# Low-Overhead Design of Soft-Error-Tolerant Scan Flip-Flops with Enhanced-Scan Capability

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ASPDAC, January 2006

PURDUE UNIVERSITY

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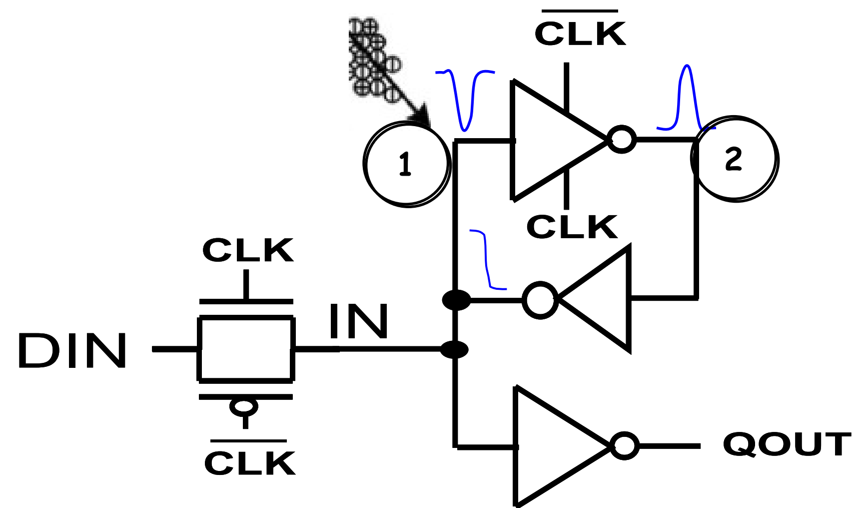
# Motivation

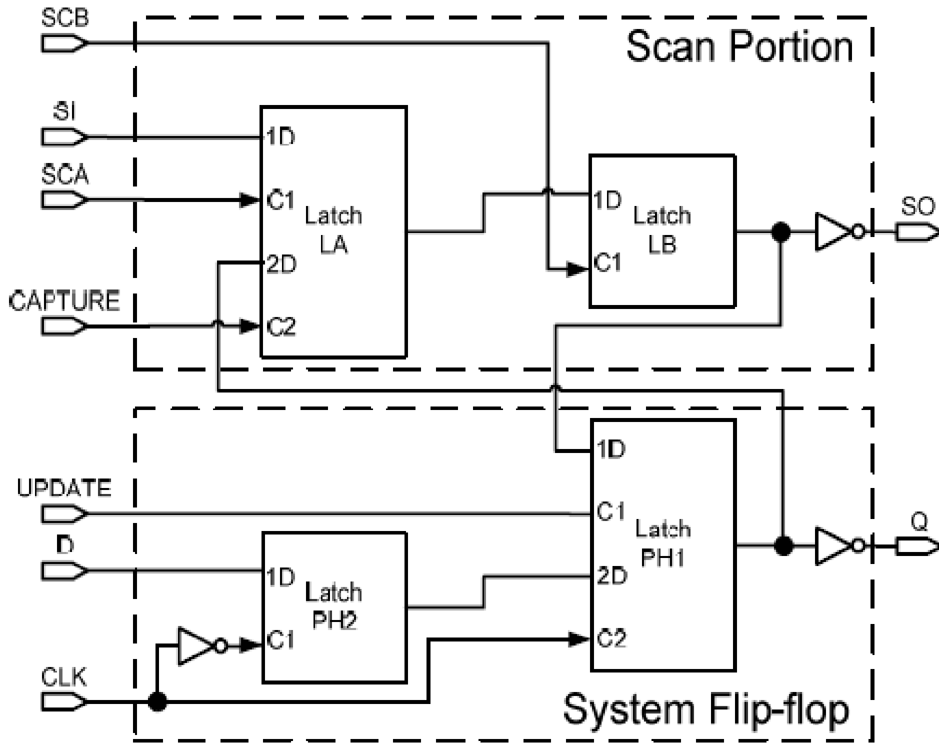
- Critical charge: Qc
- Scaling: C↓, V↓, Qc↓
- Unlike memories flip flops not protected by parity and ECC




Static Latch Cell

- **Cross-coupled inverters**
- **Feedback increases soft error vulnerability**

# Motivation

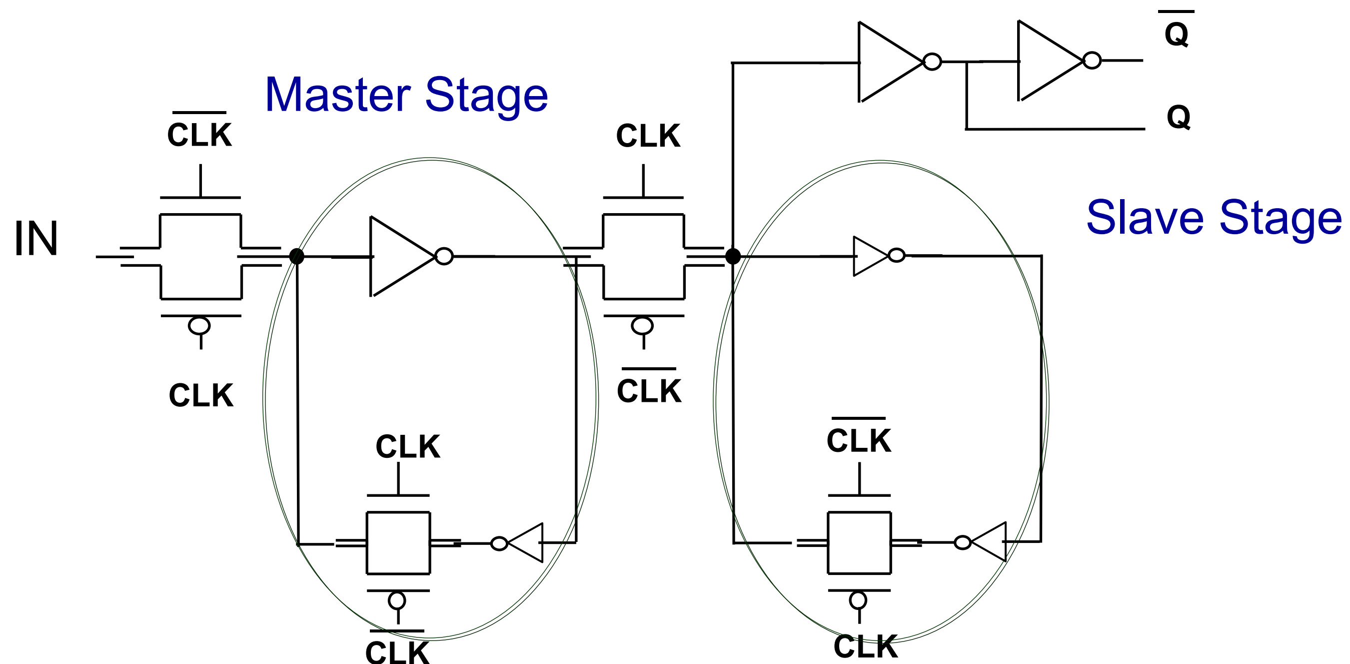



Scan Flip-flop design of a Microprocessor*

- **Reuse of on chip scan design-for-testability (DFT) resources to reduce overhead**
- **Integration of soft error tolerant flip-flops into the scan path**

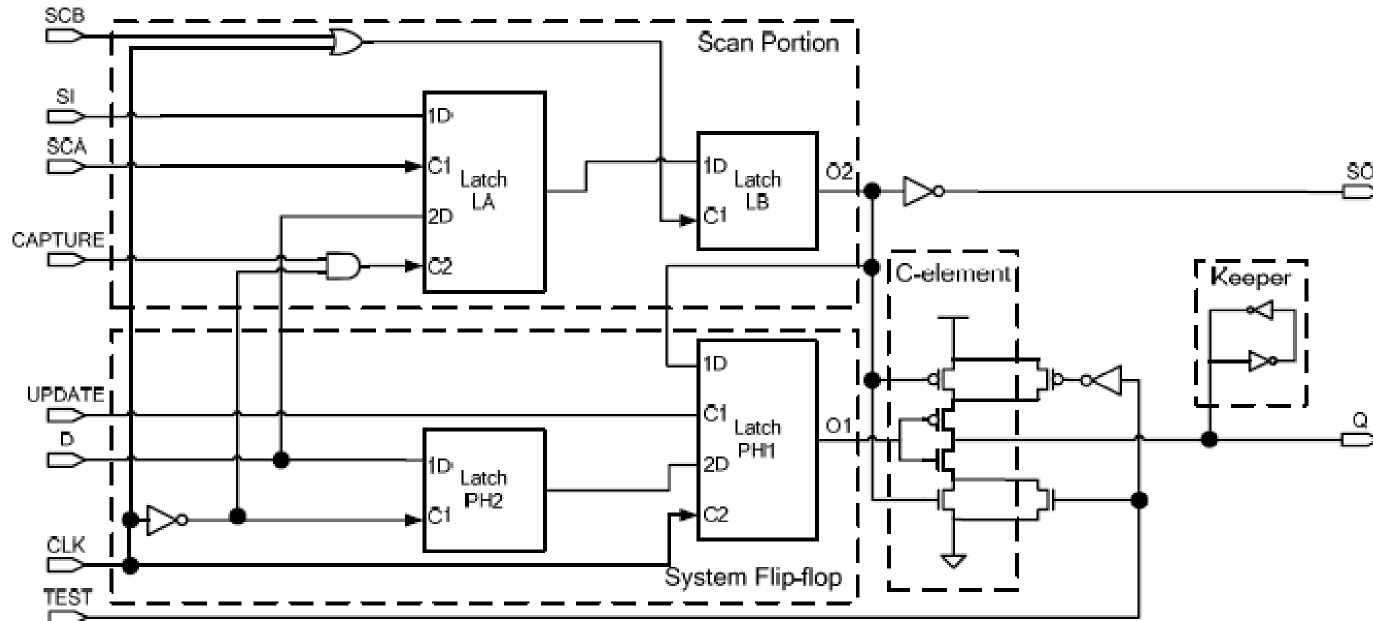
S. Mitra, N. Seifert, M. Zhang, Q. Shi, K. Kim, "Robust System Design with Built-In Soft Error Resilience," *Computer*, vol. 38, No. 2, Feb. 2005, pp. 43-52

# Soft Error in Transmission Gate Flip-Flop




- Clk = 1, Master Stage susceptible
- Clk = 0, Slave Stage susceptible
- Need a redundant copy for soft error detection / correction

# Reuse of On Chip Scan DFT resources

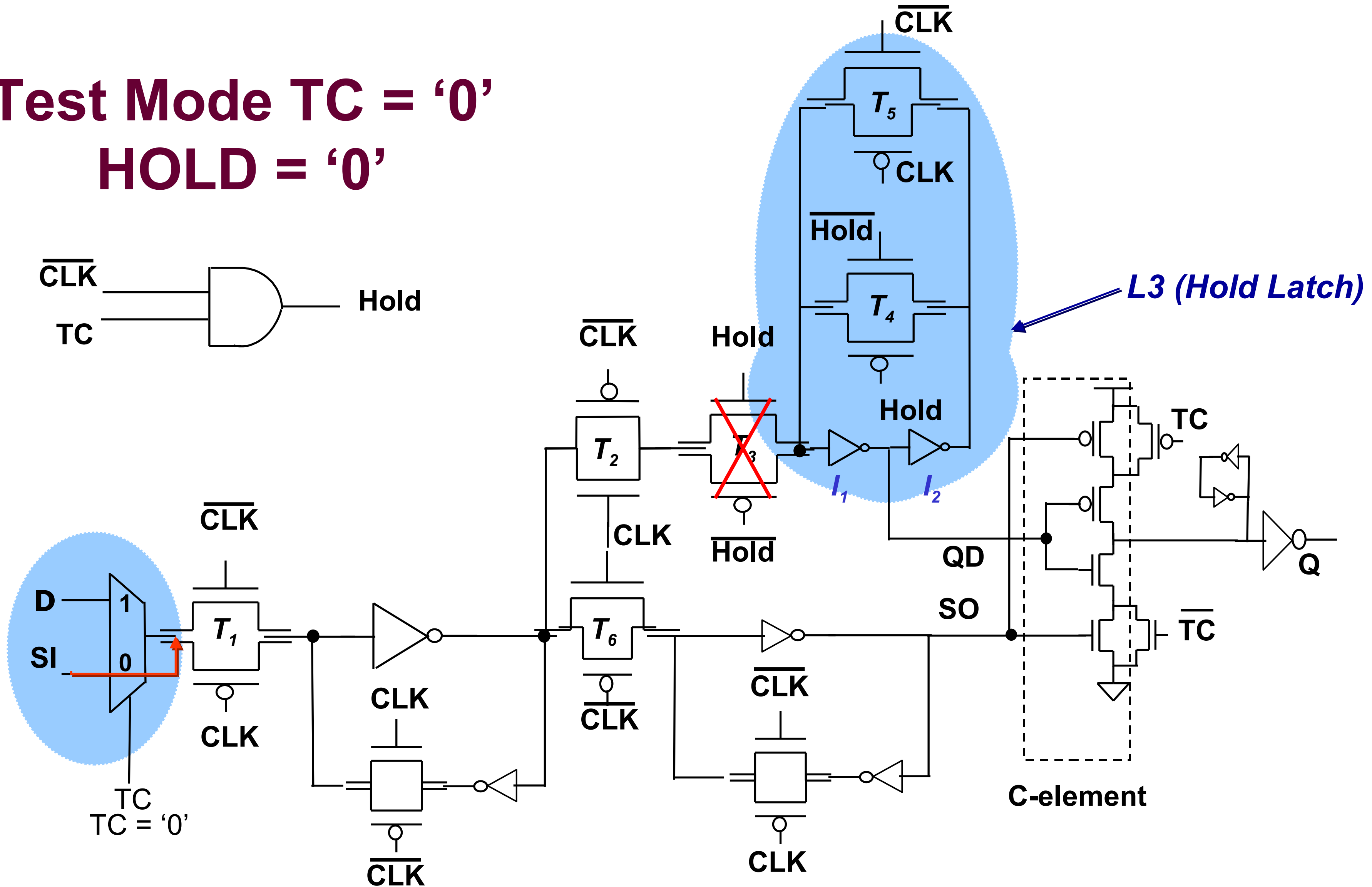



Scan Reuse for Soft Error blocking* (ISR)

- **Scan latches sized up to store a copy of data, increases area and power overhead**
- **Four latches required to store the two copies of the data_**

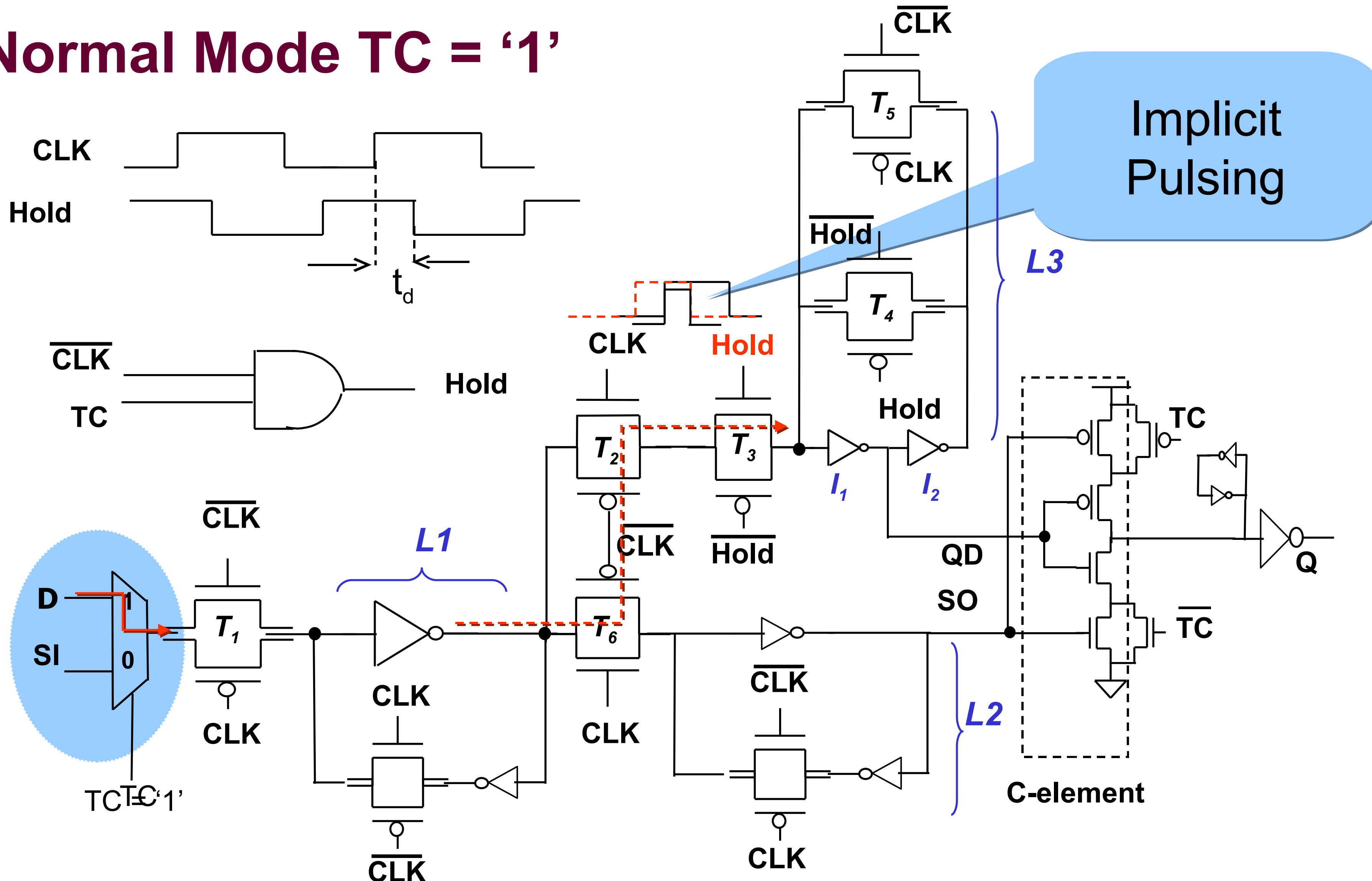
S. Mitra,N. Seifert, M. Zhang, Q. Shi, K. Kim, "Robust System Design with Built-In Soft Error Resilience," *Computer*, vol. 38, No. 2, Feb. 2005, pp. 43-52

# Proposed Design for Enhanced Scan and Soft Error Correction (ESFF-SEC)

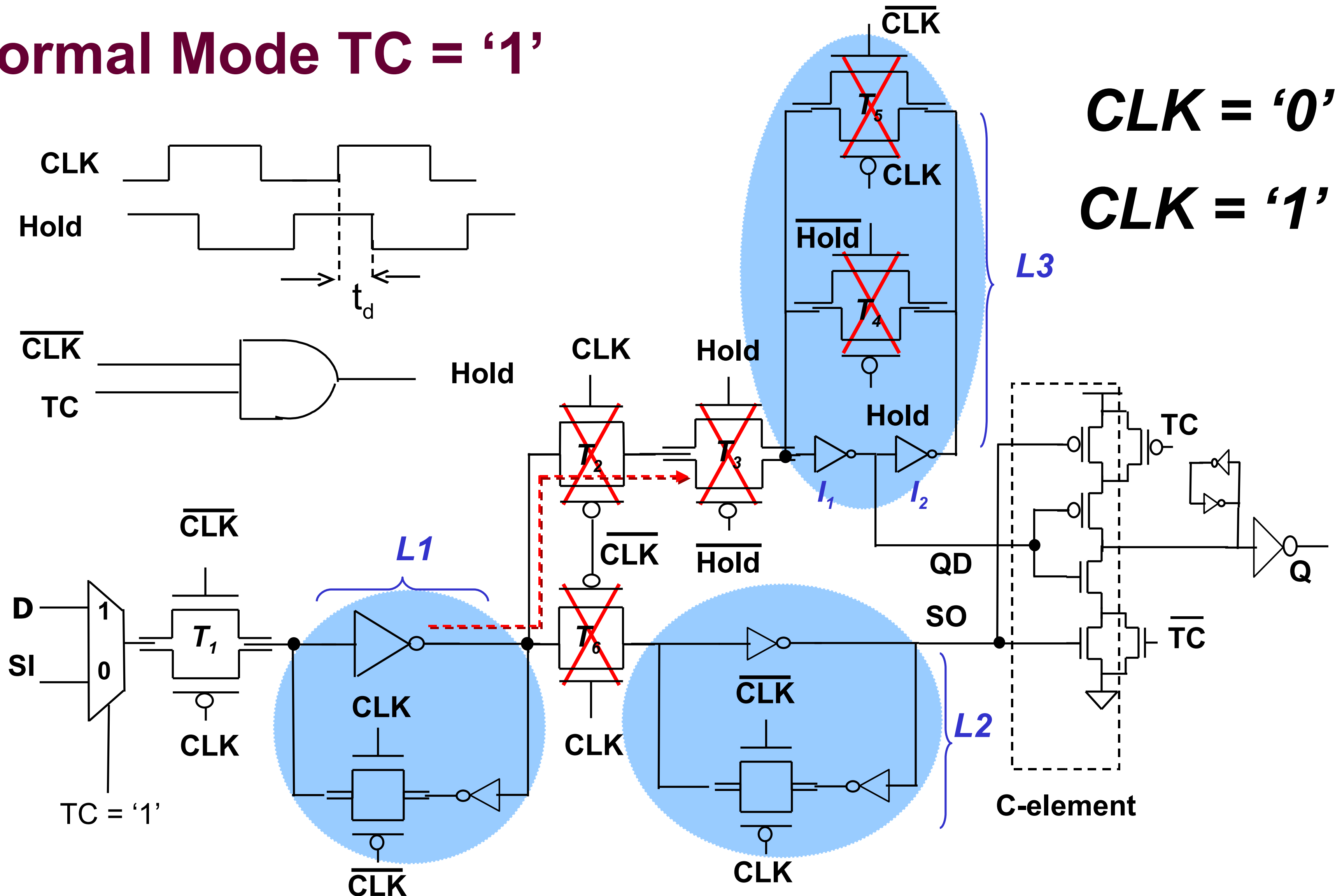


# Proposed Design (Contd.)

## Normal Mode TC = '1'



# Proposed Design (Contd.)



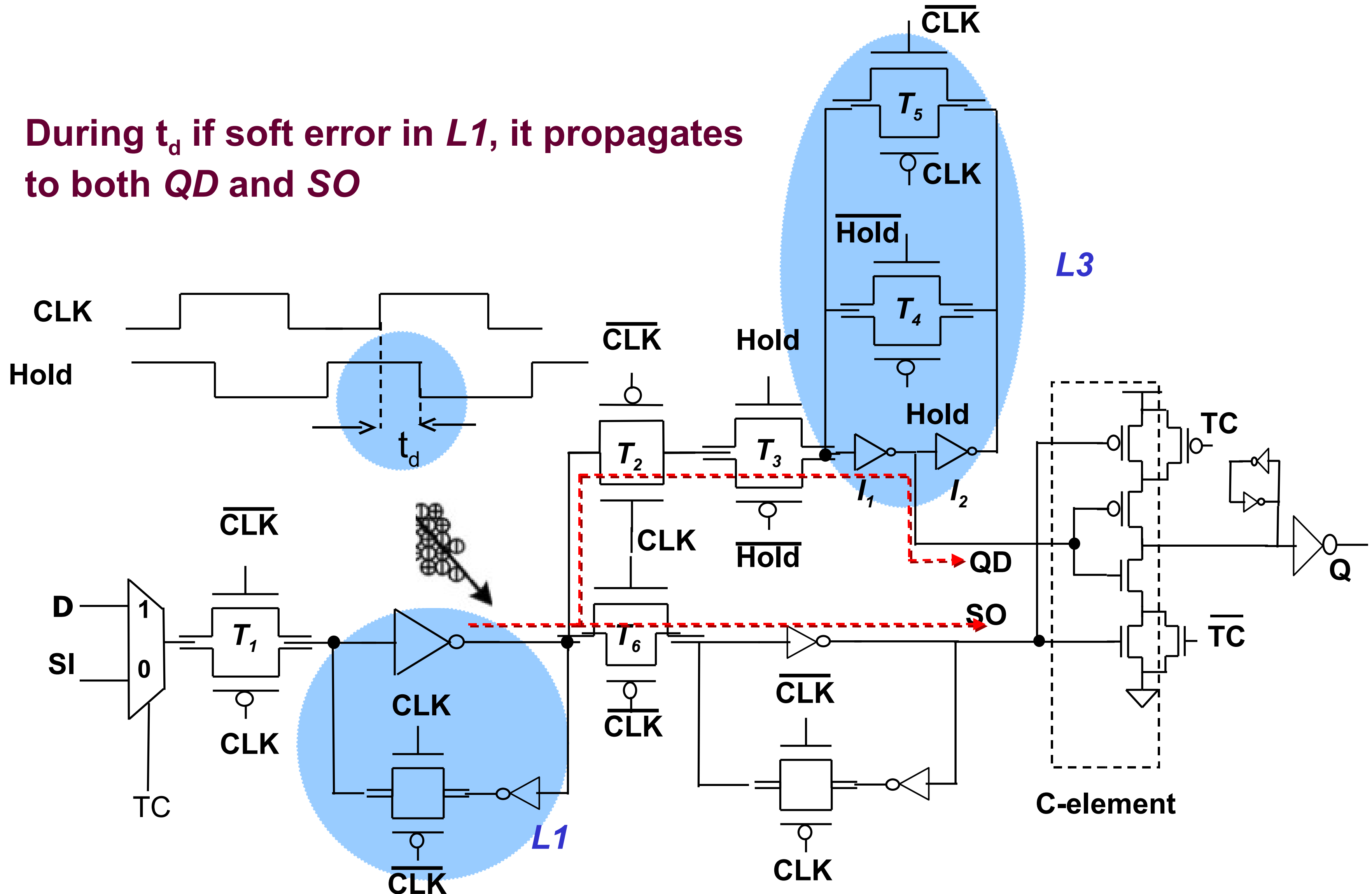
# ESFF-SEC vs. ISR

| | ESFF-SEC | ISR |
|---|---|---|
| Power | 1.0 | 1.26 |
| Area | 1.0 | 1.61 |
| Setup Time | 1.0 | 1.70 |
| C-to-Q Delay | 1.0 | 1.00 |

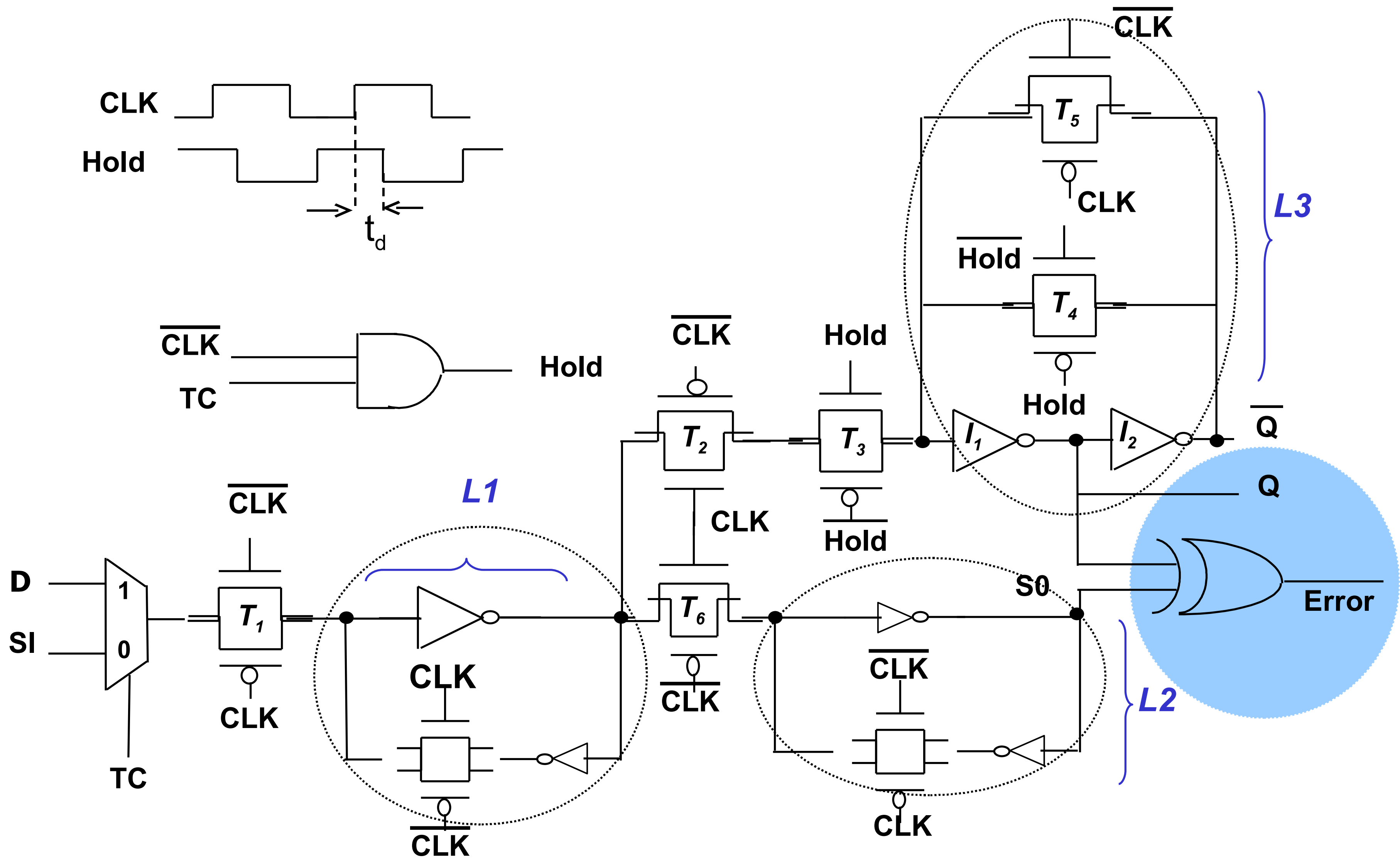
- **Power and Area - Reduction in the number of latches from four to three**
- **Setup time - Scan Latch is sized up in ISR, more load on the data driver**

# Proposed Design (Contd.)

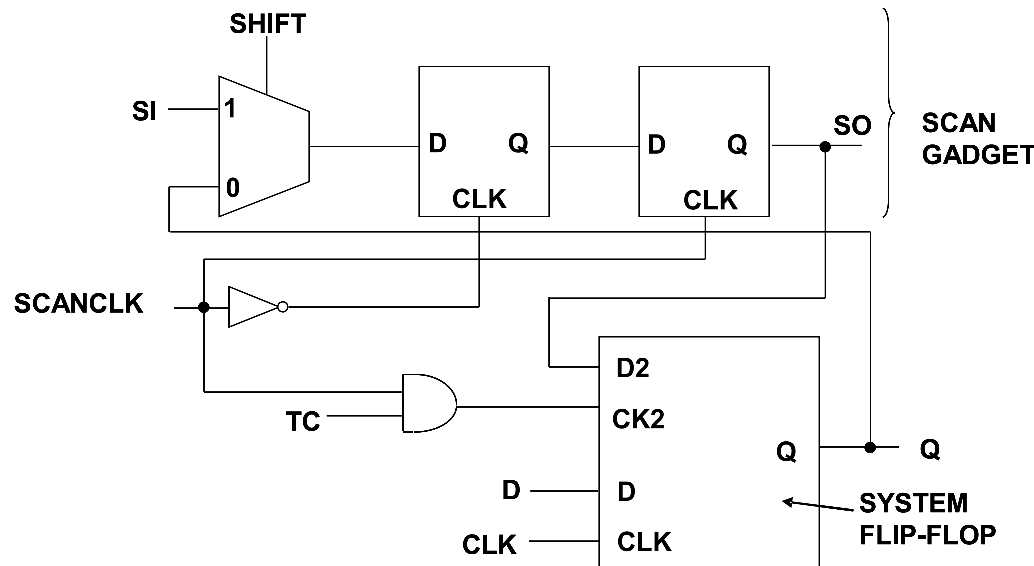
During $t_d$ if soft error in *L1*, it propagates to both *QD* and *SO*



# Proposed Design for Enhanced Scan and Soft Error Detection (ESFF-SED)



# Enhanced Scan Approach to Delay Testing

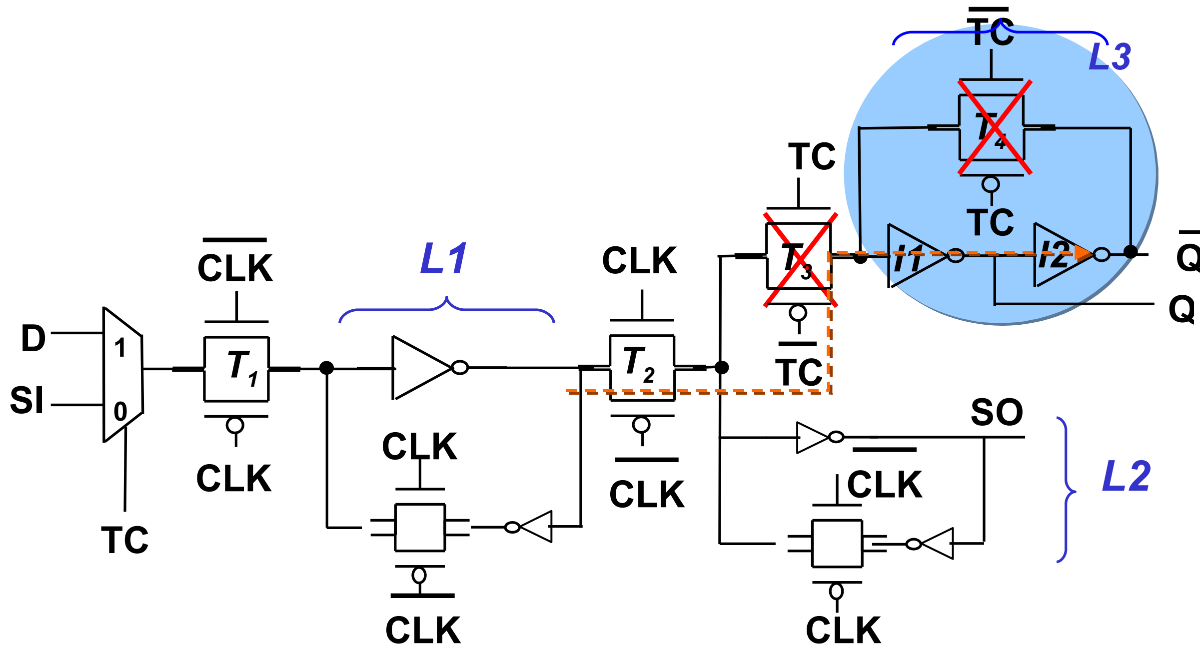



Scan Gadget Scheme (HSSG)*

- **Scan Gadget Scheme (HSSG) – uses a Scan Gadget along with system latch to scan in and hold test vector**
- **Overhead – extra latch, complicated design of system flip-flop requiring two clocks and extra timing signals required (SCANCLK, SHIFT)**

R. Kuppuswamy et al., "Full Hold-Scan Systems in Microprocessors: Cost/Benefit Analysis," *Intel Technology Journal*, Vol.8, Issue 1, Feb. 2004

# Proposed Design for Enhanced Scan Delay Testing (ESFF)




- Drivers $I_1$ and $I_2$ converted into latch *L3* using $T_3$ and $T_4$
- Normal Mode, TC = ‘1’, $T_4$ is OFF and $T_3$ is ON
- Test Mode, TC = ‘0’, $T_3$ is OFF and $T_4$ is ON, *L3* disconne-cted from *L2* and *L1*, acts as a hold latch
- No extra timing control signals required

# Results

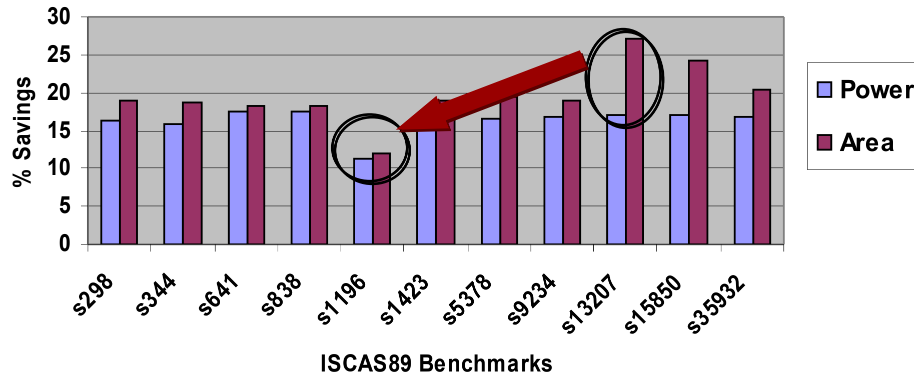



Figure. 1

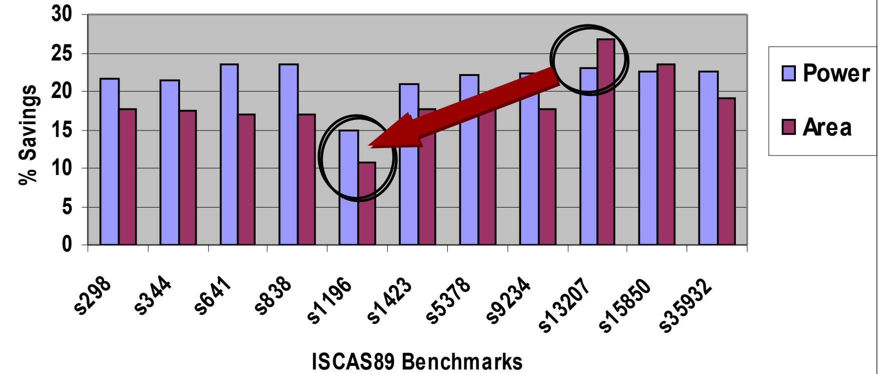



Figure. 2

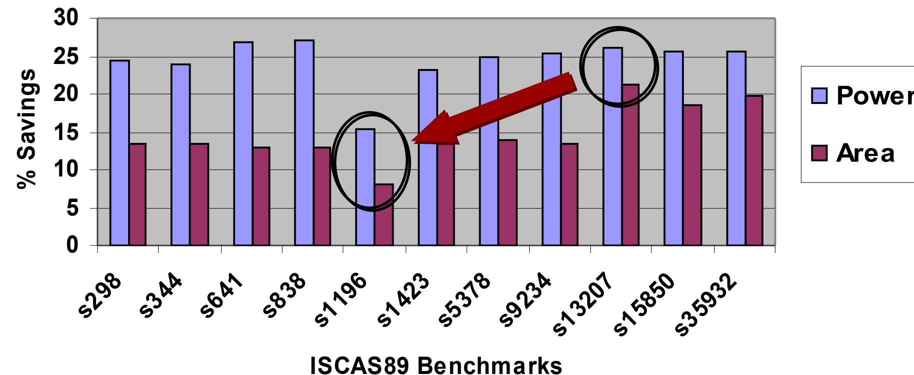



Figure. 3

- HSPICE simulation of ISCAS89 benchmarks in BPTM 70nm node
- 16% power and 17% area reduction on average at no delay overhead
- % of sequential elements in the benchmark decrease from 74% in s13207 to 22% in s1196, hence total savings decrease

# Conclusion

- **Novel Flip-Flop designs are proposed having soft error detection/correction capability along with enhanced scan based delay fault testing**

- A simplified version having enhanced scan delay fault testing capability is proposed

- Low area and power overhead due to reuse of existing hardware resources

# Thank You!

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# C-element and Keeper

| O1 | O2 | Q |
|---|---|---|
| 0 | 0 | 1 |
| 1 | 1 | 0 |
| 1 | 0 | Previous Value |
| 0 | 1 | Previous Value |

- **Keeper is used to retain the previous value when O1 and O2 are different from each other**