Display Power Characteristics

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ELEC518, Spring 2011
Display power

Display Power Issues

Display Consumes \(\sim \frac{1}{3}\) of total Average platform power alone

Backlight Consumes \(\sim \frac{1}{4}\) of total Average platform power alone

Display is the largest power consumer

Panel Electronics \(~25\%\)

MobileMark 2002* workload

Backlight \(~75\%\)

MobileMark 2002* workload

*Other names and brands may be claimed as the property of others
Display power (Contd.)

Power profile of HP iPAQ 4350 (mW)

- Basic idle, 244, 12%
- Bluetooth, 470, 23%
- Earphone, 65, 3%
- Computing, 383, 19%
- Speaker, 367, 18%
- LCD, 82, 4%
- Lighting, 444, 21%

iPAQ 4350, 2004
Display power (Contd.)

Audiovox 5600, 2004
**LCD principle**

- **Electrode**: indium tin oxide (ITO)
- **Color filter**
- **Dot addressing**
- **Luminance controller**
- **Lighting**

The principle of a Liquid Crystal Display (LCD) involves the use of indium tin oxide (ITO) as an electrode. The display includes color filters that absorb or allow light of different wavelengths to pass through, creating pixels. The luminance controller adjusts the light intensity, and dot addressing controls the display's resolution and color intensity.
Lighting

• Cavity/direct backlight

Fig. 1: An example of a cavity backlight with a multiple “stick” CCFL.

• Edge-lit light-guide backlight

Abileah’08, Information Display
Edge-lit light-guide backlight

- Reflector
- Guide
- Diffuser

Fig. 2: A cross section of an edge-lit backlight.
Edge-lit backlight (Contd.)

Fig. 3: This LED array strip is diffused into a thin light guide using material from Fusion Optix. Note the headlight effect along the edge of the glass.
Backlighting

- Cold cathode fluorescent tube (CCFL)
- LED (better white and brighter)
Addressing

• Direct addressing
  – Numeric LED display

• Dot matrix: passive
  – Slow response, poor contrast
  – Low-cost, low-power, small displays

• Dot matrix: active
  – Higher power consumption

Switch for each pixel
Common electrode
Passive matrix addressing

- Cross talk between neighboring pixels
- Long latency due to scanning

Active matrix addressing

• More expensive
Thin-film transistor (TFT) LCD

Cross-sectional diagram of an active-matrix LCD. The LC cell modulates light intensity according to the driving voltages. ITO = indium tin oxide

TFT ≈ Active Matrix

Flynn et al, 1999
LCD power consumption

- Liquid crystal cell requires polarization
- TFT panel must be on
  - DRAM
  - Refreshing at 60Hz
Bistable display (Zero power)

- Cholesteric liquid crystal cell stays polarized without voltage
- Long response time
  - Fine for ebook, bulletin board, light interaction
  - Impossible for video

Kent display

Passive or Active addressing?
E-Ink: Electrophoretic ink

Nature, 2003

L.G. Philips---E-Ink

TFT on 75um-thick steel-foil substrate

http://www.eink.com/
E-Ink product

- No back light
- Paper quality
  - High contrast
  - High resolution
OLED display

• LCD: filter white external light for colors
• OLED: generate different colors
  – Potential lower power
    • Luminance for each pixel can be changed
  – Much larger view angle
  – Bright & high contrast
  – Broad color gamut (better colors)
  – Thin & light
  – Faster response
Commercial product

- Sony OLED TV
  - XEL-1, 11”, $2,500, 3mm-think Panel

  - http://www.youtube.com/watch?v=FTEt5o_Jt30
Commercial products (Contd.)

• Samsung 12.1” OLED for laptops

Fig. 2: Samsung SDI showed several concept applications featuring OLED displays, including this stylish notebook computer featuring a 3-in. WVGA 800 × 480-pixel OLED display with a thickness of just 1.21 mm.

Fig. 3: Samsung SDI showed several concept applications featuring OLED displays, including this laptop with a 12.1-in. 1280 × 768-pixel AMOLED display.
Power efficiency

• Green is the most efficient
OLED display power management

- Darken unused areas

2.5 times power reduction

HP Labs, MobileHCI 2004
OLED display power management

• Luminance inversion

5 times power reduction
Original

Dark

\[ R' = \lambda R \]
\[ G' = \lambda G \]
\[ B' = \lambda B \]
\[ \downarrow 25\% \]

Green

\[ R' = \lambda_R R \]
\[ G' = \lambda_G G \]
\[ B' = \lambda_B B \]
\[ \downarrow 34\% \]

Arbitrary

\[ R' = R^* \]
\[ G' = G^* \]
\[ B' = B^* \]
\[ \downarrow 72\% \]

Inversion

\[ R' = \lambda(1-R) \]
\[ G' = \lambda(1-G) \]
\[ B' = \lambda(1-B) \]
\[ \downarrow 66\% \]
Human visual system

Normalized response spectra of human cones, S, M, and L types, to monochromatic spectral stimuli, with wavelength given in nanometers.

http://en.wikipedia.org/wiki/Color_vision
Color sensitivity

Single color sensitivity diagram of the human eye.