IMPROVEMENT OF THE QUASI DELAY-INSENSITIVE PIPELINE NOISE IMMUNITY

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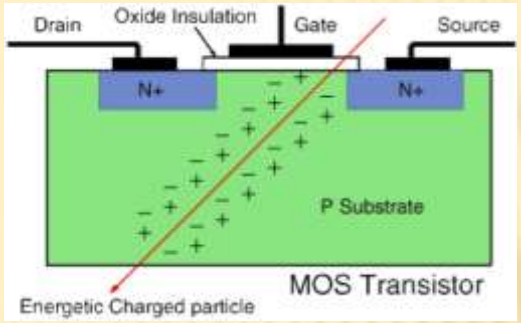
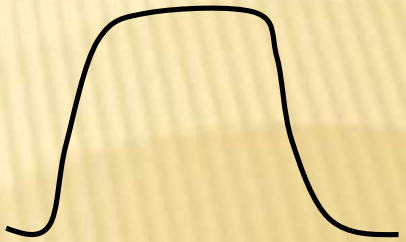
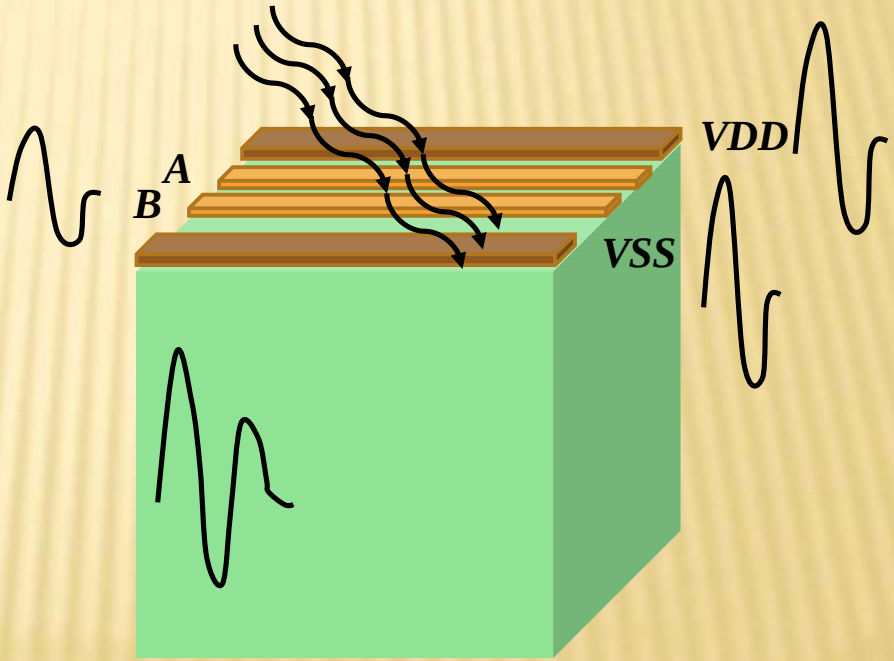
- Physical sources of soft errors
- Fail-safe discipline of QDI circuits
- Noise failure nature
- Register protection against stuck-at AS
- Conclusion and Future Work

PHYSICAL SOURCES OF SOFT ERRORS

- Nuclear particles and cosmic rays
- An external electromagnetic radiation
- Noise along signal lines (crosstalk)
- Noise on power and ground buses
- Substrate noise







SOFT ERRORS INDUCED BY NOISES

- They are shorter than soft-errors caused by particle strikes and cosmic rays
- Their appearance frequency correlates with the system clock
- They can cause a potential change in both dual-rail signal parts in different directions

QUASI DELAY-INSENSITIVE (QDI) CIRCUITS

- **Features increasing their failure tolerance:**
  - **Redundant dual-rail and two-phase signal coding**
  - **Two-phase functional discipline**
  - **Indication of all switch completion**
- **Penalties:**
  - **Hardware redundancy, especially in combinational circuits**
  - **Increased signal amount**

QDI CIRCUIT INDICATION

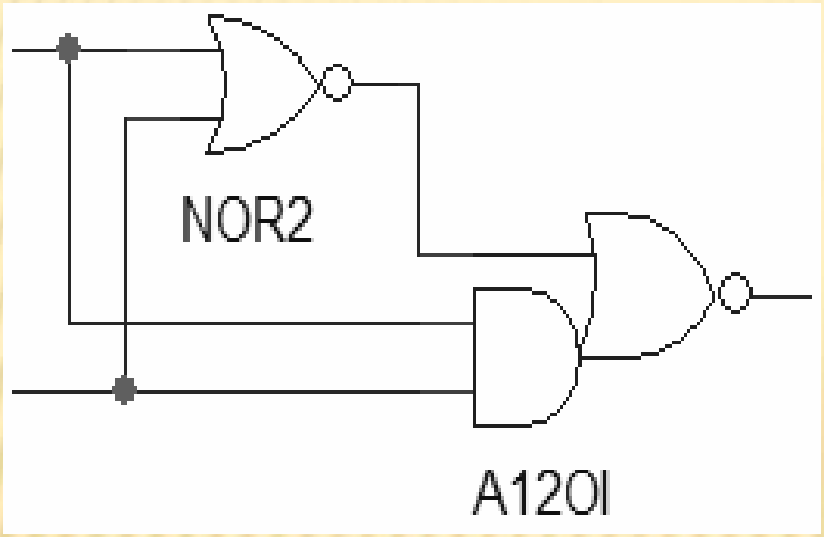
Fail-safe indication

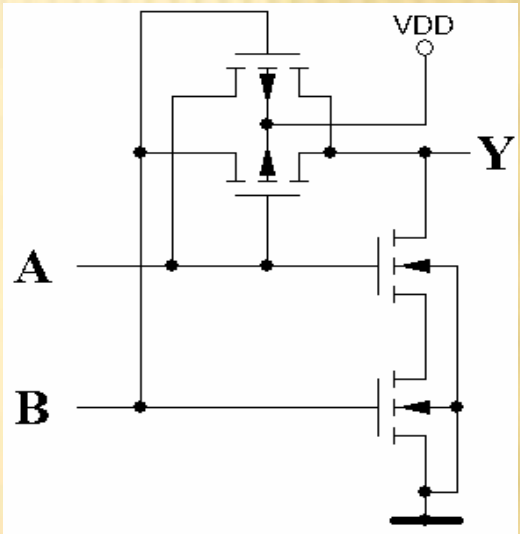
X	XB	State	Indicator
0	0	null spacer	0
0	1	Bit “0”	1
1	0	Bit “1”	1
1	1	unit spacer	0

Opposite spacer as a result of the soft error is considered to be another correct spacer

QDI CIRCUIT INDICATION

Dual-rail indication circuitry basis



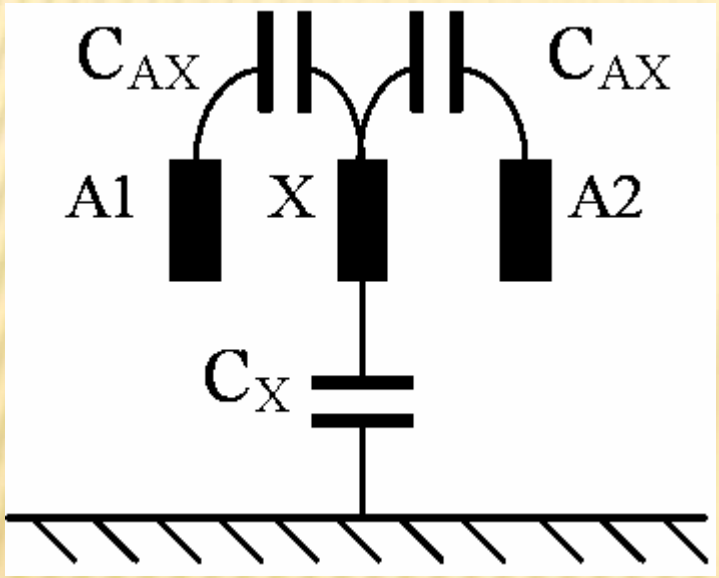


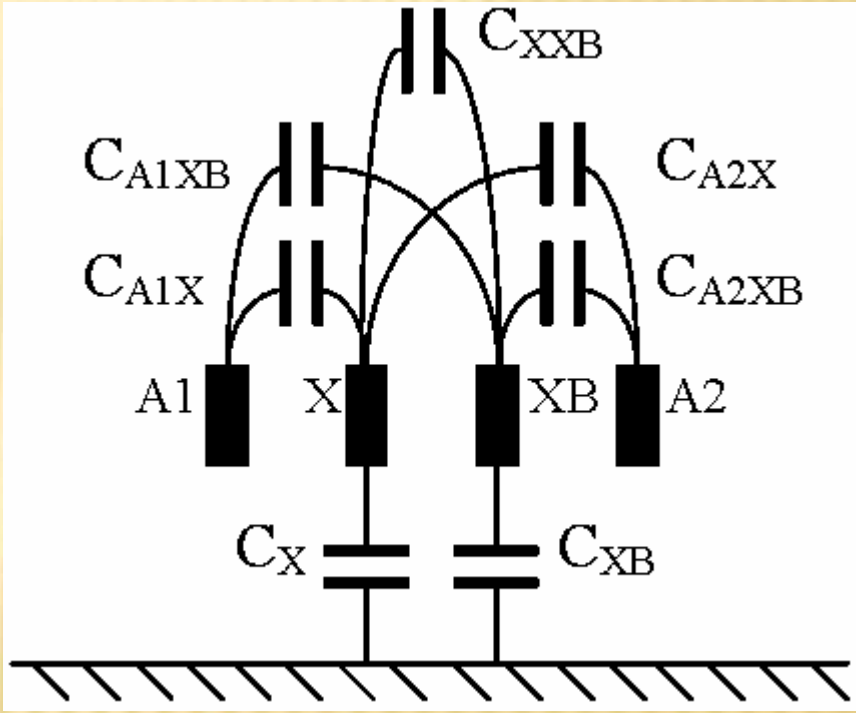
XOR on standard cells

XOR on CMOS transistors

NOISE FAILURE NATURE

Crosstalk between “victim” trace (X) and “aggressors” (A1, A2)





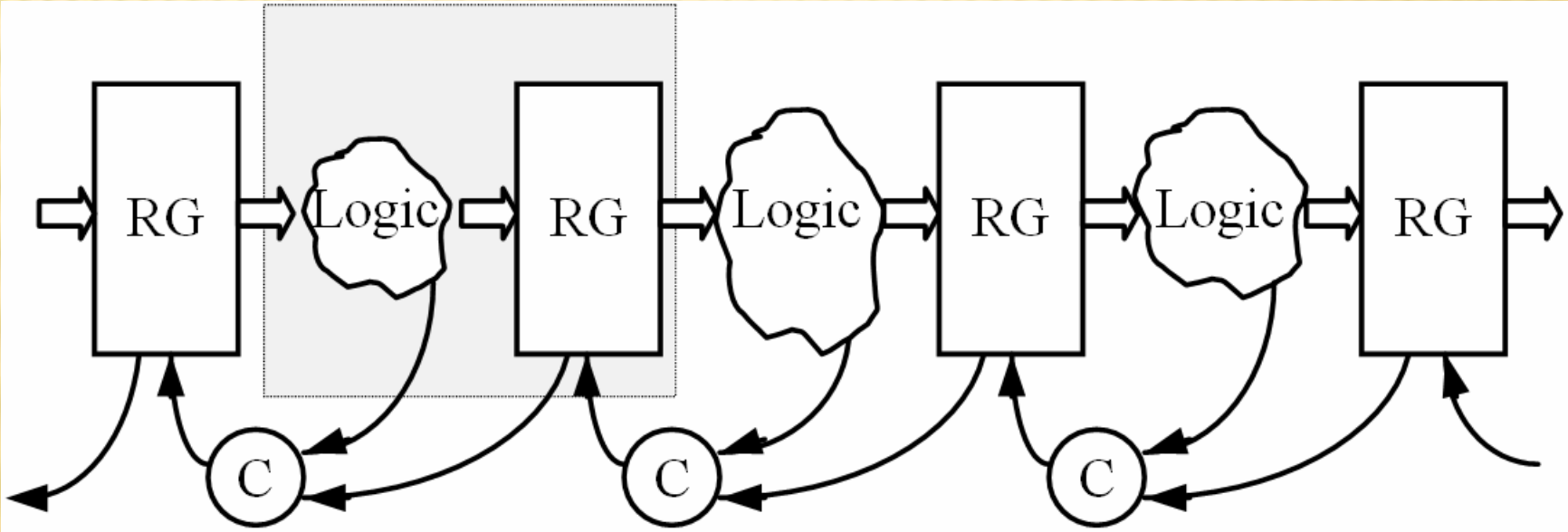
Single “victim”, X. **Dual-rail “victim” {X,XB}**

POSSIBLE SOFT ERRORS

##	Dual-rail state		Valid spacer
	Before soft error	After soft error	
1.	00	01	null
2.	00	10	null
3.	00	11	null
4.	01	00	null / unit
5.	01	11	null / unit
6.	10	00	null / unit
7.	10	11	null / unit
8.	11	00	unit
9.	11	10	unit
10.	11	01	unit

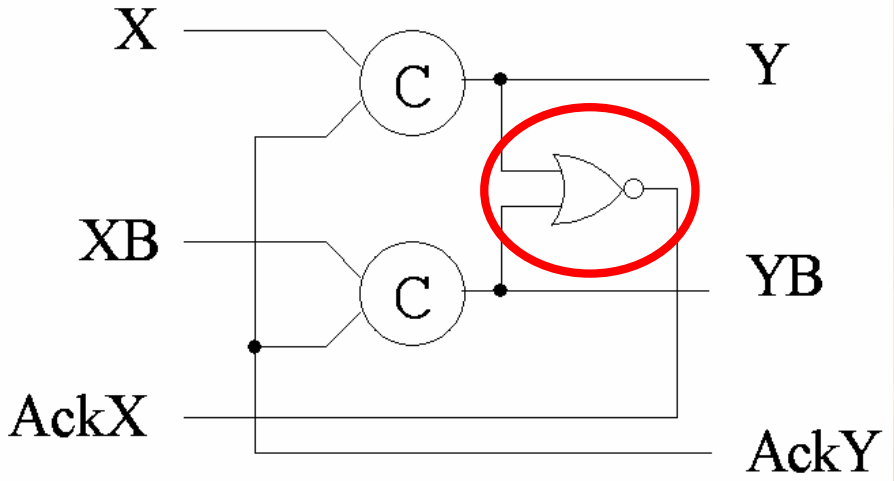
QDI PIPELINE

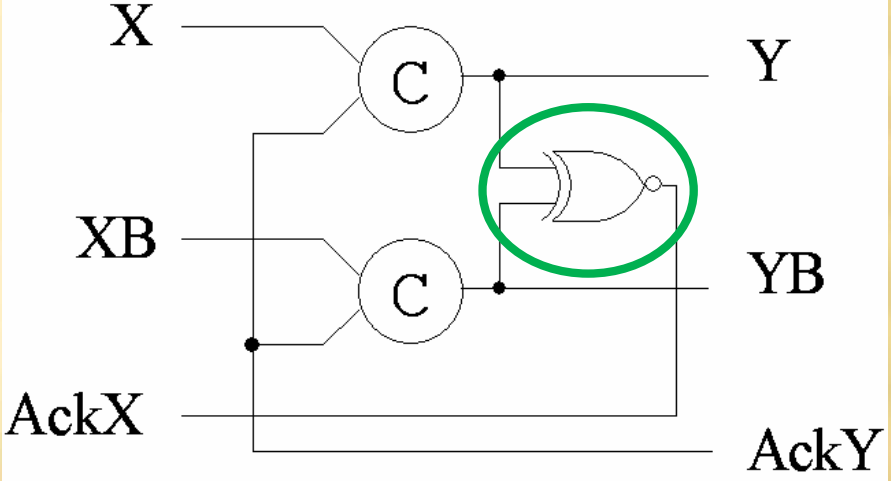
C-elements acknowledge pipeline stage switching completion and make previous register phase control



QDI-PIPELINE REGISTER

One bit implementation



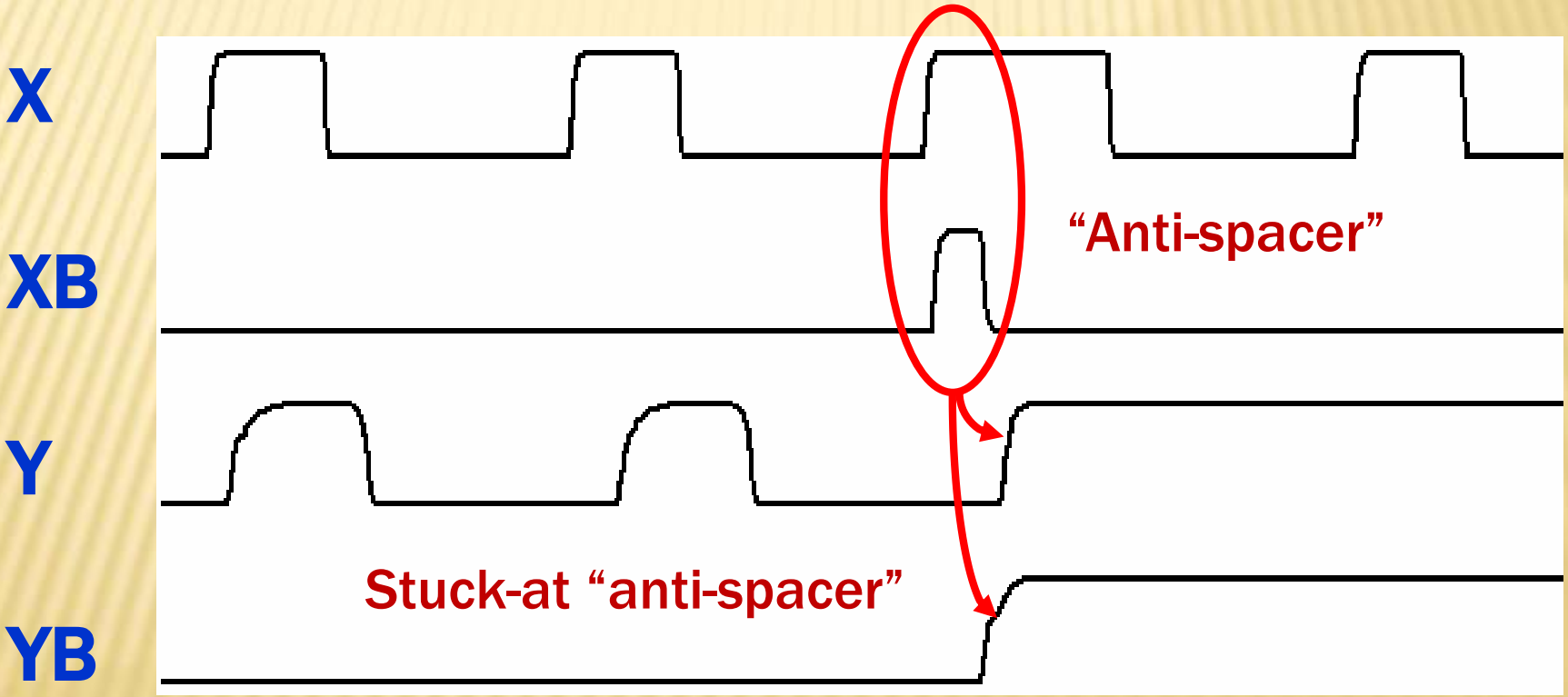


Traditional solution

Failure-safe solution masking state that is opposite to spacer

QDI-PIPELINE REGISTER

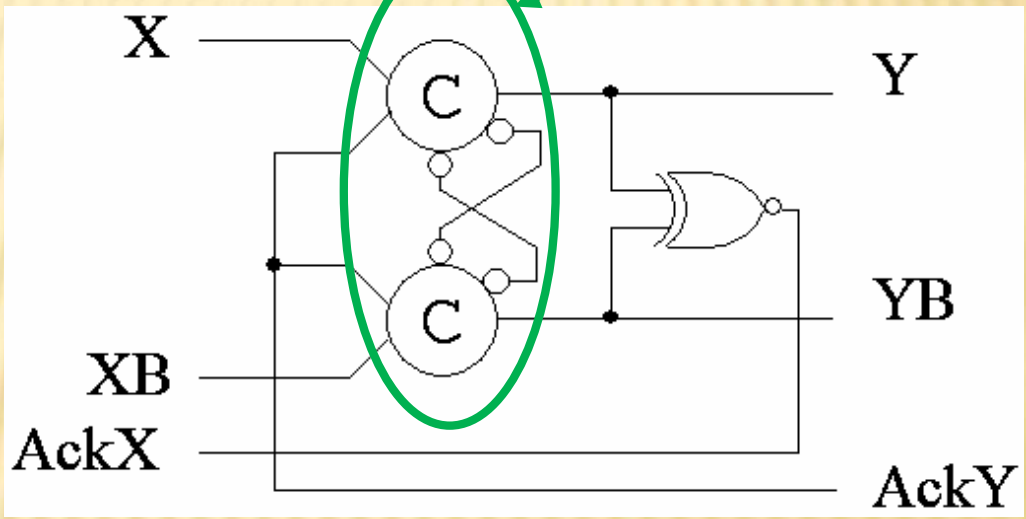
It is not enough to indicate “anti-spacer” as spacer, because it dead-locks register bit!



QDI-PIPELINE REGISTER

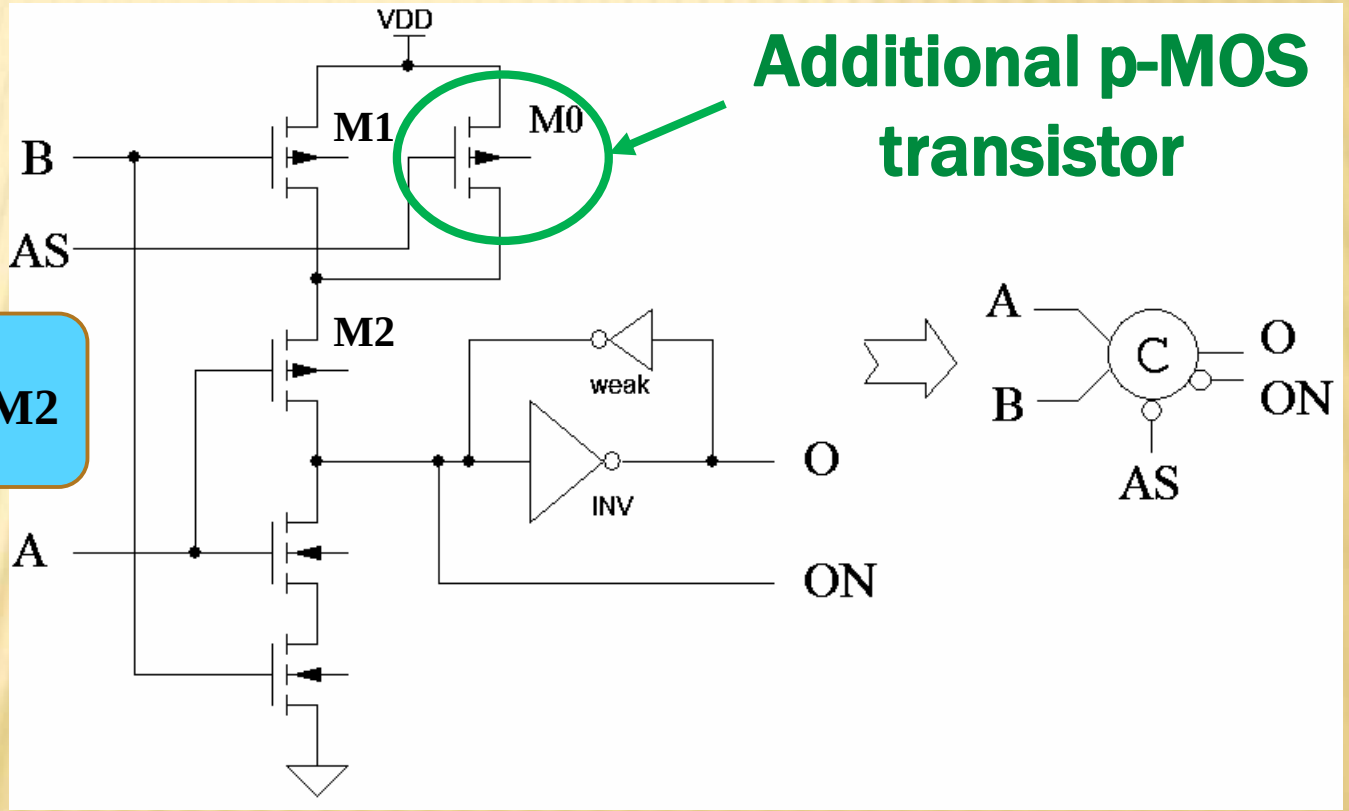
Pipeline register bit circuit protected from stuck-at “anti-spacer”

Modified C-elements



QDI-PIPELINE REGISTER

Modified semi-static C-element circuit with null spacer



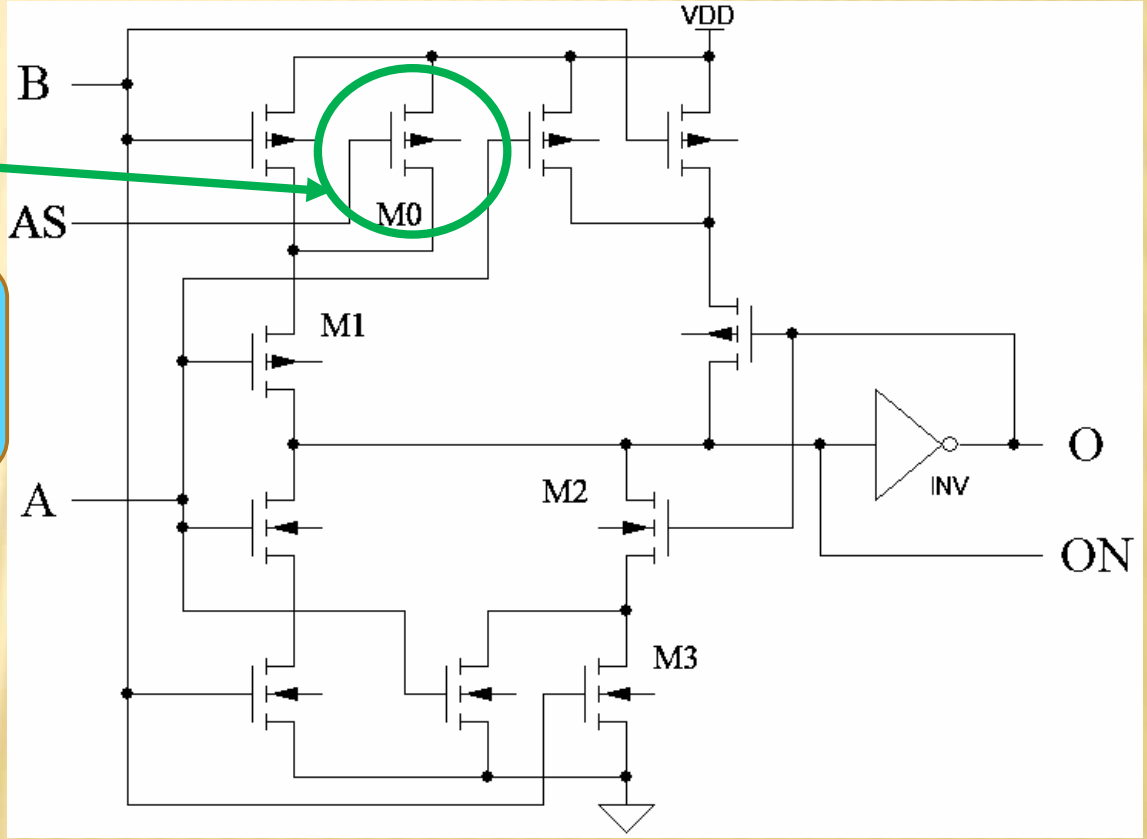
$$W_{M0} = W_{M1,M2}$$

QDI-PIPELINE REGISTER

Modified static C-element circuit with null spacer

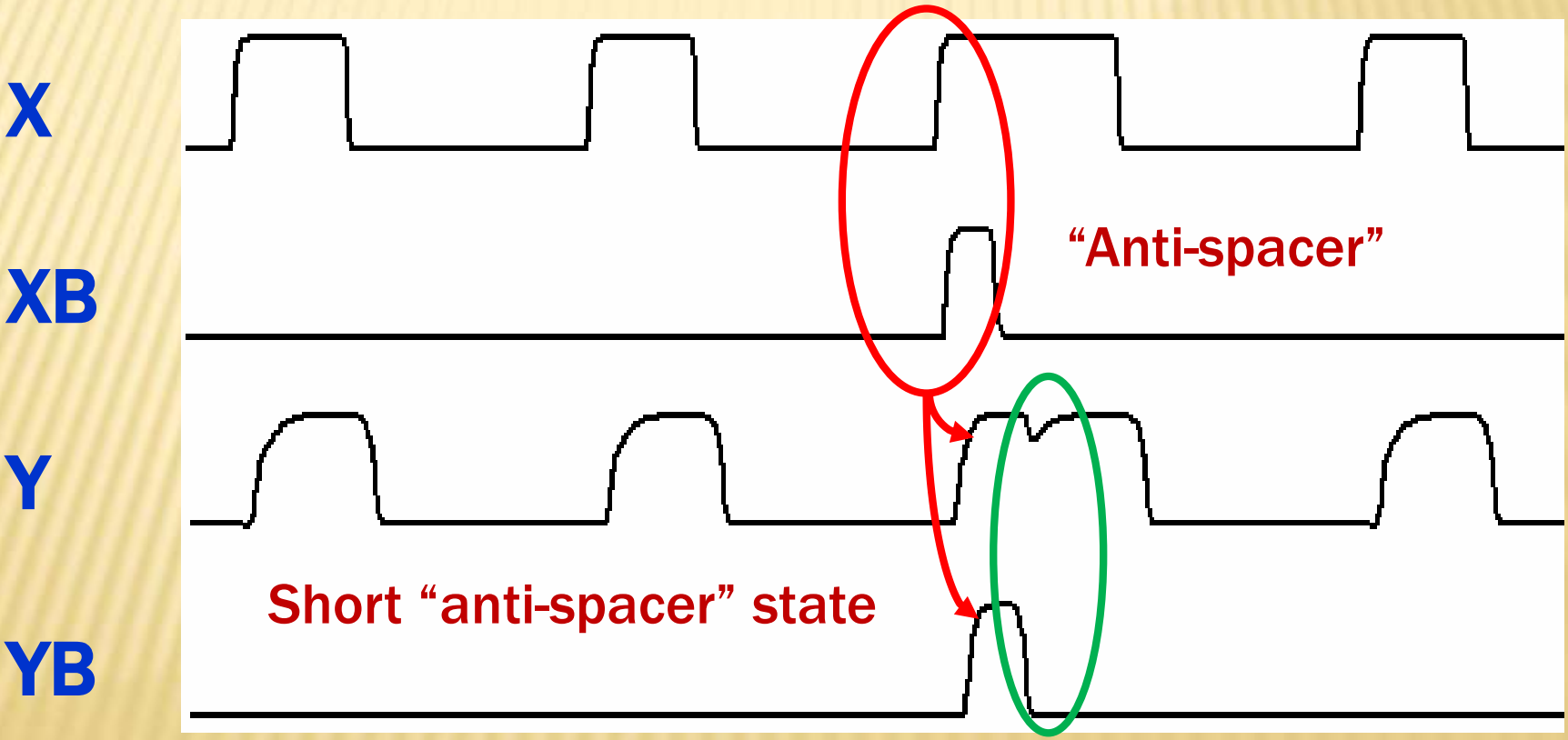
Additional p-MOS transistor

$$W_{M0,M1} > \frac{k_n}{k_p} W_{M2,M3}$$



QDI-PIPELINE REGISTER

Modified C-elements prevent dead-locking pipeline register bit at “anti-spacer”!



QDI-PIPELINE TOLERANCE

QDI-pipeline tolerance to the soft errors induced by noise:

- **Non-protected typical register bit – 82.1%,**
- **Register bit masking "anti-spacer" – 86.3%,**
- **Register bit masking "anti-spacer" and self-repairing stuck-at "anti-spacer" – 97.8%**

CONCLUSIONS

- Strict adjacent placement of the dual-rail wires on the layout makes the most critical soft error type, which is the data token inversed to the current or expected one, not feasible
- Indication of AS state as a spacer and the use of modified C-element protected against stuck-at AS in the QDI pipeline register bit together provide an increase in QDI pipeline natural immunity up to 97.8%
- Our further work will be devoted to studies of QDI pipeline immunity to the soft errors induced by noise for various circuits of the pipeline stage register and handshake control between pipeline stages

Thanks!

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