E-Paper & Flexible Displays

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Overview

Introduction

E-Paper Displays & Applications

Flexible Displays & Challenges

Summary

Some pictures etc. are courtesy of the companies named on the picture, others from, e.g., SID, …
Paper Like Displays (PLD) as Electronic Paper System

Merits
- Bi-stable
- Thin & light
- Flexible
- Design free
- Readability
- Low cost
- Ease of use

Paper + Display (System) = E-Paper (System)

Shortcomings
- Re-use
- Data access
- Static content

- Rewritable
- Re-use
- Portable
- Storage
- Data access
- Moving images

- Bi-stable
- High cost
- Rigid & heavy

Shortcomings of e-paper displays?
Electronic Paper

- **Idea**: Replacement of paper (books, price tags, billboards, ...)
- **Advantage**: 'Re-write' within seconds

- **Bi-stable and reflective**
  → Lowest power consumption

- **Small pixel size**
  → High resolution (... 200 dpi)

- **Flexible possible**
  → Requires plastics and organic electronics
Definition of “Advanced Paper”

Softcopy Type

PLD  
(Paper Like Display)

- Near display, but display
- Holds data without power
- Rewritable without printer

Hardcopy Type

RWP  
(Re-Writable Paper)

- Near paper
- No power supply needed
- Rewritable by printer

RECO-View™ Monochrome RWP
E-Paper Display Market Revenue Forecast

Million USD per year

Source: DISPLAYBANK

E-book is a large but not the only market
E-Paper Application Trends

Monochrome

Professional

Color

Low power (color) displays for professional applications can enter mass production.

Source: KB, E-INK, QUALCOMM
Main Optical Issue for E-Paper Displays: Readability

- High Whiteness (close to paper, eye adaptation)
- High reflectivity (reflectance > 40%; newspaper, magazines >80%)
- Black & white Contrast Ratio > 10:1 for readability
- Good color reproduction – the challenge for E-Paper displays
- High resolution (> 150 ppi for personal devices)
- Response time moderate if no video required

All R&D (beside materials and processes) focus on optical performance
Display Technology vs. Ambient Light: Sunlight Outdoor

- Transmissive color AM LCD
- Reflectivity of paper > 80%
- Display is ON!
- Reflective E-INK EP
- E-Paper is closest to paper

Reflective b/w PM LCD

Transflective Color AM LCD

Reflective MUX LCD
Trimode TN LCD by PIXEL QI

• **Trimode** = transmissive + transflective + reflective in one display

• **Benefit**: compromises power consumption and sunlight readability

• Best color in transmissive mode

• Monochrome (incl. grey levels) for reflective mode

<table>
<thead>
<tr>
<th>Item</th>
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<td>Dimensions</td>
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Trimode TN LCD by PIXEL QI vs. E-INK

**E-INK** : monochrome & no video, “no” power
**PIXEL QI** : monochrome (low power) or color (high power), video

---

**Indoor**

**E-INK** without frontlight but readable

**PIXEL QI** excellent & color (video) but high power (transmissive)

---

**Outdoor**

**E-INK** higher white reflectivity

**PIXEL QI** monochrome & low power (reflective)
Trimode TN LCD by PIXEL QI

Contrast Ratio

(measurements performed @ Display Lab)

Transmissive (color)

Reflective (monochrome)

Illuminance (diffuse) /lx
Why Is Color Performance of E-Paper So Poor?

100% white

33% Each color filter absorbs 33% (simple model)

+ Ideal reflector: 100%

33% Eo-layer: 30%

Poor reflectivity & non-saturated color for side-by-side color (CMY stack better)

What is not drawn: color filter and eo-layer is passed twice. This is taken into account via %-values.

Color KINDLE: IPS LCD !!!!
## Reflectivity & Color Performance of E-Paper Technologies

<table>
<thead>
<tr>
<th>Monochrome</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>White Reflectance</strong></td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>100%</td>
<td><img src="image" alt="Diagram" /></td>
</tr>
<tr>
<td>40%</td>
<td><img src="image" alt="Diagram" /></td>
</tr>
</tbody>
</table>

### Reflectivity
- **Monochrome**: 100%
- **Lateral**: 100%
- **Stack**: 100%
- **ADT**: 50%**

### Color Performance
- **White**: 100%
- **Red**: 20% (*: MAGINK, **: ADT)
- **Green**: 100%
- **Blue**: 100%
- **Yellow**: 50%**

*Typical values*
Reflectivity & Color Performance of E-Paper Technologies

• LG EPD @ IMID 2010

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Mono</th>
<th>Color</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflectance</td>
<td>45.0%</td>
<td>26.0%</td>
</tr>
<tr>
<td>Contrast Ratio</td>
<td>15 : 1</td>
<td>10 : 1</td>
</tr>
<tr>
<td>Color Saturation</td>
<td>2.9 % of NTSC</td>
<td></td>
</tr>
</tbody>
</table>

• AEG MIS ChLCD RGB stack

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reflectivity white</td>
<td>17 %</td>
</tr>
<tr>
<td>Contrast Ratio**</td>
<td>5 : 1</td>
</tr>
<tr>
<td>Color Gamut</td>
<td>10% NTSC</td>
</tr>
</tbody>
</table>

(values from spec)

• ADT EW CMY stack

White reflectance (color) : > 50%
Color gamut (but CMY) : 70% NTSC
**Power Consumption vs Display Technology**

(typical values)

<table>
<thead>
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<th>Display Technology</th>
<th>Power Consumption</th>
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</thead>
<tbody>
<tr>
<td>Standard AMLCD</td>
<td>iPad 10h</td>
</tr>
<tr>
<td>AMLCD + FSC + 2DD</td>
<td>LCD savings depend strongly from content and ambient light</td>
</tr>
<tr>
<td>AMOLED 80% black</td>
<td>Black background not good for e-books</td>
</tr>
<tr>
<td>AMOLED 80% white</td>
<td></td>
</tr>
</tbody>
</table>

- E-Paper day
  - Lack of multimedia

- E-Paper night
  - Most e-paper technologies are not transparent

Low power consumption is crucial for many applications!
Overview

- Introduction
- E-Paper Displays & Applications
- Flexible Displays & Challenges
- Summary

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E-Paper Display Fundamentals

Cross section of a typical e-paper display

Front plane

eo-layer

Back plane

Substrate incl. barrier layer
Color filter (option)

Here focus on eo-layer as panels are similar

Matrix drive, x-Si, electronics
Substrate incl. barrier layer, reflector as option

(not to scale)
Reflective Electro - Optic Layer Technology Overview

- Electrophoretic
  - Wet (E-INK)
  - Dry
  - In-plane ep
  - Electro-kinetic

- Reflective LCDs
  - Bistable TN
  - Reflective TN*
  - Smectic
  - Guest Host
  - PDLCD*
  - ChLCD

- Other
  - Electro Chemical
    - Electro-Chromic*
    - Electro Deposition
    - Electrowetting / -fluidic
    - MEMS
    - P-INK

„Not all technologies are listed or presented“

• Many technologies, but only a few in MP, some in lab status
• Reflective TN (e.g. watches) run for years on a small battery

*: low power but not fully bistable
Nomenclature for Electronic-Paper Technologies

**Electrophoresis** is the movement of an electrically charged substance under the influence of an electric field. This movement is due to the Lorentz force.

**Electrochromism** is the phenomenon displayed by some chemical species of reversibly changing color when a burst of charge is applied.

The **electrowetting** effect was originally defined as "the change in solid electrolyte contact angle due to an applied potential difference between the solid and the electrolyte". 

from WIKIPEDIA
## Typical Reflectance Values of Reflective Displays

<table>
<thead>
<tr>
<th>Display</th>
<th>Technology</th>
<th>White State Reflectance of Monochrome Display *</th>
</tr>
</thead>
<tbody>
<tr>
<td>„White paper“</td>
<td></td>
<td>80 %</td>
</tr>
<tr>
<td>„News paper“</td>
<td></td>
<td>55 %</td>
</tr>
<tr>
<td>Reflective TN 90°</td>
<td></td>
<td>25 %</td>
</tr>
<tr>
<td>White Taylor guest host</td>
<td></td>
<td>50 %</td>
</tr>
<tr>
<td>PDLC with polarizer</td>
<td></td>
<td>30 %</td>
</tr>
<tr>
<td>Ch LCD</td>
<td></td>
<td>40 %</td>
</tr>
<tr>
<td>E INK</td>
<td></td>
<td>40 %</td>
</tr>
<tr>
<td>Electrowetting</td>
<td></td>
<td>60 %</td>
</tr>
<tr>
<td>MEMS</td>
<td></td>
<td>45 %</td>
</tr>
<tr>
<td>Electrochromic</td>
<td></td>
<td>30 %</td>
</tr>
<tr>
<td>In-plane electrophoretic</td>
<td></td>
<td>70 %</td>
</tr>
</tbody>
</table>

*: Typical values from various sources

**Reflectance:** Higher means better
E-Paper Display Technologies Forecast

<table>
<thead>
<tr>
<th>Year</th>
<th>Sum</th>
<th>Electrochromic</th>
<th>EL</th>
<th>Bi-stable LCD</th>
<th>Other</th>
<th>OLED</th>
<th>Normal LCD</th>
<th>Electrophoretic</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>$85</td>
<td>$1</td>
<td>$27</td>
<td>$1</td>
<td>$6</td>
<td>$0</td>
<td>$0</td>
<td>$50</td>
</tr>
<tr>
<td>2009</td>
<td>$238</td>
<td>$4</td>
<td>$42</td>
<td>$2</td>
<td>$15</td>
<td>$0</td>
<td>$0</td>
<td>$173</td>
</tr>
<tr>
<td>2010</td>
<td>$593</td>
<td>$12</td>
<td>$57</td>
<td>$5</td>
<td>$30</td>
<td>$1</td>
<td>$4</td>
<td>$485</td>
</tr>
<tr>
<td>2011</td>
<td>$1,511</td>
<td>$24</td>
<td>$71</td>
<td>$12</td>
<td>$54</td>
<td>$6</td>
<td>$4</td>
<td>$1,312</td>
</tr>
<tr>
<td>2012</td>
<td>$2,652</td>
<td>$44</td>
<td>$83</td>
<td>$28</td>
<td>$93</td>
<td>$18</td>
<td>$32</td>
<td>$2,277</td>
</tr>
<tr>
<td>2013</td>
<td>$3,789</td>
<td>$70</td>
<td>$88</td>
<td>$59</td>
<td>$125</td>
<td>$55</td>
<td>$110</td>
<td>$3,170</td>
</tr>
<tr>
<td>2014</td>
<td>$4,871</td>
<td>$83</td>
<td>$88</td>
<td>$90</td>
<td>$146</td>
<td>$97</td>
<td>$222</td>
<td>$4,001</td>
</tr>
<tr>
<td>2015</td>
<td>$5,802</td>
<td>$85</td>
<td>$86</td>
<td>$110</td>
<td>$157</td>
<td>$109</td>
<td>$367</td>
<td>$4,697</td>
</tr>
<tr>
<td>2016</td>
<td>$6,562</td>
<td>$83</td>
<td>$84</td>
<td>$123</td>
<td>$156</td>
<td>$132</td>
<td>$558</td>
<td>$5,221</td>
</tr>
<tr>
<td>2017</td>
<td>$7,392</td>
<td>$78</td>
<td>$83</td>
<td>$135</td>
<td>$154</td>
<td>$159</td>
<td>$764</td>
<td>$5,809</td>
</tr>
<tr>
<td>2018</td>
<td>$8,188</td>
<td>$73</td>
<td>$81</td>
<td>$144</td>
<td>$153</td>
<td>$176</td>
<td>$973</td>
<td>$6,415</td>
</tr>
</tbody>
</table>

Source: DisplaySearch 2009
Electrophoretic Wet-Type: E Ink

- **Principle:** Microcapsules with black and white, opposite charged particles
- **Color by RGB(W) filter, new:** “red” as third microcapsules

- **Light State:**
  - Electrode

- **Dark State:**
  - Electrode

- Most advanced technology, in mass production
- Leader in e-book readers
- Customized displays like 8-Segments are pushed
- E Ink’s e-o layer is used by many panel makers
Selected Examples: **E INK SURF**

Power consumption:
0.5 µA while switching
@ 5 – 15 V (only display)

Reflectance ~ 40+%  

-E Ink Displays can be manufactured in any 2D Shape:

<table>
<thead>
<tr>
<th>Number of Digits/Alpha</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outline L x W x H</td>
<td>26.30mm L x 8.50mm W x 0.58mm H</td>
</tr>
<tr>
<td>Viewing Area</td>
<td>10.30mm L x 3.00mm W</td>
</tr>
<tr>
<td>Backlight</td>
<td>Without Backlight</td>
</tr>
</tbody>
</table>

Price Break | Unit Price |
---|---|
1 | 3.75000 |
10 | 3.12500 |
25 | 2.62520 |
100 | 2.25000 |
250 | 2.00000 |
500 | 1.81250 |
1,000 | 1.66250 |
2,500 | 1.56250 |

R&D temperature range: -20°C … +70 °C

Private communication: If „more“ approach E-INK

Source: E Ink

Not backlight-able
E - Paper by E-INK

Positive & negative mode via software

E-INK (left) vs. LCD (right)

E-INK SPECTRA

3 advantages:
- GUI change by software
- Higher reflectance than reflective LCD
- Vivid red

Source: E-INK
E-INK Technology

RGB + White (RGBW) square subpixel:
The white subpixel enhances the brightness and dynamic range with minimal impact on color saturation.
Examples of E INK Displays in Mass Production ≤ 2013

Sources = names

… most take only use of plastic substrate (unbreakable) !
Reflective LCDs

- **Principle**: TN LC transmission is modulated by voltage
- **Area color feasible, full color hardly to achieve due to low CF transmission**

**Features:**
- In mass production since decades
- Low reflectance: ~ 20 % (monochrome)
- Flexible easy to achieve due to MUX or PM
- Segment 8 to QVGA graphics displays
- Low voltage (~ 3 V)
- Low viewing angle performance

Source: KB
Reflective LCD Display Prototype

- High definition reflective color display
- Full color
- High color gamut
- Displays moving pictures
- No backlight

\[ P_{\text{Display Module}} \approx 50 \text{ mW} \]

Technology also very interesting for smart gear!

Black surrounding tricks vision on white reflectance

Source: KB, JDI
SHARP MEMORY LCDs

- Polymer Network Liquid Crystal
- Polarizer free → high reflectance

**Table by SHARP**

<table>
<thead>
<tr>
<th>Display Mode</th>
<th>New RLCD</th>
<th>Conventional RLCD</th>
<th>Electrophoretic</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Table by SHARP</strong></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of Pixels</strong></td>
<td>96 × 96</td>
<td>96 × 3 × 96</td>
<td>96 × 96</td>
</tr>
<tr>
<td><strong>Integrated Reflectance</strong></td>
<td>50%</td>
<td>20%</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Chromaticity (x, y)</strong></td>
<td>(0.310, 0.333)</td>
<td>(0.310, 0.335)</td>
<td>(0.308, 0.341)</td>
</tr>
<tr>
<td><strong>Contrast Ratio</strong></td>
<td>10:1</td>
<td>5:1</td>
<td>15:1</td>
</tr>
<tr>
<td><strong>Drive Voltage</strong></td>
<td>5 V</td>
<td>5 V</td>
<td>&lt; 5 V</td>
</tr>
<tr>
<td><strong>Power Consumption</strong></td>
<td>10 μW @ 1 Hz</td>
<td>25 μW @ 1 Hz</td>
<td>2 mW</td>
</tr>
<tr>
<td><strong>Operating Temperature</strong></td>
<td>-20°C to +70°C</td>
<td>-20°C to +70°C</td>
<td>-20°C to +70°C</td>
</tr>
<tr>
<td><strong>Storage Temperature</strong></td>
<td>-30°C to +80°C</td>
<td>-30°C to +80°C</td>
<td>-30°C to +80°C</td>
</tr>
<tr>
<td><strong>Response Time</strong></td>
<td>100 ms</td>
<td>100 ms</td>
<td>50 ms</td>
</tr>
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**SHARP MEMORY LCDs**

- 22:1 Contrast
- 15% Reflective

**LS012B4DG01**

**SHARP MEMORY LCDs**

- 22:1 Contrast
- 15% Reflective

www.sharpsma.com
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Indoor

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- **PIXEL QI** excellent & color (video) but high power (transmissive)

Outdoor

- **E-INK** higher white reflectivity
- **PIXEL QI** monochrome & low power (reflective)
Cholesteric LCDs (ChLCD)

- **Principle**: Special liquid crystal, no polarizer, Passive Matrix, CMY stack
- **Color by dedicated LC reflection**

![Diagram of reflective and transmissive modes of ChLCD](image)

- Reflective Mode (Bright State)
- Transmissive Mode (Dark State)

- BMGMIS, MAGINK
- KENT
- FUJITSU
Other Reflective & Bistable LCD Technologies

<table>
<thead>
<tr>
<th>Bistable Nematic</th>
<th>Zenithal Bistable</th>
<th>Smectic A</th>
</tr>
</thead>
<tbody>
<tr>
<td>BiNem by NEMOPTIC</td>
<td>ZBD</td>
<td>PolyDisplay, Kent, …</td>
</tr>
</tbody>
</table>

MP started in 2009 but quitted some years later.

Millions of electronic shelf labels sold.

No MP.
Electrochromic Displays

- **Principle:** Color changes by charging
- **Color by liquids incl. stacking (RICOH)**

**Features:**
- Reversible color change depending on charging state
- Direct, PM and AM
- Low voltage (~ 1.2 V)
- Slow update (seconds)

Sources = names
Membrane PLDs: Interferometric Modulator (IMOD)

- **Principle**: Electro-mechanical modulation of optical cavity
- **Color** by optical interference of reflected light

- **High reflectivity** as no color filters or polarizers are needed
Electrowetting Displays: Selected Prototypes, No MP

- **LIQUAVISTA**
  (PHILIPS → LIQUAVISTA → SAMSUNG → AMAZON)
  6.2” SVGA AM

- **ADT**
  Bistable
  Indicator
  7”

- **GAMMA DYNAMICS**

  ~100 DPI prototype, ~10,000 pixels

(Sources: Companies, KB)
Electrowetting PLDs: LIQUAVISTA

EW by area

Not bi-stable

‘Analogue’

Voltage response

Reflectivity at 550 nm (%)

Contrast at 550 nm

Voltage (V)

0 5 10 15 20 25

0 4 8 12 16

Pixel: 500 x 500 μm²
Wall height: 50 μm
Black walls
15 μm magenta oil
0.8 μm fluoropolymer

• Demonstrators up to VGA

SID 2009
Electrowetting Display: Droplet Moving (ADT)

- Principle: Droplet moving
- Color by fluids, CMY stack

- True ‘No Power’ display
- Passive Matrix driven (low cost)
- Pixel size 0.5 … 10mm
- High reflectivity, backlight-able
**Electrokinetic by HP: R&D**

**Figure 2: Zero-energy e-Skin: electrokinetic panels (made by HP) powered by photovoltaic cells**

**Figure 2. Schematic of HP’s Proprietary Electronic Ink.**

3(a). Colored State  
3(b) Transparent State
## Comparison of Major Bistable E-Paper Technologies

<table>
<thead>
<tr>
<th>(typical data)</th>
<th>E-INK</th>
<th>SIPIX</th>
<th>QR-LPD</th>
<th>EC</th>
<th>EW</th>
<th>xLCD</th>
<th>MEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>B/W reflectivity*</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Backlight-able</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>++</td>
<td>- … 0</td>
<td>-</td>
</tr>
<tr>
<td>Contrast ratio</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>++</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Color</td>
<td>0</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Response time</td>
<td>0</td>
<td>0</td>
<td>++</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Pixel scale-ability</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Drive</td>
<td>AM</td>
<td>AM</td>
<td>PM</td>
<td>AM</td>
<td>PM</td>
<td>PM</td>
<td>AM</td>
</tr>
</tbody>
</table>

Too many technologies (~ 12) with different merits and issues

*: Data by Heikenfeld, NATURE PHOTONICS, VOL 3, MAY 2009 / other sources: Pala, DENSO, V&V
Summary “E-Paper”

- Most of reflective displays are mono-chrome and low res.
- Optical performance of some reflective techniques better than reflective LCDs
- Many reflective and bistable display technologies exist.
- Some are already in MP, others in prototype phase.

- Reflective displays bottom line:
  - Sunlight readable
  - Low power
  - **Flexible**
  - E INK competitive to reflective LCDs
E-Paper Applications Overview for Replacing Paper

High content & function

Small size

Smart phone
Watch
Smart cards
Price tags
Status control

Low content & function

Large size

E-book
Laptop?
Billboards
Signs

Low cost

High cost

Paper & Flexible Displays
Indicators: ADTs ‘No Power’ Electrowetting

Saving green house gases by replacing LEDs by no power indicators!

Today:
LED indicators draw ~ 50mW each, resulting in MW in Europe.
EU: Stand-by ≤ 0.5 W
⇒ 1 LED ≡ 10%

Tomorrow: ADT LED replacement
2s of power, lasts for ‘years’

Other applications
Household ‘true white’ display

Design:
White display even with no power

Wireless switch
Meters … Watches basing on E-INK’s EO-Layer

The latest designs from Phosphor Watches use displays based on E Ink technology

Lowest power & reflectivity enables new designs and functionality

Feasible but yet limited acceptance

Sources = names
Smart Cards

Main requirements:

- Durability
- Bendable
- No power
  (change only when in reader or limited power to change for RFID)

Smart cards like money card or with various applications would be pushed if having a display!

Sources = names
Electronic shelf labels

Main requirements:

- No or lowest power
- Good readability
- Low cost
- Control system enabling integration into business process

- Replace paper tags
- Business case for wireless price updates

Sources = names

Source: Bridgestone
Source: Pricer - Sipix
Source: NCR
Source: ZBD Displays

Paul Drzaic – Display Applications Conference 2007
PDAs & Smart Phones

Main requirements:

• Foldable or rollable
• Good readability also for color

Slim line mobile device with large screen but potentially low acceptance without color

POLYMER VISION
READDIUS with E-INK

Sources = names
**E-Book Readers Overview (not all listed)**

- Jinke Electronics: Hanlin eBooks versions V8, V2, V3,
- Sony Portable Reader PRS-500, Libre EBR_1000, PRS-505
- IRex Technologies: iLiad ER-0100
- Hon Hai Precision Industries: Amazon Kindle
- ERead: STAreBOOK STK101, Bookeen
- Frontech-Fujitsu: FLEPia A4, FLEPia A5
- Booken: cybook
- Polymer Vision: Readius
- IRiver: Iriver e-Book
- NeoLux of South Korea: NUTT
- Ricavision: Home E-Reader
- Apple: iBook
- ... 

Not all are sold in Europe

- Larger size for newspapers (easies ‘distribution’)
- E-books compete with netbooks and smart phones
- Advantage is sunlight readability and battery life
- Is this ‘enough’ to buy an additional device? (because of limited multimedia performance)

Color prototype(s)
Signs

Main requirements:

- Large(r) size
- Sunlight readability
- System integration incl. wireless data transmission and solar powered

Many advantages but potentially limited acceptance without color for some applications

Sources = names
Billboards

Main requirements:

• Large size (10 m²)

• Sunlight readability

• Mullion-free

• Excellent color reproduction

• Wide viewing angle

Large market with only LED-walls as competitor

ChLCD RGB stacks, tiled:

AEGMIS

MAGINK
## Applications for Major Bistable E-Paper Technologies

<table>
<thead>
<tr>
<th>(typical data)</th>
<th>E-INK</th>
<th>SIPIX</th>
<th>QR-LPD</th>
<th>EC</th>
<th>ADT</th>
<th>xLCD</th>
<th>MEMS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Indicators</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>+</td>
<td>+</td>
<td>-</td>
<td>-</td>
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<tr>
<td>Watches</td>
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<td>0</td>
<td>0</td>
<td>0</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Smart Cards</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Shelf Labels</td>
<td>+</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>+</td>
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<tr>
<td>Mobile multimedia</td>
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<td>0</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>+</td>
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<tr>
<td>E-Books</td>
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<td>+</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>-</td>
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<td>Newspaper</td>
<td>0…+</td>
<td>0</td>
<td>+</td>
<td>-</td>
<td>0</td>
<td>+</td>
<td>-</td>
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<tr>
<td>Signs</td>
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<td>+</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
<tr>
<td>Billboard</td>
<td>0</td>
<td>-</td>
<td>0</td>
<td>-</td>
<td>+</td>
<td>+</td>
<td>-</td>
</tr>
</tbody>
</table>

Electrophoretic is suitable for many applications but other technologies outperform EP in some markets like signs!
Overview

- Introduction
- E-Paper Displays & Applications
- Flexible Displays & Challenges
- Summary

Some pictures etc. are courtesy of the companies named on the picture, others from, e.g., SID, …
Videos Of Flexible Displays
### What Does ‘Flexible’ Mean?

<table>
<thead>
<tr>
<th>Plastic substrate</th>
<th>Conformal (bent once)</th>
<th>Bendable*</th>
<th>Rollable*</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1" alt="Plastic substrate" /></td>
<td><img src="image2" alt="Conformal" /></td>
<td><img src="image3" alt="Bendable" /></td>
<td><img src="image4" alt="Rollable" /></td>
</tr>
<tr>
<td>• Conformable: Bent once in a large radius in production</td>
<td>• Bendable: Can be bent in a large radius by the user</td>
<td>• Rollable: Can be rolled up in a 5-25 mm radius</td>
<td>• Foldable: Can be folded in a radius of &lt; 1 mm</td>
</tr>
</tbody>
</table>

* many times
**Why Flexible Displays?**

1. More robust (30% of smart phone returns show broken display)
2. Thin and light weight as plastic or thin glass is used as substrate
3. Enables new form factors and products
4. Might be cheaper to manufacture (roll-to-roll vs. batch)

---

**SAMSUNG**

- Display Mode: TN Mode (Transmissive)
- Resolution: 480 x RGB x 272 (WqVGA)
- Panel Thickness: ~0.15 mm (w/o Pol.)
- Panel Weight: 1.65 g (w/o Pol.)
- Bending Radius: ~10 cm

---

**NOKIA**

---

Blankenbach / Pforzheim Univ. / www.displaylabor.de / E-Paper / Jan. 2015
Flexible Electronic Systems

- Printed Electronics Device (Antenna, Circuit)
- Flexible Display
- Portable Power (Flexible, thin embedded application)
- Flexible Sensor (UI, Human-scale application)

Source: ITRI
Reflections on Flat and Curved Displays

- **Diffuse ceiling**
- **Neon lights**
- **Spot lights**

... capture light from “everywhere!”

“Diffuse” illuminance from ceiling or sky is best for reflective displays

Single lamp with multiple specular reflections
What are the Requirements for ‘Flexible’?

- Substrates have to be thin and light weight

- Display material must be able to work under strain

- Most display technologies need an Active Matrix, but Passive Matrix makes the transition from glass to polymeric substrates much simpler

- Core issues that typically come up:
  - Lifetime
  - Keeping the two substrates together
  - Fabrication
  - Flexible interconnects

- What about the electronics system?

- What are the new applications, customers …?
Overview Of Technologies for Flexible Displays

Reflective
- Wet (E-INK)
- In-plane ep
- Electro-kinetic

Emissive
- Transmissive LCD
- LED (see § applications)

Electrophoretic
- Reflective TN*
- ChLCD
- PDLCD*

Other
- Electro xxx (EC, EL)
- P-INK

*: low power but not all variations are fully bistable

- Not all technologies are listed here like curved projection screens.
- Technologies, where major companies are out of business, are not listed.
Electrophoretic Wet - Type: E-INK

- **Principle**: Microcapsules with black and white, opposite charged particles
- **Color** by RGB(W) filter, new: “red” as third microcapsules

B/W  Monochrome  3 Color  “Full Color”

Bendable

Source: E-INK, Plastic Logic
Cholesteric LCDs (ChLCD)

- **Principle**: Special liquid crystal, no polarizer
- **Color**: by dedicated LC reflection

- **Reflective RGB stack without color filters etc.**
- **Passive Matrix driving (low cost) but slow update time**

The Longest R2R Bistable Display

*Source: ITRI*

*Chinese Landscape Painting, 24 cm × 300 cm, 300 dpi*

"Pure and Remote View of Streams and Mountains. 溪山清远图."

Xia Gui, National Palace Museum
Other Flexible Display Approaches

- **Polymer Dispersed LCDs**
  Principle: Standard liquid crystal in droplets, no polarizer, not bistable

- **Electrochromic Displays**
  Principle: Color changes by charging

- **Electroluminescent Displays**
  Flexible sheets used for displays, license plate, knobs, ...
  Solid state display: ruggedized for in harsh environment (ICE 1)
  Large area labels by SCHREINER GROUP

Sources = names
Other Flexible Display Approaches

- **Electrokinetic (HP)**

  Principle: Particles with charge move in plane,
  many small reservoirs within visible area

- **In-Plane Electrophoretic (CANON, PHILIPS)**

  Principle: Particles with charge move in plane,
  reservoir at edges

- **Photonic Ink (P-ink) (OPTALUX)**

  Principle: Swelling and contacting of a
  polymer by voltage

Sources = names
Organic Light Emitting Diode (OLED)

- Principle: Light emission by current like LED but organic materials
- In mass production since some years
- Challenge for lifetime is moisture etc.
- Passive Matrix easier to achieve for flexible (see picture →)
- Flexible displays in MP
- Transparent OLED demonstrated

![SAMSUNG](image1)
![LG](image2)
![Rollable demo SONY](image3)
Transmissive LCDs

Standard MP AM LCDs can be curved, if
- Thin glass and
- Flex foil with silicon driver ICs
are used.

However, the backlight has to be adapted ⇒

Advantages of transmissive AM LCDs are:
- Easier to manufacture in terms of TFTs as AM OLEDs
- Less requirements on barrier layers for plastic substrates than OLEDs

Challenges are backlight, viewing angle, cell gap, …
Entertainment

Examples of curved LCDs

High volume or small scale customized production?
Smart Watches / Wearables / Smart Gear

Curved make sense in terms of ergonomics!

OLED by LG, UDC

Curved is in favor for watches and smart gear
Clock with Curved Display

„Curved as curved can“

Is there a real benefit for the user by the curved display?

Source: SIPIX
Smartphones: Samsung Round & LG Flex

Large radius but different orientation of curvature:
Application head vs. pocket?

Horizontal, $R = 40$ cm
Vertical, $R = 70$ cm

Many reflections from light sources

Sources = names

SAMSUNG Curved AMOLED
Foldable & Rollable Smart Phones

Especially “foldable” with larger benefits for users
(small device but large screen for browsing)

But: Color is a must!

POLYMER VISION (E-INK) quitted

SAMSUNG YOUM visions: rollable
foldable

Sources = names
Mobile Applications: Smartphone, E-Reader, Tablet, …

Main demands:

• Multimedia or e-reader
• Unbreakable, light weight
• Foldable,rollable!
• Benefit for notebook?

Benefit of curved display? Touch slider?

Samsung YOUM 2013 w. OLED
**Curved TVs**

First curved OLED TV @ CES 2013.

**Benefits:** Life-like viewing experience for panorama landscapes (feeling surrounded).

MP of curved OLED- and LCD-TVs started in 2013.

---

**SAMSUNG**

Radius ~ 500 cm

---

**LG**

World’s First LG Curved OLED TV

---

Real benefits? OLED TVs were announced for hanging on the wall.

Sources = names
Curved TV Benefits

Wider Field of View → Immersive Experience

Increased Field of View

- Central Vision 30°
- Ideal Home Theater 36°
- Typical Theater 45°-54°
- Wide View Theater 70°

Curved Design Causes Less Distortion

"Eyes are round, not flat"

Curved Design Improves CR on Edges

Edge C/R by Curvature

<table>
<thead>
<tr>
<th>Against Center</th>
<th>Flat®</th>
<th>6000R</th>
<th>4000R</th>
<th>3000R</th>
<th>2000R</th>
</tr>
</thead>
<tbody>
<tr>
<td>Angle</td>
<td>66.3°</td>
<td>68.6°</td>
<td>69.8°</td>
<td>70.9°</td>
<td>73.3°</td>
</tr>
<tr>
<td>C/R</td>
<td>52%</td>
<td>71%</td>
<td>82%</td>
<td>91%</td>
<td>99%</td>
</tr>
<tr>
<td>Color Volume</td>
<td>90%</td>
<td>95%</td>
<td>97%</td>
<td>99%</td>
<td>100%</td>
</tr>
</tbody>
</table>
What is that? (captured @ Display Lab)

Reflections of a small 1 W LED on concave curved TV screen

Display: 55", focal length = 2.25 m (measured), radius = 4.5 m (R = 2f; manufacturer: 4.2 m)
LED: 1 Watt, 30°, 3,200 K, Geometry: small light source distance ~ 4.5 m, observer distance ~ 3 m
Automotive Applications

Main requirements:

• Size > 5”
• Wide viewing angle
• Seamless integration
• Automotive environment

• Design visions become reality
• Niche market compared to CE

DAIMLER

JDI: Curved (R = 50 cm) 8” WVGA
Large Area Flexible Display Applications

Signs, e-signage, rooms, ...

• Signs is large market but is there a need for flexible?
• E-signage favors color / video

ChLCD by ITRI
**Special Case: Semiconductor LEDs**

Basically not flexible but can be attached to flexible substrates due to small size of individual LED.

**Advantages: MP LEDs + easy to customize**

LED video walls
Curved provided by many companies.

---

Source: V&V, KB
# Comparison of Flexible Display Technologies

<table>
<thead>
<tr>
<th>Type</th>
<th>LCD</th>
<th>E-Paper</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Reflective</td>
<td>Transmissive</td>
<td>Reflective</td>
</tr>
<tr>
<td>Flexibility</td>
<td>+</td>
<td>+</td>
<td>+ ... ++</td>
</tr>
<tr>
<td>Image Quality</td>
<td>Indoor</td>
<td>++</td>
<td>0 ... +</td>
</tr>
<tr>
<td></td>
<td>Outdoor</td>
<td>++</td>
<td>0</td>
</tr>
<tr>
<td>Power consumption</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>Multimedia</td>
<td>–</td>
<td>++</td>
<td>–</td>
</tr>
<tr>
<td>Issues</td>
<td>Mono-</td>
<td>Cell gap,</td>
<td>Mono-</td>
</tr>
<tr>
<td></td>
<td>chrome,</td>
<td>TFTs (less</td>
<td>chrome,</td>
</tr>
<tr>
<td></td>
<td>cell gap</td>
<td>critical than</td>
<td>frontlight</td>
</tr>
<tr>
<td></td>
<td></td>
<td>OLED)</td>
<td></td>
</tr>
</tbody>
</table>

Overall comparison difficult because of very different application requirements.
Flexible Displays – Merits vs. Shortcomings

• Advantages
  + Thin, light weight
  + Rugged, non-breakable, especially impact stress
  + Flexible: new freedom of design
  + Potentially much lower cost (R2R process)

• Shortcomings
  – Initially more expensive
  – Initially inferior optical performance
  – Reduced lifetime compared to glass based displays
  – Thin substrates must be mechanically protected and supported

Benefits may overweight drawbacks in future!
Challenges for Flexible Displays (Short Overview)

**Bending Radius**
- Smaller is more challenging
- Bend once easier than often (1,000+ x)

**Flexible Substrate**
- Low temperature processes (TFTs !)
- OLED lifetime (barrier layer)
- Thin Glass can break, only 1D bending

**TFT AM more challenging than PM**

**Ambient Light**
... capture light from “everywhere!”

Single lamp with multiple specular reflections

PLASTIC LOGIC
Trends: Transparent & Flexible Displays

Goal: High transparency

Goal: Plastic substrate, low bending radius
## Market Drivers Of Flexible Displays

<table>
<thead>
<tr>
<th>Why hot?</th>
<th>Smartphone, Tablet</th>
<th>Notebook Monitor, TV</th>
<th>Other apps (wearables, smart gear, automotive, e-signage, …)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Why not?</strong></td>
<td>Price for foldable &amp; rollable</td>
<td>Maybe no need, high cost</td>
<td>Markets can be too small</td>
</tr>
</tbody>
</table>

**Why hot?**

- Thin, light weight, unbreakable.
- Vision: foldable, rollable

**Why not?**

- Price for foldable & rollable
- Maybe no need, high cost
- Markets can be too small
## Summary of Flexible Substrates Technologies

<table>
<thead>
<tr>
<th></th>
<th>Metal Foil</th>
<th>Thin Glass</th>
<th>Plastics</th>
<th>Fabric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Unbreakable</td>
<td>+</td>
<td>–</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Weight</td>
<td>–</td>
<td>0</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Surface smoothness</td>
<td>–</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>(needed for display layers)</td>
<td>(planarization)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Thermal stability</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Dimensional stability</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Chemical durability</td>
<td>0</td>
<td>+</td>
<td>–</td>
<td>0</td>
</tr>
<tr>
<td>Transmission</td>
<td>–</td>
<td>+</td>
<td>0</td>
<td>–</td>
</tr>
<tr>
<td>Barrier layer (OLED)</td>
<td>+</td>
<td>+</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>Other topics</td>
<td>Charge coupling</td>
<td></td>
<td>TCE of plastic ≠ TFT</td>
<td>θ OTFT</td>
</tr>
</tbody>
</table>

There are more characteristics to compare.
Flexible Displays – Merits vs. Shortcomings

• Advantages

+ Thin, light weight
+ Rugged, non-breakable, especially impact stress
+ Flexible: new freedom of design
+ Potentially much lower cost (R2R process)

• Shortcomings

– Initially more expensive
– Initially inferior optical performance
– Reduced lifetime compared to glass based displays
– Thin substrates must be mechanically protected and supported

Benefits may overweight drawbacks in future!
Overview

Introduction

E-Paper Displays & Applications

Flexible Displays & Challenges

Summary

Some pictures etc. are courtesy of the companies named on the picture, others from, e.g., SID, ...
E-Paper is Green: Saving Materials & Preserving Nature

wireless 'delivery'

Go green
Green: Saving Space and Energy with New Displays

From 100 W via 10 W to nearly zero power!
# E-Paper Panel Strategies

<table>
<thead>
<tr>
<th>Electro-optic Layer</th>
<th>Today</th>
<th>Current Target</th>
<th>Future Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>B/W</td>
<td></td>
<td>Color (reflectivity)</td>
<td>Moving Picture (response time)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Back Plane</th>
<th>Today</th>
<th>Current Target</th>
<th>Future Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>a-Si, p-Si</td>
<td>Printed O-TFT (manufacturability)</td>
<td>All printed back plane incl. drivers</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Panel</th>
<th>Today</th>
<th>Current Target</th>
<th>Future Target</th>
</tr>
</thead>
<tbody>
<tr>
<td>rigid</td>
<td>Flexible R2R (manufacturability)</td>
<td>(current target will need long time)</td>
<td></td>
</tr>
</tbody>
</table>
### Basic Comparison of Professional Display Technologies

<table>
<thead>
<tr>
<th></th>
<th>LCD</th>
<th>E-Paper</th>
<th>OLED</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Type</strong></td>
<td>Reflective</td>
<td>Transmissive</td>
<td>Reflective</td>
</tr>
<tr>
<td><strong>Size (mass production)</strong></td>
<td>1” … 5”</td>
<td>2” … &gt;100”</td>
<td>1” … 10”</td>
</tr>
<tr>
<td><strong>Image Quality</strong></td>
<td>Indoor</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Indoor</strong></td>
<td>0</td>
<td>++</td>
<td>0 … +</td>
</tr>
<tr>
<td><strong>Outdoor</strong></td>
<td>++</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td><strong>Power consumption</strong></td>
<td>+ … ++</td>
<td>0</td>
<td>++</td>
</tr>
<tr>
<td><strong>Multimedia</strong></td>
<td>-</td>
<td>++</td>
<td>-</td>
</tr>
<tr>
<td><strong>Flexible</strong></td>
<td>0</td>
<td>0 … +</td>
<td>++</td>
</tr>
<tr>
<td><strong>Relative cost</strong></td>
<td>Low</td>
<td>Moderate</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>Main issue</strong></td>
<td>Reflectance</td>
<td>Outdoor</td>
<td>Mono-chrome</td>
</tr>
</tbody>
</table>

Overall comparison difficult because of very different application requirements.
Summary

E-paper has the potential to revolutionise mobile computing

(Too ?) Many technologies for e-paper today

There are many applications beside e-readers for e-paper displays

To do: color reproduction, switching speed and flexible (AM) substrates

Flexible displays enable new products and roll-to-roll manufacturing

What is your idea for a striking e-paper application?
Summary

Flexible displays enable new products or enhance features of existing ones.

To do or optimize for flexible:
- Substrates
- Materials
- Manufacturing

User benefit decides on market success. However flexible display technologies may be profitable in niche markets.
Case Study / Questions to think about

• Reasons why E-paper will revolutionise mobile computing

• Arguments why this would not happened for many applications

• How can we select (invest) today in the most promising candidates

• Flexibility will give (bi-stable) displays break-through applications

• Flexible technology enables roll-to-roll manufacturing – but what is about cost and benefit for high resolution displays?

• Compare today’s notebooks vs. (future) e-readers

• E-Paper applications for the industry
Case Study: E-Reader

Kindle eReader, Wi-Fi, 15 cm (6 Zoll) E Ink Display, deutsches Menü
von Amazon

⭐⭐⭐⭐⭐ (984 Kundenrezensionen) | Gefällt mir (1,370)

EUR 99,00 Kostenlose Lieferung. Details

Like paper but comfort for mobile reading?

- Compare price to laptops!
- Business model similar to mobile phones?
Case Study: E-Reader

<table>
<thead>
<tr>
<th>Weitere Ausgaben</th>
<th>Amazon-Preis</th>
<th>Neu ab</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kindle Edition</td>
<td>EUR 12,99</td>
<td>--</td>
</tr>
<tr>
<td>Taschenbuch</td>
<td>EUR 14,90</td>
<td>EUR 12,00</td>
</tr>
</tbody>
</table>

German laws vs. US

Print List Price: $26.95
Kindle Price: $9.99
You Save: $16.96 (63%)
(includes FREE wireless delivery)
## Case Study: E-Reader

<table>
<thead>
<tr>
<th>Display</th>
<th>15 cm (6 Zoll) E Ink-Display, optimiert mit geschützter Waveform- und Font-Technologie, Auflösung von 600 x 800 Pixel bei 167 dpi, 16 Graustufen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Abmessungen (in cm)</td>
<td>166 mm x 114 mm x 8,7 mm</td>
</tr>
<tr>
<td>Gewicht</td>
<td>170 Gramm</td>
</tr>
<tr>
<td>Systemanforderungen</td>
<td>Keine, der eReader funktioniert drahtlos und benötigt keinen Computer</td>
</tr>
<tr>
<td>Gerätespeicher</td>
<td>2 GB intern (ca. 1,25 GB stehen für Nutzerinhalte zur Verfügung)</td>
</tr>
<tr>
<td>Cloud-Speicher</td>
<td>Unbegrenzt für Amazon-Inhalte</td>
</tr>
<tr>
<td>Akku-Laufzeit</td>
<td>Ein vollgeladener Akku hält bei ausgeschalteter Wi-Fi-Funktion bis zu einem Monat, wenn Sie täglich bis zu einer halben Stunde lesen. Mit dauerhaft eingeschalteter Wi-Fi-Funktion hält er bis zu 3 Wochen. Die Akku-Laufzeit variiert je nach Nutzung, z. B. ob Sie im Kindle-Shop einkaufen, den Browser benutzen oder Inhalte herunterladen.</td>
</tr>
<tr>
<td>Ladezeit</td>
<td>Lässt sich mithilfe des mitgelieferten USB 2.0 Kabels über einen Computer in 3 Stunden voll aufladen. Optionales Netzteil separat erhältlich.</td>
</tr>
</tbody>
</table>
### Case Study : E-Reader

| **Wi-Fi / WLAN** | Unterstützt öffentliche und private Wi-Fi-Netzwerke und Hotspots, die einen folgender Standards nutzen: 802.11b, 802.11g oder 802.11n (im b- oder g-Kompatibilitätsmodus). Kindle unterstützt die Sicherheitstechnologien WEP, WPA und WPA2 mit Kennwortauthentifizierung; er verbindet sich nicht mit WPA- und WPA2-gesicherten Netzwerken mit 802.1X Authentifizierungsmethoden; unterstützt keine Ad-hoc (oder Peer-to-Peer) Wi-Fi-Netzwerke. |
| **USB-Anschluss** | USB 2.0 (Micro-B USB) |
| **Unterstützte Formate** | Kindle (AZW), TXT, PDF, ungeschützte MOBI, PRC nativ; HTML, DOC, DOCX, JPEG, GIF, PNG, BMP nach Konvertierung. |
| **Dokumentation** | Kurzanleitung (im Lieferumfang enthalten); Kindle Benutzerhandbuch (auf dem eReader vorinstalliert). Weitere Informationen sind online erhältlich. |
| **Garantie** | 1 Jahr Herstellergarantie . 2 Jahre Extragarantie kann für Kunden aus Deutschland optional von Squaretrade erworben werden. Die Benutzung des Kindle unterliegt der Lizenzvereinbarung und Nutzungsbedingungen. |
| **Lieferumfang** | Kindle eReader, USB 2.0 Kabel, and Kurzanleitung. |
**Case Study: E-Reader**

And color ??

E.g. for internet, multimedia, ...

### Technical Details

<table>
<thead>
<tr>
<th><strong>Display</strong></th>
<th>7&quot; multi-touch display with IPS (in-plane switching) technology and anti-reflective treatment, 1024 x 600 pixel resolution at 169 ppi, 16 million colors.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Size (in inches)</strong></td>
<td>7.5&quot; x 4.7&quot; x 0.45&quot; (190 mm x 120 mm x 11.4 mm).</td>
</tr>
<tr>
<td><strong>Weight</strong></td>
<td>14.6 ounces (413 grams).</td>
</tr>
<tr>
<td><strong>Battery Life</strong></td>
<td>Up to 8 hours of continuous reading or 7.5 hours of video playback, with wireless off. Battery life will vary based on wireless usage, such as web browsing and downloading content.</td>
</tr>
</tbody>
</table>

(AMAZON has announced over the years that they will come up with color E-INK display!)
Case Study: E-Reader

• Will monochrome e-book readers survive?
  (additional device for commuting, travel, etc. as smartphone is a must)

• Will color e-book readers survive with “dedicated” hardware or will they be replaced by tablets?

• What is the business model of the future?
  Hardware, content for various devices, …