Liquid Crystal Displays
(LCDs, Flüssigkristall-Anzeigen)

Grundlagen - Eigenschaften - Ausführungen

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Overview

1 Introduction

2 LCD - Basics

3 Direct Drive & Passive Matrix

4 Active Matrix

5 Backlights

6 LCD - Optimization

„The LCD Monster takes it all !?"
Liquid Crystal Displays

LCD from Segmented to E-Signage

Size, price, complexity, …

Embedded system approach

Monochrome graphics

Character

Segment 8

Direct drive MUX Passive Matrix Active Matrix

Resolution

Color graphics
Fundamental Flat Panel Display Principle

Electronics Point of View

From (digital) input to TFT drive

Pixel converts voltage/current to light
AM LCD - Panel with Digital RGB - Input

Electronics Point of View
Display Driving: Matrix Drive

Electronics Point of View

- Scanning of rows
- Write data to columns
- Select one row
- Write data of all columns at one time

→ Parallel data: Row-at-a-time addressing

Fixed resolution!
Panel Electronics for Mid Resolution AM LCDs

Row (gate) driver

Column (data) driver
Example of Row and Column Drivers

Column (data) driver

Row (gate) driver
Fundamental Flat Panel Display Principle

Electro-optics (pixel) Point of View

Pixel converts voltage/current to light

Cross section of a pixel of a typical display

- Front plane
  - Substrate (glass, plastic)
  - Color filter (option)
  - Matrix drive, x-Si, electronics
  - Substrate, additional backlight for LCDs

- eo-layer

- Back plane

Display input data are converted to matrix drive data and converted to appropriated voltage/current for the pixel.
Fundamental Flat Panel Display Principle Keywords

• **Display module**: Device which covers all subassemblies from data input interface over data adaptation for matrix drive (PM, AM), electro-optical conversion, pixel drive (e.g. TFT) and electro-optical layer (e.g. LC, OLED)

• **Electro-optical layer/conversion**: Voltage (e.g. LCD) or current (e.g. OLED) is converted to light (transmission for LCD). Display types differ in electro-optical layer. Panel electronics is basically identical but must be adapted to electro-optical characteristics

• **Panel electronics**: Digital display input data are converted of matrix drive data and converted to appropriated voltage/current for the pixel. Matrix drive consists of row and columns (electrodes and drivers)

• **Front plane**: Part of the display facing the observer. Consists typically of color filter (LCD), electrode, reflection reduction, …; all mounted on a substrate (mostly glass)

• **Back plane**: Part of the display opposite the observer. Consists typically of TFTs (for AM drive) and pixel electrodes…; all mounted on a substrate (mostly glass)
Power Consumption and Cost

- Panel electronics, front and backplane have similar impact on module price: ~ 25%
- Backlight draws about 75% of total power

Typical values for 10.4” VGA Color AM LCD

- Panel electronics, front and backplane have similar impact on module price: ~ 25%
- Backlight draws about 75% of total power
Liquid Crystal Displays

**LCD Display World**

- **Resolution**
  - QXGA
  - HDTV
  - SXGA
  - XGA
  - SDTV
  - VGA
  - QVGA

- **Display Size**
  - 1
  - 10
  - 20
  - 40
  - 60

- **Projections**
  - Smartphone, tablet
  - Notebook
  - Car
  - Industrial

- **Technology**
  - p-Si
  - a-Si

- **Low information content displays**

- **Further reading**
  - See § Active Matrix
  - (not relevant for exam)

Further reading:
- Car
- TV
- PC
- Monitor
- Notebook
- Smartphone, tablet
- Car
- Industrial

PDP (for comparison)
Beyond Industrial: Avionics & Automotive

Harsh environment:
- Aircraft (PHILIPS), automotive (SHARP)
Beyond Commodity: High Resolution Displays $\geq 5$ MPixel

- Only LCDs
- Applications: Medical, CAD, Simulation, …

Traffic control

PLANAR 21” 5 MPixel
Overview

1. Introduction
   Liquid Crystal fundamentals
   principle of operation

2. LCD - Basics

3. Direct Drive & Passive Matrix

4. Active Matrix

5. Backlights

6. LCD - Optimization
Liquid Crystal Displays

- **TN**
  - Direct
    - Twisted Nematic
  - Multiplex, Passive Matrix
    - Standard TN
    - Supertwisted
  - Active Matrix
    - 3 Terminal
    - Silicon
    - Amorphous Si
    - Diode
    - Threshold enhanced (MIM, Varistor, ...)
    - 2 Terminal
    - Non-Silicon
  - TN, VA, IPS, ...
    - Bi-stable
      - Smectic A
        - Thermal, electric
      - Smectic C
        - Ferroelectric, Guest Host
    - LC-class
    - Driving
    - Mainstream

- **STN**
  - Nematic
    - ECB
    - OMI

- **ET/IT & TI**

Blankenbach / Pforzheim Univ. / www.displaylabor.de / May 2013
**Liquid Crystal Displays**

### LCD History

- **1888**
  - Discovery of LC materials

- **1980’s**
  - Passive Matrix LCD

- **1990’s**
  - Segment LCD

- **2000’s**
  - **Active Matrix**
    - Low temp. p-Si TFT-LCD
    - LCD TV

From small size displays for characters to large area displays for graphics and movies.
LCD Cross Section

Principle: Voltage driven 'switching' of light

U

(Back-) Light

Polarizer
Glass 1 mm
ITO 50 nm
LC 10 μm
Alignment layer 50 nm
Spacer
Analyzer

Colour TFT
TFT plane
back plane

CF plane
front plane
Basic Technologies

• **Reflective**
  (low resolution and monochrome)
  + Power consumption
  - Night vision
  Mainstream low res.

• **Transflective**
  (good performance but too expensive)
  + Power consumption
  + Night & day vision

• **Transmissive**
  (high resolution and color)
  + Vivid Colors
  - Power consumption
  - Daylight vision
  Mainstream high res.
Characteristics of Liquid Crystals

- Chemistry

\[
\text{R} - \text{X} - \text{R'}
\]

- Mechanics

- Physics

\( \varepsilon_\perp \) \( n_\perp \)
\( \varepsilon_\parallel \) \( n_\parallel \)

- Effects in electric field

LC molecule align to electric field:
- Mechanical orientation within ms
- Induced charge adapt within ns

Examples | ZLI-3125 | ZLI-2585
---|---|---
\( T_C /^\circ C \) | 63 | 70
\( \Delta \varepsilon \text{ (1kHz, 20}^\circ \text{C)} \) | +2.4 | -4.4
\( n_\perp = n_o \) | 1.467 | 1.469
\( n_\parallel = n_e \) | 1.519 | 1.506
\( \Delta n \text{ (589nm, 20}^\circ \text{C)} \) | 0.052 | 0.037
Temperature Characteristics of Liquid Crystals

LC molecules have the orientation properties of crystals (fixed atoms, high order) and the mobility of a liquid (low order) for a temperature range between melting and clearing (LC phase). One can regard LCs as a material with a wide T range for the phase transition from solid to liquid. This unique material was discovered in 1888. Within the liquid crystal phase, the LC molecules are “self-aligned” but can orientate to an external electric field. LC properties incl. optical ones depend on temperature.

Useful range for LCDs: 0 … 40°C (except automotive etc.)
Properties of Liquid Crystals

• Anisotropic properties
  - Electric permittivity ($\Delta \varepsilon = \varepsilon_|| - \varepsilon_\perp$)
  - Refractive index ($\Delta n = n_|| - n_\perp$)
  - Elastic constants ($k_{ii}$)

• Alignment
  - On surfaces $\rightarrow$ Alignment layer (see next slide)
  - By electric fields $\rightarrow$ orientation to E-field from pixel voltage $U$

![Diagram showing anisotropic properties and alignment](image-url)
Interaction LC ↔ Alignment Layer

• **Side view**
  (example TN 90°)

• **Top view**
  (example TN 90°)

• **Tilt angle**
  \(~ 2°\)

Alignment layer

10 µm

90° twist

- STN multiplexing
- Domain free orientation
- Switching time \(T_{Rise}\)

Relevant for
LC Principle: Alignment on Surfaces vs. Electric Field

Fundamental to most LCDs; Principle by Fredericksz (1929)

LC aligned to surface (alignment layer)

LC aligned to E-field

To control the transmission of pixel: polarizer needed
Polarization Filter

Light parallel to polarizer

Light perpendicular to polarizer
TN (90°) : Light guide principle

- **Positive Mode**
- **Lower polarizer || orientation**

- **Direct Drive & Active Matrix**
- **Contrast: Difference of luminance**

Other LC principles like IPS and xVA see § Optimizations
TN 90°: Light guide principle

TN 90°: Twisted nematic LC with 90° helix (no voltage)

**Polarizer**: Let only polarized part of light pass in its direction

**Alignment layer**: Set Orientation direction of LC

**ITO**: Indium Tin Oxide, a transparent conducting material (use in all displays)

**LC**: Forms helix without voltage, polarized light “follows” LC orientation

Light orientation is the same as polarizer orientation at the “bottom” of the pixel → light passes polarizer → pixel is “white”

With “high” driving voltage:

LC orientates to E-field set by voltage

No helix, polarized light orientation is unchanged, lower polarizer cannot be “passed” → pixel is “black”
TN (90°) : Light guide principle

Negative Mode

Lower polarizer $\perp$ orientation

- Direct Drive & Active Matrix
- Contrast: Difference of luminance
STN (180°-270°) : Birefringence Principle

Index ellipsoid

180° twist

- Passive Matrix
- Contrast: difference of luminance + color
Liquid Crystal Displays

Electro-optic Curve of LC

Transmission

Pixel

90 %

Positive mode

eo curve

10 %

0

Driving Voltage

\( U_{\text{off}} \)

\( U_{\text{on}} \)

Slope and Shape:
- Viewing Angle
- Twist
- Pre-tilt
- T
- LC Type
- ...

Electro-optic Curve of LC

Positive mode

Viewing Angle

Twist

Pre-tilt

T

LC Type

...
Summary & Questions

• Why is a twist of 90° used for direct and AM drive and > 180° for PM?

• Why need LCDs a DC-free driving signal?

• Explain the principle of TN 90° LCDs

• Discuss resolution and OFF state color for (S)TN LCDs (no AM)
Overview

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6. LCD - Optimization

Fundamental rule of LC driving:
No DC offset is allowed for LCD driving thus applying DC-free pulse waveforms

Driving signals
8 - Segment
Multiplex
Passive Matrix
Direct Drive

Principle: Each pixel (Dot) is driven by one dedicated signal.

Plate, electrode

\[ U_{\text{Pixel}} = U_{\text{Front}} - U_{\text{Back}} \]

Direct Drive Principle: Each pixel (Dot) is driven by one dedicated signal.

\[ f = 30 \text{ - } 70 \text{ Hz} \]

DC-free!
Transmission and Driving Voltage

For $U_{\text{off}}$ (10%) and $U_{\text{on}}$ (90%),
$\rightarrow C_R = 9 : 1$

(10-90 definition in electronics)
but larger for $0 \ldots U_{\text{drive}}$

For direct drive the driving pixel voltage is not limited!
Simple driving with XOR because of automatic inversion - just set pixel!

Direct Drive for Segment 8 (I)

Control input to Exclusive OR gate

Osc input (clock) to Exclusive OR gate

180° phase shifted output of Exclusive OR gate

Resultant display waveform measured segment to common plate

DC-free!
Direct Drive for Segment 8 (II)

Driving principles and display controller see § Embedded Systems

Segment plate  Common plate
Basics of Low Res LCD - Production (I)

ITO deposition
Photoresist printing
Mask align
Exposition

Developing, Etching

Alignment layer printing

Rubbing (LC orientation)

Seal-printing
Spacer

AMLCD: + TFT and CF

Further reading (not relevant for exam)
Basics of Low Res LCD - Production (II)

Cell alignment
Baking
Scribe & break

LC filling by vacuum
UV-seal

Final assembly:
Polariser
Driver
Bezel
# Liquid Crystal Displays

## LC Driving

Direct drive is limited to 40 segments (pixel, MUX 400)

Solution: Matrix drive by rows and columns

<table>
<thead>
<tr>
<th>Method</th>
<th>Static</th>
<th>Matrix</th>
</tr>
</thead>
<tbody>
<tr>
<td>Direct: Every pixel has a dedicated driver output</td>
<td>Passive (PM)</td>
<td>Active (AM, TFT)</td>
</tr>
<tr>
<td>LC - Types</td>
<td>TN</td>
<td>STN</td>
</tr>
<tr>
<td>Principle</td>
<td><img src="image1" alt="Static Principle" /></td>
<td><img src="image2" alt="Matrix Principle" /></td>
</tr>
</tbody>
</table>
Challenges of LCD Matrix Driving

• **Matrix drive:**
  - Rows are scanned subsequentially
  - Columns provide grey level for each pixel in the activated row (line)
  - Each pixel is activated only by a short time (16.7 ms / number of rows for 60 Hz frame frequency)
  - What happen for the rest of the time until this pixel is activated again?

• **Passive Matrix**
  The pixel is exposed to the voltage of the other pixel in the column. Thus driving waveforms are complex and ghosting takes place.

• **Active Matrix**
  The pixel is isolated electrically by a TFT (MOS FET) from the rest of the column (and line). This results in best quality (contrast, viewing angle, …)
Matrix Driving Parameter

Activation time for a pixel

\[ T_{on} = \frac{1}{N \cdot f_{frame}} \]

where

- \( N \): number of rows (e.g. 480)
- \( f_{frame} \): frame frequency (e.g. 60 Hz)

Example for 60 Hz:

- VGA  \( T_{on} \approx 35 \mu s \)
- SXGA  \( T_{on} \approx 16 \mu s \)

Scan signal waveform

Frame time

\( T_{frame} \approx \frac{1}{60} \text{s} \)

Row

1
2
3

Pulse width (\( T_{on} \approx 34.7 \mu s \))

VGA - Panel, 60 Hz frame rate, 480 lines (rows)
Passive Matrix (PM) Addressing

Passive Matrix LCDs are easy to manufacture as only ITO line electrodes have to be manufactured (lines + 1 TFT per pixel for AM)

Scan and data on different planes

(Scheme for reference only)

|U| is not intended resulting in an unwanted grey level → Ghosting for PM!
Driving Waveforms for 2 x 2 Passive Matrix

Waveforms for Pixel 'a' and 'b'

PM is reasonable for ≤ QVGA and possible up to SVGA.
Contrast Adjustment for High Multiplex Ratios

Transmission

\[ \Delta \text{Trans.} \]

\[ 90 \% \quad \text{to} \quad 10 \% \]

\[ \Delta \text{Trans.} \]

\[ U_{\text{select}} \]

\[ (\text{mux}) \]

\[ U_{\text{select}} \]

\[ (\text{static}) \]

\[ \text{twist} \ 270° \]

\[ 1.134 \ U_{\text{non-select}} \]

See poti @ copy machine

Issue: Ghosting
Electrical black is not optical black (same for white)

Alt & Pleshko

Alt & Pleshko

\[ \Delta \text{Trans.} \] by \[ U_{\text{contrast}} \]
PM: Calculation of Driving Voltages

Alt & Pleshko - formula

\[ R = \frac{U_{\text{select}}}{U_{\text{non-select}}} = \sqrt{\frac{\sqrt{N} + 1}{\sqrt{N} - 1}} \]

N : # of lines = Multiplex ratio

Example for Low Resolution Graphics

N = 64 \rightarrow R = 1.134 \rightarrow \Delta U \approx 13 \% 

e.g. \( U_{\text{sel}} = 10 \text{ V} \rightarrow \Delta U \approx 1.3 \text{ V} \)

\rightarrow 20 \text{ mV per gray level for 6 Bit} 

\( (U_{\text{select}} \text{ temperature dependent}) \)

Reduced contrast ratio compared to direct drive:

\[ C_R \approx \frac{1}{N} C_R^{\text{direct}} + 1 \]
Contrast Voltage - Contrast Ratio (I)

- Not readable
- OK
- Ghosting

Optimum contrast voltage depends on temperature and must be controlled during operation at different temp.
Summary & Questions

• What is the basic operation principle of an TN LCD? What are the functions of each layer, part, ...?

• DC-free driving required (results in Image Sticking, similar to Burn-In)

• How can a simple direct drive for 8-Seg. LCDs be achieved?

• Matrix drive increases the number of display pixels as they are driven by sharing rows and columns

• What are limitations for PM drive?

• The only benefit for PM drive is cost but AM LCDs become more and more cheaper as of smartphone mass production and yield improvements!
Overview

1 Introduction

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5 Backlights

6 LCD - Optimization

• The challenge for AM is yield (Ausbeute) in mass production
• AM is pushed by high resolution multimedia trend with great image quality (contrast, color, ...)

AM Module

a-Si TFTs vs. LTPS p-Si TFTs
AM LCD Side View

- **Driving Circuit Unit**
  - TCP
  - PCB
  - LDI

- **Backlight and Chassis Unit**
  - Lamp

- **LCD Panel**
  - Polarizer
  - Color Filter Substrate
  - Color Filter
  - ITO
  - TFT Array Substrate
  - TFT
  - LC
  - Spacer
  - Seal
  - Black Matrix
  - Glas

- **Diffusors**

- **Light guide**
Active Matrix Subpixel

- Scan and data signal on one plate
- 1 TFT per pixel (AM OLED ≥ 2)
- Capacitor stores pixel voltage (data) during frame time

- 1 pixel = 3 RGB subpixel
- Aperture ratio ≈ 60%
- SXGA: 1280 x 1024 x 3 TFTs
≈ 4 Mio. TFTs
Basic Driving Waveforms for 2 x 2 Active Matrix

Waveforms for Pixel 'a' and 'b'

AM pixel voltage not limited → high contrast ratio.
No ghosting as TFT “isolates” pixel

(simplified example)
Basic Driving Waveforms for 2 x 2 Active Matrix

Row by Row Addressing

- Each row of pixels is addressed in sequence
  - Achieved by applying a positive pulse to the row electrode
  - Closes the switches (turns the TFTs on)

- Pixel data is then applied to the column electrodes
  - Charges up the pixel capacitance, $C_{LC}$

- When the pixel is charged the TFT switch is opened
  - Charge remains on pixel

AM pixel voltage is not limited compared to PM drive
Active Matrix Cell: Elements

- Diffusor
- Scan / Gate electrode
- Glass
- Data / source electrode
- Polariser
- TFT
- Pixel electrode
- ITO - frontplane
- Color filter
- Glass
- Front polarizer
- 5% to viewer
- 100% backlight
Active Matrix Cell: Layers & Equivalent Circuit

TFTs are made of:
- amorphous Si (a-Si) for monitors
- polycrystalline Si (p-Si) for mobile

p-Si is manufactured as Low Temperature Poly Silicon (LTPS)

Front plane

'Same price'

Back plane
a-Si vs. p-Si

All high ppi LCDs like APPLEs RETINA LCD are p-Si

→ p-Si for projection LCDs (small size & high resolution)
**TFT Technologies**

<table>
<thead>
<tr>
<th></th>
<th>Single Crystal Si</th>
<th>Polycrystalline Si</th>
<th>Amorphous Si</th>
</tr>
</thead>
<tbody>
<tr>
<td>e - Mobility / cm²/Vs</td>
<td>500</td>
<td>50</td>
<td>0.5</td>
</tr>
<tr>
<td>Process Temperature /°C</td>
<td>&gt; 900</td>
<td>600 - 900</td>
<td>250 - 350</td>
</tr>
<tr>
<td>LTPS</td>
<td>≈ 300°C</td>
<td>(not relevant for exam)</td>
<td></td>
</tr>
<tr>
<td>Substrate</td>
<td>Single crystal</td>
<td>Quartz / glass</td>
<td>Glass</td>
</tr>
<tr>
<td>Substrate size</td>
<td>4”… 12”</td>
<td>… 25” x 32”</td>
<td>… 60” x 72”</td>
</tr>
<tr>
<td>Display application</td>
<td>μDisplays</td>
<td>Small size</td>
<td>Large area</td>
</tr>
</tbody>
</table>

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**Further reading**

- (not relevant for exam)
Summary & Questions

• Explain how AM driving works.

• The challenge of AM LCDs is TFT manufacturing.

• The benefit of AM driving is image quality and higher resolution as for PM.

• What is the function of major AM LCD subassemblies?

• Which limit of PM driving is not applicable for AM?

• What are the benefits of LTPS p-Si?
Overview

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6 LCD - Optimization

• Backlight is needed for color LCDs as it’s light is modulated by LC grey levels and passes RGB color filters

• Backlight draws about 75% of the AM LCDs power consumption.
Backlight Requirements

- High luminance
- Uniformity of luminance
- High dimming ratio specifically for automotive applications
- No flicker
- Low power consumption
- Low profile
- Low weight
- Low heating
- Choice of color
- Extended temperature range
- High life time
- Low cost
- ...

All these requirements cannot be fulfilled by a single technology!
AMLCD Module

Focus: Backlight unit

- front cover
- polarizer + retarder
- diffusor
- display
- lensfilms
- protective coating
- ACF connection
- display frame
- back cover

- CCFL
- light guide
- white reflector film
- ACF connection
- TCP-driver ICs on tape
- reflector
- electronics PCB
- white dot printing
Luminance Loss for AMLCD

Light efficiency:

\[ \eta = 5\% \]

\[ 0.6 \times 0.4 \times 0.7 \times 0.3 \approx 5\% \]

White light is RGB filtered, only 1/3 of white intensity passes.

Only light with same polarization as polarizer pass.
AM LCD Optimizations: **Selected topics**

- Increase $\eta_{LED}$
- Intelligent dimming
- No CF for sequential color backlight
- Edge-light $100\%$
- Light CF or RGBW (gamut $\downarrow$)
- Rise aperture
- Directional films

**$\eta = 5\%$**

- Front Polarizer
- ITO Coated Glass
- Color Filter (30\%)
- Liquid Crystal Layer (70\%)
- Active Matrix (70\%)
- Rear Polarizer (40\%)
- Light Guiding Plate (60\%)
AMLCD Backlight Tasks: Homogeneous Light Output

- Diffusor
- Prism Film II
- Prism Film I

- Diffusing
- Refraction
- Reflection

LED

Diffuse Reflector
Light Guide
Reflector
Mirror
Increasing Luminance by **Brightness Enhancement Films**

Enhances perpendicular luminance at the cost of viewing angle degradations
Backlight & Colour Filter Fundamentals

RGB LED backlight only for high end, all other white LEDs

Backlight spectrum \( \times \) colour filter spectra = Light output spectra

Match backlight spectra and colour filter transmission spectra for maximum light output with respect to colour management.
White LED - Backlight & Colour Filter
Basic Backlight Configurations

- **Direct type for point and line light sources**
  - Typical applications: Monitor, TV sets
  - Light guide (design) relative simple
  - Many light sources necessary
  - Local (and global) dimming easy

- **Side light type for point and line light sources**
  - Typical applications: Mobile LCDs, slim line monitors and TV sets
  - Light guide (design) complex
  - Few light sources necessary
  - Global dimming easy, local complex

- **Direct type for area light sources**
  - For all applications
  - Only OLEDs (and EL)
  - Global dimming easy, local complex

: LED (or CCFL) (not to scale)
LED - Backlight

- **Direct Type**

- **Side light type**

Point source

**Monitor, TV**

Mobile LCDs, high end TVs
LED Backlight LCD Examples

12.1"
Needle Slim LED NotePC
Slim & Light 1.64mm & 120g

24"
Needle Slim LED Monitor
Slim 3.5mm
Liquid Crystal Displays

LED - Backlight Characteristics

LED backlights degrade mostly by high junction temperature!
RGB LED - Backlight

Prototype of 82” LED backlight, draws 1,000 W for 1120 LEDs

- Colour management for each LED by current & PWM
- Wider colour gamut than white LED
- Too costly and high power consumption
LED – Backlight Power Saving Methods

• Adaptive light output by ambient light sensor (also applicable for CCFL)

• Local dimming (image content)

• Sequential color (no color filter, 1/3 of pixel [TFTs, …], higher aperture, …)

• Power savings up to 90%
Liquid Crystal Displays

LED – Backlight: Adaptive Light Output

Power Savings by Ambient Light Sensor
To detect the amounts of lights available & adjust display brightness accordingly to save power.

Backlight power consumption

Well-Lit Room  On Flight  Presentation Room

100%  20%
Trends for LCD TV

- Local LED backlight dimming & motion blur reduction
  - ~ 50% power saving
  - also larger gamut as CCFL

... see § Video on FPDs
LED Backlight Dimming Examples

Without | with dimming
---|---

Same image quality but 60% less power
LED – Backlight: Adaptive Global Dimming

Grey levels not used

Spread GL

Power Saving strongly depends on image:
dark images – large savings vs. bright image virtual no saving

+ reduce backlight for same luminance

50% power saving!
LED – Backlight: Adaptive Local Dimming

**Traditional Full-On LED**

**Individual LED On/Off & Level Control**

Power Saving 50% avg. (image dependant)

High Contrast

\[ L_{\text{max}} = 630 \text{ cd/m}^2 \]

\[ L_{\text{min}} = 0.03 \text{ cd/m}^2 \]

\[ C_R = \frac{630}{0.03} = 21,000 \]
# LED – Backlight: Adaptive Light Output (I)

When LEDs are dimmed, grey levels of pixels have to be increased.

<table>
<thead>
<tr>
<th>Dimming</th>
<th>No</th>
<th>0D</th>
<th>1D</th>
<th>2D</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power consumption</strong></td>
<td>100 %</td>
<td>80%</td>
<td>70%</td>
<td>50%</td>
</tr>
<tr>
<td><strong>Principle</strong></td>
<td>All LEDs 100 % ON</td>
<td>All LEDs dimmed</td>
<td>LED in lines, # of lines drivs</td>
<td>LED matrix, h x v drivers</td>
</tr>
<tr>
<td><strong>Visualization</strong></td>
<td>(white ≡ yellow)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Contrast ratio ↑**
LED – Backlight: Adaptive Light Output (II)

Dimming of white LEDs vs. color dimming of RGB LEDs

When LEDs are dimmed, grey levels of pixels have to be increased.

<table>
<thead>
<tr>
<th>Dimming</th>
<th>No</th>
<th>2D white</th>
<th>2D color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power consumption</td>
<td>100 %</td>
<td>50%</td>
<td>20%</td>
</tr>
<tr>
<td>Principle</td>
<td>All LEDs 100 % ON</td>
<td>LED matrix, h x v drivers</td>
<td>RGB LED matrix, h x v x 3 drivers</td>
</tr>
<tr>
<td>Visualization (white ≡ yellow)</td>
<td><img src="image" alt="White visualization" /></td>
<td><img src="image" alt="Color visualization" /></td>
<td><img src="image" alt="Color visualization" /></td>
</tr>
</tbody>
</table>
Backlights: CCFL vs. LED (III)
LCD Power Saving by Improved Backlight

Bachelor thesis of Jan Jarosch @ Display Lab 2013

presented at:

11:30-12:00 Energieeinsparung bei LCDs mit LED-Backlights durch adaptierte Dimmung und HMI-Optimierung
Jan Jarosch, Prof. Dr. Karlheinz Blankenbach, Hochschule Pforzheim

The following slides are part of this presentation
**Prinzip des Local Dimmings / “Unsere” Methode**

„Standard-LCD“
- Alle LEDs immer aktiviert
- Meist einseitig angebracht
- Nur Global-Dimming

„Local Edgelight Dimming“
- LEDs meist an einer Seite
- Individuelles Dimming

„Unsere“ Methode
- LEDs an allen Seiten
- Individuelles Dimming

**Energieverbrauch**

16 LEDs an: 100%
8 von 16 LEDs an: 50%
aber entfernte Elemente dunkel

7 von 16 LEDs an: 44%
und helle Elemente

Beispiele vereinfacht
Software - Blockdiagramm

Aktueller Bildinhalt

LED-Lichtverteilung

Berechnung der LEDs, die am meisten zum Bildinhalt beitragen

Graustufen anpassen

Individuelle LED-PWMs

Implementierung in MATLAB

Für alle LEDs gemessen

Inhomogenes Backlight → GS anpassen → Uniformity

“nur LEDs “an”, die zur Bildhelligkeit wesentlich beitragen”
Blockdiagramm des Versuchsaufbaus zur Evaluierung

PC steuert Bildinhalte und Backlight-Dimming

PC

USB

Micro-controller

SPI

LED-Treiber

LED-Backlight (selbst erstellt inkl. Lightguide)

7" LCD*
800 x 480

Display Controller Board*

VGA, DVI

LVDS

*: Mit freundlicher Unterstützung von

DATA MODUL
DISPLAYS AND EMBEDDED SOLUTIONS
Liquid Crystal Displays

Hardware

LED Backlight mit 48 weißen LEDs und Lichtleiter

Ausschnitt Backlight

Display
Display Controller Board

Wärmebild-Aufnahme

LED-Treiber-ICs

USB (PC)

VGA (PC)

µC
## Ergebnisse

Beispiel “Balken unten”

ähnliche Ergebnisse für andere Testbilder

<table>
<thead>
<tr>
<th>Topic</th>
<th>Backlight</th>
<th>Standard-Backlight LED 100%</th>
<th>Intelligent („unsere“ Methode)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>LEDs normal hell</td>
<td>LEDs sehr hell*</td>
</tr>
<tr>
<td>Bildinhalt</td>
<td>W</td>
<td>S</td>
<td>W</td>
</tr>
<tr>
<td>Leuchtdichte (cd/m²)</td>
<td>200</td>
<td>0,45</td>
<td>120</td>
</tr>
<tr>
<td>Kontrastverhältnis</td>
<td>440 : 1</td>
<td>800 : 1</td>
<td>800 : 1</td>
</tr>
<tr>
<td>LED Leistungs-</td>
<td>4,90</td>
<td>1,55</td>
<td>2,58</td>
</tr>
<tr>
<td>aufnahme (W)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*: linear angepasst

\[ \approx 50\% \]
Sequential Colour LCD with RGB LED Backlight

- Fast LC required (6 x 60 Hz = 360 Hz) or scanned backlight (180 Hz)
- No colour filter → high aperture ratio, lower pixel pitch possible
- Loss of luminance → high power LED backlight required

In total power saving because of no color filter loss & high aperture!

- Colour break-up can occur
Motion Blur Basics

- Motion blur is caused by AM techniques due to lack of 'auto-tracking' by human vision (PDP has similar problems)

- Impulsive displays like CRTs don’t suffer of motion blur

Motion blur reduction is the “driver” for high frame rates (≥ 100 Hz) of modern TV sets!

<table>
<thead>
<tr>
<th>Visualisation</th>
<th>Perceived</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>AM</strong></td>
<td>'Display &amp; hold'</td>
</tr>
<tr>
<td><strong>CRT</strong></td>
<td>'Flashing'</td>
</tr>
</tbody>
</table>
Motion Blur Reduction Techniques

- **Commercial (1x0 & 2x0 Hz)**
  - No luminance loss
  - Fits for LCD and PDP
  - Fast & advanced signal processing

- **Frequency Doubling**
  - No luminance loss
  - Fits for LCD and PDP
  - Fast & advanced signal processing

- **Impulsive Drive (like CRT)**
  - Luminance loss
  - Flicker may occur

- **Data**
  - Luminance loss
  - Flicker may occur

- **Backlight**
  - Only for LED LCDs
  - Luminance loss
  - Flicker may occur

- **Professional**
  - Luminance loss
  - Flicker may occur

- **Motion Blur reduction**
  - Like FRC incl. motion compensation & 24p
LED Backlight Driving

... seems to be ‘simple’

**but**

- apply failure reduction methods like clustering LEDs in two or separate chains instead of one (if a single LED fails, the backlight is then dark)

- Thermal management of point like sources is more complex
LED Backlight Driver ICs

2.7V to 5.5V
L = 2.7μH

PWM dimming

INDB
V_{IN}
A1
A2
B1
B2

INDA
V_{OUT}
GND
CH2
CH1
NC

FAN5608DHMPX

4.7μF

V_{OUT}

LED Backlight Driver ICs
LED Backlight Driver ICs

IC needs no coils, I²C input for dimming
LED Backlight Driver ICs

Single string design not recommended, no light if a single LED fails (open).
## LED vs. CCFL: 5.7” AM LCD

<table>
<thead>
<tr>
<th>Artikel</th>
<th>TX14D12VM1CBC(CPC)</th>
<th>TX14D11VM1CBA(CAA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hersteller</td>
<td>Hitachi Europe</td>
<td>Hitachi Europe</td>
</tr>
<tr>
<td>Diagonale</td>
<td>5.7</td>
<td>5.7</td>
</tr>
<tr>
<td>Helligkeit cd/m²</td>
<td>350 (280)</td>
<td>350 (280)</td>
</tr>
<tr>
<td>Auflösung (BxH)</td>
<td>320 x 240</td>
<td>320 x 240</td>
</tr>
<tr>
<td>Farben</td>
<td>262k</td>
<td>262k</td>
</tr>
<tr>
<td>Bel.</td>
<td>LED</td>
<td>CCFL</td>
</tr>
<tr>
<td>Schnittstelle</td>
<td>Digital RGB 6 bit</td>
<td>Digital RGB 6 bit</td>
</tr>
<tr>
<td>Kontrast Verhältnis</td>
<td>350:1</td>
<td>350:1</td>
</tr>
<tr>
<td>Blickwinkel (r/l/o/u)</td>
<td>70/70/80/70</td>
<td>65/65/70/50</td>
</tr>
<tr>
<td>Abmessung (BxHxT) in mm</td>
<td>131.00 x 102.00 x 10.90</td>
<td>167.00 x 109.00 x 9.00</td>
</tr>
<tr>
<td>Sichtbarer Bereich (BxH) in mm</td>
<td>115.20 x 86.40</td>
<td>115.20 x 86.40</td>
</tr>
<tr>
<td>Leistungsaufnahme</td>
<td>1.2W</td>
<td>3.5 W</td>
</tr>
</tbody>
</table>

*Note: The LED and CCFL have different characteristics.*
### CCFL vs. LED: 10.4” AM LCD

<table>
<thead>
<tr>
<th>Artikel</th>
<th>NL6448BC33-70</th>
<th>NL6448BC33-64R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hersteller</td>
<td>NEC</td>
<td>NEC</td>
</tr>
<tr>
<td>Diagonale</td>
<td>10.4</td>
<td>10.4</td>
</tr>
<tr>
<td>Helligkeit cd/m²</td>
<td>450</td>
<td>450</td>
</tr>
<tr>
<td>Auflösung (BxH)</td>
<td>640 x 480</td>
<td>640 x 480</td>
</tr>
<tr>
<td>Farben</td>
<td>262 k</td>
<td>262 k</td>
</tr>
<tr>
<td>Bel.</td>
<td>LED</td>
<td>CCFL</td>
</tr>
<tr>
<td>Schnittstelle</td>
<td>Digital RGB 6 bit</td>
<td>Digital RGB 6 bit</td>
</tr>
<tr>
<td>Kontrast Verhältnis</td>
<td>900:1</td>
<td>600:1</td>
</tr>
<tr>
<td>Blickwinkel (r/l/o/u)</td>
<td>80/80/80/80</td>
<td>80/80/80/60</td>
</tr>
<tr>
<td>Abmessung (BxHxT) in mm</td>
<td>243.00 x 185.10 x 10.50</td>
<td>243.00 x 185.10 x 10.50</td>
</tr>
<tr>
<td>Sichtbarer Bereich (BxH) in mm</td>
<td>211.20 x 158.40</td>
<td>211.20 x 158.40</td>
</tr>
<tr>
<td>Leistungsaufnahme</td>
<td>3.7 W</td>
<td>6.2 W</td>
</tr>
</tbody>
</table>
### CCFL vs. LED: 15” AM LCD

<table>
<thead>
<tr>
<th>Artikel</th>
<th>G150XG01 V2</th>
<th>G150XG01 V1/Touch</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hersteller</td>
<td>AUO</td>
<td>AUO</td>
</tr>
<tr>
<td>Diagonale</td>
<td>15.0</td>
<td>15.0</td>
</tr>
<tr>
<td>Helligkeit cd/m²</td>
<td>350</td>
<td>350</td>
</tr>
<tr>
<td>Auflösung (BxH)</td>
<td>1024 x 768</td>
<td>1024 x 768</td>
</tr>
<tr>
<td>Farben</td>
<td>262 k / 16.2 M</td>
<td>262 k / 16.2 M</td>
</tr>
<tr>
<td>Bel.</td>
<td>LED</td>
<td>CCFL</td>
</tr>
<tr>
<td>Schnittstelle</td>
<td>LVDS 1ch. 6/8 bit</td>
<td>LVDS 1ch. 6/8 bit</td>
</tr>
<tr>
<td>Kontrast Verhältnis</td>
<td>700:1</td>
<td>700:1</td>
</tr>
<tr>
<td>Blickwinkel (r/l/o/u)</td>
<td>80/80/80/60</td>
<td>70/70/65/60</td>
</tr>
<tr>
<td>Abmessung (BxHxT) in mm</td>
<td>326.50 x 253.50 x 12.00</td>
<td>326.50 x 253.50 x 12.00</td>
</tr>
<tr>
<td>Sichtbarer Bereich (BxH) in mm</td>
<td>304.13 x 228.10</td>
<td>304.10 x 228.10</td>
</tr>
<tr>
<td>Leistungsaufnahme</td>
<td>8.8 W</td>
<td>8.9 W</td>
</tr>
</tbody>
</table>
Summary

• Overall efficiency of LCDs is very low (~ 5%)
• Nearly all LCDs are equipped with LED backlights, mostly white LEDs
• Slim design by edge light
• LED backlights offer unique advantages of power saving methods like local dimming
• Driving LEDs is simple compared to old fashioned CCFL
• However there are some pitfalls of LED driving like single string
• Other challenges of LED backlights refer to uniformity and color shifts (see WS, display measurements)
Questions

• What are the main requirements for backlights?
• Which parameters are more relevant for automotive backlights?
• What are benefits of LEDs compared to CCFLs?
Overview

1 Introduction

2 LCD - Basics

3 Direct Drive & Passive Matrix

4 Active Matrix

5 Backlights

6 LCD - Optimization

Viewing angle
White pixel
Response time (overdrive)
Improvement of Viewing Angle (I)

- **TN** (Twisted Nematic)
  - (Vertical Alignment)
  - OFF
  - ON

- **IPS** (In Plane Switching)
  - OFF
  - ON

- **VA** (Vertical Alignment)
  - OFF
  - ON

- (special LC) „Blue Phase“
  - OFF
  - ON

L-Crystal Displays

- LCD TV
- LCD TV
- LCD TV prototypes

Electrode, Polarizer, Glass substrate, Optically Compensating Film
Improvement of Viewing Angle (II)

<table>
<thead>
<tr>
<th></th>
<th>TN</th>
<th>IPS</th>
<th>VA, OCB</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Low driving voltage</td>
<td>Very wide viewing angle</td>
<td>High contrast ratio</td>
</tr>
<tr>
<td></td>
<td>Limited viewing angle</td>
<td>Slow response speed</td>
<td>Wide viewing angle</td>
</tr>
<tr>
<td></td>
<td>Low brightness</td>
<td>Low brightness</td>
<td>Fast response speed</td>
</tr>
</tbody>
</table>

Viewing angle value without minimum $C_R$ or $\Delta E$ is useless!
TN Viewing Angle

**Bright State**
Symmetric brightness

**Medium Grey Level**
Asymmetric brightness

**Dark State**
Light leakage

\[ V < V_{th} \]

\[ V_{op} > V > V_{th} \]

\[ V = V_{op} \]
A pixel is divided into 4 'subpixels' (but with 1 TFT). 4 different alignment directions instead of one enhance the viewing cone significantly.

Improvement of Viewing Angle by 4 - Domain TN 90°
**Improvement of Viewing Angle:** In Plane Switching

E-field is not between front- and back plane as for TN. ITO electrodes are only on back plane for IPS.
Improvement of Viewing Angle: Multi Domain Vertical Alignment

E-field between protrusions
Improvement of Viewing Angle: Multi Domain Vertical Alignment
Further Improvements on (AM) LCDs: Colour Filters

RGBW for higher luminance

6 primaries for larger colour gamut
Further Improvements on (AM) LCD: Dedicated Filters

Automotive Improvements

Reflection reduction

Vikuiti™ Inverted BEF Film (IBEF) splits the backlight distribution towards off axis viewers

AG

AR + BEF

NITTO DENKO
Improvement of LCD Response Time by HW & SW

Same idea (higher set point for short time) as reducing settling time in automation control

Boost grey level is GS dependent and has to be calculated, e.g. in TCON with frame buffer
Overdrive Principle

Definitions

Grey level

Target grey level

Boost grey level

Previous grey level

Rel. L

Ideal response

Boost luminance

Hardware block diagram

Frame Buffer FIFO

Look up table

Previous grey level

Boost grey level

Target grey level
AMLCD Response Time between Grey Levels

Without -

with Overdrive

Grey shade dependent!
Summary & Questions

• What makes LCDs so unique and universal for display applications?

• What are the main issues to solve for LCDs?

• What are today's hot topics when promoting LCDs?

• Issues of LCDs where other display technologies are superior:
  - Ambient light performance: e-paper but no color
    (for low res: reflective LCDs)
  - Response time & viewing angle, depth: OLED but higher cost

→ LCDs are the most universal technology today and is available
  from 8 Segment (< 0.5”) to Quad HD, large size (up to 108”)
  at best price and optimized for special requirements like automotive!