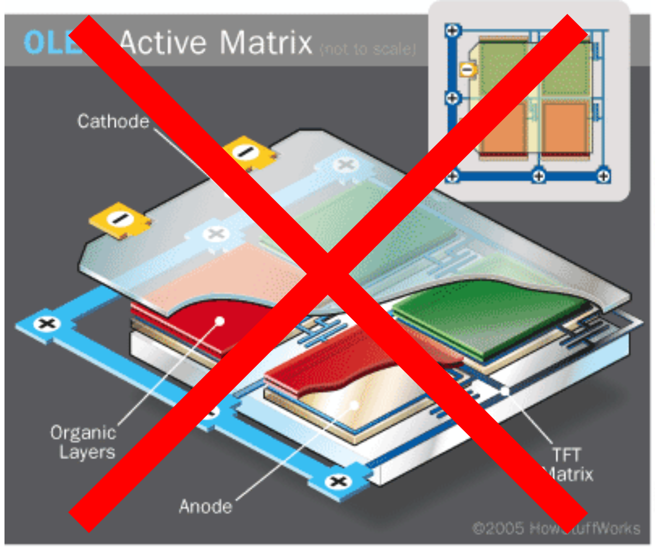
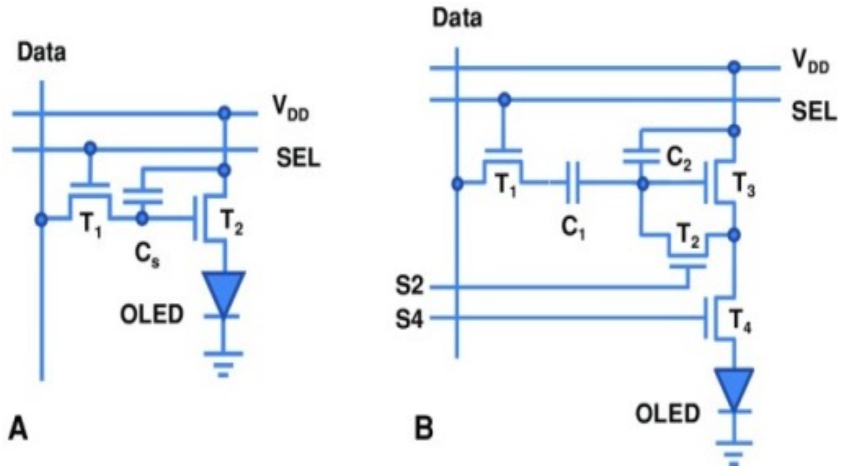




SECTION 9

OLED DISPLAY <u>ELECTRONICS</u>

HANDBOOK OF VISUAL DISPLAY TECHNOLOGY 2ND EDITION (2016)

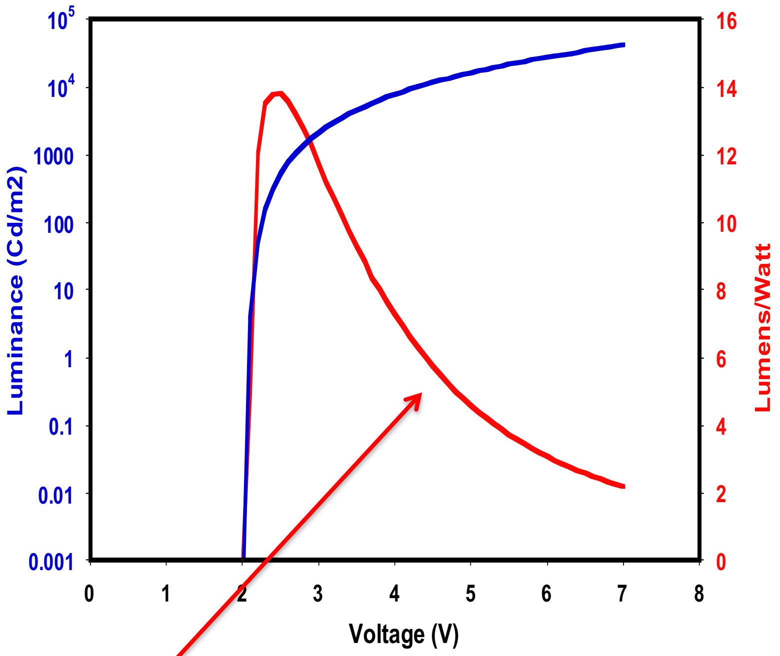
Active Matrix for OLED Displays

Ruiqing Ma

Pages 1821-1841

Example device performance

CDT Yellow, Ink Jet Printed – Luminance and Efficiency



Parameters
• Turn-on Voltage – 2.1 V • At 100 Cd/m^2 – 10 Lm/W – 2.2 V • At 1,000 Cd/m^2 – 12 Lm/W – 2.6 V

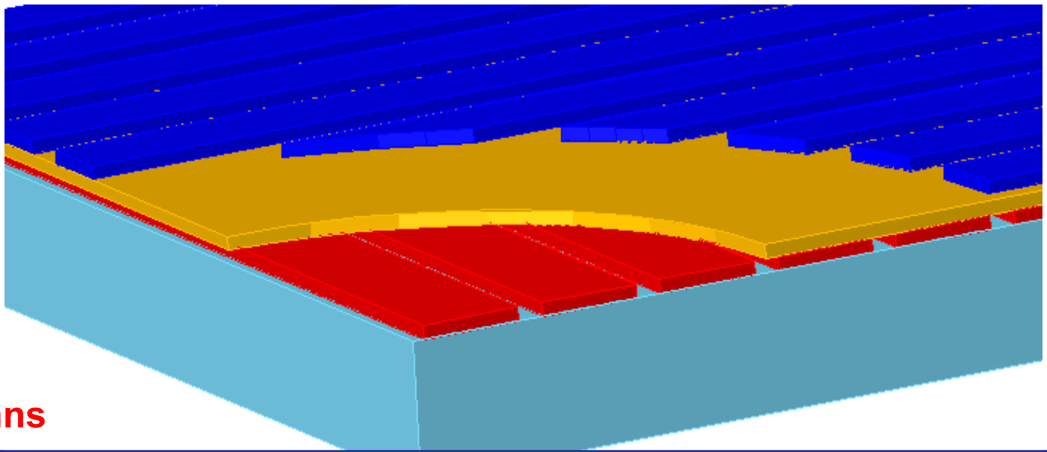
Beware efficiency drop!

OLED / LCD Addressing - Compare

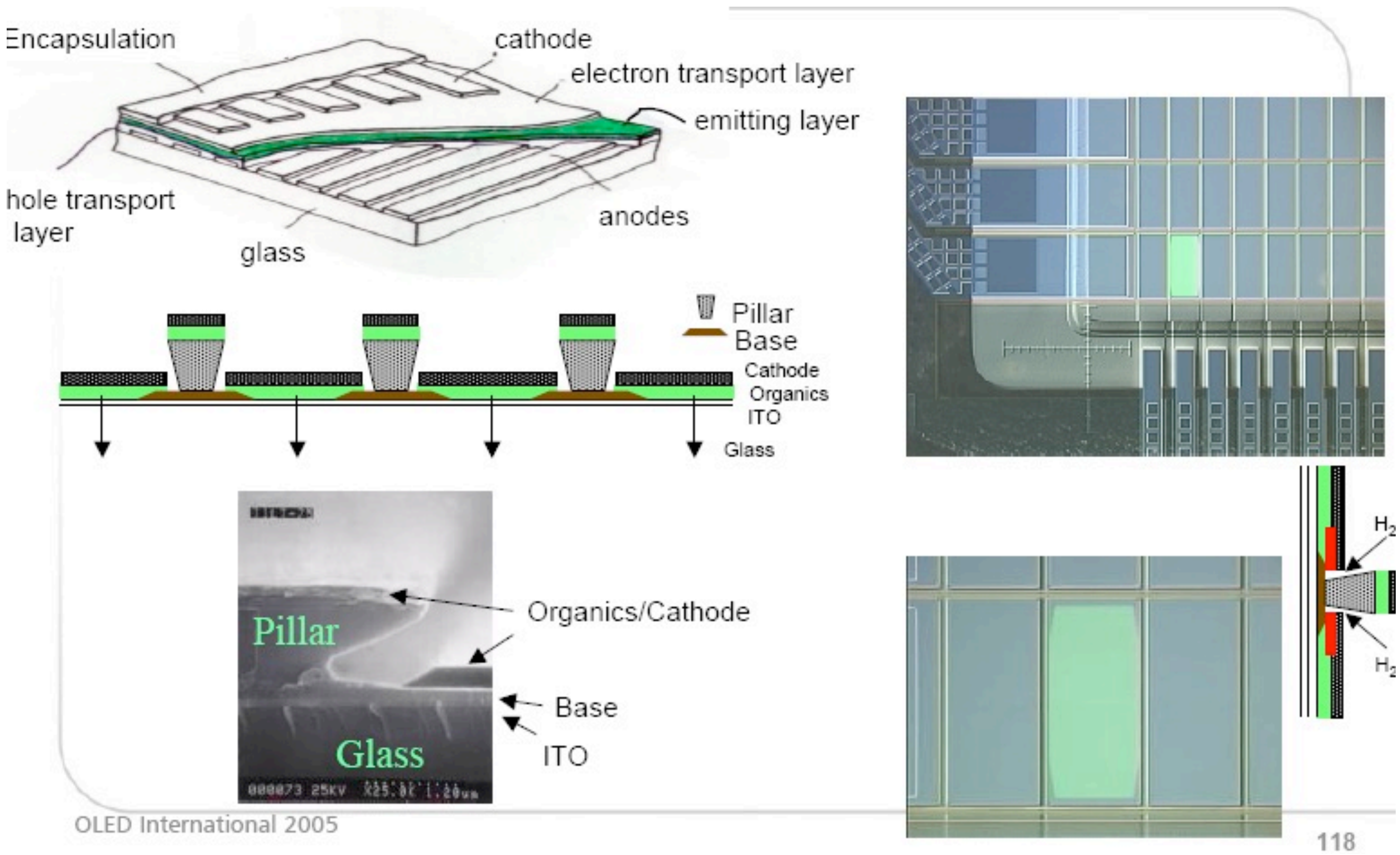
Parameter	LCD	OLED
Optical	Modulating (backlit)	Emissive
Electronic	Capacitive	Diodic
Drive	Voltage	Current
Polarity	a.c. (rms)	d.c.
Switching	>ms	<μs

Passive Matrix OLED Displays

- Simplest structure for a matrix display
  - Usually ITO anodes are ‘columns’ and Al cathodes are ‘rows’ due to the large peak currents the rows must cope with
  - Only one row active at any time, rows are activated in sequence within one ‘frame’
  - Columns are driven, illuminating the pixels on the currently active row
- Devices are less efficient at high pulsed brightness
  - Inevitable due to higher drive voltage



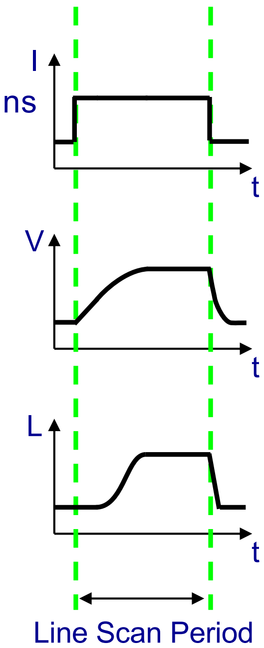
Passive Matrix OLED construction

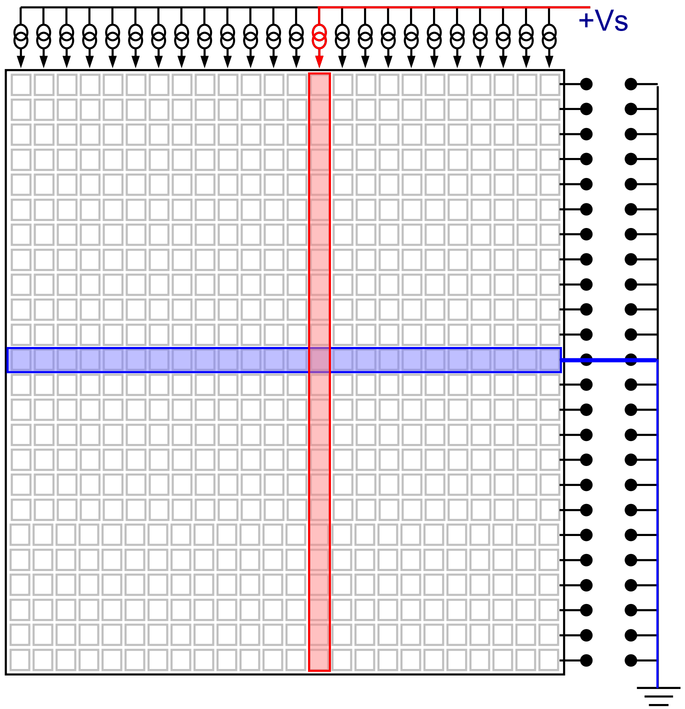


Passive Matrix Driving

Line-scan Sequence

1. Row is selected
2. Current driven onto all columns (only 1 is shown)
3. Capacitance of column charges up
4. Pixel starts to emit light
5. Pixel on full brightness
6. Row is deselected

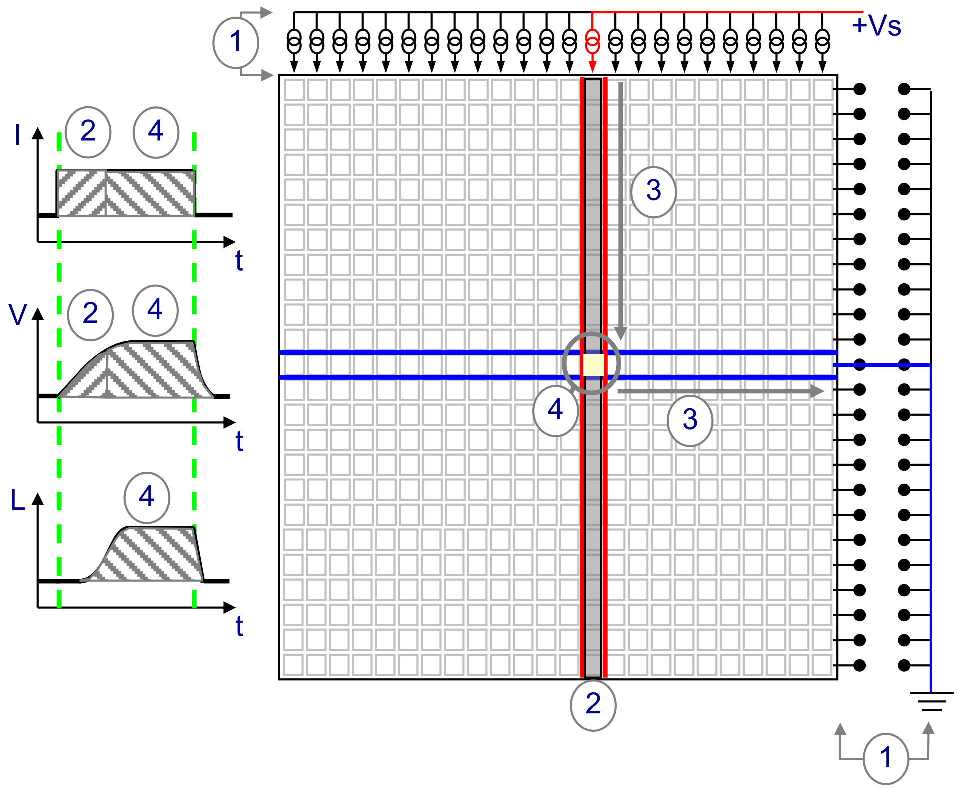




Passive Matrix Driving – Power Consumption

Four Factors Dominate

1. **Driver compliance**
2. **Column capacitive charging**
3. **Resistive losses**
4. **Diode Power**



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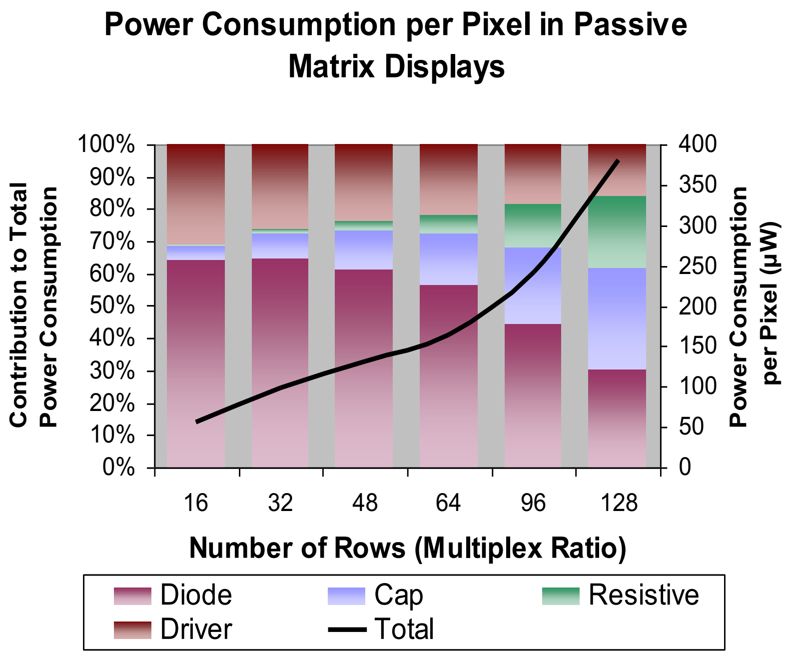
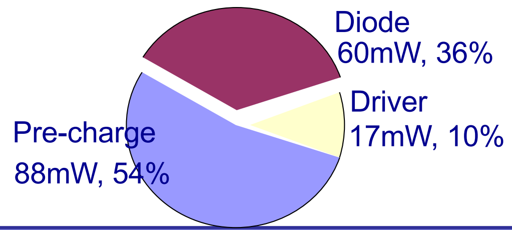


Example

Clare Micronix presented, at OLED 2001 in San Diego, power consumption data for a 100 x 80 display panel driven with their MXED series of OLED/PLED passive matrix drivers.



Passive Matrix Drive Scheme

The simplest scheme to examine is the commonly use current driven Pulse Width Modulation (PWM)

- As the OLED is always driven with the same current density, linearity is good.
- The use of pre-charge can remove the charge-up time resulting in superb linearity.
- many discernable grey-scale levels can be achieved.
- Uniformity is also good as the use of current drive is insensitive to variations in threshold voltage.
- At the end of each line period, the charge is removed from the display, thus leading and trailing edges are not susceptible to the cross-talk that can occur.
- HOWEVER, the continual charge-up and discharge can result in a high power consumption.

Passive-Matrix enhancements

Skipping blank lines

- There are often blank rows on a screen, for example between lines of text.
- Skipping blank rows effectively reduces the multiplex ratio and therefore the power consumption per pixel.

A built-in reduced multiplex ‘screensaver’ or ‘standby’ mode

- Displaying, say, only the centre 16 rows, or a logo only 16 rows high scrolling over the screen.

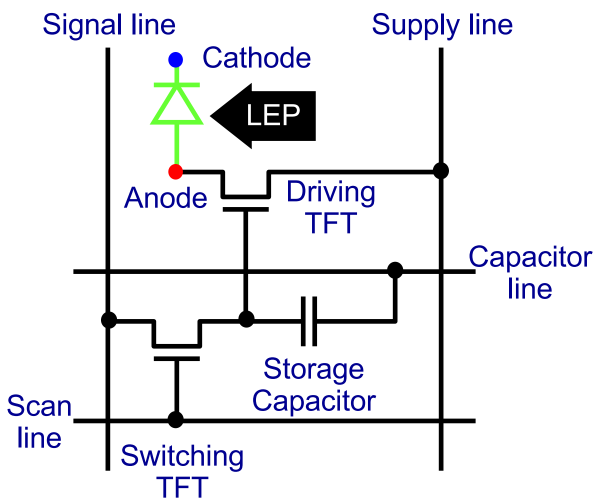
	Standard	Line skip
All on 96x64 monochrome	118mW	
Screen of text	41mW	36mW
Screen-saver mode	12mW	5mW

Active Matrix Displays

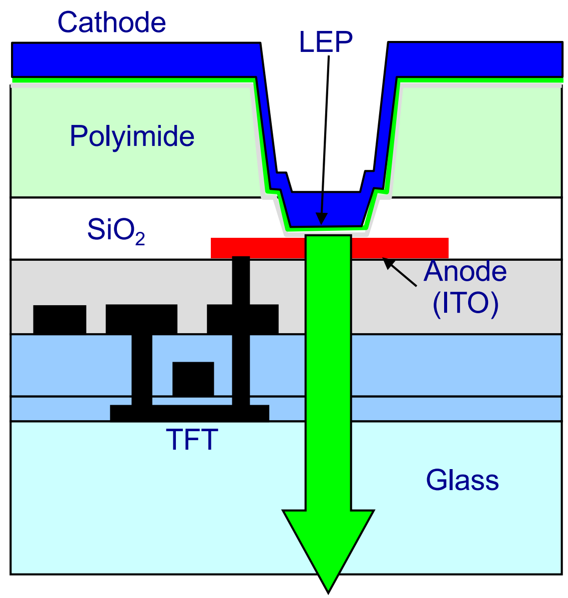
TFT (Thin Film Transistor) active matrix displays

- DC driven pixellated displays scalable up to large area
- Monochrome and full colour already demonstrated

PLED TFT Pixel Circuit



PLED TFT Cross-section



Active Matrix OLED

Active matrix driving of OLED displays allows

- Longer, less intense current pulse in the pixel

Leading to

- Ease of design of driver circuits
- Reduction in I^2R power dissipation
- Reduction in IR voltage drop
- Improvement in OLED efficiency / reduction in OLED power

Pixel circuits for LCD are designed to supply a voltage (analog or digital)

Pixel circuits for OLED are usually designed to supply a current

This involves either

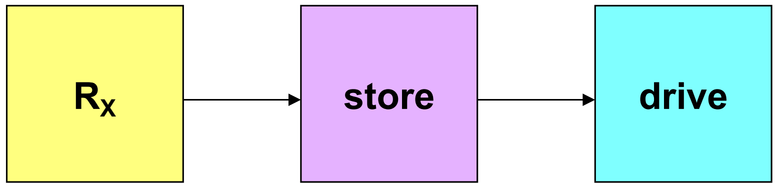
- Sending a voltage and converting it to a current
- Sending a current

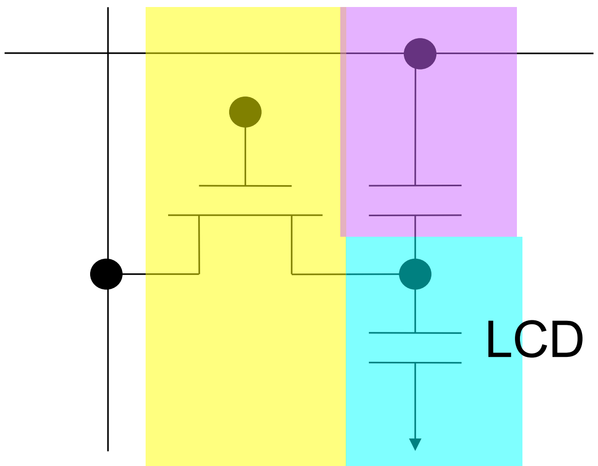
These circuits are more complex and more prone to manufacturing variation

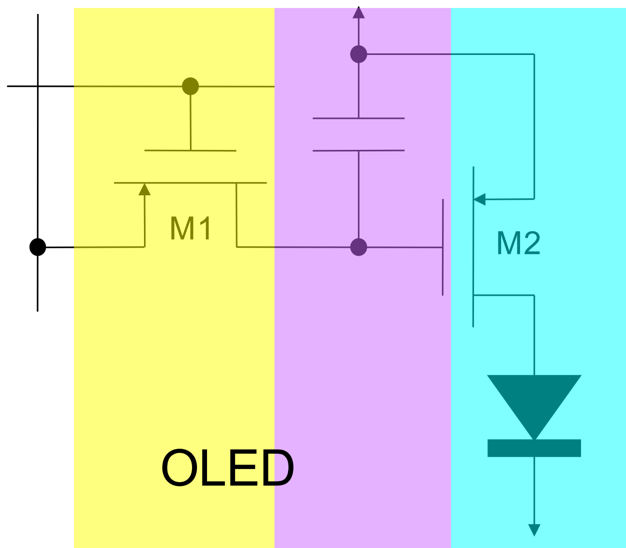
AM-OLED Backplane Technologies

	LTPS	Oxide (IGZO)
Type	CMOS	NMOS
TFT structure	Coplanar	Inverted staggered w ES
Mobility (cm^2/Vs)	50~100	10~30
Process	Laser	Sputtering
Uniformity	Issue	OK
Stability	Excellent	Issue
Environment sensitivity	Low	High
Off current	Low	Extremely low
Pixel circuit	>5 T, 1~2C	2T1C, 5T2C
Compensation	In-pixel	External
Manufacturability	Matured	Maturing
Run-to-run reproducibility	Excellent	Issue
Mask steps	8~11	4~5
Scaling up	Difficult	Good
Cost	High	Low

Simple Pixel Circuit



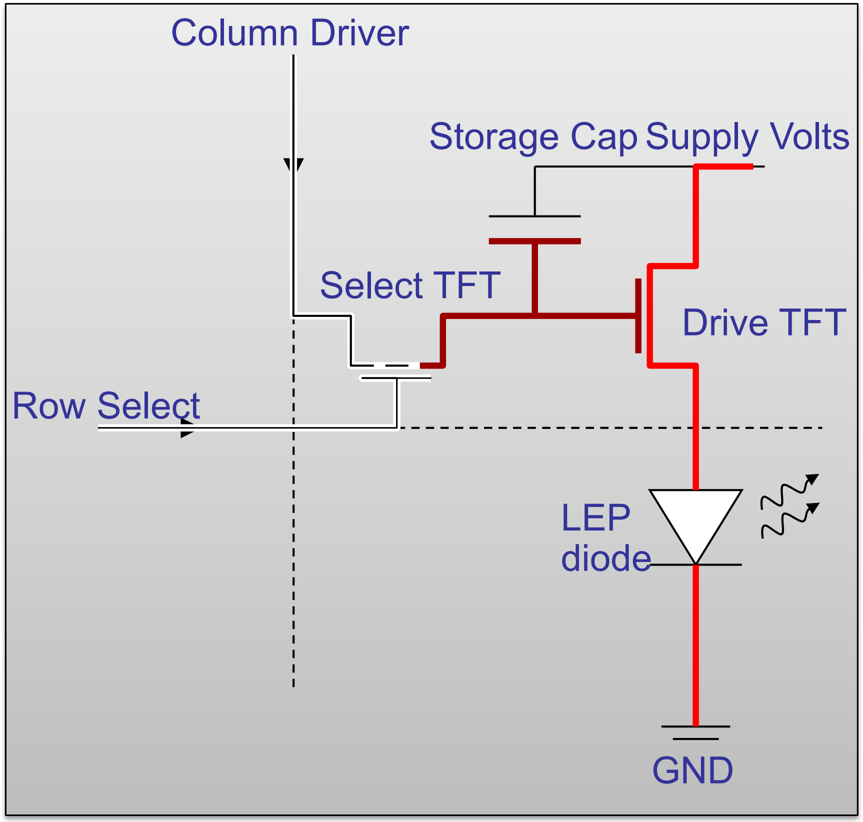




Voltage Control (Source Follower)

- Row is selected
- Driver TFT gate voltage set by column driver
- Row select is off, gate voltage held by capacitor until next frame

- Very simple (low TFT count)
- I_{DS} varies with V_G^2 (gamma 2 control by default)
- Sensitive to TFT variations (can be compensated) and LEP variations
- V_{DS} can be high (4-7V)



AMOLED limitations

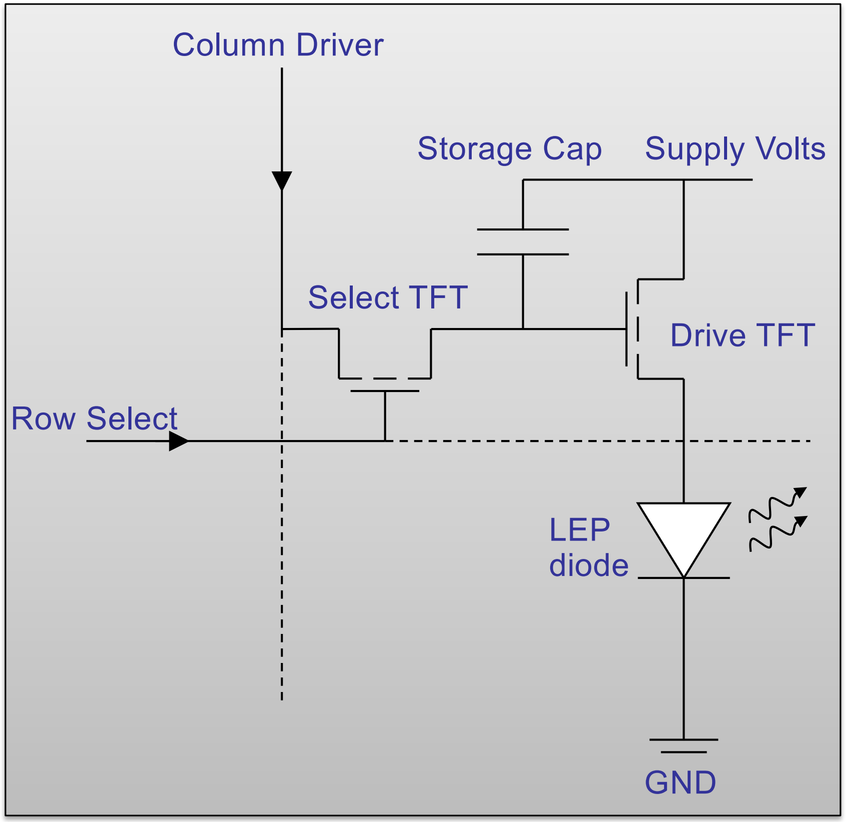
The limitations of <u>simple</u> AMOLED

No allowance for

- OLED process variation
  - Batch variability
- TFT process variation
  - Fixed pattern noise
- TFT aging & OLED luminance decay
  - Lifetime reduction
  - Image sticking
  - Differential decay of RGB

Pulse Coded Modulation (PCM) Voltage Drive

- Address period split into sub-frames
- Drive TFT acts as a switch
- OLED effectively voltage controlled
- Not sensitive to TFT properties
- V_{DS} low (~0.5V) efficient operation
- Accelerated pixel aging – LEP V_t increases with time reduce operating current
- Very susceptible to burn-in and differential aging
- Image artifacts possibly introduced
- Higher data rates



Threshold Voltage Correction

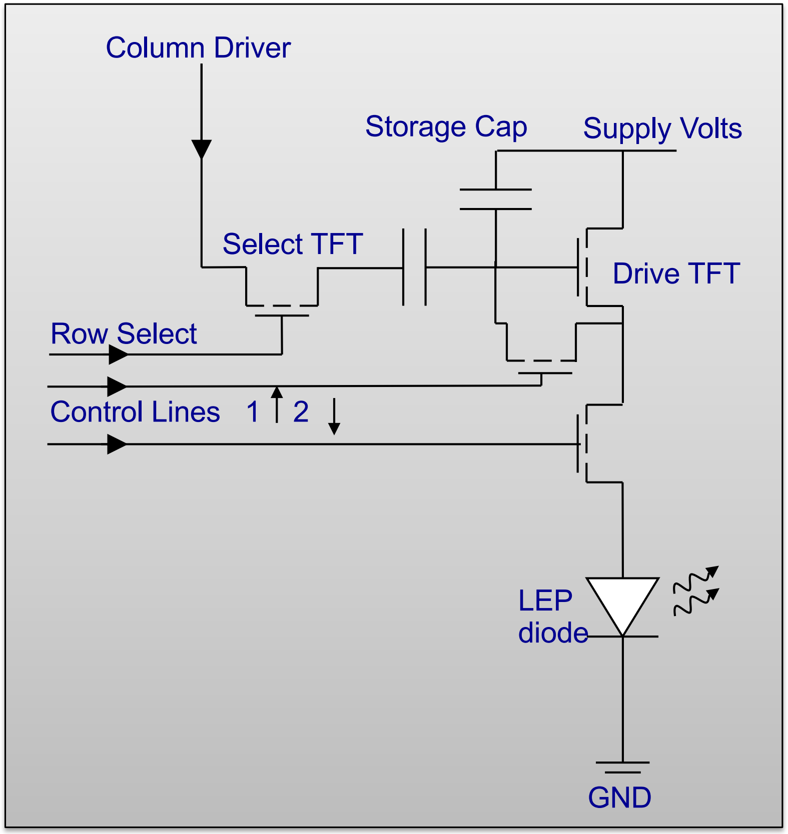
Selected with 0V data, C1 off, C2 on

C1 turned on, Discharging the gate voltage to threshold

C2 turned off then C1, holding the threshold at the gate

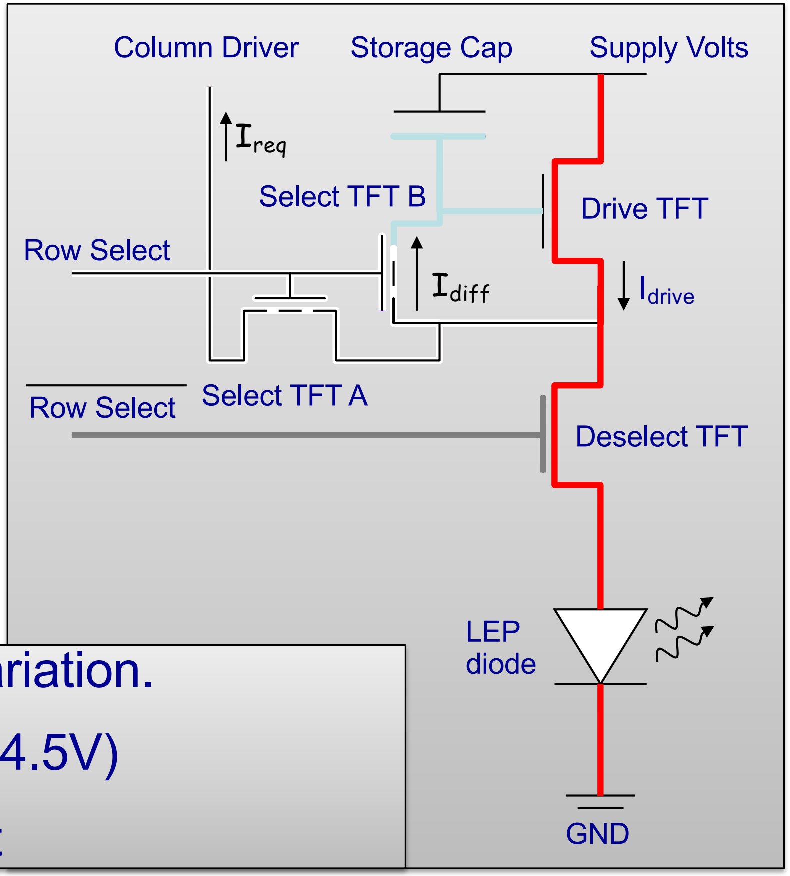
Any voltage applied by the column driver is now offset by the threshold voltage

- 2 large TFTs
- V_{DS} high (4V+0.5V)



Current Control (Sarnoff method)

- Row is selected, diverting the drive current into the column driver
- Required drive current is sunk by the column driver.
- Any difference in the currents flows into the capacitor, modifying the drive voltage until the current is correct
- Row is deselected, redirecting the drive current through the LEP diode



- Linear current drive, insensitive to TFT variation.
- Complex, high TFT count, large V_{DS} (4V+4.5V)
- 3 of the TFTs must cope with max current

Amplifying Current Mirror

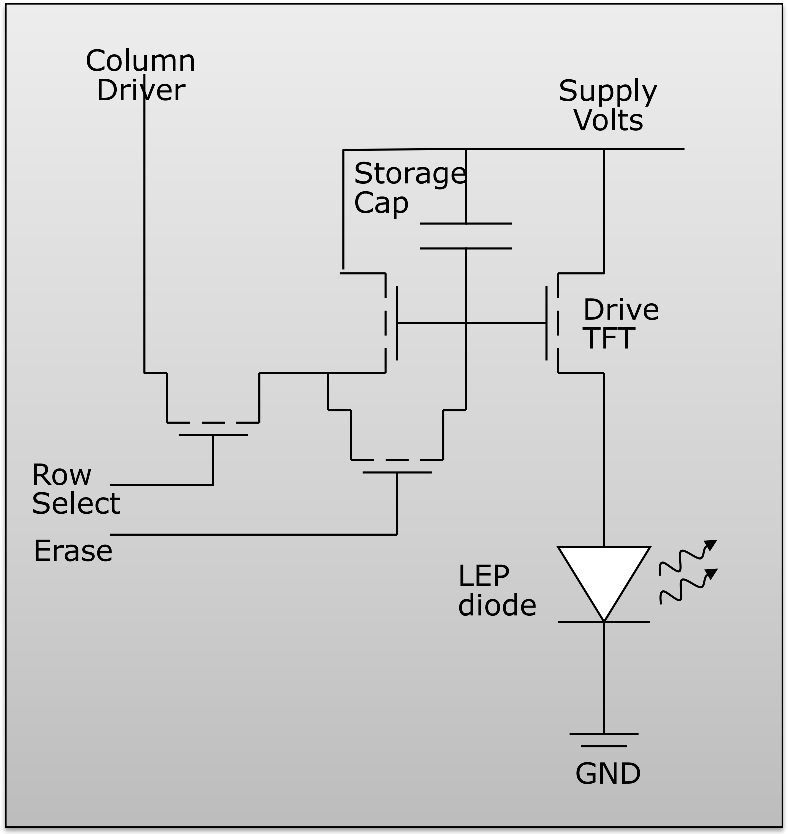
In use primarily by Sony

A similar feedback mechanism (to the Sarnoff circuit) sets the current on a 'mirror' TFT

The mirror TFT is geometrically scaled by a known factor (k) to the drive TFT

The drive TFT will exactly pass k times the mirror TFT current for a given gate voltage

- Three small TFTs and low currents on the column line
- Very linear and demonstrated on 13" diagonal display
- V_{DS} still ~4V



Charge programmed optical feedback

Very simple circuit

A charge is put on the capacitor

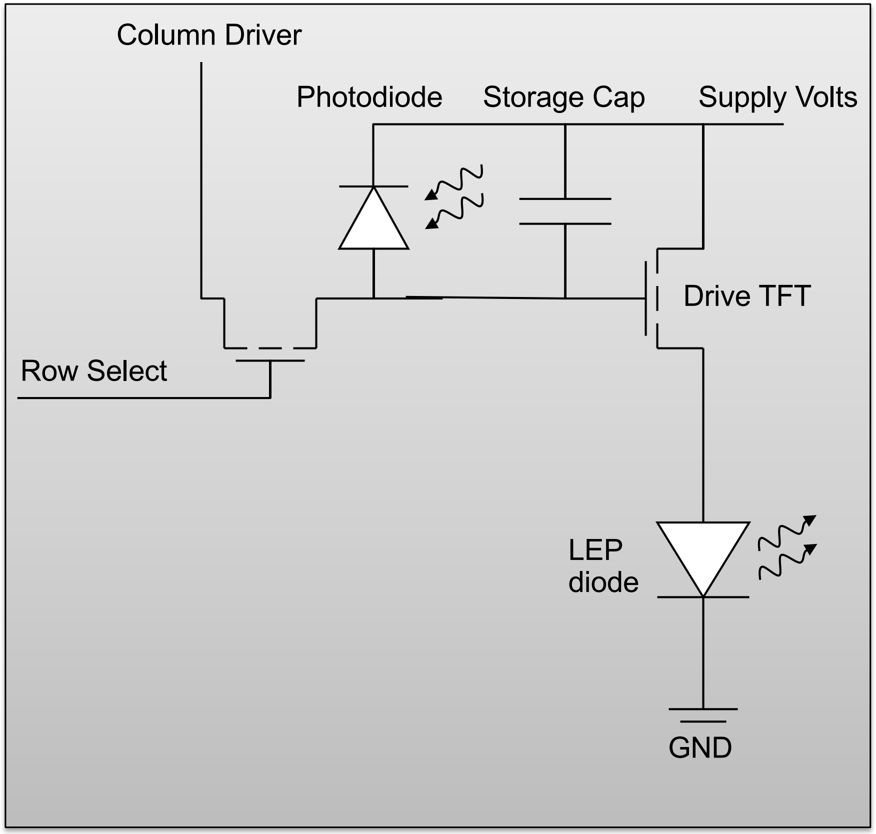
The photodiode will discharge the capacitor until the gate voltage drops sufficiently to turn off the OLED

The light output should be proportional to the charge

Sensitive to ambient light.

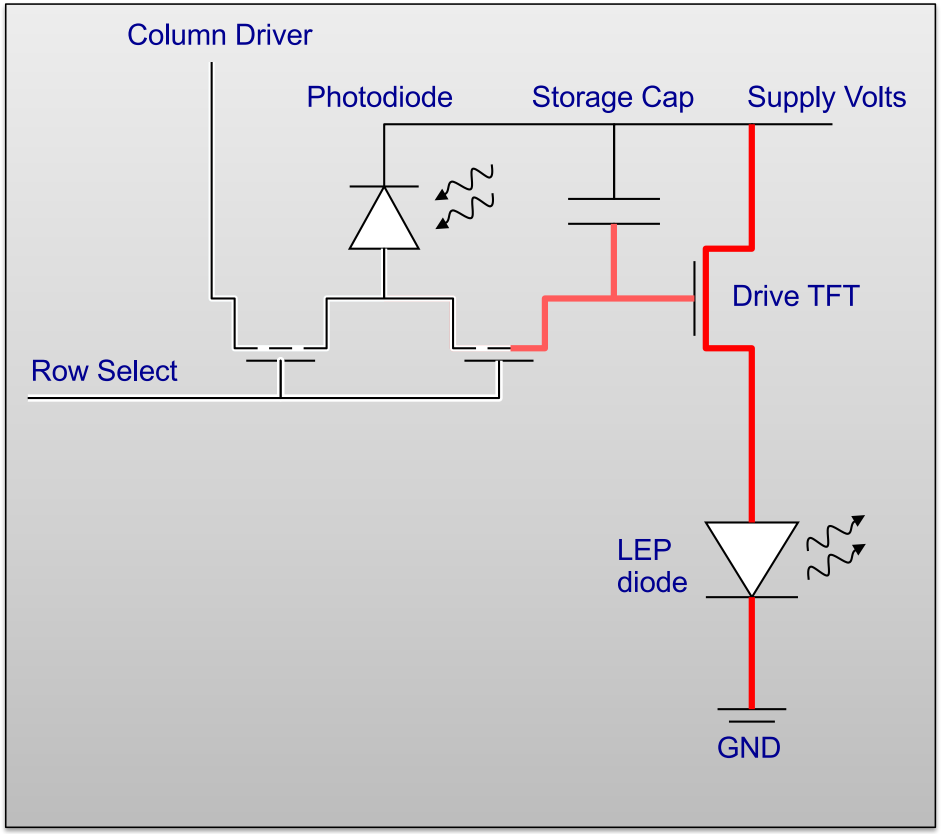
OLED is pulsed – less efficient

Long tail of pulse can cause nonlinearities

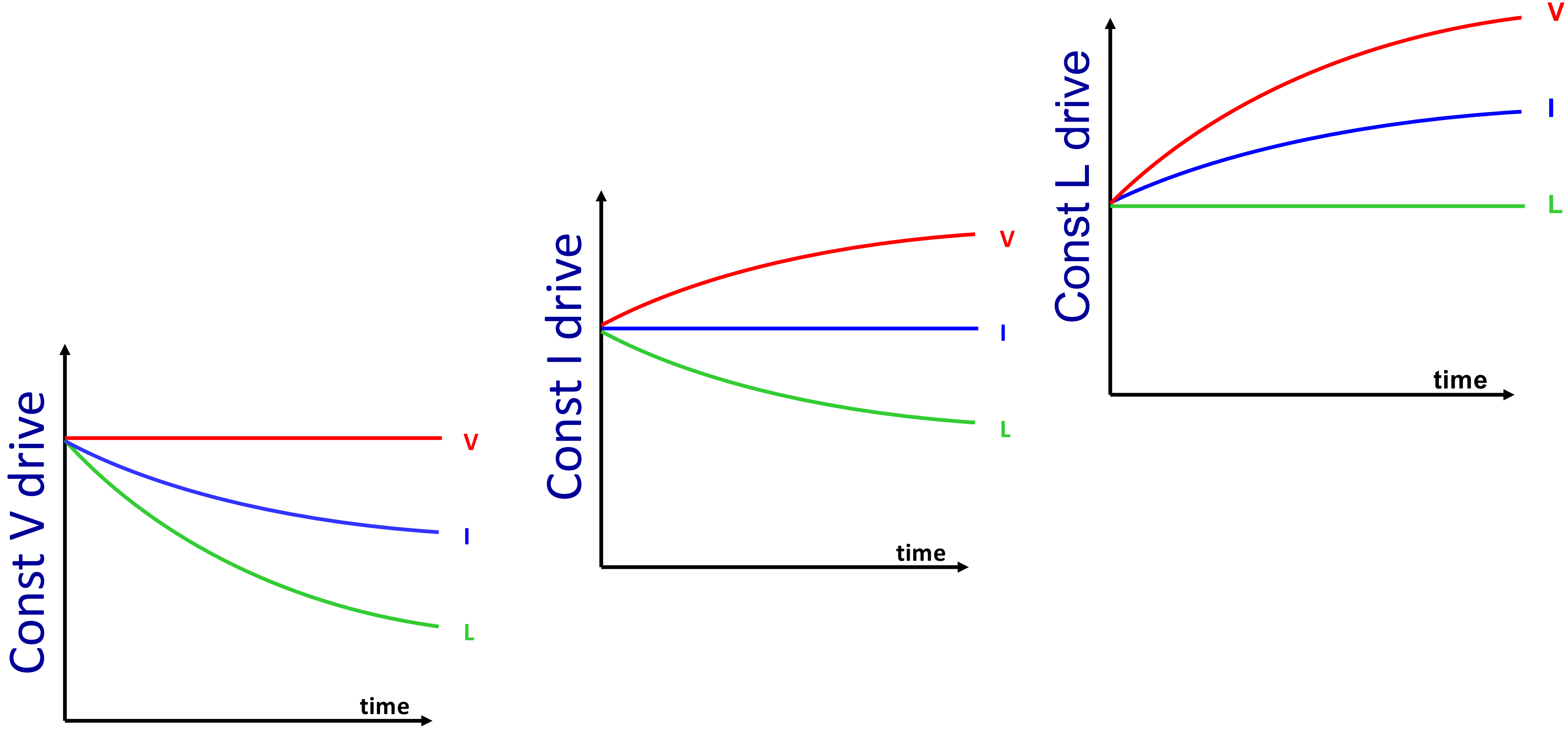


Current programmed optical feedback

- Row is selected
- Column driver requests photocurrent
- Current difference flows into the capacitor
- Row is deselected, holding the drive level on the storage cap
- Developed by CDT
- Medium TFT count, only one TFT needs to handle max current
- Insensitive to TFT and LEP variation, depends only on photodiode sensitivity – highly linear
- Automatically compensates for non-uniformities and aging



Summary of OLED Drive schemes



OLED Drive Circuit and Process Variability

CAUSE AND EFFECT	Effect of TFT Process variation	Effect of OLED process variation	Reduced lifetime due to resistive effects	Reduced lifetime due to reduced conversion efficiency
Voltage program Voltage drive	V small	Medium	Medium	Medium
Voltage program Current drive	Medium	Small	Very Small	Medium
Voltage program VT compensated current drive	Small	Small	Very Small	Medium
Current programmed current drive	Small	Small	Very Small	Medium
Optical feedback	Medium	Small	Very small	Very small