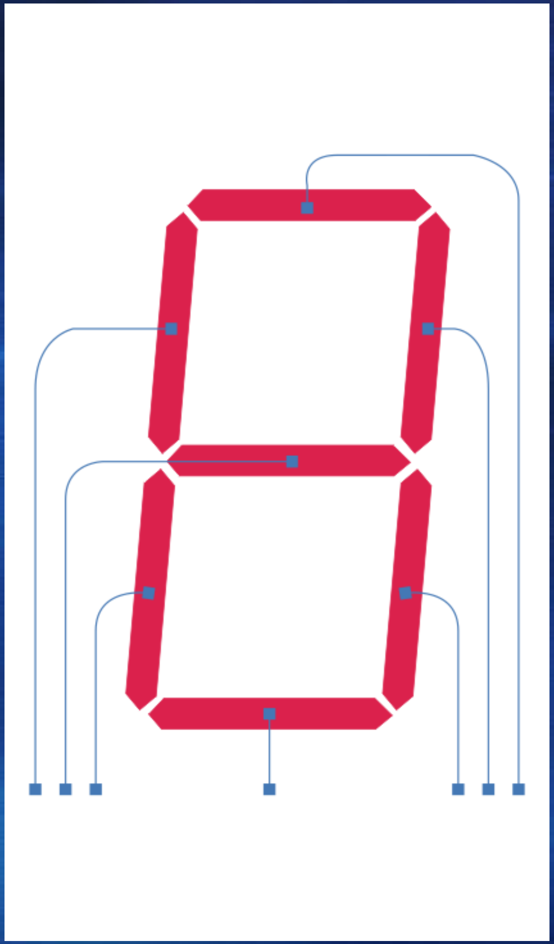
Liquid Crystal Displays

- Liquid Crystals
- Twisted Nematic Technology
- Backlighting Types
- Addressing Techniques
- Display Parameters
- Vertical Alignment Technology
- In-Plane Switching Technology

Addressing Techniques

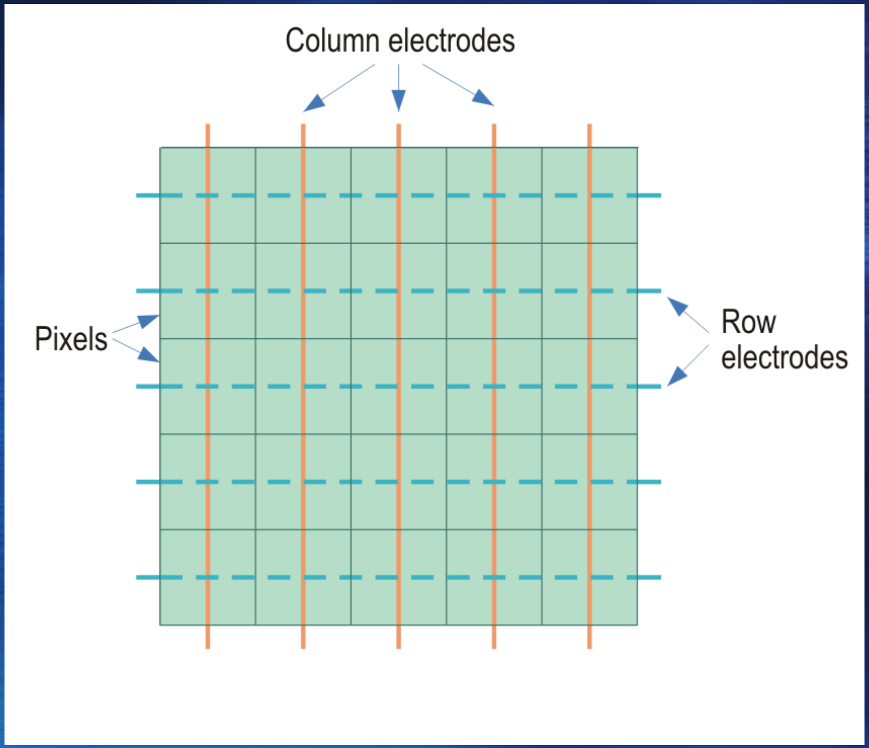
- Addressing Techniques
  - Direct and Multiplexed Addressing
  - Passive-Matrix Displays
  - Active-Matrix Displays
  - Defective Pixels

Direct and Multiplexed Addressing (1)



- Direct addressing
  - Used for displays with a small number of display elements
  - Each element (segment or pixel) can be addressed or driven separately
  - A voltage should be applied to each element to change orientation of the molecules

Direct and Multiplexed Addressing (2)



- Multiplexed addressing
  - Used for displays with a large number of pixels
  - The pixels can be addressed by a matrix of rows and columns
  - Each pixel sits at the intersection of a row electrode and a column electrode

Direct and Multiplexed Addressing (3)

- Advantage:
  - Reduced complexity of the circuits
  - For a matrix of 1000 x 1000 pixels, 2000 drivers are needed (compared to 1,000,000 with direct addressing)
- Disadvantage:
  - Reduced contrast
  - TN displays have been improved through various techniques

Addressing Techniques

- Addressing Techniques
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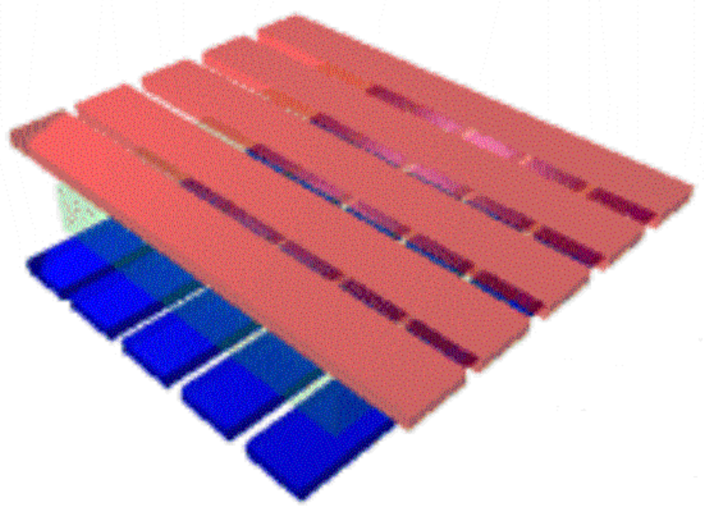
  - Passive-Matrix Displays
  - Active-Matrix Displays
  - Defective Pixels

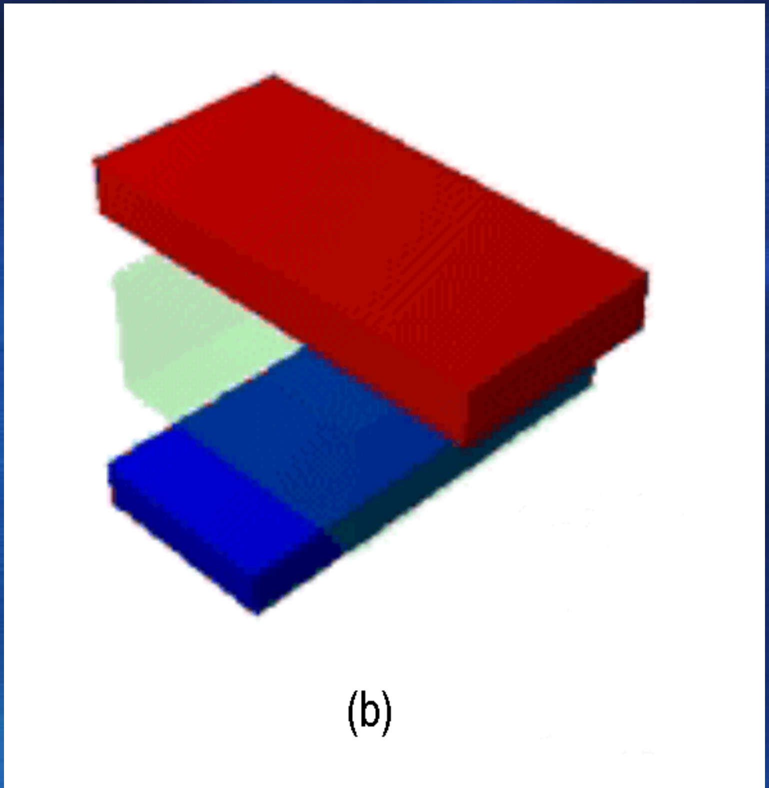
Passive-Matrix Displays (1)



(a)

- Use a set of multiplexed transparent electrodes
- A transistor is connected to each row electrode or each column electrode
- The liquid crystal layer is placed between the electrodes
- The electrodes are composed of indium tin oxide (ITO)

Passive-Matrix Displays (2)



- A pixel – addressed when a voltage is applied across it
- The pixel becomes opaque when it is addressed
- When the voltage is removed, the pixel deactivates slowly

Passive-Matrix Displays (3)

- The display controller scans across the matrix of pixels
- Delay since the voltage is applied to a pixel until it is turned on → response time
- Inertia of the pixels after the voltage is removed
- The time to scan the entire matrix must be shorter than the time needed for the pixels to deactivate

Passive-Matrix Displays (4)

- Disadvantages:
  - Crosstalk – interference between neighboring pixels
    - Causes the occurrence of shadows for bright objects
  - Viewing angle is limited
  - Response time is relatively slow
    - The current image is still maintained on the screen after a new image is displayed

Addressing Techniques

- Addressing Techniques
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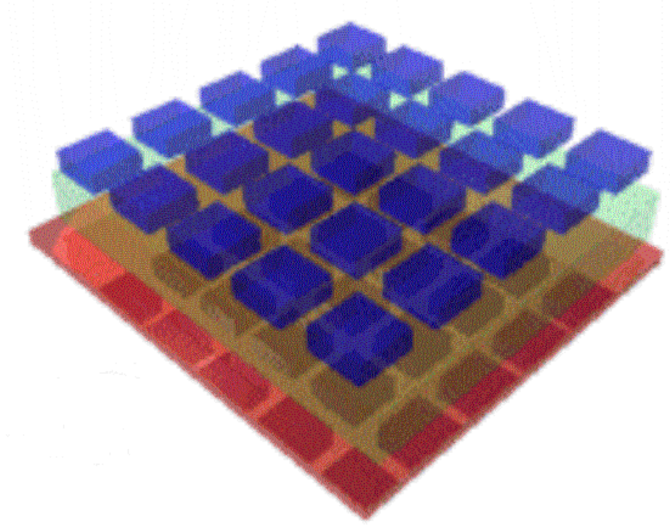
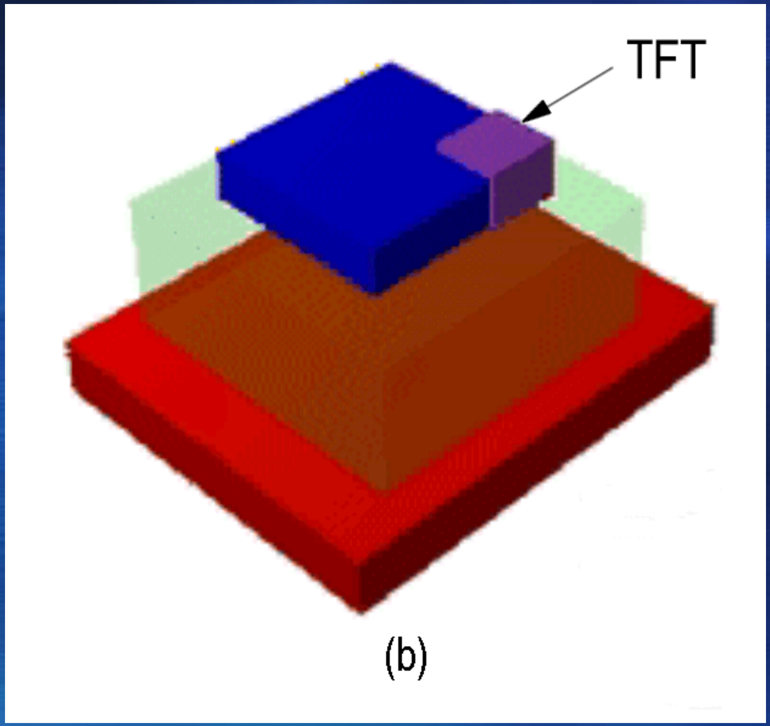
Active-Matrix Displays (1)


(a)

- The front glass plate of the display is coated with a continuous electrode
- The rear glass plate is coated with electrodes divided into pixels
- Each pixel is connected in series with a thin film transistor (TFT)
  - Also called TFT displays
- A storage capacitor can also be connected in series

Active-Matrix Displays (2)

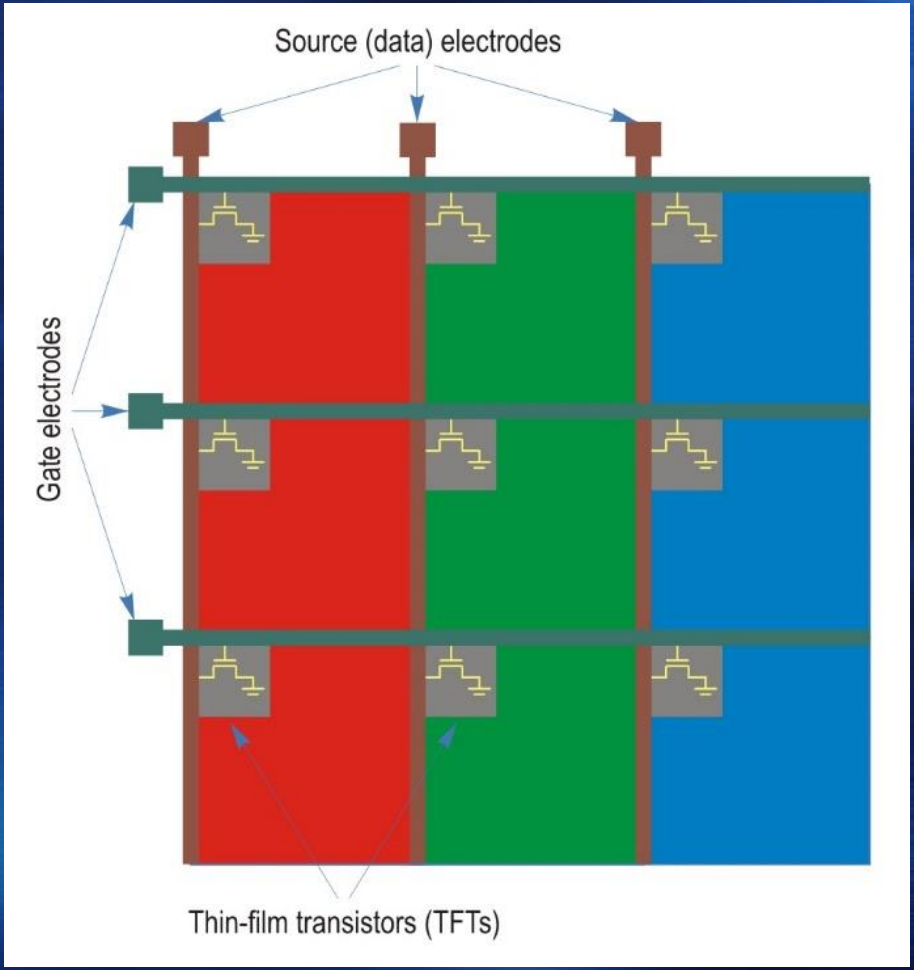


- A pixel of the active-matrix display
- Active element: field effect transistor (FET)
- Semiconductor material: silicon
- Crystalline silicon (c-Si)
  - Expensive
  - High mobility of charge carriers → enable to integrate the drivers

Active-Matrix Displays (3)

- Amorphous silicon (a-Si)
  - Simple manufacturing process
  - Mobility of electrons is relatively low
  - Hydrogenated a-Si (a-SI:H) increases the mobility of electrons
- Polysilicon (p-Si)
  - Consists of small silicon crystals
  - High mobility of charge carriers
- Semiconducting metal oxides
  - Indium Gallium Zinc Oxide (IGZO)

Active-Matrix Displays (4)



Active-Matrix Displays (5)

- An image is created by scanning the matrix
  - A row of pixels is selected by applying voltage to the row electrode connected to the transistor gates on that row
  - Voltages corresponding to the image are applied to the column electrodes connected to the transistor sources
  - The operations are repeated for each row
  - Refresh rate of the screen: 50 or 60 Hz

Active-Matrix Displays (6)

- Advantages (compared to passive matrix displays):
  - Faster response time
  - Higher contrast
  - Higher brightness level
  - Wider viewing angle
- Disadvantages:
  - More intense backlight is required
  - Higher cost

Addressing Techniques

- Addressing Techniques
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  - Active-Matrix Displays
  - Defective Pixels

Defective Pixels (1)

- For high resolutions, many transistors are needed
  - 4K resolution: $3840 \times 2160 \times 3 \cong 24.9$ million transistors
- Defective transistors due to impurities
  - Lit pixel (permanently on)
  - Black pixel (permanently off)
  - Stuck pixel (one or two sub-pixels on or off)
- Manufacturers set limits for an acceptable number of defective pixels

Defective Pixels (2)

- ISO standards: ergonomic requirements for flat panel displays
  - ISO 13406, Part 2 (2001)
  - ISO 9241, Part 303 (2008, 2011)
  - Image-quality requirements:
    - Three types of defective pixels
    - Four display classes (Class II: common)
    - Maximum number of defective pixels of each type per million pixels for each class
    - Maximum number of defective pixels within a block of 5x5 pixels

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Display Parameters

- Display Parameters
  - Response Time
  - Contrast Ratio
  - Color Depth
  - Color Gamut
  - Viewing Angle

Response Time (1)

- Time required for the liquid crystals to change orientation $\rightarrow$ color transition
- Especially important for dynamic images
- Standard way of measuring response time
  - Total time of a black-to-white (*rise time* – t_R) and white-to-black transition (*fall time* – t_F)
  - Example for a TN display: t_R=20 ms, t_F=5 ms
  - Brightness variation: 10% $\rightarrow$ 90% $\rightarrow$ 10%
  - ISO standard

Response Time (2)

- Response time is dependent on the LCD technology used
- Varies with the color transition
  - The speed of orientation is proportional to the intensity of the applied electric field
  - Most of the transitions are between shades of grey
  - Diagram: dependence of response time on the final grey level (black-to-grey transitions)

Response Time (3)

- *x* axis: grey level (code)
- *y* axis: pixel response time (ms)

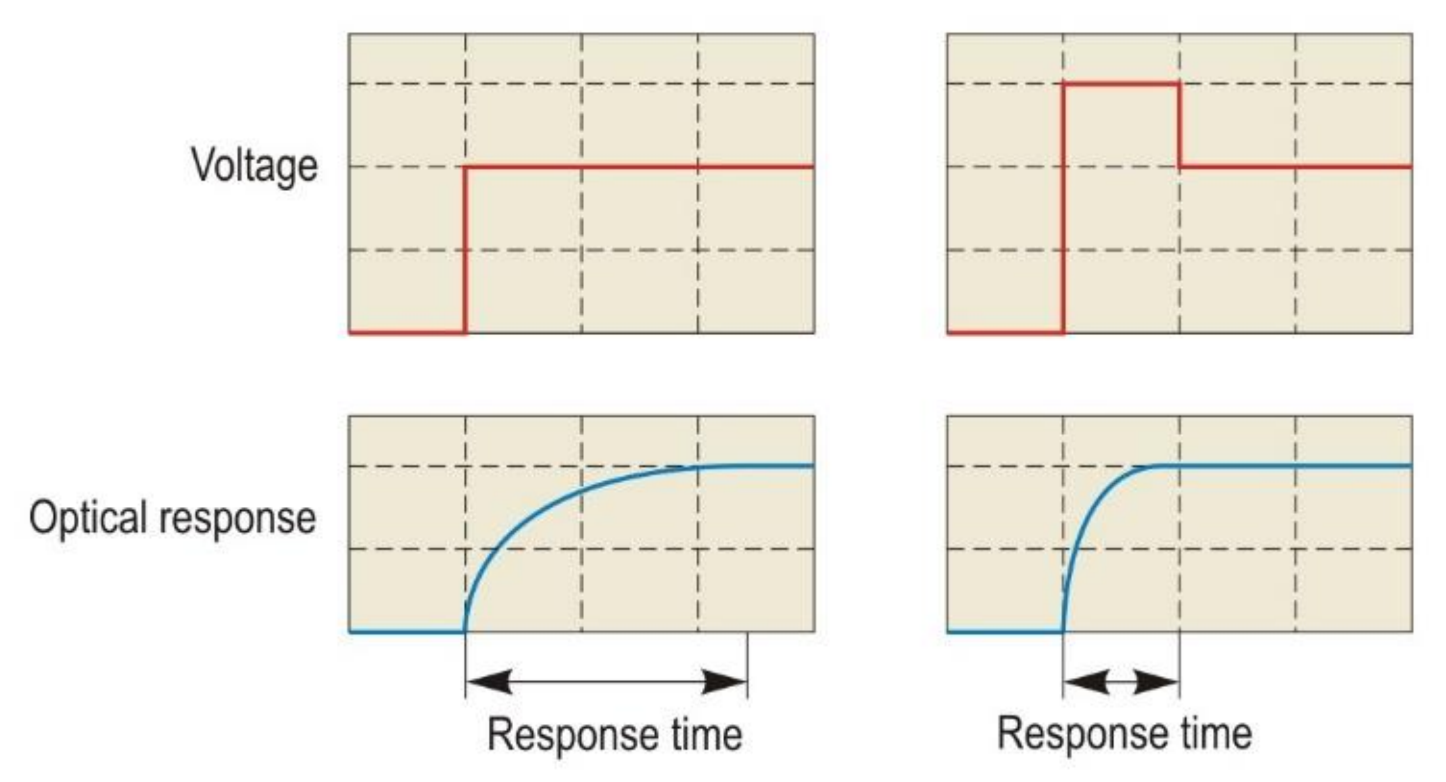
Response Time (4)

- Response time depends on the contrast setting of the display
  - The orientation with the minimum angle (white color) is only reached at the maximum contrast
  - Reducing the contrast increases response time
- Dependence on the brightness setting
  - At low brightness, response time may increase
  - Controlling the brightness by adjusting the backlight intensity: response time not affected

Response Time (5)

- Response Time Compensation (RTC)
  - Also called “overdrive”
  - Technique for improving response time for grey-to-grey transitions
  - Applying an over-voltage to the crystals → are forced into an intermediate position
  - Displays using the RTC technique have response times quoted for grey-to-grey (G2G) transitions

Response Time (6)



Response Time (7)

- Response times for TN displays:
  - Without RTC: 5 .. 10 ms
  - With RTC: 1 .. 5 ms
- Problems of the RTC technique
  - Video noise may be visible
  - Image trailing due to the intermediate state

Response Time (8)

a) No image trailing

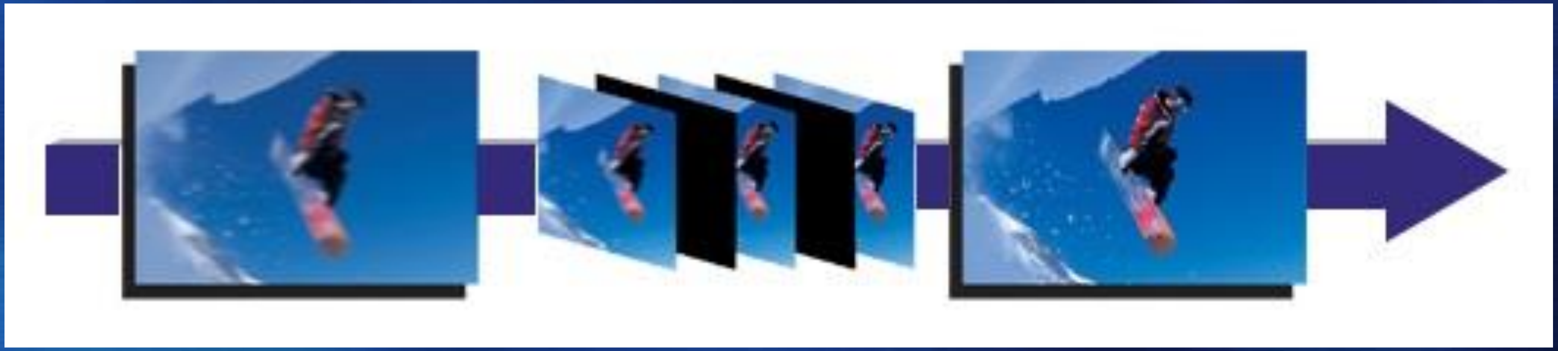
b) Image trailing

Response Time (9)

- Variations of the RTC technique
  - ViewSonic: ClearMotiv
    - Advanced RTC: also improves black-to-black (B2B) transitions
    - Backlight shuttering: the backlight is turned off briefly
  - LG Display: Over Driving Circuit (ODC)
  - Samsung: MagicSpeed / Response Time Acceleration (RTA)
  - NEC Display Solutions: Rapid Response

Response Time (10)

- BenQ: Advanced Motion Accelerator (AMA)
  - Reducing the motion blur with the Black Frame Insertion (BFI) technique
  - AMA Z: the AMA technique combined with BFI



Display Parameters

- Display Parameters
  - Response Time
  - Contrast Ratio
  - Color Depth
  - Color Gamut
  - Viewing Angle

Contrast Ratio (1)

- Static Contrast Ratio
  - Luminosity ratio of white and black colors
  - Measured at the center of the screen
  - Achieving a high contrast is more difficult
  - Passive display: it modulates the backlight
  - It is not possible to block out the backlight completely → the contrast is reduced
  - Static contrast ratios for TN displays: < 1000:1
  - With other technologies: up to 3000:1

Contrast Ratio (2)

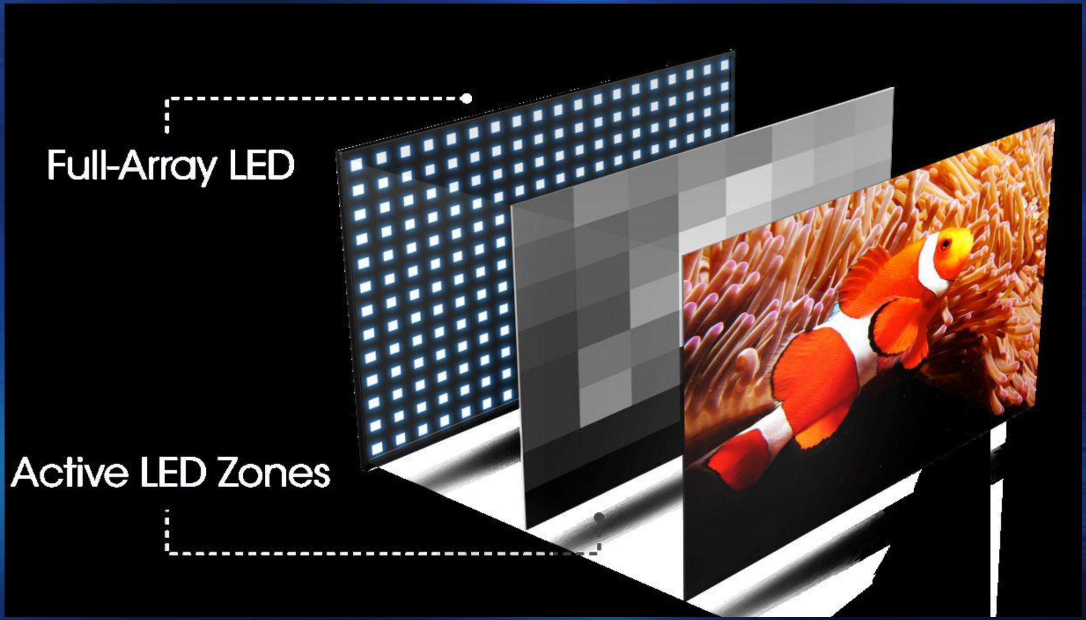
- Dynamic Contrast Ratio (DCR)
  - Dynamic contrast control: achieved by adjusting the intensity of the backlighting
  - Reducing the intensity in dark scenes
  - Increasing the intensity in bright scenes
  - The luminosity of white/black color: measured at the maximum/minimum backlight intensity
  - LED backlighting: very high values of DCR can be achieved (> 1,000,000:1)

Contrast Ratio (3)

- Fluorescent lamps or rows of LEDs: the brightness of the whole screen is changed
- Array of LEDs: brightness can be changed selectively in different areas

Contrast Ratio (4)

- The FALD (*Full-Array Local Dimming*) feature may improve the dynamic contrast ratio
  - A single backlight zone affects the intensity of many pixels → it may create visual artifacts



Display Parameters

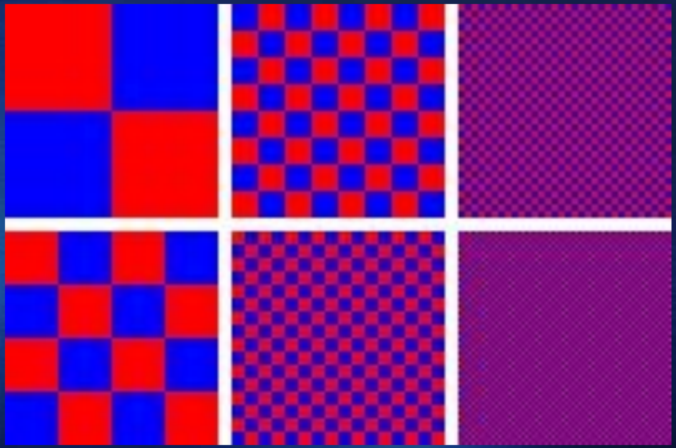
- Display Parameters
  - Response Time
  - Contrast Ratio
  - Color Depth
  - Color Gamut
  - Viewing Angle

Color Depth (1)

- Represents the number of colors that can be reproduced by the display
  - Determined by the number of possible orientations in each sub-pixel
- TN technology: only 64 orientations
  - Color depth: 262,144
  - 6 bits per sub-pixel → 18-bit color
  - Techniques for improving the color depth: spatial dithering and Frame Rate Control

Color Depth (2)

- Spatial Dithering
  - A new color is created by several neighboring pixels of slightly different colors
  - The eye will combine the colors of close-by pixels



Color Depth (3)

- Frame Rate Control (FRC)
  - Represents a temporal dithering
  - The color of a pixel or group of pixels is changed slightly during successive frames
  - When four frames are combined: the color depth may increase to 16.2 million
  - The quality of color reproduction may be affected
    - Slanting stripes
    - Flickering

Color Depth (4)

  - The quality of the FRC technique may depend on the brightness and contrast settings
- VA, IPS technologies: 24-bit color, without any special technique
- 30-bit color (10 bits per sub-pixel)
  - Color depth of over 1 billion colors
  - Sometimes 24-bit color + FRC is used
  - True 30-bit color: for professional-grade monitors

Display Parameters

- Display Parameters
  - Response Time
  - Contrast Ratio
  - Color Depth
  - Color Gamut
  - Viewing Angle

Color Gamut (1)

- Gamut: the subset of colors that can be reproduced within a reference color space
- Color spaces
  - sRGB (standard RGB): Created by Microsoft and HP for monitors, printers, and Internet content
  - Adobe RGB: Developed by Adobe Systems to include the colors achievable on CMYK printers, but by using RGB primary colors
  - NTSC: Defined by the *National Television System Committee*
  - BT.2020 (Rec. 2020): Defined by the *International Telecommunication Union* (ITU)

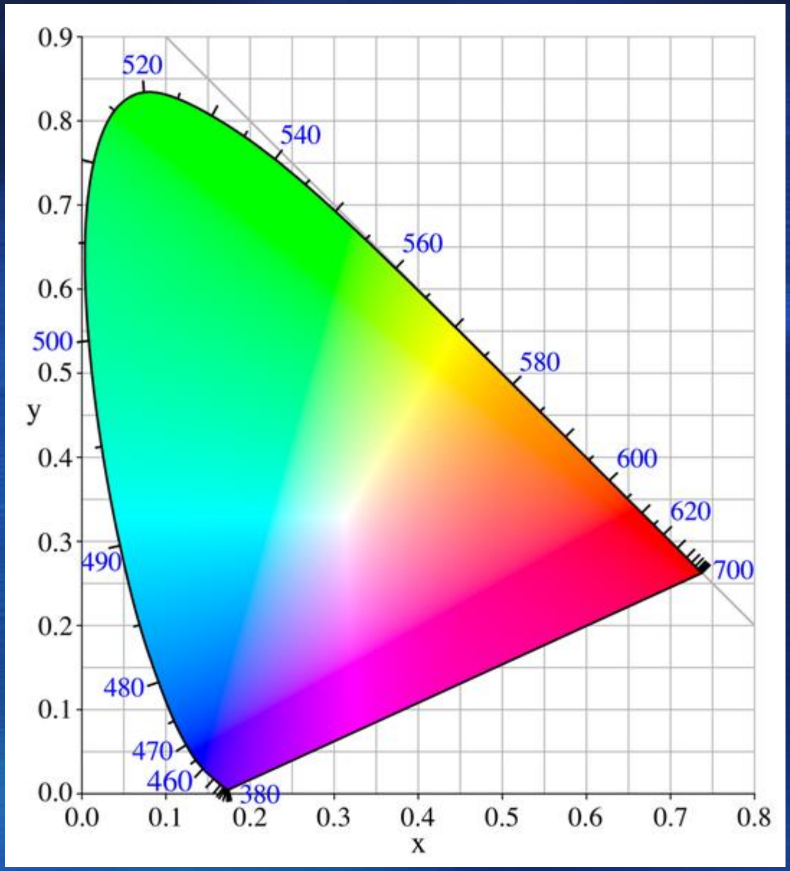
Color Gamut (2)

- Concepts related to color
  - Color: brightness (luminance) + chromaticity
  - Luminance: measure of the luminous intensity per unit area $\rightarrow$ Cd/m^2 (Nits)
  - Chromaticity: specifies the quality of a color regardless of its luminance
  - Chromaticity: defined by the hue and saturation
  - Hue: related to the wavelength of light in the visible spectrum

Color Gamut (3)

- Saturation: ratio of the dominant wavelength to other wavelengths in the color; color purity
- CIE chromaticity diagram
  - CIE – *Commission Internationale de l'Éclairage*
  - Representation of the human color perception
  - 3D model projected onto a plane → 2D diagram
  - Chromaticity coordinates x, y: map the color based on the hue and saturation values

Color Gamut (4)

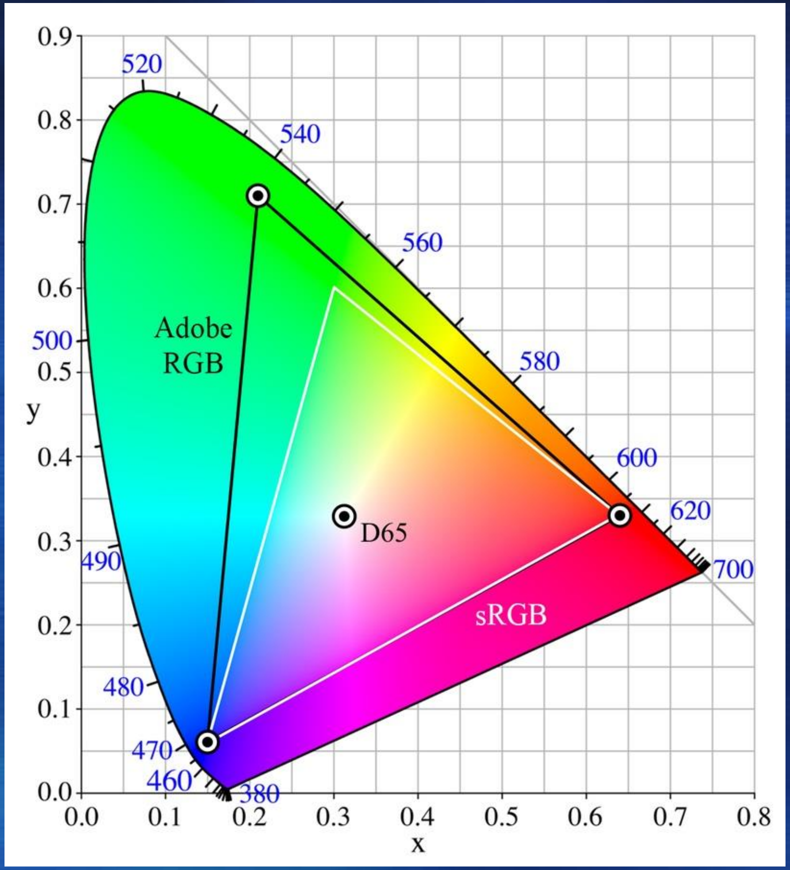


- Color gamut of the average person
- Boundary of diagram: monochromatic light
- sRGB: covers 35.9% of the colors perceived by the human eye
- Adobe RGB: 52%
- NTSC: 54%
- BT.2020: 75.8%

Color Gamut (5)

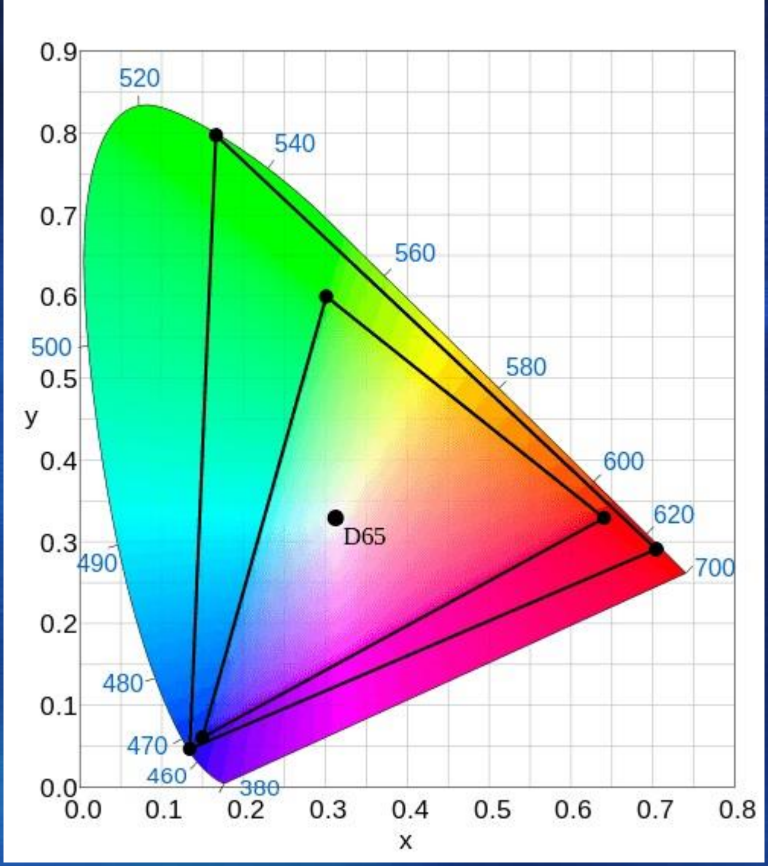
- Color gamut of LCD monitors: also depends on the type of backlighting
  - Standard CCFL: the gamut covers approximately the sRGB color space (72% of NTSC color space)
  - Enhanced CCFL: 92% .. 102% of NTSC color space
  - White LEDs: 68% .. 72% of NTSC color space
  - RGB LEDs: > 114% of NTSC color space

Color Gamut (6)



- Color triangle: joining the locations of the primary colors
- D65: represents the white point
  - D65 is related to standard illumination conditions (CIE)
  - It corresponds to the average midday light

Color Gamut (7)



- Gamut of the BT.2020 space (outer triangle) compared to sRGB
  - Covers entirely the sRGB and Adobe RGB color spaces
  - Covering the entire BT.2020 color space is extremely difficult
    - Special backlighting; high-quality color filters; color enhancement technology (e.g., quantum dot film)

Display Parameters

- Display Parameters
  - Response Time
  - Contrast Ratio
  - Color Depth
  - Color Gamut
  - Viewing Angle

Viewing Angle (1)

- Specified for the horizontal / vertical fields
  - Example: 170 / 160
- Contrast ratio
  - Usually, at the maximum viewing angle it is reduced to 10:1
  - Some manufacturers consider a value of 5:1
  - Images become distorted even when the contrast ratio decreases to about 100:1
  - The contrast ratio at lower viewing angles is more important

Viewing Angle (2)

- Color shifting
  - At increasing viewing angles, colors may not be reproduced correctly
  - Usually, it is not considered when measuring viewing angles
- TN technology:
  - Viewing angles are limited, especially vertically
- Other technologies:
  - Viewing angles are wider

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Vertical Alignment Technology

- Vertical Alignment (VA) Technology
  - Principle of VA Technology
  - Multi-Domain VA Technology
  - Patterned VA Technology

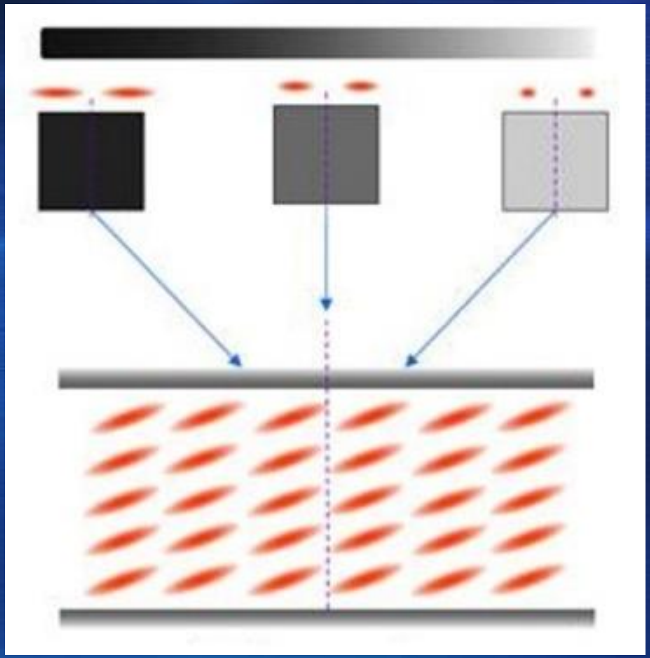
Principle of VA Technology (1)

- VA – *Vertical Alignment*
- Developed by Fujitsu Ltd.
- Uses a different type of liquid crystal, known as with “vertical alignment”
- No voltage is applied between two electrodes: the molecules are aligned perpendicularly to the glass plates
  - The light is obstructed by the polarizer on the front of the screen

Principle of VA Technology (2)

  - The obstruction of light is almost complete $\rightarrow$ a high-quality black color is achieved
- A voltage is applied between the two electrodes: the molecules tilt with up to 90°
  - Allow passing the light in a degree proportional to the applied voltage
  - The molecules are aligned uniformly
  - The brightness of a cell changes with the viewing angle

Principle of VA Technology (3)



- Cell viewed from the front: only part of the light is visible
- In the direction of the tilt: bright cell
- In the direction normal to the tilt: dark cell
- Viewing angles are limited

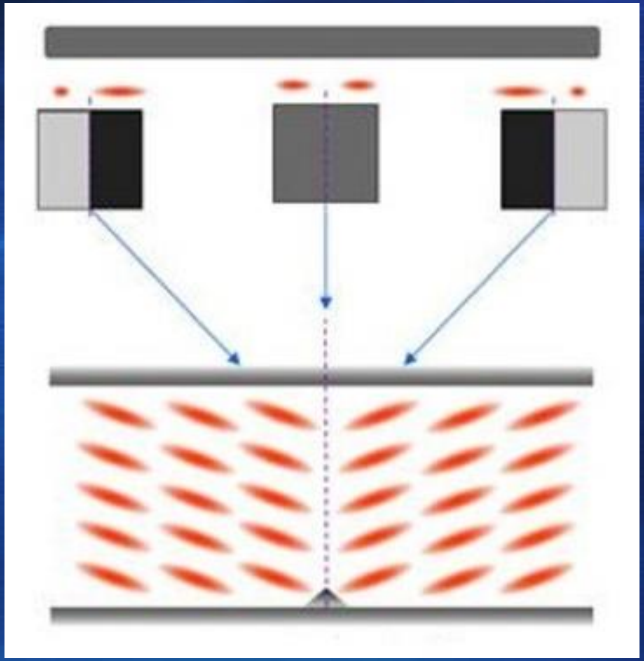
Vertical Alignment Technology

- Vertical Alignment (VA) Technology
  - Principle of VA Technology
  - Multi-Domain VA Technology
  - Patterned VA Technology

Multi-Domain VA Technology (1)

- MVA – *Multi-Domain Vertical Alignment*
- Improvement of the VA technology
  - Reduces the brightness dependency on the viewing angle
- When no voltage is applied, the molecules are tilt at a certain angle
- Each cell is divided into two or more regions (domains)
  - In each domain, the molecules are aligned differently than in the neighbor domains

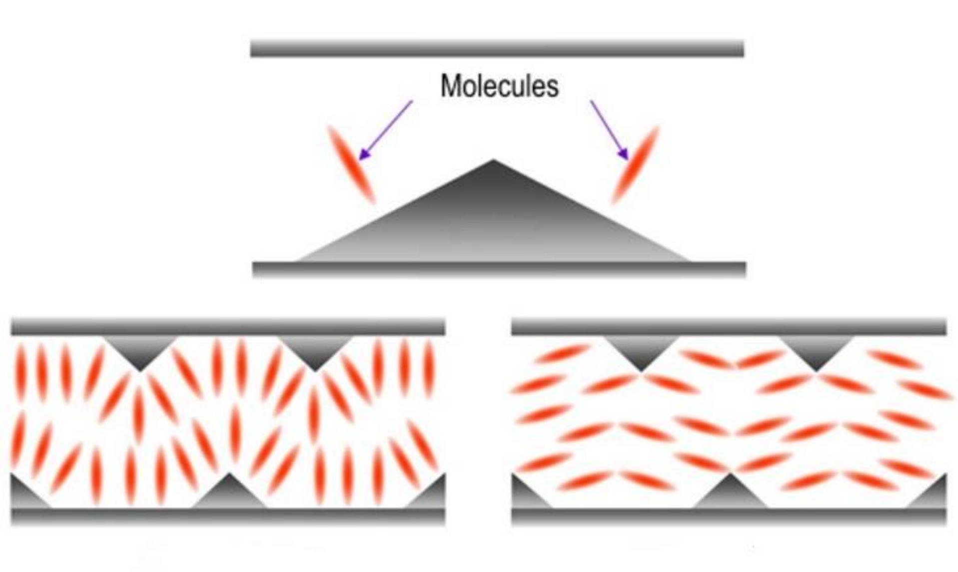
Multi-Domain VA Technology (2)



- MVA display with two domains
  - Combining areas of molecules oriented in opposite directions
  - More uniform brightness of the cells
  - Creating the domains: with pyramidal ridges
  - Changing the arrangement of the ridges: more domains can be created

Multi-Domain VA Technology (3)

- OFF state: the molecules align perpendicularly to the sides of the protrusions
- ON state: the molecules tilt horizontally



MVA cell in OFF state (left) and ON state (right)

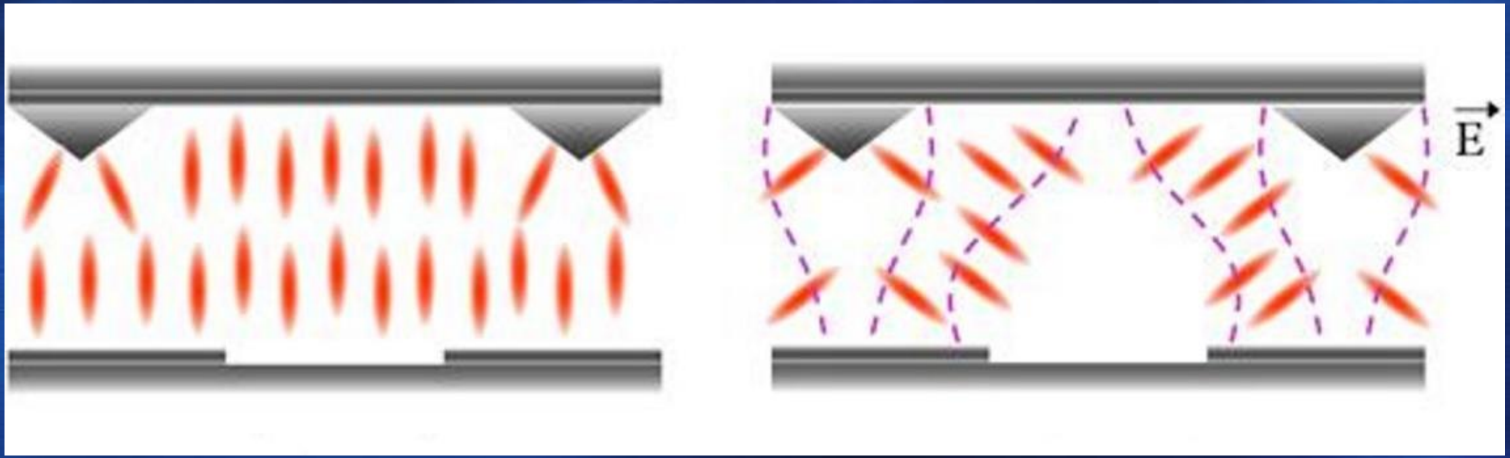
Multi-Domain VA Technology (4)

- At least four domains are required
  - Arranging the protrusions in various patterns (e.g., in a chevron pattern)
- Disadvantages
  - The contrast ratio is reduced due to the light leakage around the protrusions
  - Two photolithographic processes are required to form the protrusions on both substrates

Multi-Domain VA Technology (5)

- Improved MVA technology
  - The protrusions on one substrate are replaced by transparent electrodes for each pixel
  - The oblique electrical fields around the remaining protrusions maintain the same alignment of liquid crystal molecules
  - Advantages:
    - Reduced production cost
    - Increased contrast ratio

Multi-Domain VA Technology (6)



Improved MVA cell in OFF state (left) and in ON state (right)

Multi-Domain VA Technology (7)

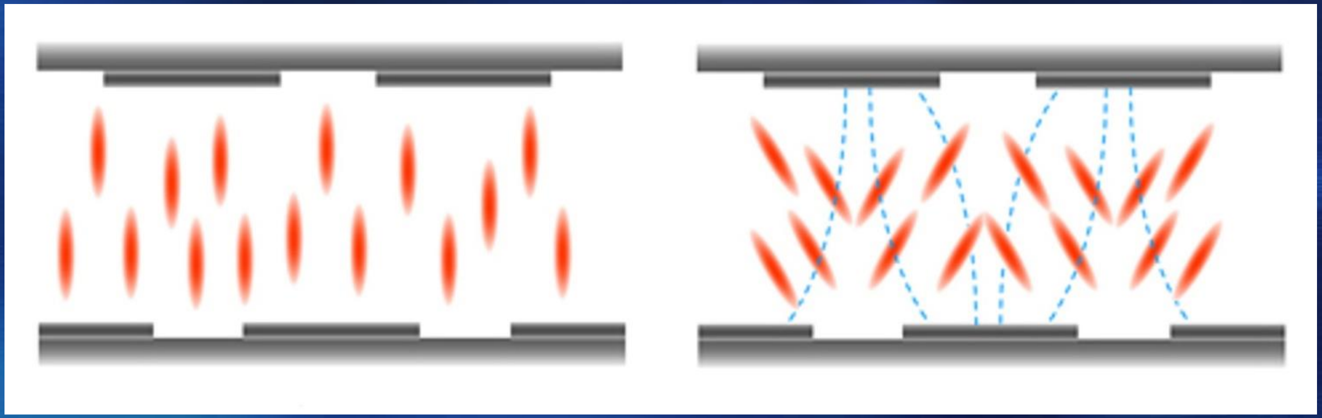
- Characteristics of MVA technology
  - Response time: ~ 12 ms (without RTC)
  - Response time increases significantly when the color change required is small
  - Contrast ratio: is improved compared to that of TN technology
  - Viewing angles: much wider, e.g., 160° both horizontally and vertically
  - Color reproduction: improved compared to TN, but problematic in a perpendicular direction

Vertical Alignment Technology

- Vertical Alignment (VA) Technology
  - Principle of VA Technology
  - Multi-Domain VA Technology
  - Patterned VA Technology

Patterned VA Technology (1)

- PVA – *Patterned Vertical Alignment*
- Developed by Samsung Electronics
- The protrusions on both substrates are replaced by electrodes → chevron pattern



PVA cell in OFF state (left) and in ON state (right)

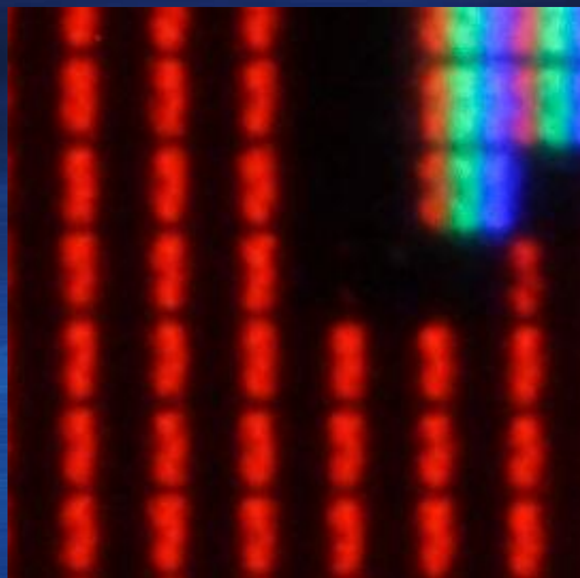
Patterned VA Technology (2)

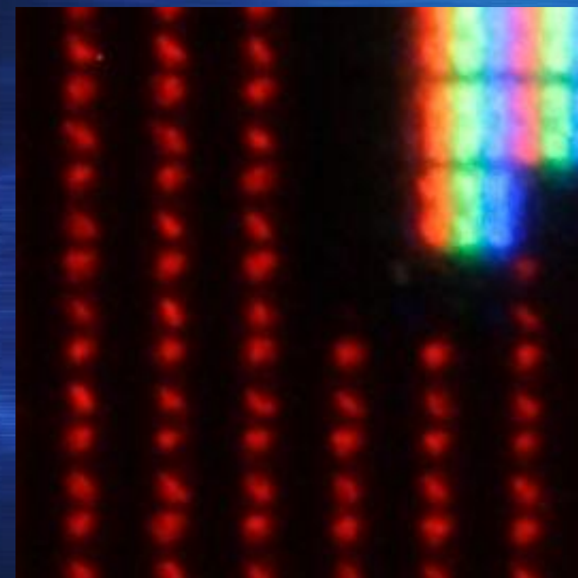
- Contrast ratio: improved (up to 3000:1)
- Response time: similar to MVA technology
  - Increases significantly when the difference between the two color shades is small
  - Can be improved with the RTC technique
- Color depth
  - Inexpensive displays may use 18-bit color and the Frame Rate Control technique
- Color quality: problematic for a direction strictly perpendicular to the screen

Patterned VA Technology (3)

- Improved PVA technology
  - S-PVA (*Super-PVA*)
  - Improved response time → advanced RTC method (*Dynamic Capacitance Compensation*)
    - Example: 50 ms → 8 ms
  - No color simulation methods are used → 24-bit or 30-bit color
  - The sub-pixel structure is changed → two sections aligned in opposite directions

Patterned VA Technology (4)





- Red sub-pixels at full/low brightness (left/right)
- Sub-pixel: two zones, four domains each
  - The structure may compensate the color shift effect
- Viewing angles are asymmetric

Summary (1)

- There are two addressing methods for the display elements:
  - Direct addressing
  - Multiplexed addressing
- Displays with multiplexed addressing may use a passive-matrix or an active-matrix
  - Active-matrix displays have important advantages compared to passive-matrix displays
- Liquid crystal displays require special techniques for improving some parameters

Summary (2)

- Response time is especially important for dynamic images
  - Depends on several factors
  - The RTC technique improves response time for grey-to-grey transitions
- Dynamic contrast control can be performed by adjusting the intensity of the backlighting
- Color depth is problematic for the TN technology
  - Increasing the color depth: spatial dithering, frame rate control

Summary (3)

- The color gamut can be represented on the CIE chromaticity diagram
  - Is wider when RGB LEDs are used
- Viewing angle is the narrowest with the TN technology
- The MVA technology improves the contrast ratio, viewing angle, and color reproduction compared to the TN technology
  - The PVA technology improves the contrast ratio
  - The S-PVA technology improves the response time and color depth

Concepts, Knowledge (1)

- Direct and multiplexed addressing
- Principle of passive-matrix displays
- Principle of active-matrix displays
- Semiconductor materials used for active-matrix displays
- Response time
- Response time compensation (RTC)
- Static contrast ratio
- Dynamic contrast ratio

Concepts, Knowledge (2)

- Spatial dithering technique
- Frame rate control (FRC) technique
- Color gamut
- Viewing angle
- Principle of VA technology
- MVA and improved MVA technologies
- Features of MVA technology
- PVA and improved PVA (S-PVA) technologies