SECTION 4
LIQUID CRYSTAL DISPLAY –
PASSIVE MATRIX ADDRESSING

Liquid Crystal Displays (3rd Edition)
Ernst Leuder. Pub Wiley / SID 2022
Ch2 Passive Matrix Addressing of TN Displays

Handbook of Visual Display Technology (2nd Edition)
Pub Springer 2016

Direct Drive, Multiplex, and Passive Matrix
Karlheinz Blankenbach, Andreas Hudak, Michael Jentsch
Pages 621-644

Objective and Contents

Objective

Introduce passive matrix (PM) addressing for LCDs of medium definition, complexity, performance and price

Usually monochrome or simple colour alphanumeric panels

Understand the constraints of PM LCD.

Contents

Review of background

Explanation of PM addressing

Derivation of Alt and Pleshko Criteria

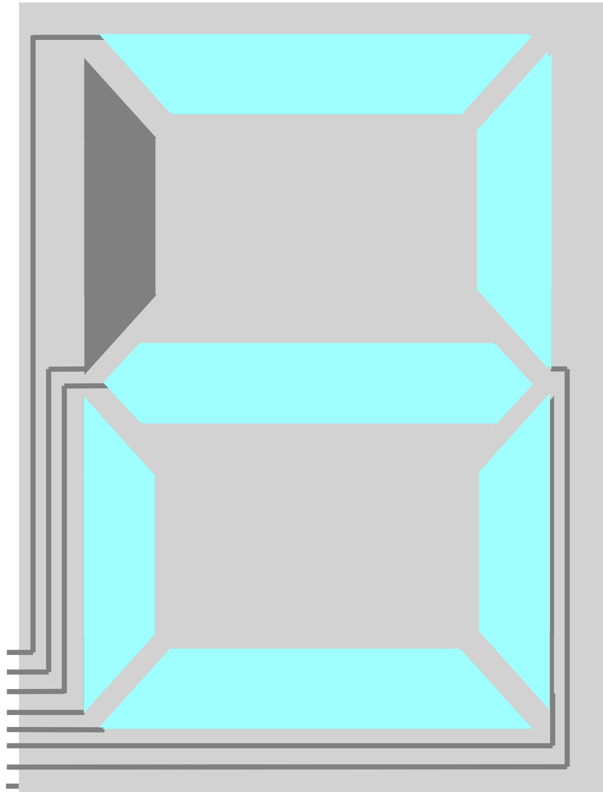
- leads to significant constraints of PM

Workarounds

Summary

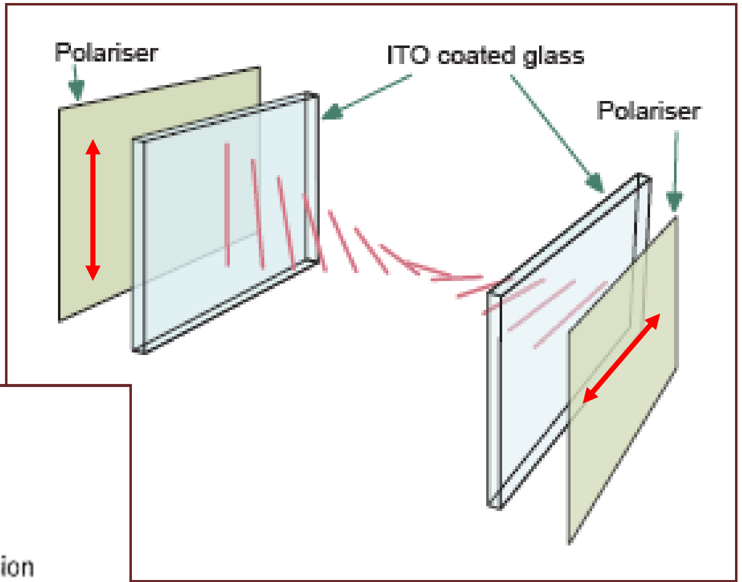
Direct Drive

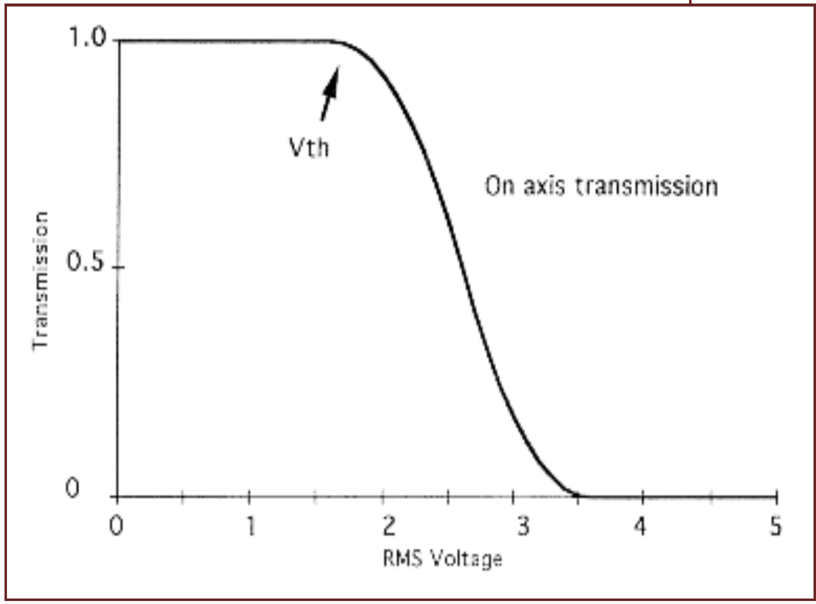
- Common (or front) electrode
- Patterned (or back) electrode
- Per display segment
  - One driver
  - One connecting wire
- For higher pixel count displays this quickly becomes unmanageable



Revision – TNLC Config & Response

Electro-optic response of Liquid Crystal Display





***Q.** What if the polarisers are aligned parallel?*

Threshold Voltage – Twisted Nematic

General (i.e., parallel) nematic LC

$$E_C = \frac{\pi}{d}\left(\frac{K_{11}}{|\Delta\varepsilon|}\right)^{0.5}$$

$$V_{th} = \pi\left(\frac{K_{11}}{|\Delta\varepsilon|}\right)^{0.5}$$

Where d = LC thickness

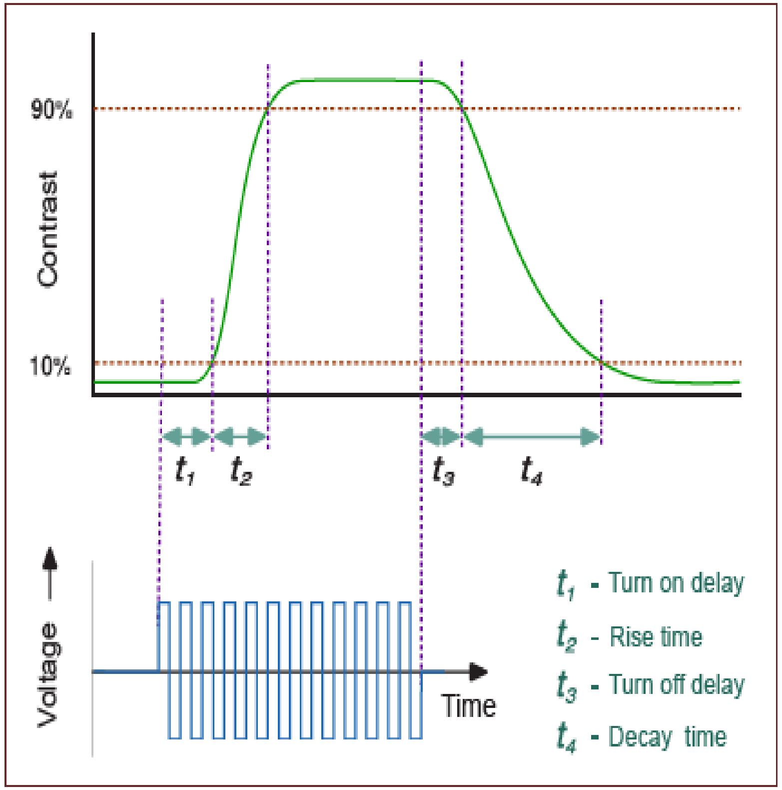
All the K_{11} K_{22} K_{33} etc are defined in Section 3

Twisted nematic LC

$$V_{th} = \pi\left(\frac{K_{11} + \boxed{(K_{33} - 2K_{22})/4}}{|\Delta\varepsilon|}\right)^{0.5}$$

Nb. It's the voltage!
(not the E field?)

Switching Time – twisted nematic



Switching time constants for LC material

Rise (***drive***) time

- Typical 20 – 80 ms*

$$\tau_r = \frac{\eta_r d^2}{\varepsilon_0 |\Delta\varepsilon| V^2 - \left(K_{11} + \boxed{\frac{K_{33} - 2K_{22}}{4}}\right)\pi^2}$$

Fall / decay (***relax***) time

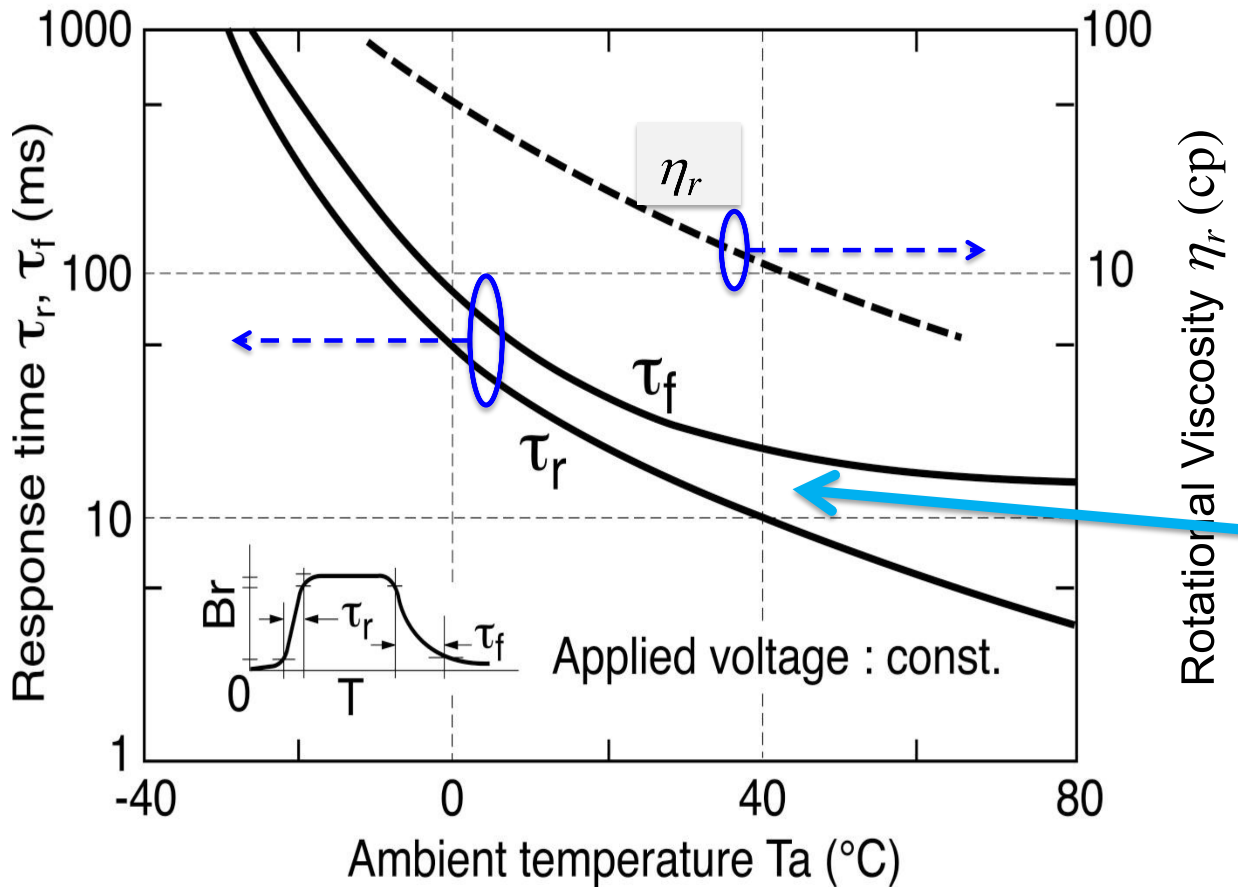
- Typical 60 – 150ms*

$$\tau_f = \frac{\eta_r d^2}{\left(K_{11} + \boxed{\frac{K_{33} - 2K_{22}}{4}}\right)\pi^2}$$

Both very temperature dependent

* Want fast for active matrix
Want slow for passive matrix

Response Time Characteristic

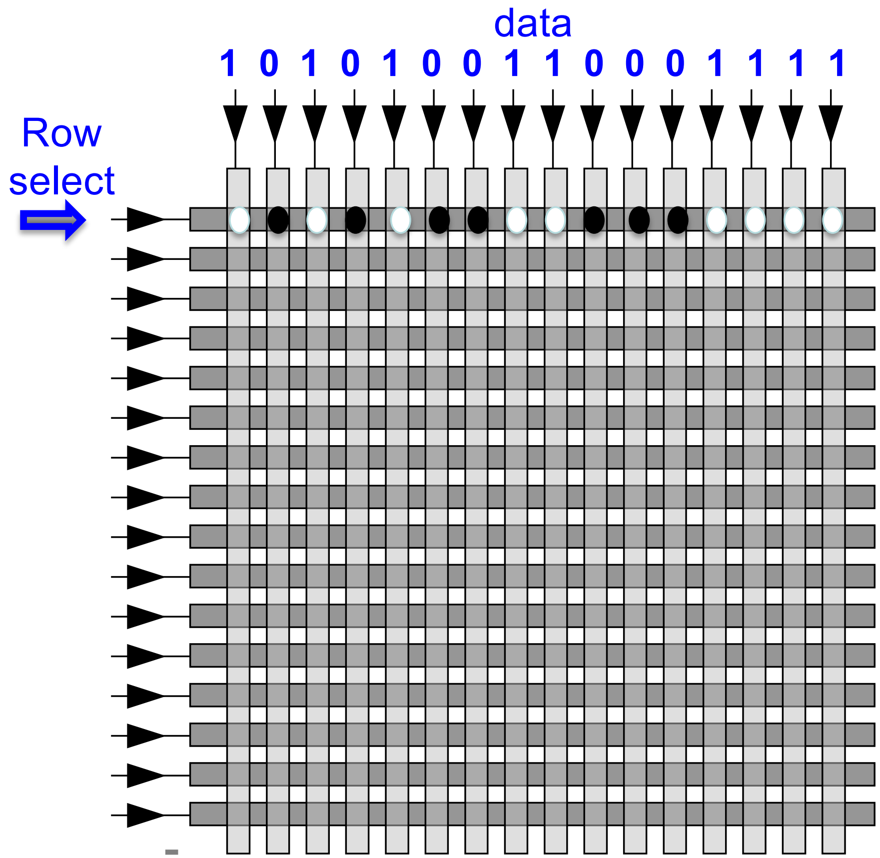


Suggests electronic driving force stronger than mechanical restoring force

Passive Matrix

Q. Does it matter?

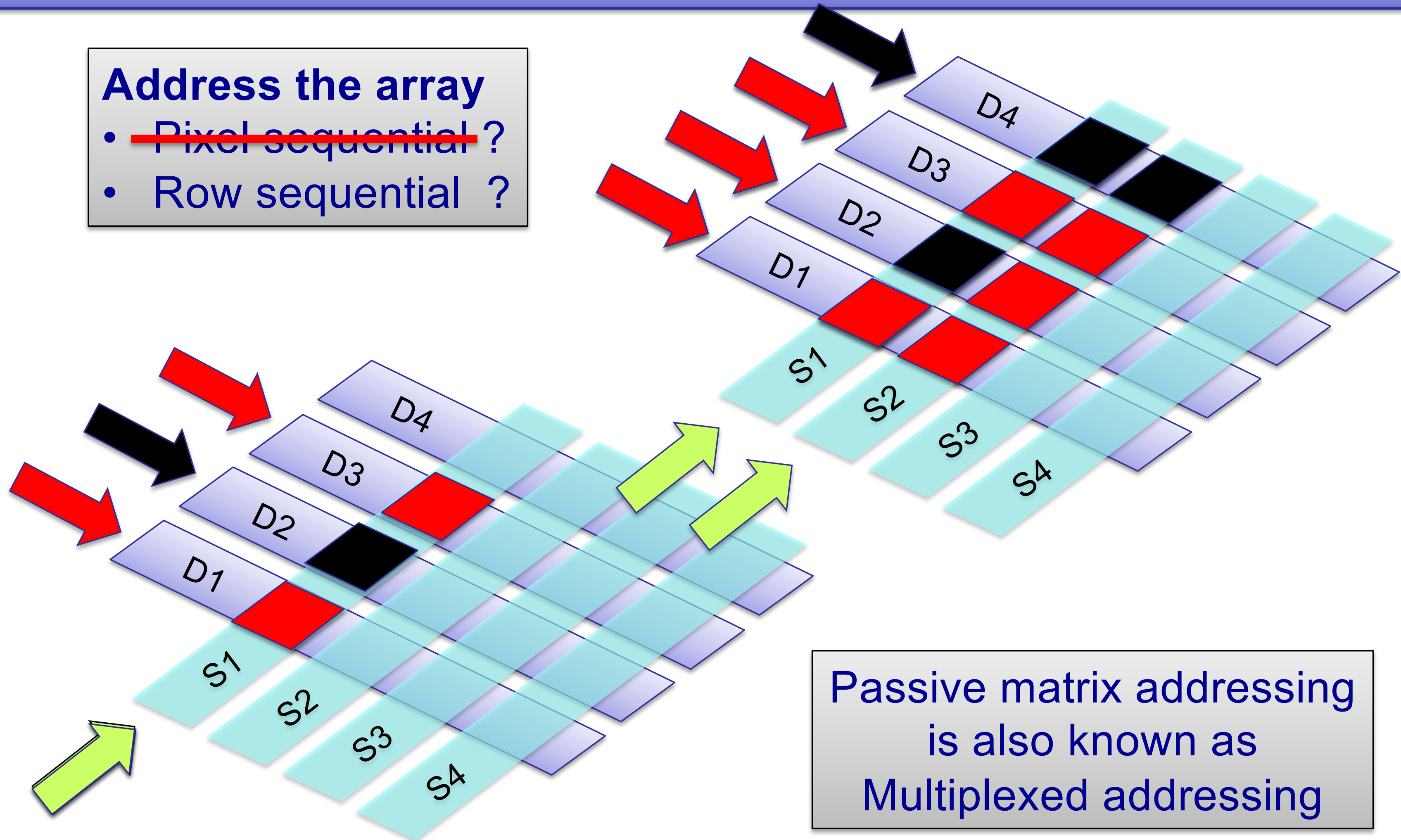
- Back electrode is vertical columns
- Front electrode is horizontal rows
- Per row / column
  - One driver
  - One connecting wire
- MxN pixels requires only M+N drivers



Passive Matrix Pixel Array

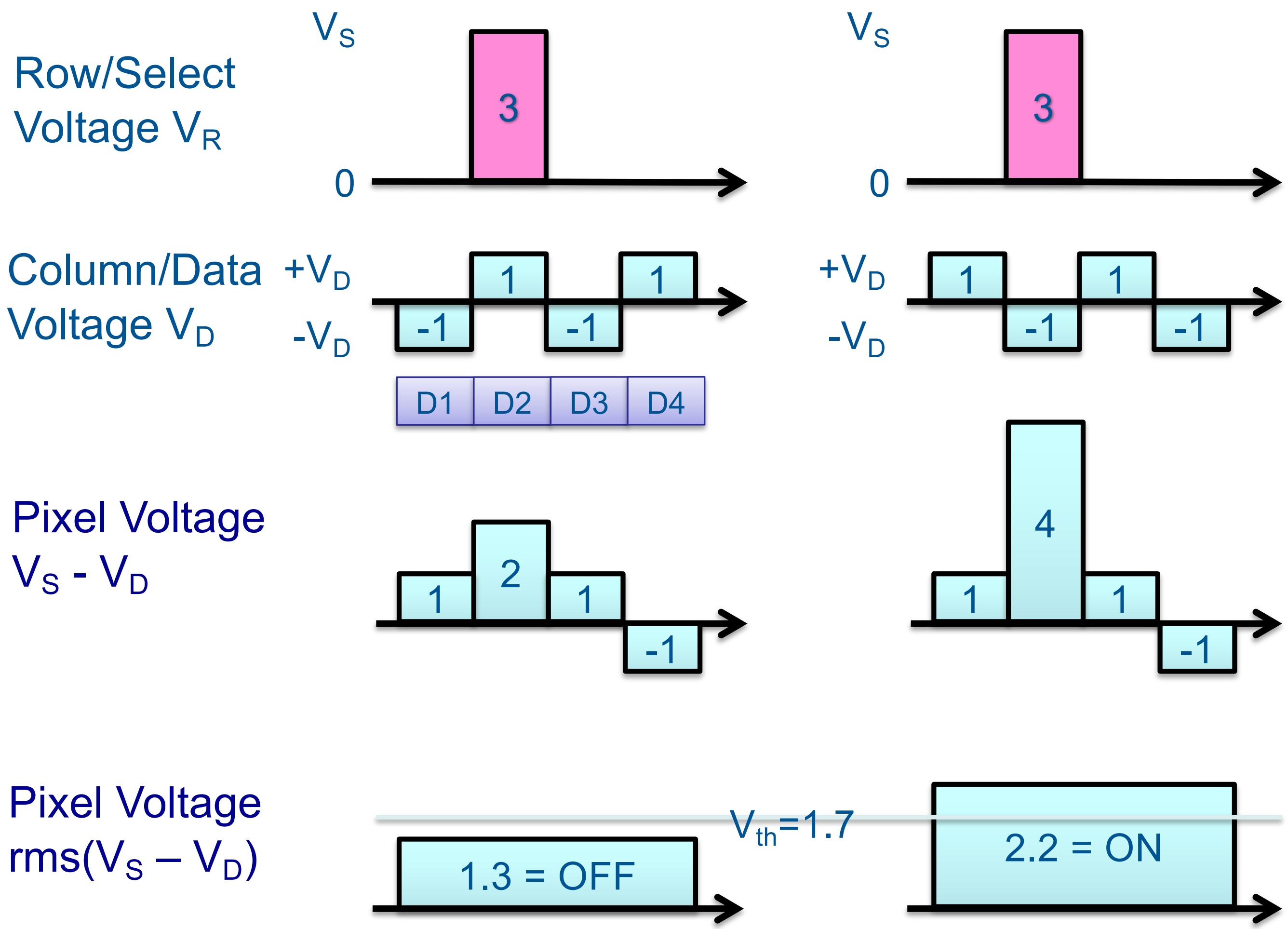
Address the array

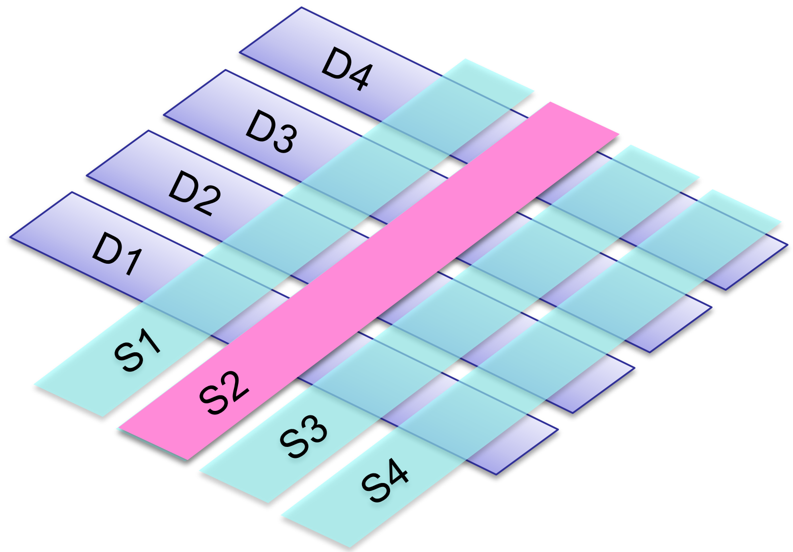
- ~~Pixel sequential~~ ?
- Row sequential ?



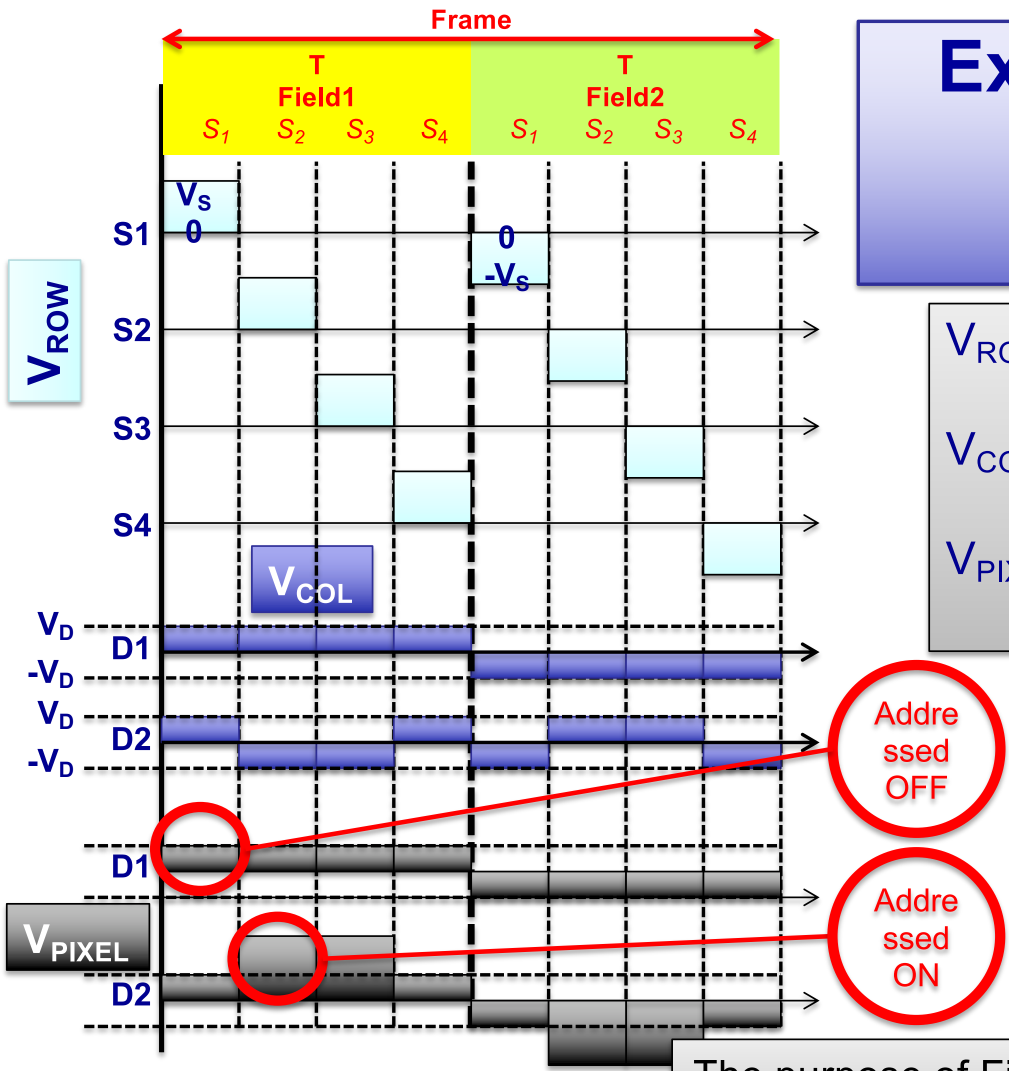
Passive matrix addressing is also known as Multiplexed addressing

Single Pixel Response and Drive Waveform





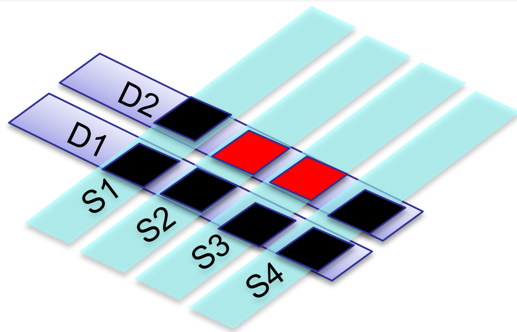
Example of Array Addressing Waveforms



$V_{ROW} = 0, V_S$

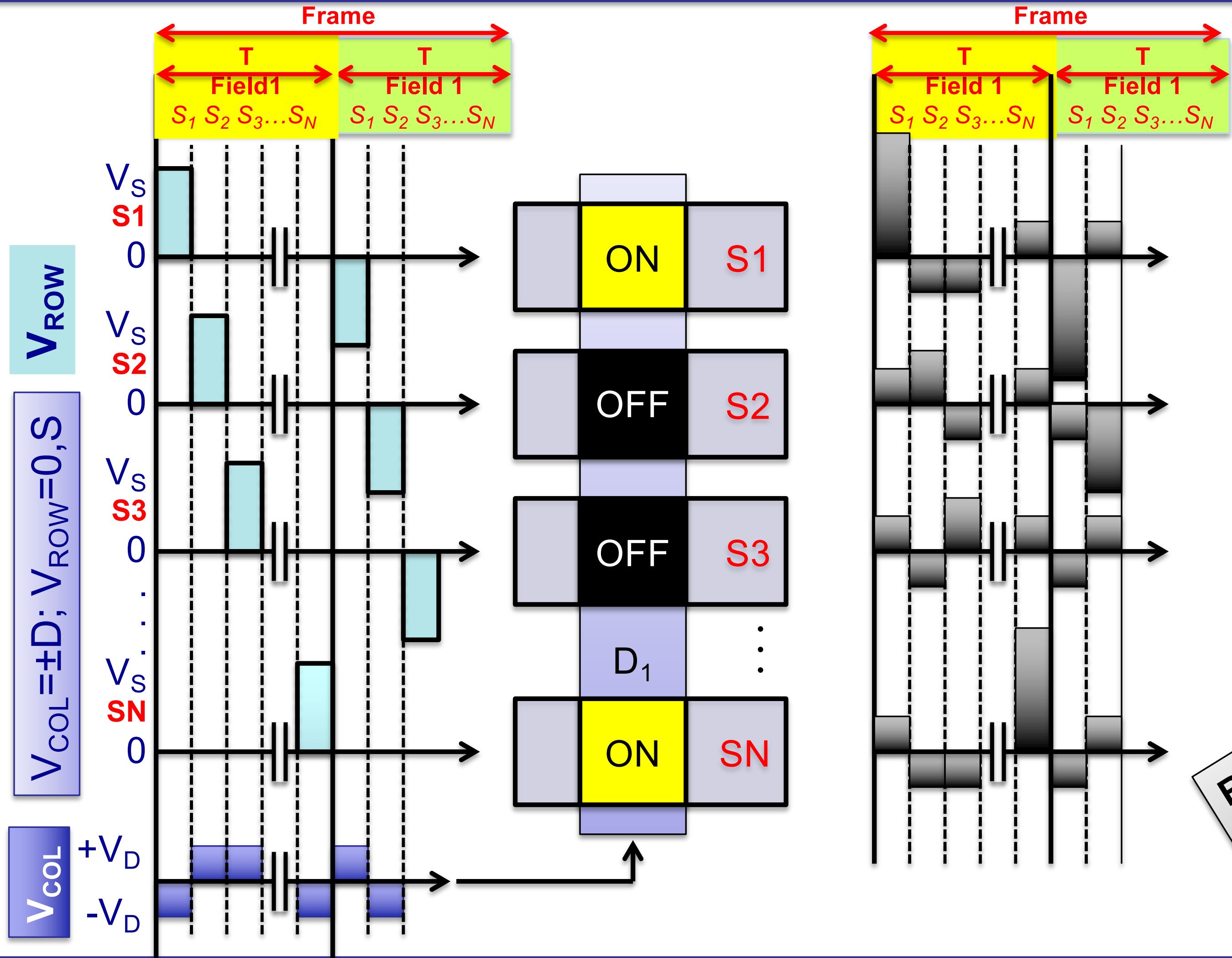
$V_{COL} = \pm V_D$

$V_{PIXEL} = V_S \pm V_D$ (addressed)
$0 \pm V_D$ (not-addressed)



The purpose of Field 2 is to repeat Field 1 with all signals reverse polarity to achieve dc balancing

Example of Array Addressing Waveforms



Multiplexed LCD

RECALL. LC responds slowly to the long-term rms voltage, not the instantaneous value

Alt and Pleshko Criteria (1)

ON pixel

$$V_{PIX,RMS} = \left[\frac{1}{T} \int_0^T \left[V(t) \right]^2 dt \right]^{1/2}$$

N rows means
the line time is T/N
where T is the frame time
If the pixel is **ON**
the voltage it "sees" is
- V_S+V_D for 1/N of the time
- $\pm V_D$ for (N-1)/N of the time

Define η = 1/N
Sometimes use η

$$V_{on}^2 = \frac{1}{T} \int_0^{T/N} \left(V_S + V_D \right)^2 dt + \frac{1}{T} \int_{T/N}^{T} V_D^2 \, dt$$

$$V_{on}^2 = \frac{1}{T} \left[\left(V_S + V_D \right)^2 \left[t \right]_0^{T/N} + V_D^2 \left[t \right]_{T/N}^{T} \right]$$

$$= \frac{1}{T} \left[\left(V_S + V_D \right)^2 \frac{T}{N} + V_D^2 \left(N - 1 \right) \frac{T}{N} \right]$$

V_{on} is the rms voltage experienced by an on pixel

$$V_{on} = \left[\frac{(V_S + V_D)^2 + V_D^2 (N-1)}{N} \right]^{1/2}$$

cf Slide 10 ***ON***

$$\left[\frac{4^2 + 3}{4} \right]^{\frac{1}{2}} = \sqrt{4.75} = 2.2$$

Alt and Pleshko Criteria (2)

OFF pixel

$$V_{PIX,RMS} = \left[\frac{1}{T}\int_0^T [V(t)]^2\,dt\right]^{1/2}$$

N rows means
the line time is T/N
where T is the frame time
If the pixel is **OFF**
the voltage it "sees" is

- V_S-V_D for 1/N of the time
- $\pm V_D$ for (N-1)/N of the time

Define η = 1/N
Sometimes use η

$$V_{off}^2 = \frac{1}{T}\int_0^{T/N}(V_S - V_D)^2\,dt + \frac{1}{T}\int_{T/N}^{T} V_D^2\,dt$$

$$V_{off}^2 = \frac{1}{T}\left[(V_S - V_D)^2\,[t]_0^{T/N} + V_D^2\,[t]_{T/N}^{T}\right]$$

$$= \frac{1}{T}\left[(V_S - V_D)^2\,\frac{T}{N} + V_D^2\,(N-1)\frac{T}{N}\right]$$

V_{off} is the rms voltage experienced by an off pixel

$$V_{off} = \left[\frac{(V_S - V_D)^2 + V_D^2(N-1)}{N}\right]^{1/2}$$

cf Slide 10 ***OFF***

$$\left[\frac{2^2 + 3}{4}\right]^{\frac{1}{2}} = \sqrt{1.75} = 1.3$$

Alt and Pleshko Criteria (3)

$$\frac{V_{on}}{V_{off}} = \left[\frac{(V_S + V_D)^2 + V_D^2(N-1)}{(V_S - V_D)^2 + V_D^2(N-1)}\right]^{1/2} = \left[\frac{\left[\left(V_S/V_D\right)+1\right]^2 + {}^2(N-1)}{\left[\left(V_S/V_D\right)-1\right]^2 + (N-1)}\right]^{1/2}$$

Now pose

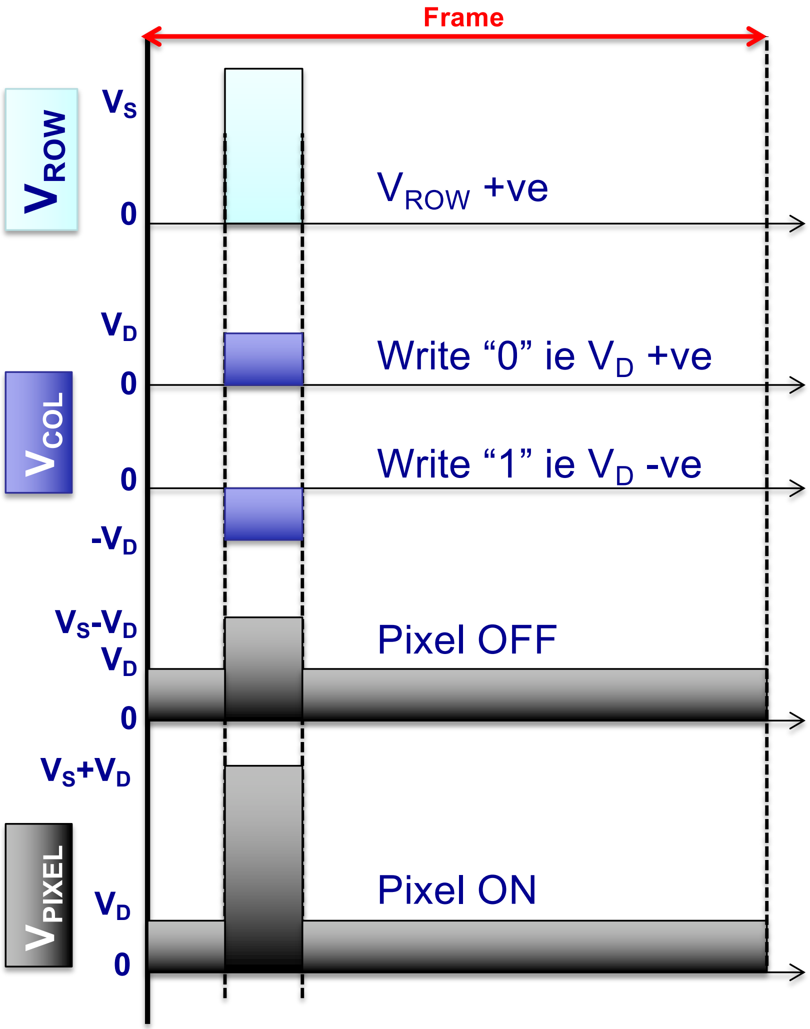
$$u = V_S/V_D \quad \Rightarrow \quad \frac{V_{on}}{V_{off}} = \left[\frac{(u+1)^2 + N - 1}{(u-1)^2 + N - 1}\right]^{1/2} \qquad \left(\frac{f}{g}\right)' = \frac{f'g - g'f}{g^2}$$

$$\frac{d}{du}\left(\frac{V_{on}}{V_{off}}\right) = 0 \quad \Rightarrow \quad u = \boxed{\sqrt{N} = V_S/V_D}$$

$$\boxed{\left(\frac{V_{on}}{V_{off}}\right)_{\max} = \sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}}$$

Iron Law of multiplexing for LCDs

Signal to Single Pixel of M × N array for ON/OFF

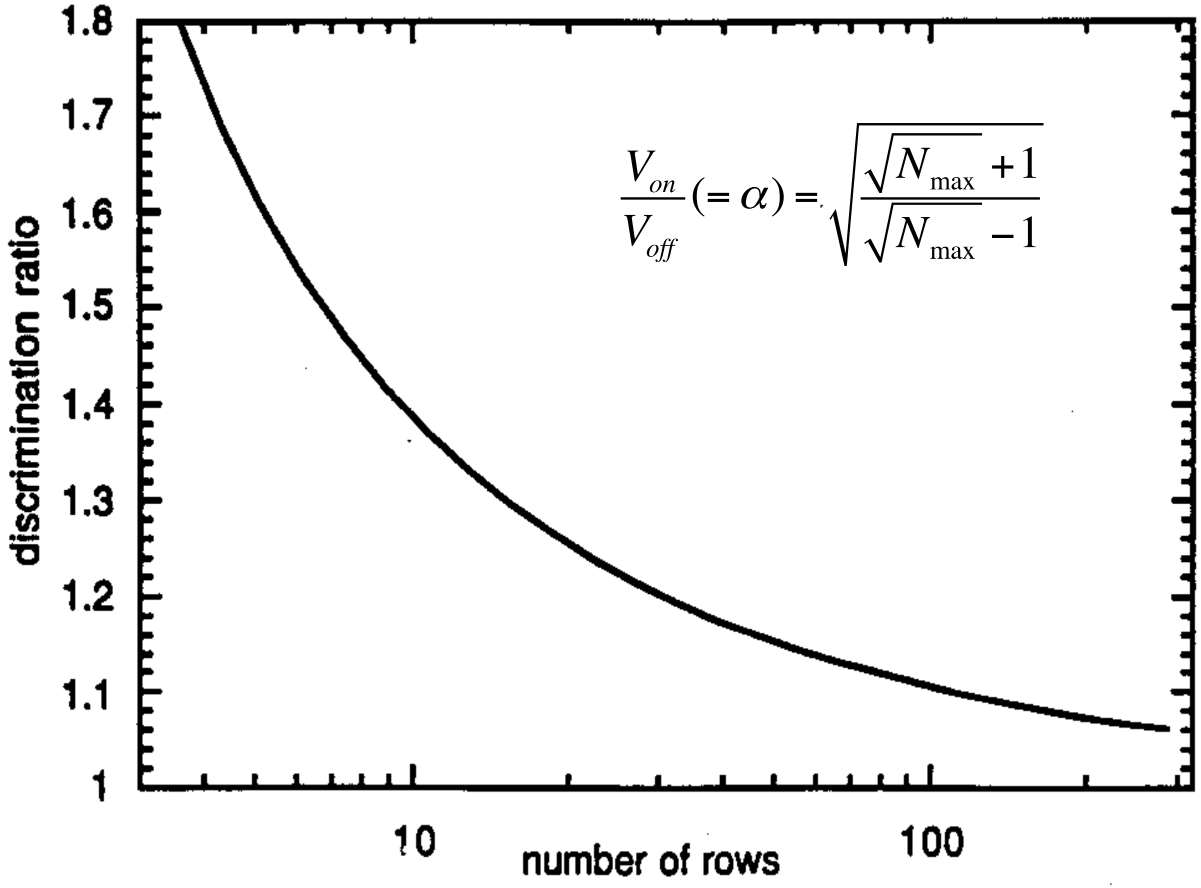


Over a whole field- or frame-time -

$$V_{off}^2 = \frac{1}{N}(V_S - V_D)^2 + \frac{(N-1)}{N}V_D^2$$

$$V_{on}^2 = \frac{1}{N}(V_S + V_D)^2 + \frac{(N-1)}{N}V_D^2$$

V_{on}/V_{off} vs N (# rows) for multiplexed LCD



Alt-Pleshko Limit for Passive-Matrix Displays

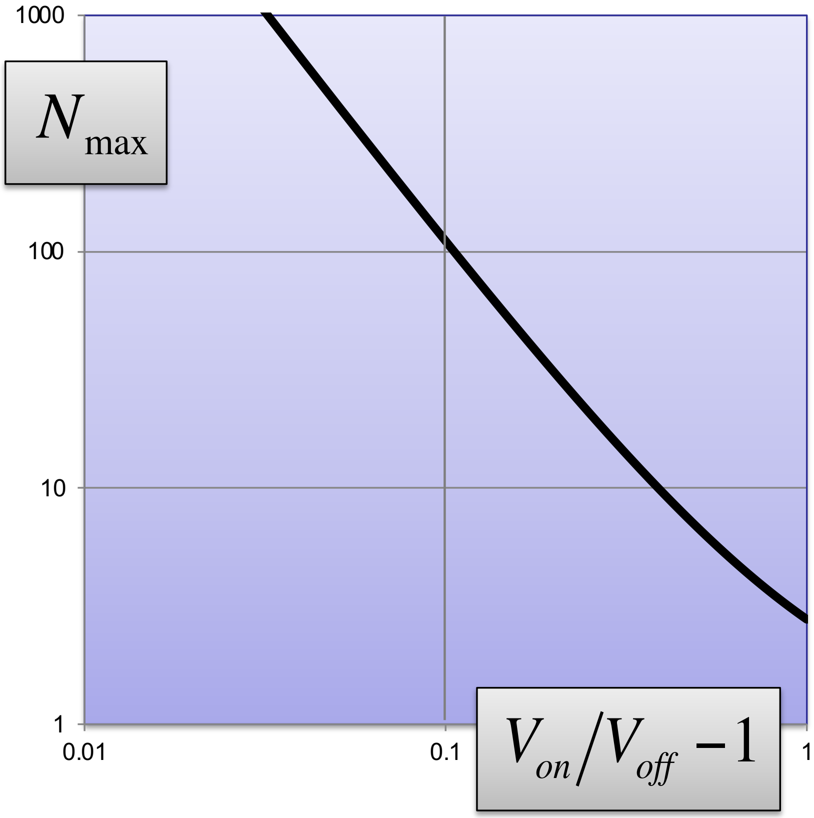
How many lines can we address?

$$\left(\frac{V_{on}}{V_{off}}\right)_{\max} = \sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}$$

Solving for N (See tutorial)

$$N_{\max} = \left(\frac{V_{on}^2 + V_{off}^2}{V_{on}^2 + V_{off}^2}\right)^2$$

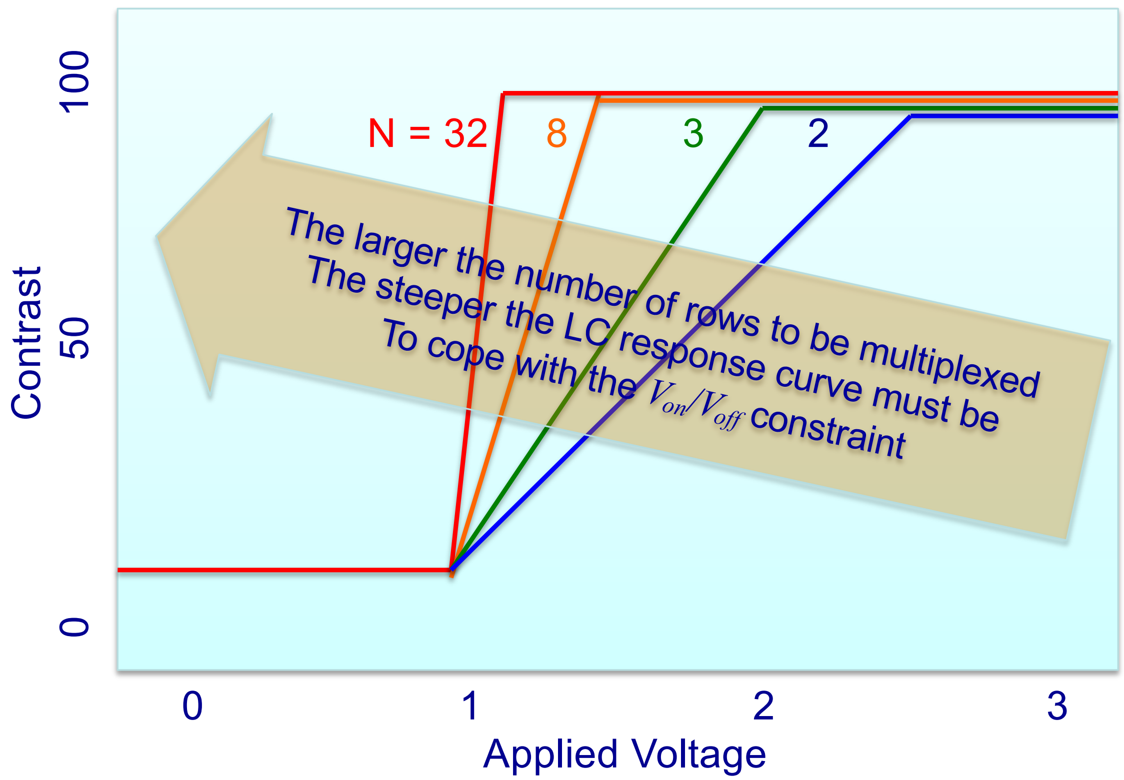
$$N_{\max} = \left(\frac{V_{on}^2 / V_{off}^2 + 1}{V_{on}^2 / V_{off}^2 - 1}\right)^2$$



Scanning limitations

$$\left(\frac{V_{on}}{V_{off}}\right)_{\max} = \sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}$$

N_{max}	V_{on}/V_{off}
2	2.41
3	1.93
4	1.73
8	1.45
16	1.29
32	1.20
100	1.10



Contrast loss when N increases

$$\alpha_{\max} = \sqrt{\frac{\sqrt{N}+1}{\sqrt{N}-1}}$$

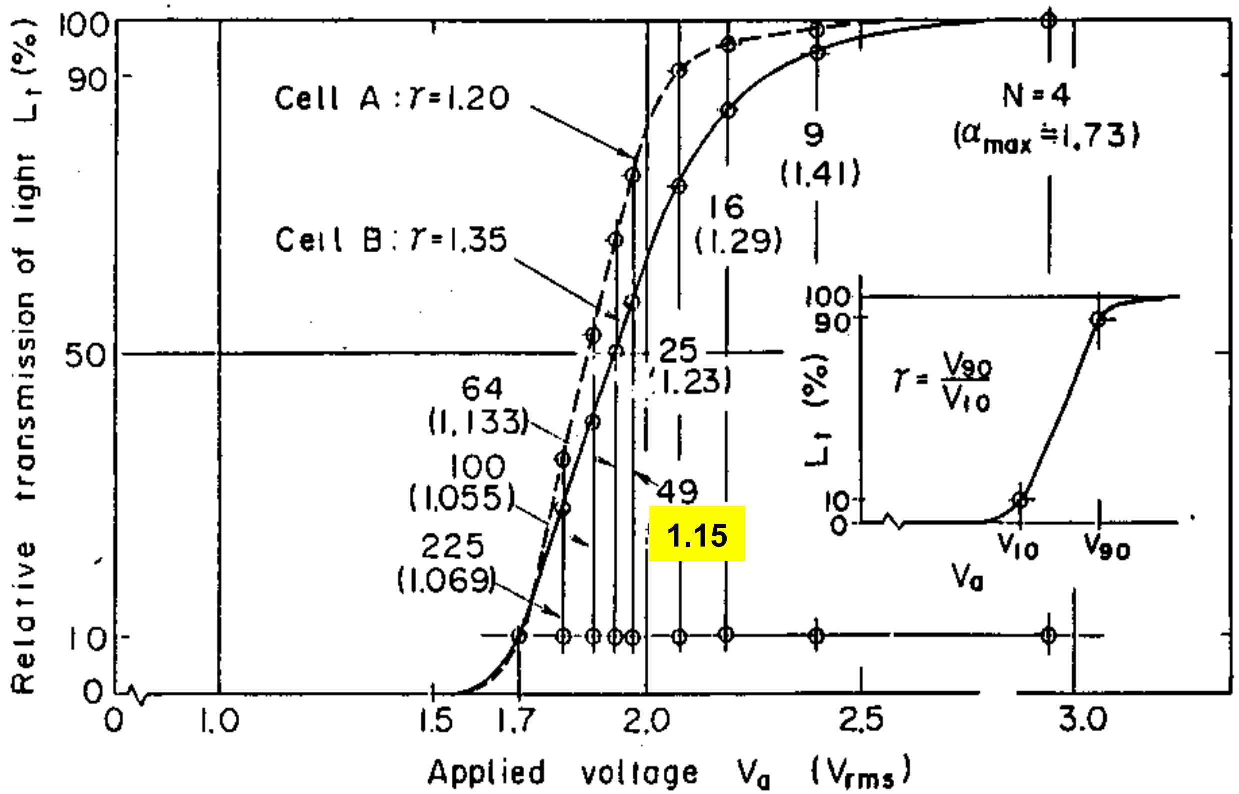
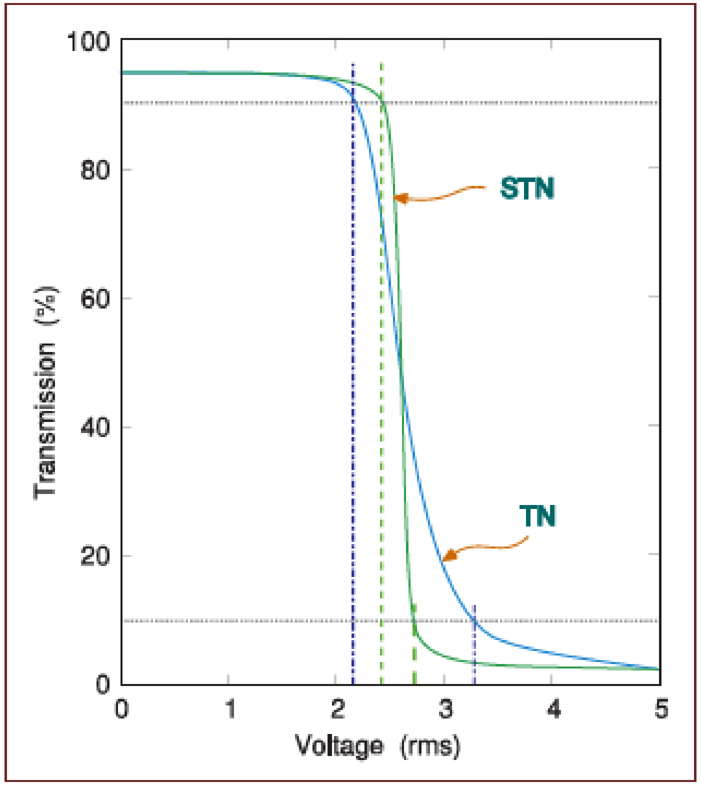


Fig. 4.9. Relation between light transmission ranges and number of scanning electrodes of two liquid crystal display panels.

Beating A&P - Super Twist Nematic LC



TN

90° twist

$V_{10}/V_{90} = 1.6$

STN

180° - 270° twist

$V_{10}/V_{90} = 1.06$

Improved STN LC material

IMPORTANT

$V_{90} = V_{OFF}$

$V_{10} = V_{ON}$

Super Twist Nematic (STN) has much steeper response than regular TN
This allows many more rows to be addressed (see slide 21)

Beating A&P - Dual Scan Addressing

Address pixel matrix as follows

- One half of rows from top
- Other half from bottom

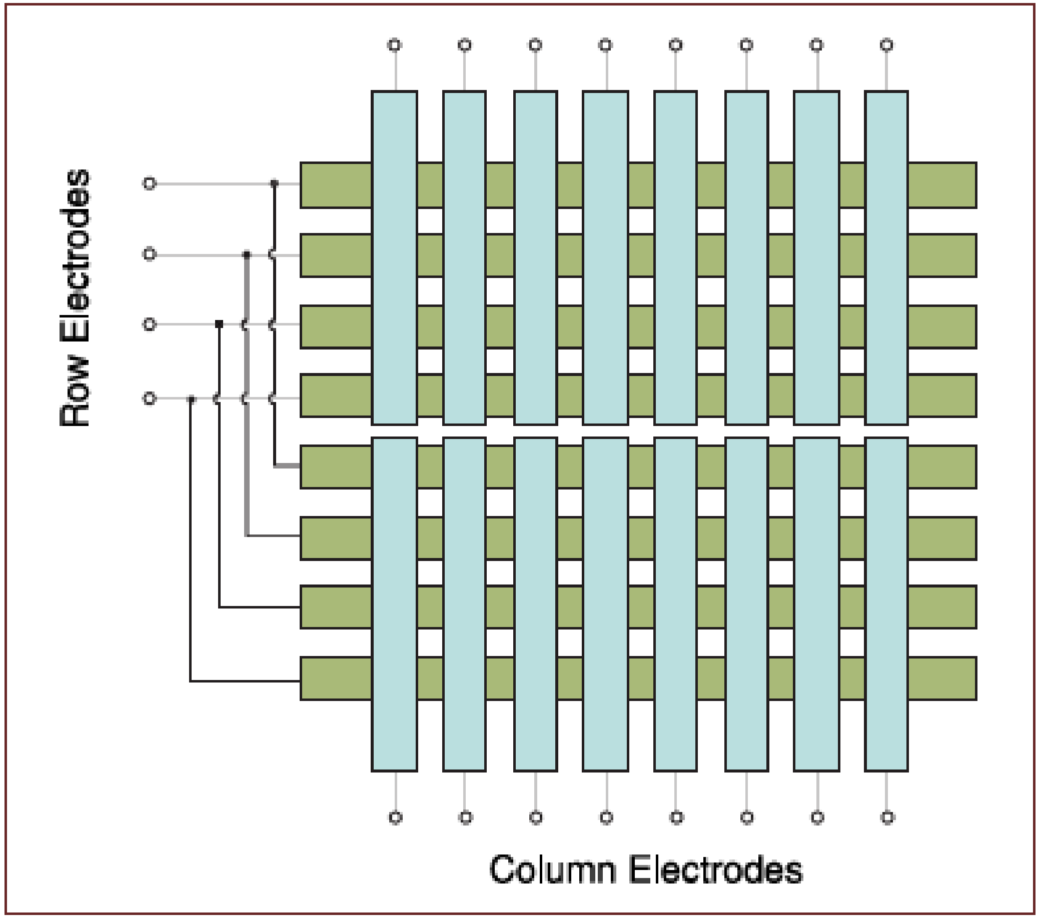
ie

2 half-matrices

each of N/2 rows

= M × N/2 pixels

Multi-line addressing is another potential solution *but is not covered here*



Matrix layout for doubled vertical resolution

Passive Matrix LCD

Advantages of passive matrix

- more lines than segmented
- Lower cost substrate than active matrix

Disadvantages of passive matrix

- Limited number of lines of definition
- As number of lines rises
  - Limited contrast as more lines
  - Crosstalk between pixels
  - More stringent requirements on drive waveforms
  - Severe requirements on LC materials

Passive Matrix Addressing - Summary

Review

- Explanation of PM addressing
- Derivation of Alt and Pleshko Criteria leading to
- Significant constraints of PM
- Work-arounds
- Summary

Comment

- Today’s lecture has introduced some quite new concepts
- Please take time to familiarise yourself and absorb the new material

Additional Resources

- HBVDT is limited on analysis of PM LCD
- I have loaded Chapter 2 of Lueder (2022) on to Learn
  - *I strongly recommend that you study it*

Next lecture – Active Matrix (AM) LCD