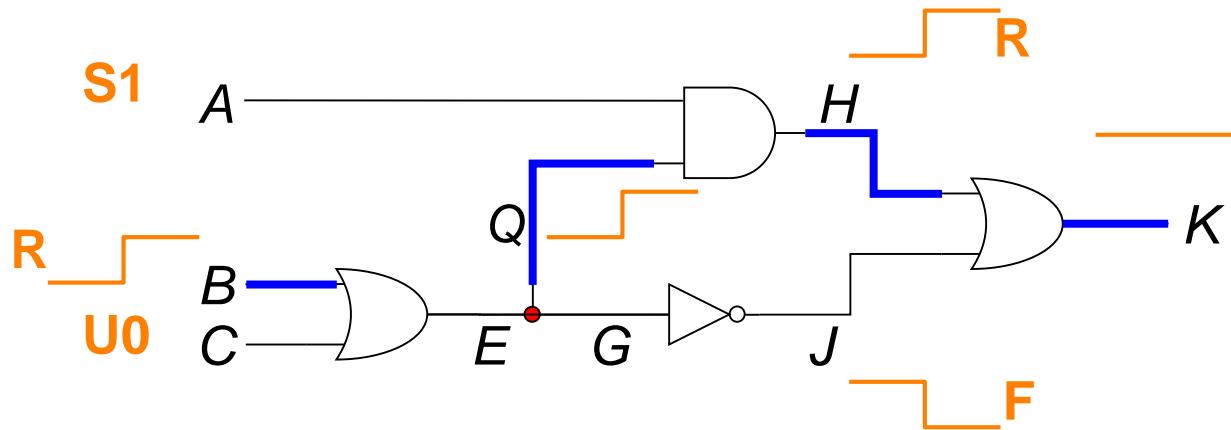


- Example: hazard-free path delay test for $\text{PDF} \downarrow \text{BEGJK}$
 - ◆ C is now S0, instead of U0



Hazard-free Test is Good, but...

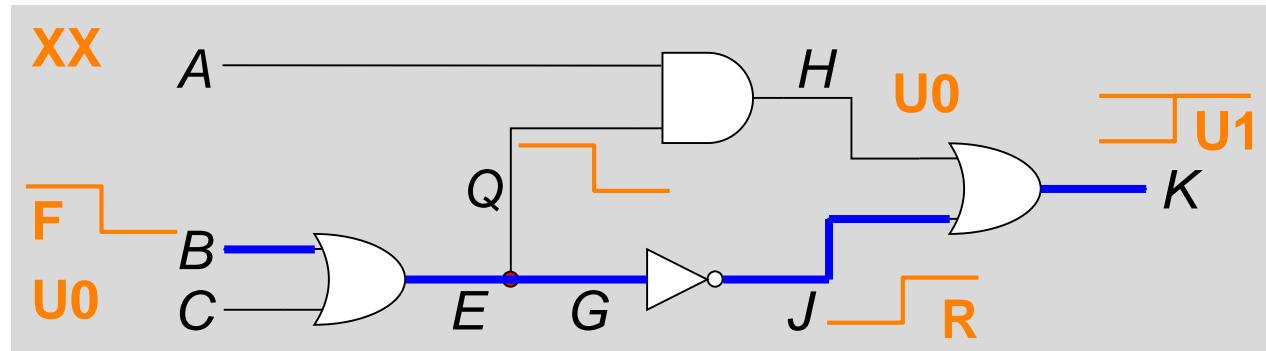
- Only a small number of PDF have hazard-free test
- Example: no hazard-free test for PDF ↓ BEQHK



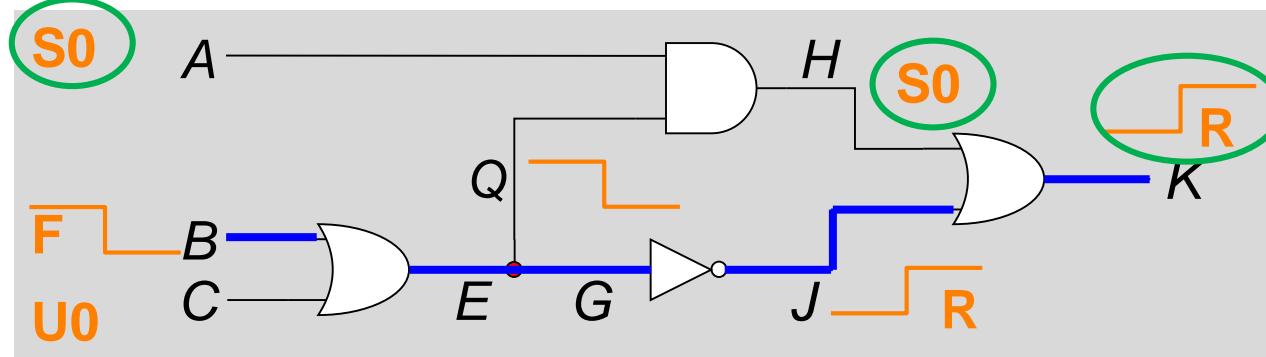
HF tests are good but very few

Summary (PDF ↓ BEGJK)

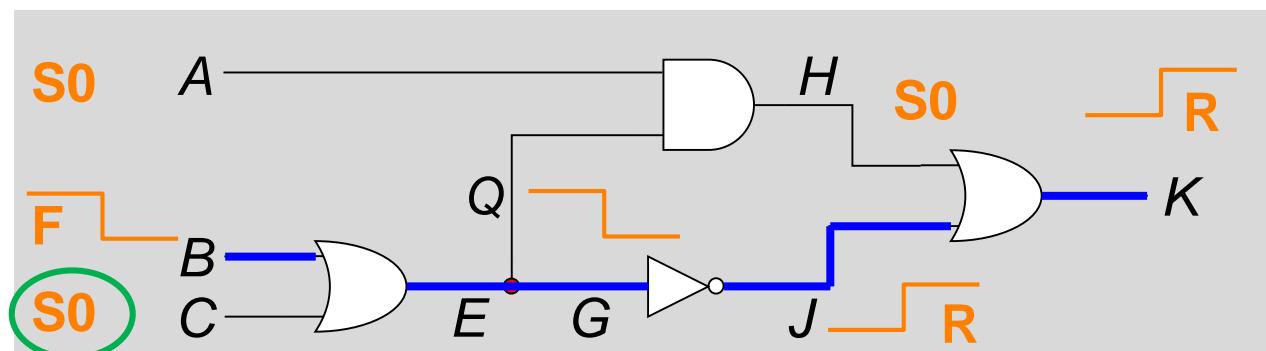
- Non-Robust



- Robust



- Hazard-free

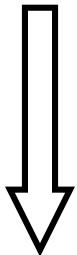


3 Types Path Delay Tests

- A PDF is ***hazard-free testable*** if a test exists such that
 - ◆ all gates on that path are hazard-free sensitized
 - ◆ If no such test, it is ***hazard-free untestable***
- A PDF is ***robustly testable*** if a test exists such that
 - ◆ all gates on that path are robustly (including hazard-free) sensitized
 - ◆ If no such test, it is ***robustly untestable***
- A PDF is ***non-robustly testable*** if a test exists such that
 - ◆ at least one gates on the path is non-robustly sensitized
 - ◆ the other gates on the path are robustly/hazard-free sensitized
 - ◆ If no such test, it is ***non-robustly untestable***

Summary

loose

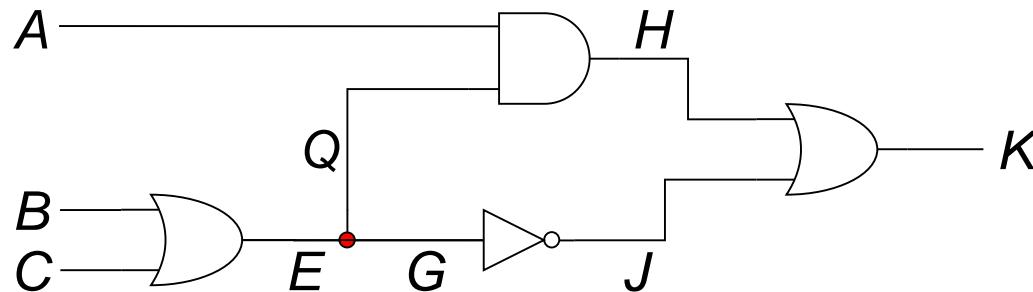


Type	On-input	Off-input	good 	bad 
Non-robust	C → NC NC → C	X → NC X → NC	Easy to find	Invalidate by other PDF
Robust	C → NC NC → C	X → NC NC → NC	Effective even other PDF	Invalidated by hazard Few
Hazard-free	C → NC NC → C	NC → NC NC → NC	Effective	Very few

stringent

FFT

- Q1: How many PDF in this circuit?
- Q2: Please show if $\uparrow\text{BEQHK}$ is non-robust, robust or HF testable



PDF	Non-robustly Testable?	Robustly testable?	Hazard-free testable
$\downarrow\text{BEGJK}$	Y	Y	Y
$\uparrow\text{BEQHK}$			

FFT2

- Q: How can we detect fault if output K is S1?

