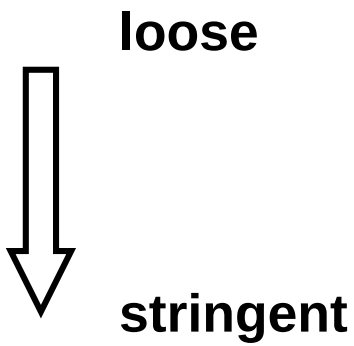
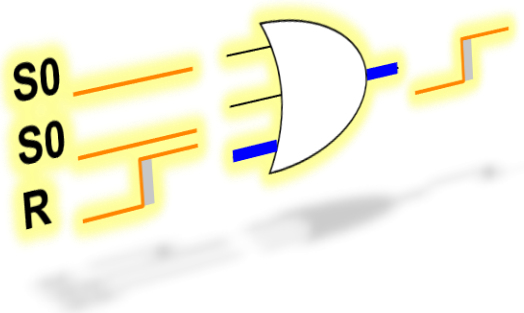
Delay Test

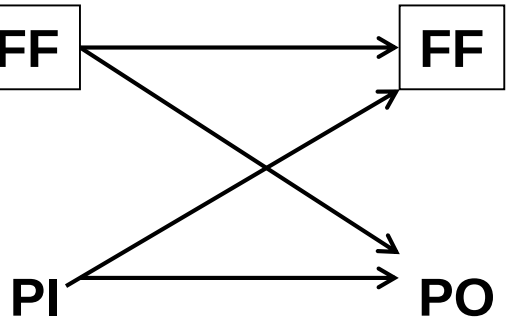
- Introduction and delay fault models
- **Path Delay Fault**
  - **Path Sensitization**
    - **Nonrobust**
    - **Robust**
    - **Hazard-free**
  - **Fault Simulation**
  - **Test Generation**
- Transition Delay Fault
- Experimental Results* (not in exam)
- Issues of Delay Tests* (not in exam)
- Conclusions

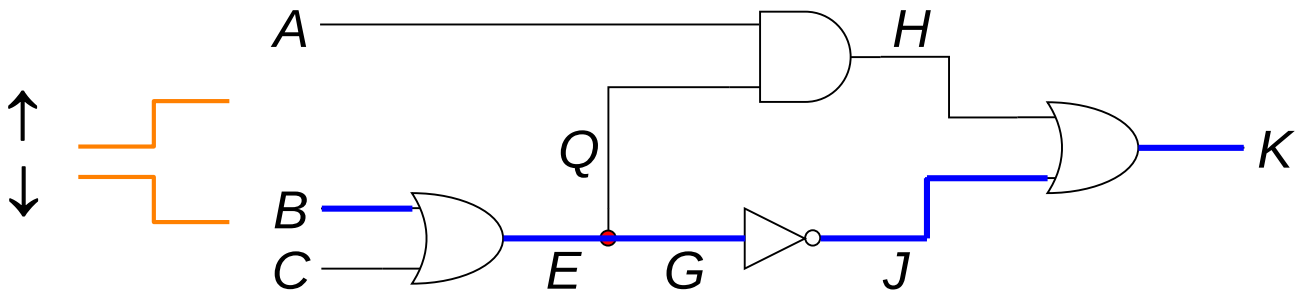




Path / Path Delay Fault

- 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 ↑)
  - Falling (notation ↓)
- Example: BEGJK is a path
  - 2 PDF: ↓BEGJK, ↑ BEGJK



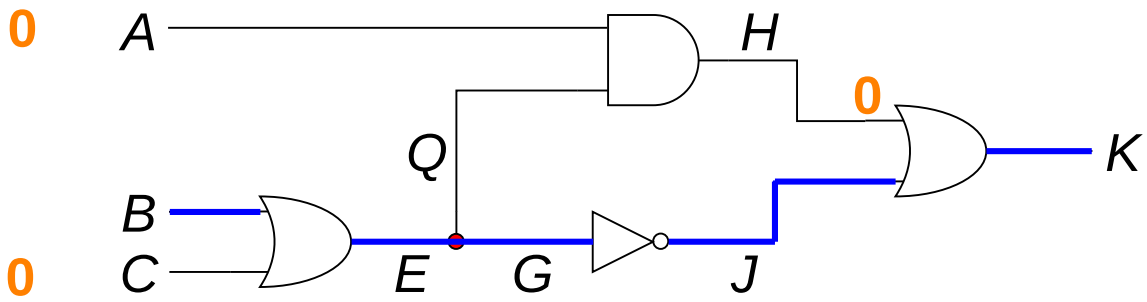


Testable Path

- A path is *testable* if a transition can propagate from input to output along the path under certain *sensitization criteria (condition)*
  - tesetable 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

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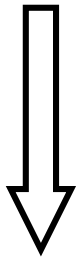
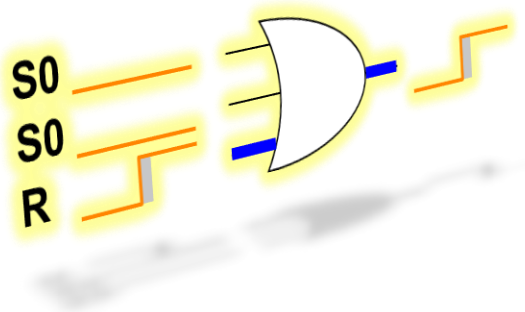
loose



stringent



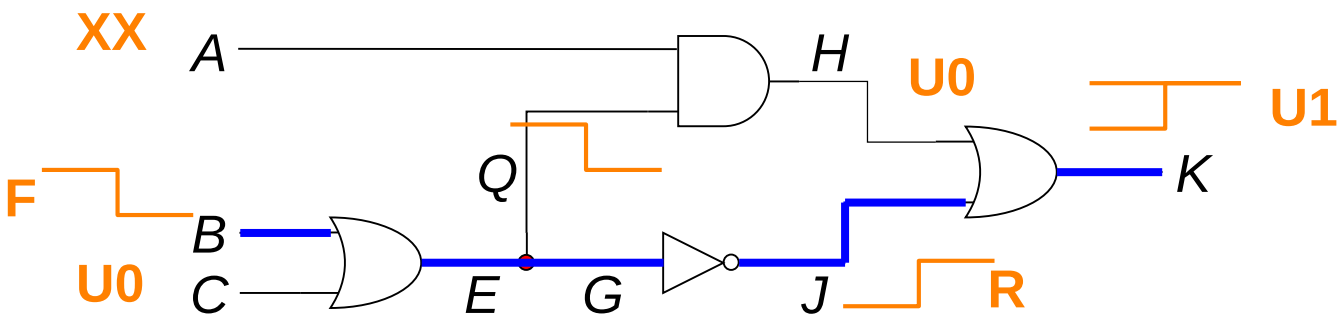
9-valued Logic

- *9-valued logic* for two-pattern test
  - R: rising 0→1
  - F: falling 1→0
  - U0: X→0
  - U1: X→1
  - S0: static zero , 0→0
  - S1: static one, 1→1
  - 0*: static 0-hazard , 0→1→0
  - 1*: static 1-hazard, 1→0→1
  - XX: unknown for both patterns X→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?

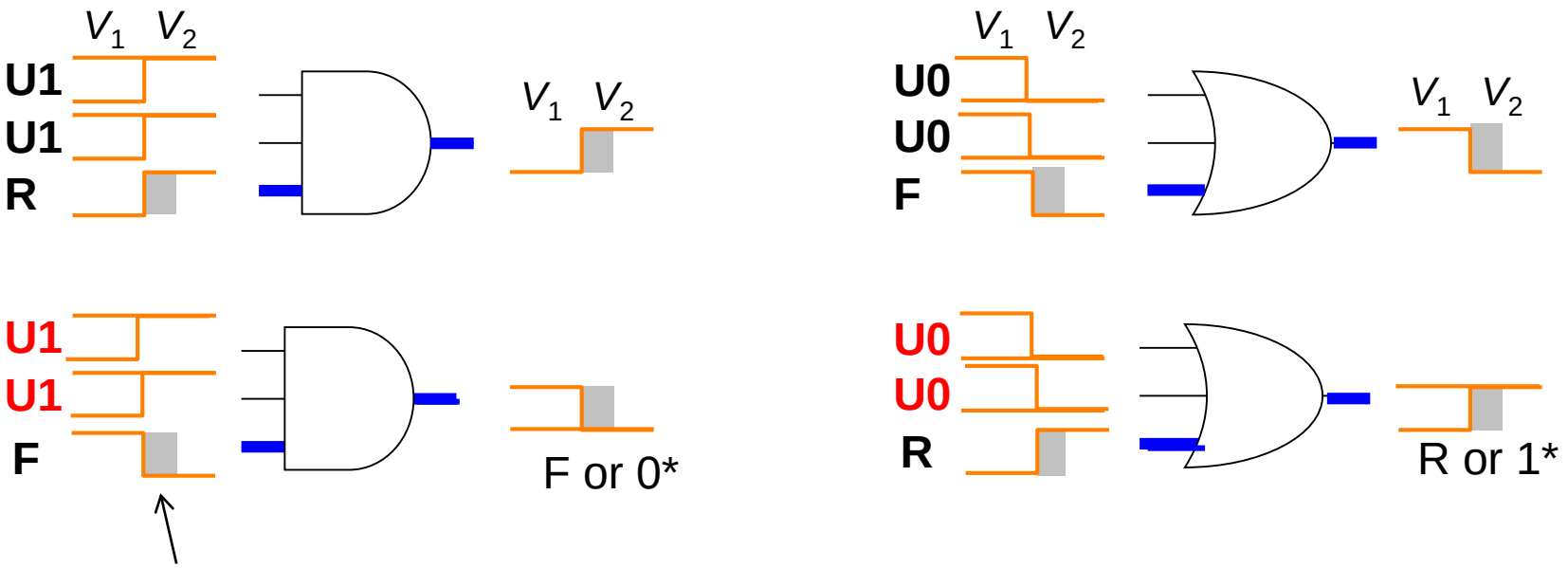
- PDF requires 2-pattern test
- How to sensitize target path in 2-pattern test?
  - Simple idea: all off-input hold non-controlling (NC) in 2nd pattern
- Example: PDF ↓BEGJK
  - C is U0; H is U0



- 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→nc**
- **Example: target path in blue**

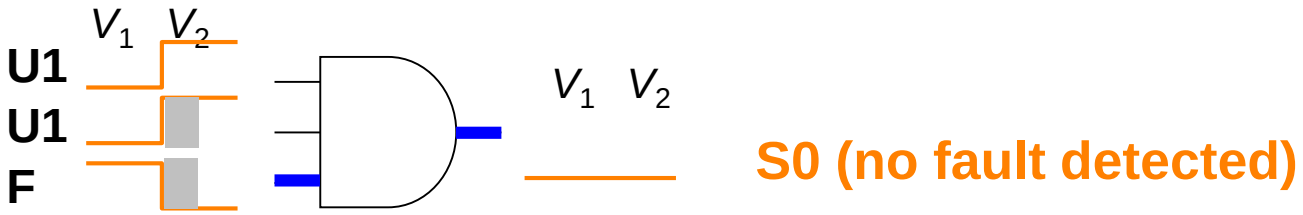


Gray area represents delay fault effect

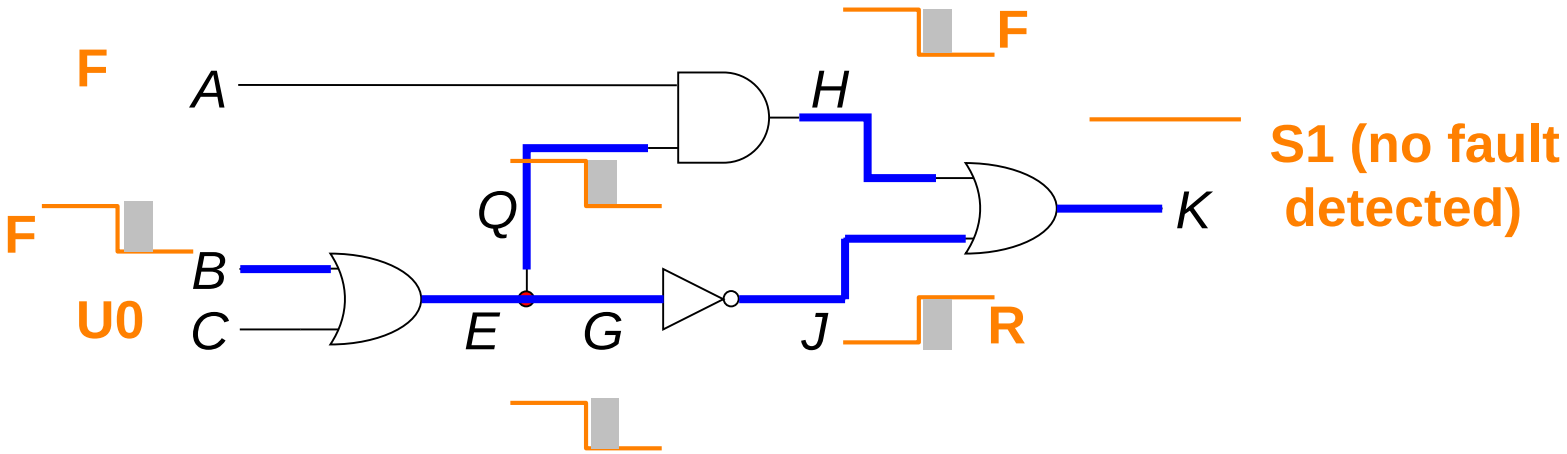
NR Sensitization: off-input is NC in 2nd pat.

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



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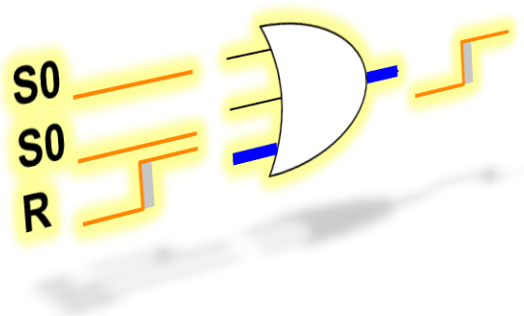
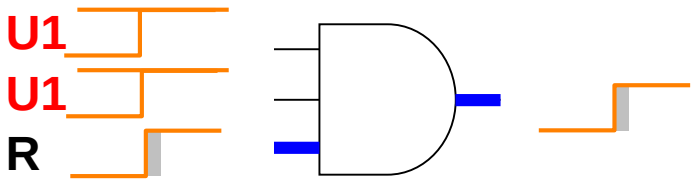
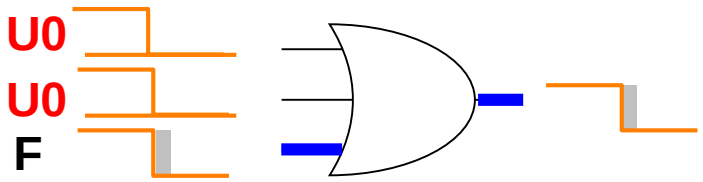
Need more stringent sensitization criterion than NR!



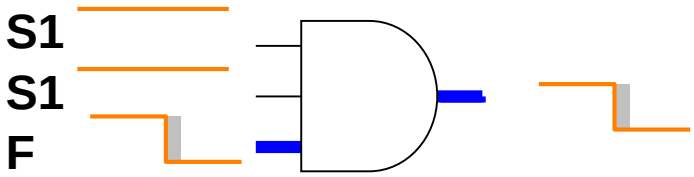
Robust Sensitization Criterion

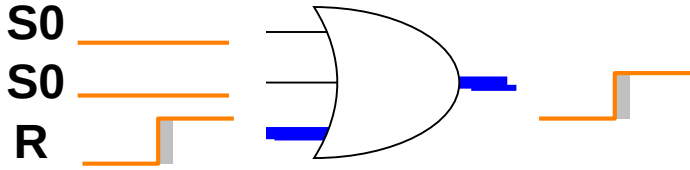
- **Idea**
  - **Output *cannot* change *before* the on-input change**
- **Robust Sensitization Criterion: (NC=*non-controlling*, C = *controlling*)**
  - **(1) when on-input is C→NC, off-inputs X→NC (same before)**





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

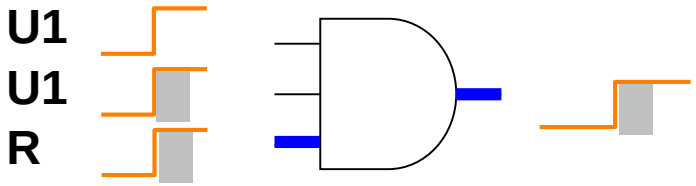




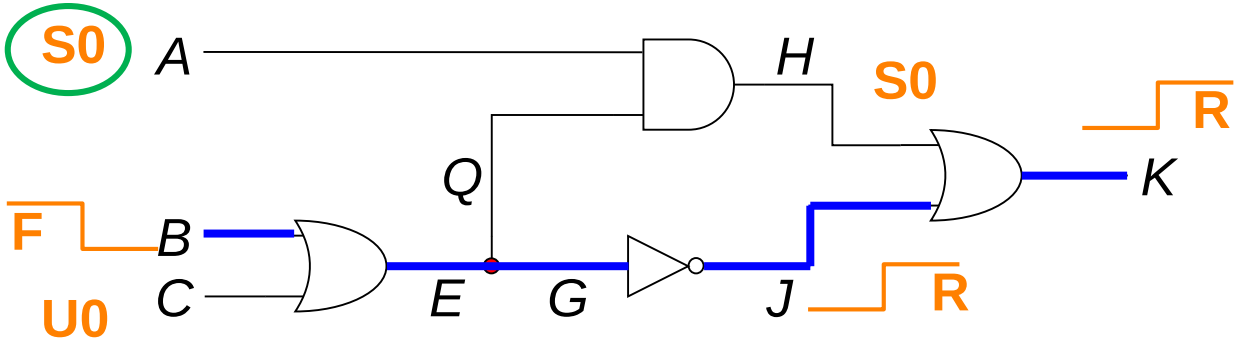
Robust: on-input NC→C, off-input keep NC

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



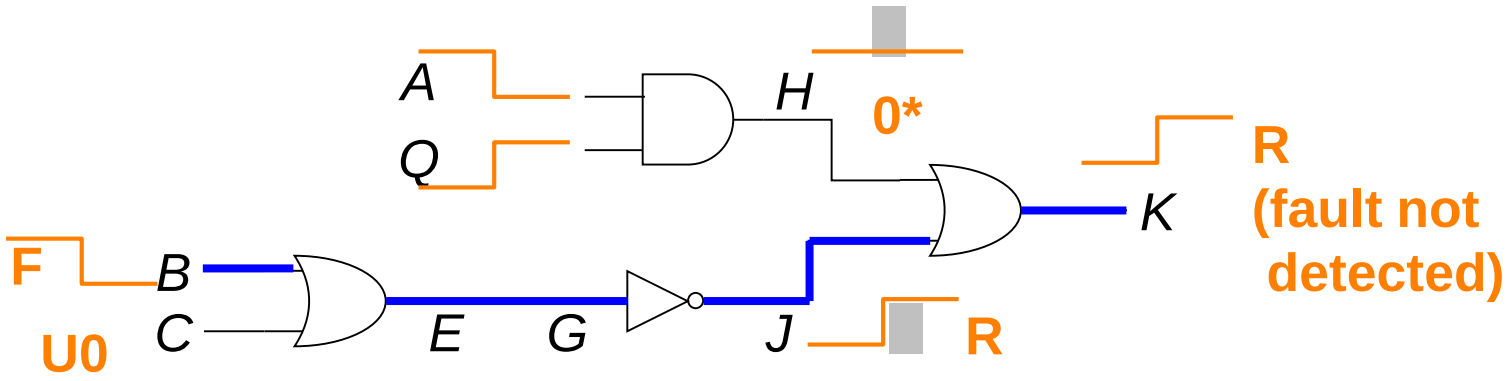
- Example 2: PDF ↓BEQHK now can't invalidate robust test for ↓BEGJK
  - A is now S0, instead of XX



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**



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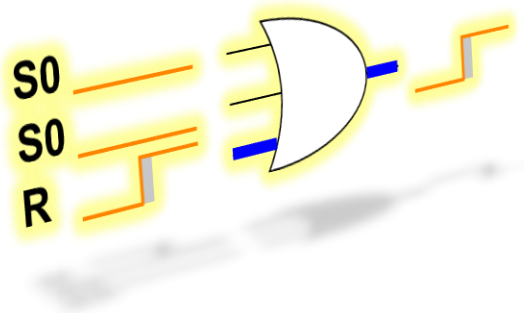
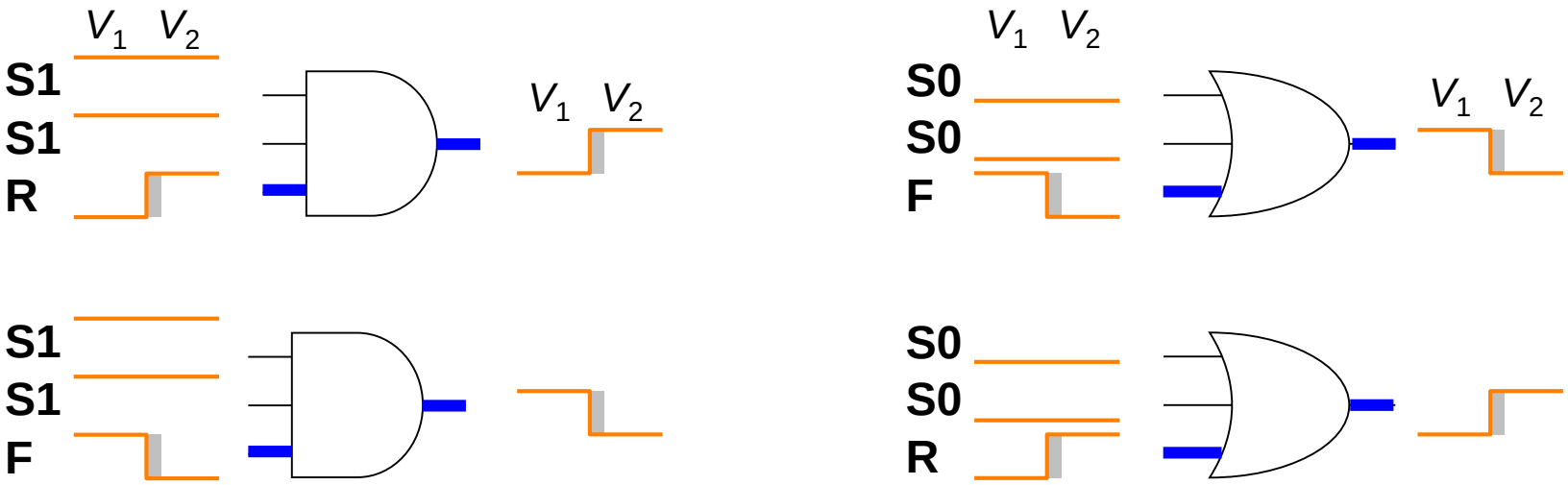


Hazard-free Sensitization Criterion

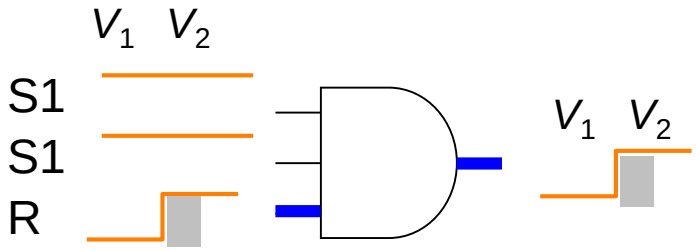
- **Criterion: off-inputs are *stable non-controlling* NC→NC**
  - **Regardless on-input values**
- **Example: target path is blue**



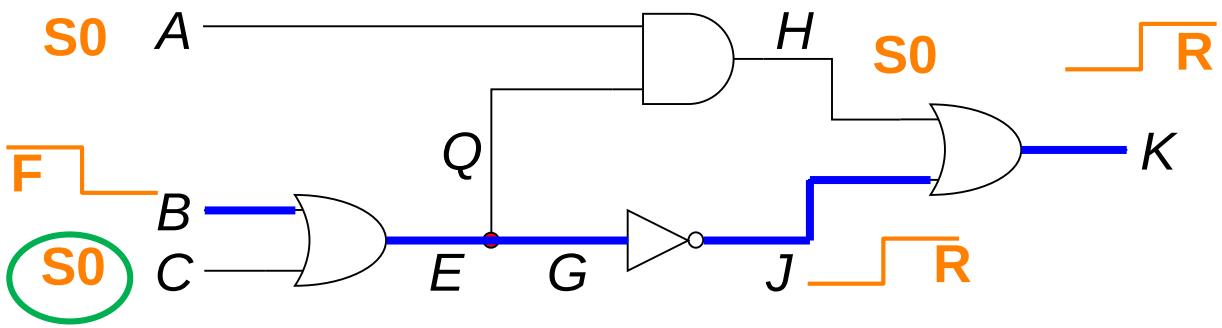
HF test requires off-inputs are stable NC

Hazard-free Path Delay Test

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

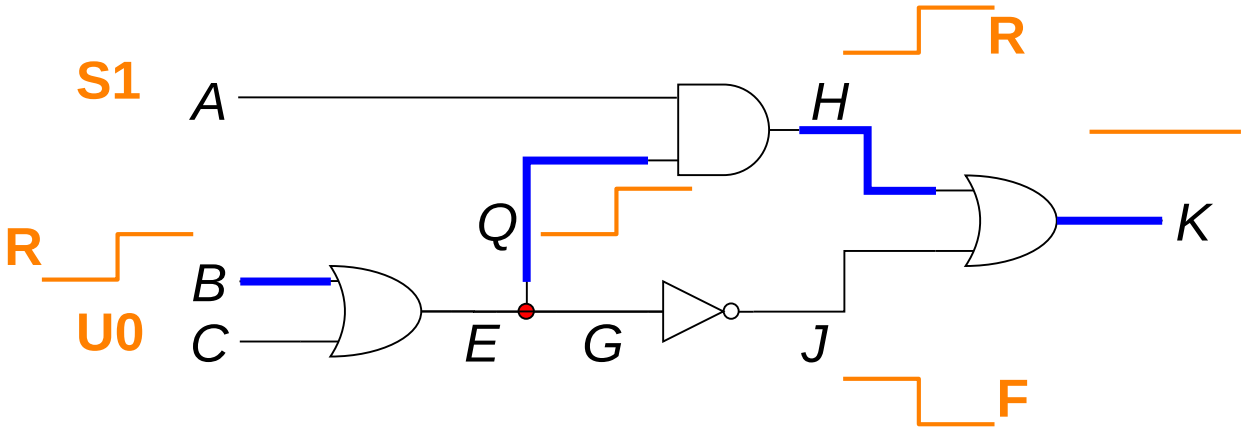


- Example: hazard-free path delay test for PDF ↓BEGJK
  - C is now S0, instead of U0



Hazard-free Test is Good, but…

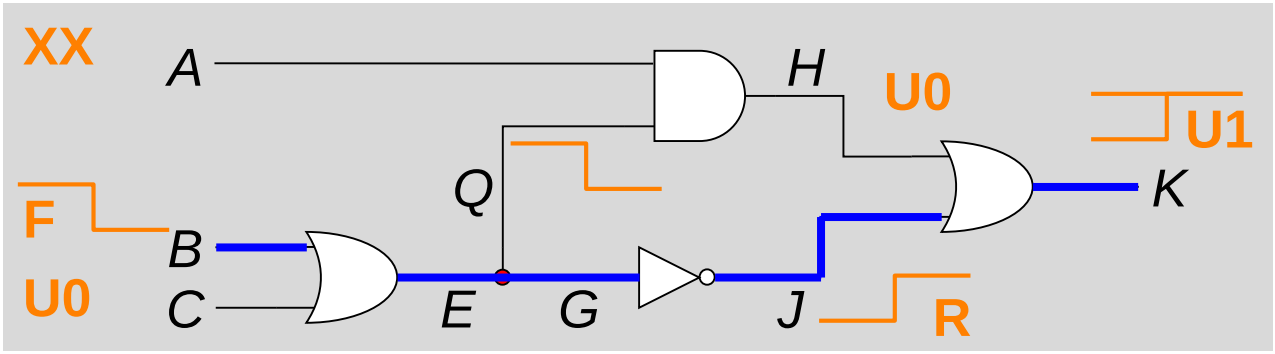
- Only a small number of PDF have hazard-free test
- Example: no hazard-free test for PDF ↓ BEQHK



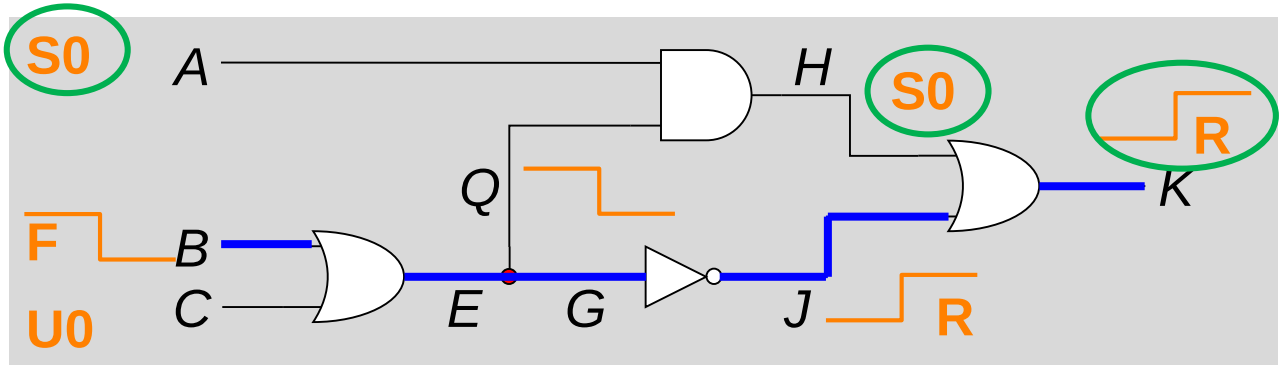
HF tests are good but very few

Summary (PDF ↓ BEGJK)

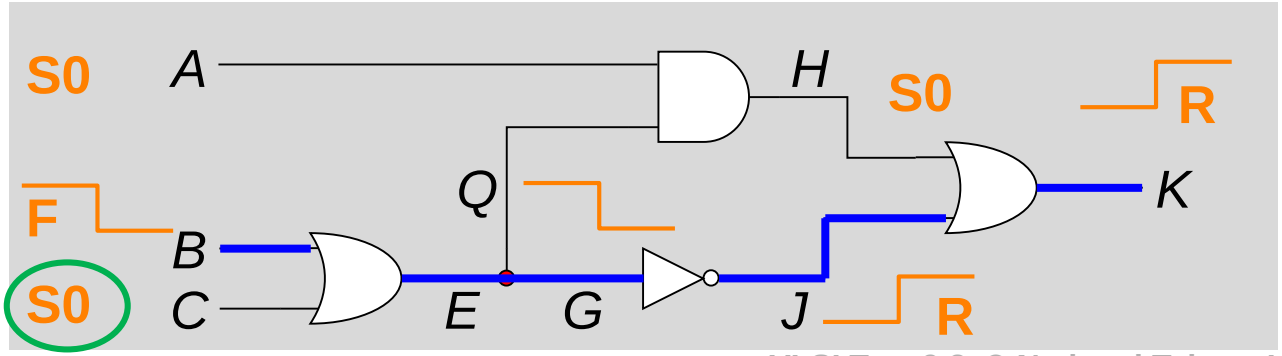
- **Non-Robust**



- **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

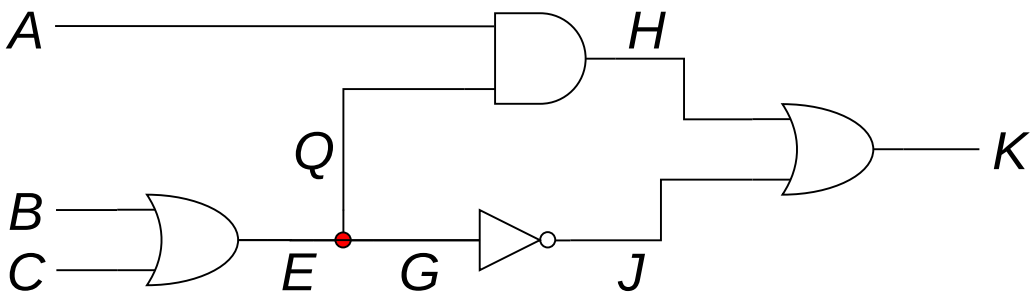
loose

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 ↑BEQHK is non-robust, robust or HF testable



PDF	Non-robustly Testable?	Robustly testable?	Hazard-free testable
↓BEGJK	Y	Y	Y
↑BEQHK			

FFT2

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