7th International Symposium on Turbo Codes & Iterative Information Process
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A Space-Time Redundancy Technique for Embedded Stochastic Error Correction

- A Decoder Against Internal Faults

A Collaborative Work of

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TELECOM Bretagne, France

***Pr.* Michel Jézéquel**

OUTLINE

1. Emerging Challenge in Electronic Device

2. Previous Work: Coded Dual-Modular Redundancy (cDMR)

3. Latest Solution: A Decoder Against Internal Faults

4. Space-Time Redundancy Technique

5. Conclusions & Discussions

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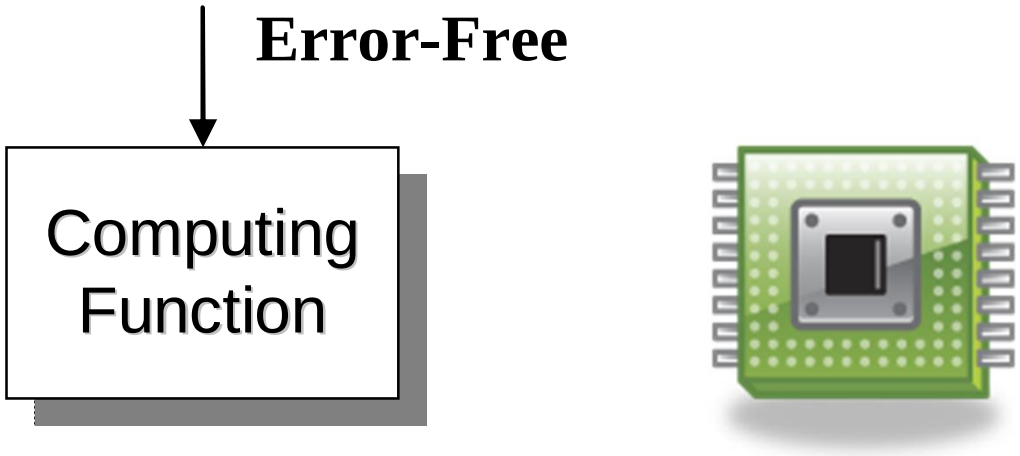
Electronic Device: Phase 1 ï Error Free

- **Phase 1: Reliable, Computation is Error-Free.**



Emerging Challenge: Transient Fault Sources

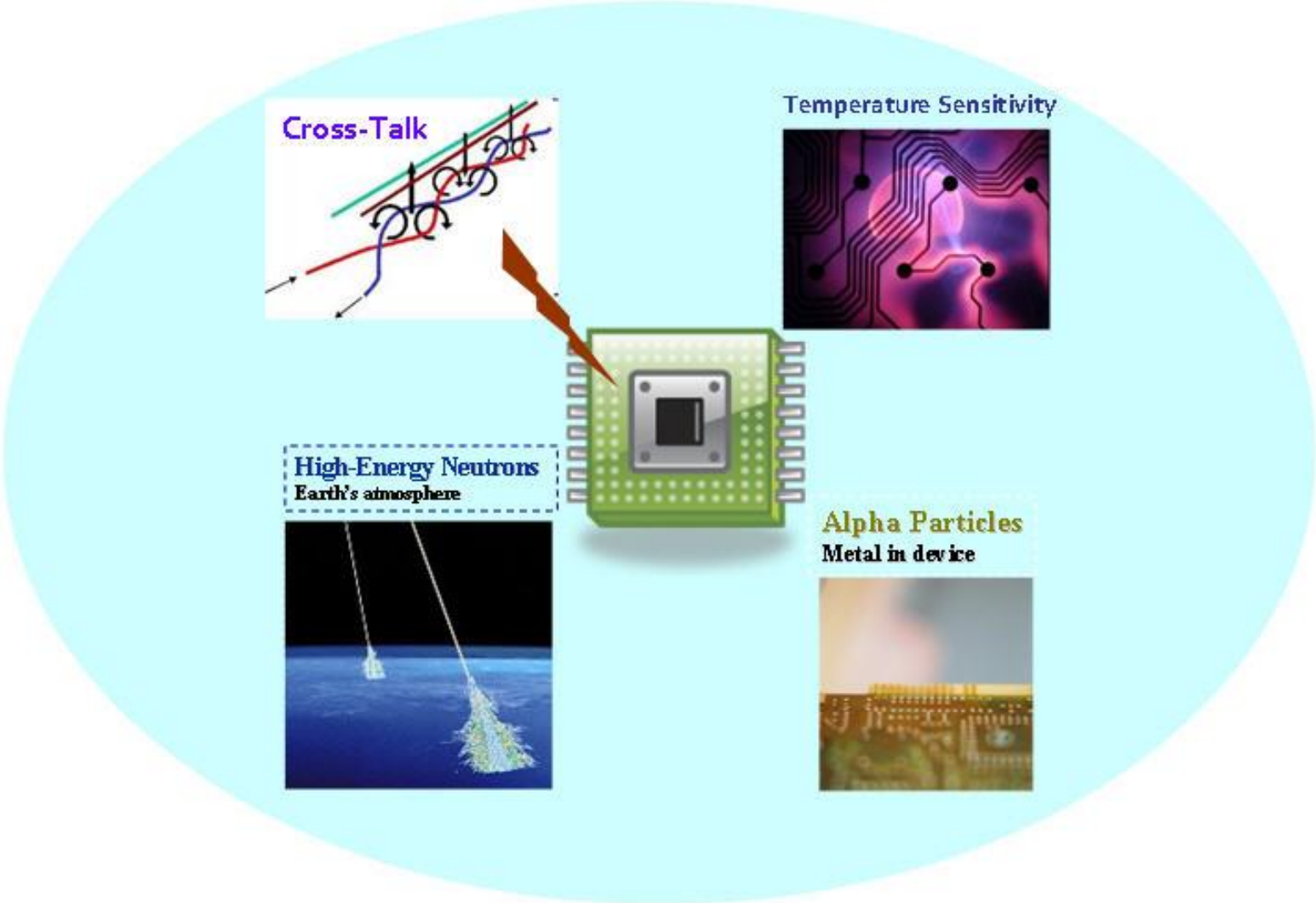
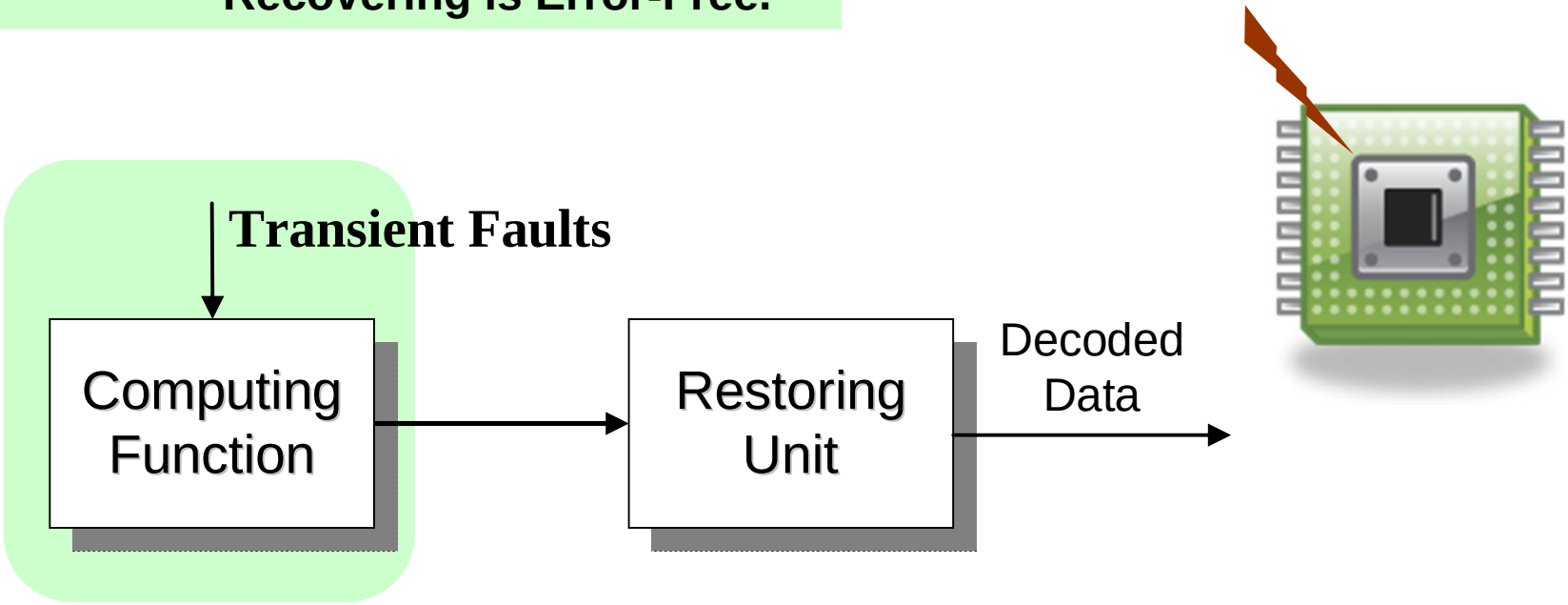


Fig. 1: Transient Fault Sources: Cross-Talk, Thermal, Soft-Error: by High-Energy Neutron and Alpha Particles, and etcé

Electronic Device: Phase 2 ï Recovering is Error-Free

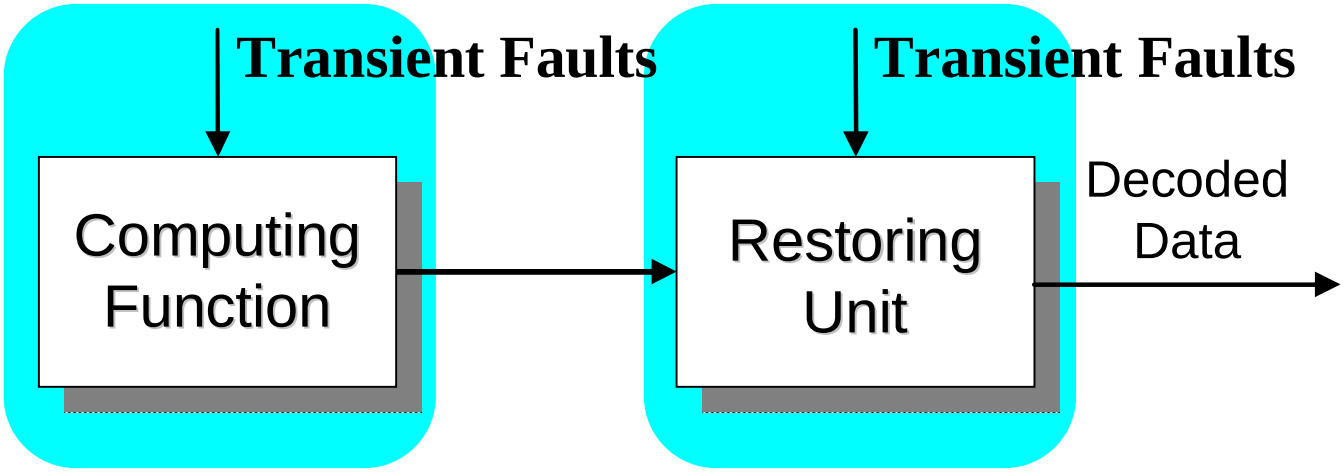
Å **Phase 2: Computation is Erroneous, Recovering is Error-Free.**

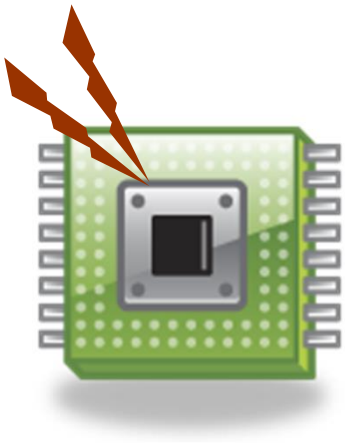


Unreliable Function & Unreliable Restoration

Å **Phase 3: Computation is Erroneous, Recovering is Erroneous as well.**

Sample: Y. Tang, E. Boutillon, M. Jézéquel, C. Jégo, 2011





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Coded Dual Modular-Redundancy (cDMR)

Sample of C. Winstead's work in 2009 and also our work at ISCAS 2012.

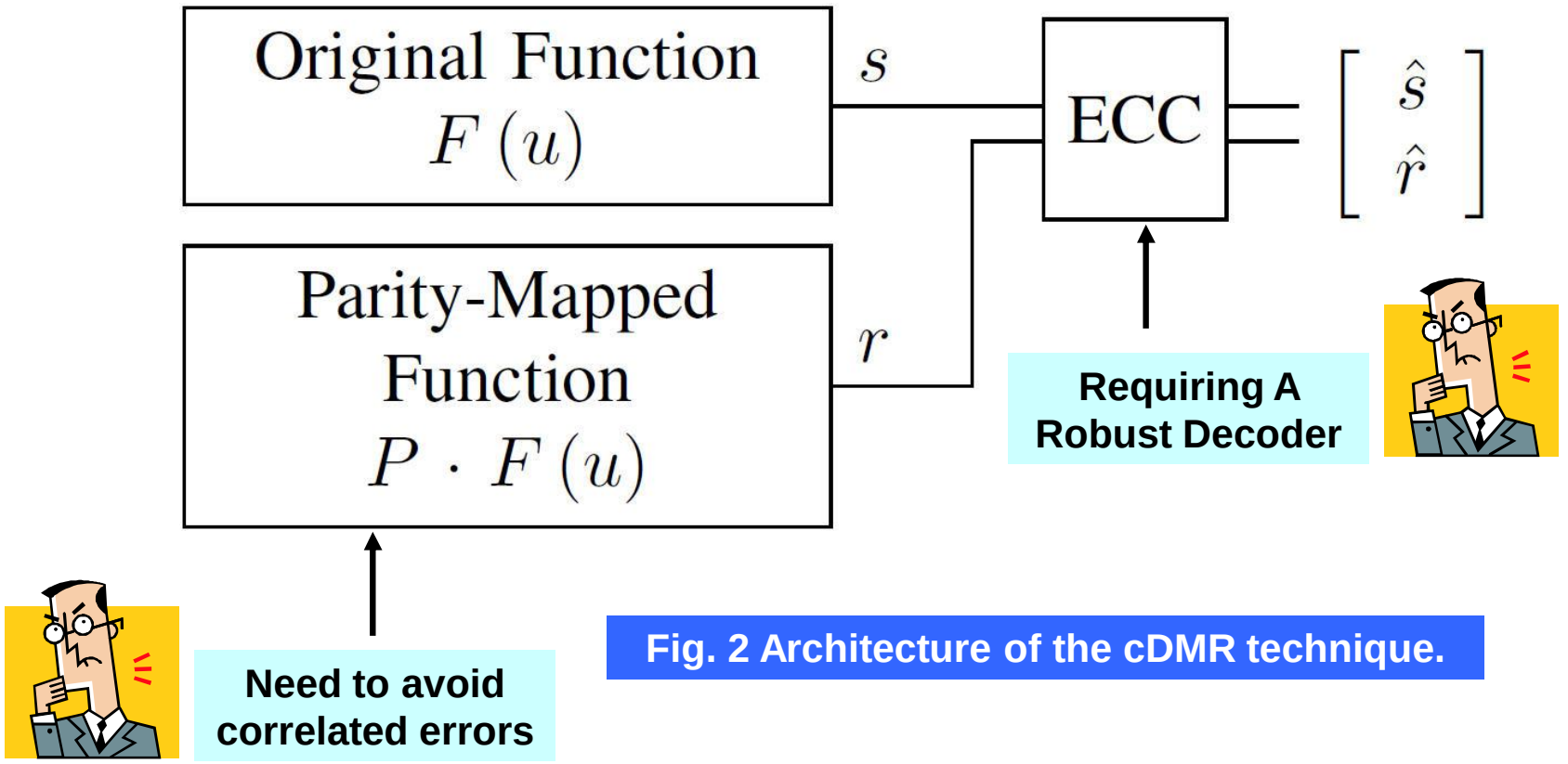


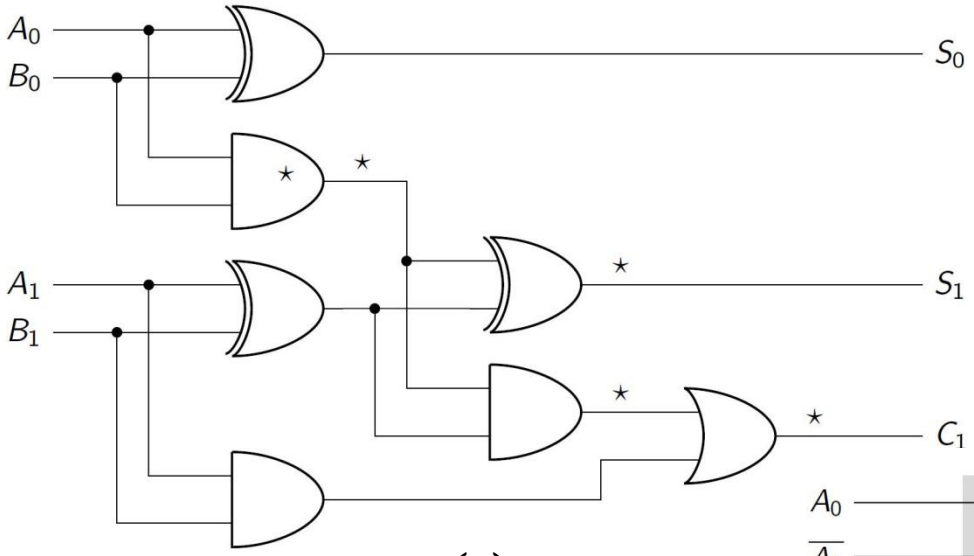
Fig. 2 Architecture of the cDMR technique.

ÅThe original logic function *F*(u) is composed with a block ECC code to create the parity-mapped function *P* Å*F*(u).

Parity-Mapped Function

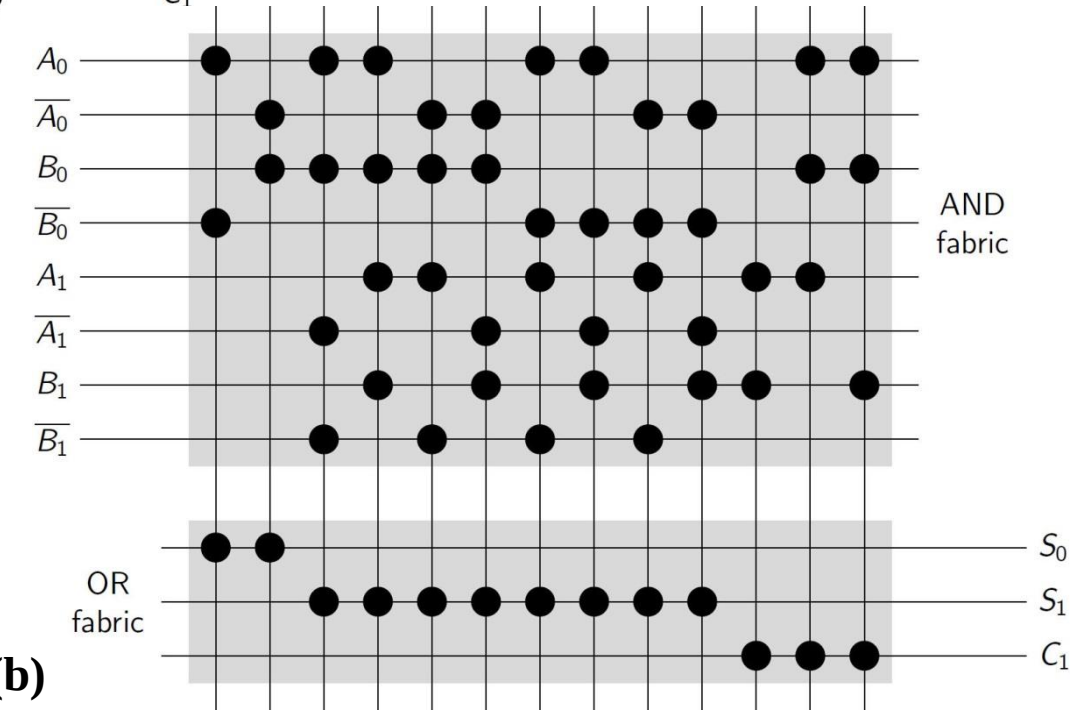
Sample of our work at ULSI 2012.

An approach to built Parity-Mapped Function without correlated error occurrence.



(a)

Fig. 3 (a) Traditional ripple-carry design, ðô symbol indicates the occurrence of an error.



(b)

Fig. 3 (b) Crossbar design suitable for some nanoelectronic device families.

Decoder for Binary Symmetric Channel

Ref: Gallager-A decoding Method, R. Gallager, 1963.

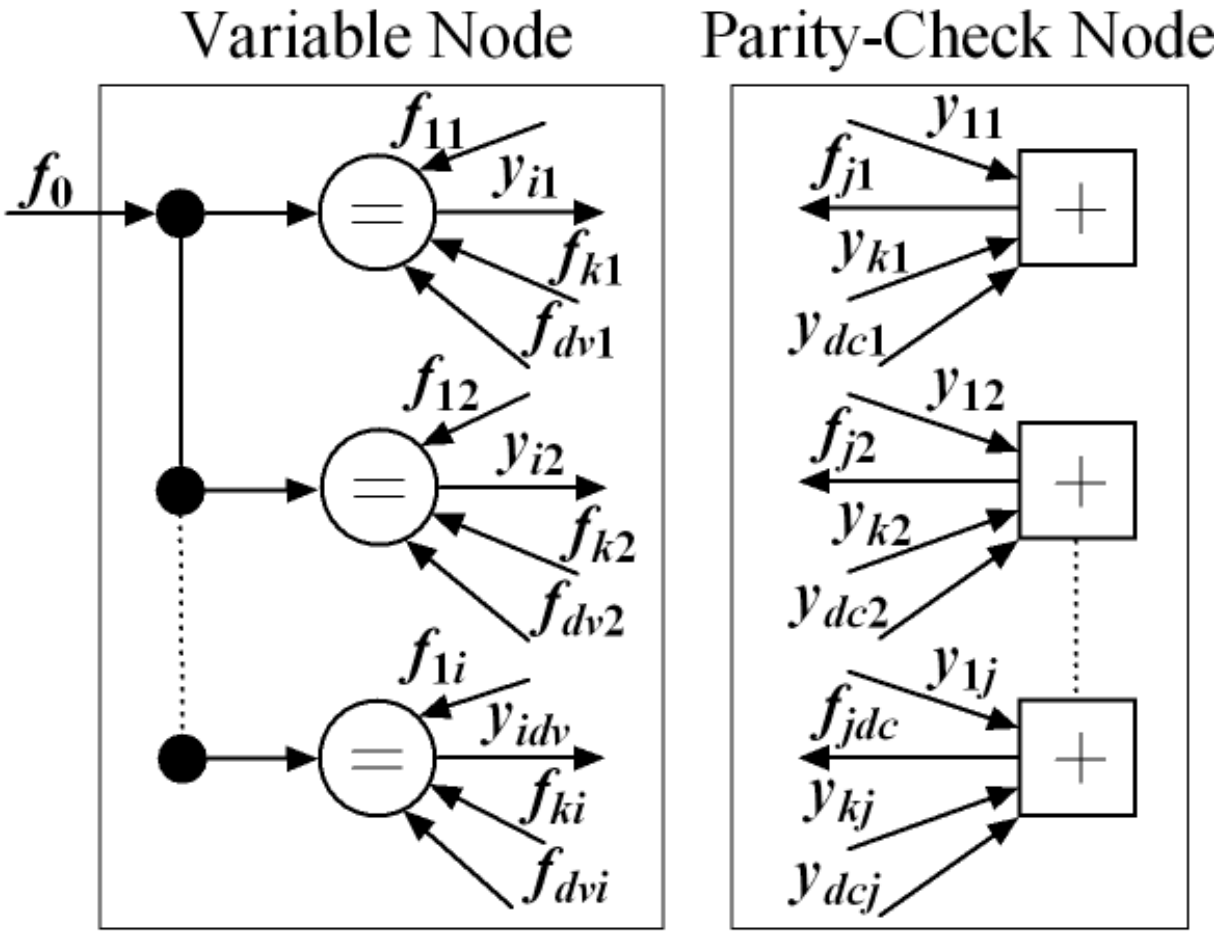


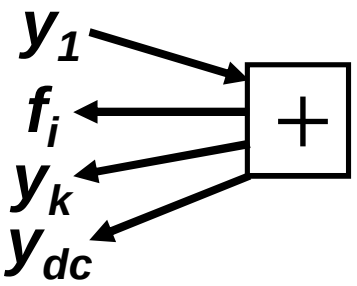
Fig. 4 Message-Passing Decoding Variable-Node & Check-Node

Ref: message-passing decoding, T. Richardson and R. Urbanke, 2001.

Gallager-A Decoder

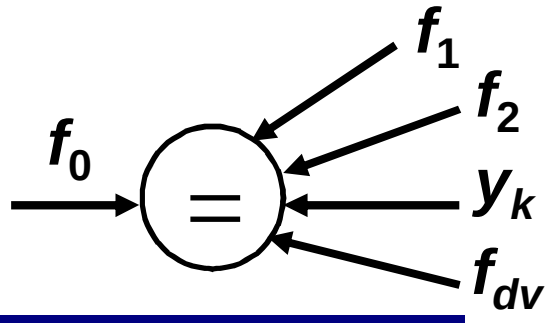
Check Node Processing

$f_i = \oplus y_k$, $k \neq i$



Variable Node Processing

$y_k = f_0$ if (f_i, $i \neq k$) disagree, f_1 elsewise



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Muller C-element: *Error-Resilience in Nature*

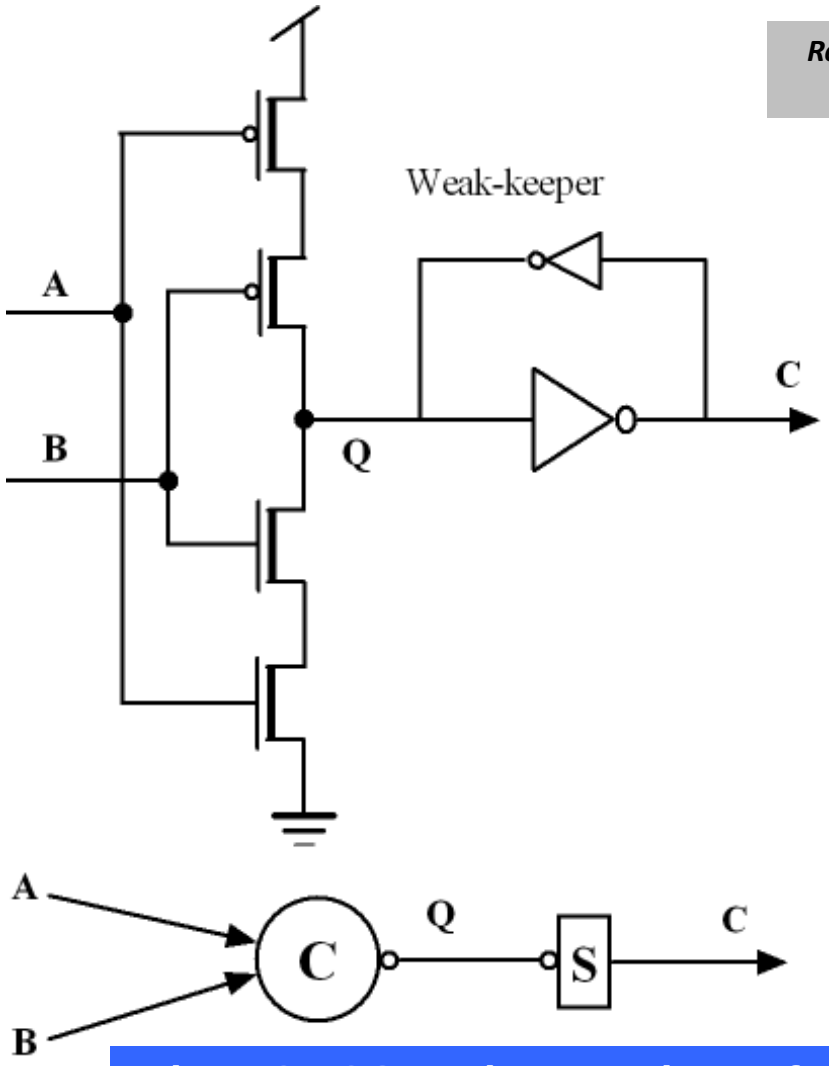


Fig. 5 CMOS Implementations of binary C-element

Ref : D. E. Muller and W. S. Bertky, 1959

C-element

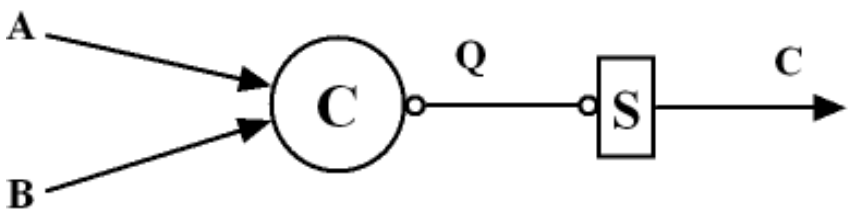
Tab. 1 Truth-Table of Binary C-element

A	B	C
0	0	0
0	1	C_{n-1}
1	0	C_{n-1}
1	1	1

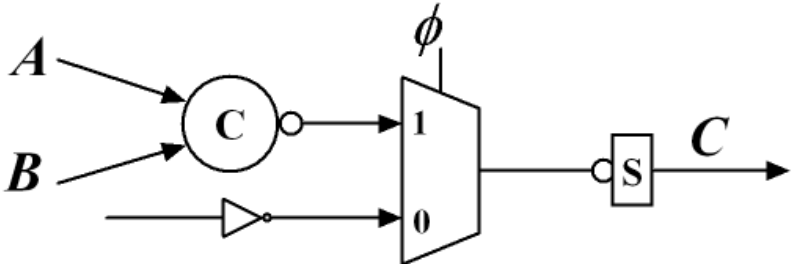
C_{n-1} denotes the state maintained via weak feedback.

Muller C-element: *Error-Resilience in Nature*

C-element



Initializing the state memory.



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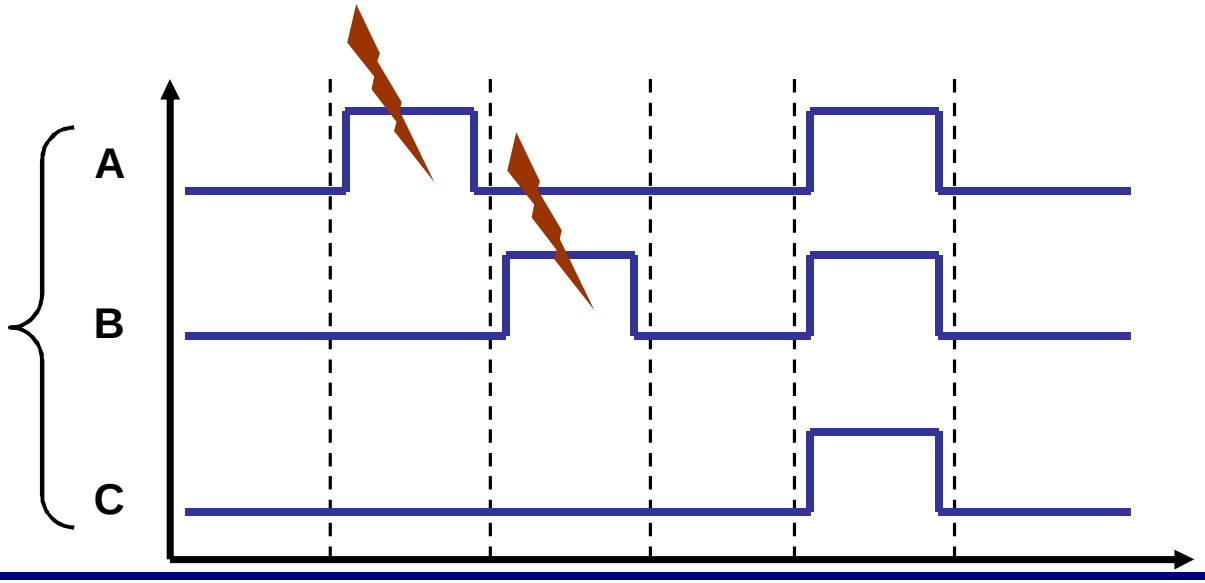
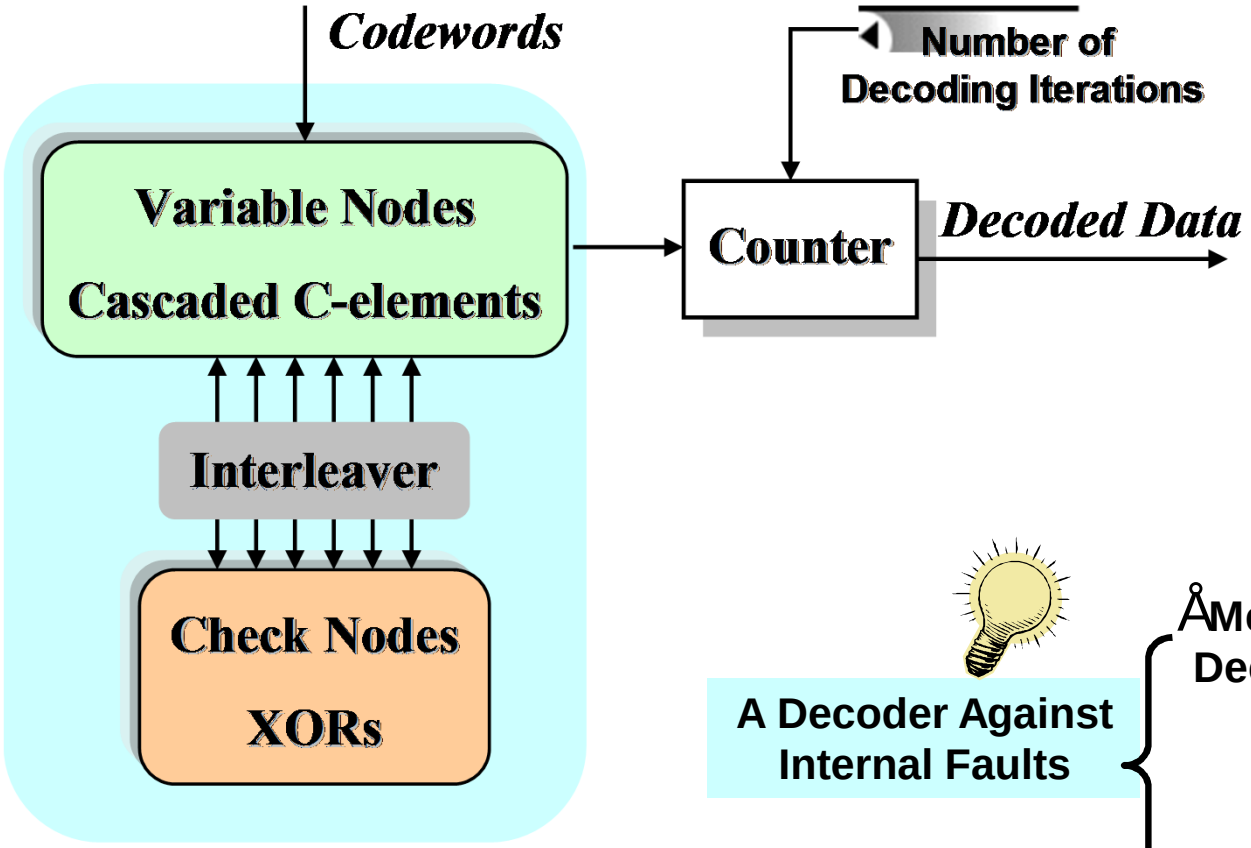
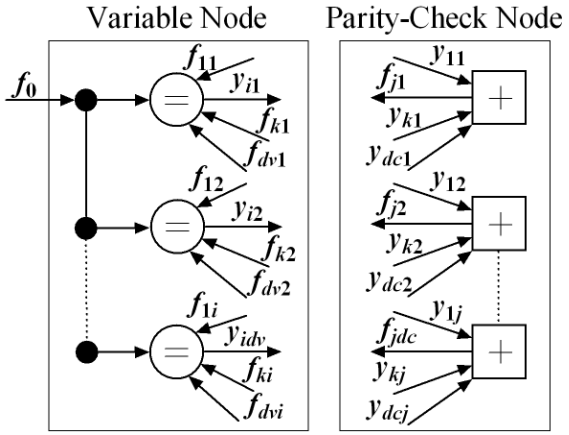
Error-Resilience in Nature



LDPC Stochastic Decoding Method (LSD)

Sample of our work 2012 at ISCAS 2012.





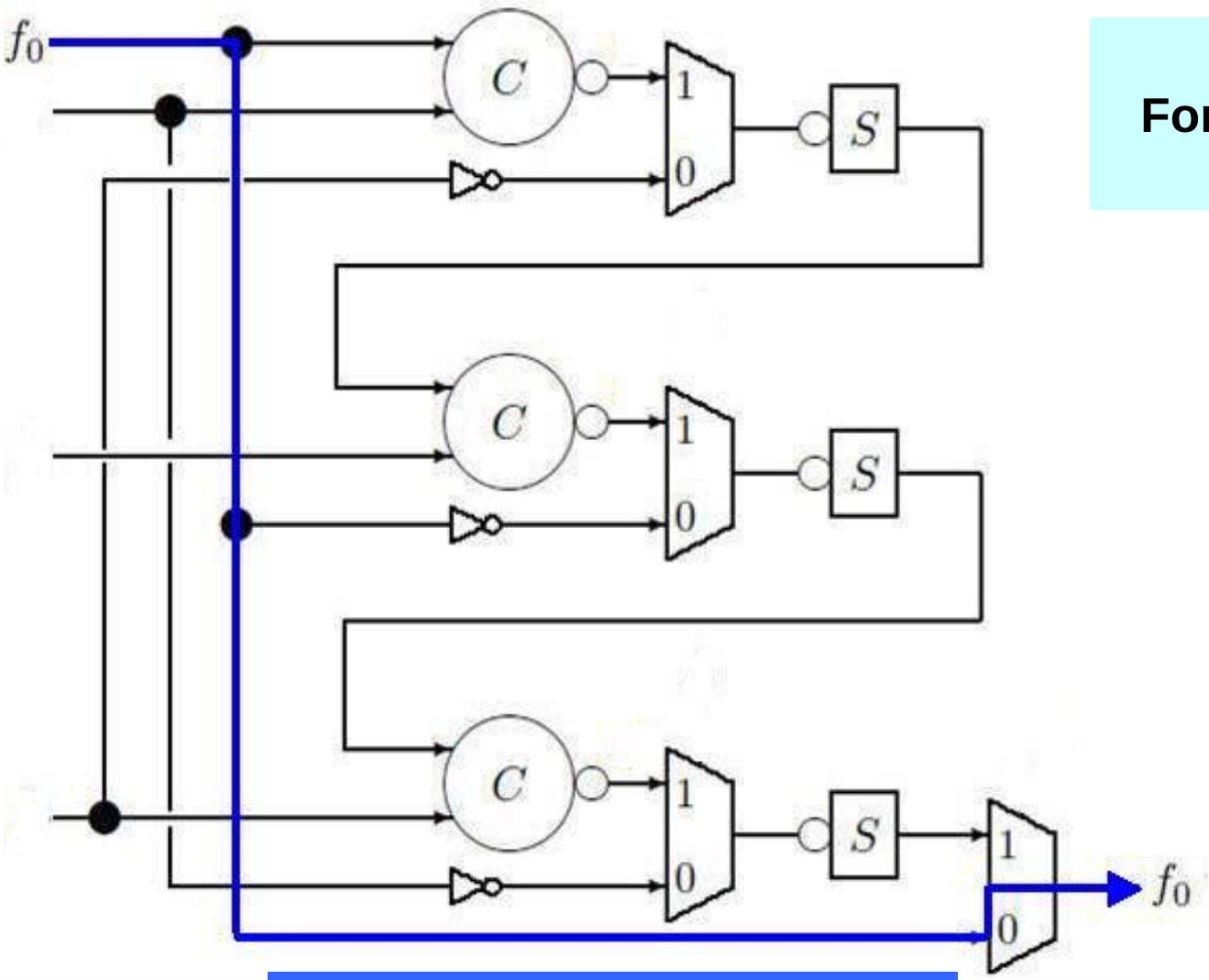
A Decoder Against Internal Faults

- Message-Passing Decoding Method
- Inherent error-resilience C-element

C-element

Fig. 6 Diagram of Decoding Process for LDPC Stochastic Decoding Method (LSD)

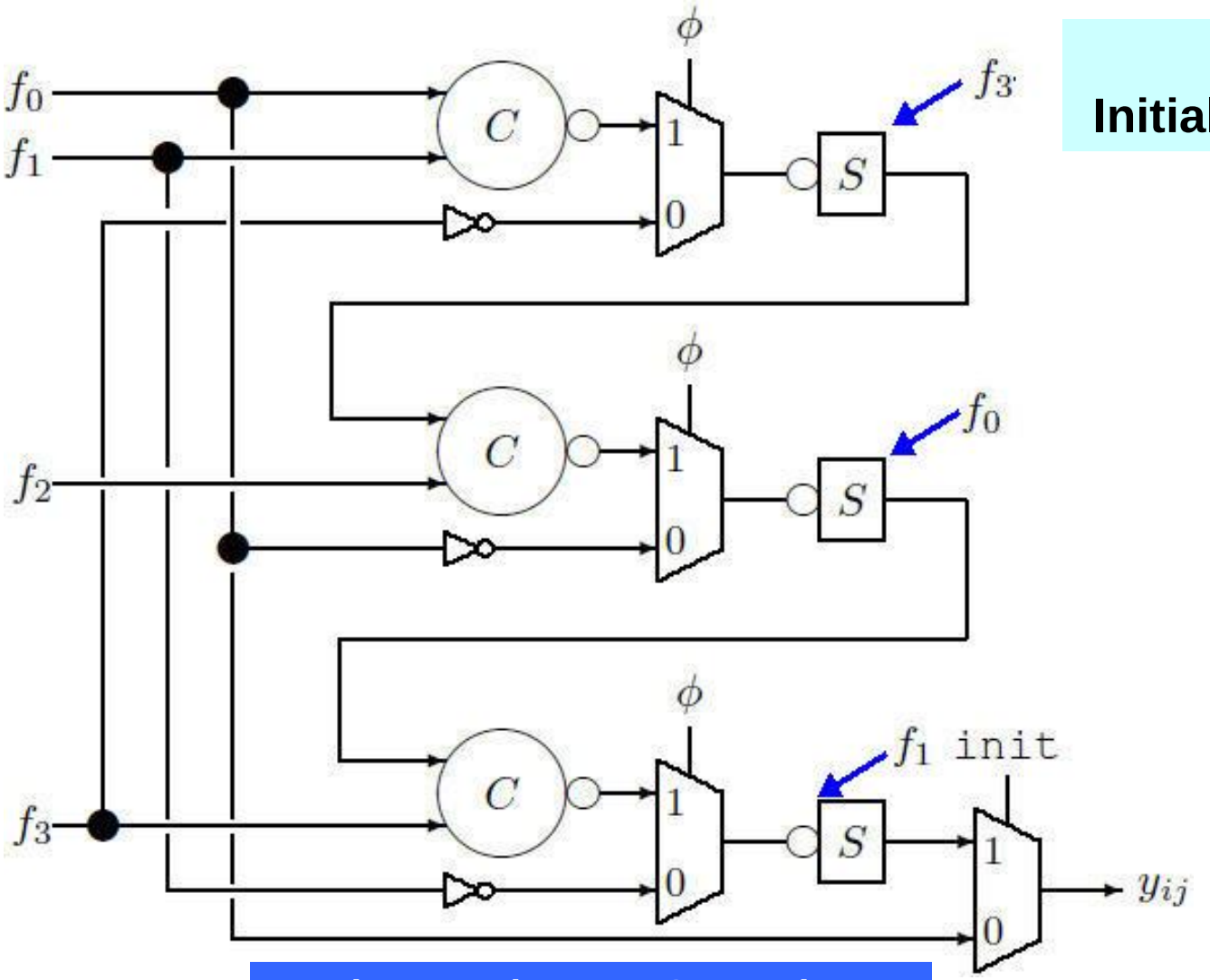
Variable Node in LSD ï Phase 0



Phase 0
Forward Channel
Message

Fig. 7 Basic Error-Correction Unit Cascaded C-elements, d_v=4

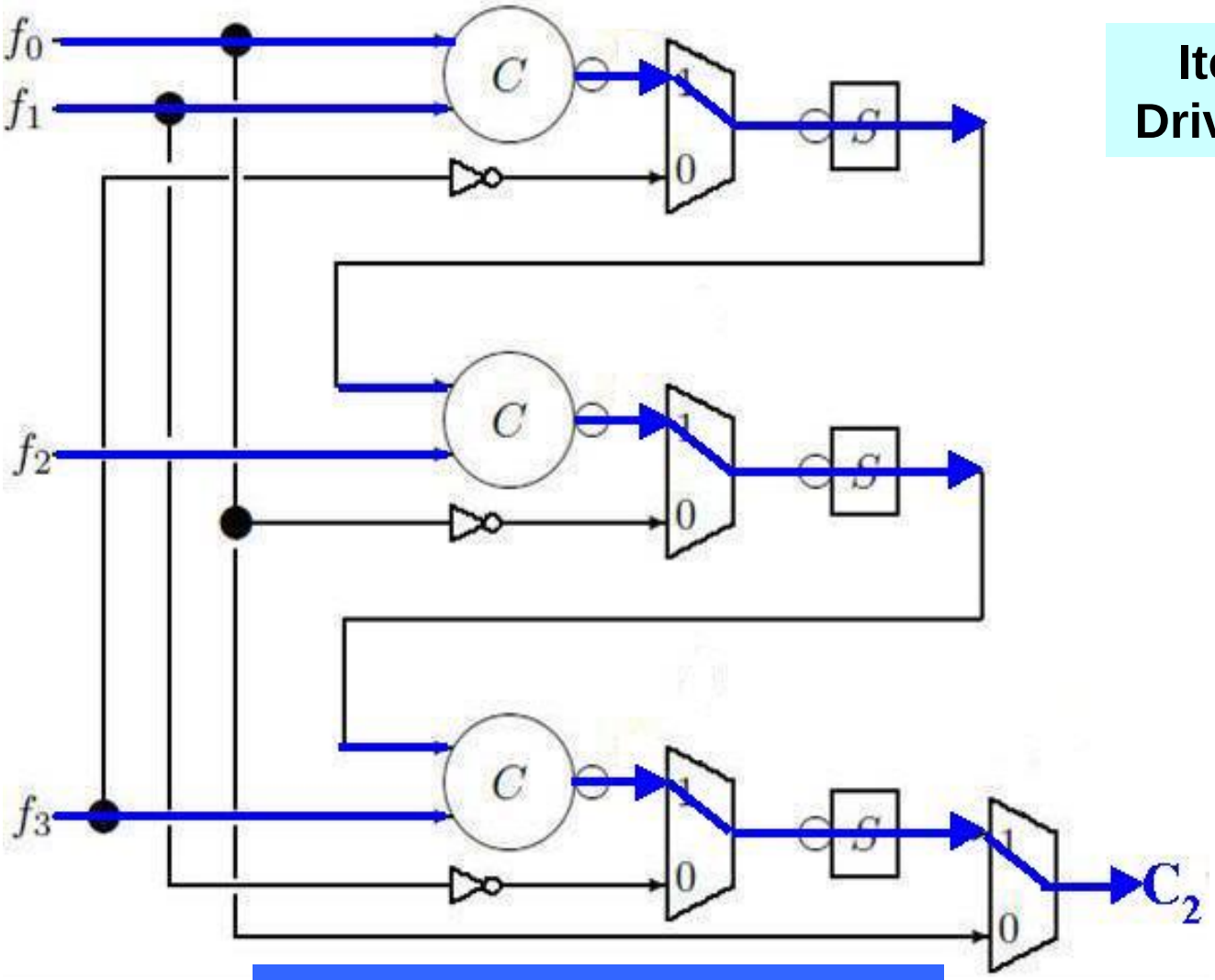
Variable Node in LSD ï Phase 1



Phase 1
Initialization Phase

Fig. 7 Basic Error-Correction Unit Cascaded C-elements, d_v=4

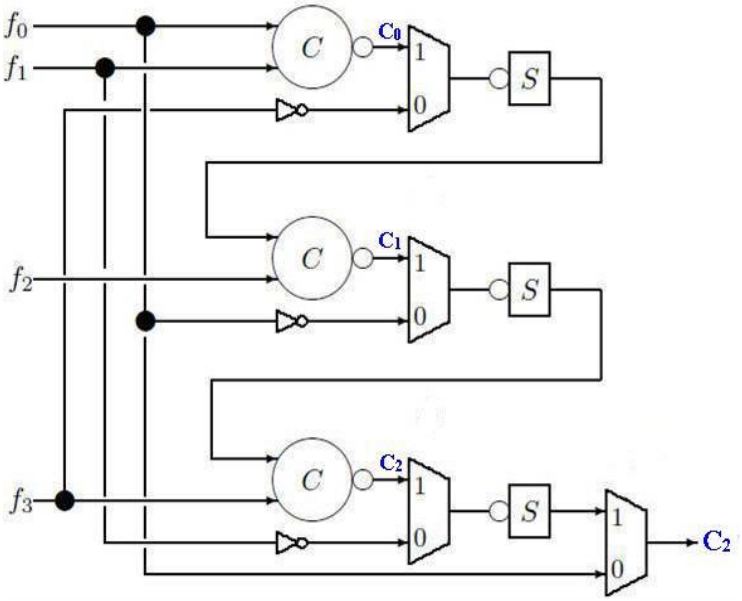
Variable Node in LSD ï Phase 2



Iterative Phase 2
Driven by C-element

Fig. 7 Basic Error-Correction Unit Cascaded C-elements, d_v=4

Variable Node in LSD



Variable Nodes

Cascaded C-elements

Cascaded C-element is able to correct a single error during one iteration

Tab. 2 A truth table that illustrates the behaviors of error-correction

					Initialization			In 1 Iteration		
	f_0	f_1	f_2	f_3	c_0	c_1	c_2	c_0	c_1	c_2
Error-Free	0	0	0	0	0	0	0	0	0	0
Error in f_0	1	0	0	0	0	1	0	0	0	0
Error in f_1	0	1	0	0	0	0	1	0	0	0
Error in f_2	0	0	1	0	0	0	0	0	0	0
Error in f_3	0	0	0	1	1	0	0	0	0	0

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A Modified LSD (LSDfb): Feedback Mechanism

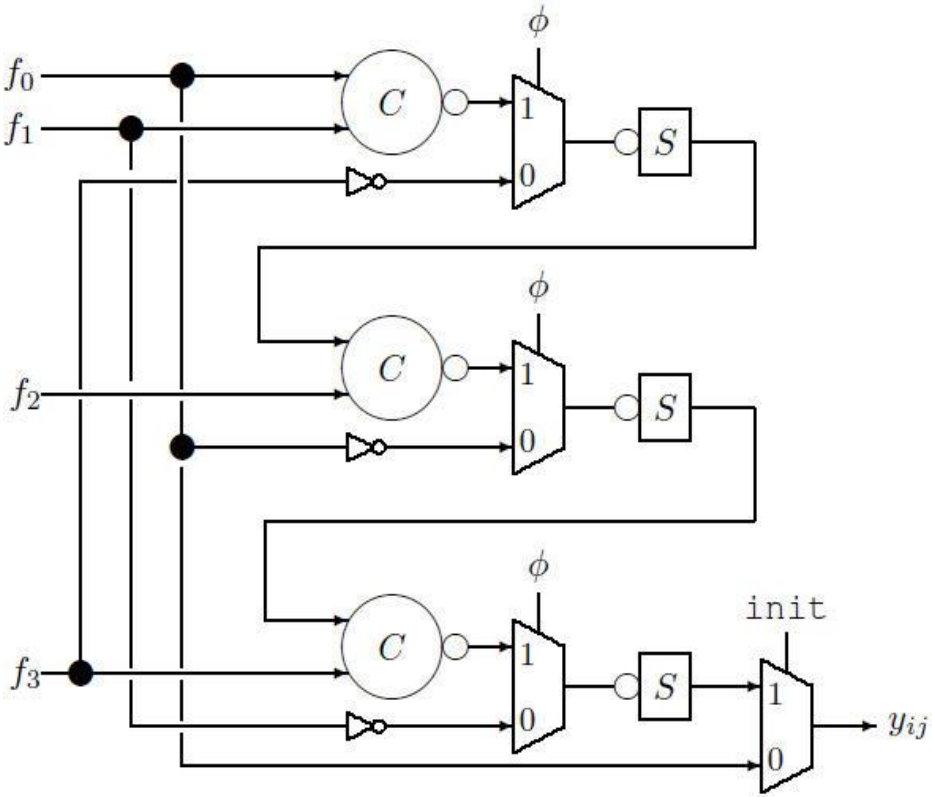


Fig. 7 LSDôs variable-node architecture, d_v=4

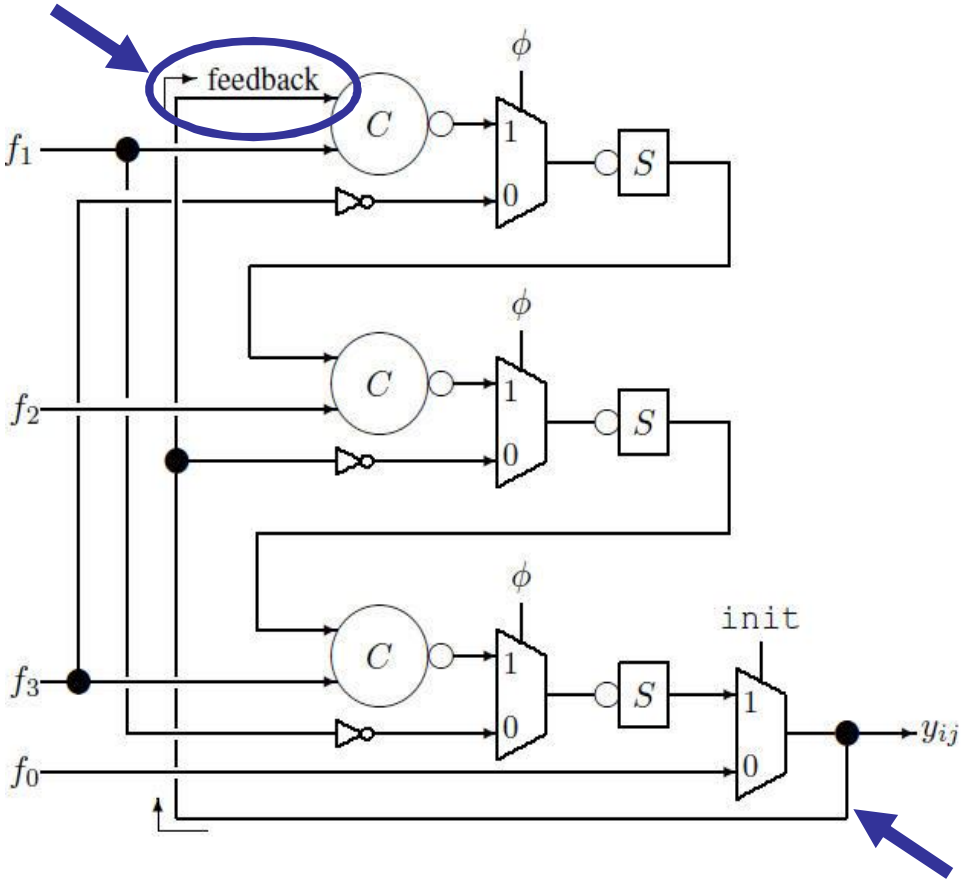


Fig. 8 LSDfbôs variable-node architecture, d_v=4

A Contribution of this work : A feedback mechanism employed to suppress internal fault event.

Space-Time Redundancy Technique

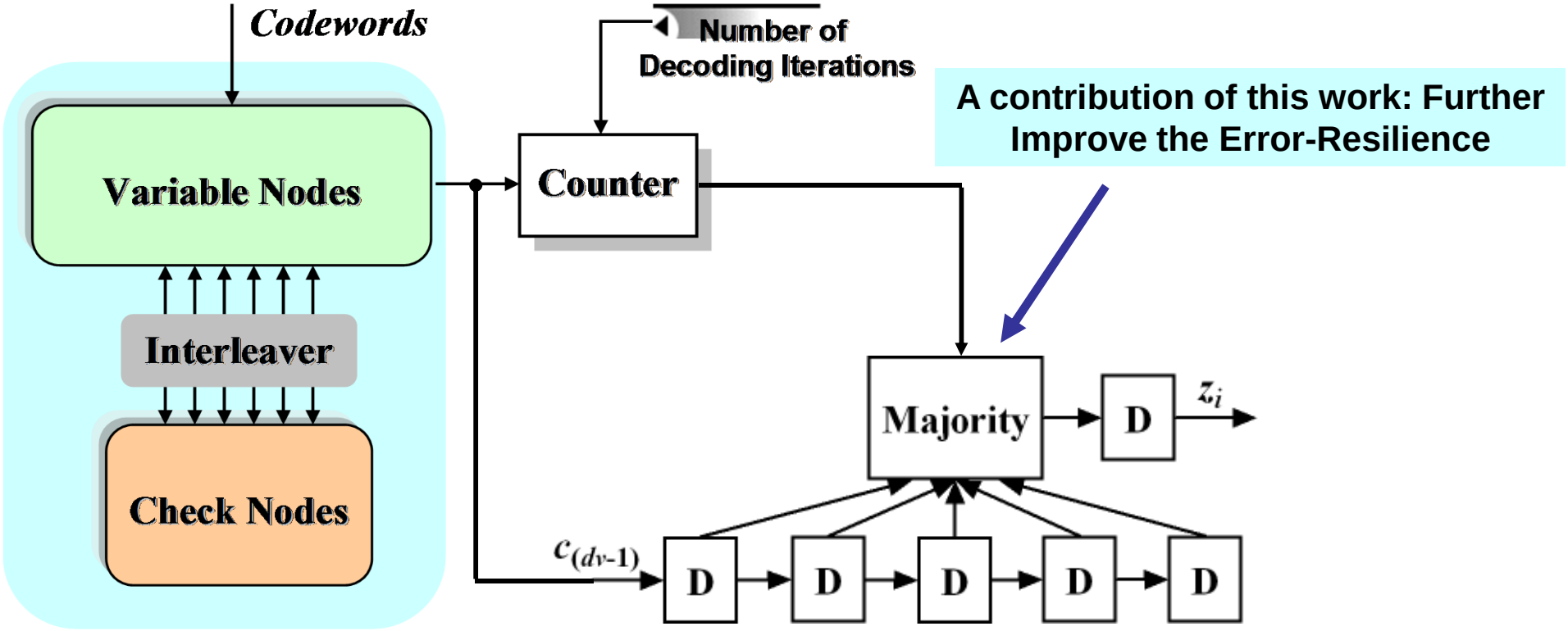
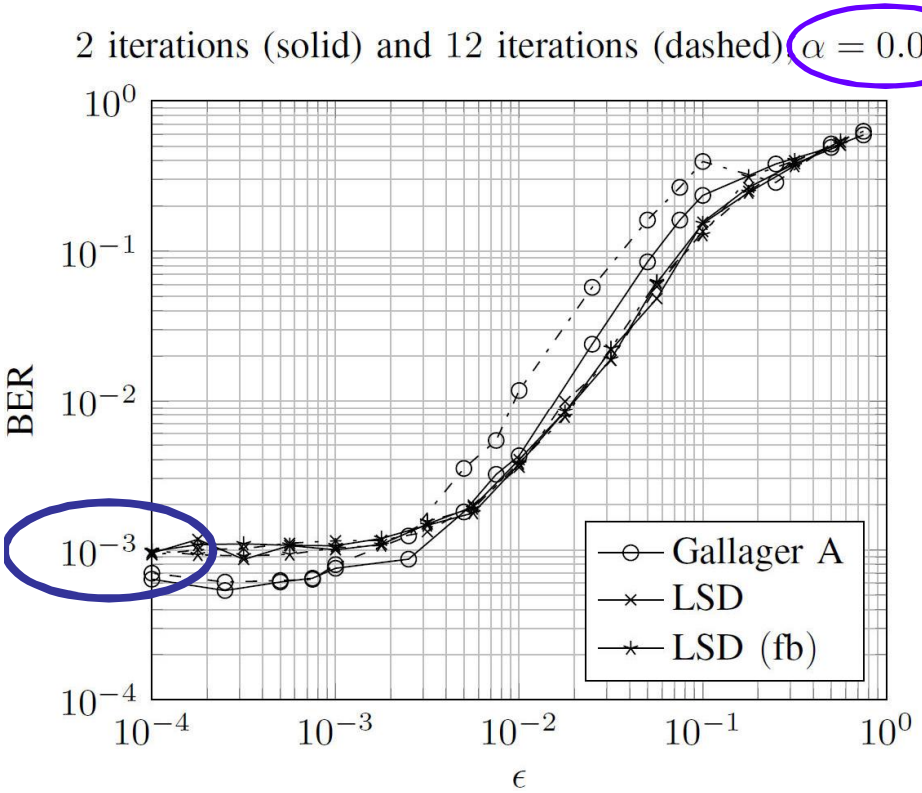


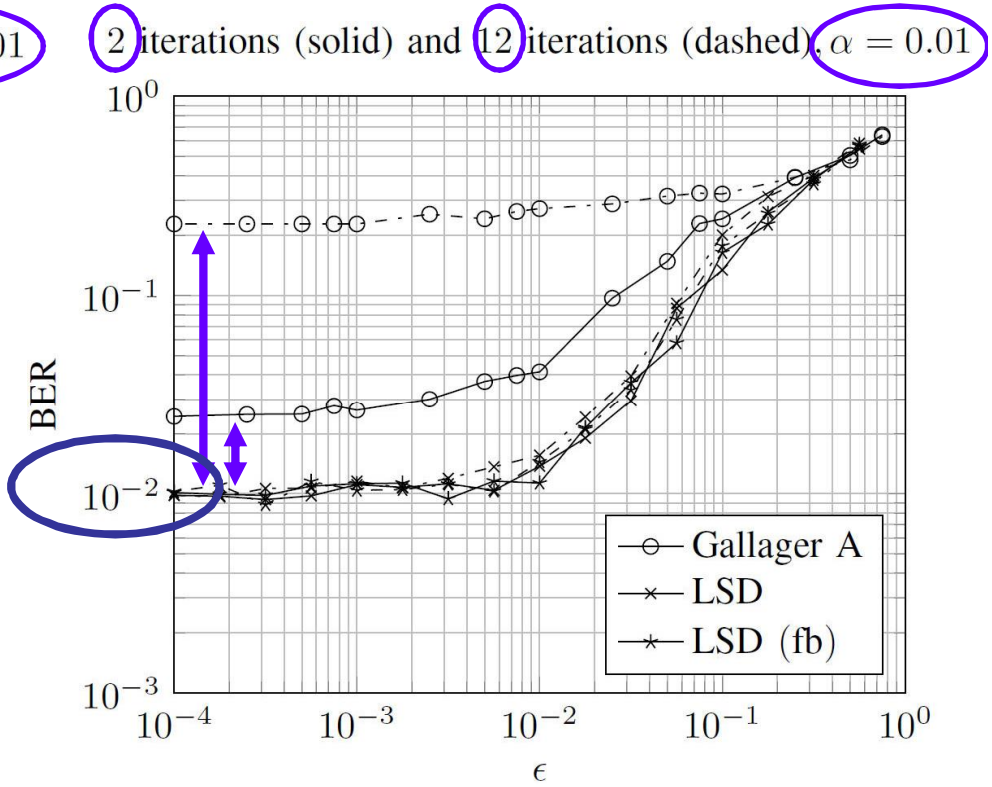
Fig. 9 Message-Passing Decoder with Space-Time Redundancy Technique. For instance, the Majority unit can be a 3-of-5 voter.

BER Results Without Space-Time Redundancy

WITHOUT Space-Time Redundancy

- **Internal Fault Injection: *Alpha***
- **(3,6) LDPC code of length 64 over a BSC parameter of *Epsilon***





- **Gallager-A performance worsens with increased iterations when internal faults rate is high.**
- **But LSD does not exhibit this degradation.**

BER Results WITH Space-time Redundancy

WITH Space-Time Redundancy

- **Internal Fault Injection: *Alpha***
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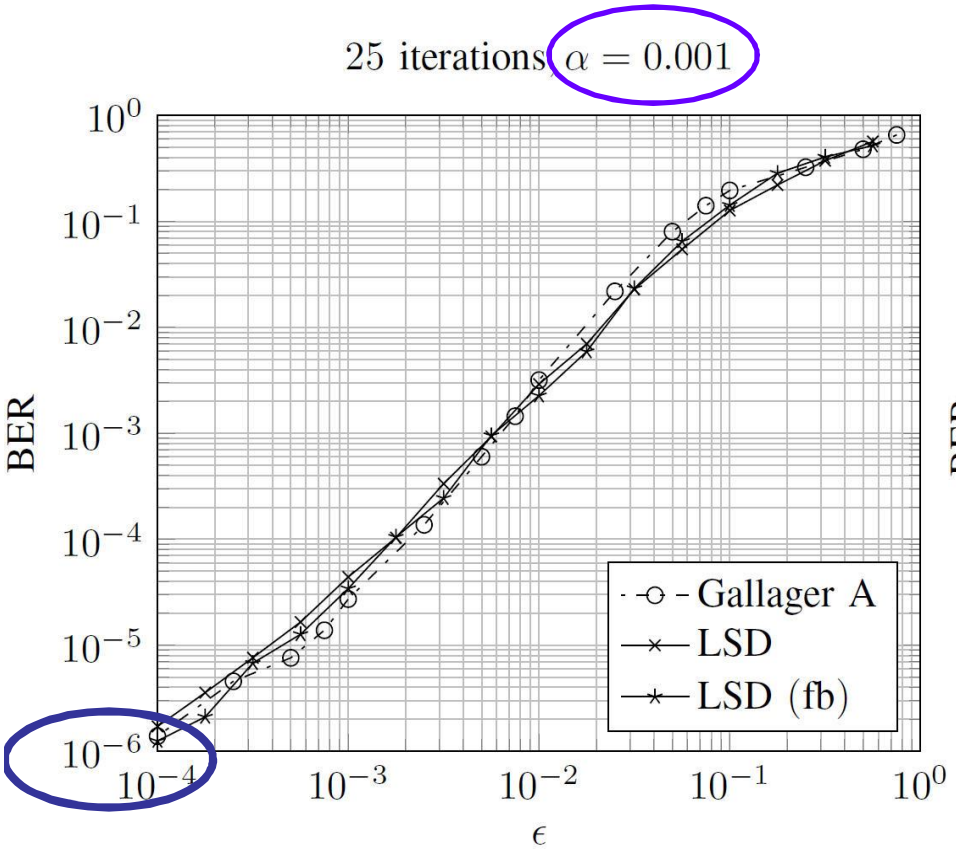

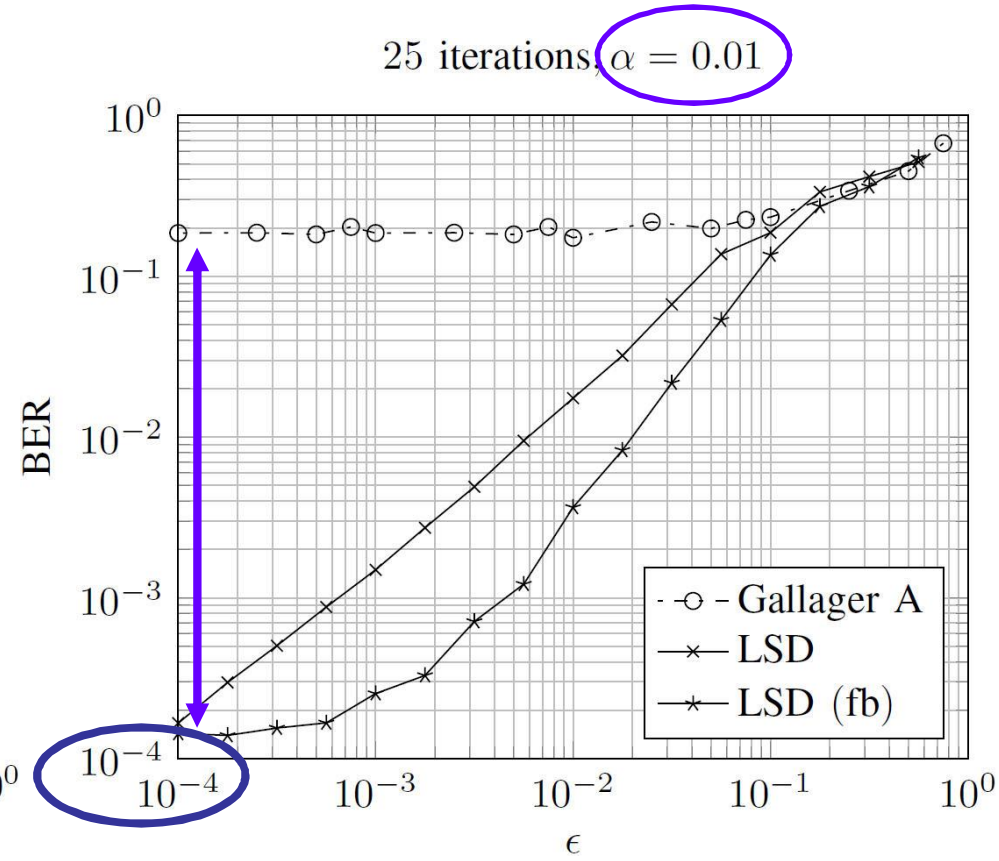

- **The majority voter significantly improves the decoderôs BER performance.**
- **Feedback-Mechanism is helpful as well.**

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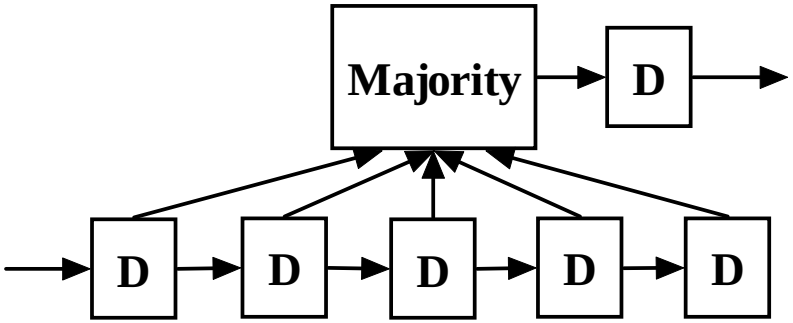
Discussions: Space-Time Redundancyô Implementation



Easy Implementation for Space-Time Redundancy Unit

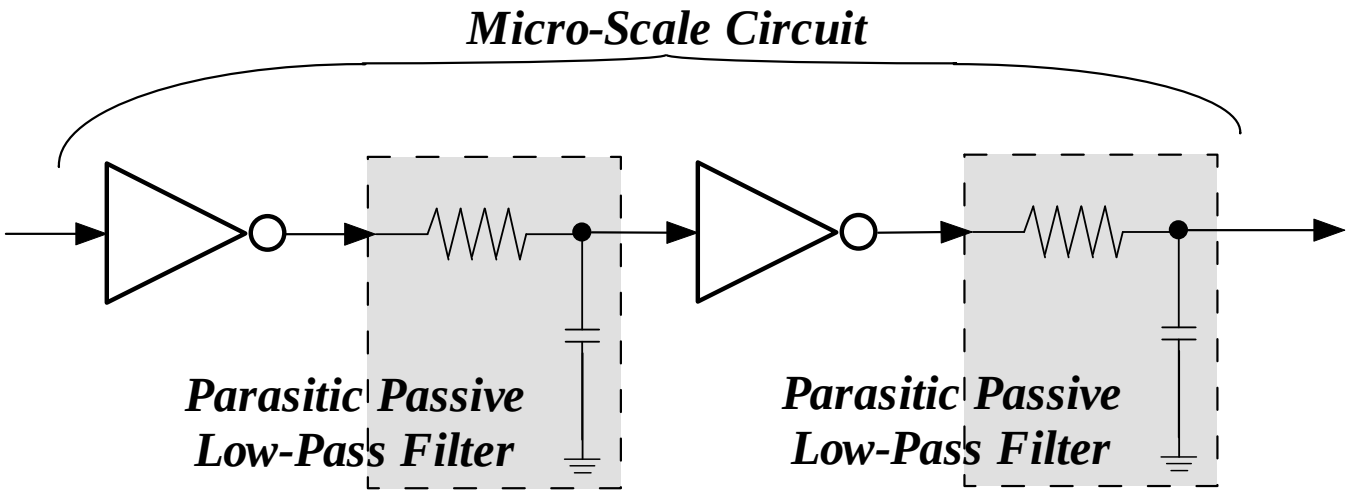


Fig. 10 This approach may be implemented, for instance, with the native R-C parasitics in a large-size output buffer.

Conclusions

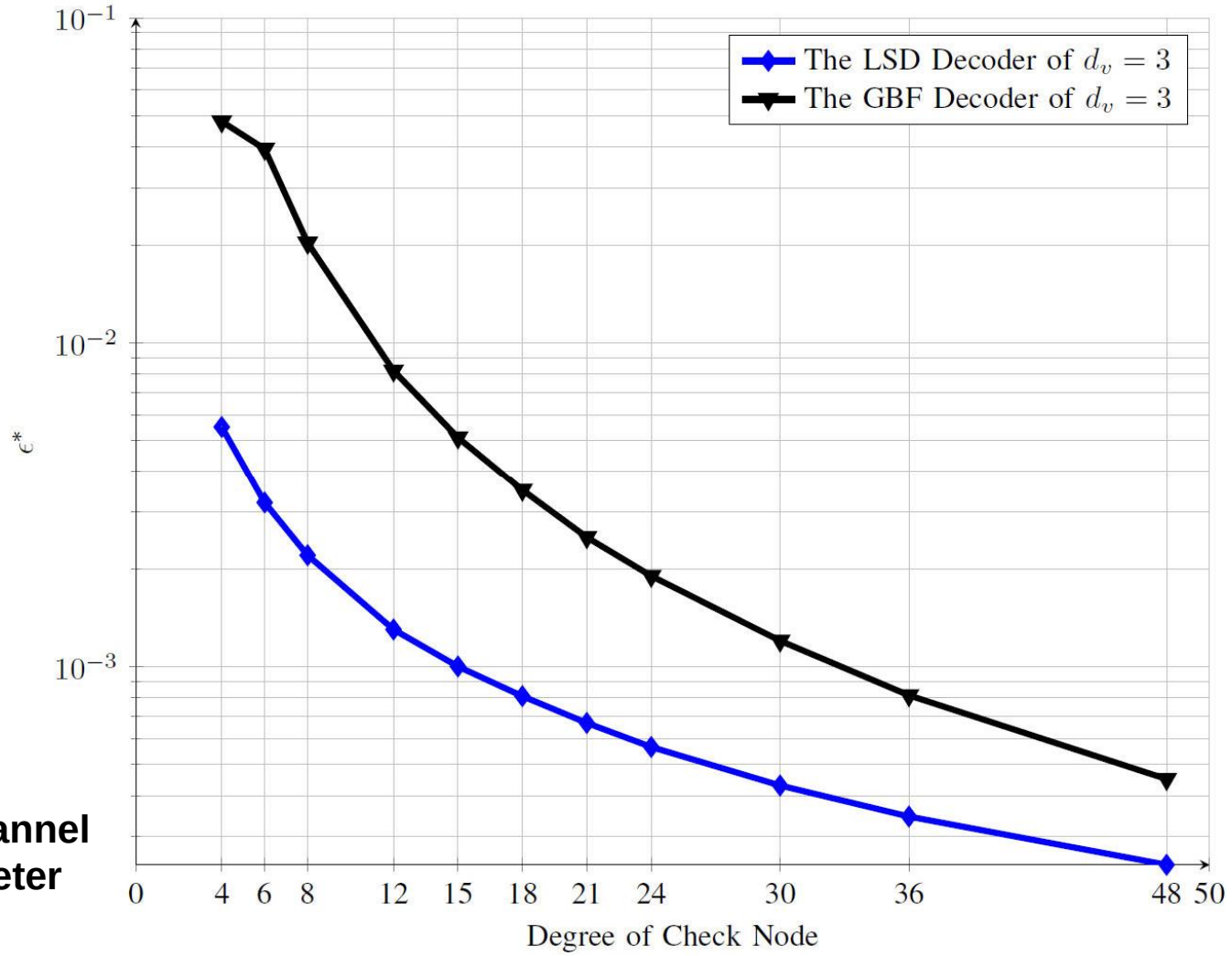
- Previous Work: A Decoder Against Internal Faults - LSD
  - Gallager-A performance worsens with increased iterations when internal faults rate is high.
  - But LSD does not exhibit this degradation.
- Contributions: Feedback Mechanism
  - Improve the error-resilience for embedded error-correction.
- Contributions: Space-Time Redundancy Technique
  - Requiring few overhead & Easy to be implemented as reliable unit.
  - Significantly suppress internal faults.
- Prospect: A Decoder Against Internal Faults
  - A New Interesting Area: Embedded Error-Correction in Faulty Process.
  - Still requiring further work to make it ripe for the application/implementation.

Acknowledgement

ÅThis work was supported by the US National Science Foundation under award ECCS-0954747.


Thank You For Your Attention!

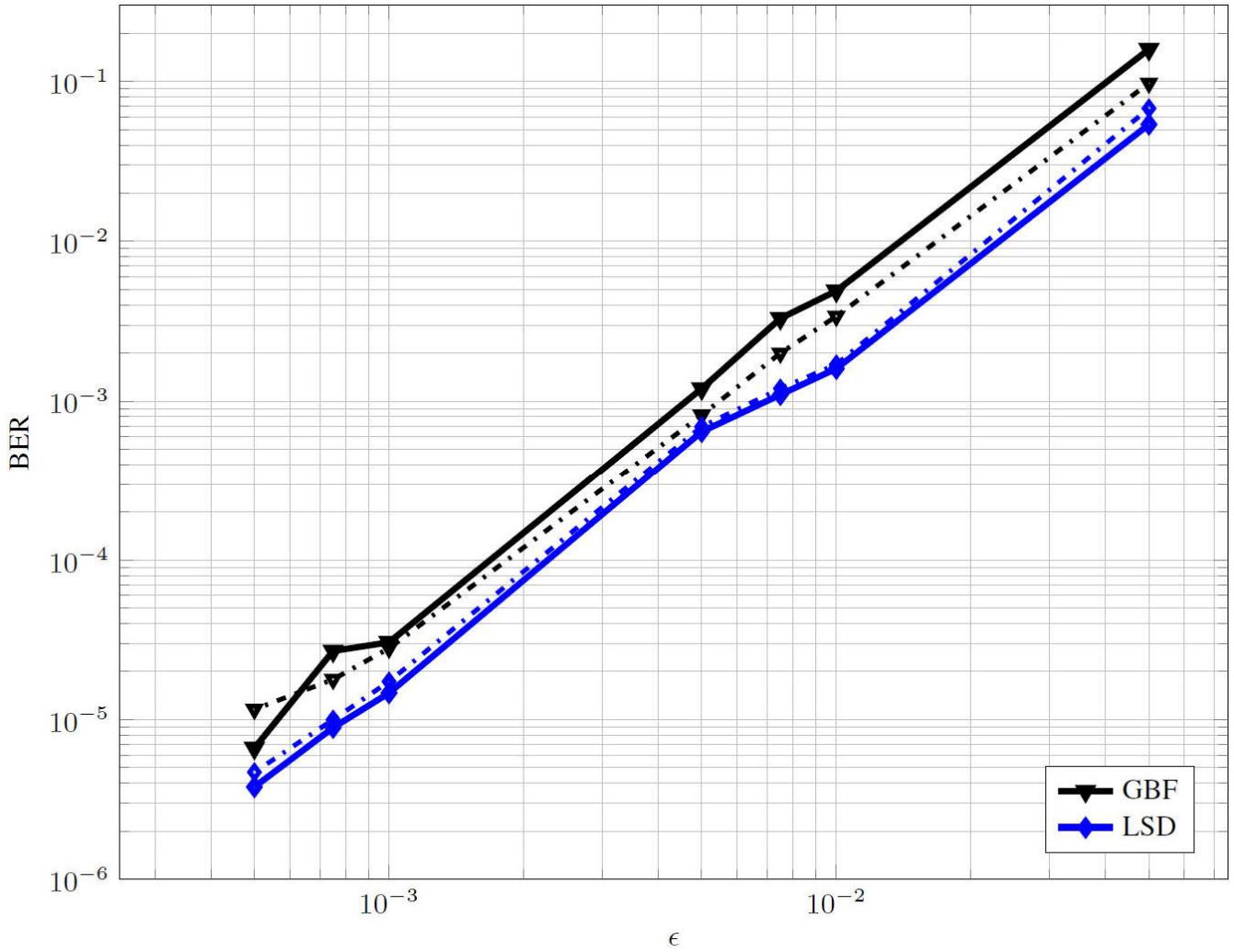
Back-ups: Threshold Determinations



$\mathring{U}$: **BSC Channel Parameter**

Fig. 11 Threshold of channel parameter over BSC for GBF (Gallagerôs Bit-Flipping method) and LSD, if the decoder process is error-free.

Back-ups: Special Case ï Short-length Decoder



$\mathring{U}$: BSC Channel Parameter

Fig. 12 Simulation results of (3,6) LDPC code of length 64 under an error-free decoding process, dash lines for 2-iteration, solid lines for 20-iteration.

Back-ups: Threshold Determinations

	GBF	LSD			
	(d_v, d_c)	(d_v, d_c)	(d_v, d_c)	(d_v, d_c)	(d_v, d_c)
	(3,6)	(3,6)	(3,12)	(3,24)	(3,48)
α^*	0.0082	0.0303	0.0096	0.0032	0.0011
ϵ^*	0.0126	0.0690	0.0199	0.0059	0.0011

$\check{U}$: **Decoderôs Internal Transient Error Rate**

$\mathring{U}$: **BSC Channel Parameter**

Tab. 3 Maximal Parameter $\check{U}^*$ and Maximal Parameter $\mathring{U}^*$ are determined when it is beneficial to use the decoder under a faulty decoder process.