Variation-Tolerant and Self-Repair Design Methodology for LTPS LCD and OLED Display

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Outline

- Introduction
- Proposed System
  - Detector
  - Memory Unit
  - CLK Generator
- Device Modeling
- Simulation Results
  - Conclusion

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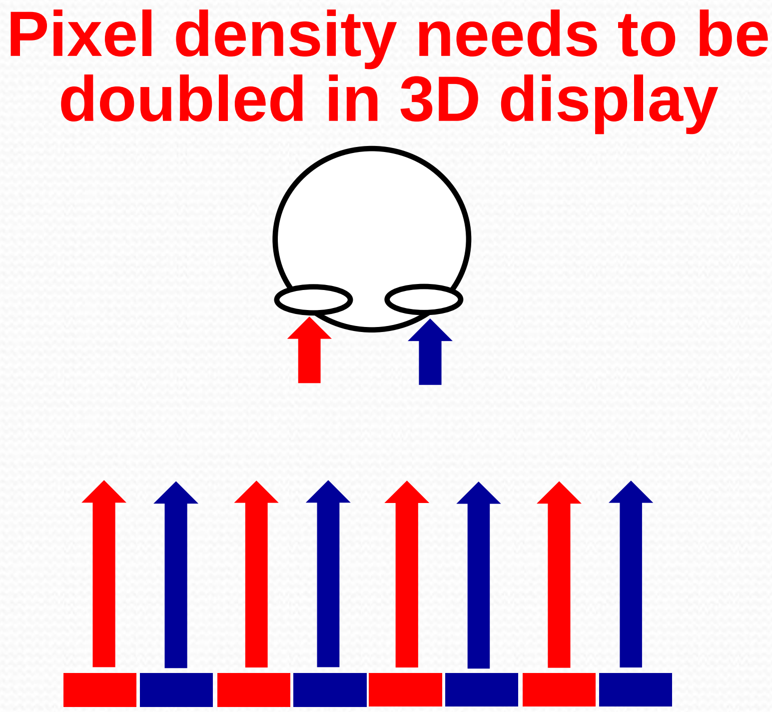
Introduction

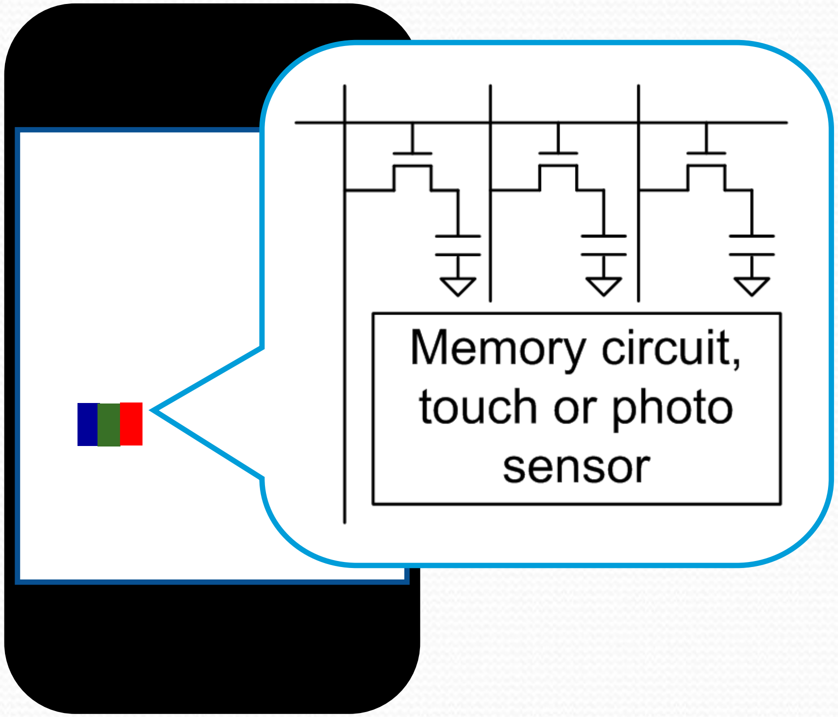
Emerging Displays

- 3D Display
  - More attractive and exciting experience

- Touch Display
  - Intuitive Screen Operation
- Memory-Integrated Display
  - Low Power consumption
- Photo-Sensor Display
  - Scan and Security

Challenges in Future Displays



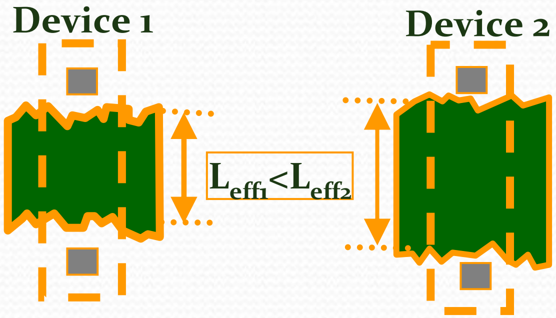


- Low transmittance of pixel circuit
- ~70% of power consumption of LCD module comes from backlight

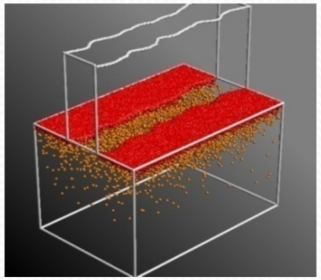
- **Scaling of Device Size is Important**

Scaling Issues in Poly-Si TFT

- **Device Degradation**
  - Hot carrier
  - Self-heating
- **Process Variation**
  - Variation of device parameters
  - Grain boundary (GB) induced variation (dominant)

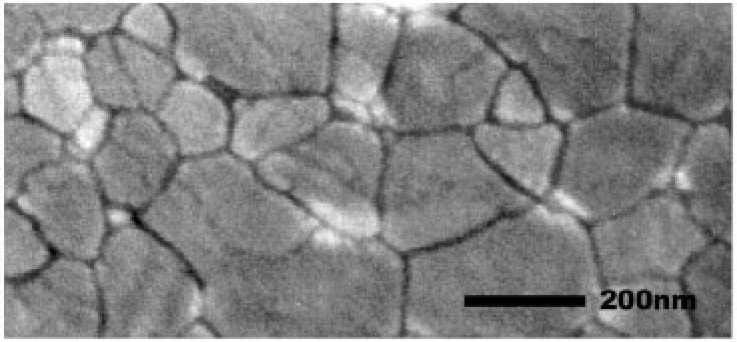


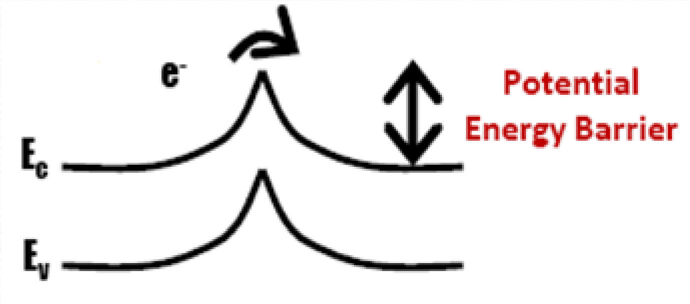
Variation in channel length

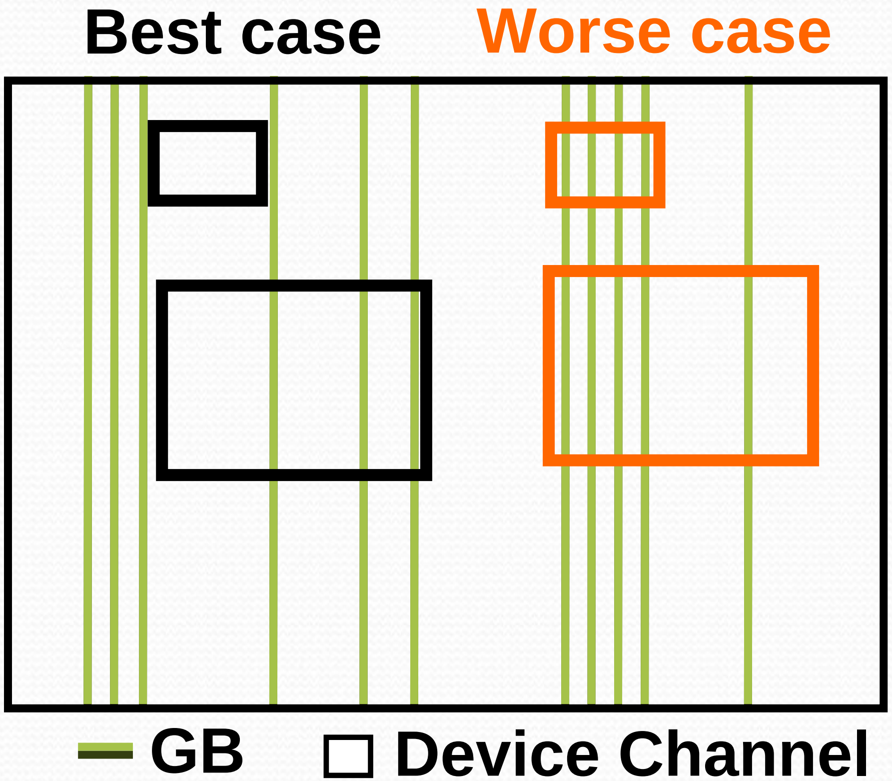


Random dopant fluctuation

Grain Boundary in Poly-Si TFT

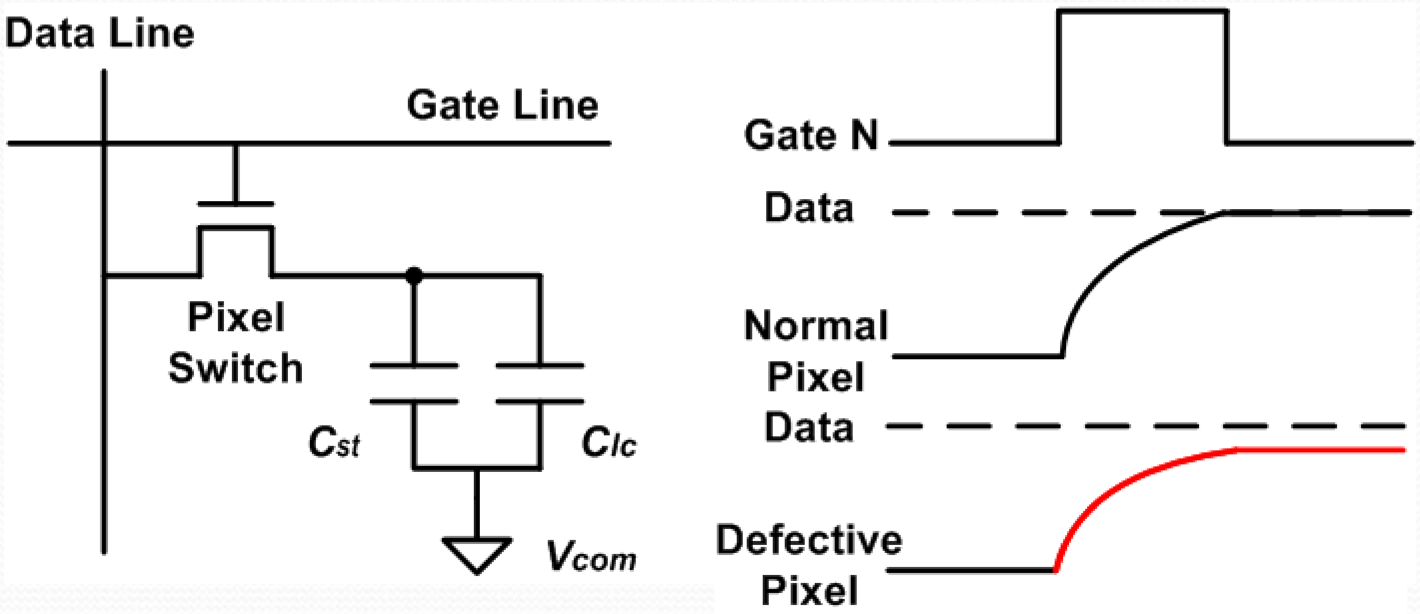






- GB position is difficult to control
- GB acts as energy barrier for carriers
- Mobility and *Vth* depend on the number of GBs in channel
- GB Variation increases as device size decreases

Pixel Circuit: Parameter Variations

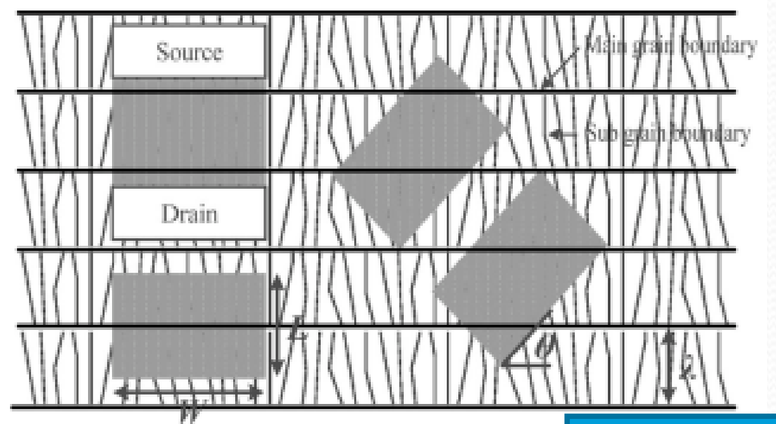


Conventional pixel structure of LCD

- **Variation caused by insufficient drivability of pixel switches induces defective pixels**
- **Large supply voltage margin for addressing worst-case variability**

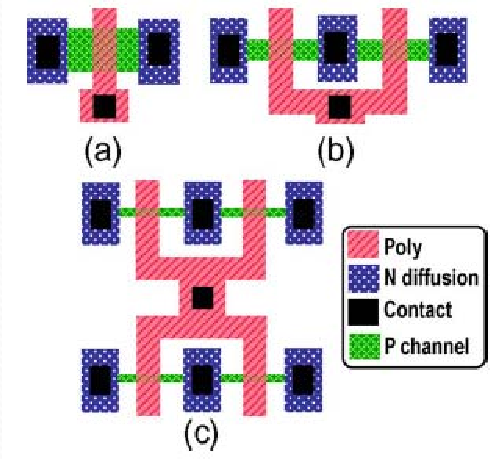
Related Work

- **Tile alignment**
  - **Uniformity is still bad as the size of device is comparable to the grain size**



[Hsieh, ESSL'2006]

- **Multi-Finger**
  - **Not suitable for pixel switch considering the transmittance**



[Li, TCAD'2009]

- **GB-induced variation is unavoidable**
- **System-level compensation technique is required**

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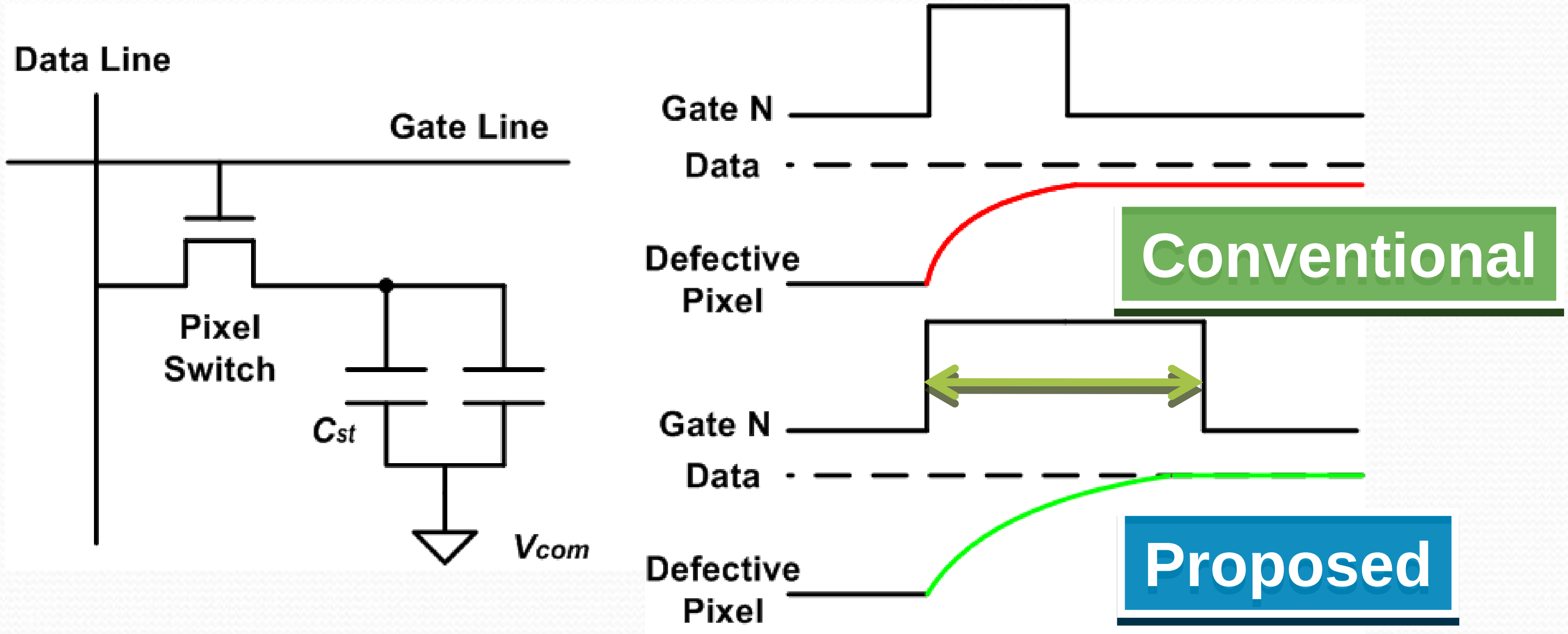
Proposed Compensation Technique



- Charging time for defective pixels is extended
- Margin of supply voltage can either be decreased for lower power, or kept the same for higher yield
- Better reliability can be achieved

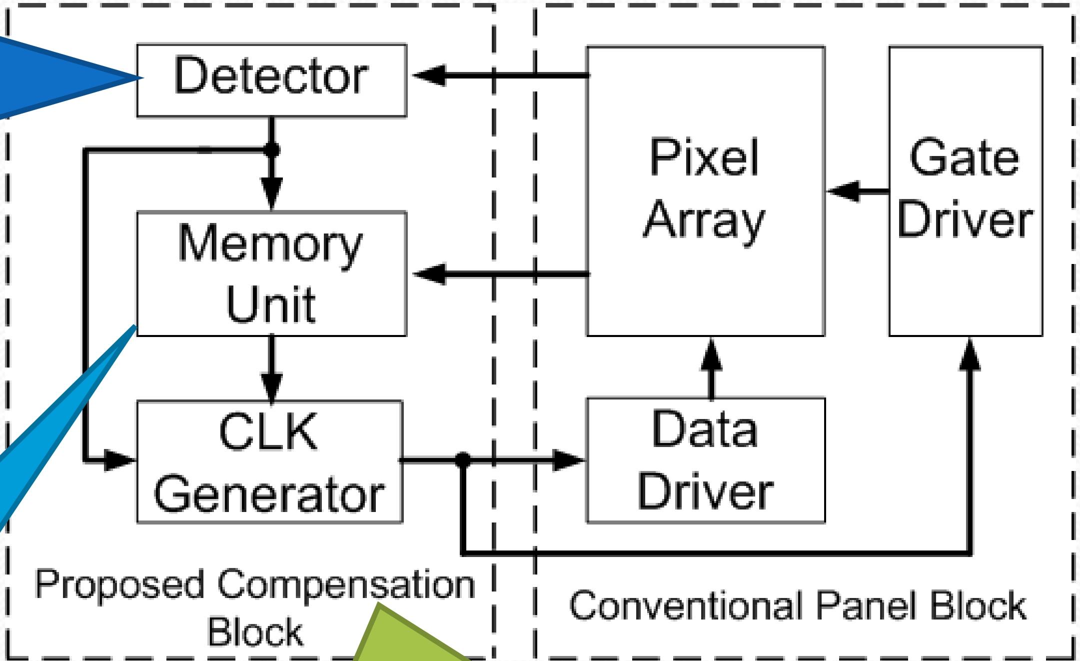
Proposed System

Detect the defective pixels

Output the result to memory unit and CLK generator

Store the detected signals

Generate two-cycle enable signal for CLK generator

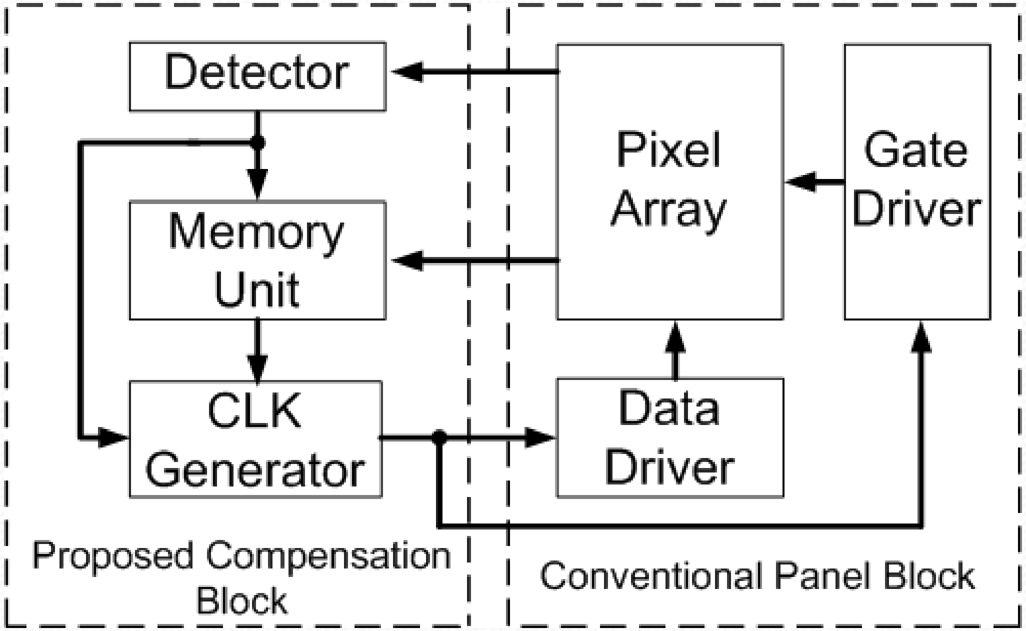


Determine the CLK frequency

Generate the modified CLK

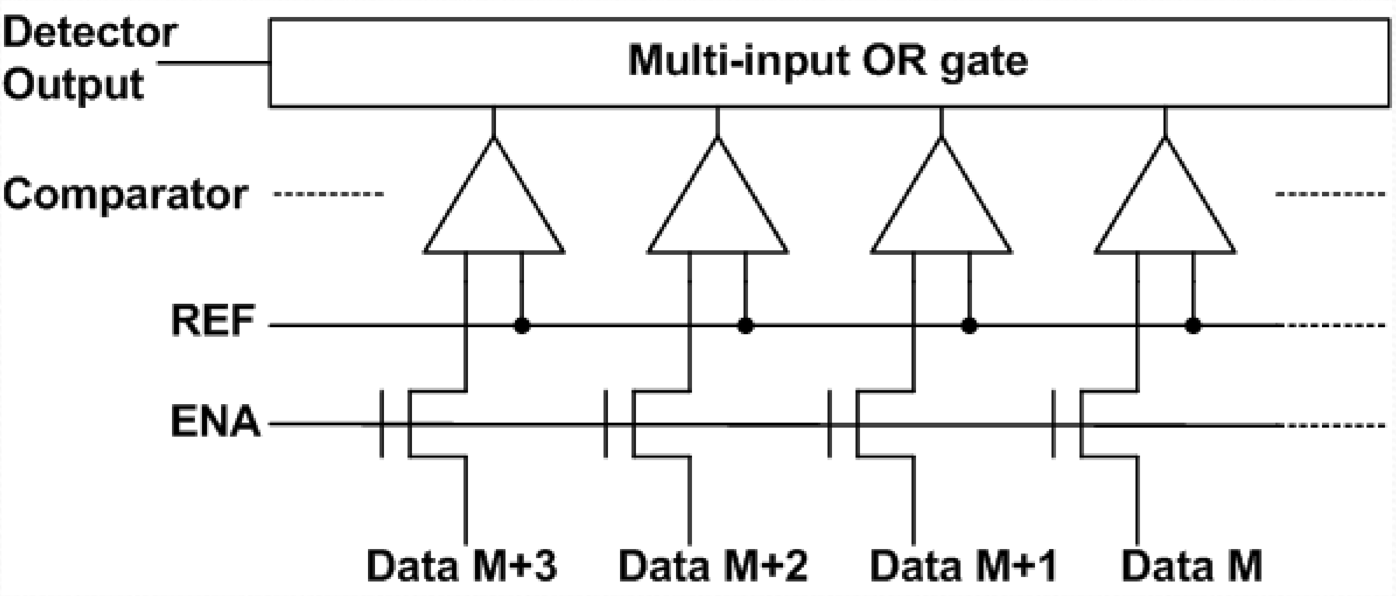
Operation Phases

- **Setup Phase**
  - ➢ **Setup the worse charging case for detection**
- **Detection Phase**
  - ➢ **Determine and record the locations of defective pixel**
- **Display Phase**
  - ➢ **Adaptive CLK is applied for compensation**



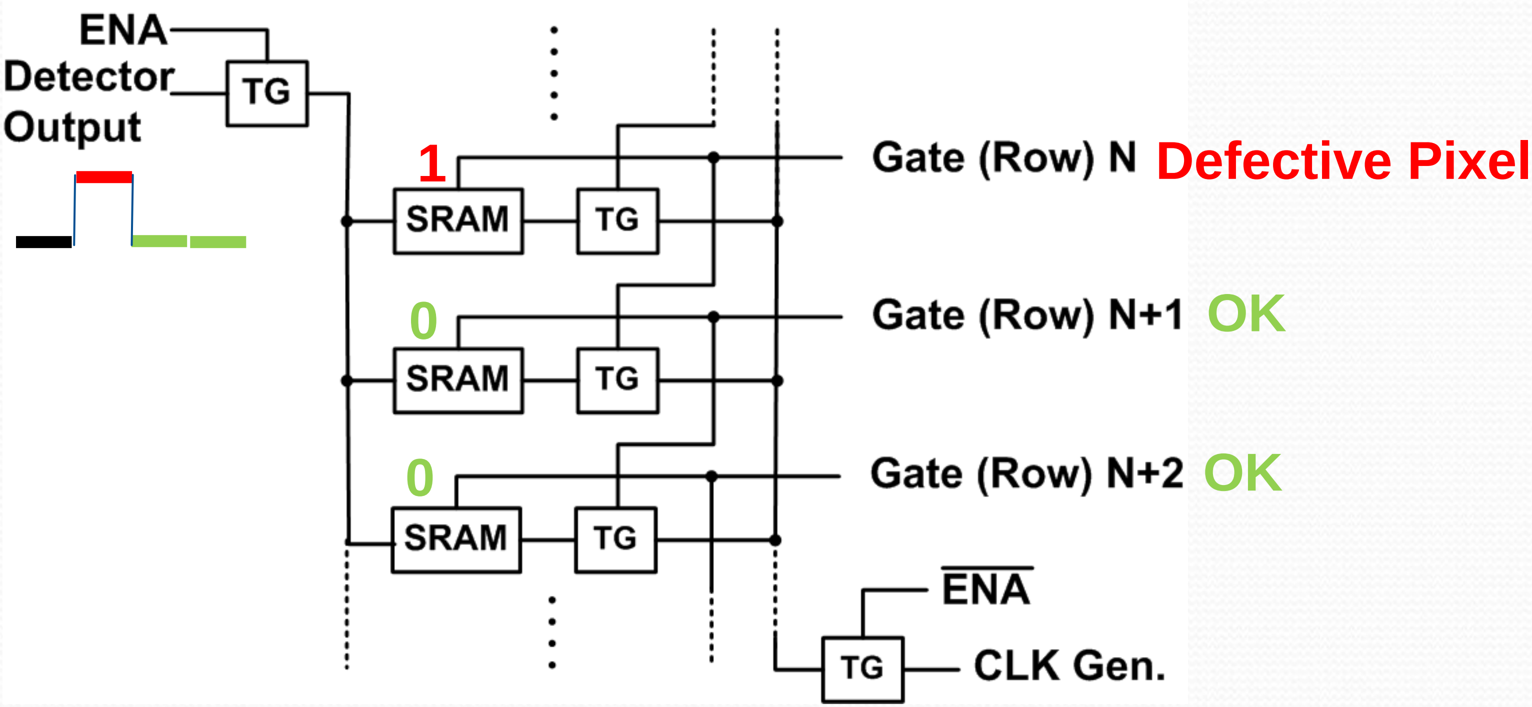
Setup and detection phases performed only once

Detector Structure



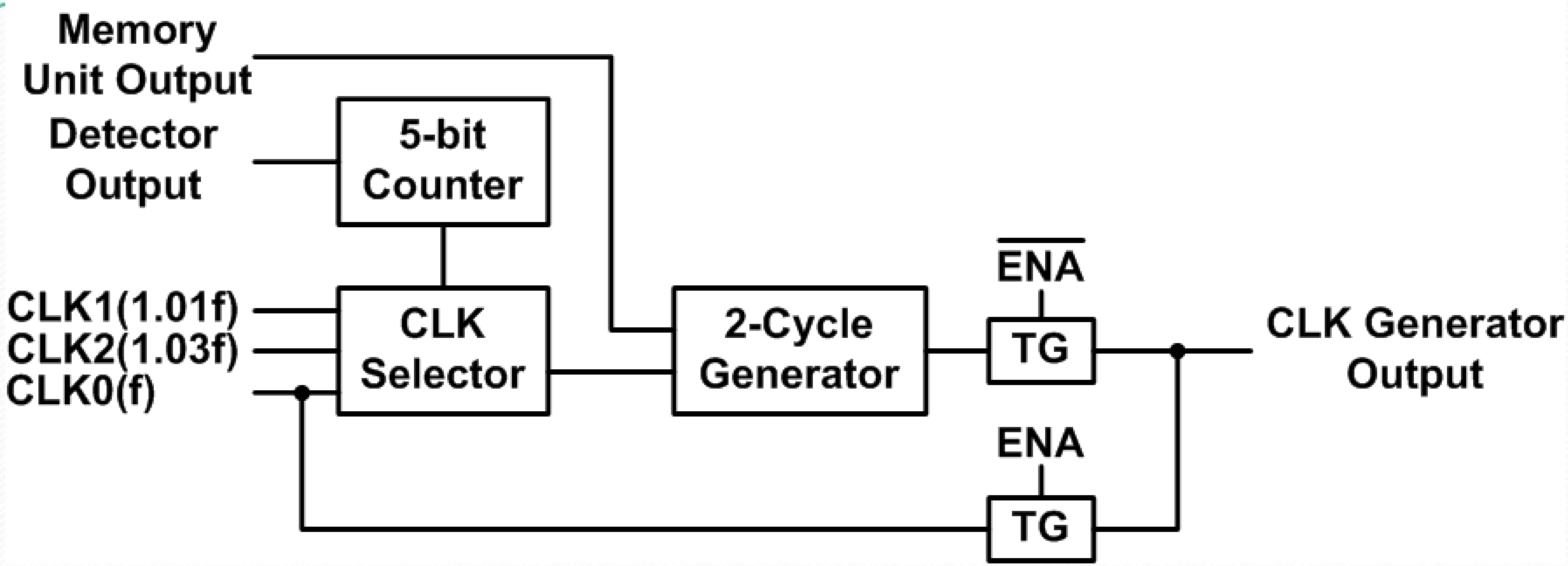
- Data lines are precharged to the maximum level
- Charge sharing starts after one row of pixel switches is turned on by gate driver
- Voltage drop is detected by comparator
- If detective row contains defective pixel, a pulse is generated

Memory Unit Structure



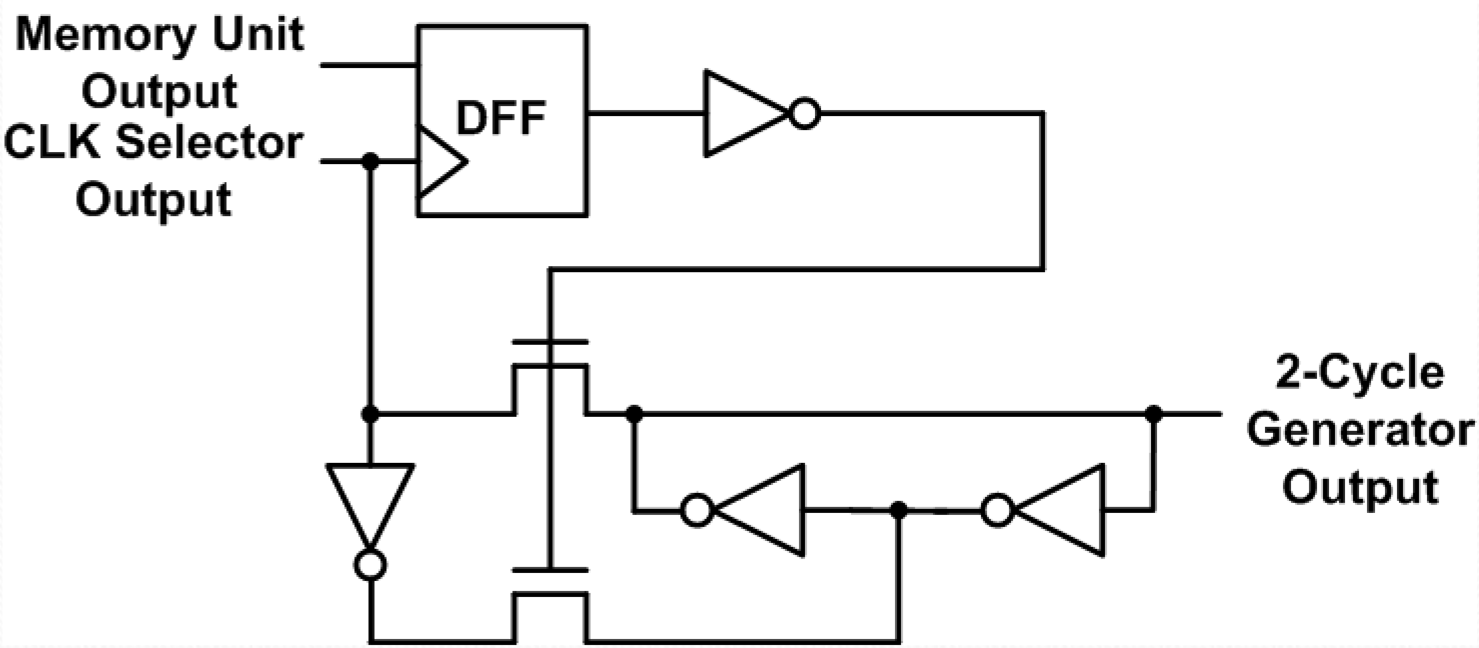
- **Detection Phase**
  - **The output of the detector is recorded in SRAMs**
- **Display Phase**
  - **The values in SRAMs are forwarded sequentially to CLK Gen.**

CLK Generator Structure



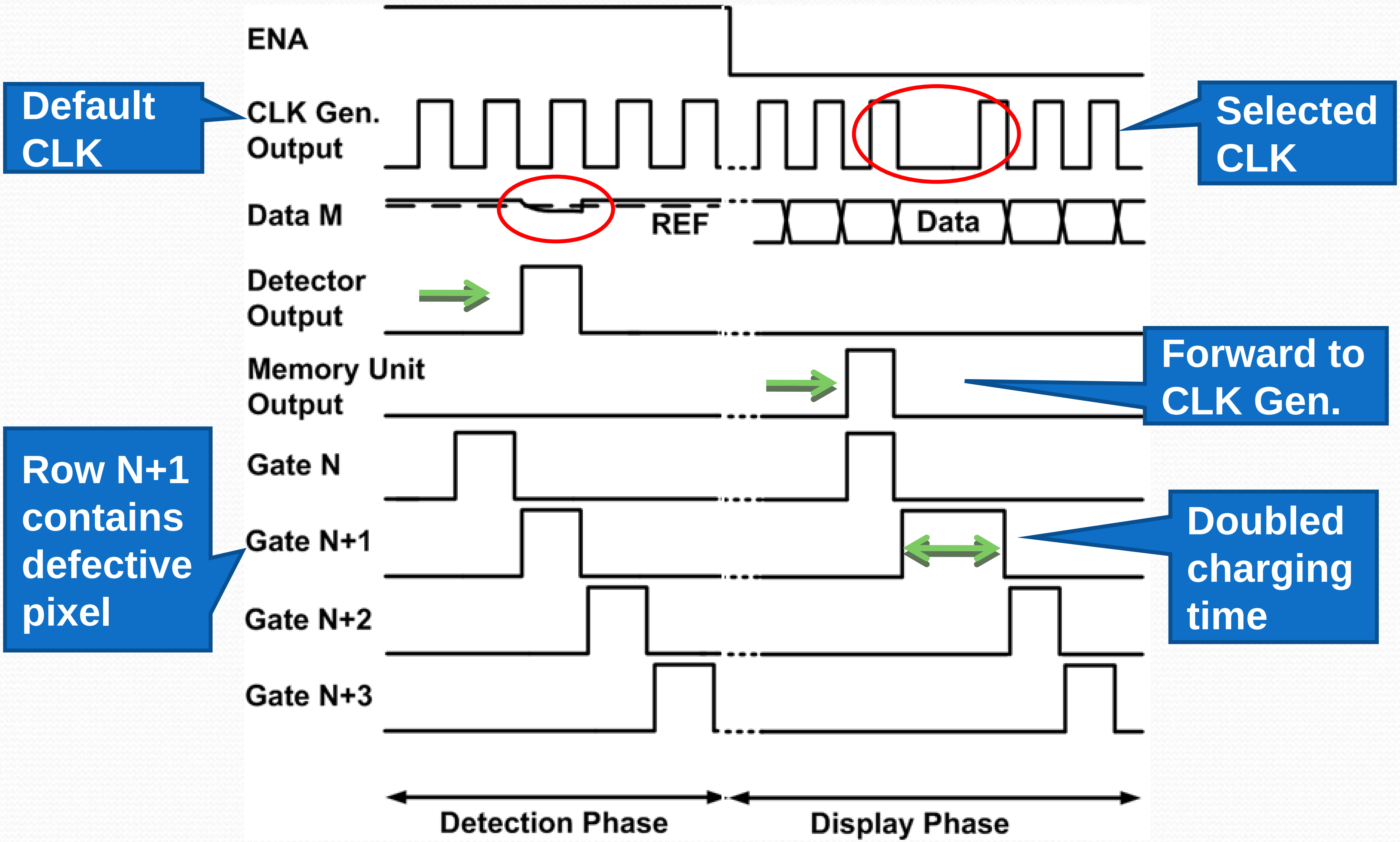
- **Five-bit Counter**
  - Counting the number of defect rows
- **CLK Selector**
  - Selecting CLK according to four-bit counter
- **Two-cycle Generator**
  - Generating Adaptive CLK

Two Cycle Generator Structure



- If output of memory unit is high (defective row)
  - ➢ Selected CLK is isolated from the output
  - ➢ Output value of previous cycle is held
- If output of memory unit is low
  - ➢ Selected CLK proceeds without modification

Timing Diagram



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Device Modeling

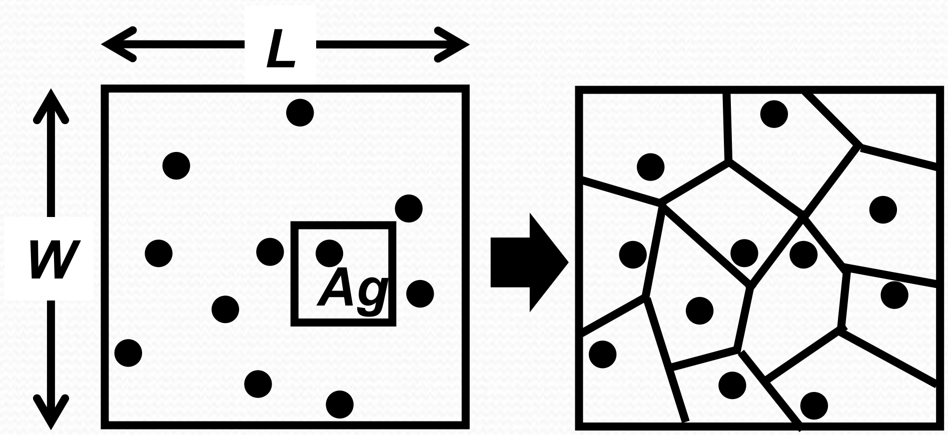
- **Poisson area scatter distribution**

$$\mathrm{P}(k)=\left[\exp(-\lambda)\cdot\lambda^{k}\right]/k!$$

- ***k* is Poisson random variable with mean *λ***
- **To correlate the average grain size ($L_{g,TFT}$) with *k*, *k* is assume to be the number of grains in this channel**

$$k=(W\cdot L)/A_g$$

$$L_{g,TFT}=\sqrt{W\cdot L/k}$$



- **A_g is the average area of one grain**

[Wang, TED'2006]

Device Modeling (cont.)

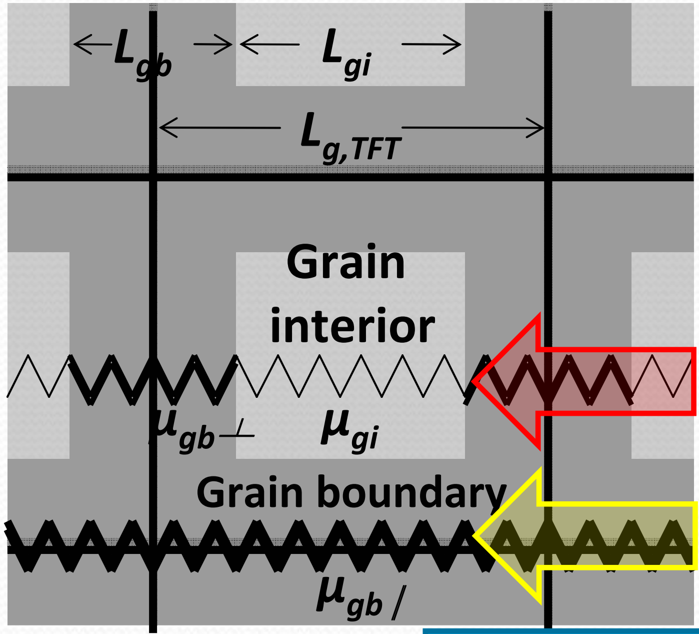
- **Threshold Voltage Model**

$$V_{th}=V_{FB}+\left[1-\left(\frac{\varepsilon_{Si}E_{sc}L_{g,TFT}}{qN_{tr}L}\right)\right]\sqrt{\frac{8kTN_{tr}t_{ox}}{C_{ox}L_{g,TFT}}\sqrt{\frac{\varepsilon_{Si}}{\varepsilon_{oxi}}}}$$

- **Mobility Model**

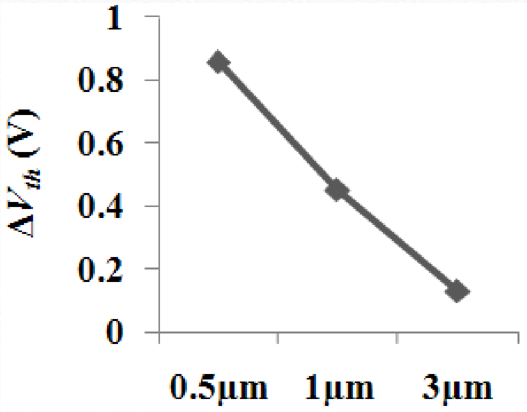
$$\mu=\left(\frac{l_{gb}}{L_{g,TFT}}\right)\cdot\mu_{gb,\parallel}+\left[1-\left(\frac{l_{gb}}{L_{g,TFT}}\right)\right]\mu_{g}$$

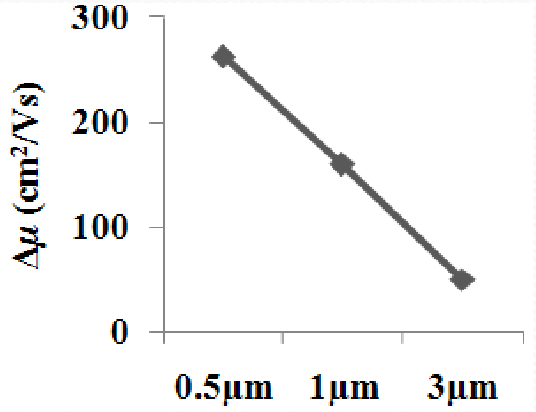
$$\mu_{g}=\mu_{gi}L_{eff}\left\{(N-1)\left[l_{gi}+\left(\frac{\mu_{gi}}{\mu_{gb,\perp}}\right)l_{gb}\right]+L_{g,TFT}\right\}^{-1}$$



[Wang, TED'2006]

- **Deviation of *Vth* and Mobility**





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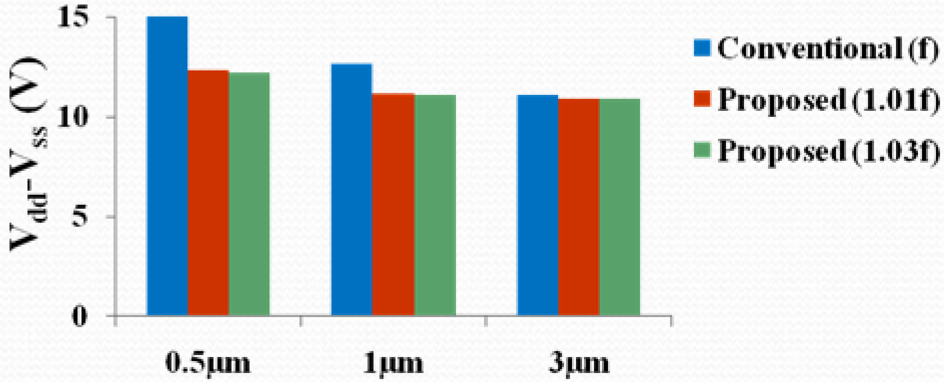
Panel Simulation Setting

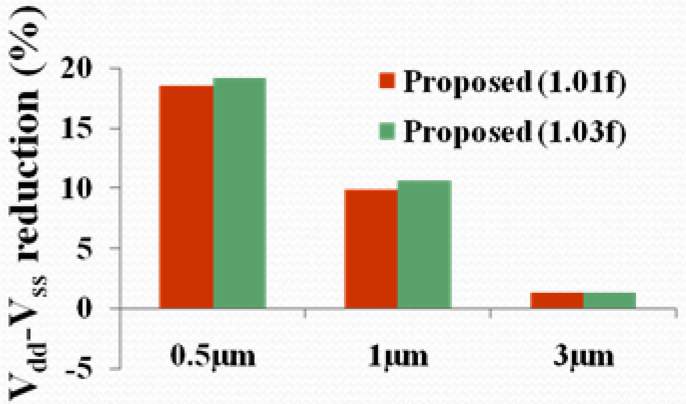
Panel size (inch)	3.9	0.85	0.4
Switch TFT (W/L)	3/3μm	1/1μm	0.5/0.5μm
Resolution (H/V)	640/480		
Gray level	256		
V_{th} of LC (V)	3.3		
Refresh rate (Hz)	60		

- **Three different sizes of TFT are evaluated**
- **Simulation results are obtained by Monte Carlo simulations (640x480x100)**
- **One pixel model with 12 sets of RC loading is applied for simplicity**
- **The power consumption is evaluated by HSPICE**

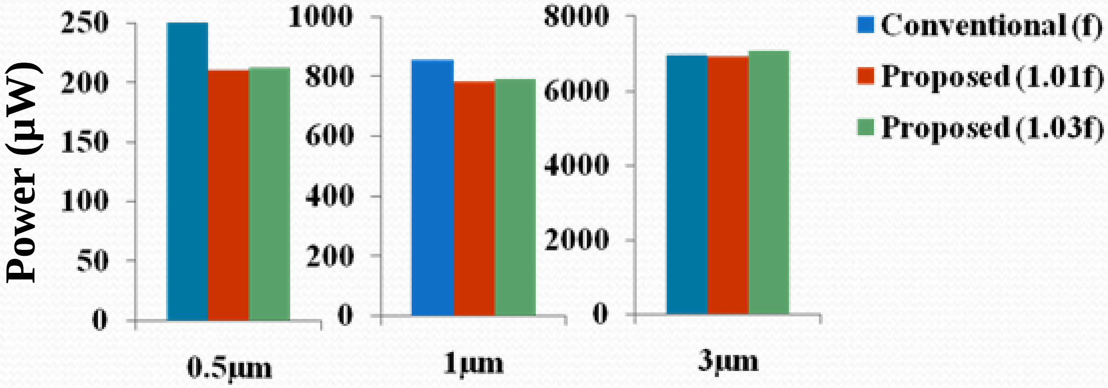
Simulation Results

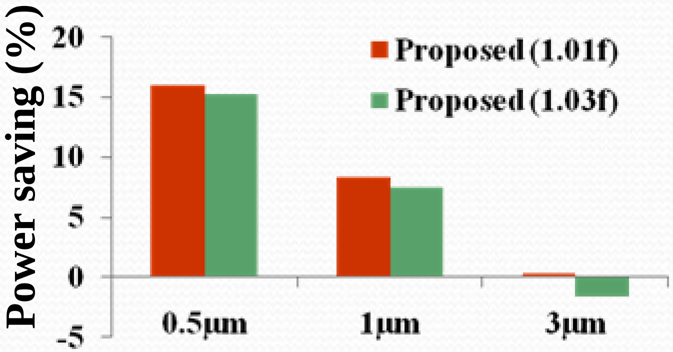
- **Smaller supply voltage (Iso yield : 99%)**
  - ➢ **Advantage becomes more apparent as the device size shrinks**





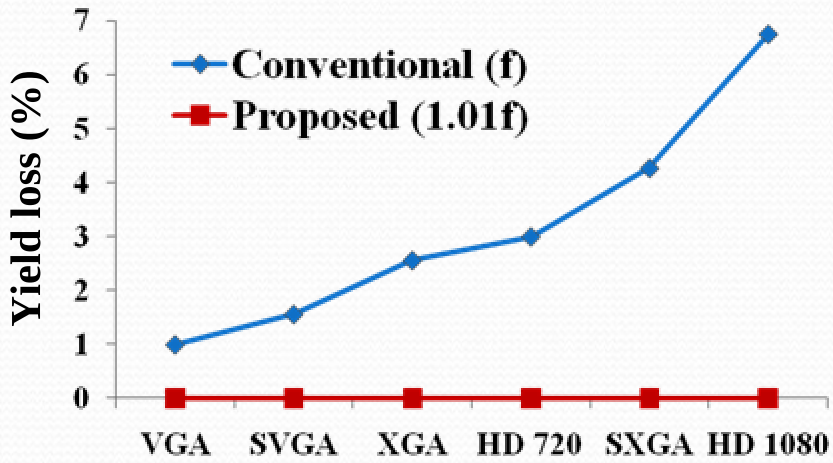
- **Lower power consumption (Iso yield : 99%)**
  - ➢ **Power saving increases as device size decreases**





Panel Simulation Results

- **Higher yield (Same supply voltage)**
  - ➢ **Better yield improvement as resolution increases**



- **Better reliability**
  - ➢ **Smaller supply voltage**
  - ➢ **Self-repair capability as the three phases are redone**

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Conclusion

- An adaptive design technique for variation tolerant and self-repair display panel is reported

- Adaptive CLK eliminates the need for large voltage margin

- **Lower power (up to 16%)** for small sized display (less variation) or **higher yield (up to 7%)** for large sized and high resolution display (large variation)

THANK YOU