Signal Processing Scheme for MLC

session 305 – Flash Controller Design

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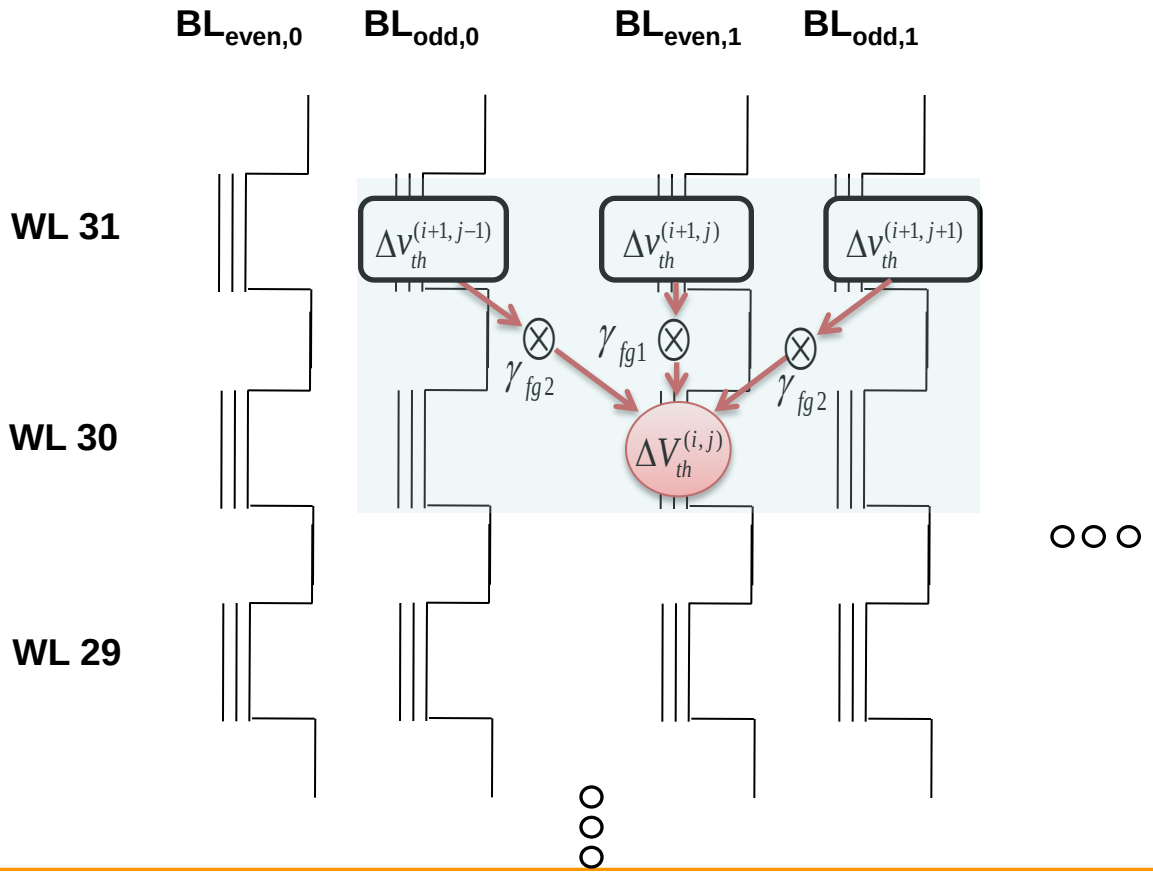
Understanding coupling noise

- Coupling occurred by adjacent cells programming. If the order of page program is restricted to ascending order in a block, the coupling noise of (i,j) position is as follows:

$$\Delta V_{th}^{(i,j)} = \gamma_{fg1}\Delta v_{th}^{(i+1,j)} + \gamma_{fg2}\Delta v_{th}^{(i+1,j-1)} + \gamma_{fg2}\Delta v_{th}^{(i+1,j+1)}$$

Reference: IEEE JSSC vol.36, no. 11, pp. 1700-1706, Nov. 2001.

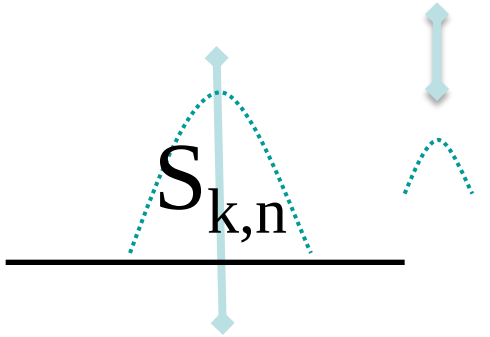
Figure model of coupling noise



$$\Delta V_{th}^{(i,j)} = \gamma_{fg1}\Delta v_{th}^{(i+1,j)} + \gamma_{fg2}\Delta v_{th}^{(i+1,j-1)} + \gamma_{fg2}\Delta v_{th}^{(i+1,j+1)}$$

Sample voltage

- Define ‘sample voltage’ of each level for simple computation.



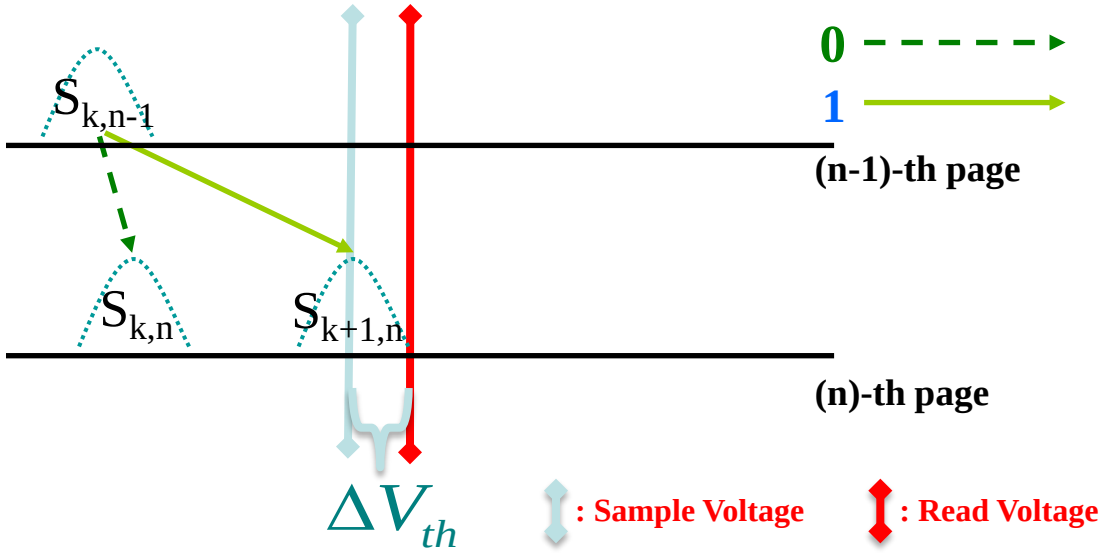
: Sample voltage, k-th level, n-th page

: Voltage distribution

- ‘sample voltage’ is calculated by center, average, highest frequency voltage, etc.

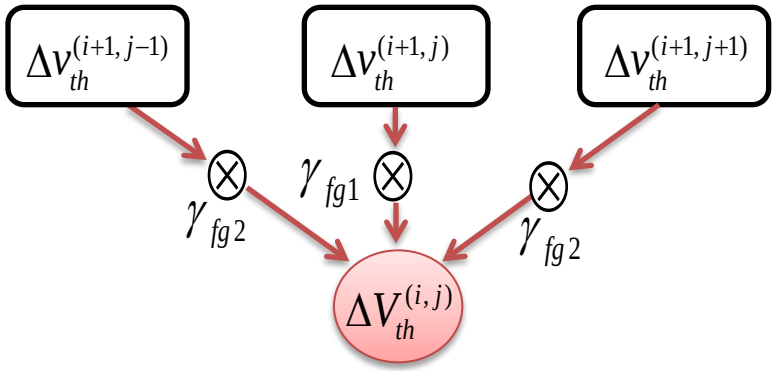
Simplify coupling noise

- Difference between ‘sample voltage’ and ‘read voltage’ is a noise. The dominant noise is coupling.

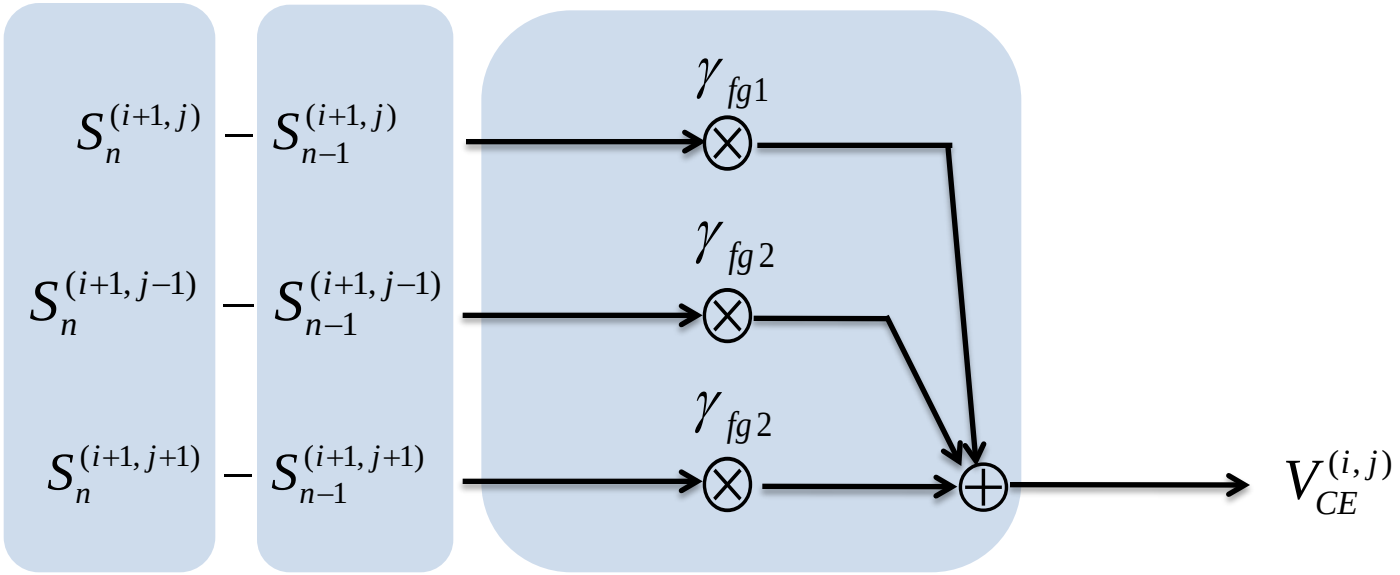


Compute the coupling noise

- If we know changed voltage ($\Delta v_{th}^{(i+1,j-1)}$, $\Delta v_{th}^{(i+1,j)}$, $\Delta v_{th}^{(i+1,j+1)}$) of neighbor cells and gamma (γ_{fg1} ,γ_{fg2}), we get the coupling noise using below.



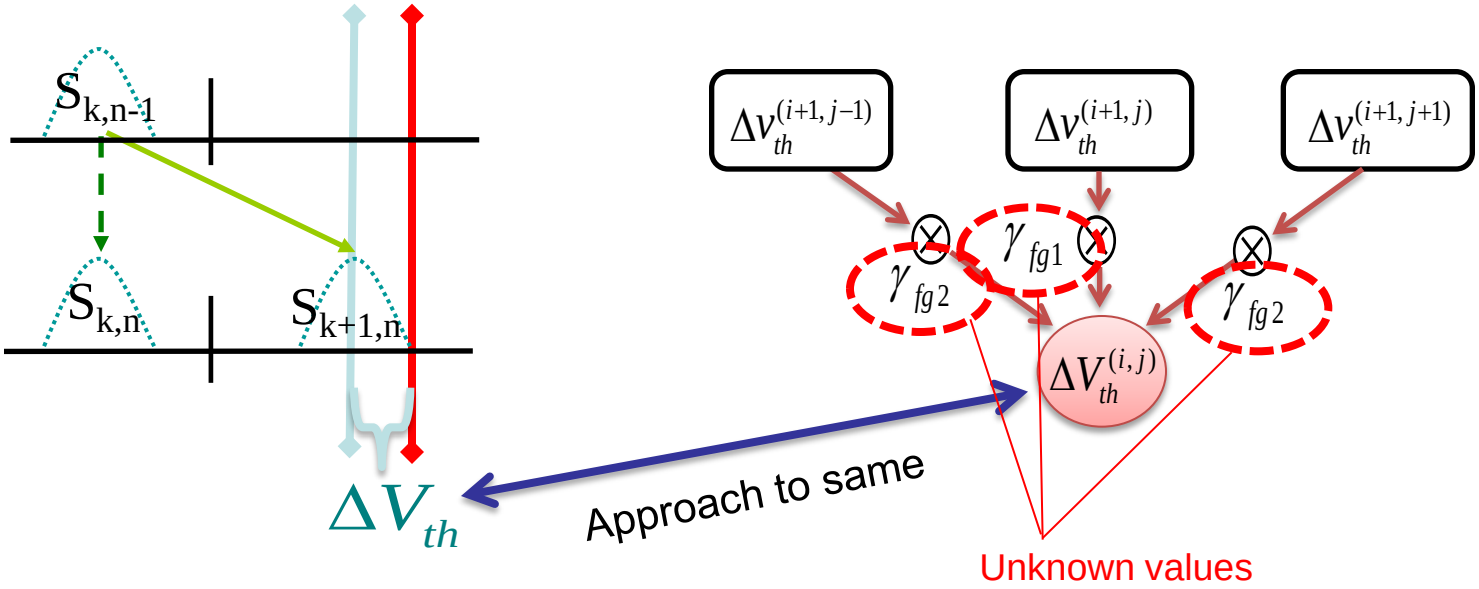
Coupling computing filter



- $V_{CE}^{(i,j)}$: coupling noise at (i,j) cell.
- $S_n^{(i,j)}$: sample voltage at (i,j) cell, n-th page
- Filter coefficient is gamma.

Idea for computing coupling noise

- Filter design, two noises are approaching to same. If we use known data.



Coupling computing filter

- Gamma update (using LMS algorithm)

$$\gamma_{fg,n,m+1} = \gamma_{fg,n,m} + \theta \cdot error \cdot \Delta v$$

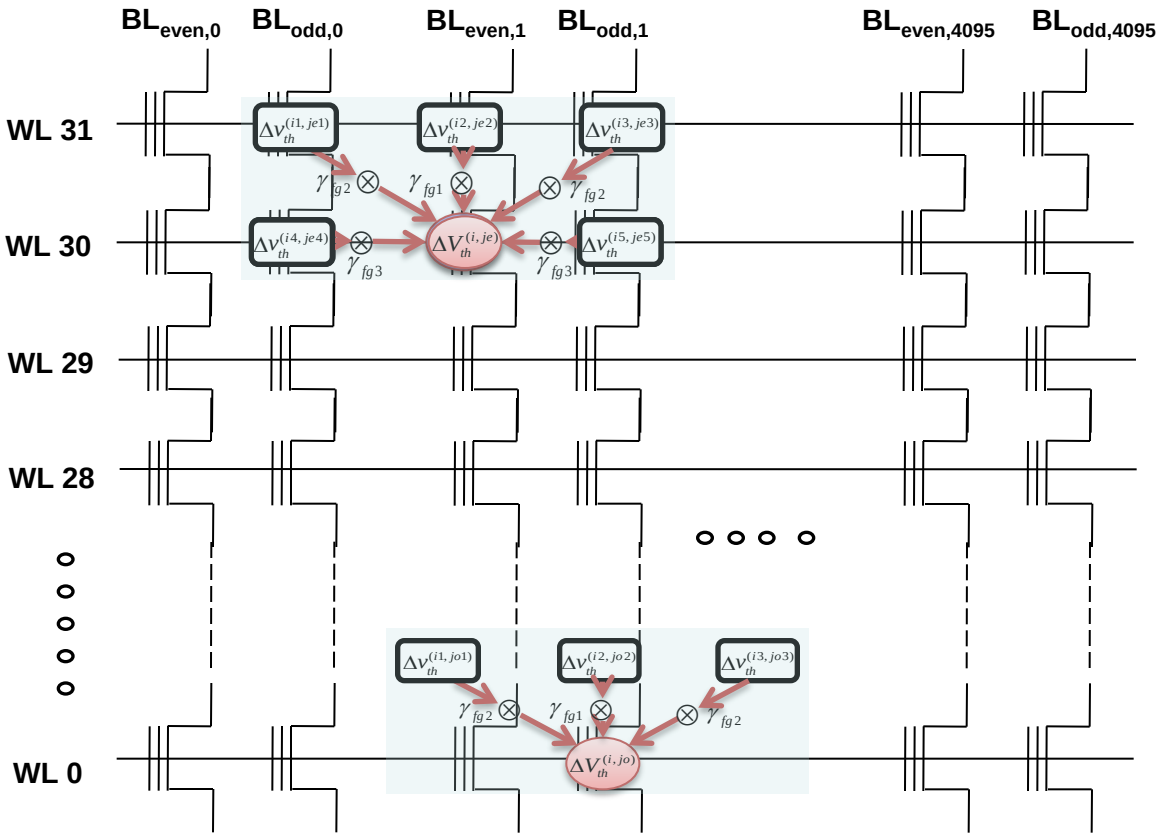
θ : update constant

error : $\Delta V_{th} - \Delta V_{th}^{(i,j)}$ (make approach to same)

Δv : changing voltage of neighbor cell

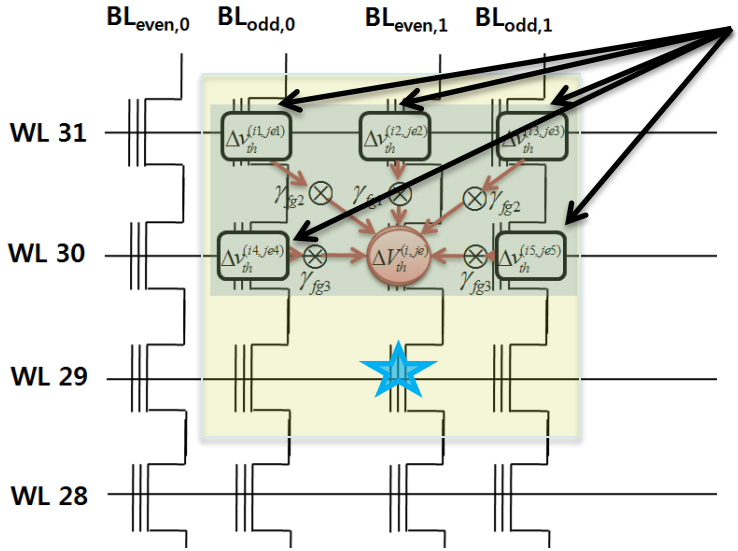
Coupling structure

- Even line cell (coupling from five neighbor cell)
- Odd line cell (coupling from three neighbor cells)



Two steps coupling compute

1st step



: Read by conventional detection

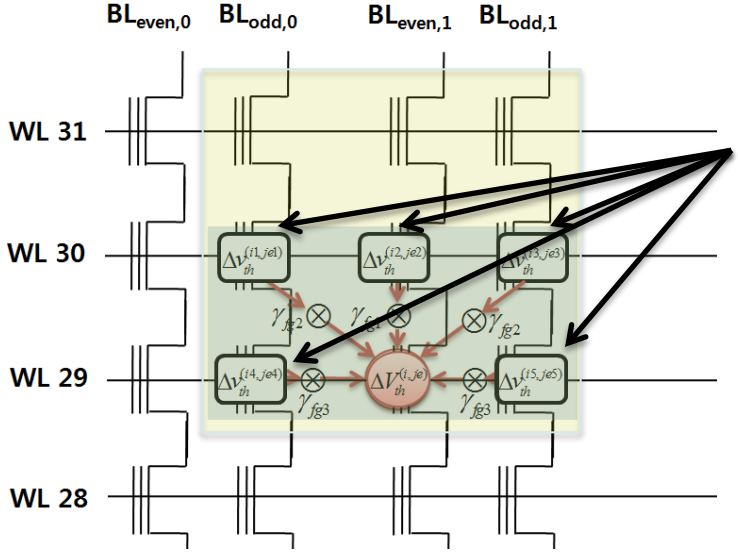
: Read target

: Coupling cancellation target

Δv_{th} : Changed voltage of adjacent cell

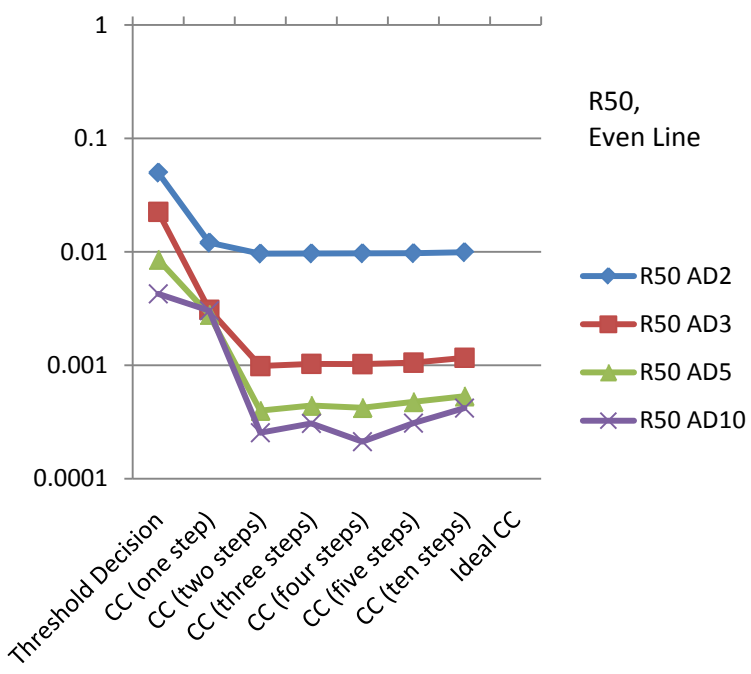
: Step region

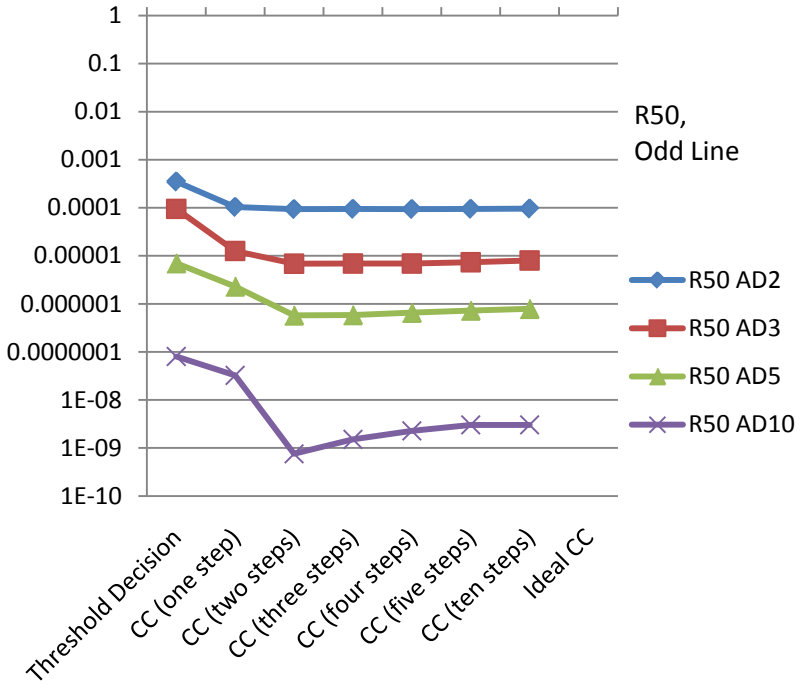
2nd step



: Read by coupling cancelled voltage by upper procedure

Symbol error rate performance





- CC : coupling cancellation by coupling computing filter
- R : coupling factor (channel modeling)
- AD: AWGN factor (channel modeling)

Challenges

- FIR filter (named coupling canceller)
  - ➡ low complexity (five, three taps filter)
- Additive read operations
  - ➡ performance increasing
- One-step coupling cancellation
  - ➡ upper even & odd page read, coupling cancellation op.
- Two-step coupling cancellation
  - ➡ two-step upper even & odd page read,
    upper even & odd page read, coupling cancellation op.

Question?

Thank you for your attention

Appendix (data programming)