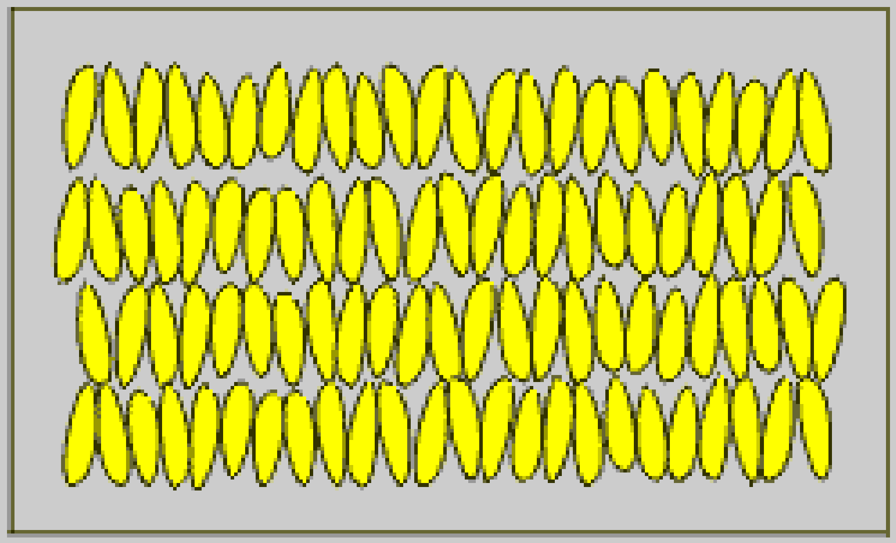
Contents of the Lecture

4. Liquid Crystal Displays

- Liquid Crystals
- Principle of Liquid Crystal Displays
- Constructive Elements
- Color Displays
- Characteristics
- Addressing Methods
- Types of Passive Matrix Displays
- Types of Active Matrix Displays

Liquid Crystals (1)

- Molecules of a crystal
  - Form a three-dimensional matrix by the strong link between them
  - All the molecules are oriented in the same direction



Liquid Crystals (2)

- Liquid crystals have been discovered in 1888
  - Changing the state of a material known as cholesteryl benzoate from solid into liquid
- Substances that exhibit an anisotropy of properties → variable depending on the direction of measurement
- Equilibrium state – mesomorphic
  - State between the solid and liquid states
  - Mobility of molecules is lower

Liquid Crystals (3)

- Light passing through liquid crystals follows the alignment of the molecules → property of solid matter
- Applying an electric or magnetic field changes the molecular alignment of liquid crystals → property of liquid matter
- Two types of liquid crystals:
  - Nematic
  - Cholesteric

Liquid Crystals (4)

- Nematic liquid crystals:
  - Become opaque under the effect of an electric or magnetic field
  - Nematic – threadlike structure
  - Nematic – mesomorphic state in which a linear orientation of the molecules causes anisotropic properties
  - The threadlike molecules in the various layers have a parallel orientation

Liquid Crystals (5)

- Cholesteric liquid crystals:
  - Change color under the influence of an electric or magnetic field
  - Cholesteric – mesomorphic state in which molecules in the successive layers are oriented at an angle relative to each other (rather than parallel)
  - State characteristic to many substances called cholesterils (cholesterol esters) → cholesteric

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Principle of Liquid Crystal Displays (1)

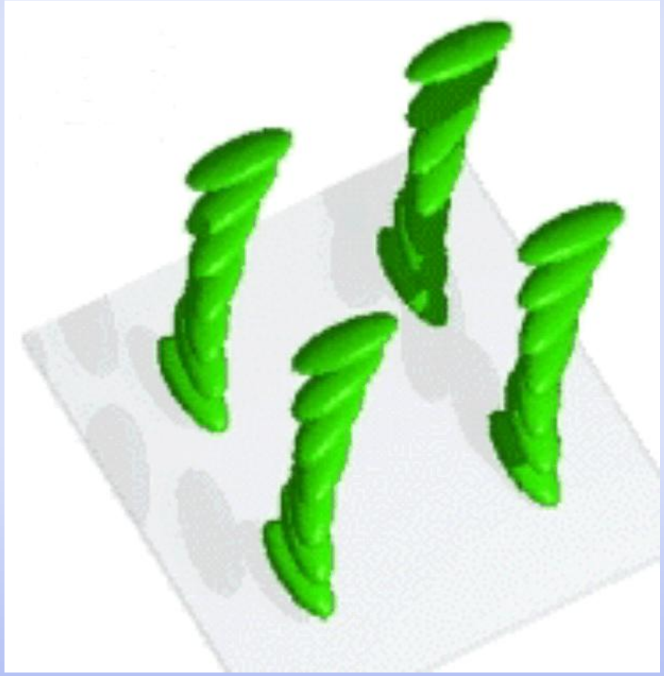
- Liquid crystal displays are passive
- Directing a white backlight through a liquid crystal layer
- The color components are achieved through filtering of the white light
- Control of molecule alignment through a surface provided with grooves
- When the grooves are parallel, the alignment of the molecules also becomes parallel

Principle of Liquid Crystal Displays (2)

- Common displays: TN (*Twisted Nematic*)
  - Nematic liquid crystals introduced between two transparent plates
  - The plates are provided with grooves
  - The grooves on the two panels are perpendicular to each other
  - This results in a 90° twist of the longitudinal axis of molecules on the two plates

Principle of Liquid Crystal Displays (3)

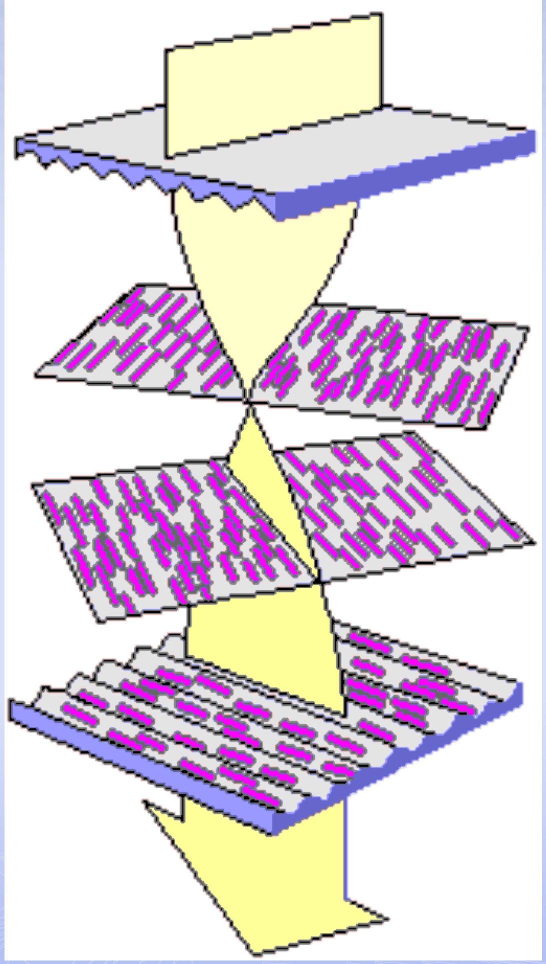
- Molecules in the middle of the liquid crystal are forced into intermediate positions



Principle of Liquid Crystal Displays (4)

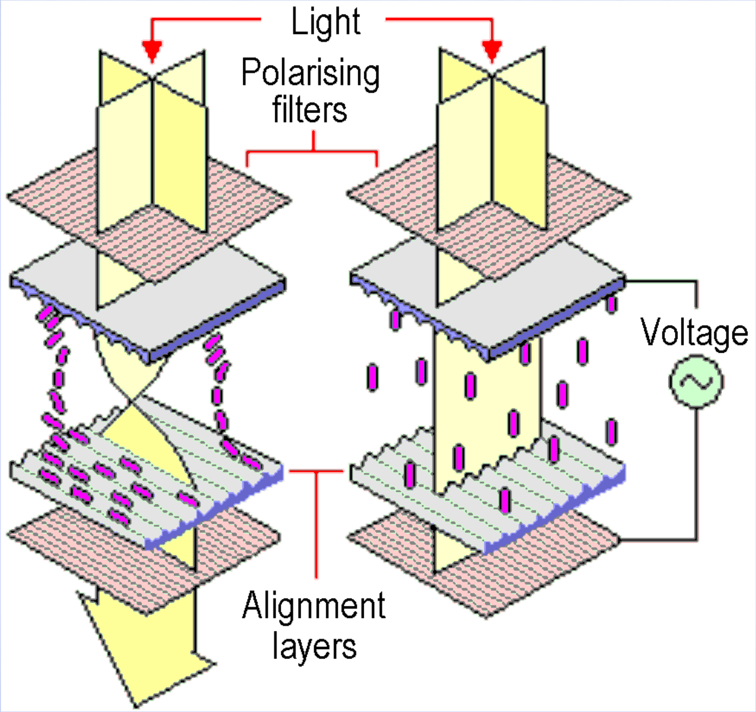
- Natural light – the waves are oriented at random directions
- Polarized light – the waves are oriented in parallel with a specific direction
  - Can be obtained with a polarizing filter
  - Follows the alignment of liquid crystal molecules
  - The polarizing direction is changed depending on the molecules' twist

Principle of Liquid Crystal Displays (5)



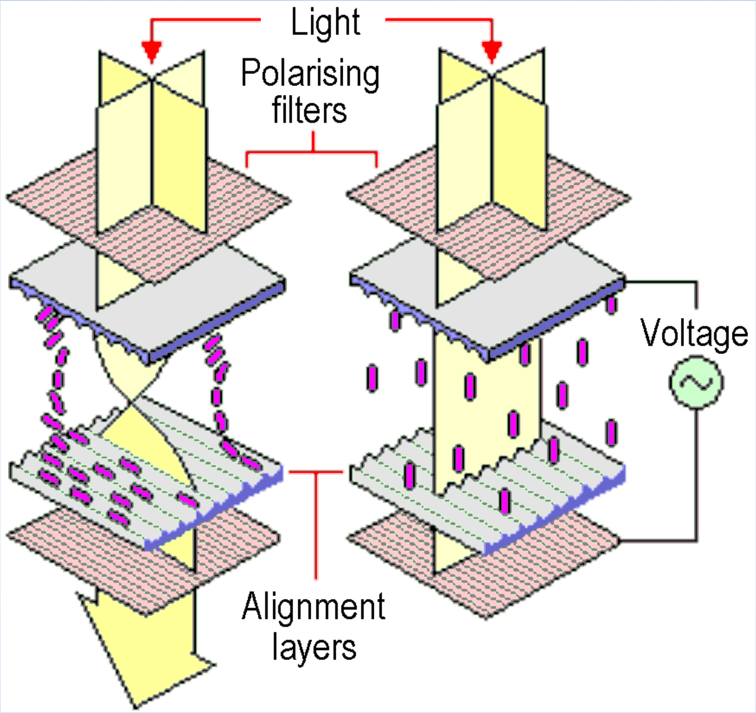
- The polarizing direction of the light is parallel to the grooves on the top plate
- When the light passes through the crystals, the polarizing direction is twisted
- When passing through the bottom part of the display, the polarizing direction will be twisted with 90°

Principle of Liquid Crystal Displays (6)



- Two polarizing filters
- Transparent plates between which the liquid crystal layer is placed
- The light is polarized by the first filter
- The polarizing direction is twisted with 90°
- The light will also pass through the second filter

Principle of Liquid Crystal Displays (7)



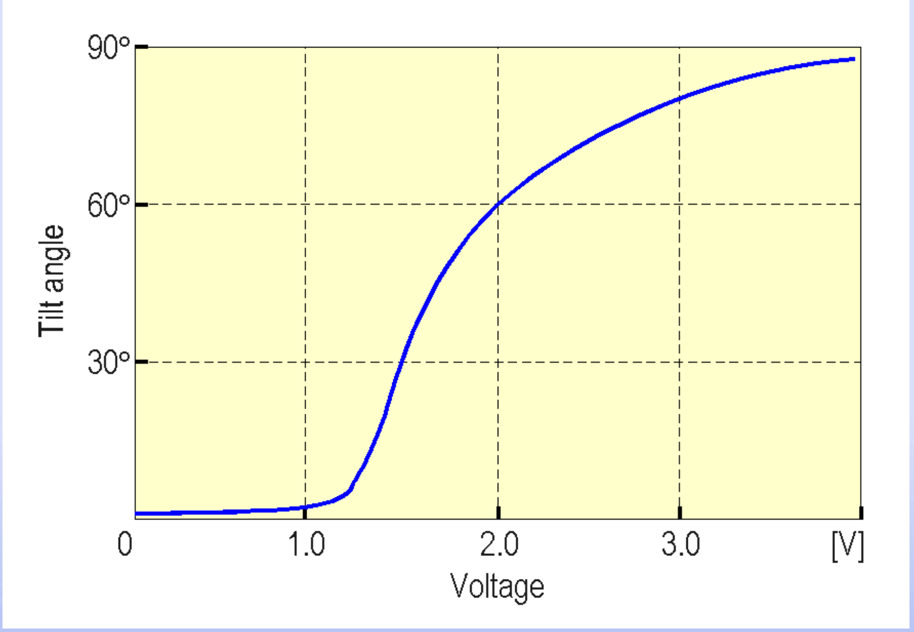
- When an electrical voltage is applied, the molecules realign
- The direction of longitudinal axes will be parallel to the field
- The light is not twisted → will be blocked by the second polarizer

Principle of Liquid Crystal Displays (8)

- The display is lit up by a light source
  - Areas with no voltage applied: bright
  - Areas with voltage applied: dark
- Displays for which the light is blocked in the areas with no voltage applied
- First variant: reduces power consumption
- Reflective displays: mirror placed at the bottom of the display

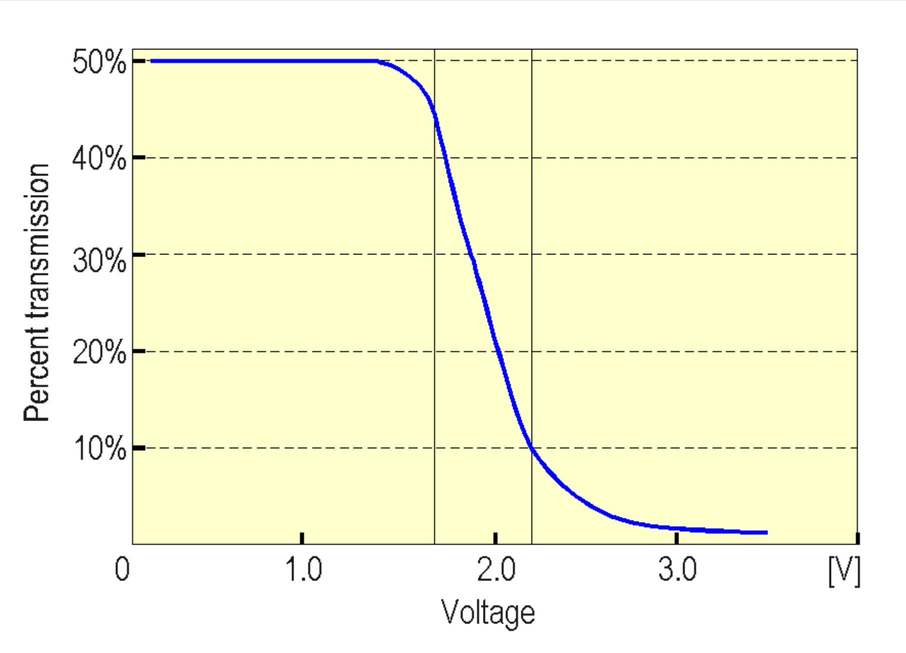
Principle of Liquid Crystal Displays (9)

- The response of a TN cell to an applied voltage



Principle of Liquid Crystal Displays (10)

- Percent transmission of light
  - For reflective TN displays, maximum percent transmission is 50%



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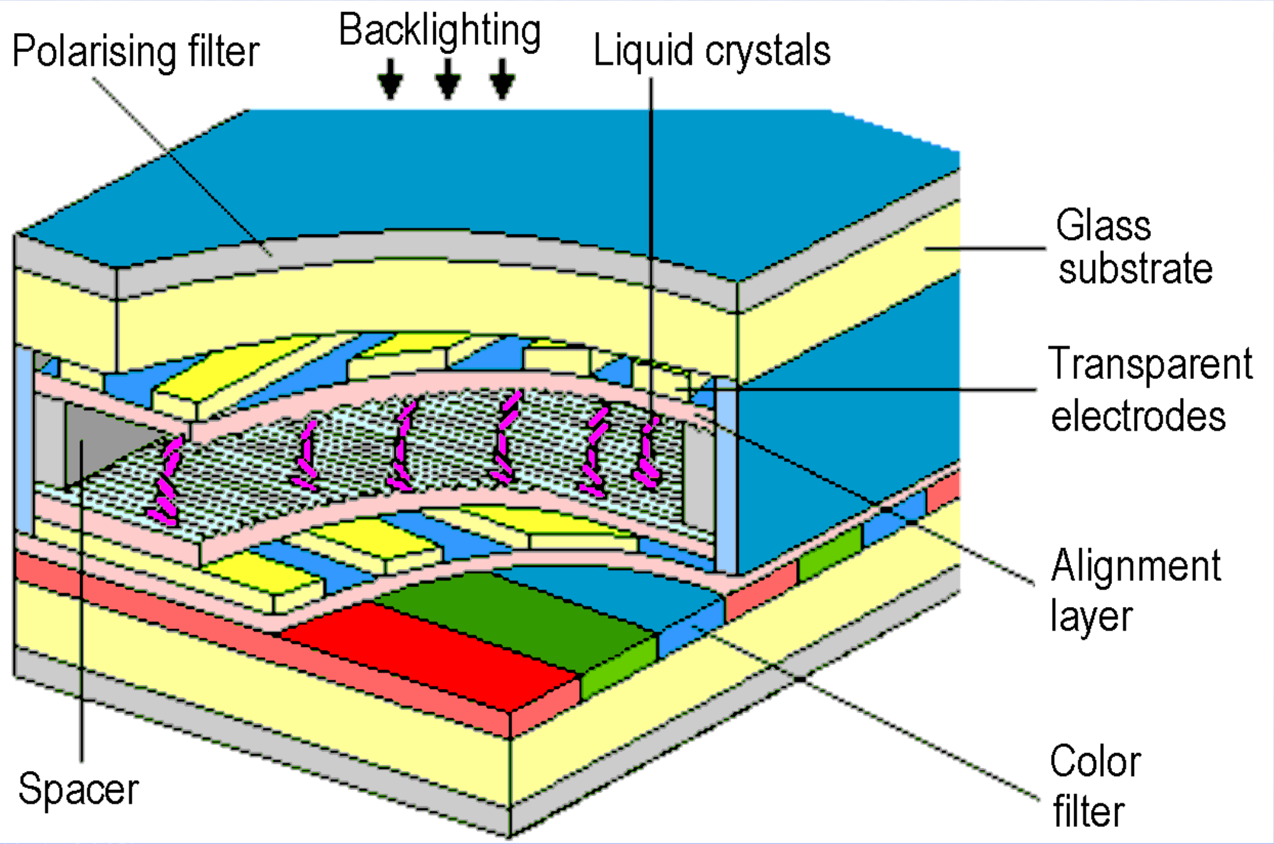
- Types of Active Matrix Displays

Constructive Elements



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Color Displays

- Intermediate levels of brightness are required
  - Are achieved by changing the voltage applied to the liquid crystals
- The white backlight contains all the wavelengths
- Color filters are used
- Each pixel is composed of three subpixels for the primary colors
- Some manufacturers use the subtractive synthesis

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Characteristics (1)

- Response time
  - Reaction speed of the display to a command of changing a pixel's state
  - Faster response time → clearer moving images
  - Slow response time → ghosting effect, cursor disappearance
  - Typical values: 4 .. 8 ms

Characteristics (2)

- Luminance
  - Indicates the brightness of images
  - Measured in Cd/m^2
  - Acceptable values: > 200 Cd/m^2
- Contrast
  - The ratio between the brightness of an on-pixel and the brightness of an off-pixel
  - Typical values: 500:1 .. 3000:1

Characteristics (3)

- Viewing angle
  - Narrower compared to cathode ray tubes
  - The backlight will be directed through the liquid crystal layer
  - When the image is viewed from a certain angle, it may appear dark
  - Special techniques to increase the viewing angle $\rightarrow$ 110° .. 170°

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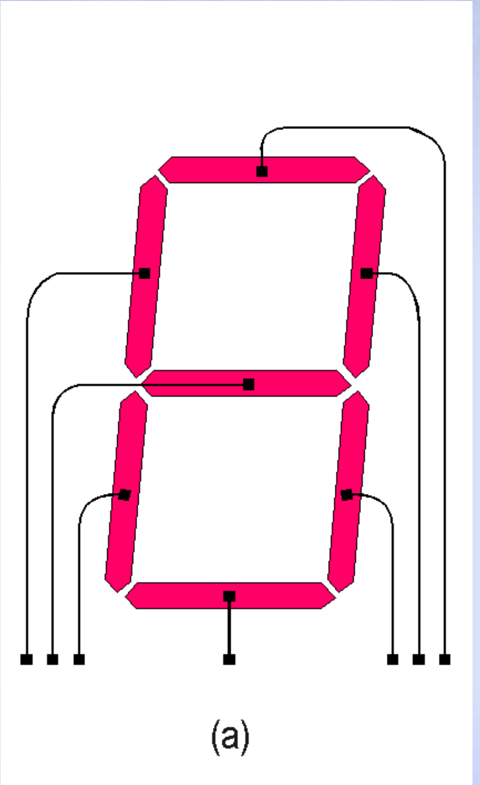
Addressing Methods

- Addressing Methods
  - Direct Addressing
  - Multiplexed Addressing
    - Passive Matrix Displays
    - Active Matrix Displays

Direct Addressing

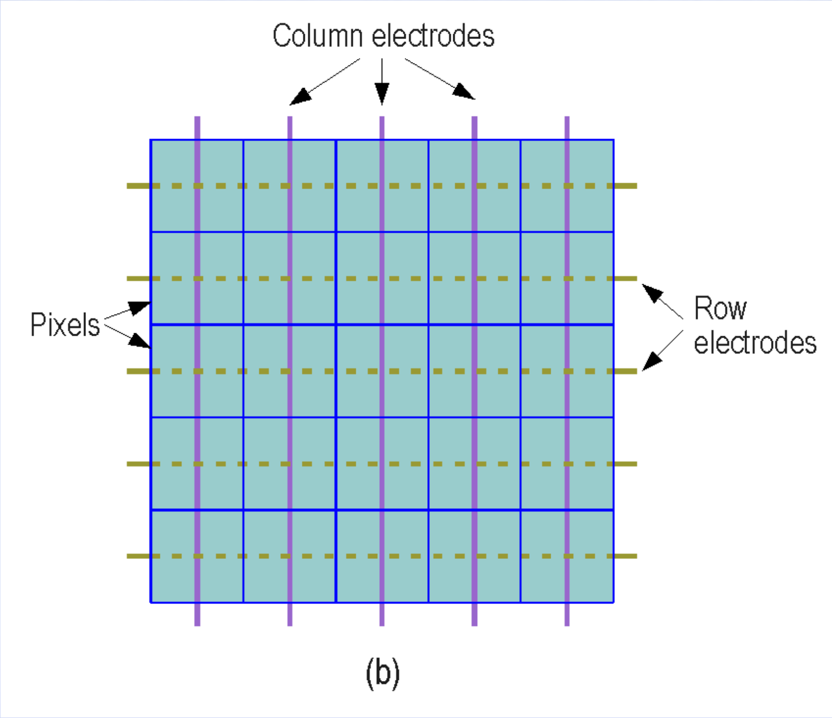


- Used for displays with a small number of display elements
- Each element (segment or pixel) can be addressed or driven separately
- A voltage should be applied to each element to change orientation of the crystals

Addressing Methods

- Addressing Methods
  - Direct Addressing
  - Multiplexed Addressing
    - Passive Matrix Displays
    - Active Matrix Displays

Multiplexed Addressing (1)



- Used for displays with a large number of pixels
- Each pixel sits at the intersection of a row electrode and a column electrode

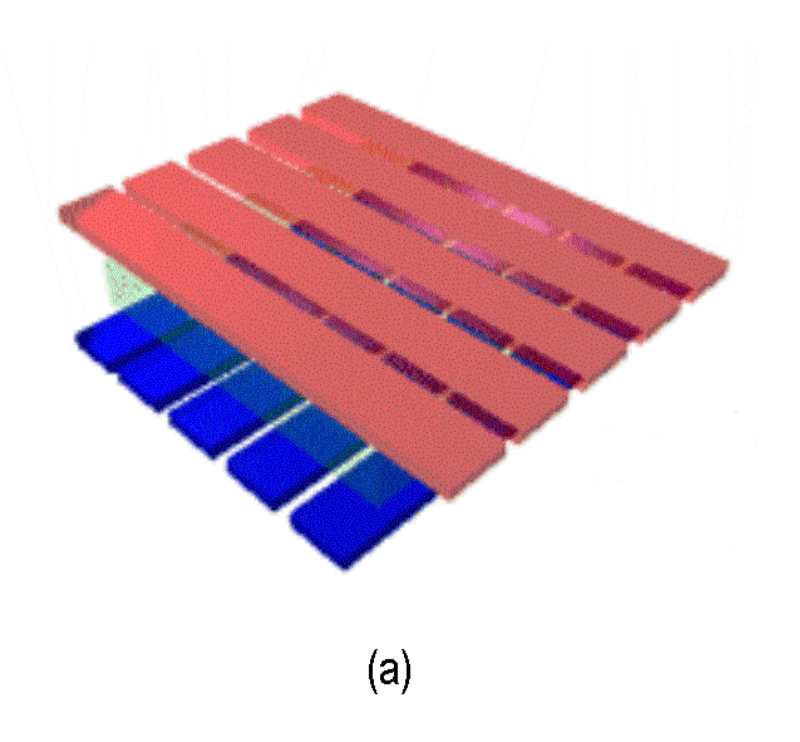
Multiplexed Addressing (2)

- Advantage: reduced complexity of the circuits
  - For a matrix of 100x100 pixels, 200 drivers are needed (compared to 10,000 with direct addressing)
- Disadvantage: reduced contrast
  - For a common TN display, the contrast is reduced to 5:1 (compared to 100:1 with direct addressing)
  - TN displays have been improved through various methods

Addressing Methods

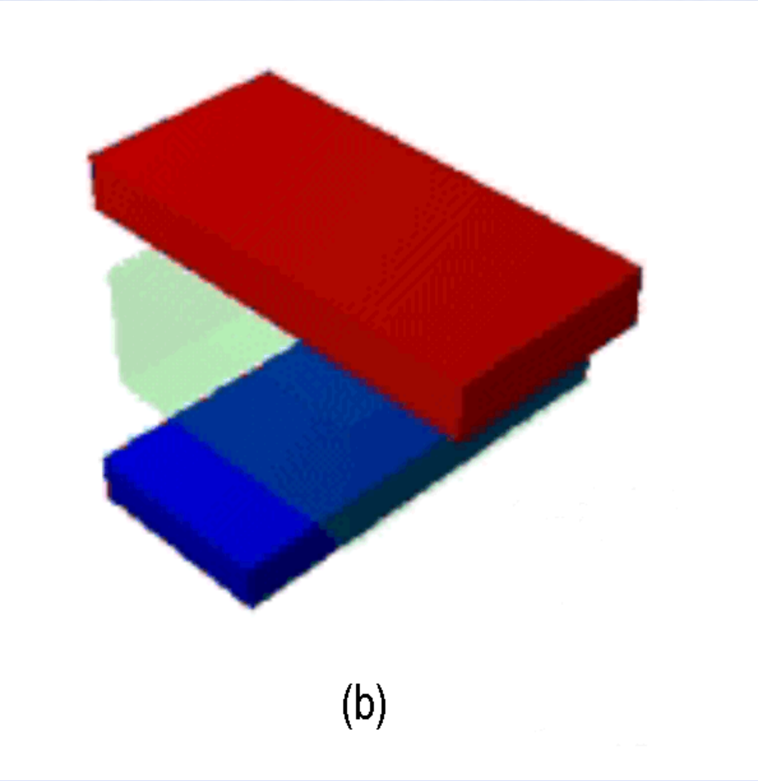
- Addressing Methods
  - Direct Addressing
  - Multiplexed Addressing
    - Passive Matrix Displays
    - Active Matrix Displays

Passive Matrix Displays (1)



- Use a set of multiplexed transparent electrodes
- The liquid crystal layer is placed between the electrodes
- The electrodes are constructed of indium tin oxide (semi-transparent)

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 (turn-off time)

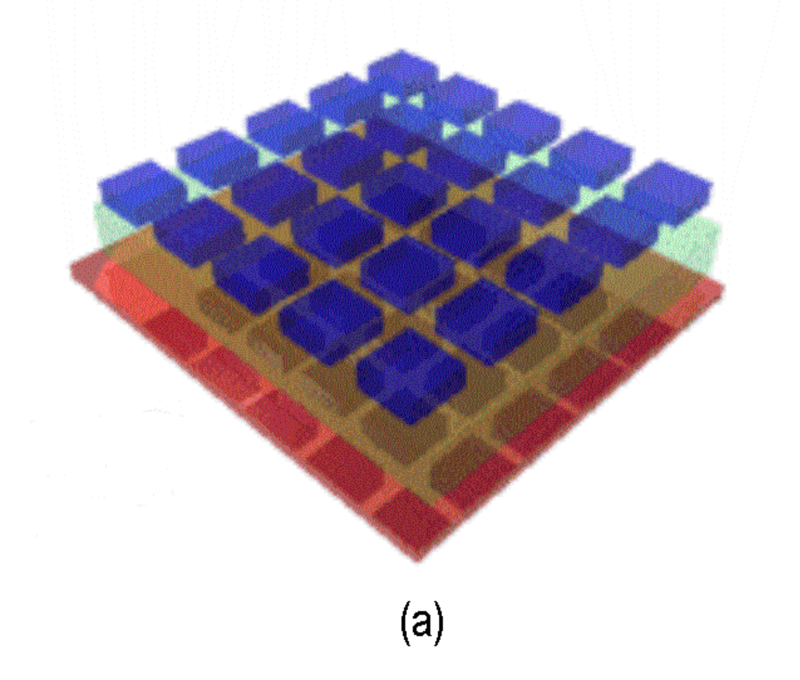
Passive Matrix Displays (4)

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

Addressing Methods

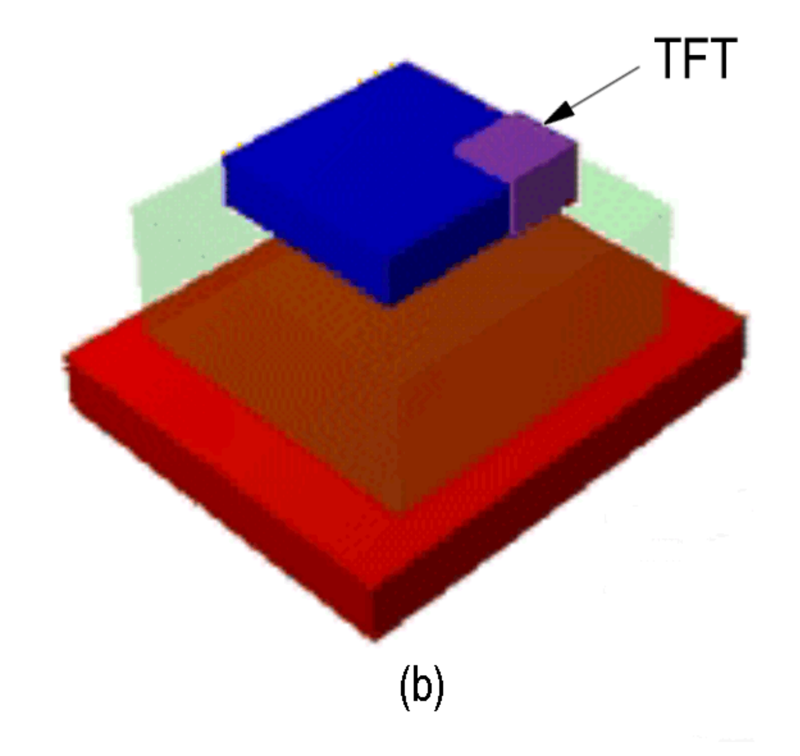
- Addressing Methods
  - Direct Addressing
  - Multiplexed Addressing
    - Passive Matrix Displays
    - Active Matrix Displays

Active Matrix Displays (1)



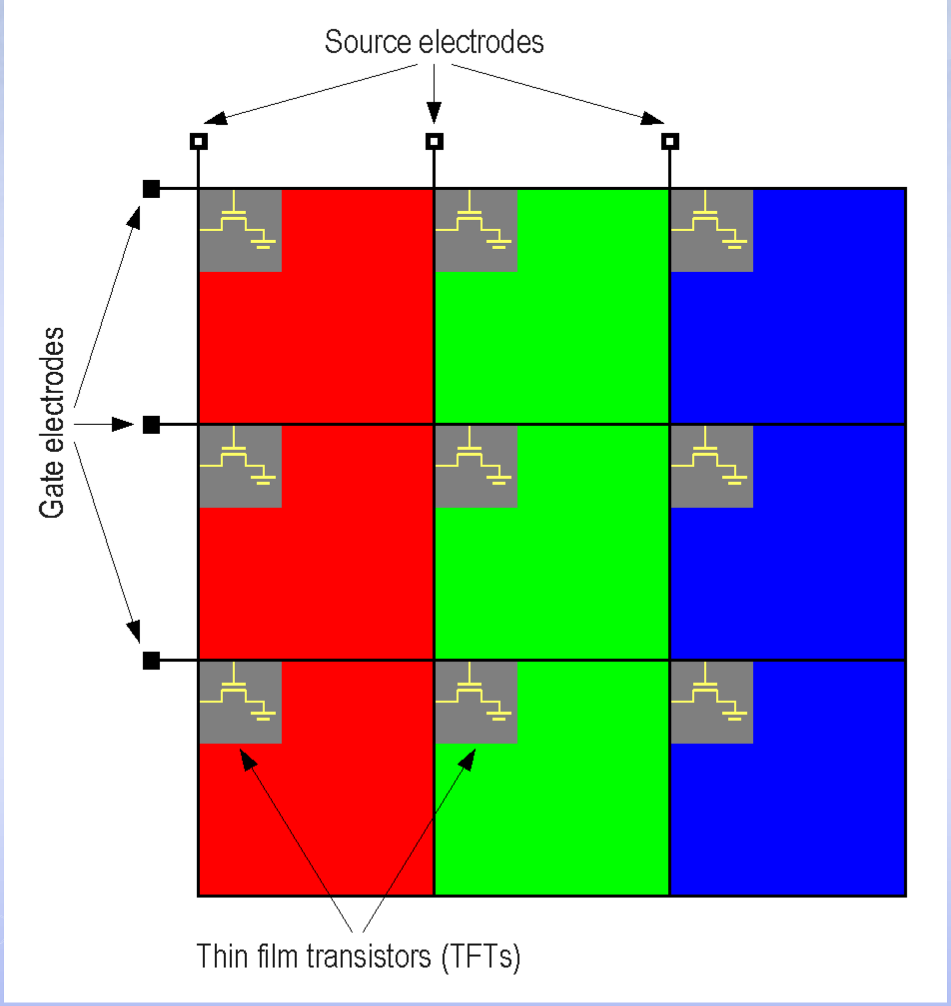
- The front glass plate of the display is coated with a continuous electrode
- The rear glass plate is coated with electrodes divided into pixels
- Each pixel is connected in series with a thin film transistor (TFT)

Active Matrix Displays (2)



- A pixel of the active matrix display
- Active elements: field effect transistors (FET)
  - Based on amorphous silicon (a-Si)
  - Based on polysilicon (p-Si)

Active Matrix Displays (3)



Active Matrix Displays (4)

- Selection of a row of pixels by applying voltage to the electrode that connects the transistor gates on that row
- Applying voltage to some pixels on the selected row via the electrodes connected to the transistor sources of those pixels
- Pixels that are not selected will be isolated from the voltages applied to the selected pixels in the matrix

Active Matrix Displays (5)

- An image is created by scanning the matrix:
  1. The select voltage is applied to the row electrode connected to the transistor gates of the first row
  2. Voltages corresponding to the image are applied to the column electrodes connected to the transistor sources
  3. The first row of pixels is deselected
  4. Steps 1-3 are repeated for each row

Active Matrix Displays (6)

- Advantages (compared to passive matrix displays):
  - Faster response time
  - Higher contrast
  - Higher brightness level
  - Wider viewing angle (> 50°)
- Disadvantages:
  - Require a more intense backlight
  - Higher cost

Active Matrix Displays (7)

- Defective pixels
  - For high resolutions, a large number of transistors are needed
    - For an SXGA resolution: 1280x1024x3 ≅ 3.93 million transistors
  - Defective transistors due to impurities
  - A lit pixel (permanently turned on)
  - A black pixel (permanently turned off)
  - Manufacturers set limits for an acceptable number of defective pixels

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Types of Passive Matrix Displays

- The performances of TN displays are low
- Various technologies have been developed:
  - STN
  - DSTN
  - FSTN
  - HPD
  - HPA

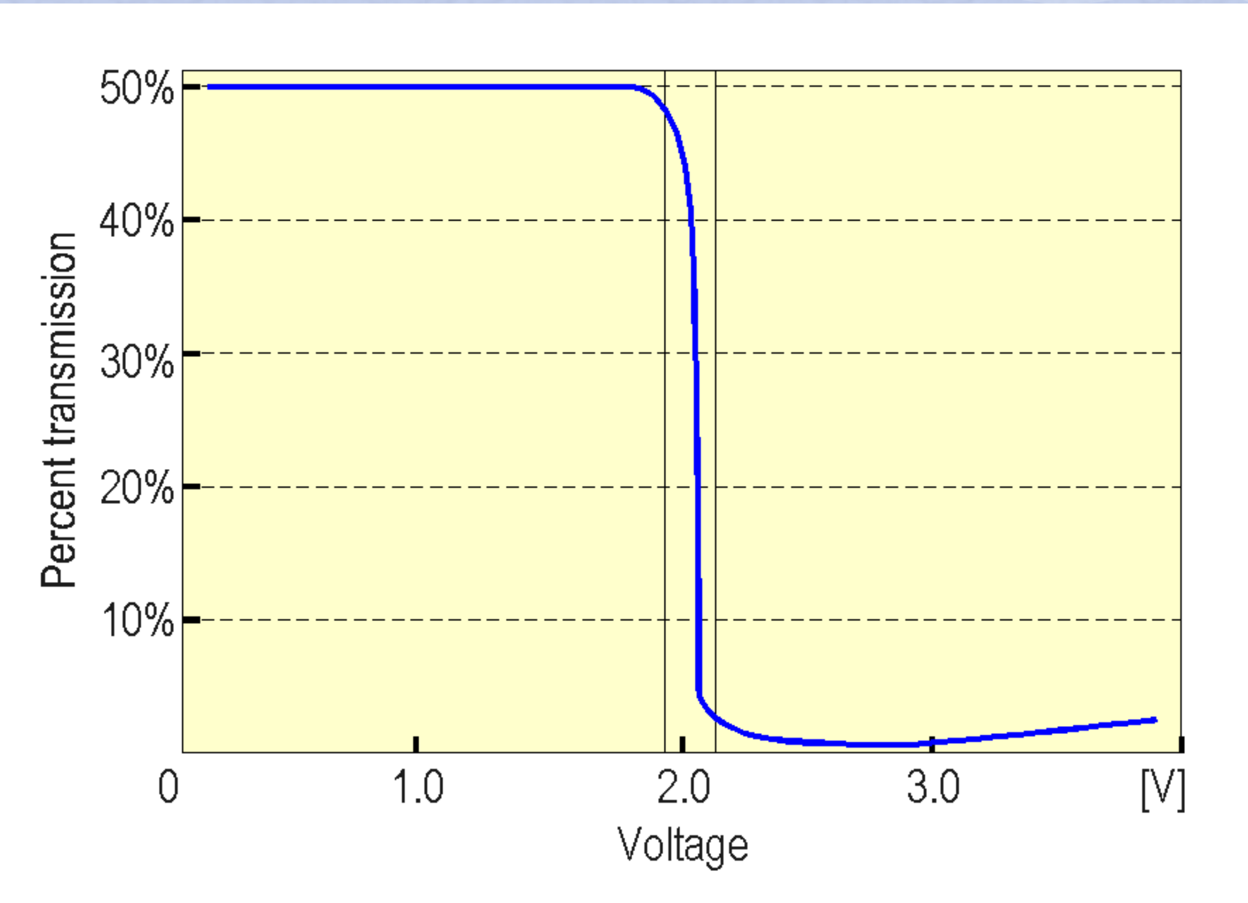
Types of Passive Matrix Displays

- Types of Passive Matrix Displays
  - STN Display
  - DSTN Display
  - FSTN Display
  - HPD Display
  - HPA Display

STN Display (1)

- STN – *Super-Twisted Nematic*
- The difference between the voltages for which a cell is on / off must be very small
- The TN display is impractical for large sizes with conventional addressing
- STN display: the direction of the polarized light is rotated with an angle of 180° .. 270°
- The diagram indicating the light transmission becomes more abrupt as the twist angle is increased

STN Display (2)



STN Display (3)

- Advantages of the STN display compared to the TN display:
  - Higher contrast
  - Wider viewing angle (40°)
  - Simpler control for the percent transmission of the light through the liquid crystal cells

STN Display (4)

- Disadvantages of the STN display:
  - Slower response time compared to the TN display (300 ms)
  - Lower brightness level
  - Higher manufacturing costs
  - The first STN displays presented an undesirable coloration because of a shifted transmission spectrum
    - In the on state: yellow
    - In the off state: bluish

Types of Passive Matrix Displays

- Types of Passive Matrix Displays
  - STN Display
  - DSTN Display
  - FSTN Display
  - HPD Display
  - HPA Display

DSTN Display (1)

- DSTN – *Double Super-Twisted Nematic*
- Solved the coloration problem of the STN display by adding a new STN layer
- For the second layer, the twisting direction of the polarized light is opposite compared to that of the first layer
- In the off state, the phase shift due to the first layer is compensated by the second layer → black pixel

DSTN Display (2)

- The on state of the pixel is not affected by the second STN layer → white pixel
- Both layers consist of the same type of liquid crystal → the characteristics are constant
- Disadvantages:
  - A more intense backlight is required to compensate for transmission losses
  - Higher cost
  - Higher thickness and weight

Types of Passive Matrix Displays

- Types of Passive Matrix Displays
  - STN Display
  - DSTN Display
  - FSTN Display
  - HPD Display
  - HPA Display

FSTN Display

- FSTN – *Film Super-Twisted Nematic*
- Color compensation is achieved with a thin polymer film instead of the additional glass layer
- Advantages compared to the DSTN display:
  - Lower cost
  - Lower thickness and weight
  - Lower-power light source
- Disadvantage:
  - Reduced contrast

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- Types of Passive Matrix Displays
  - STN Display
  - DSTN Display
  - FSTN Display
  - HPD Display
  - HPA Display

HPD Display (1)

- HPD (*Hybrid Passive Display*)
- Technology developed by Toshiba and Sharp Electronics
- Uses a new type of liquid crystal → quality improvement with little additional costs
- Lower viscosity of liquid crystals
  - More rapid orientation of the molecules → reduced response time

HPD Display (2)

- The glass plates are closer to one another
  - Increased intensity of the electric field used for turning on the pixels
- The contrast is reduced → the molecules return faster to their initial state
- The number of pulses per frame sent to each line for addressing it was increased → four pulses

HPD Display (3)

- A static RAM has been added, which allows the drivers to send pulses to multiple lines simultaneously
- The frame refresh rate increases from the typical value of 120 Hz to 150 Hz
  - The flickering effect is reduced
  - The contrast is improved
- Response time: 150 ms (300 ms for DSTN)

Types of Passive Matrix Displays

- Types of Passive Matrix Displays
  - STN Display
  - DSTN Display
  - FSTN Display
  - HPD Display
  - HPA Display

HPA Display

- HPA (*High Performance Addressing*)
- Technology developed by Hitachi; Sharp Electronics has developed its own version
- Uses the technique called multiline addressing
  - The incoming video signal is analyzed
  - The image is refreshed with a frequency as high as possible
- Can be used for video applications
- The cost is lower compared to that of active matrix displays