Lec 3

C3A - Display Technology

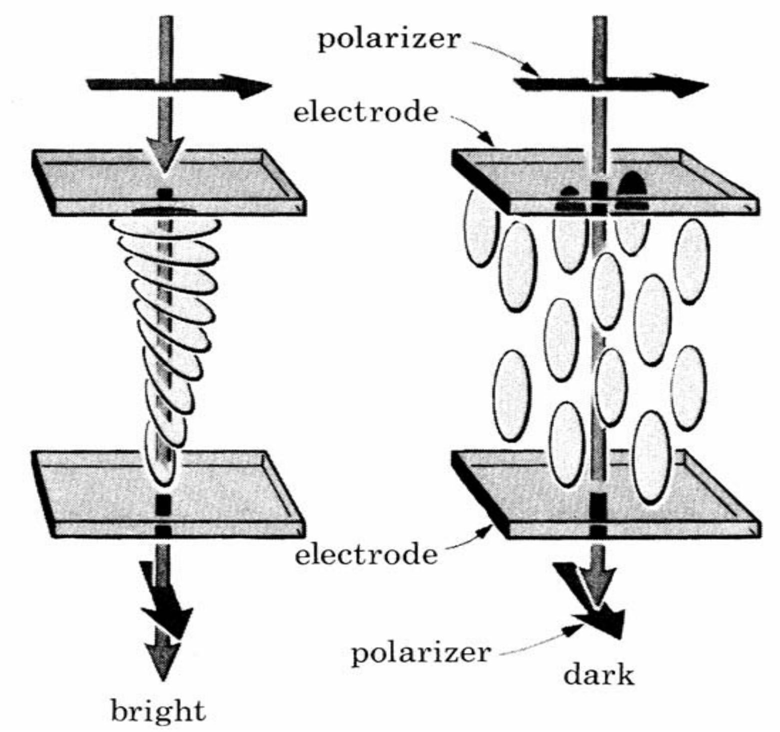
Peter Raynes

Lecture 3

- Twisted nematic (TN) LCD
  - Device structure
  - Defects
  - Properties
- Passive addressing
  - RMS addressing
  - Alt & Pleshko analysis
- Continuum Theory
  - Energy due to distortions
  - Energy due to electric fields
  - Total energy

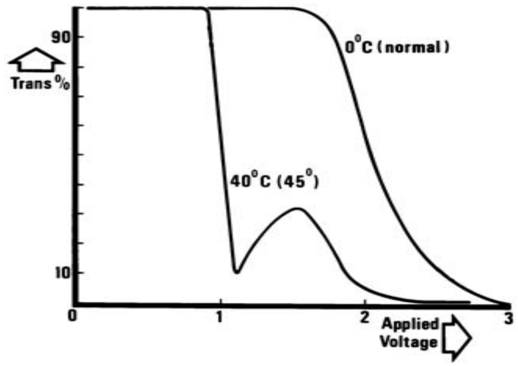
TN Device Structure

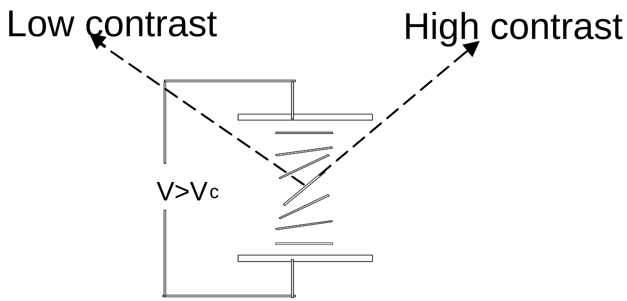
- Schadt& Helfrich 1971
- Planar alignment
- 90° twist angle
  - Rotates polarised light by 90°
- Voltage switches device
  - $\Delta\varepsilon > 0$
  - $V \geq 1$ Volt
- Operation
  - Reflection: 'Normally white' mode
  - Transmission: 'Normally black' mode



TN Mode - Switching

- Switches between
  - 1~3 Volts
- Depends on
  - Temperature
  - Viewing angle
    - Polar angle
    - Depends on **n**
- Produces multiplexing problems





TN Optics

- TN transmission (parallel polars)
  (Gooch-Tarry equation 1975)

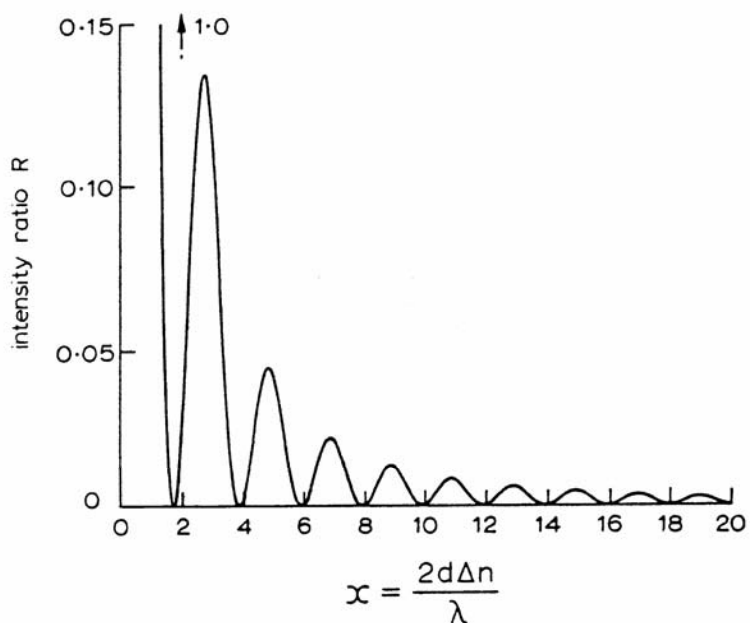
$$T_{TN} = \frac{\sin^2\left(\pi/2\right)\left[1+\left(2\,\Delta n.d/\lambda\right)^2\right]^{\frac{1}{2}}}{1+\left(2\,\Delta n.d/\lambda\right)^2}$$

- $T_{TN} = 0$ when either:

$\Delta n.d > \lambda$ (Mauguin 1911)

or: $\left(\Delta n.d/\lambda\right)^2 = \left(m^2 - 1/4\right)$ (G-T)

$\Rightarrow \quad \Delta n.d > 0.87\lambda, 1.94\lambda, ...$

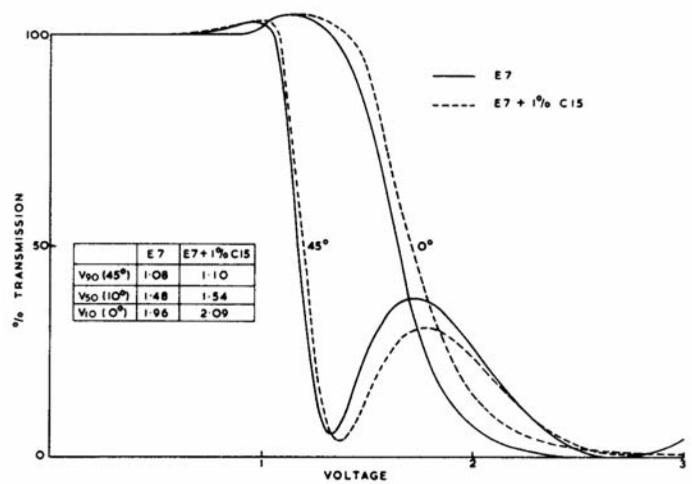


Reverse Twist and Tilt Defects

- Thin lines (all voltages)
  - $\pm\frac{\pi}{2}$ twist
- Thick lines (V > Vc)
  - $\pm\theta$ reorientation
  - Only present in one twist
  - Twist $\Leftrightarrow$ alignment pre-tilt
- Degrade appearance
  $\Rightarrow$ Must eliminate the defects

Elimination of Defects

- Want twist with no defects
- Use chiral nematic
- Pitch of chiral nematic
  - Sign must match surface pre-tilt (Raynes 1975)
  - Magnitude
    - Matching *(P = 4d)*
    - $\Rightarrow P \approx 20\ \mu m$
    - Degrades contrast severely

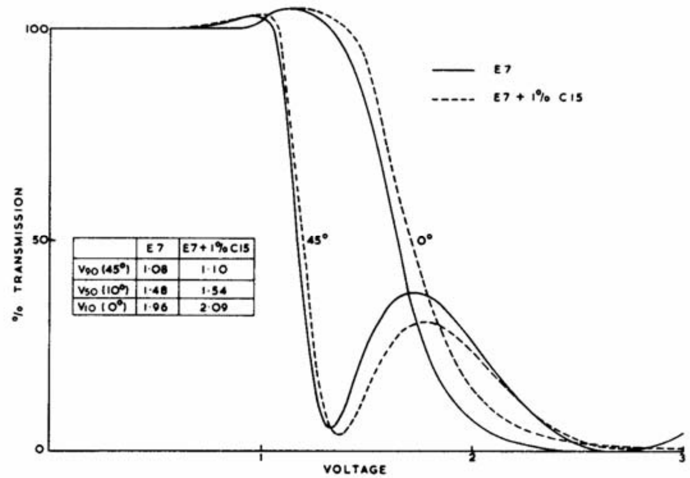


Effect of Pitch on Transmission

- Difference in twist across layer for matching pitch (P = 4d)
- Influences transmission
- Transmission at $V>V_c$ given by:

$$T \approx \left(\frac{2\pi\, d\, V_c}{P V} \right)^2$$

- Use $P \approx 200\ \mu m$

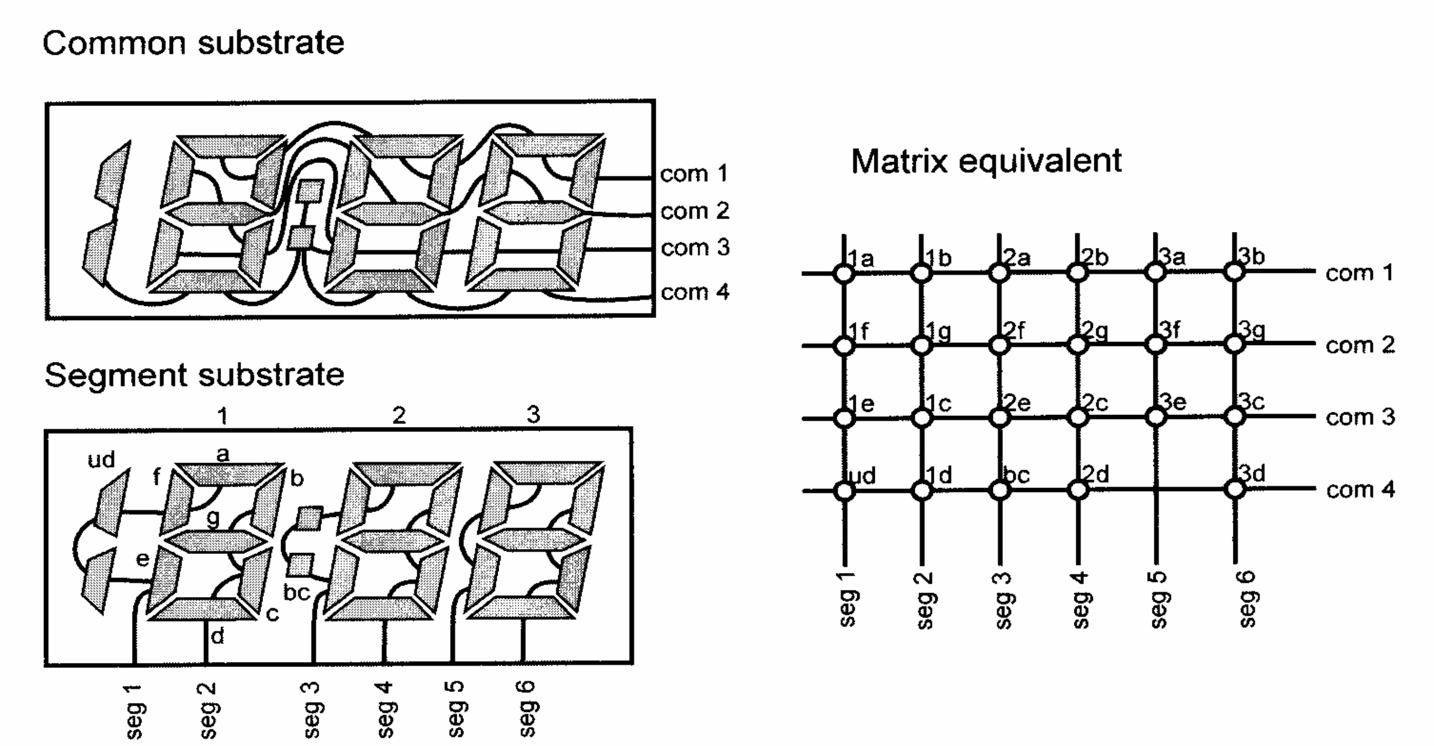


Surface Pre-tilt

- Needed to eliminate defects

- What magnitude?
  - Too large (>3°)
    - Rounds the threshold
    - Bad for multiplexing
  - Too small (<1°)
    - Allows defects
    - Grow new defects at pixel corners
      - Electrode edge effects
  - Usually use 1~2 °

Passive Multiplexed Displays



Passive Multiplex Addressing

Driving signals

V_S scanned down rows
$\pm V_D$ on columns

Speeds

$\tau_{\text{liquid crystal}} >> \tau_{\text{addressing}}$

$\Rightarrow$ Square of RMS voltage

$$\Rightarrow \quad V_{RMS}^2 = \frac{1}{T}\int_0^T V^2(t)\,dt$$

	$-V_D$	$+V_D$	$-V_D$
0	$+V_D$	$-V_D$	$+V_D$
V_S	$V_S + V_D$	$V_S - V_D$	$V_S + V_D$
0	$+V_D$	$-V_D$	$+V_D$

Optimum Conditions

$$V_{RMS}^2 = \frac{1}{T}\int_0^T V^2(t)\,dt$$

For N rows

$$V_{ON}^2 = \frac{1}{N}\left(V_S^2 + 2V_SV_D + NV_D^2\right)$$

$$V_{OFF}^2 = \frac{1}{N}\left(V_S^2 - 2V_SV_D + NV_D^2\right)$$

Addressing maximised (ie $\frac{V_{ON}}{V_{OFF}}$ max.) when $\frac{V_S}{V_D} = \sqrt{N}$

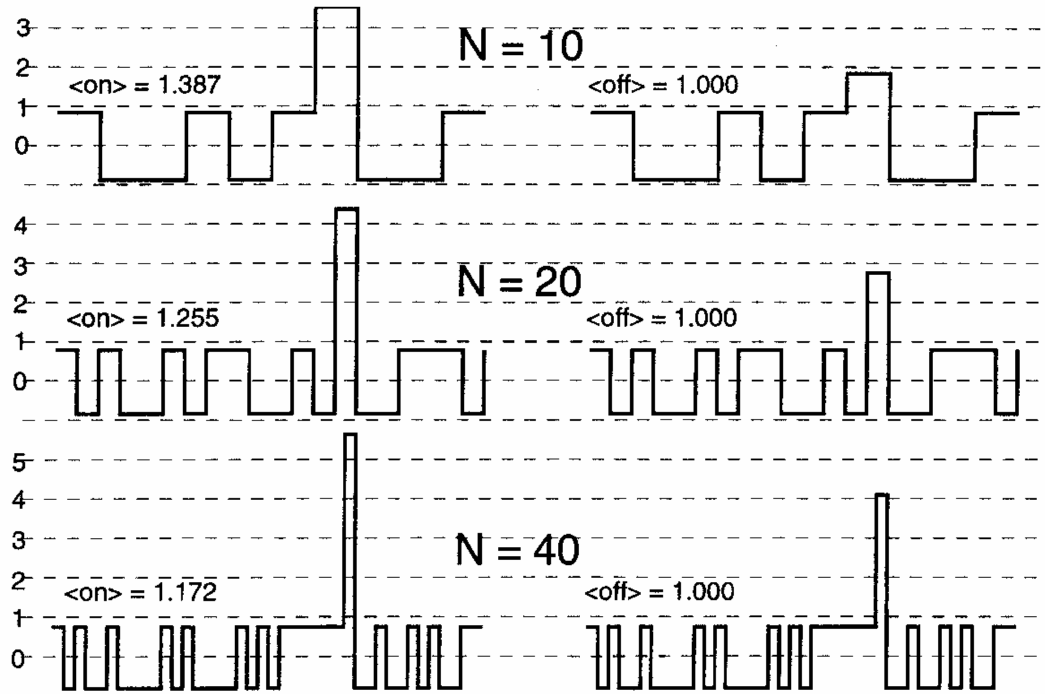
Giving $\left(\frac{V_{ON}}{V_{OFF}}\right)_{\max} = \sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}$ (Alt & Pleshko 1975)

Resulting Waveforms

$$\frac{V_S}{V_D} = \sqrt{N}$$

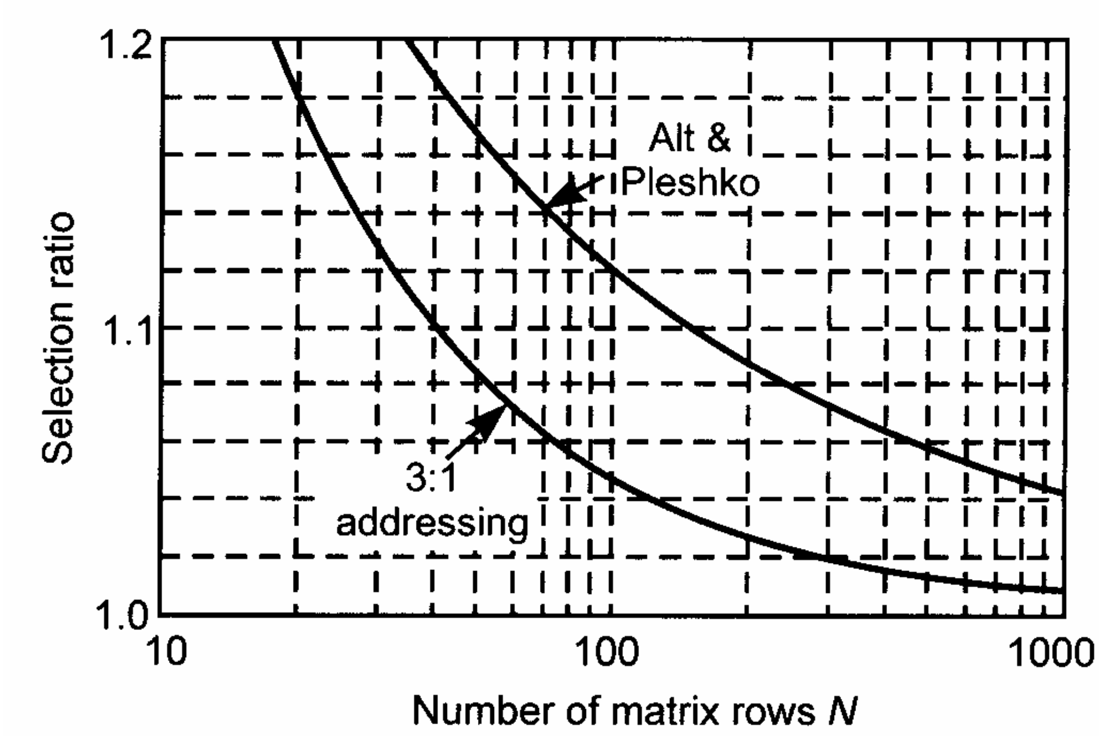
Invert voltages:

- So that DC = 0
- Every few lines



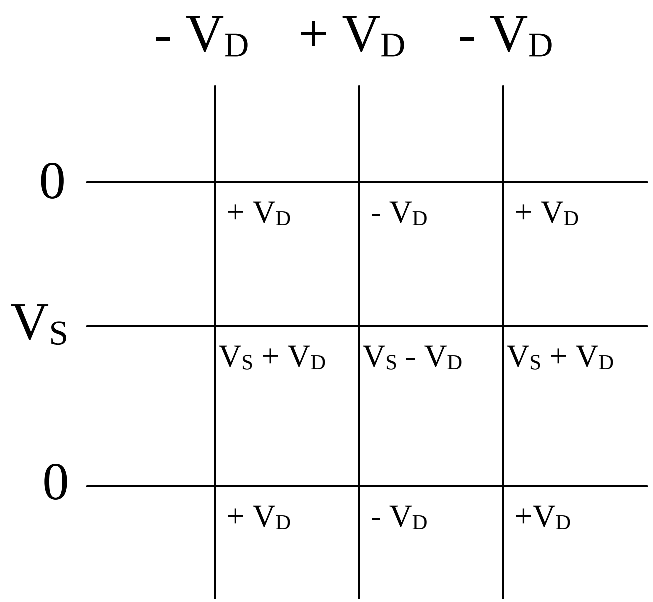
Resulting Performance

$$\frac{V_{ON}}{V_{OFF}} = \sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}$$



Driver Voltages

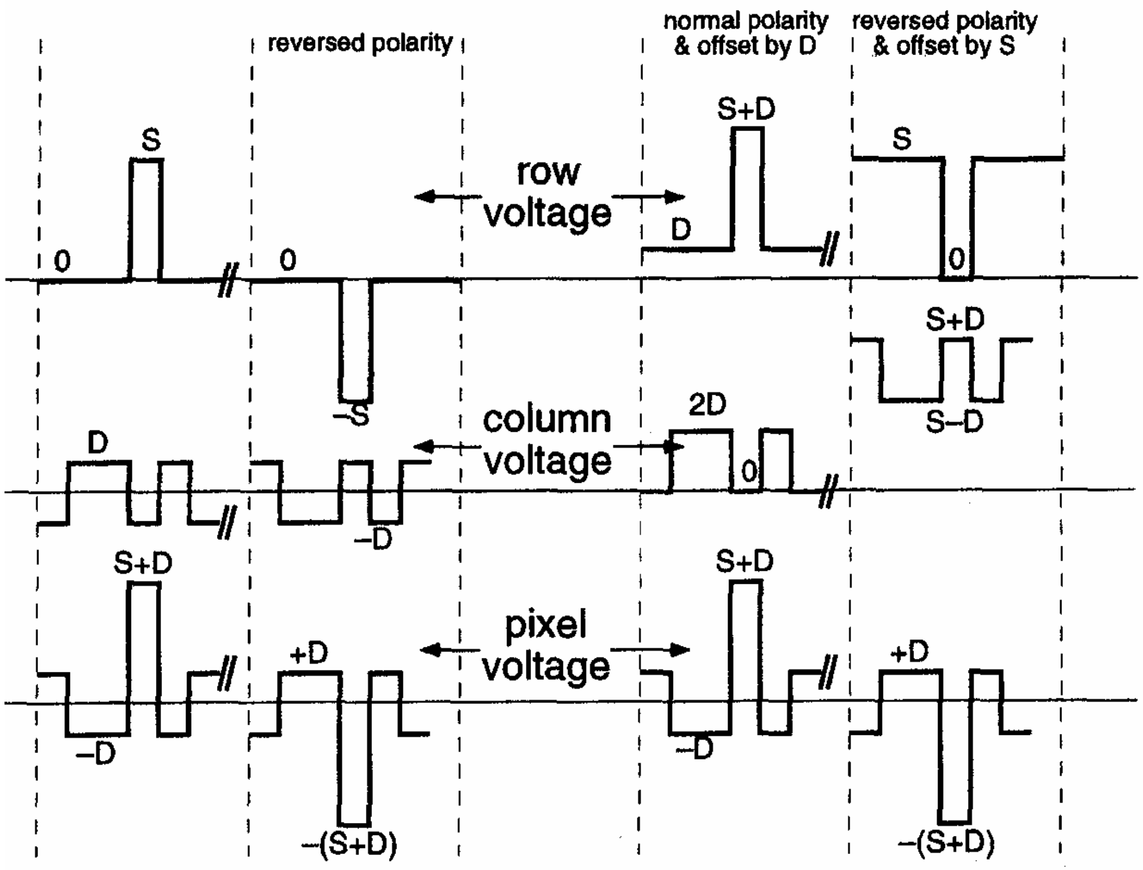
- $\frac{V_S}{V_D} = \sqrt{N}$
  - e.g. $\frac{V_S}{V_D} = 20$ (N = 400)
    - $V_D \approx 2V$
    - $V_S \approx 40V$
  - Voltage swings
    - $V_D \approx \pm 2V$
    - $V_S \approx \pm 40V$
  - Uneven between V_D and V_S
  - Large for V_S (80V)
  - Negative voltages



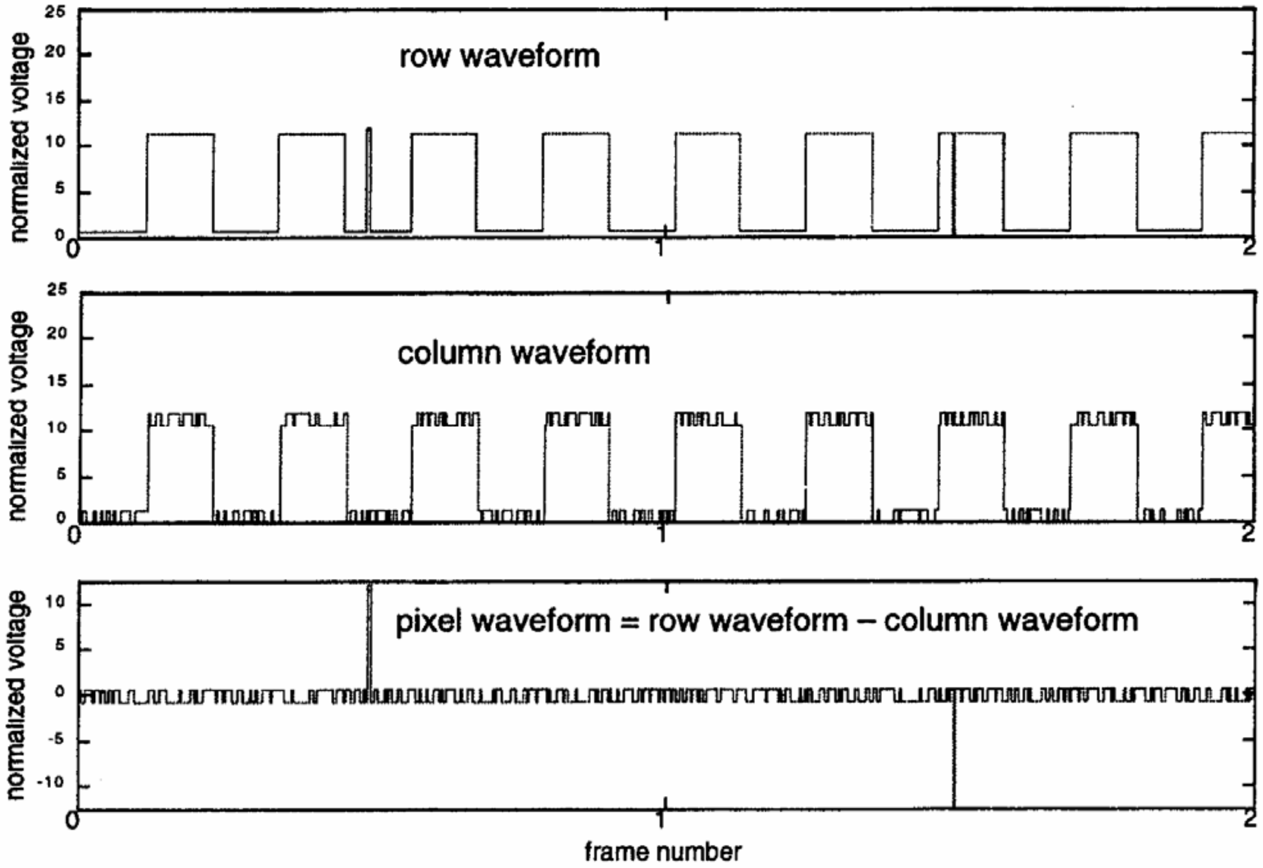
Driver Voltage Reduction - 1

- Adding same voltage to rows and columns does not change pixel voltage
- For example:
  - In positive cycle add V_D
  - In negative cycle add V_S
- Voltage $\approx$ 1/2

Driver Voltage Reduction - 2



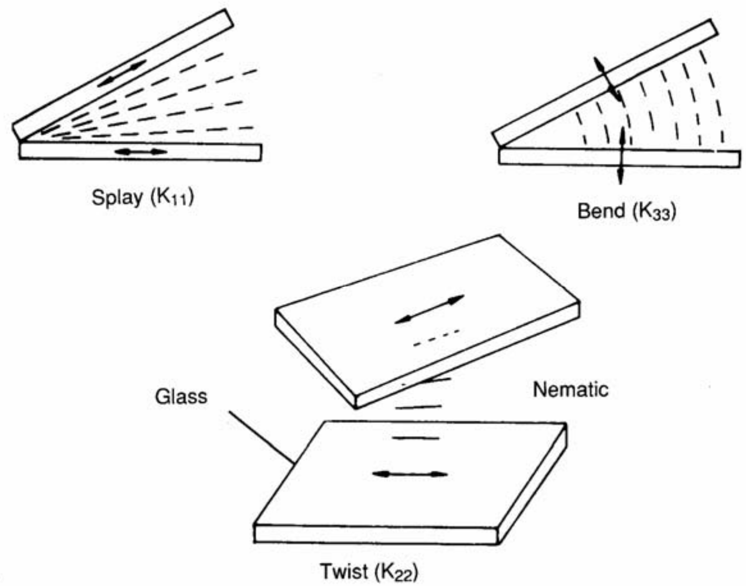
Resulting Waveforms



Continuum Theory – Energy Due to Distortions

- Distortion energy density of director n (Frank 1958)

$$F_k = 1/2\left\{k_{11}\left(div\,\underline{\mathrm{n}}\right)^2 + k_{22}\left(\underline{\mathrm{n}}.curl\,\underline{\mathrm{n}}\right)^2 + k_{33}\left(\underline{\mathrm{n}}\,x\,curl\,\underline{\mathrm{n}}\right)^2\right\}$$



- Elastic constants
  - k_{11} splay, k_{22} twist and k_{33} bend
  - Magnitude $\approx 10^{-11}$ N

Continuum Theory – Adding an Electric Field

- Dielectric energy density:

$$F_E = 1/2\,\underline{D}.\underline{E}$$

- Total energy density:

$$W = F_k + F_E$$

$$\Rightarrow \qquad W = 1/2\left\{\begin{array}{l} k_{11}(div\,\underline{\mathrm{n}})^2 + k_{22}(\underline{\mathrm{n}}.curl\,\underline{\mathrm{n}})^2 \\ + k_{33}(\underline{\mathrm{n}}\,x\,curl\,\underline{\mathrm{n}})^2 + \underline{D}.\underline{E} \end{array}\right\}$$

- Find solutions for $\underline{n}(x, y, z)$
  - which minimise total energy $\int W\,dx\,dy\,dz$
  - with relevant boundary conditions imposed

Next Lecture

- Minimising the total energy
  - 1-D solutions
  - Critical voltage for Freedericksz transition
  - Useful analytical solutions for TN devices
- Supertwisted nematic LCDs
  - Basic device performance
  - Director modeling
  - Material optimisation