Lecture 13

6.976 Flat Panel Display Devices

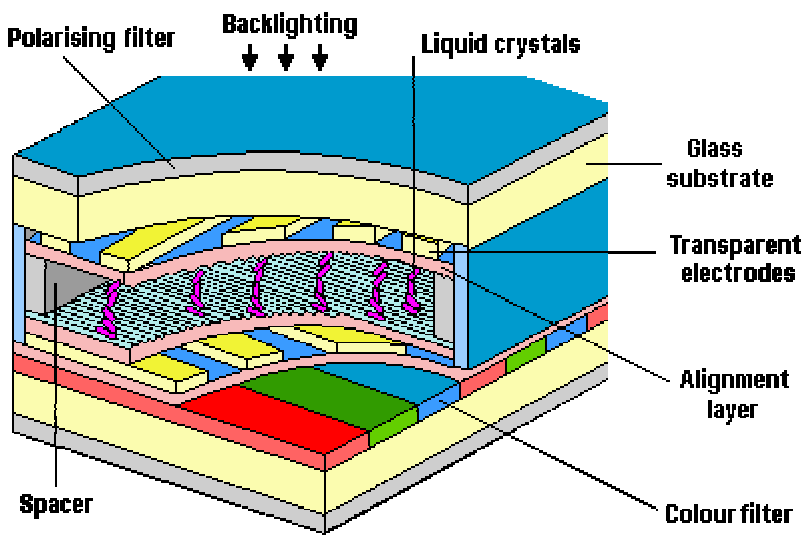
Passive Matrix Liquid Crystal Displays

Outline

- **Twisted Nematic (TN) Liquid Crystal Display**
- **Supertwisted Nematic Liquid Crystal Display**

Summary of Today's Lecture

- Passive matrix liquid crystal displays have simple structure and are easy to manufacture
- TN-LC do not have sufficient contrast for high information content displays
- STN-LCs have sufficient contrast for medium information content displays; however are not are not bright enough nor power efficient
- Rendering images in high information content displays based on TN and STNs is very challenging



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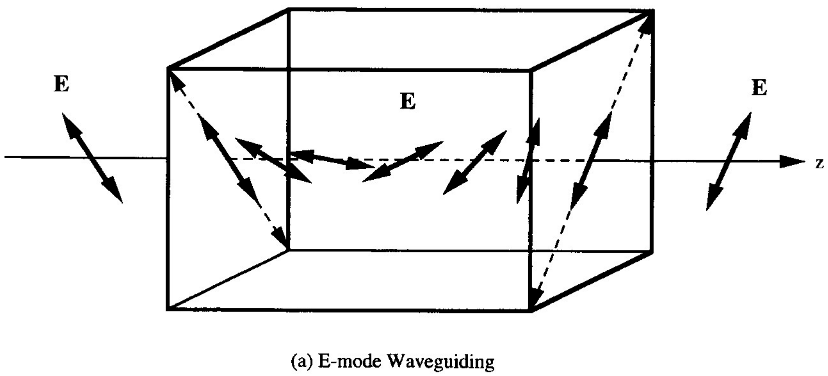
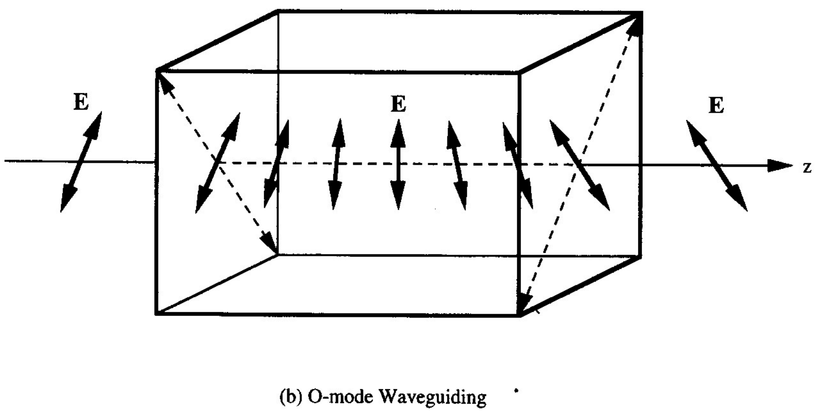
90º Twisted Nematic LC





E-mode Wave Guiding

O-mode Wave Guiding

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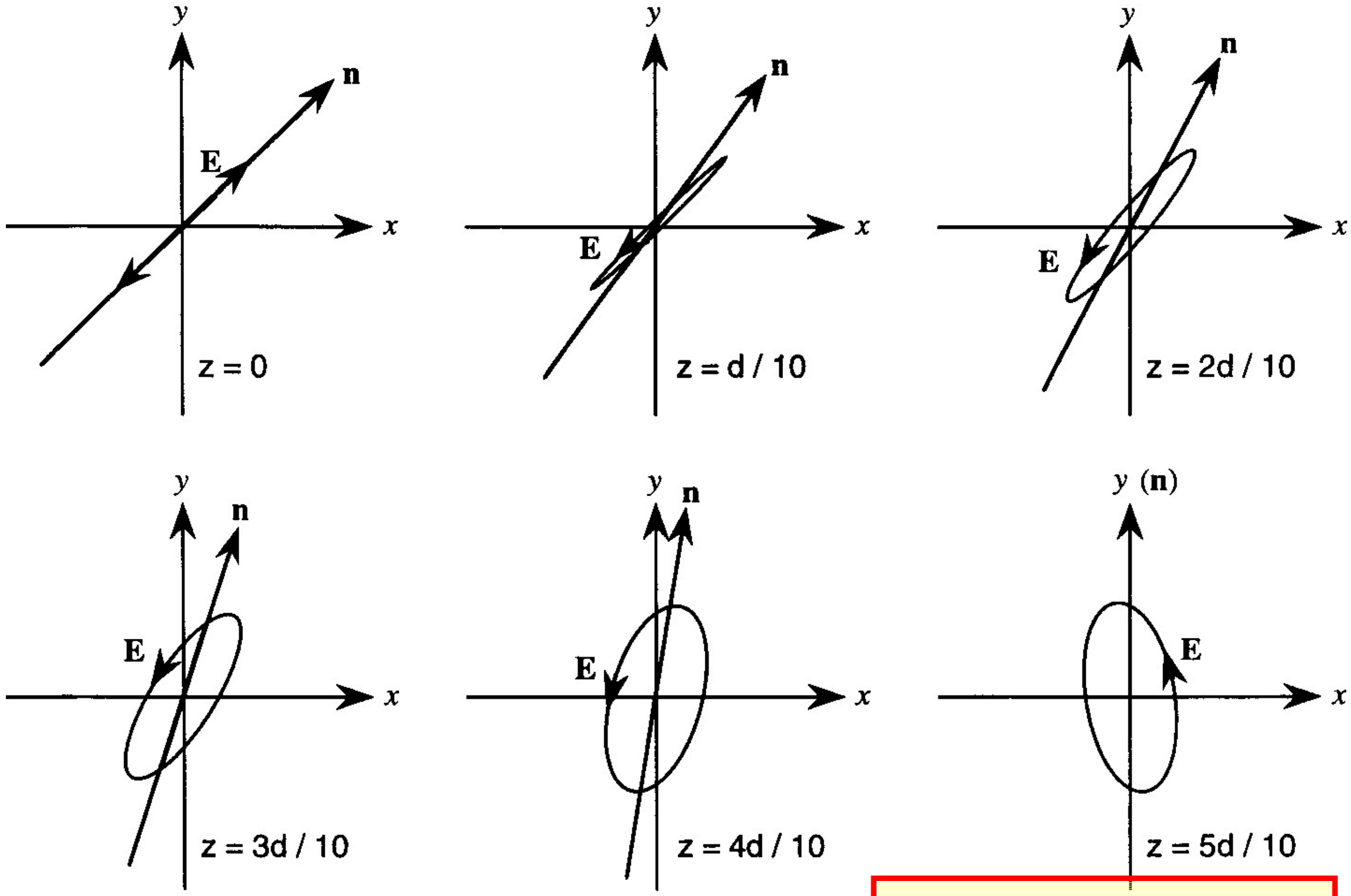
$$T = \frac{\sin^2\left[\phi\sqrt{1+u^2}\right]}{1+u^2}$$

$$u = \frac{\Gamma}{2\phi} = \frac{2}{\lambda}(n_e - n_o)d \quad \equiv \quad \text{Mauguin Parameter}$$

Γ is retardation
ϕ is twist

90º Twisted Nematic LC



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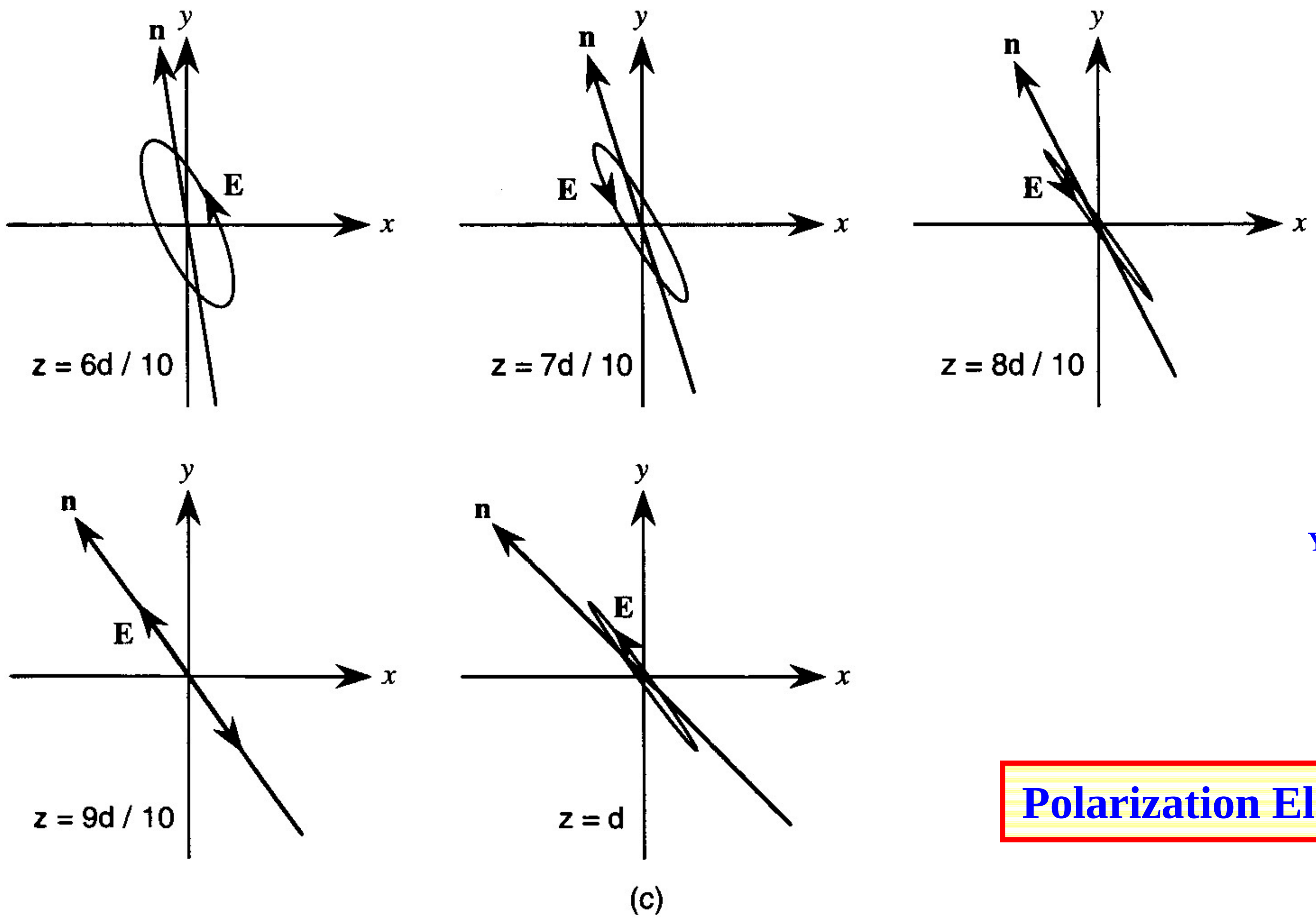
Polarization Ellipses

90° Twisted Nematic LC



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Polarization Ellipses

Exact Expression for Transmission

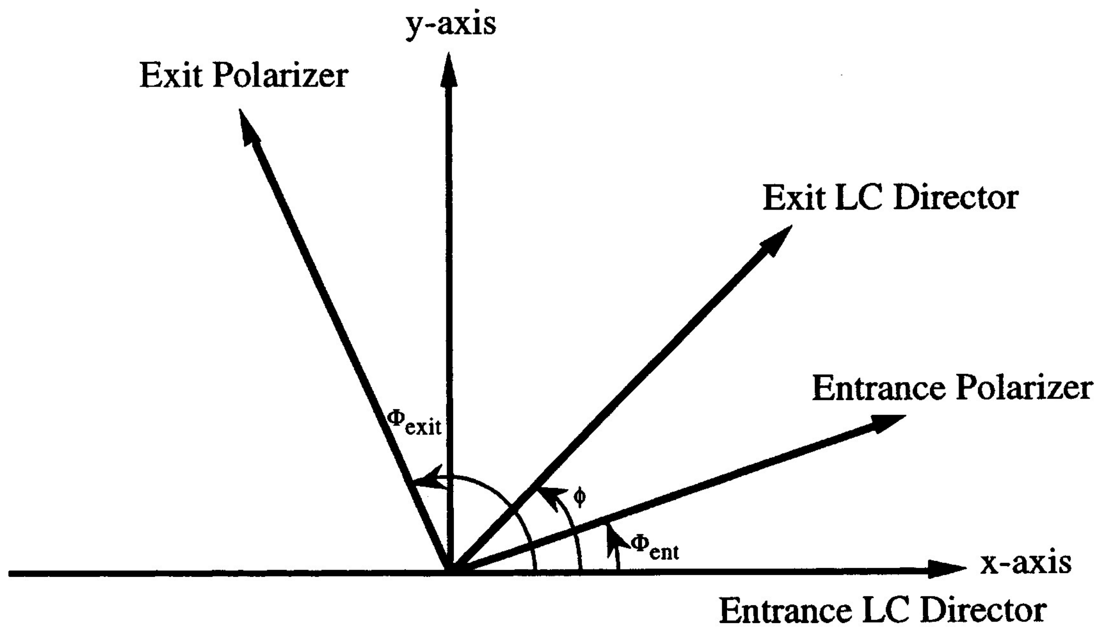
$$T_M = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{bmatrix} \cos X - j\frac{\Gamma}{2}\frac{\sin X}{X} & \phi\frac{\sin X}{X} \\ -\phi\frac{\sin X}{X} & \cos X + j\frac{\Gamma}{2}\frac{\sin X}{X} \end{bmatrix}$$

$$X = \sqrt{\phi^2 + \left(\frac{\Gamma}{2}\right)^2}$$

When $\phi << \Gamma$, then

$$T_M = \begin{pmatrix} \cos\phi & -\sin\phi \\ \sin\phi & \cos\phi \end{pmatrix} \begin{pmatrix} e^{-j\frac{\Gamma}{2}} & 0 \\ 0 & e^{+j\frac{\Gamma}{2}} \end{pmatrix}$$

Transmission for a General TN-LCD



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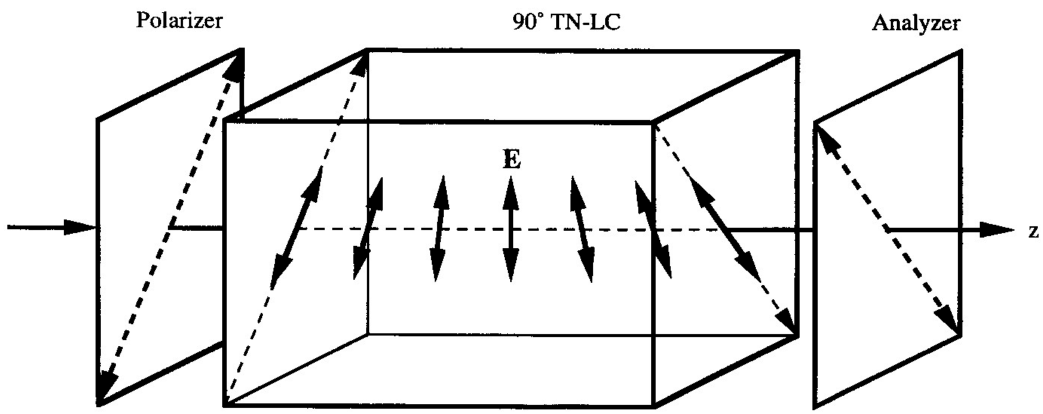
$$\begin{pmatrix} V_x \\ V_y \end{pmatrix} = \begin{pmatrix} \cos\Phi_{ent} \\ \sin\Phi_{ent} \end{pmatrix} \qquad \begin{pmatrix} V'_x \\ V'_y \end{pmatrix} = \begin{pmatrix} \cos\Phi_{exit} \\ \sin\Phi_{exit} \end{pmatrix}$$

$$T = \cos^2(\phi - \Phi_{exit} + \Phi_{ent}) + \sin^2 X \sin 2(\phi - \Phi_{exit}) \sin 2\Phi_{ent}$$
$$+ \frac{\phi}{2X} \sin 2X \sin 2(\phi - \Phi_{exit} + \Phi_{ent})$$
$$+ \phi^2 \frac{\sin^2 X}{X^2} \cos 2(\phi - \Phi_{exit}) \cos 2\Phi_{ent}$$

Twisted Nematic Liquid Crystal Display

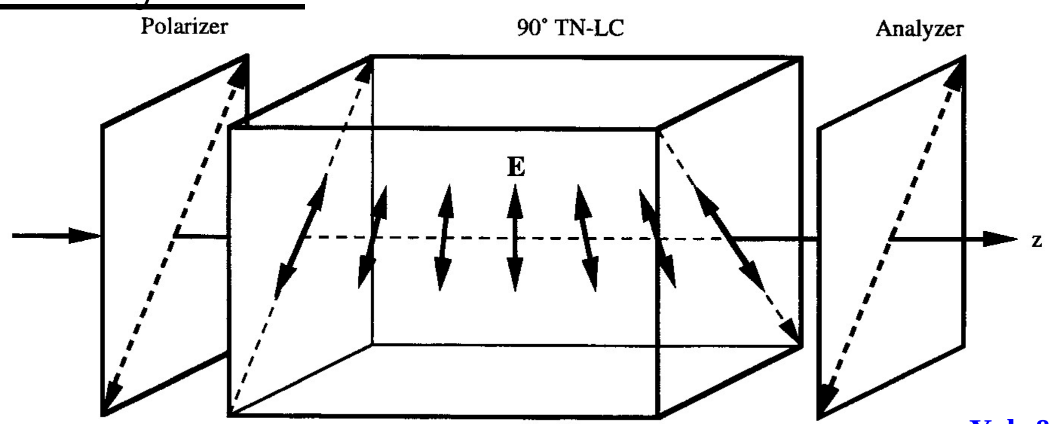
Principles of Operation

Normally White



(a)

Normally Black



(b)

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Figure 5.1. Principle of operation of TN displays (*E* mode): (*a*) NW operation; (b) NB operation. The dashed arrows on the surface of the TN-LC cell indicate the rubbing directions.

$$\begin{pmatrix} V_e \\ V_o \end{pmatrix} = \begin{pmatrix} 1 \\ 0 \end{pmatrix}$$

$$\begin{pmatrix} V_e' \\ V_o' \end{pmatrix} = \begin{pmatrix} \cos X - j\dfrac{\Gamma}{2}\dfrac{\sin X}{X} \\ -\phi\dfrac{\sin X}{X} \end{pmatrix}$$

where

$$\Gamma = \frac{2\pi}{\lambda}(n_e - n_o)d$$

$$X = \sqrt{\phi^2 + \left(\frac{\Gamma}{2}\right)^2}$$

Normally Black (NB) Mode

(Field Off)

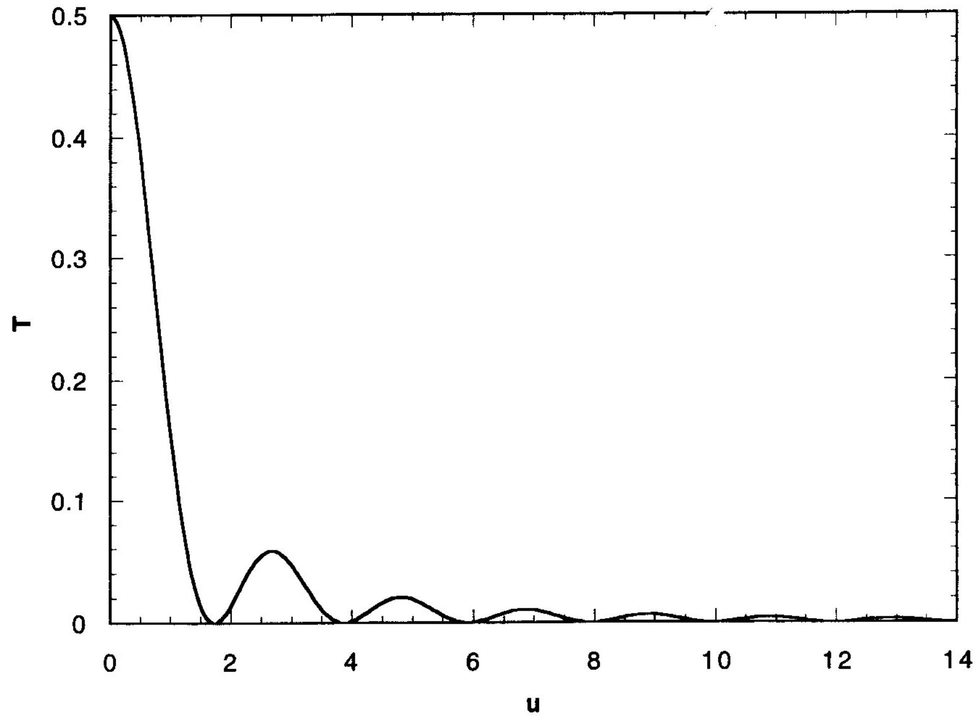

Figure 5.2. Transmission of NB TN displays (T vs. u), with $u = 2d\,\Delta n/\lambda$.

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$$T = \frac{1}{2}\phi^2 \frac{\sin^2 X}{X^2} = \frac{1}{2}\frac{\sin^2\left[\frac{\pi}{2}\sqrt{1+u^2}\right]}{1+u^2}$$

$$u = \frac{\Gamma}{2\phi} = \frac{2}{\lambda}(n_e - n_o)d$$

Normally White (NW) Mode

(Field Off)

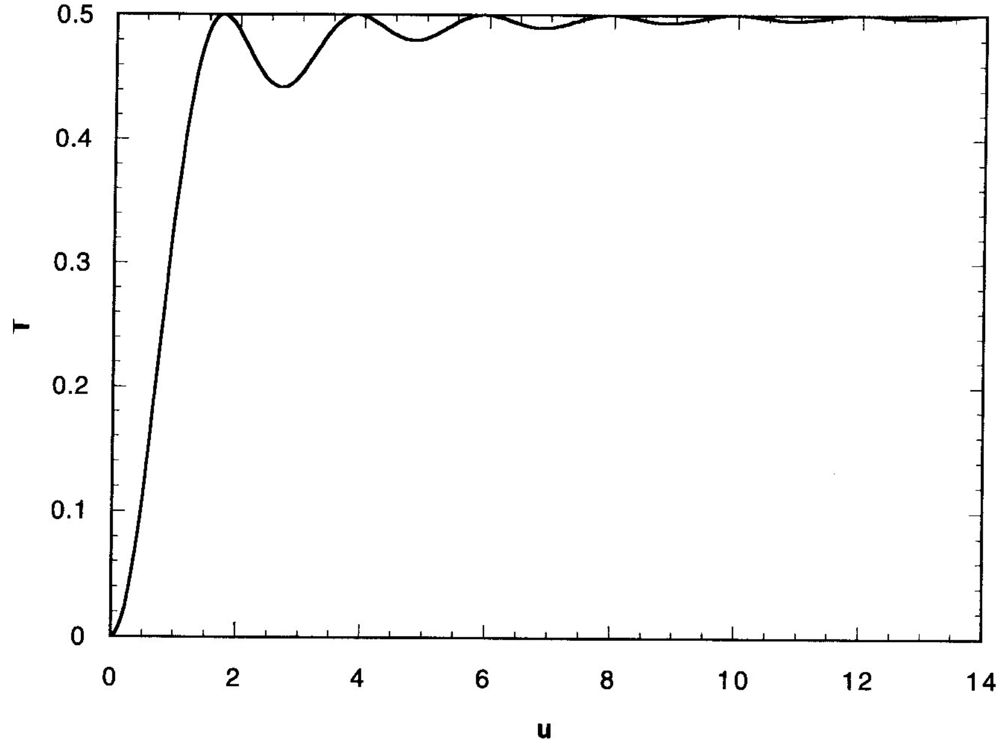

Figure 5.3. Transmission of NW TN displays (T vs. u), with $u = 2d\,\Delta n/\lambda$.

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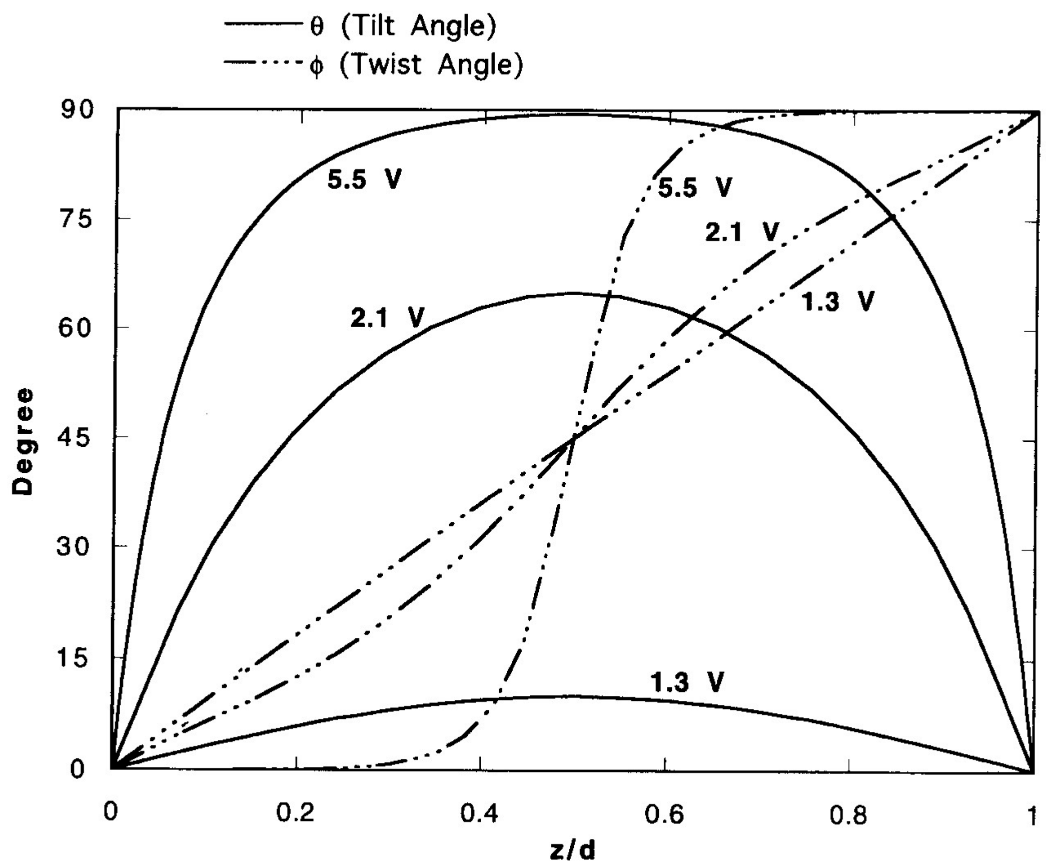
$$T = \frac{1}{2} - \frac{1}{2}\frac{\sin^2\left[\frac{\pi}{2}\sqrt{1+u^2}\right]}{1+u^2}$$

$$u = \frac{\Gamma}{2\phi} = \frac{2}{\lambda}\left(n_e - n_o\right)d$$

Transmission Properties of Field-On State

- Cell is 5-10 μm thick
- A voltage of 1.5 V leads to E= 1.5-3.0 kV/cm
- LC molecules align parallel to field to minimize energy
  - Re-distribution of LC directors

Field Induced Director Re-orientation



$$V_T = V_{c1}\left[1 + \frac{\Phi^2}{\pi^2}\left(\frac{k_3 - 2k_2}{k_1}\right)\right]^{1/2}$$

$$V_{c1} = \pi\sqrt{\frac{k_1}{\Delta\varepsilon}}$$

For Twisted Nematic

$$V_T = V_{c1}\left[1 + \left(\frac{k_3 - 2k_2}{4k_1}\right)\right]^{1/2}$$

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Mid-Layer Tilt Angle

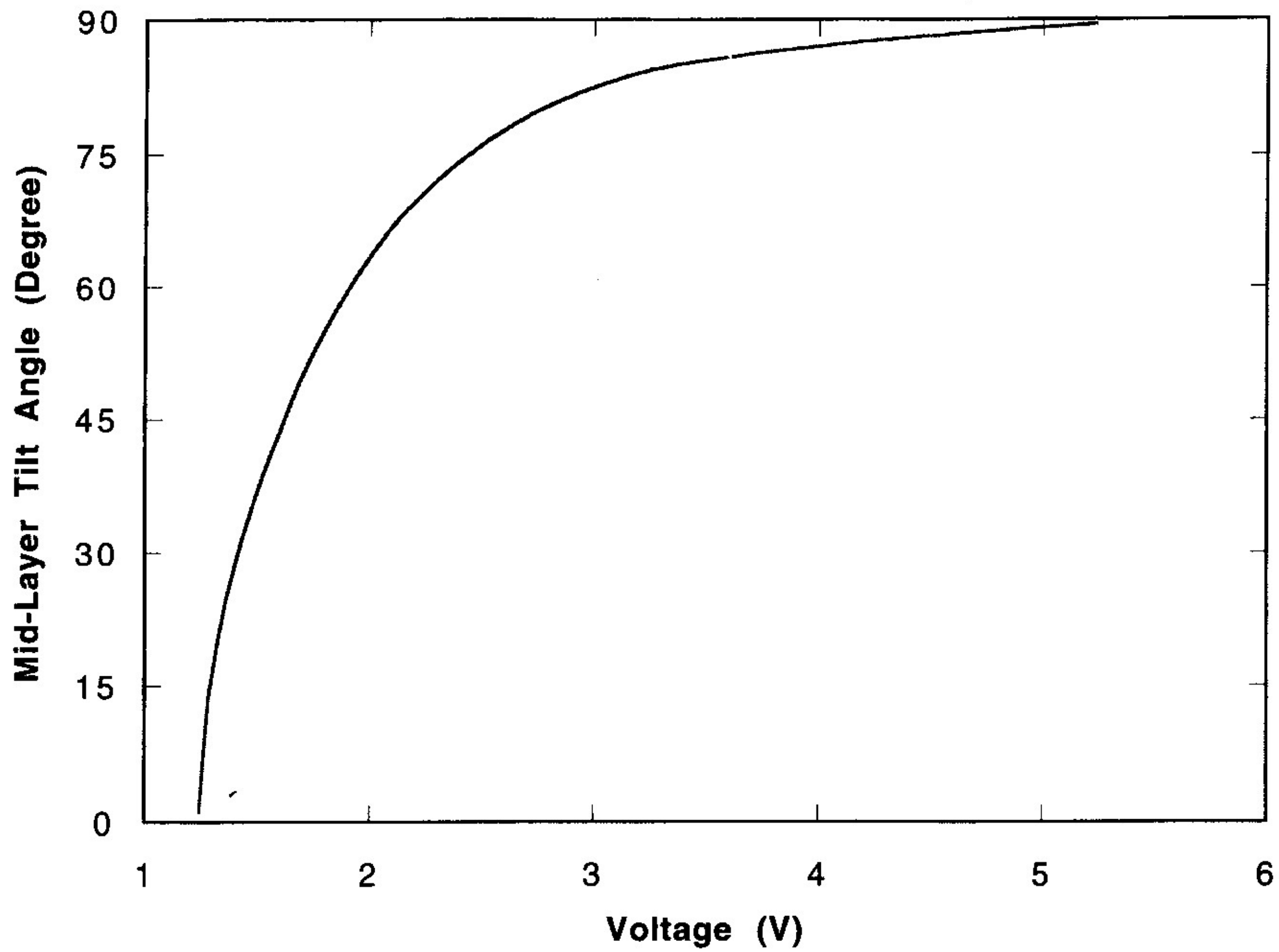

Figure 5.7. The midlayer tilt angle as a function of the applied voltage.

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Transmission of NB-TN Cell

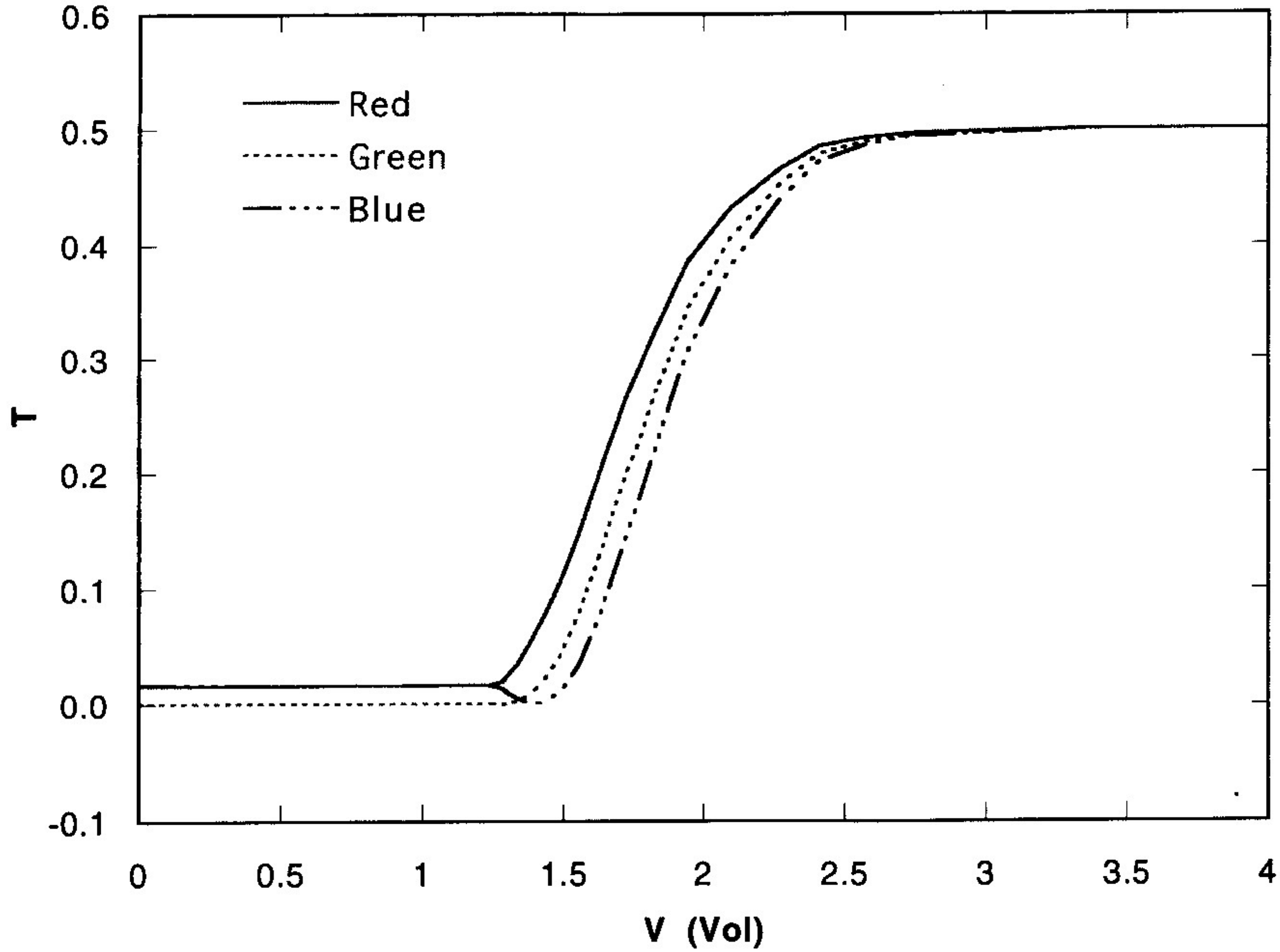

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Figure 5.8. Transmission of a TN cell in the NB mode as a function of the applied voltage.

Transmission of NW-TN Cell

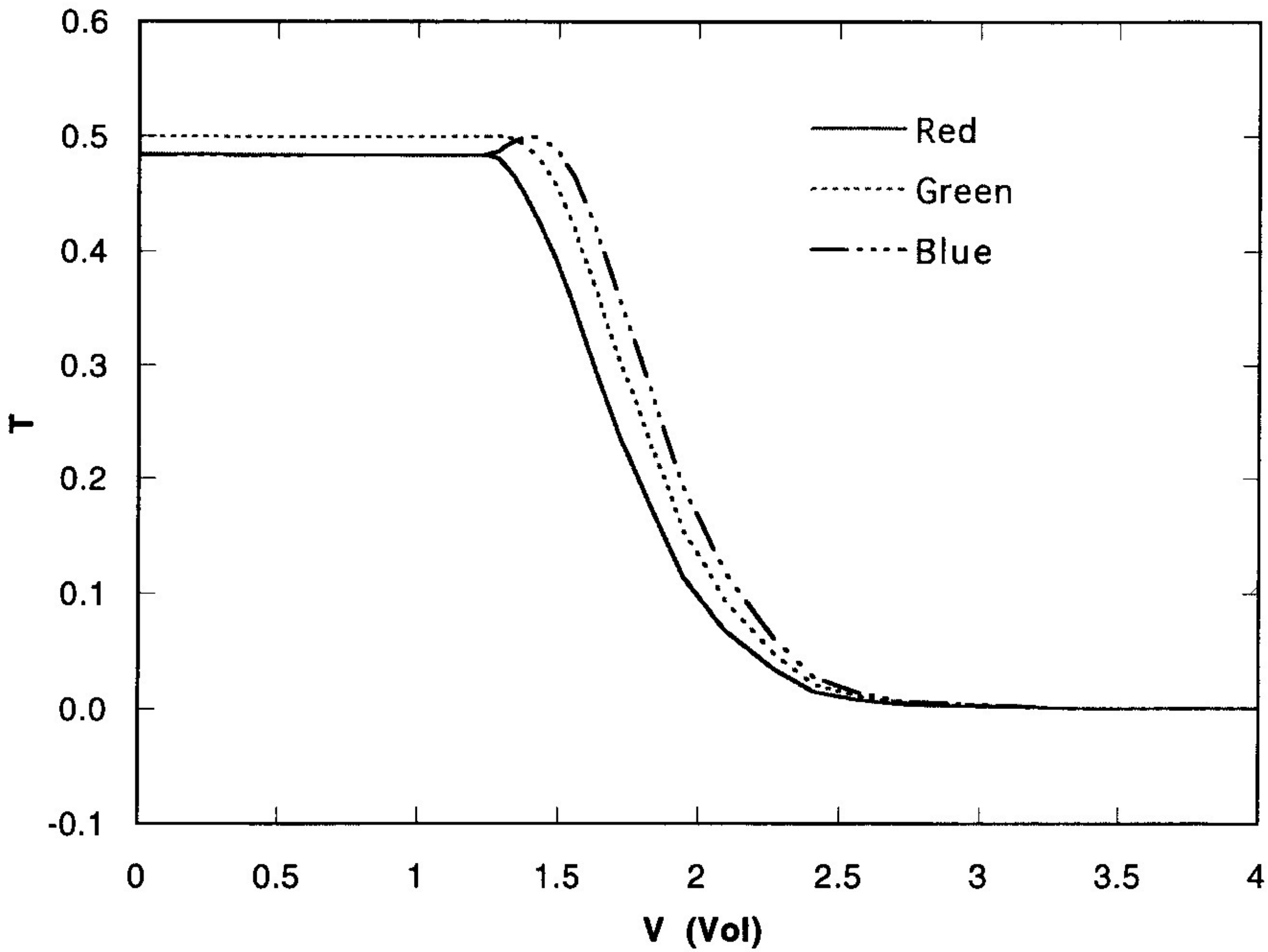

Figure 5.9. Transmission of a TN cell in the NW mode as a function of the applied voltage.

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Contrast Ratio of TN Cell
(Normal Incidence)

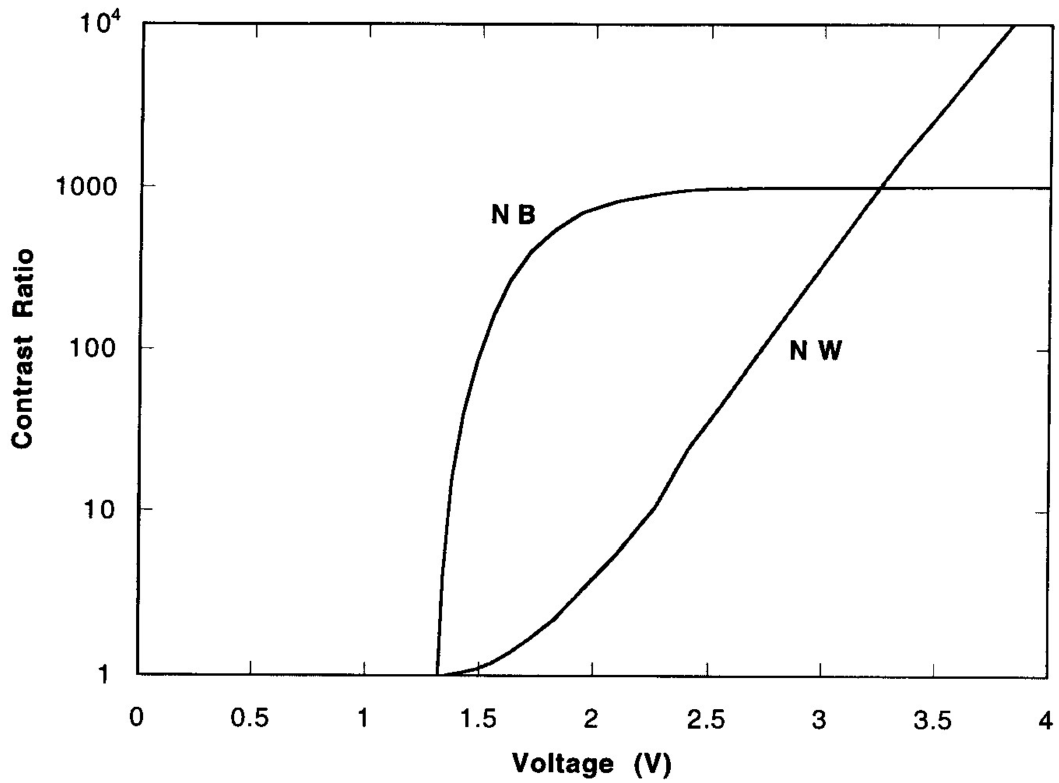

Figure 5.10. Contrast ratio as a function of the applied voltage.

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$$C_{NB} = \frac{T_{NB}(V)}{T_{NB}(0)}$$

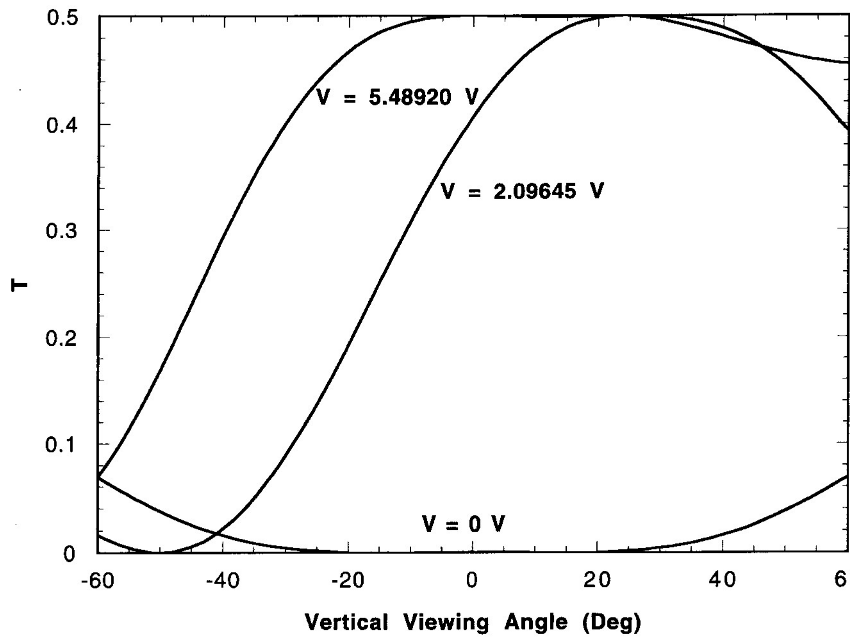
$$C_{NW} = \frac{T_{NW}(0)}{T_{NW}(V)} = \frac{0.5 - T_{NB}(V)}{0.5 - T_{NB}(0)}$$

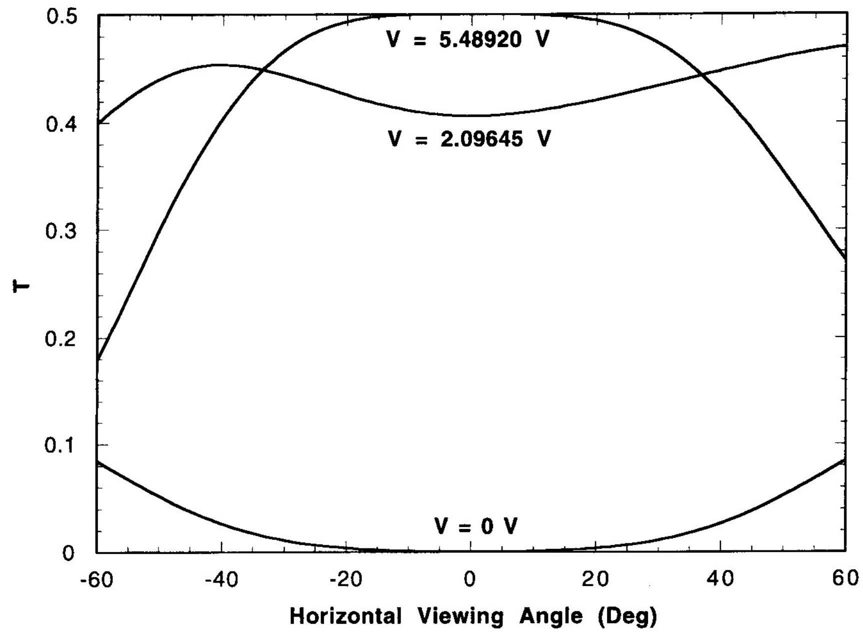
If $T_{NB}(0)=T_o$ and $T_{NB}(V)=T_1$

$$C_{NB} = \frac{T_1}{T_0}$$

$$C_{NW} = \frac{0.5 - T_0}{0.5 - T_1}$$

Viewing Angle of NB TN-LCD





Vertical Viewing Angle

Horizontal Viewing Angle

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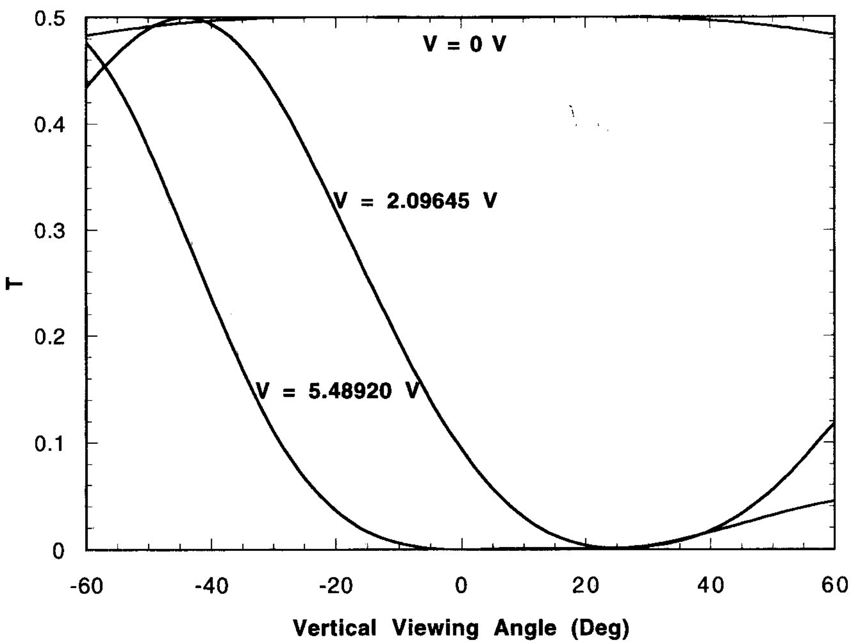
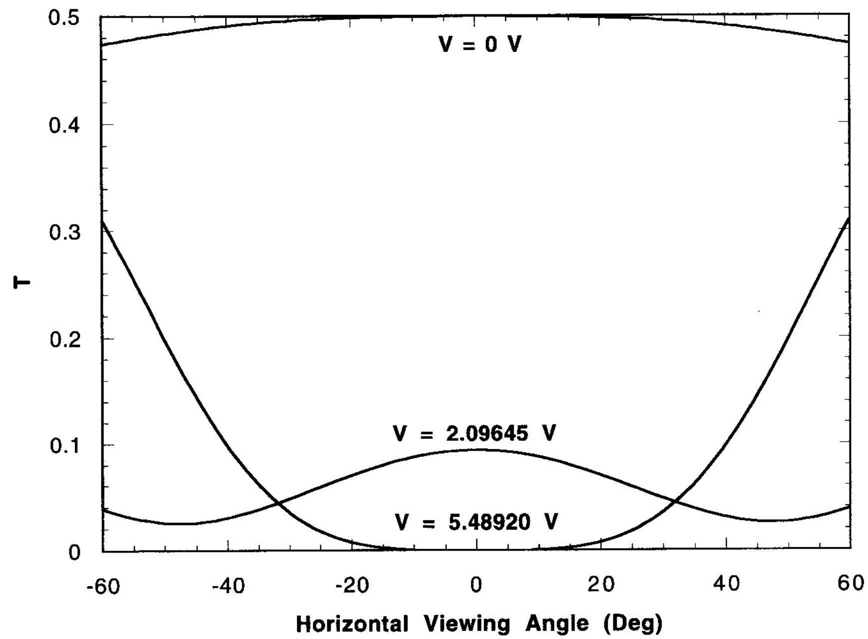
Viewing Angle of N~~B~~ TN-LCD



Vertical Viewing Angle



Horizontal Viewing Angle

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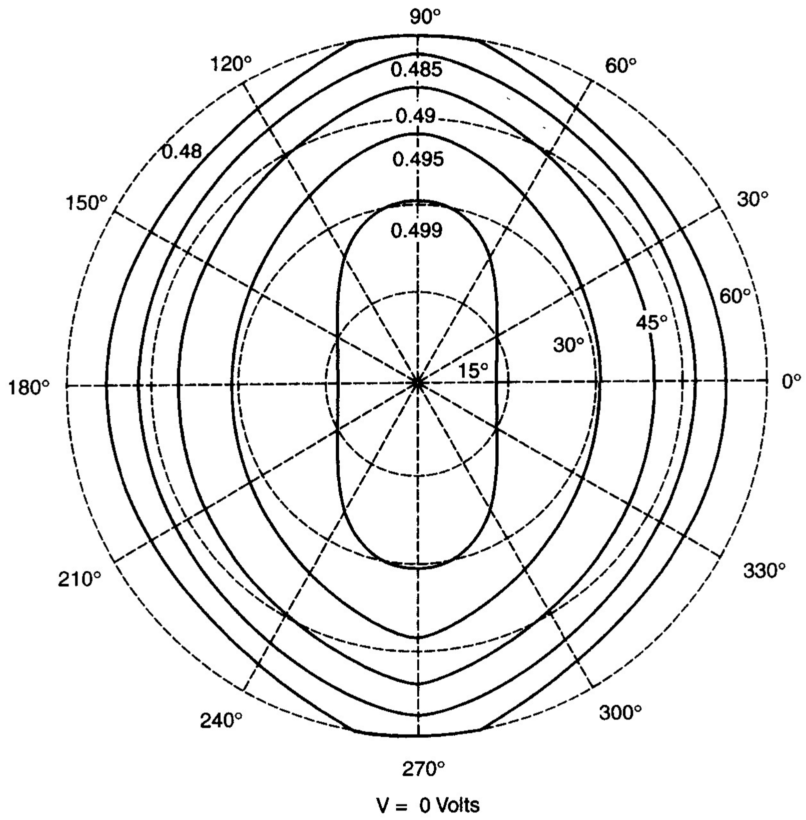
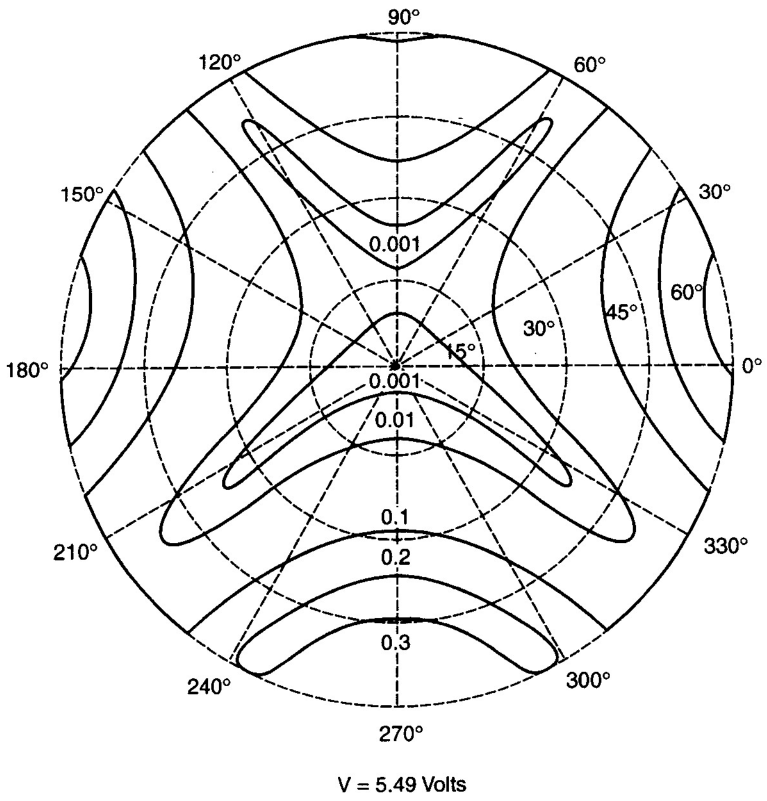
Isotransmittance





V= 0 V

V= 5.49 V

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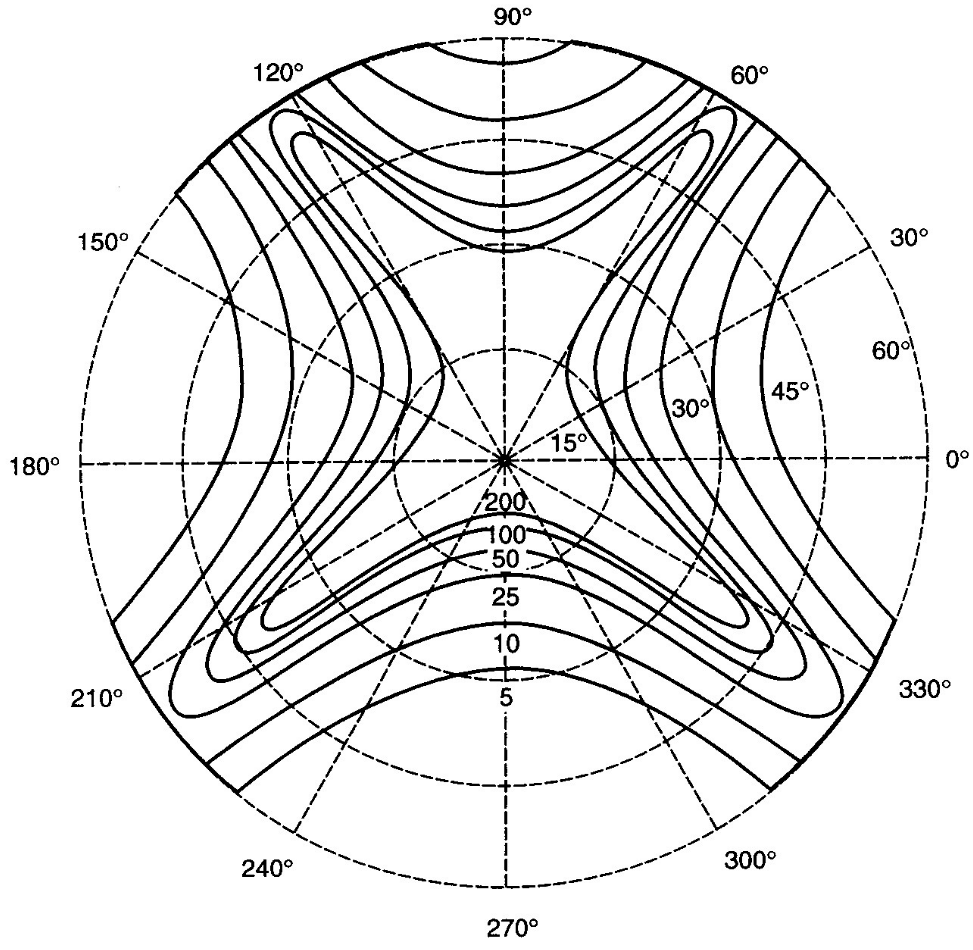
Iso-Contrast Plot

(NW-TN-LCD)



(b)

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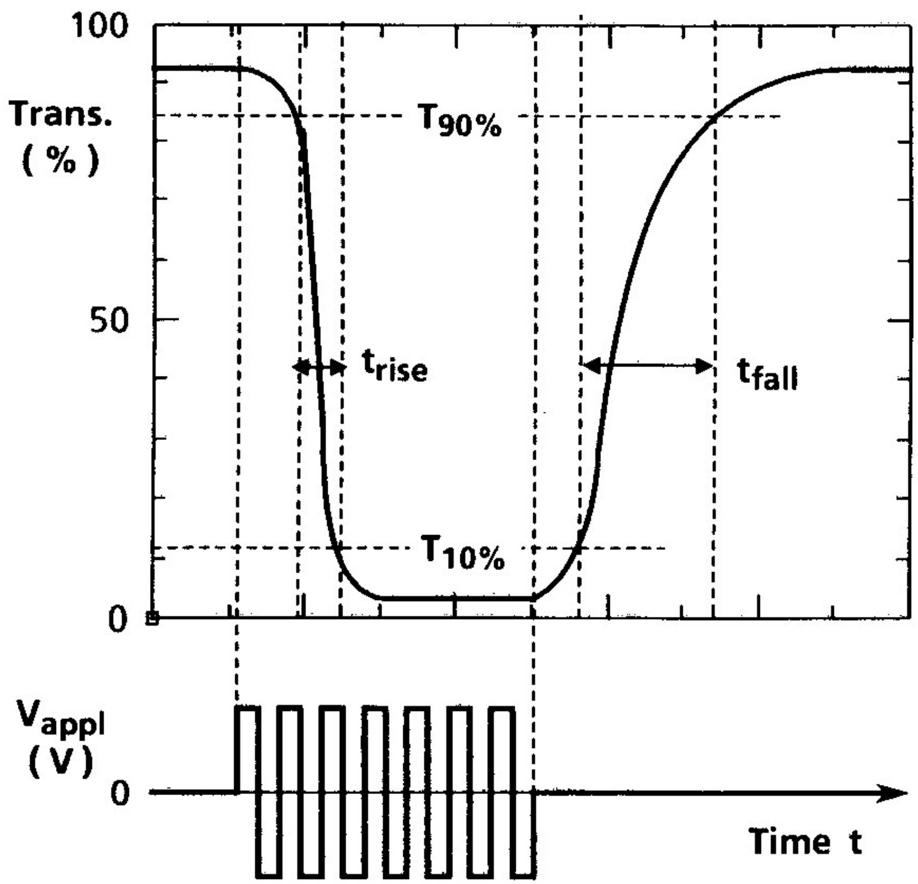
V=5.49 Volts

Transient Response of TN Cell



For $V_{appl} > V_{90}$:

$t_{rise} \propto \eta / (\Delta\varepsilon . V_{appl}^2)$

$t_{fall} \propto \eta . d^2 / K$

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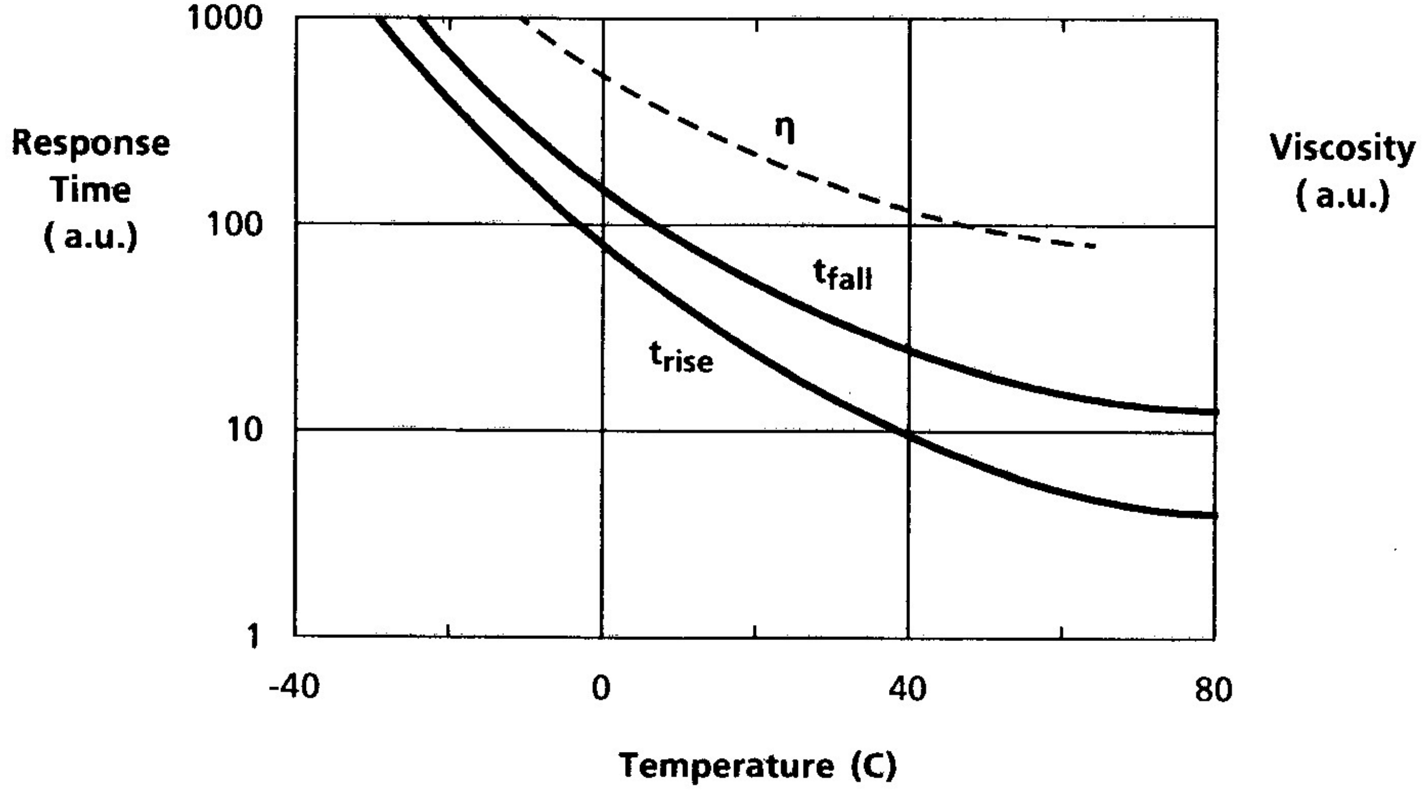
Transient Response of TN Cell



At 20C: t_{rise} ~ 15 ms
t_{fall} ~ 25 ms

At 0C: t_{rise} ~ 30 ms
t_{fall} ~ 60 ms

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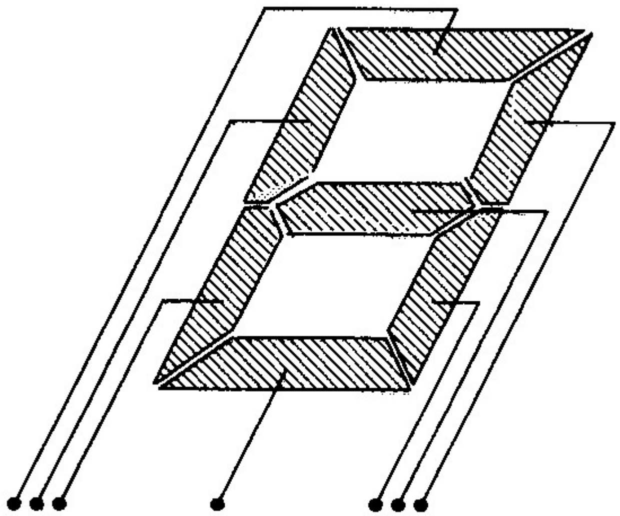
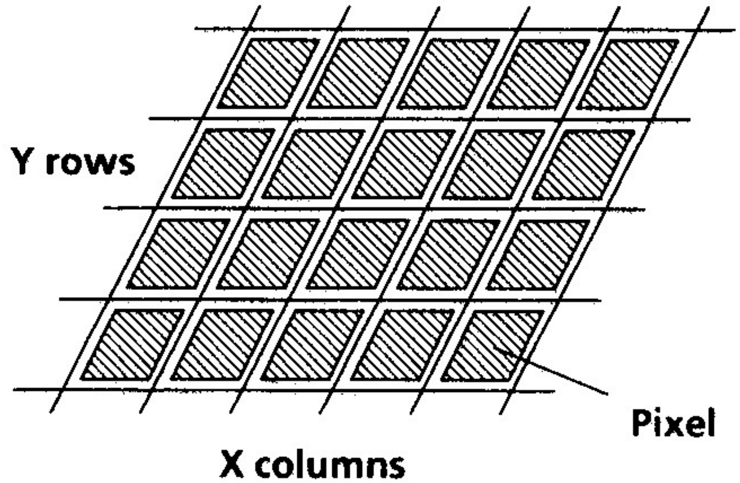
Rendering LCD Images



Electrode configuration of "7 segment " LCD



XY addressing of a 'dot matrix' LCD

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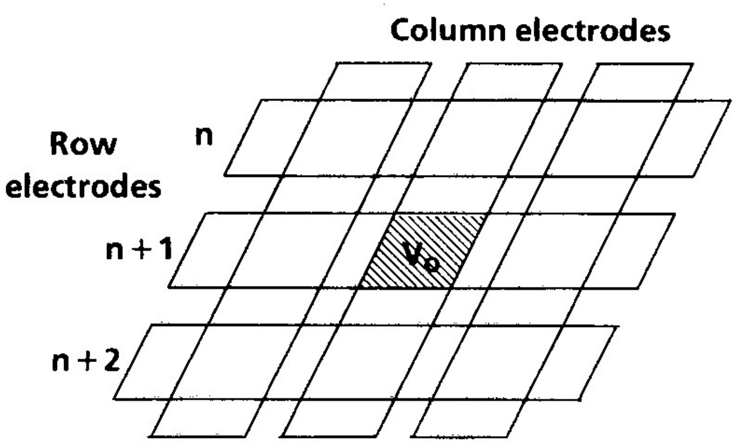
- Direct addressing requires X×Y electrical connections
- Multiplexing requires X + Y electrodes

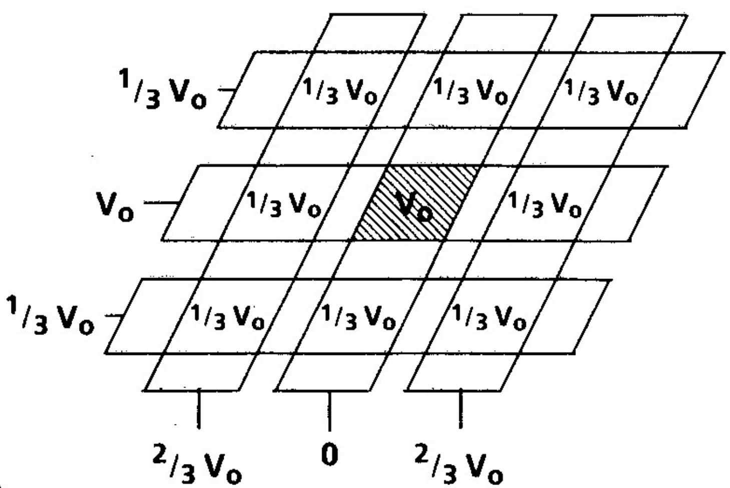
Multiplexed Displays

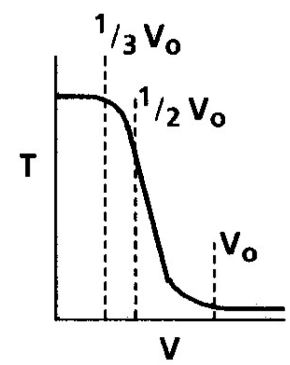
- Positive voltage Vs applied to one row at a time starting from row 1
  - M elements on first row can be turned ON or OFF depending on the applied voltage [-V_d, V_d]
- Instantaneous voltage drops at pixel in row selected
  - ON state; $V=V_s-(-V_d)$
  - OFF state; $V=V_s-V_d$
- Voltage drops exist at other pixels
  - $\pm V_d$ at the pixels on non-selected rows
  - V_s-V_d at OFF pixels of selected row
- In each multiplex cycle, row selected for 1/N of the frame time
- Difference between rms voltage of ON state versus OFF state is very small when N is large

$$\text{Selection Ration} = \frac{V_{ON}}{V_{OFF}} = \sqrt{\frac{\sqrt{N_{\mathbf{max}}}+1}{\sqrt{N_{\mathbf{max}}}-1}}$$

Addressing a Passive Matrix LCD







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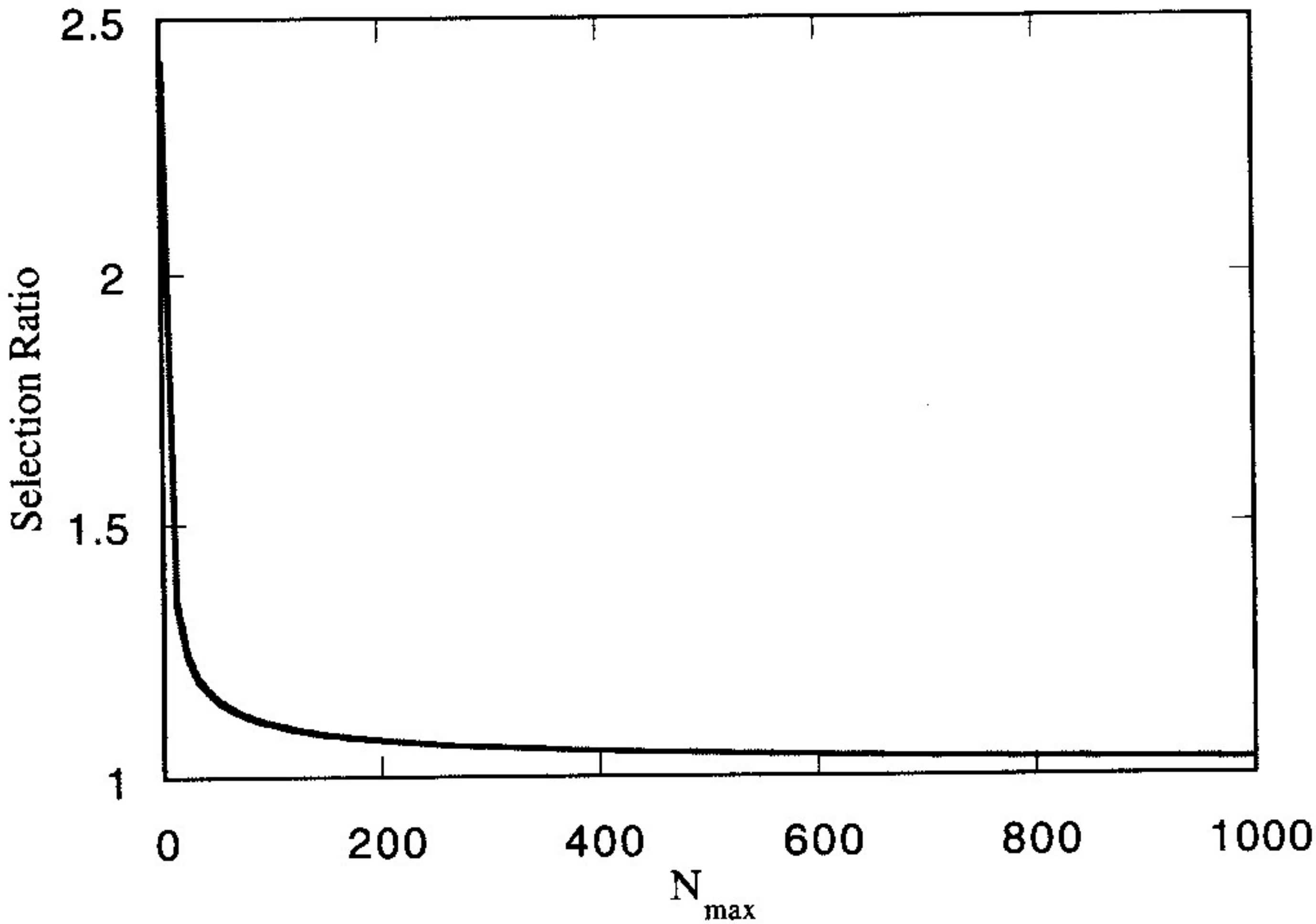
Limitations of Multiplexed TN-LCD

- Multiplexing results in Crosstalk
- Limited difference between ON and OFF voltages
- Display contrast limited

- High contrast and High information content display requires significant redistribution of LC directors at a reasonable voltage

Solution
Supertwisted Nematic LCs—chiral nematic LC
Nematic LCs doped with material with intrinsic optical rotatory power

Selection Ratio



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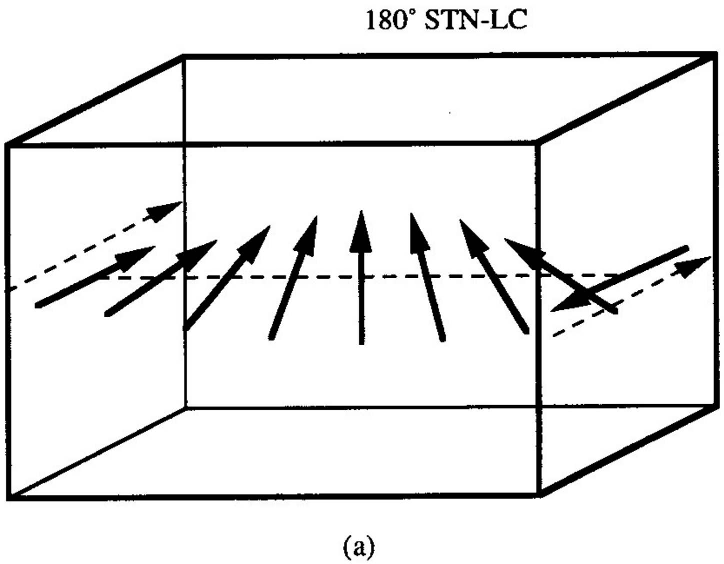
STN-LC Cell



180º STN-LC Cell

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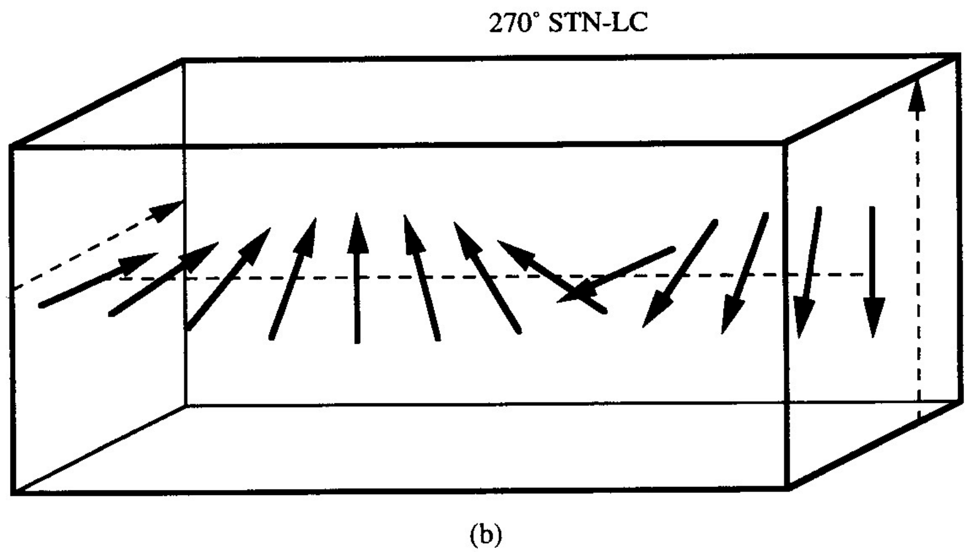
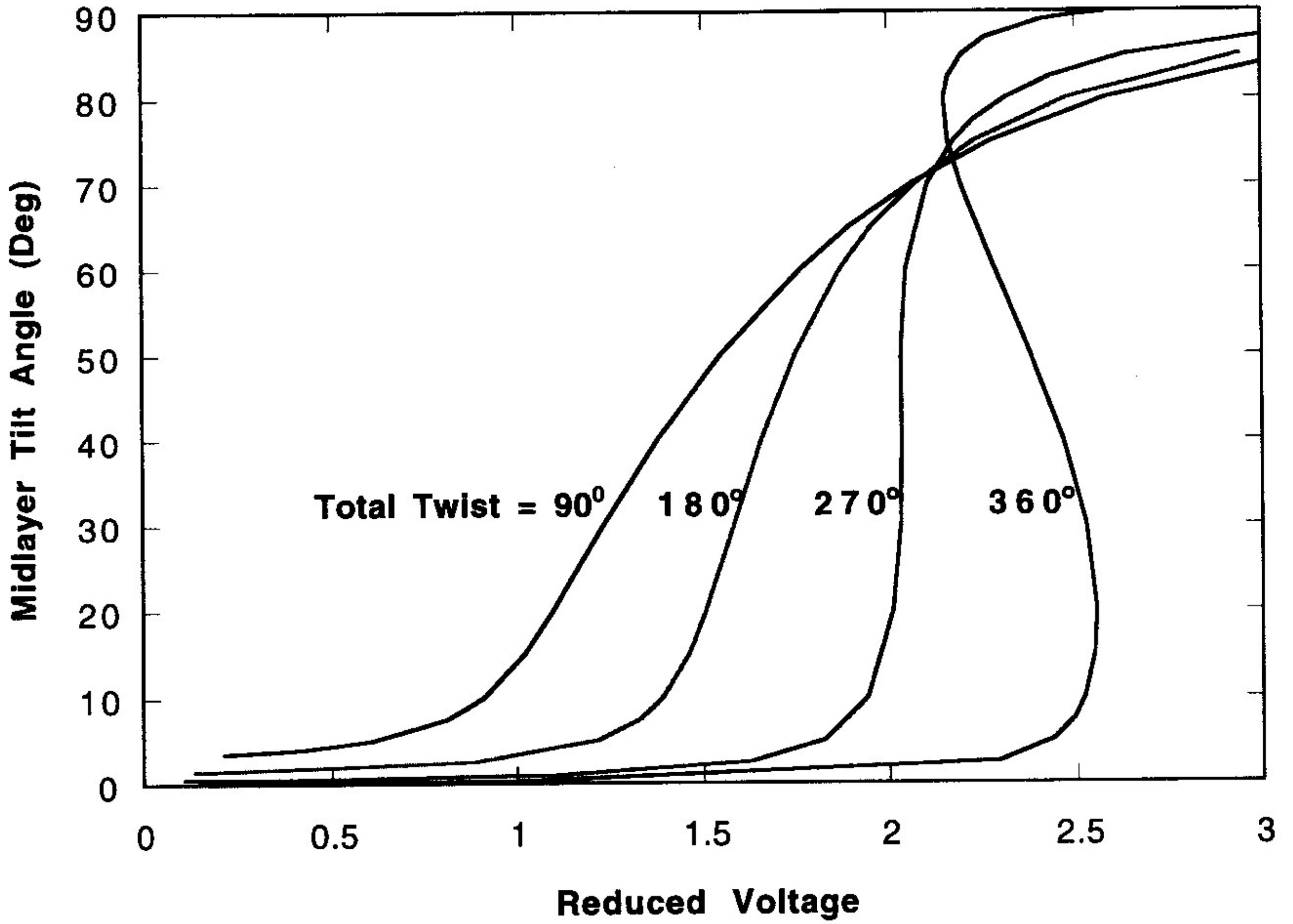


270º STN-LC Cell

Electro-distortional Curve for TN and STN



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STN-LCD Transmission

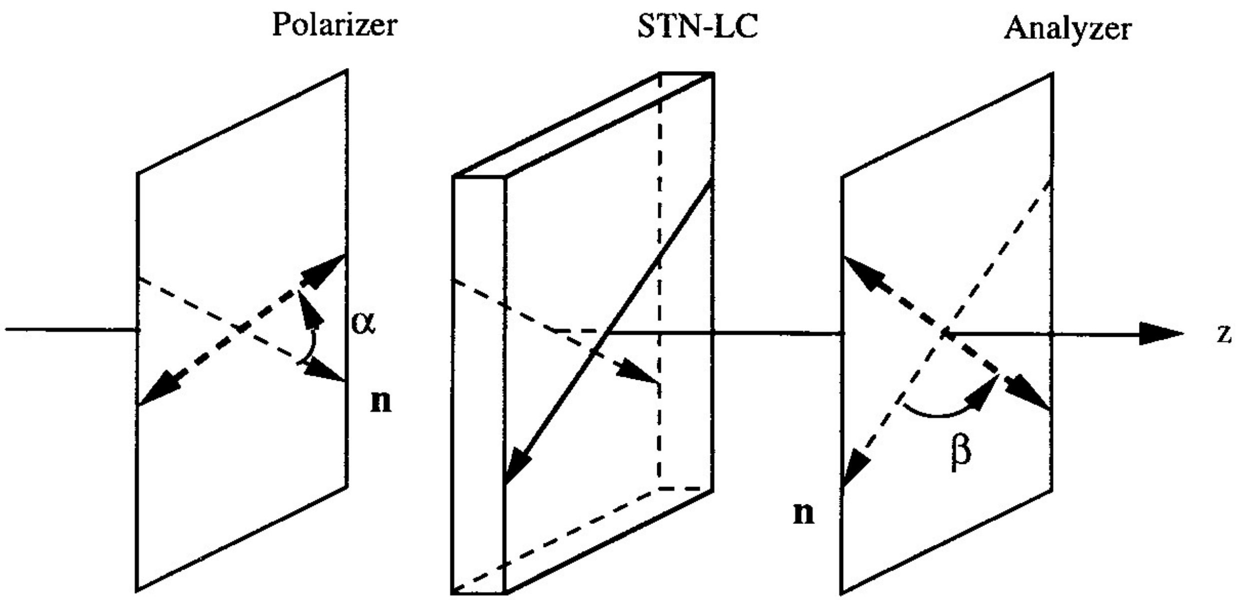

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Figure 5.19. Schematic drawing of an STN-LCD, where α is the azimuth angle of the polarizer measured from the local director $\mathbf{n}(z = 0)$ and β is the azimuth angle of the analyzer measured from the local director $\mathbf{n}(z = d)$, where d is the cell thickness. The arrows on the STN cell indicate the director orientations at the surfaces. The double arrows indicate the transmission axes of the polarizers.

$$T = \cos^2(\alpha - \beta) + \sin^2 X \sin 2\beta \sin 2\alpha + \frac{\phi}{2X}\sin 2X \sin 2(\alpha - \beta) + \phi^2 \frac{\sin^2 X}{X^2}\cos 2\beta \cos 2\alpha$$

$$X = \sqrt{\phi^2 + \left(\frac{\Gamma}{2}\right)^2}$$

$$\Gamma = \frac{2\pi}{\lambda}(n_e - n_o)d$$

Transmission Spectra

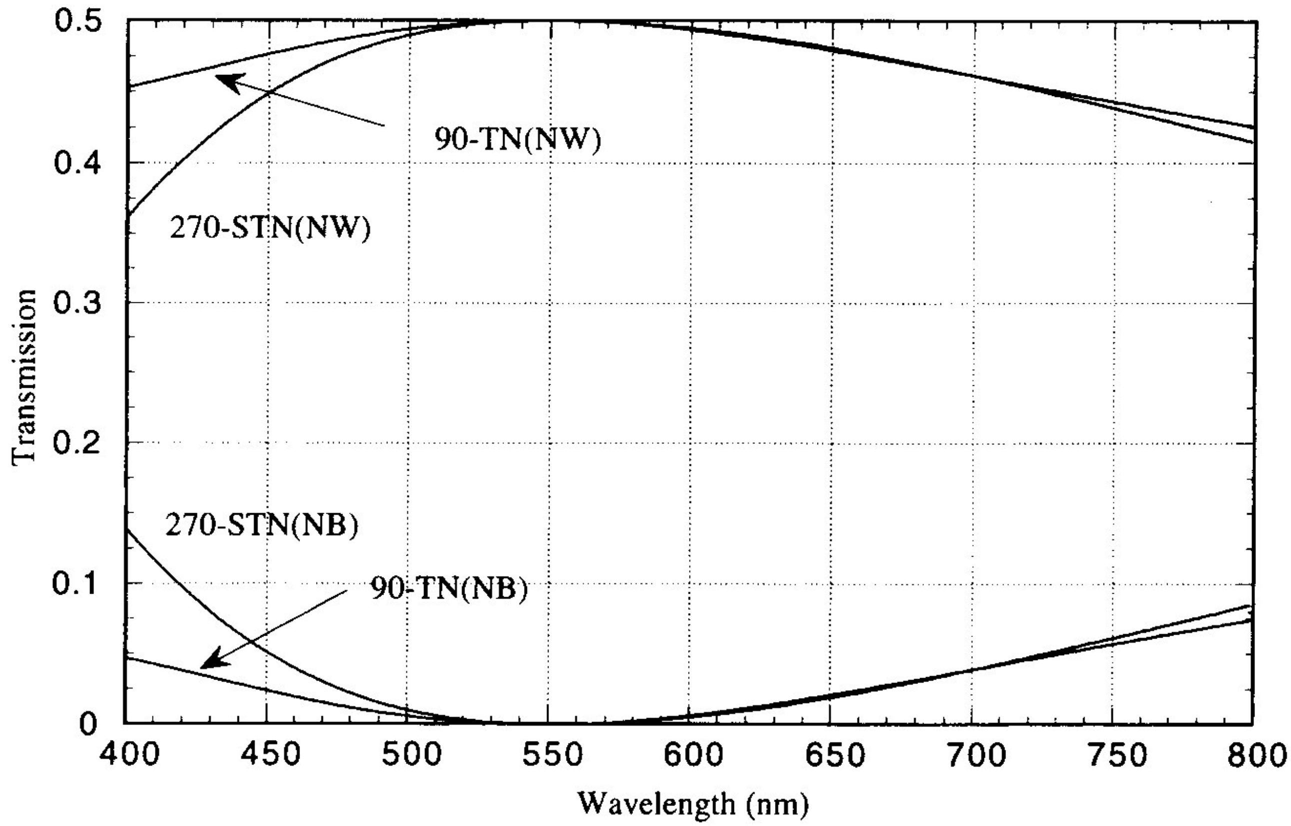

Figure 5.20. Transmission spectra of a 270° STN cell in the field-OFF state with $\alpha = -22°$, $\beta = 22°$, $\Delta nd = 0.48\ \mu m$, and a 90° TN cell in the field-OFF state with $\alpha = 0°$, $\beta = 0°$, $\Delta nd = 0.48\ \mu m$. The polarizer azimuth angles are chosen to have maximum (or zero) transmission in the field-OFF state for $\lambda = 550$ nm.

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Director Distribution for 270º STN-LC

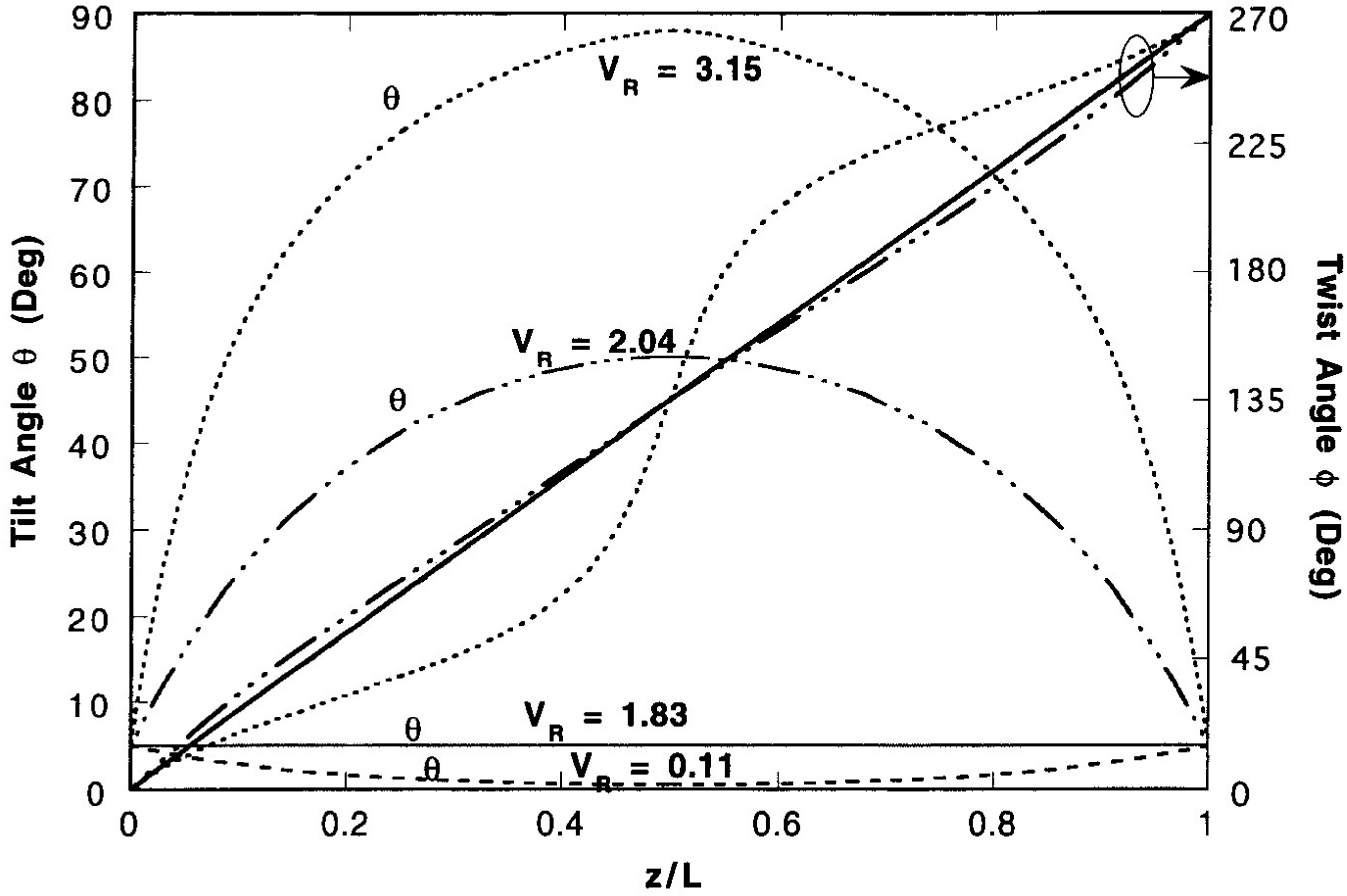

Figure 5.21. Director distribution θ(z) and ϕ(z) in an STN cell with 270° total twist angle at different reduced voltages. Reduced voltage $V_R = V/V_{c1}$.

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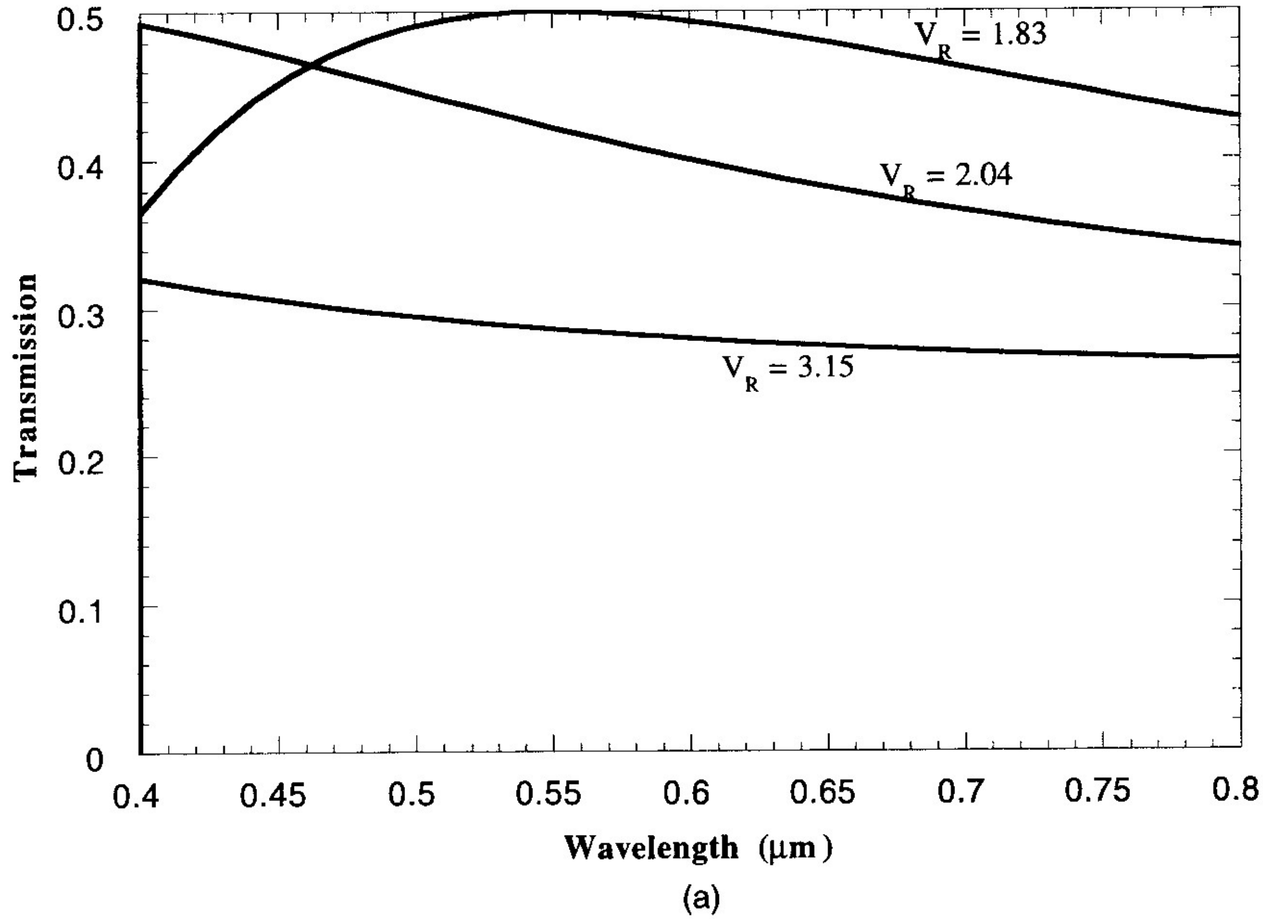
Transmission Spectra



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Electro-distortional Curve

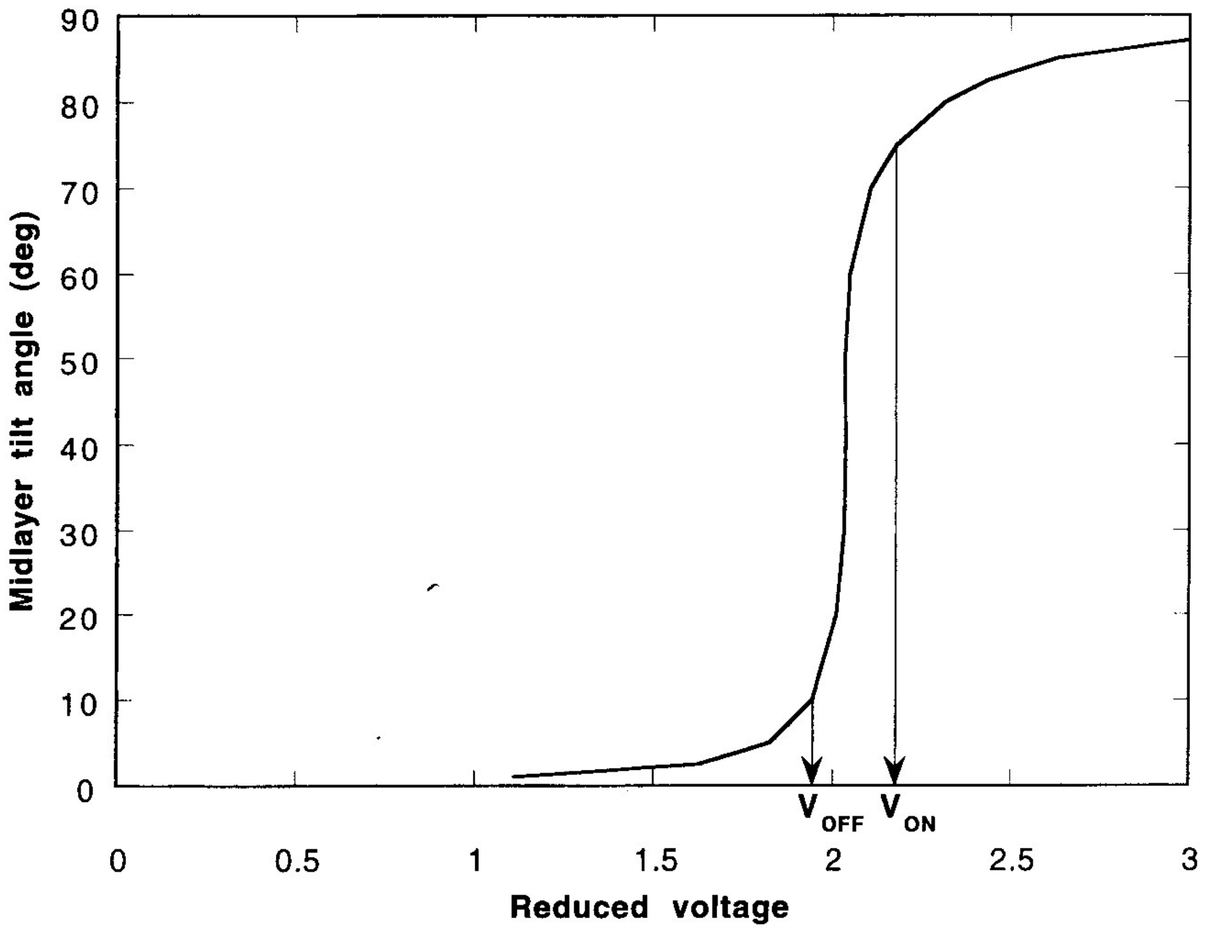

Figure 5.23. Electrodistortional curve of a 270° STN cell. The vertical lines indicate the nonselect voltage V_{OFF} and the select voltage V_{ON}.

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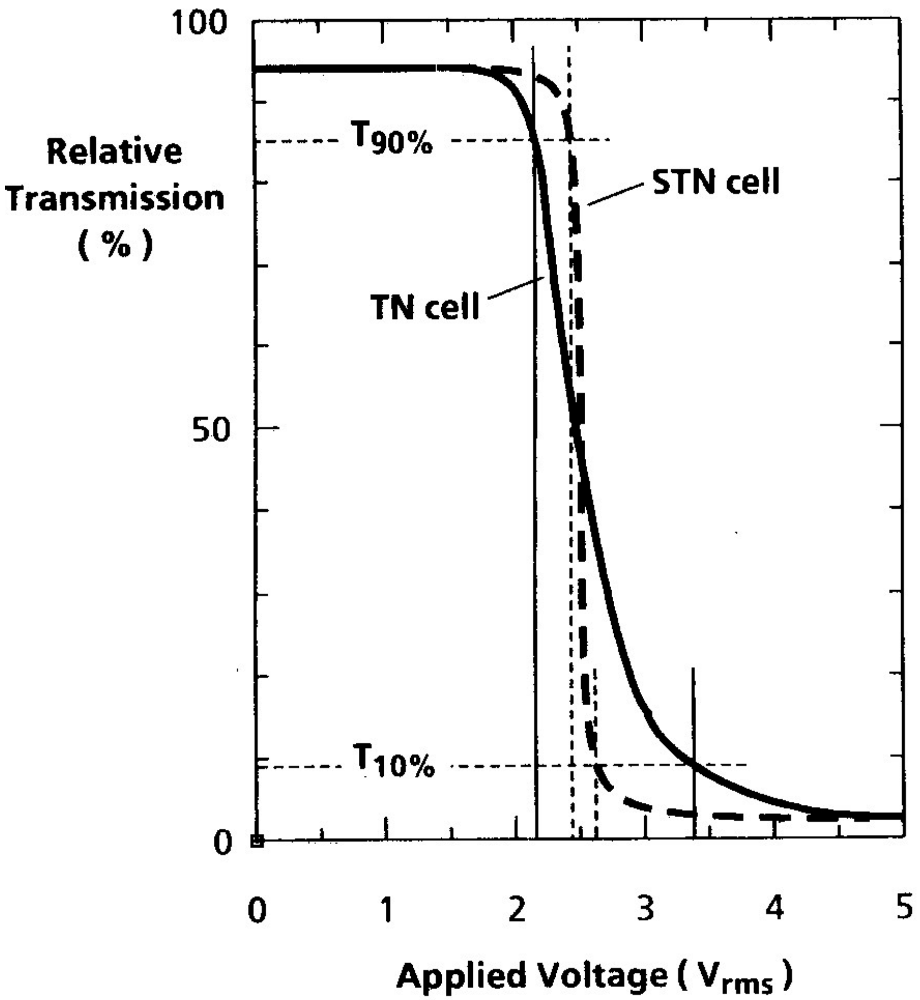
Contrast Ratio

$$C_{NW} = \frac{T(V_{OFF})}{T(V_{ON})}$$

$$C_{NB} = \frac{T(V_{ON})}{T(V_{OFF})}$$

Electro-Optic Response of TN and STN Cells



- TN cell 90° twist
- STN cell 180° - 270° twist (SuperTwisted Nematic)

V_{10} / V_{90} (TN) = 1.6

$\Rightarrow$ N = 5

V_{10} / V_{90} (STN) = 1.06

$\Rightarrow$ N = 295

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Horizontal Viewing Angle

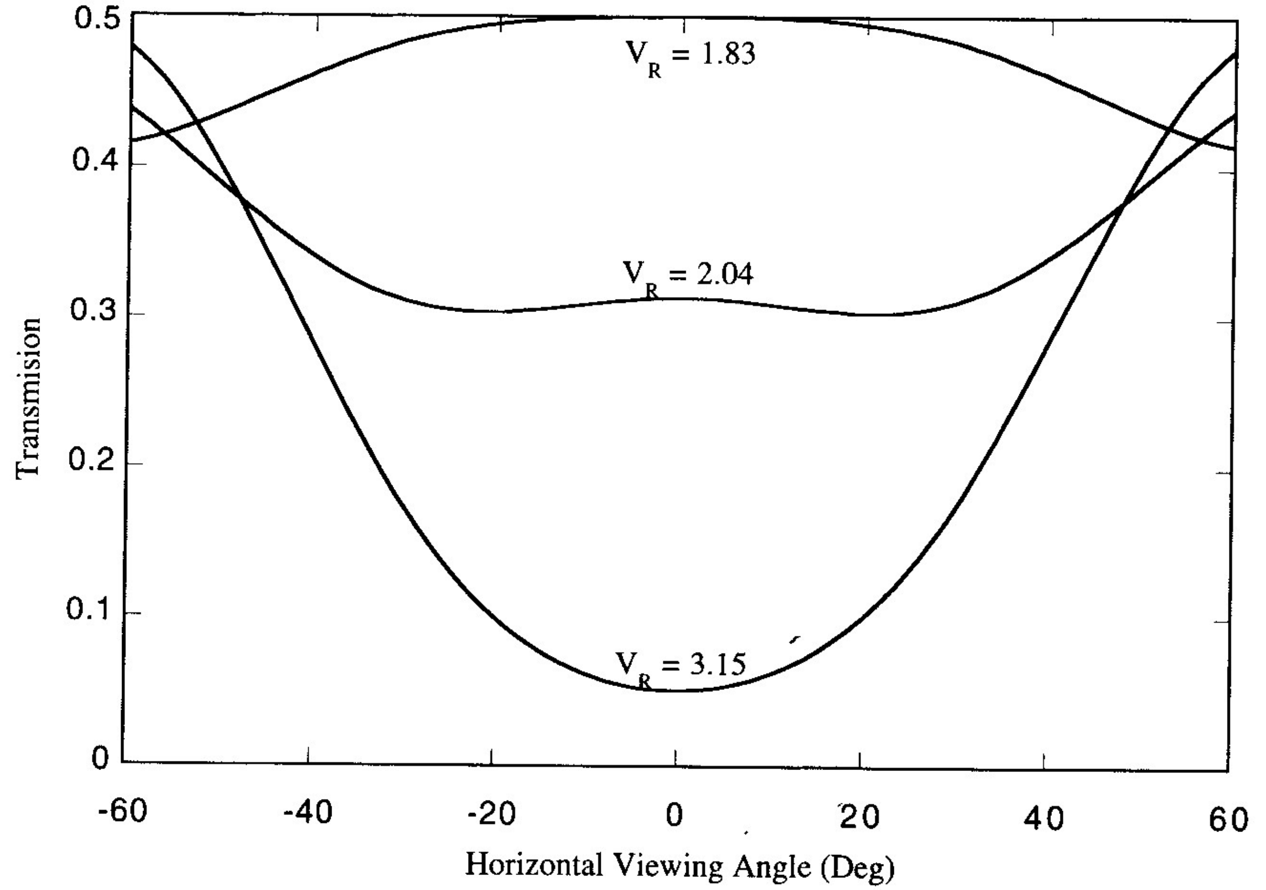

Figure 5.24. Horizontal viewing characteristics of a 270° STN-LCD at different reduced voltages, with $\alpha = 1.8°$, $\beta = -1.8°$, $\Delta nd = 0.75\ \mu m$, $\lambda = 0.55\ \mu m$. Reduced voltage $V_R = V/V_{c1}$, where V_{c1} is as given by Eq. (5.2-34).

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Vertical Viewing Angle

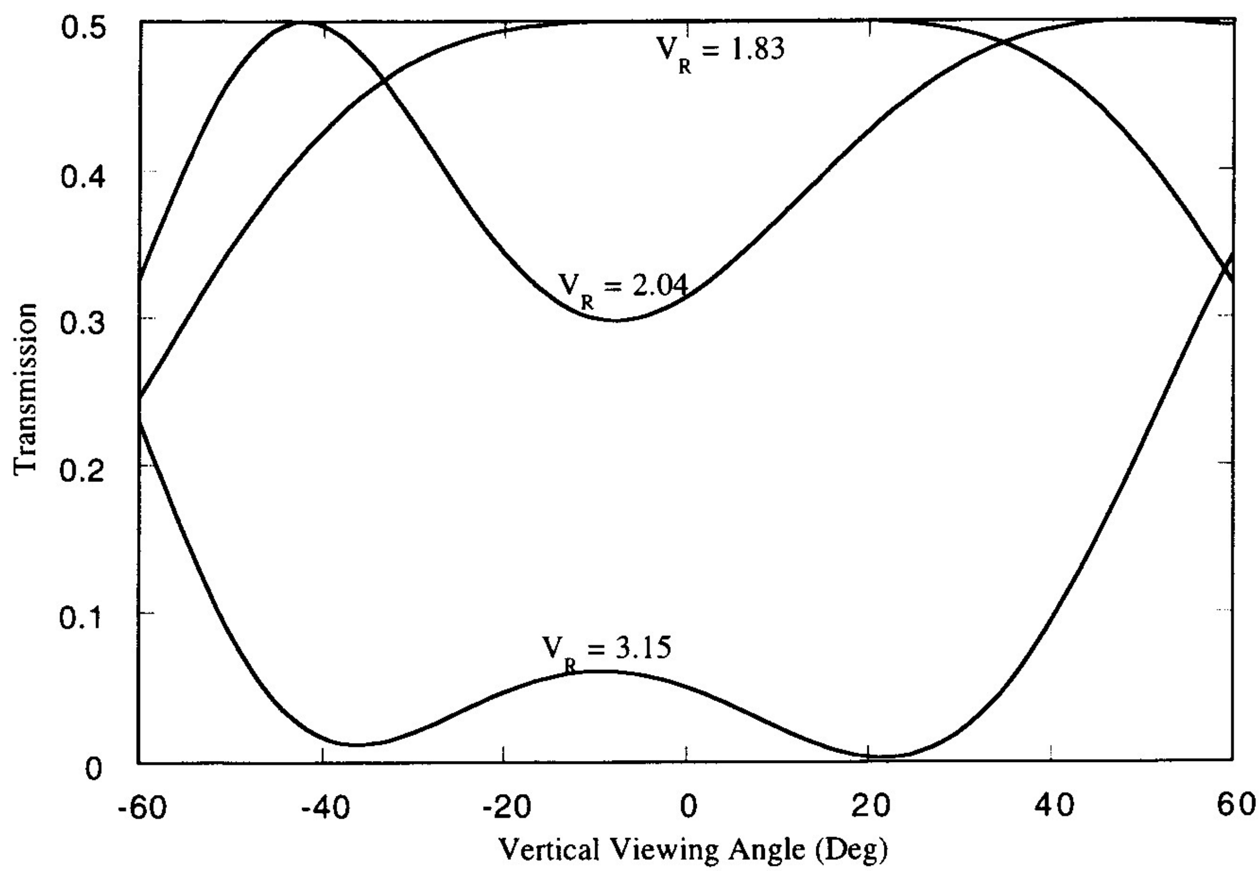

Figure 5.25. Vertical viewing characteristics of a 270° STN-LCD at different reduced voltages, with $\alpha = 1.8°$, $\beta = -1.8°$, $\Delta nd = 0.75\ \mu m$, $\lambda = 0.55\ \mu m$. Reduced voltage $V_R = V/V_{c1}$, where V_{c1} is as given by Eq. (5.2-34).

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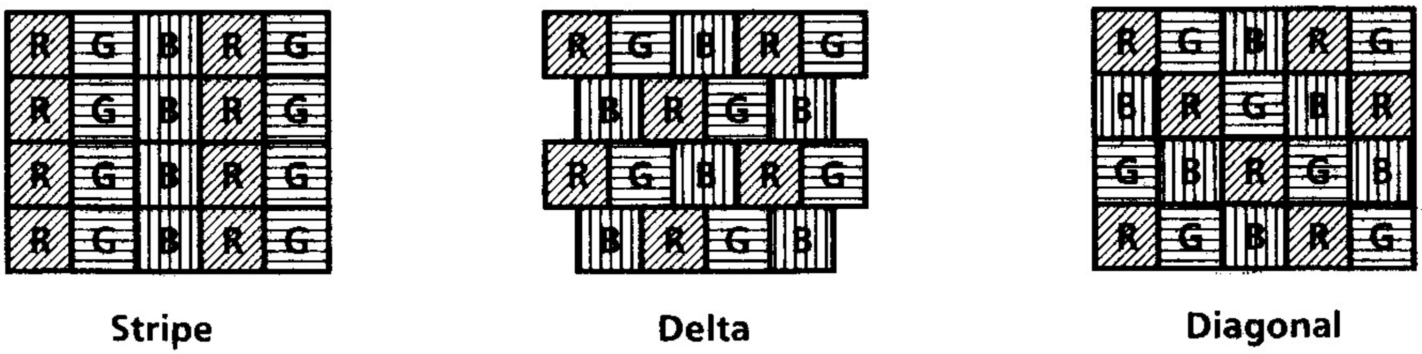
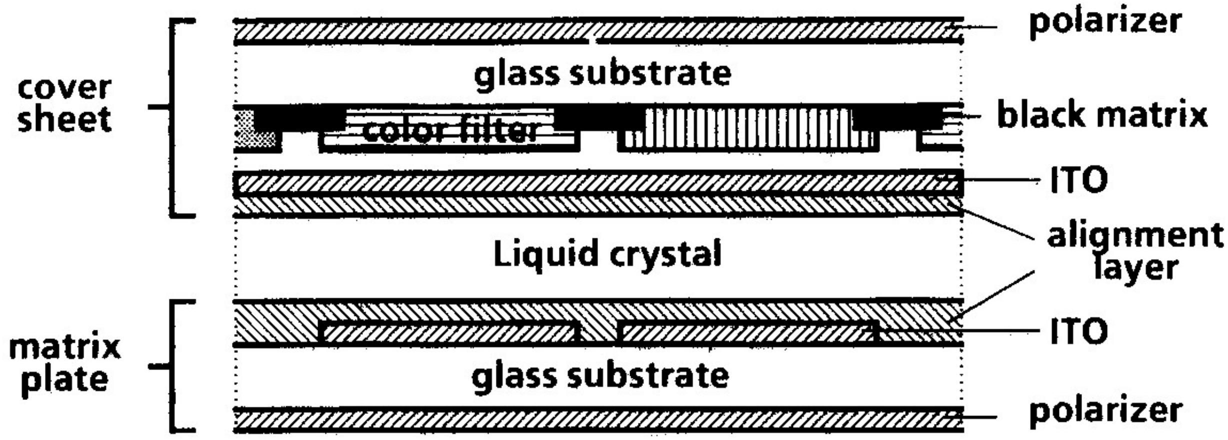
Color LCD



Color filter mosaics



Cross-section of color LCD

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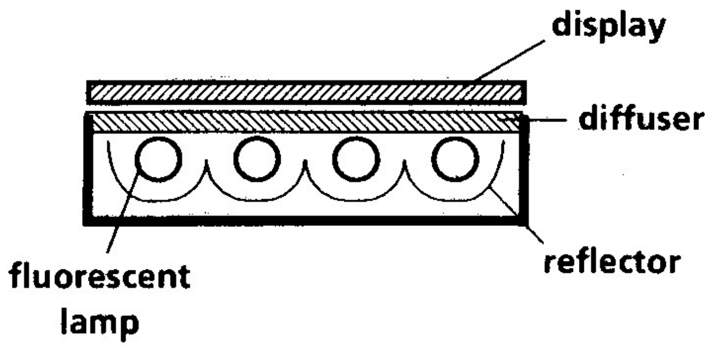
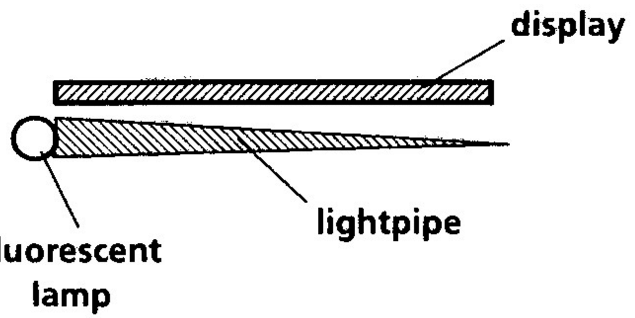
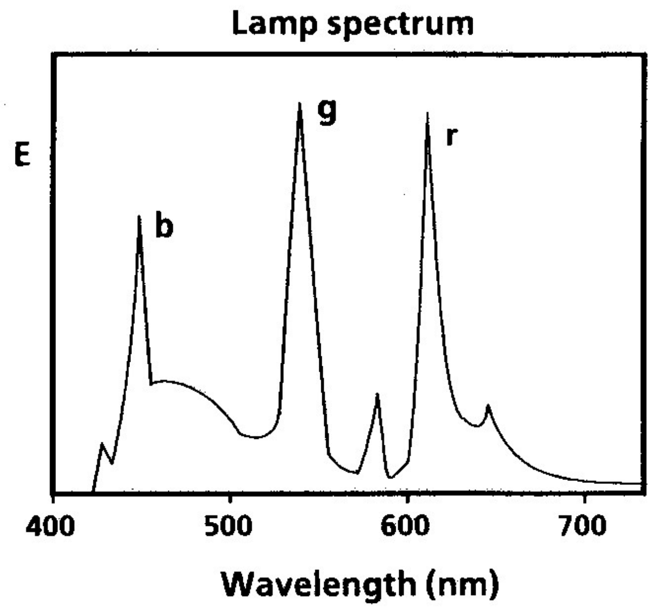
LCD Backlight

- Consists of light source, reflector, and diffuser
- Goals are compactness, high efficiency, uniformity, long life







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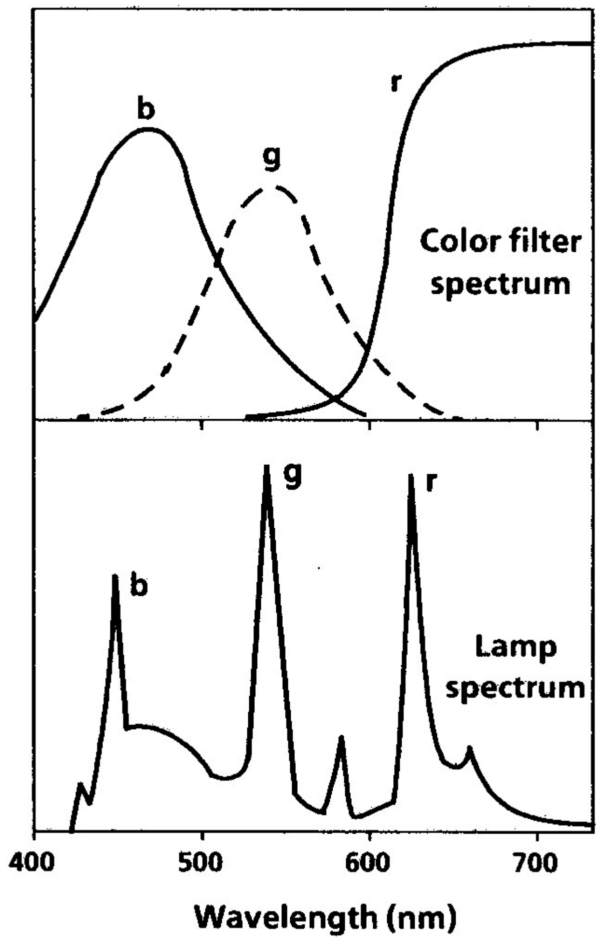
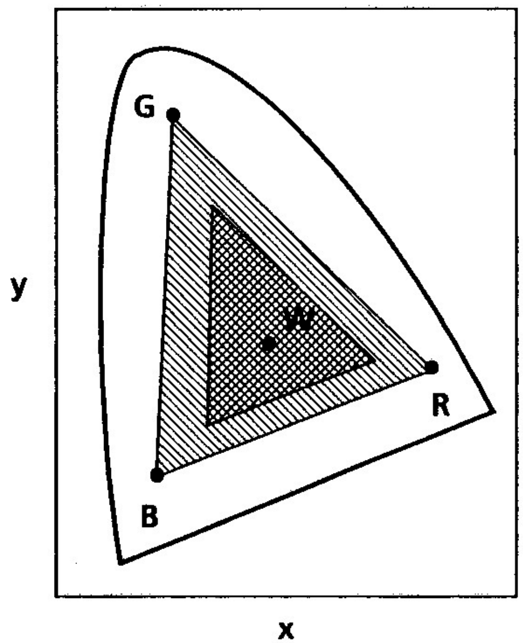
Achieving Good Color





- Match lamp spectrum to color filter spectrum
- Trade-off between saturation and brightness

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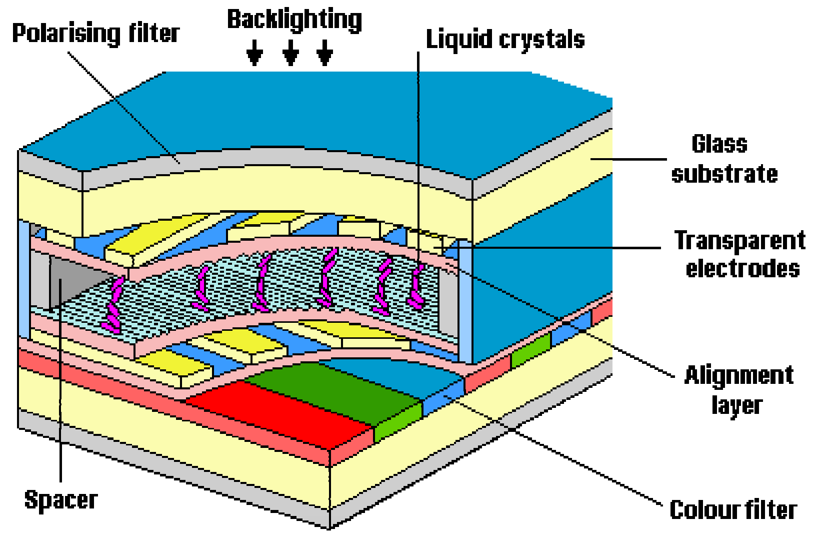
Summary of Today's Lecture

- Passive matrix liquid crystal displays have simple structure and are easy to manufacture
- TN-LC do not have sufficient contrast for high information content displays
- STN-LCs have sufficient contrast for medium information content displays; however are not are not bright enough nor power efficient
- Rendering images in high information content displays based on TN and STNs is very challenging



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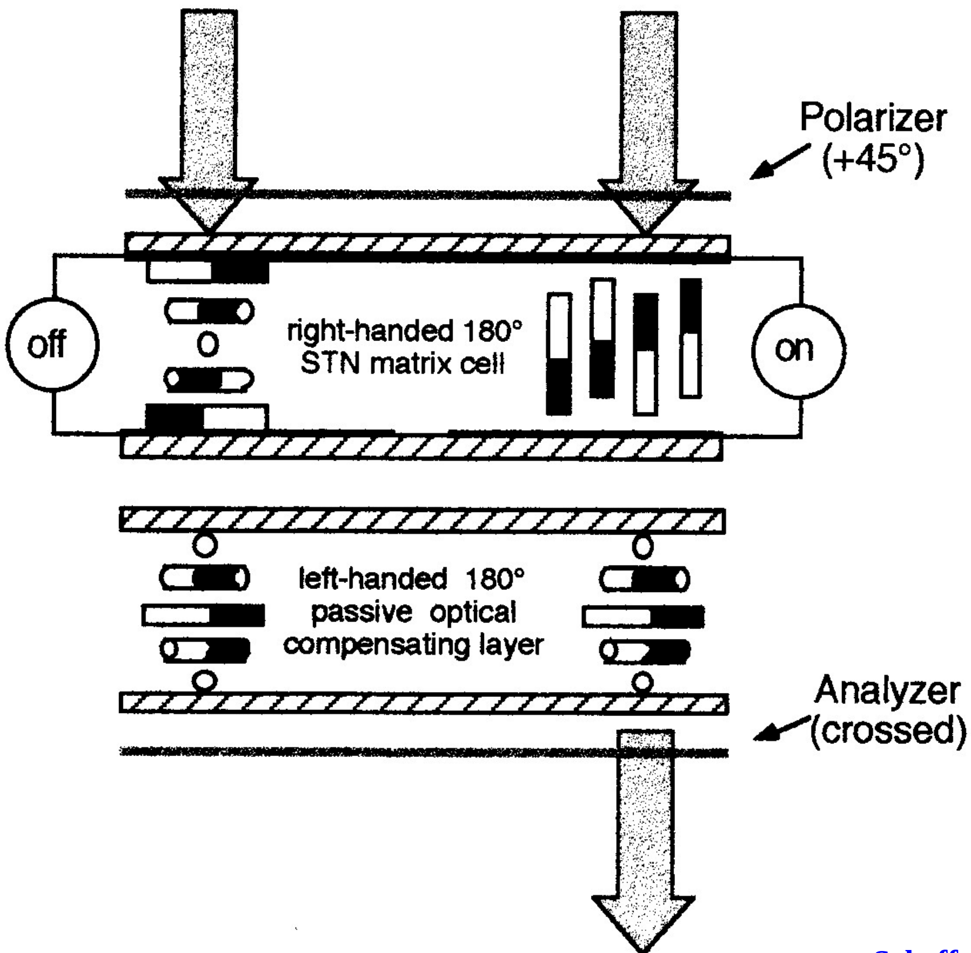
Double-Layer STN-LCD



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