Video Lectures on Computer Graphics

Section – II:

<u>CRT DISPLAY DEVICES</u>

Examples of Computer Graphics Devices:

CRT, EGA/CGA/VGA/SVGA monitors,

plotters, data matrix, laser printers, Films,

flat panel devices, Video digitizers, scanners,

LCD panels, keyboard, joystick, mouse,

touch screen, track ball, etc.

The most commonly used display device is the

CRT monitor

Types of CRT display devices

- DVST (Direct View Storage Tube)
- Calligraphic or Random Scan display system
- Refresh and raster scan display system

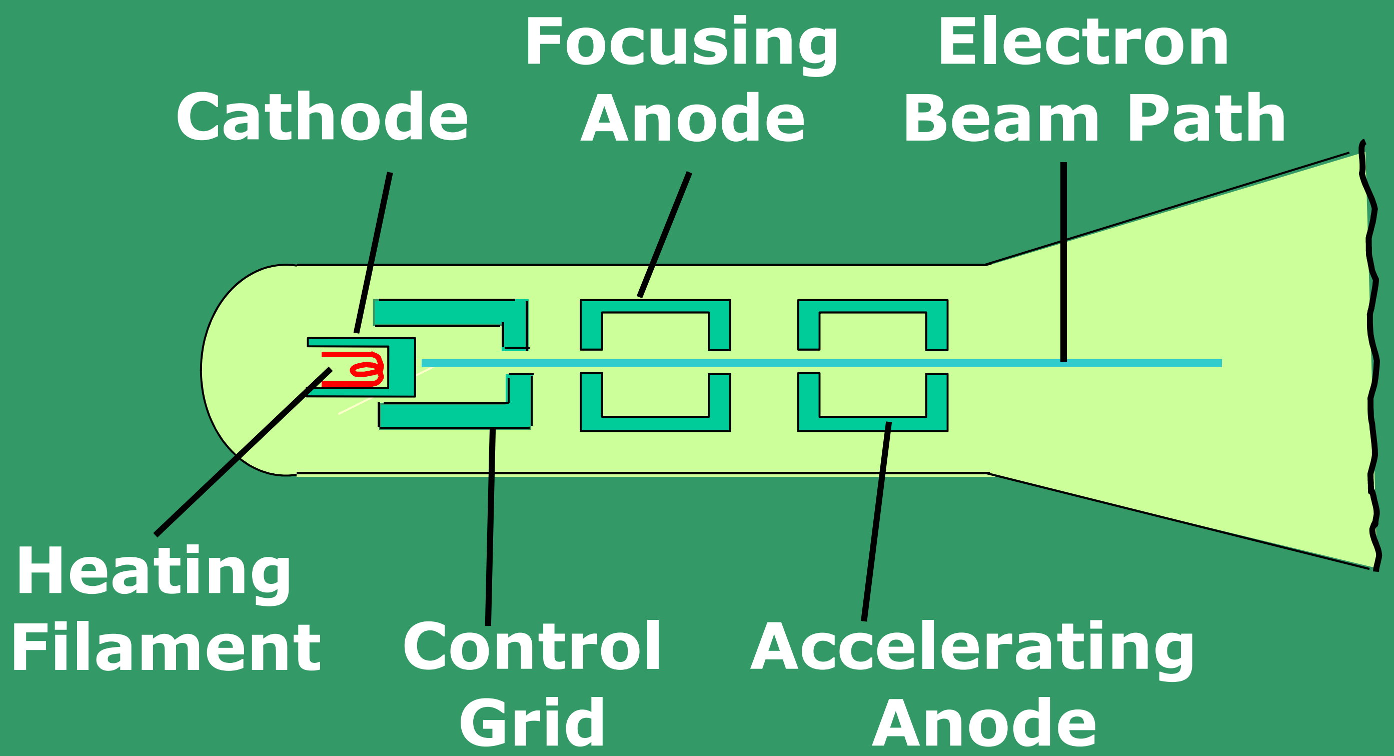
DVST - Direct View Storage Tube

- Storage Tube – it is a CRT with a long persistence phosphor
- Provides flicker-free display
- No refreshing necessary

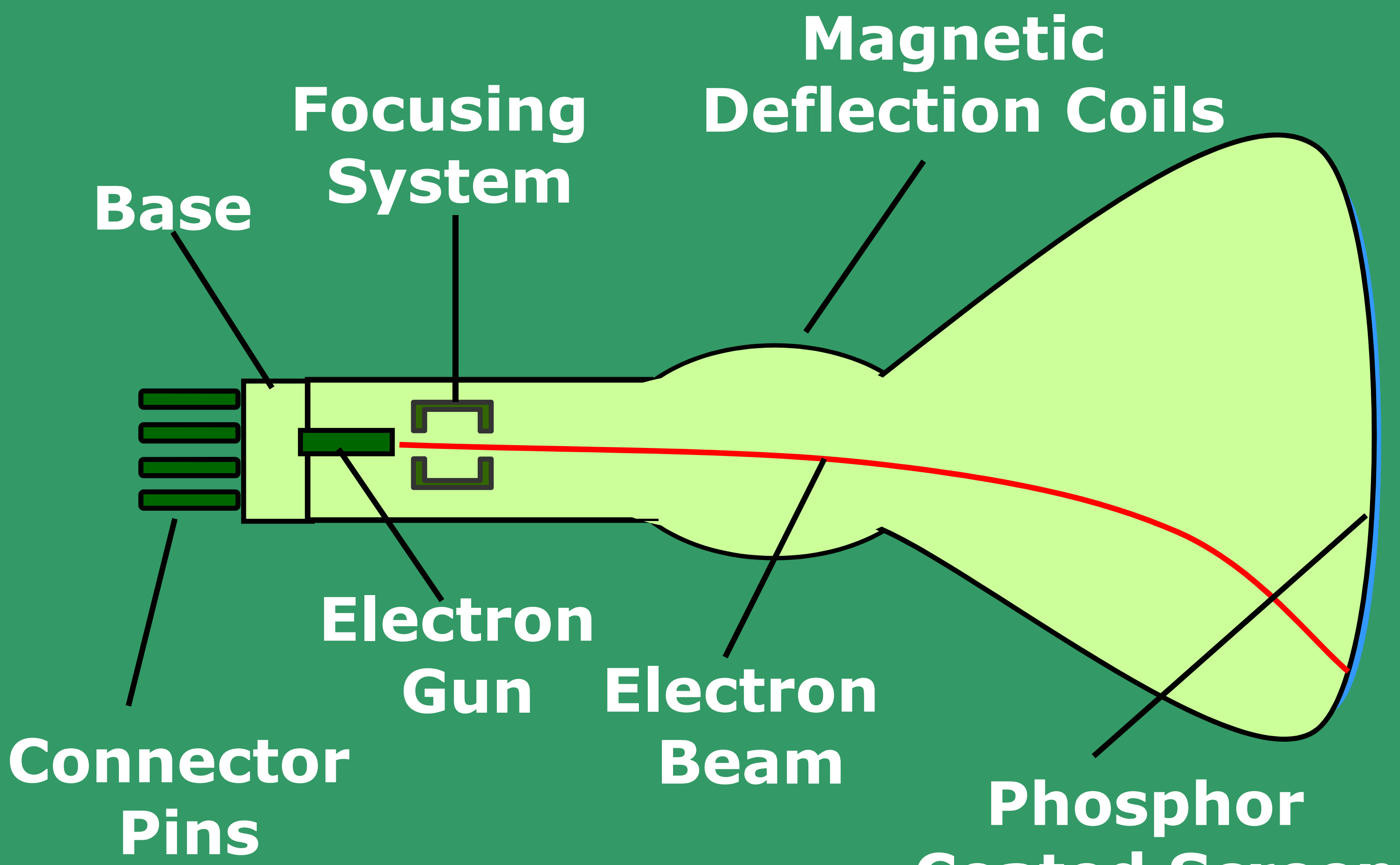
DVST - Direct View Storage Tube (contd.)

- A slow moving electron beam draws a line on the screen
- Screen has a storage mesh in which the phosphor is embedded
- Image is stored as a distribution of charges on the inside surface of the screen
- Limited interactive support

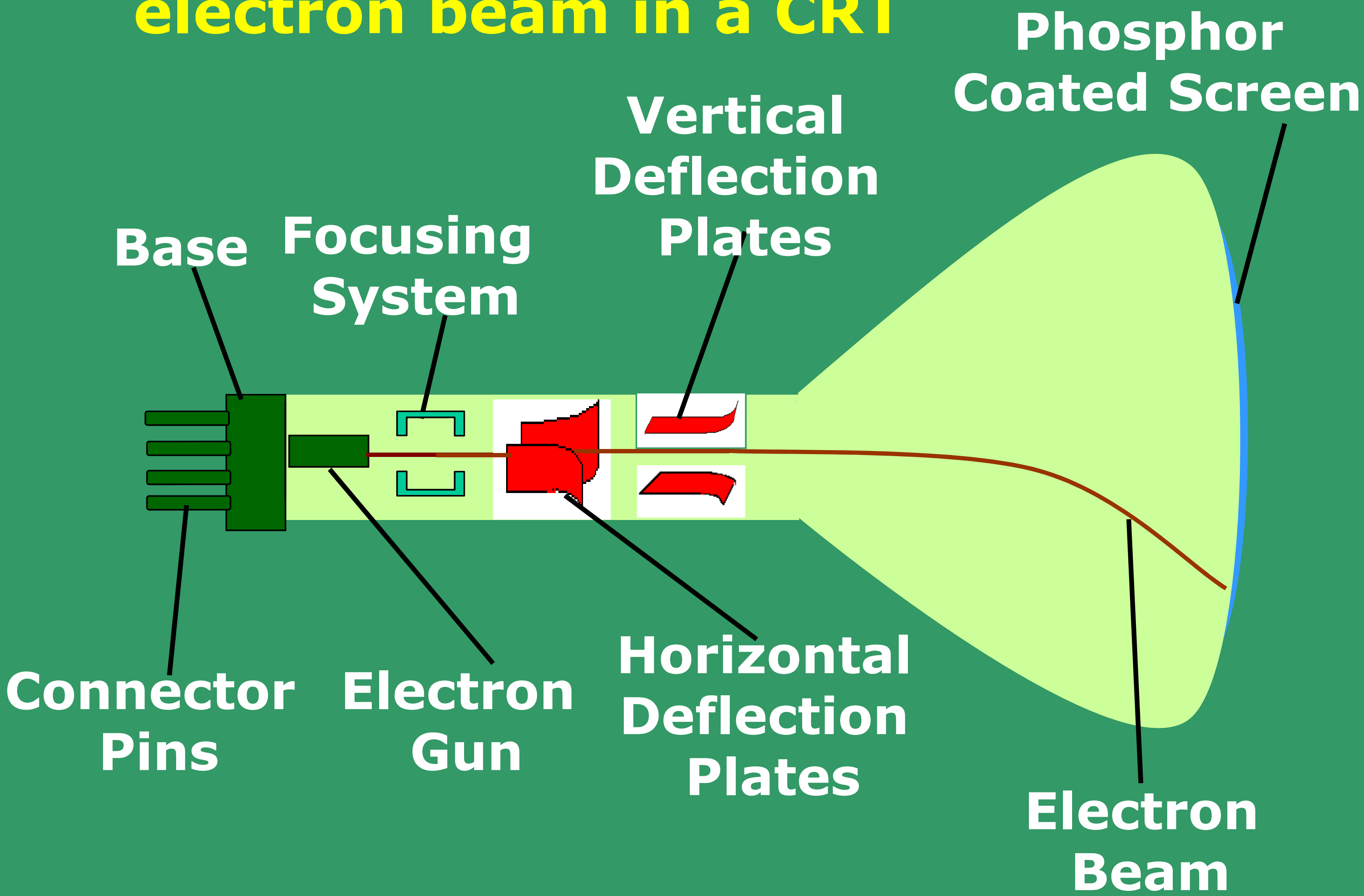
Operation of an electron gun with an accelerating anode

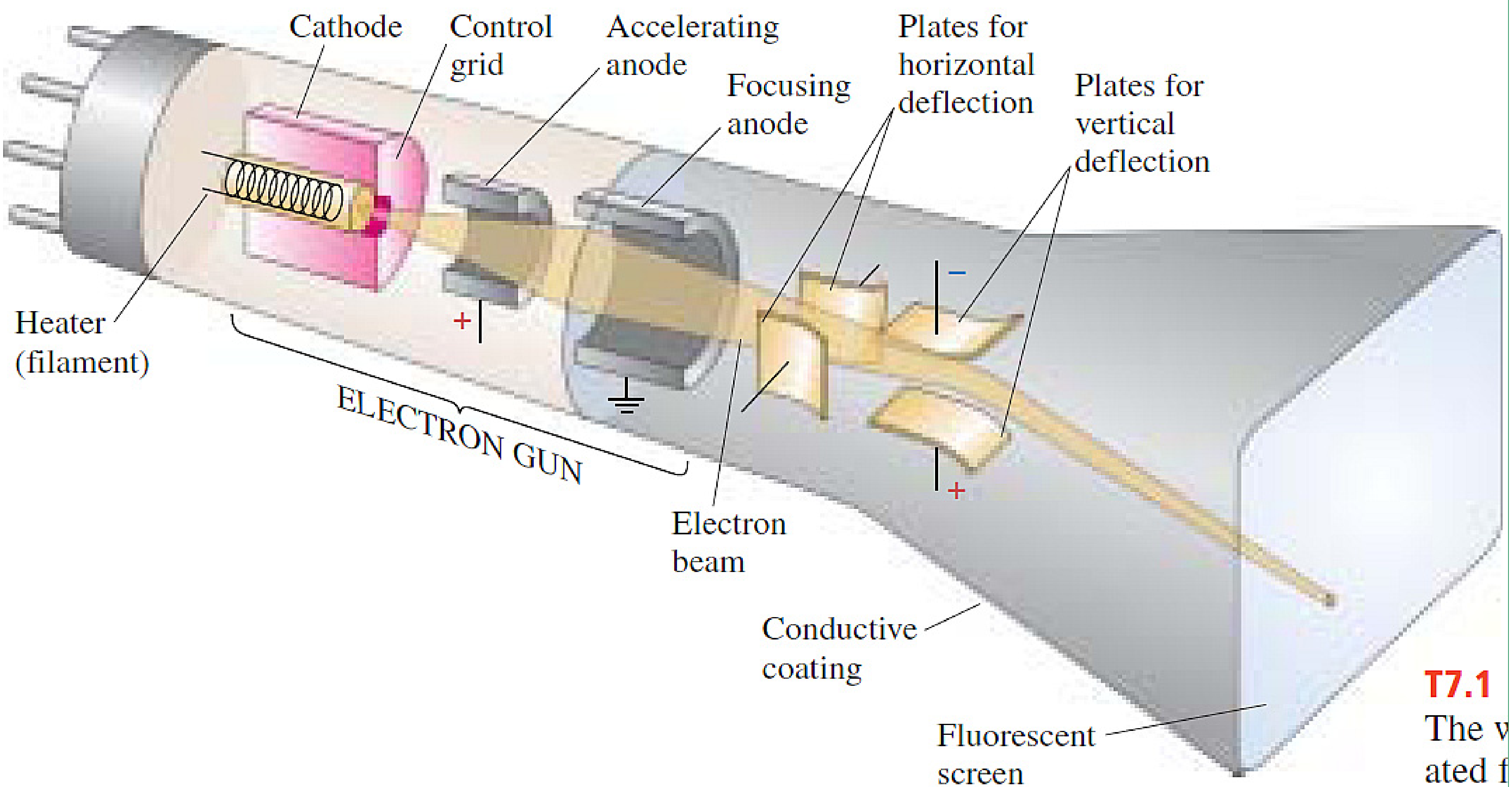


Basic design of a Magnetic deflection CRT



Electrostatic deflection of the electron beam in a CRT





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DVST - Direct View Storage Tube (contd.)

Drawbacks

- Modifying any part of the image requires redrawing the entire modified image
- Change in the image requires to generate a new charge distribution in the DVST
- Slow process of drawing – typically a few seconds are necessary for a complex picture
- Erasing takes about 0.5 seconds. All lines and characters must be erased
- No animation possible with DVST

Calligraphic or Random Scan display system

- Also called Vector, Stroke, Line drawing displays
- Characters are also made of sequences of strokes (or short lines)
- Vectored – electron beam is deflected from end-point to end-point
- Random scan - Order of deflection is dictated by the arbitrary order of the display commands
- Phosphor has short persistence – decays in 10-100 μs

Calligraphic or Random Scan display system (contd.)

- The display must be refreshed at regular intervals – minimum of 30 Hz (fps) for flicker-free display

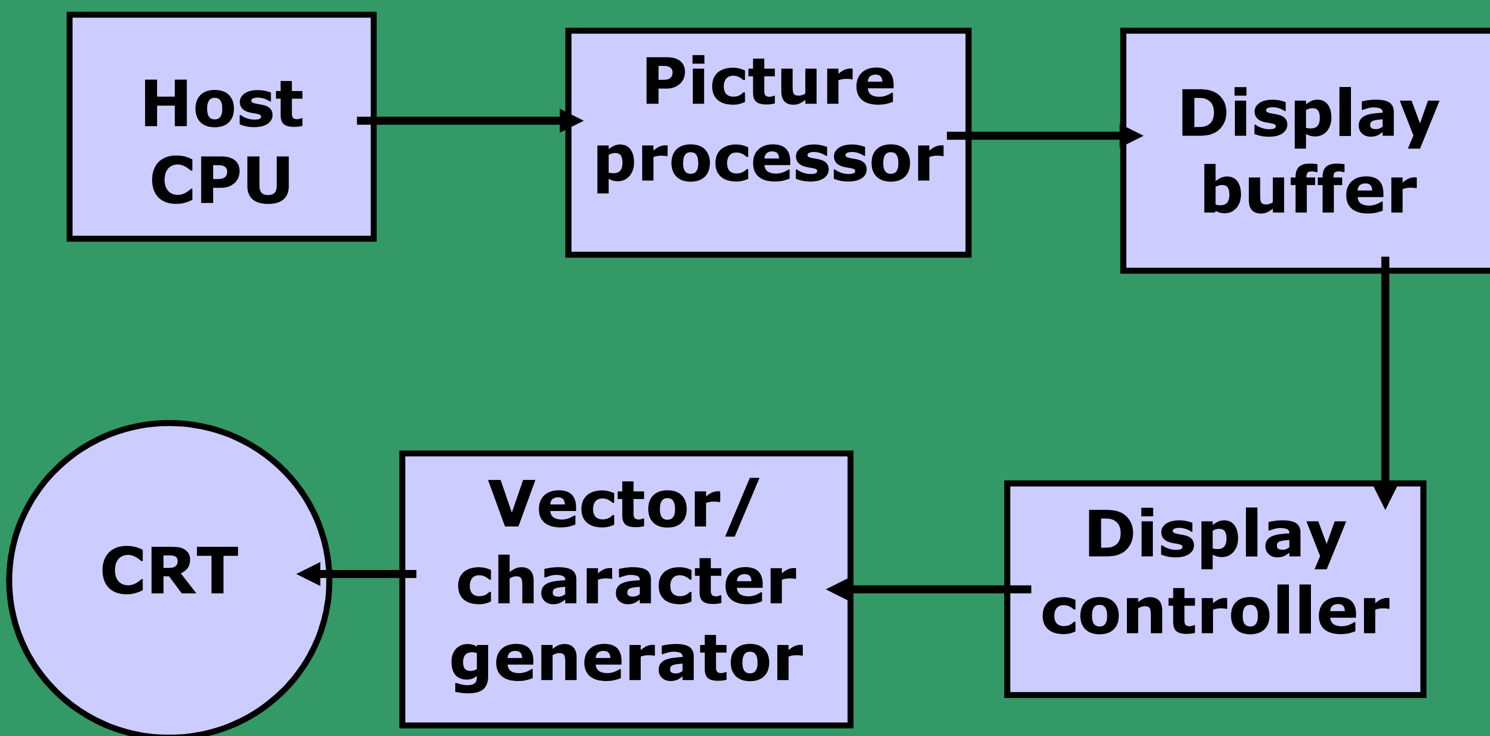
- Refresh Buffer – memory space allocated to store the display list or display program for the display processor to draw the picture

- The display processor interprets the commands in the refresh buffer for plotting

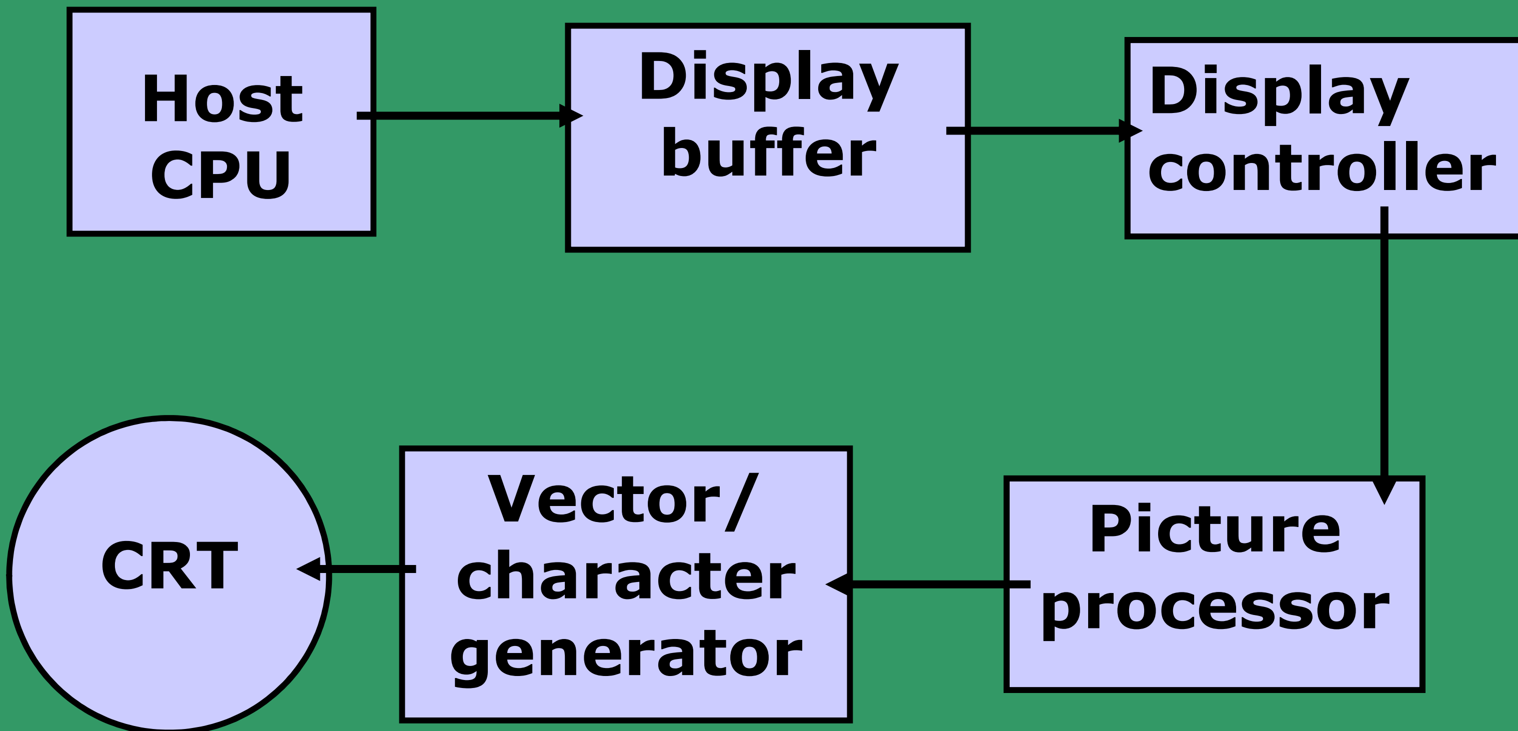
- The display processor must cycle through the display list to refresh the phosphor

- The display program has commands for point- , line–, and character plotting

Conceptual block diagram of calligraphic refresh display - I



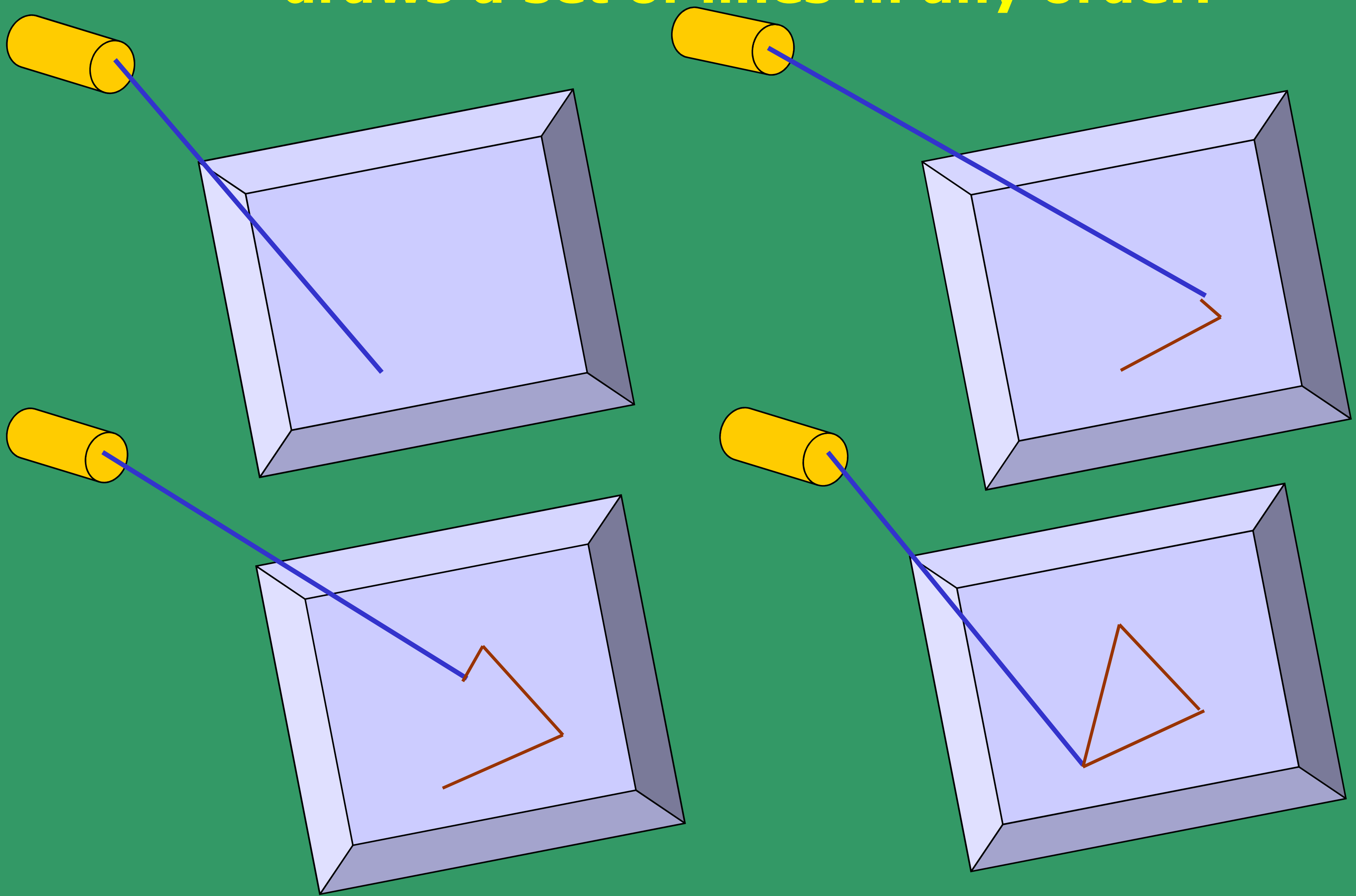
Conceptual block diagram of calligraphic refresh display - II

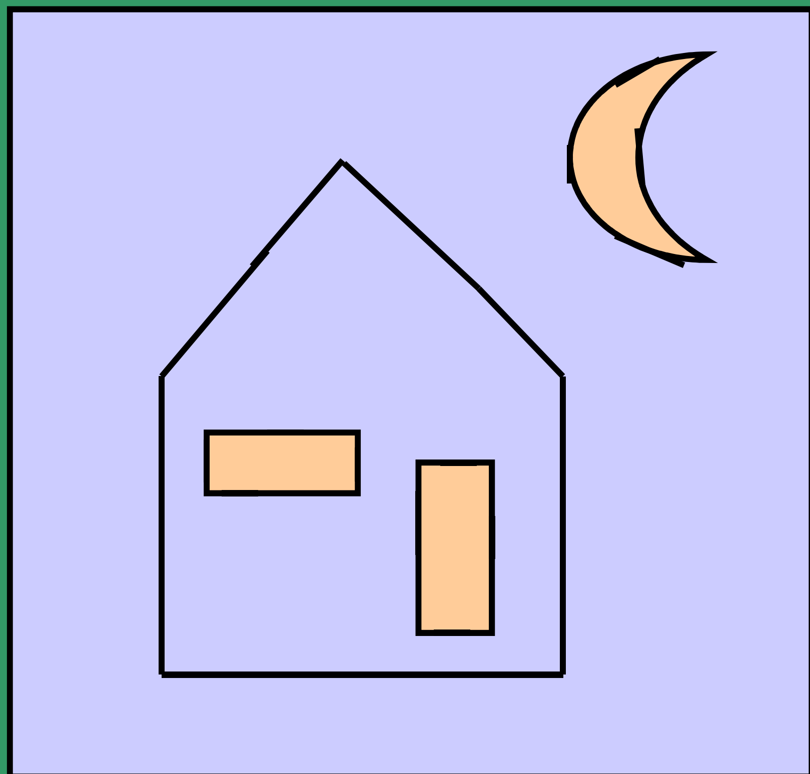


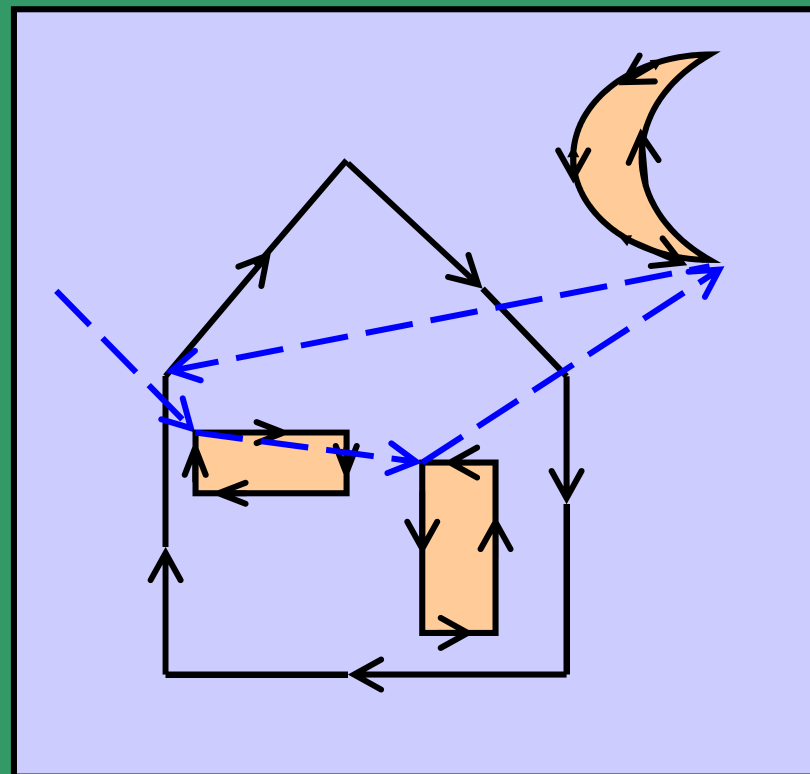
Calligraphic or Random Scan display system (contd.)

- The display processor sends digital and point coordinate values to a vector generator
- The vector generator converts the digital coordinate values to analog voltages for the beam-deflection circuits
- The beam-deflection circuits displace the electron beam for writing on the CRT's phosphor coating
- Recommended refresh rate is 40 – 50 Hz.
- Scope of animation with segmentation – mixture of static and dynamic parts of a picture

Random-scan display system draws a set of lines in any order.







(a) Ideal line drawing **(b) Vector scan**

Calligraphic or Random Scan display system (contd.)

- Phosphor’s <u>Fluorescence</u> is the light emitted as electrons (unstable) lose their excess energy while the phosphor is being struck by electrons
- <u>Phosphorescence</u> is the light given off by the return of the relatively more stable excited electrons to their unexcited state once the electron beam excitation is removed
- Phosphor’s <u>persistence</u> is defined as the time from the removal of excitation to the moment when phosphorescence has decayed to 10% of the initial light output (decay is exponential).
  - long persistence : several seconds
  - short persistence : 10-60 μs (common in modern displays)

Refresh and raster scan display system

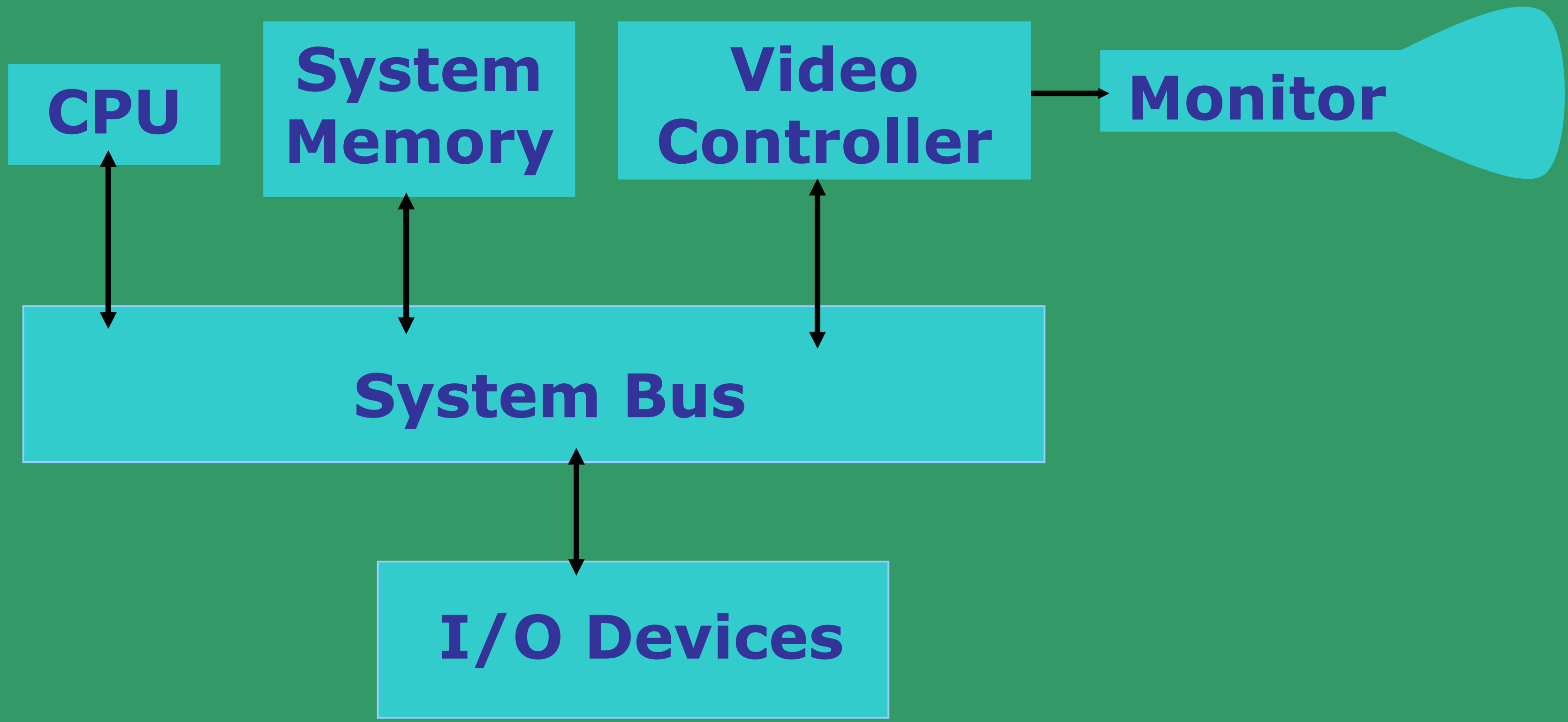
- **Used in television screens**

- **Unlike DVST and random-scan which were line-drawing devices, refresh CRT is a <u>point-plotting device</u>**

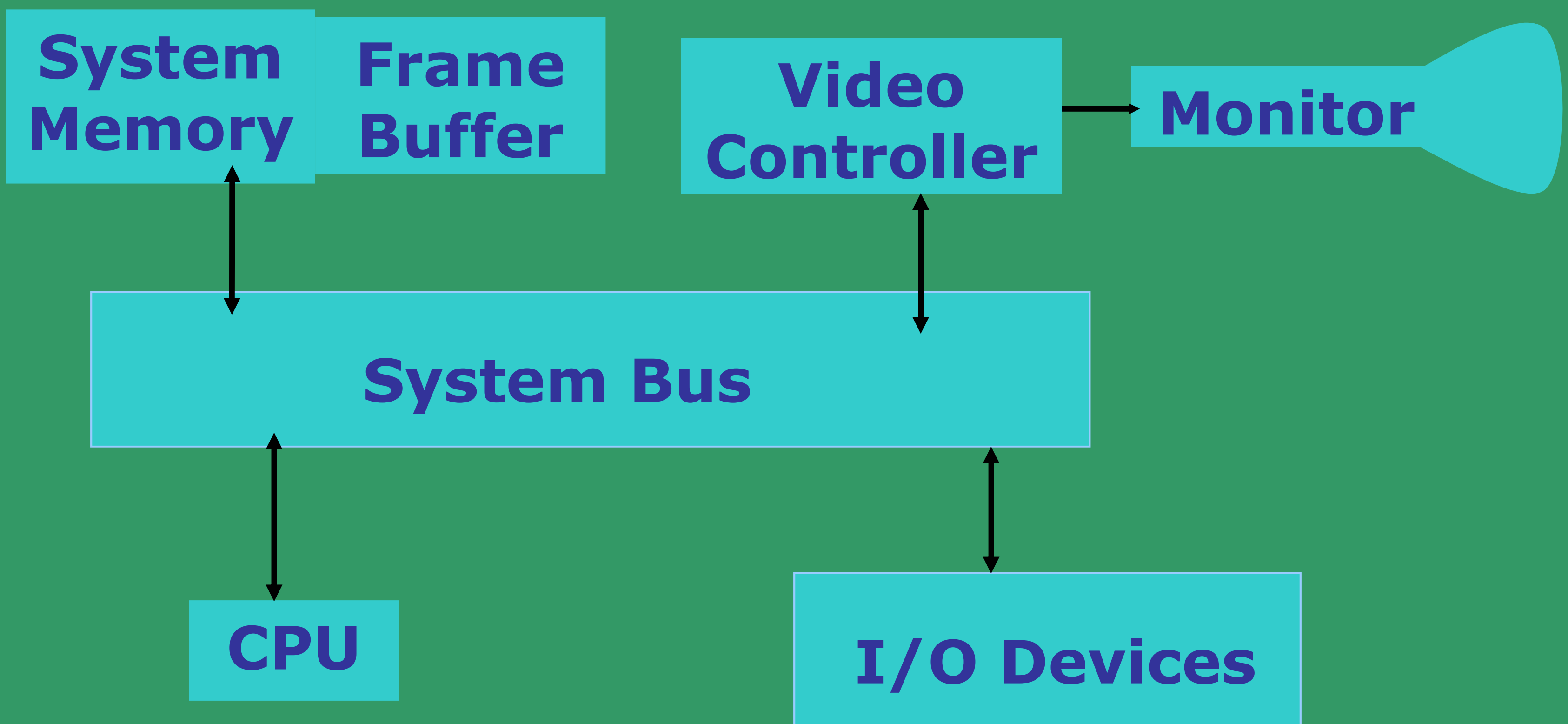
- **Raster displays store the display primitives (lines, characters, shaded and patterned areas) in a refresh buffer**

- **Refresh buffer (also called frame buffer) stores the drawing primitives in terms of points and pixels components**

Architecture of a simple raster graphics system



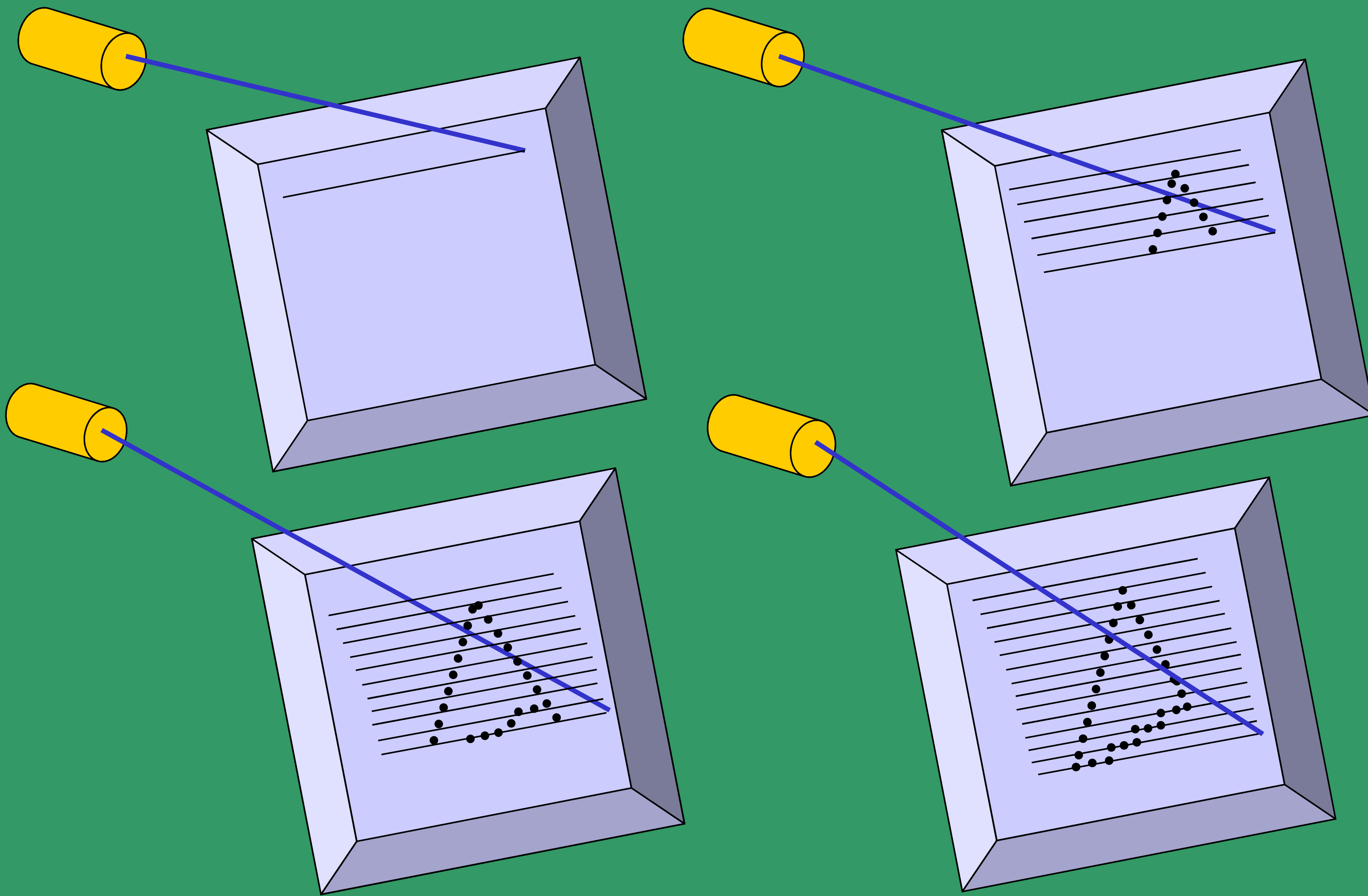
Architecture of a raster system with a fixed portion of the system memory reserved for the frame buffer



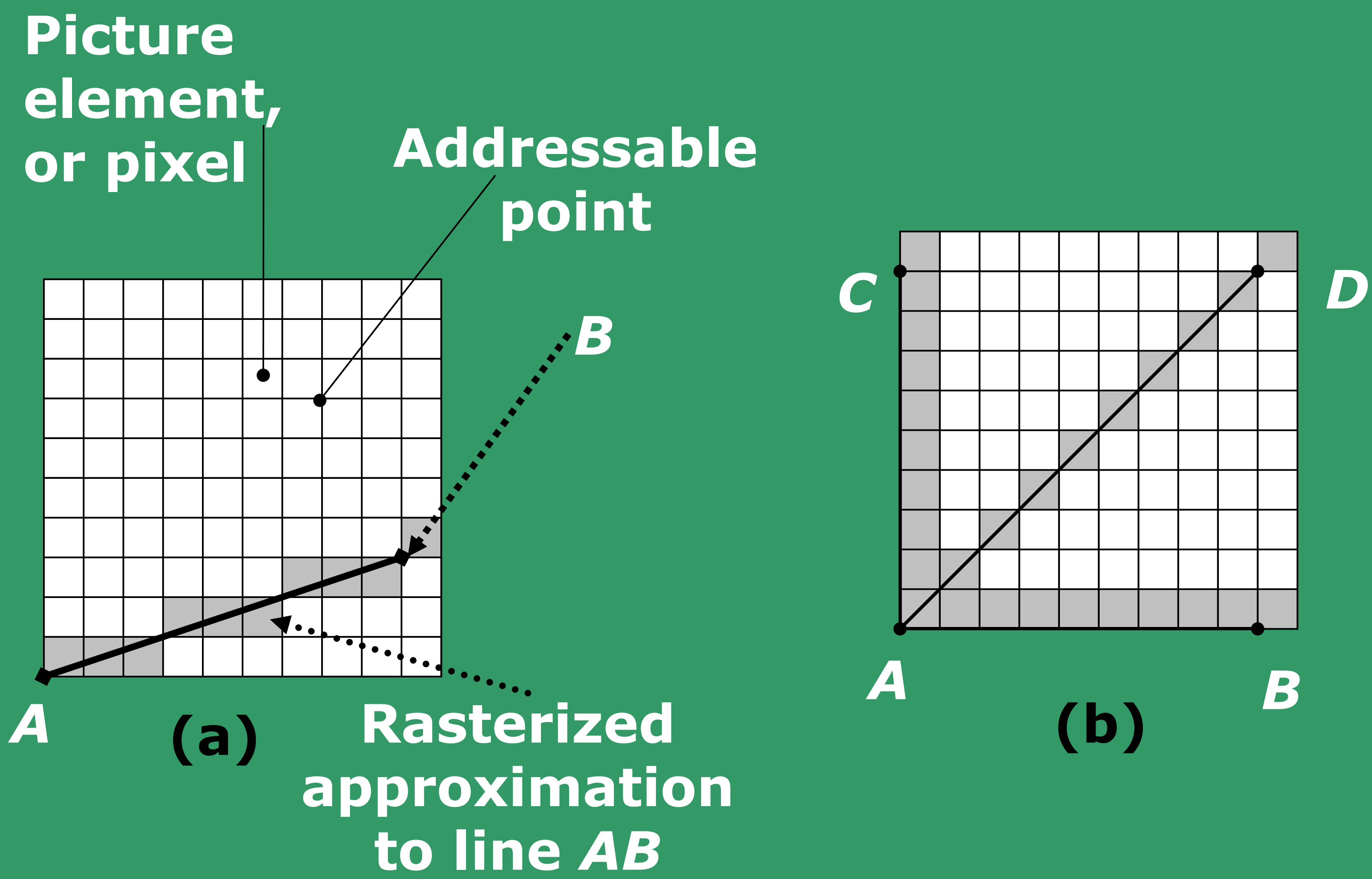
Refresh and raster scan display system (contd.)

- Entire screen is a matrix of pixels
- Each pixel brightness can be controlled
- Refresh buffer can be visualized as a set of horizontal raster lines or a row of individual pixels
- Each point is an addressable point in screen and memory
- Line cannot be drawn directly from one point to another
- This causes the effect of ‘aliasing’, ‘jaggies’ or ‘staircase’ effect
- Refresh/Frame buffer is also called Bit-plane

Raster-scan display system draws a discrete set of points



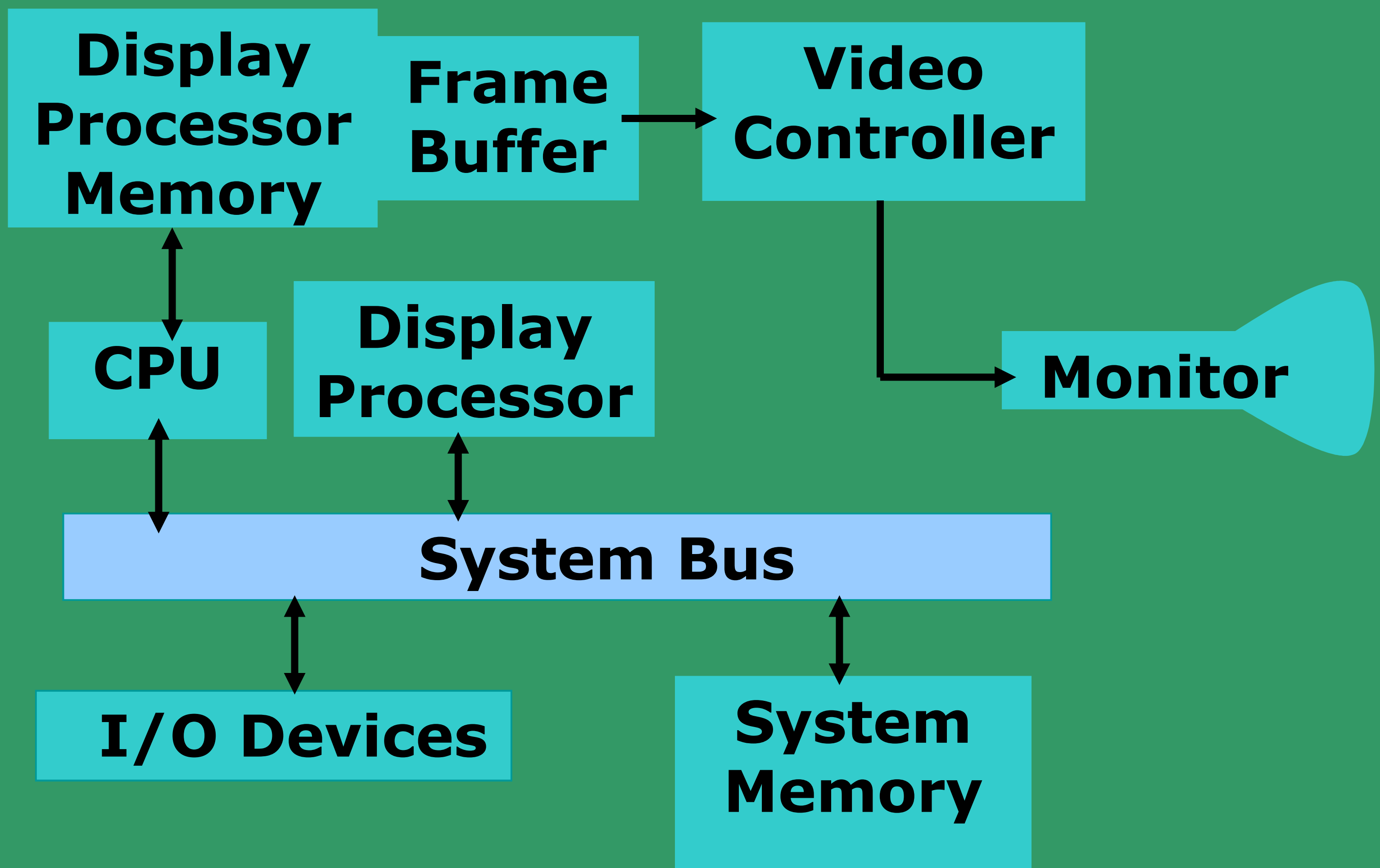
Rasterization: (a) General line ; (b) special cases



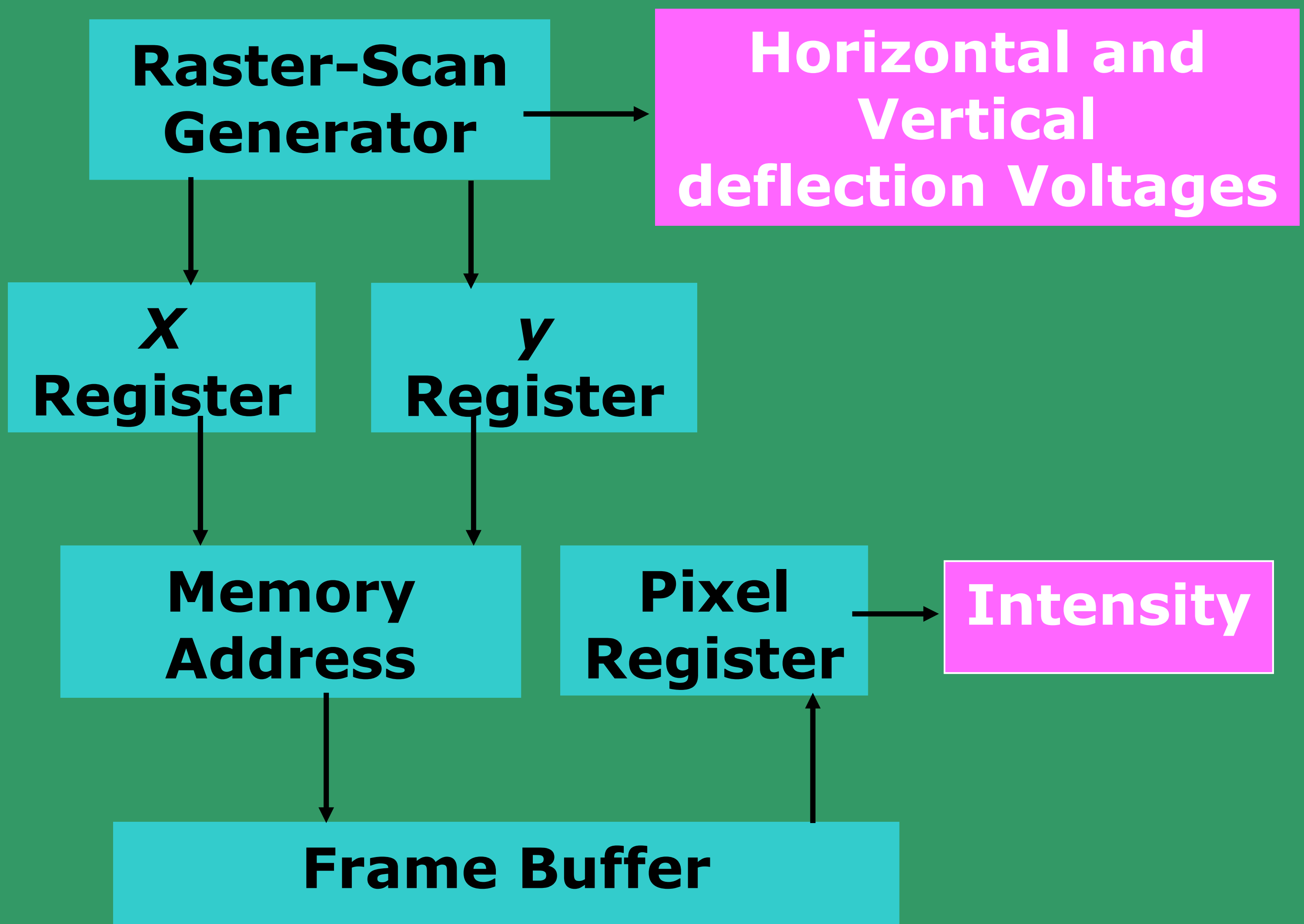
Refresh Rate, Video basics and Scan Conversion

- Raster is stored as a matrix of pixels representing the entire screen area
- Entire image is scanned out sequentially by the video controller (one raster line at a time)
- The raster lines are scanned from top to bottom and then back to the top
- The intensity of the beam decides the brightness of the pixel
- At least one memory bit for each pixel (called bit-plane)

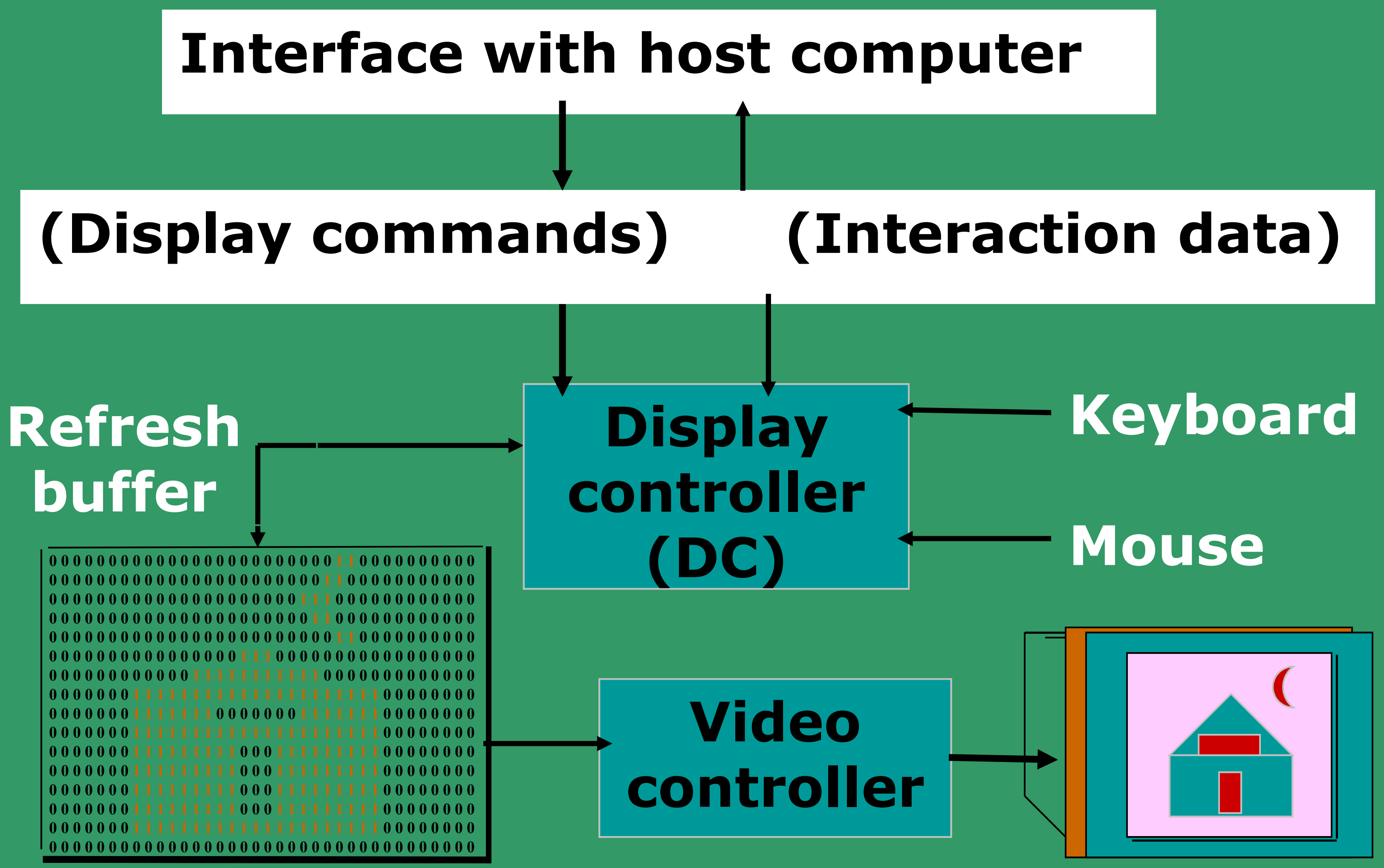
Architecture of a raster-graphics system with a display processor



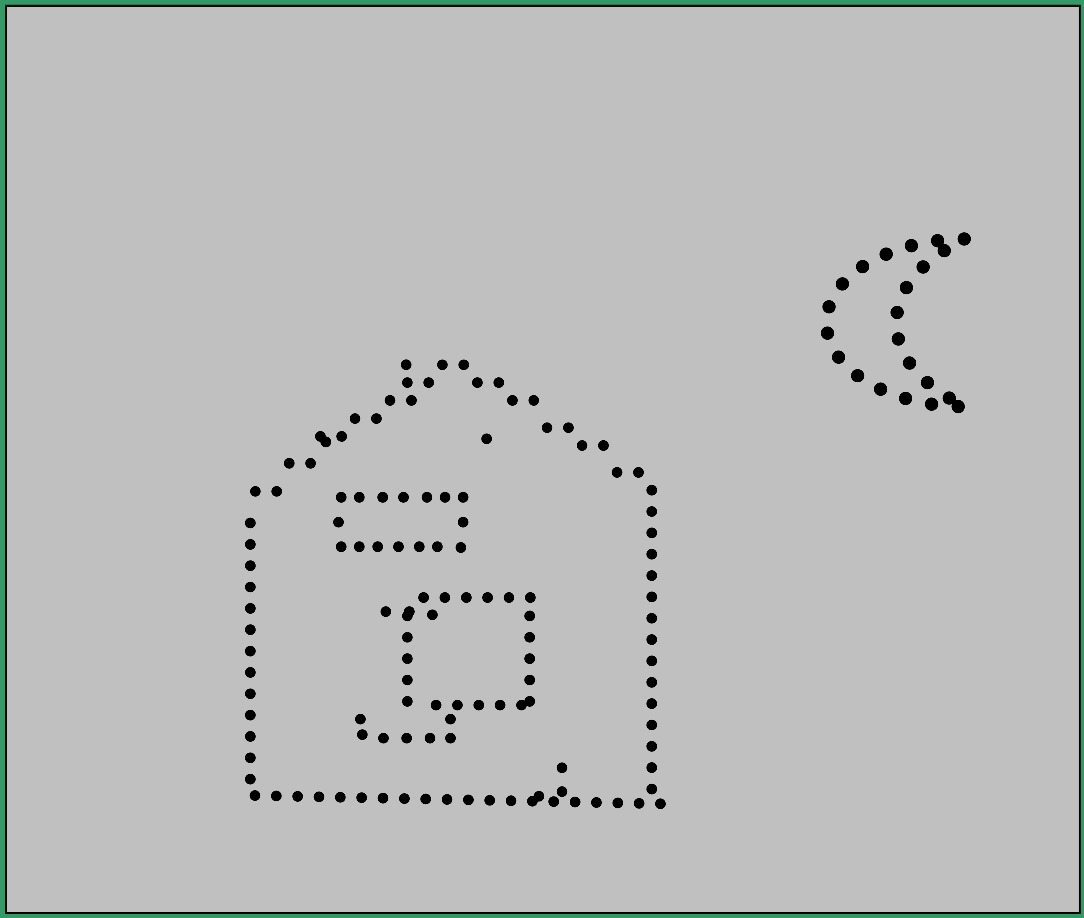
Basic video-controller refresh operations



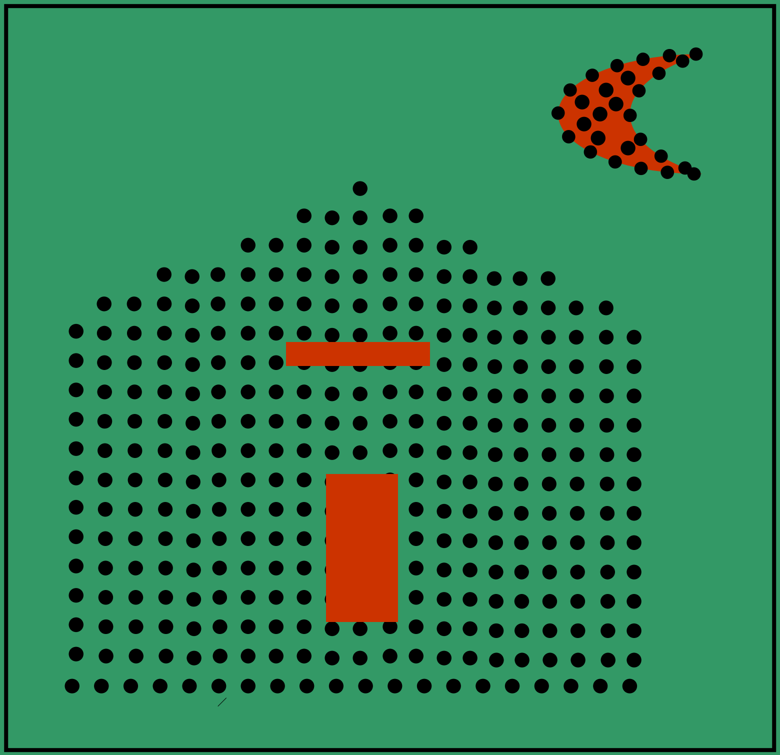
Architecture of a raster display



Raster scan with outline primitives



Raster scan with filled primitives



Refresh Rate, Video basics and Scan Conversion (contd.)

A typical example:

If one uses a 512x512 element raster display, then 2^{18} bits are necessary in a single bit plane. Memory size required: 32 KB

A DAC (digital-to-analog converter) is used to convert the bit value (0, 1) to analog signals for refreshing the screen

Memory size required for N-bit plane gray level frame buffers:

N	Size in KB
3	96
8	256
24	768

Refresh Rate, Video basics and Scan Conversion (contd.)

Refresh rate to avoid flickering – 60 Hz

If one uses a 1024x1024 high resolution CRT:

N	Display Color	Memory Size
1	Black & White	128 KB
8	256 colors	1 MB
24	16 million colors	3 MB
32	16 million colors	4 MB

Even 32 bits per pixel with 1280x1024 pixels raster are available.

Refresh Rate, Video basics and Scan Conversion (contd.)

- Refresh rate of a CRT is the number of times the image is drawn on the screen per second.
- Reducing refresh rate increases flicker.
- Horizontal scan rate is the number of scan lines the circuit drives a CRT display per second
  = refresh rate x number of scan lines
- Resolution of the screen depends on spot size
- CRT resolution is not a function of bitmap resolution
- For larger spot size, resolution decreases
- Horizontal resolution depends on spot size and beam switching (ON/OFF) speed

Refresh Rate, Video basics and Scan Conversion (contd.)

Bandwidth of the display:

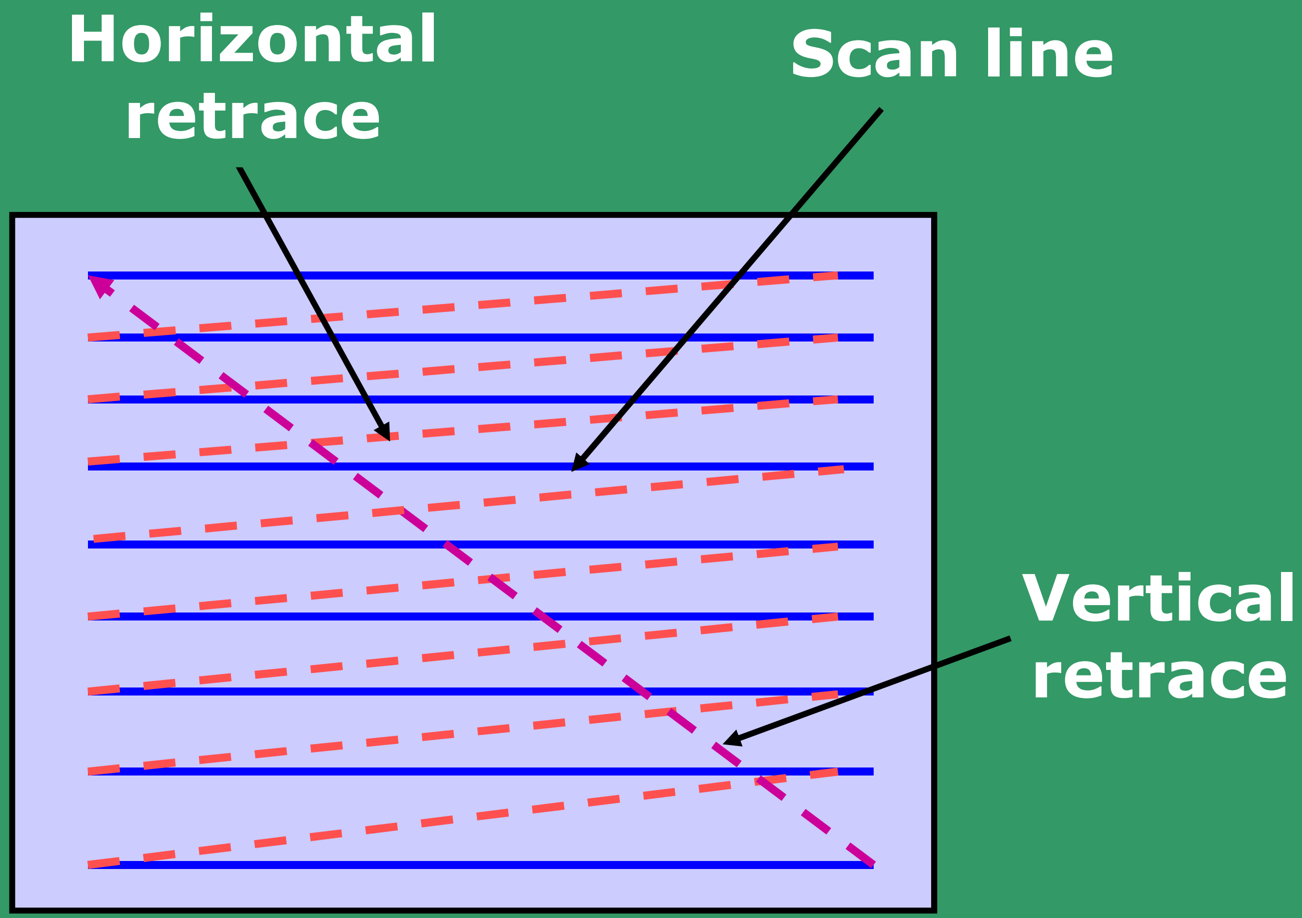
The rate at which the beam can be turned OFF to ON and vice-versa.

For N pixels per scan line, it is necessary to turn the electron gun at a maximum rate of:
N/2 times ON and
N/2 times OFF;

This will create alternate black and white lines on the screen.

Let us now look at some concepts of Video basics and Scan conversion.

Raster Scan



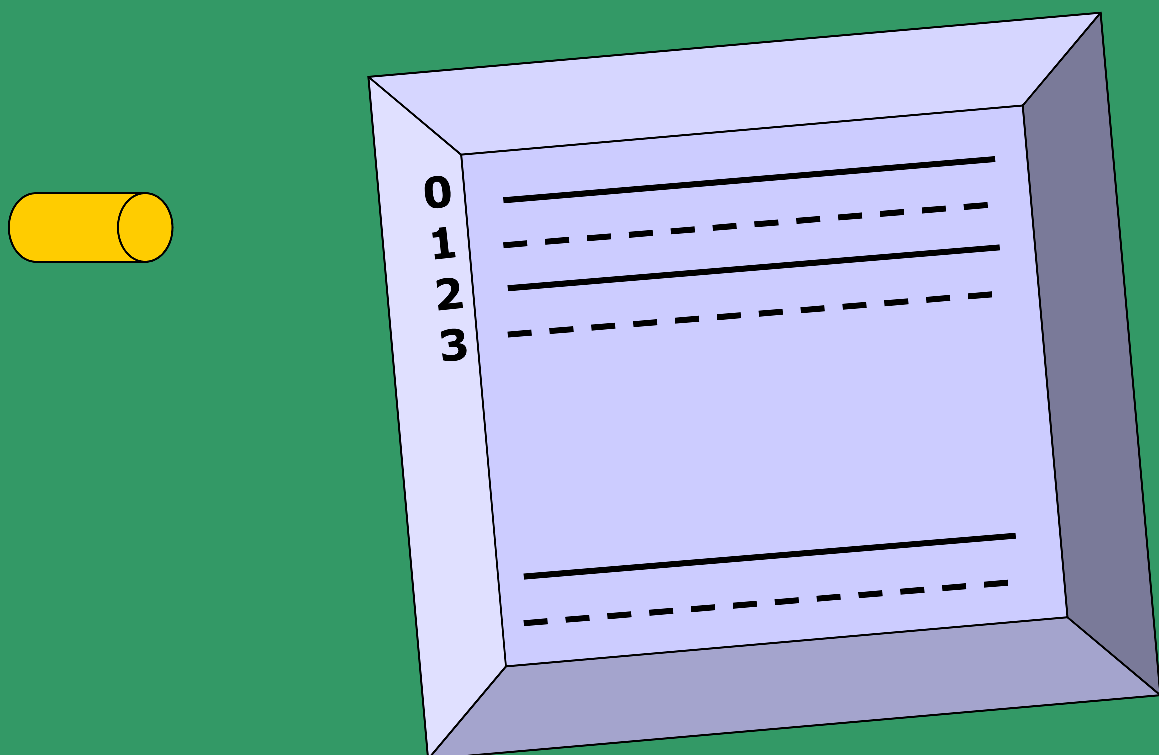
Refresh Rate, Video basics and Scan Conversion (contd.)

NTSC (American Standard Video) has 525 horizontal lines with a frame rate of 30 fps.

Viewing aspect ratio is 4:3

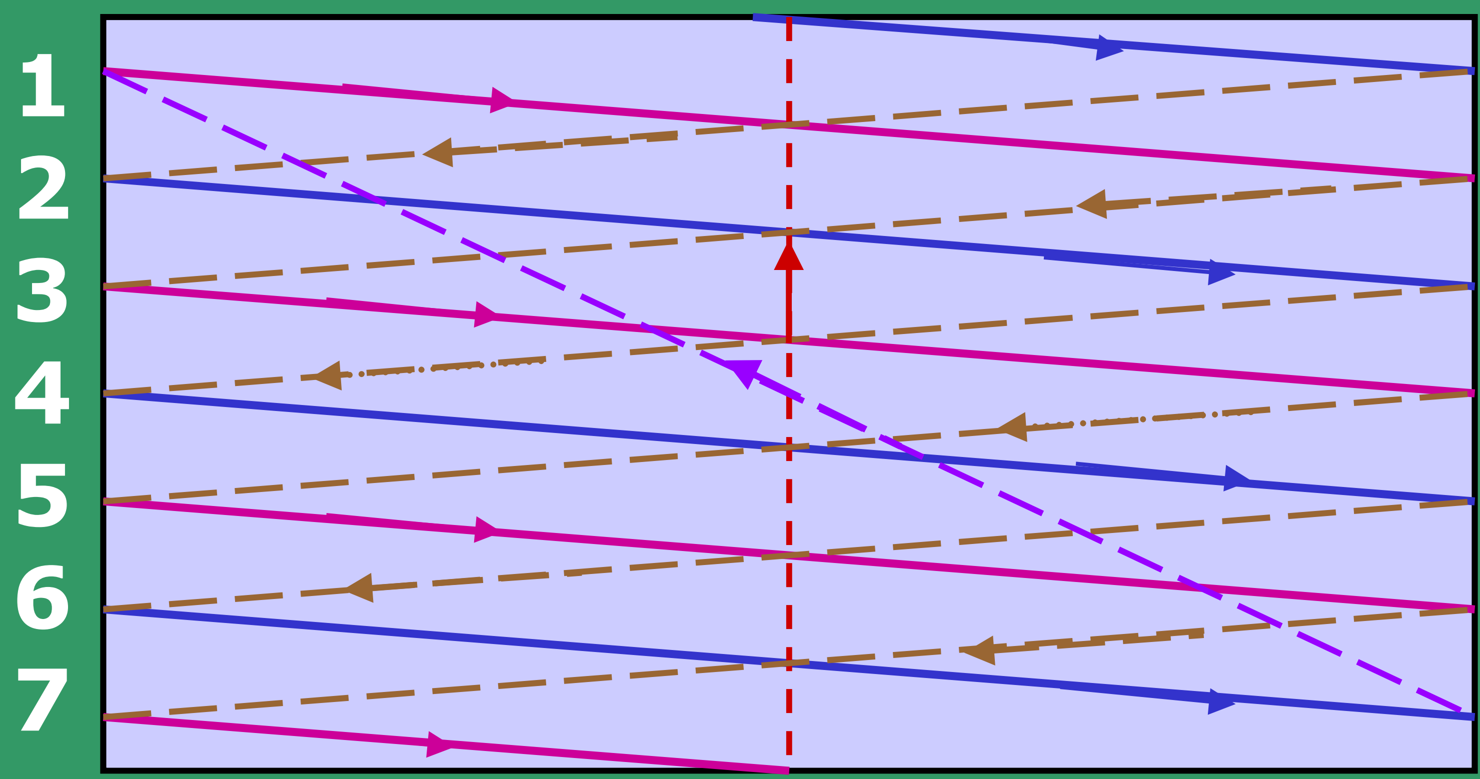
- **Each frame has two fields, each containing half the picture.**
- **Fields are interlaced or interwoven**
- **Fields are presented alternately every other 1/60-th of a sec.**
- **One field contains odd scan lines (1,3,5,…)**
- **The other contains even scan lines (2,4,6,…)**
- **Two types of retrace after every field**

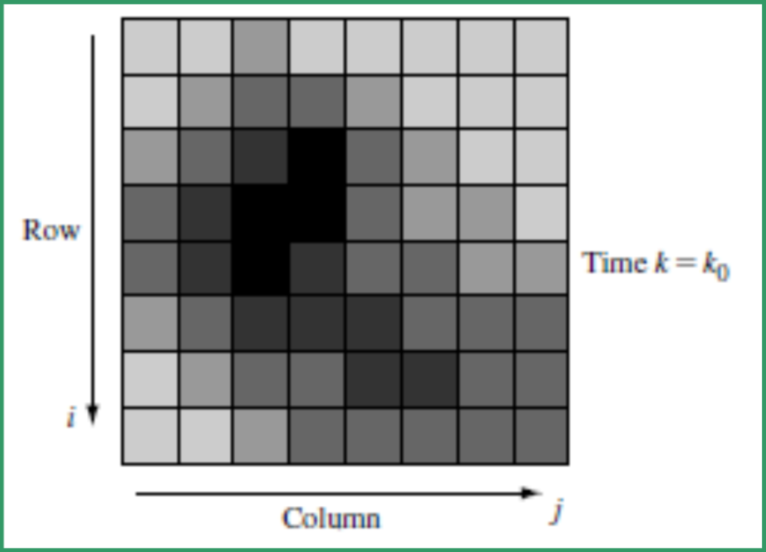
Interlacing scan lines on a raster scan display; First, all points on the even-numbered (solid) scan lines are displayed; then all points along the odd-numbered (dashed) lines are displayed

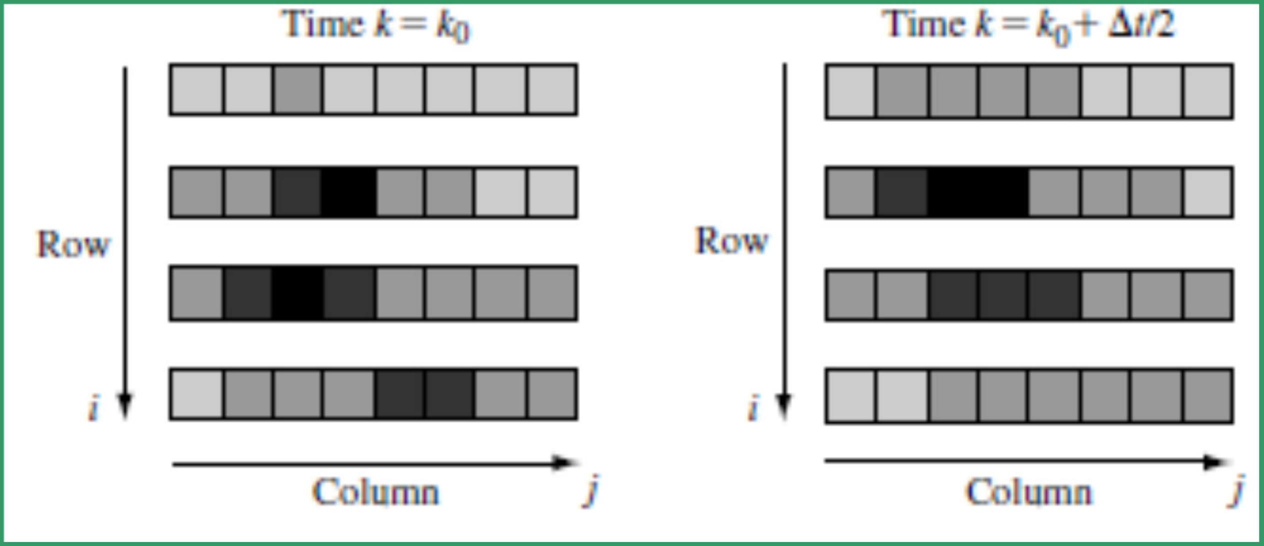


Schematic of a 7-line interlaced scan line pattern.

The odd field begins with line 1. The horizontal retrace is shown dashed. The odd field vertical retrace starts at the bottom center. The even field vertical retrace starts at the bottom right.




Row
i
Time $k = k_0$
Column
j


Time $k = k_0$
Row
i
Column
j
Time $k = k_0 + \Delta t/2$
Row
i
Column
j

Refresh Rate, Video basics and Scan Conversion (contd.)

Horizontal retrace - As the electron beam reaches the right edge of the screen, it is made invisible and rapidly returns to the left edge

- Time taken for horizontal retrace is typically **17%** allotted for a scan line.
- After odd field scan conversion is complete, the beam is at the bottom center of the screen.
- After even field scan conversion is complete, the beam is at the bottom right of the screen.
- **Odd field vertical retrace** returns the beam (switched OFF) to the top center of the screen
- **Even field vertical retrace** returns it to the upper left corner of the screen

Refresh Rate, Video basics and Scan Conversion (contd.)

- Two fields are presented alternately for each frame. So we present 60 frames per second.
- In NTSC, generally 483 lines are visible.
- This is because, the vertical retrace after each field requires a time equivalent of 21 scan lines
- So for each field we have time to display: 262.5 *(=525/2)* – 21 = 241.5 lines.
- So with both fields together, we have: 241.5*2 = 483 lines to display.
- This is the reason for 42 (= 525-483) invisible lines.

Refresh Rate, Video basics and Scan Conversion (contd.)

- Let the time available for each scan line be T.
- Thus, we have: $T * 525 * 30 = 1$ sec.
- Thus, T =
- This includes the vertical retrace time.
- When we consider the horizontal retrace time, the actual time to display all pixels in a scan line (time to scan from left to right only):

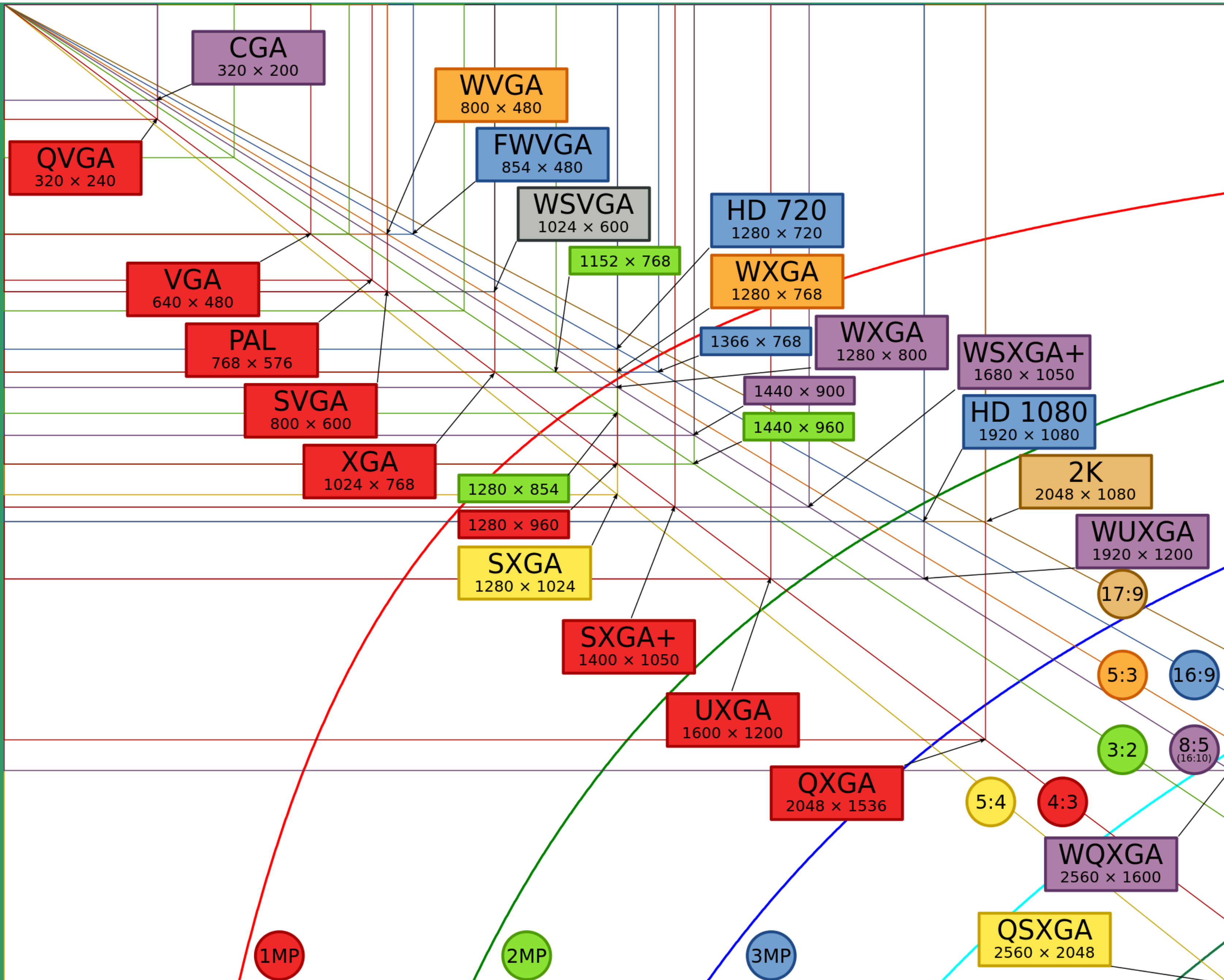
$T' = 0.83*T =$

- Considering 4:3 aspect ratio, the number of pixels per scan line = 483*4/3 = 644
- Thus, time available for the beam to access and display a pixel = .

Refresh Rate, Video basics and Scan Conversion (contd.)

Some examples of pixel access times:

Frame Rate	Display Resolution	Pixel access time
30	512 x 512	105 ns
25	500 x 625	105 ns
60	1000 x 1000	26 ns
60	1024 x 1024	24 ns
90	3840 x 2400	?? ns



QXGA, or Quad eXtended Graphics Array, display standard

Computer Standard	Resolution	Ratio	Ratio (Decimal)	Pixels
QWXGA	2048×1152	16:9	1.78	2.4M
QXGA	2048×1536	4:3	1.3333	3.1M
WQXGA	2560×1600	16:10	1.6	4.1M
QSXGA	2560×2048	5:4	1.25	5.2M
WQSXGA	3200×2048	25:16	1.5625	6.6M
QUXGA	3200×2400	4:3	1.3333	7.7M
WQUXGA	3840×2400	16:10	1.6	9.2M

WQUXGA, or Wide Quad Ultra eXtended Graphics Array.

[redacted] **Computer display standards**

Video hardware	MDA · HGC · CGA · PGC · EGA · VGA · MCGA · 8514 · XGA
Display resolutions	QQVGA · HQVGA · QVGA · HVGA · VGA · SVGA · XGA · XGA+ · SXGA · SXGA+ · UXGA · QXGA · QSXGA · QUXGA · HXGA · HSXGA · HUXGA
Widescreen variants	WQVGA · WVGA/FWVGA · WSVGA · WXGA · WSXGA/WXGA+ · WSXGA+ · WUXGA · WQXGA · WQSXGA · WQUXGA · WHXGA · WHSXGA · WHUXGA
HD Resolutions (16:9, 16:10)	WSVGA · HD · WXGA · 900p · FHD · WQHD · QFHD

	CAS latency (read) in ns	Peak Data Rate	Burst length	Data Word	Internal Clock	Bandwidth (GB/S)
DDR3						
GDDR 5						

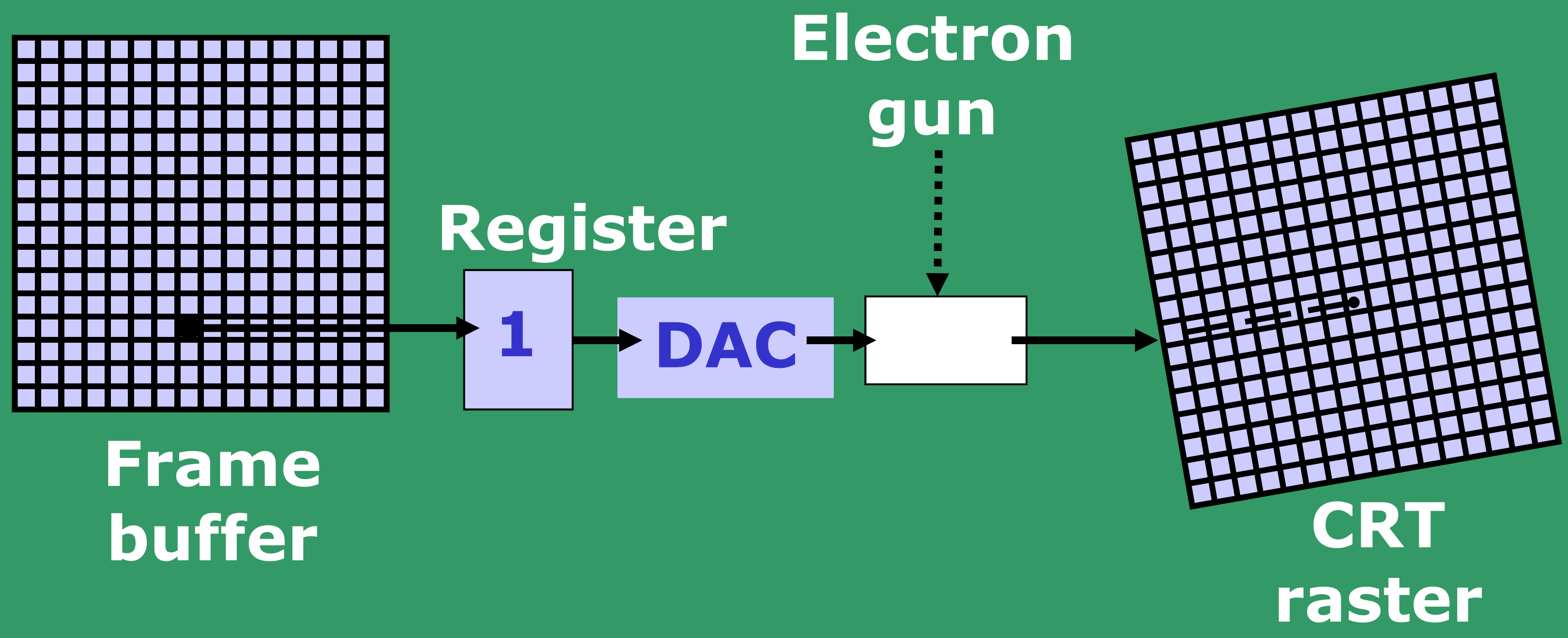
Data transfer rate is:
Channel width (bits/transfer) × transfers/second = bits transferred/second.

On February 20, 2013, it was announced that the PlayStation 4 will utilize 16x4 Gbit (i.e. 16x512 MiB) GDDR5 memory chips for 8 GiB of GDDR5 @ 176 GB/s (CK 1.375 GHz and WCK 2.75 GHz) as combined system and graphics RAM for use with its AMD-powered APU.

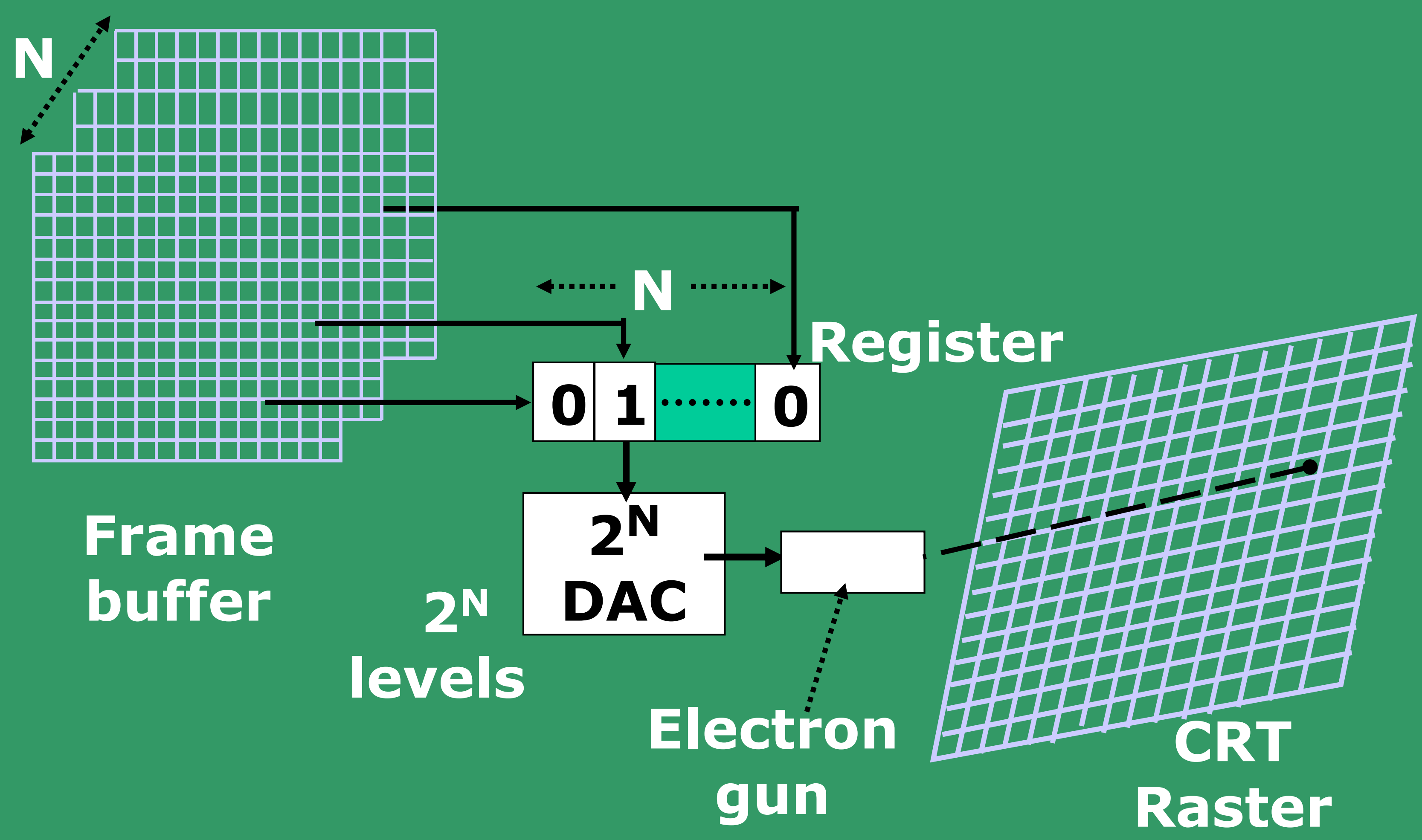
N-bit plane gray level Frame buffer

- Choice of the number of gray scales and colors depend on the value of N (bit plane size)
  - N = 1 – two colors (B&W)
  - N = 3 – 8 gray scales or colors
  - N = 8 – 256 gray scales or colors
  - N = 24 – 16 million colors
- For colored displays (raster-scan), three separate color guns must be used.
- Each bit/byte plane drives a color gun.

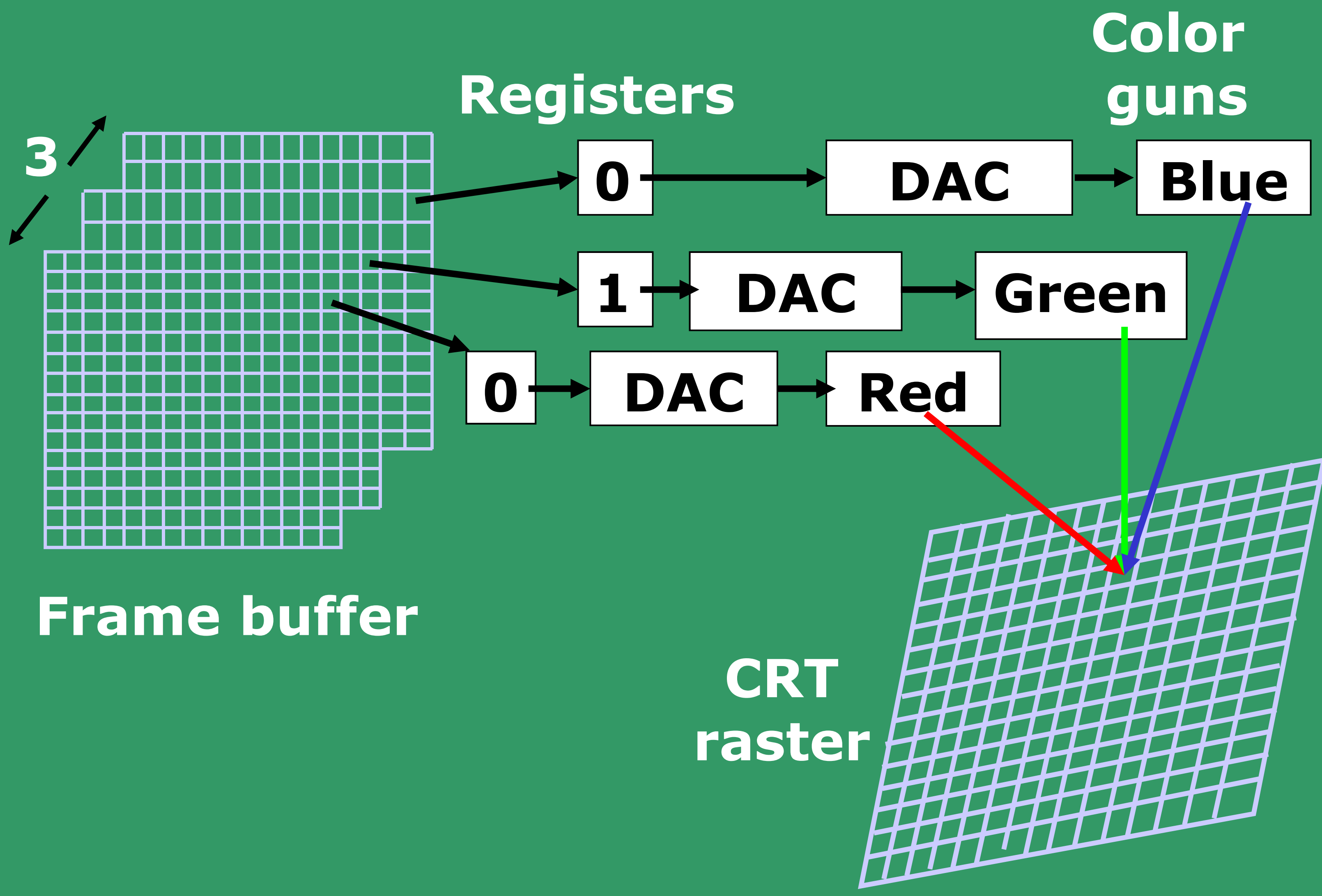
A single bit-plane black&white frame buffer raster CRT graphics device.



An N-bit plane gray level frame buffer



Simple color frame buffer

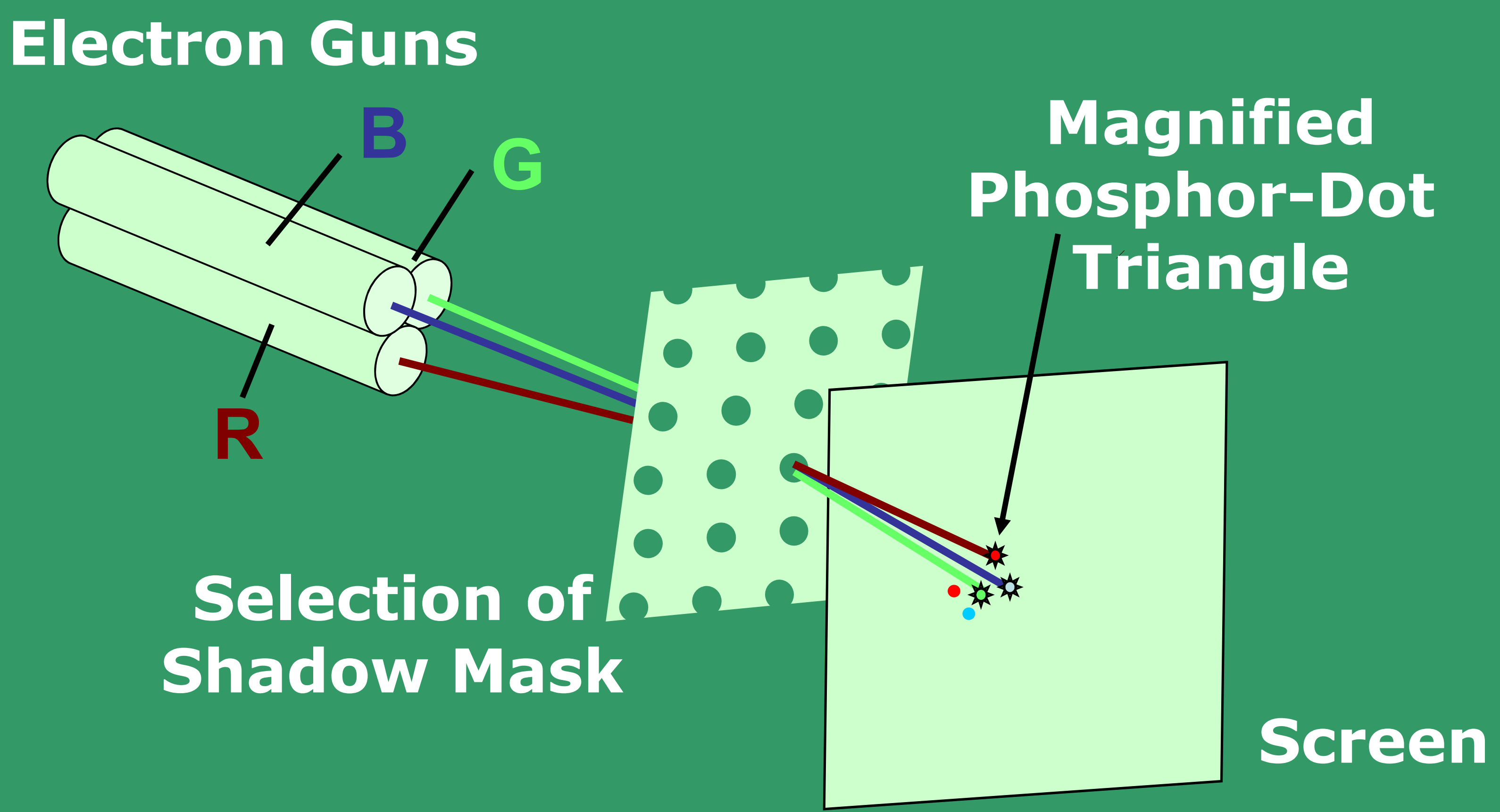


N-bit plane gray level Frame buffer (Contd.)

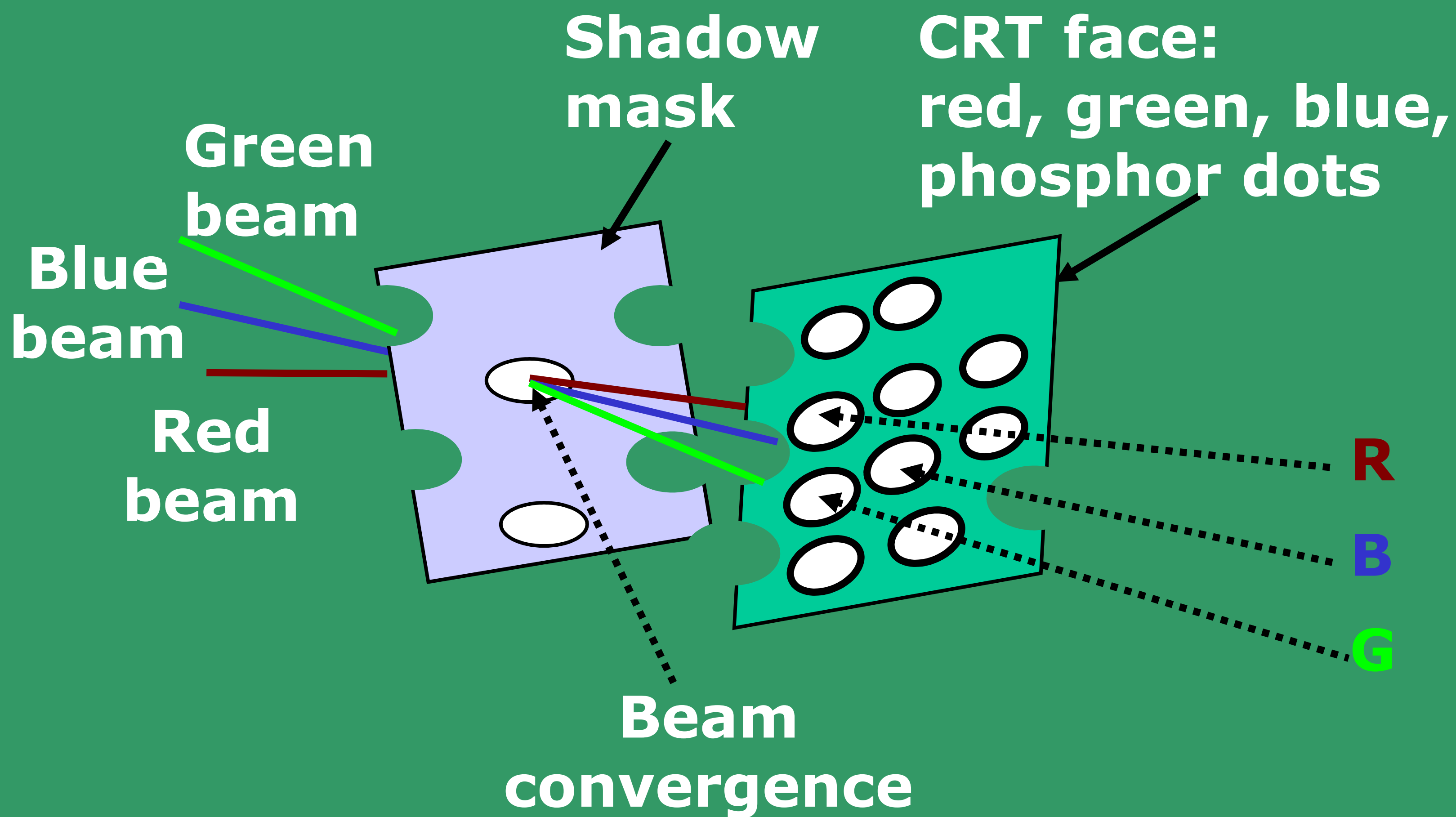
- In case of one-bit for each color frame buffer, we get 8 colors as:

COLOR	RED	GREEN	BLUE
BLACK	0	0	0
BLUE	0	0	1
GREEN	0	1	0
CYAN	0	1	1
RED	1	0	0
MAGENTA	1	0	1
YELLOW	1	1	0
WHITE	1	1	1

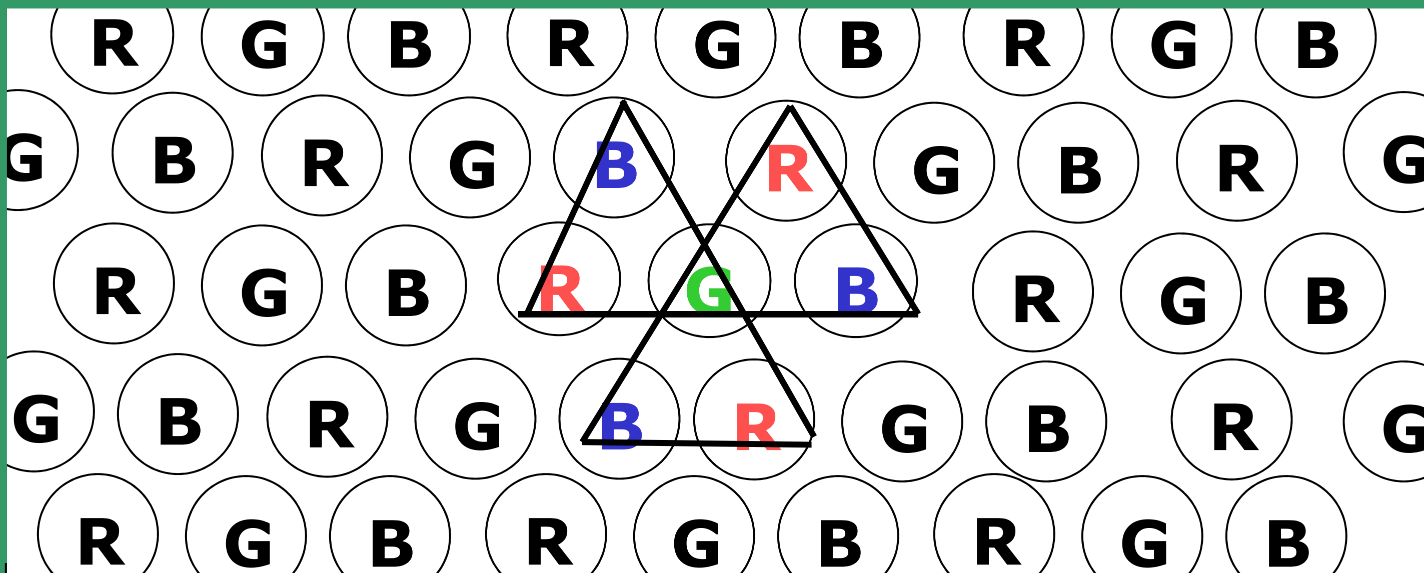
Operation of a delta-delta, shadow-mask CRT. Three electron guns, aligned with the triangular color-dot patterns on the screen, are directed to each dot triangle by a shadow mask.

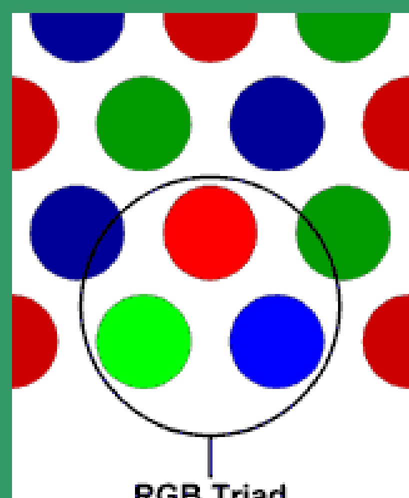


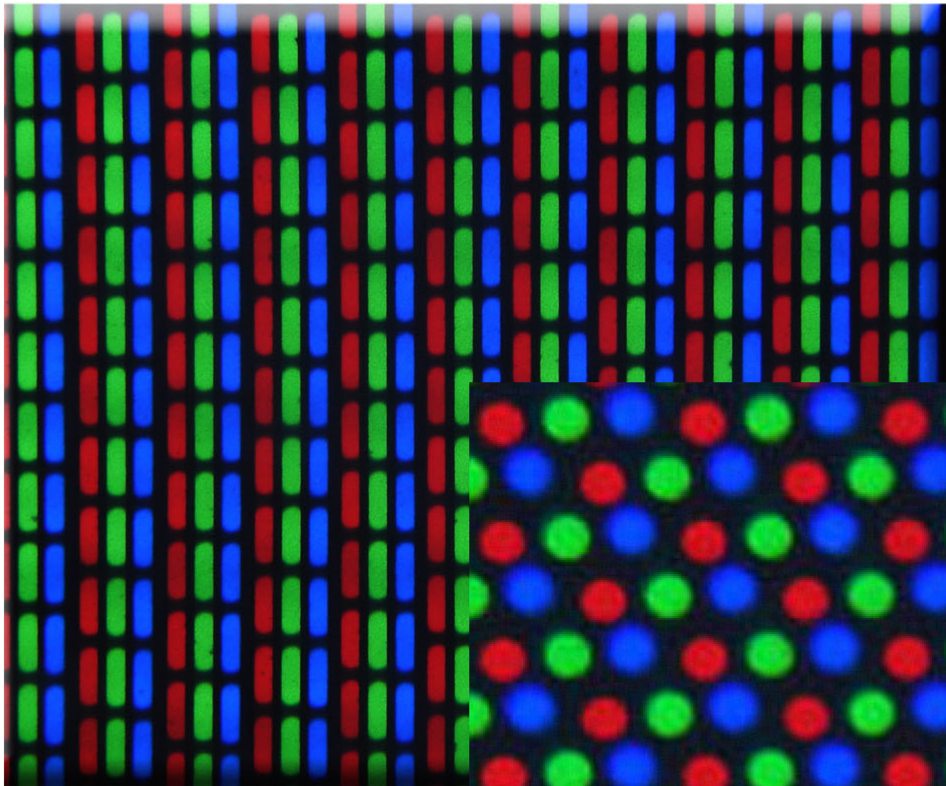
Color CRT electron gun and shadow mask arrangement

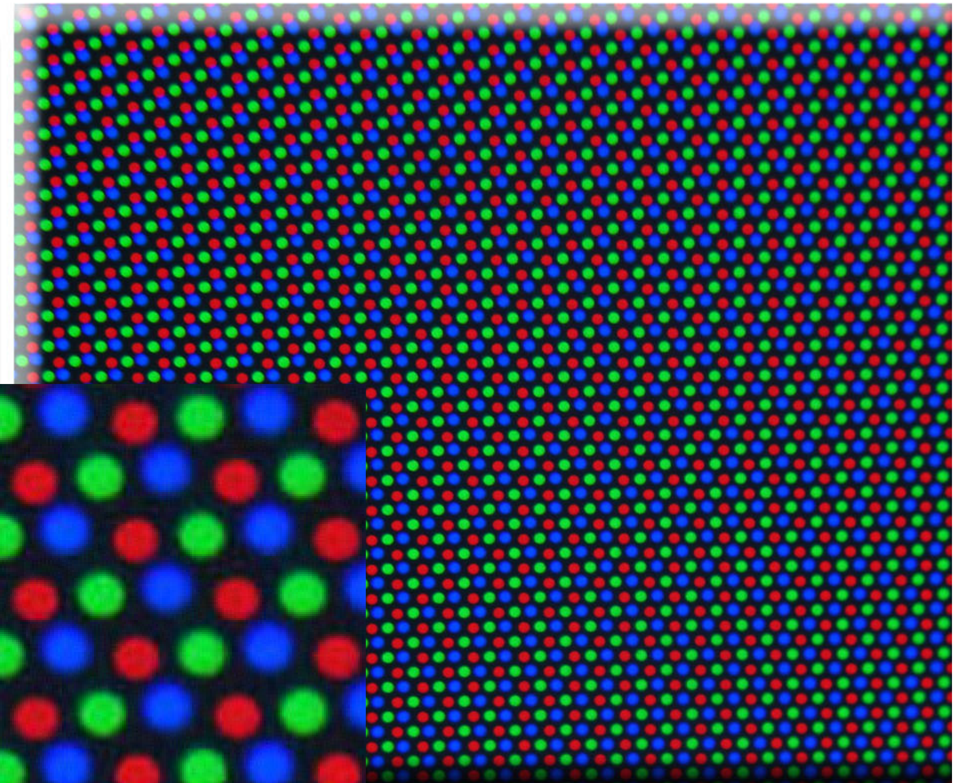


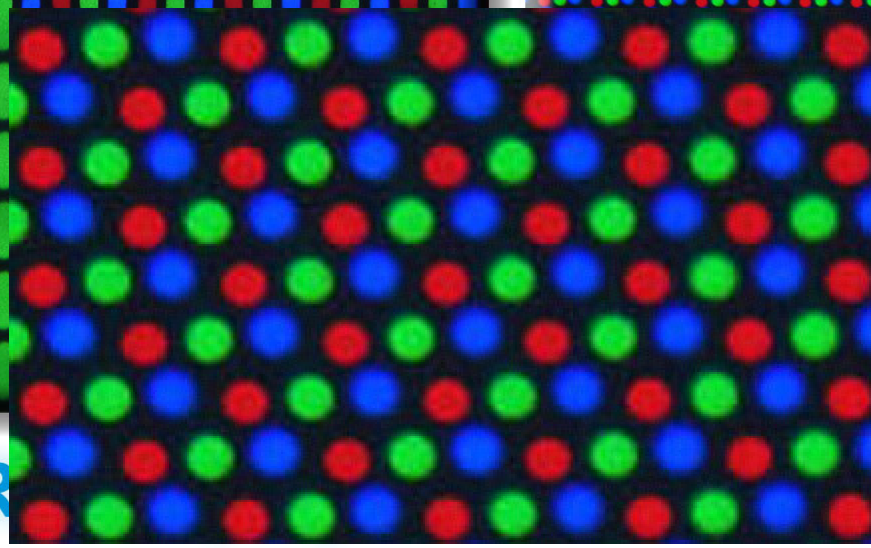
Phosphorus dot pattern for a shadow mask CRT







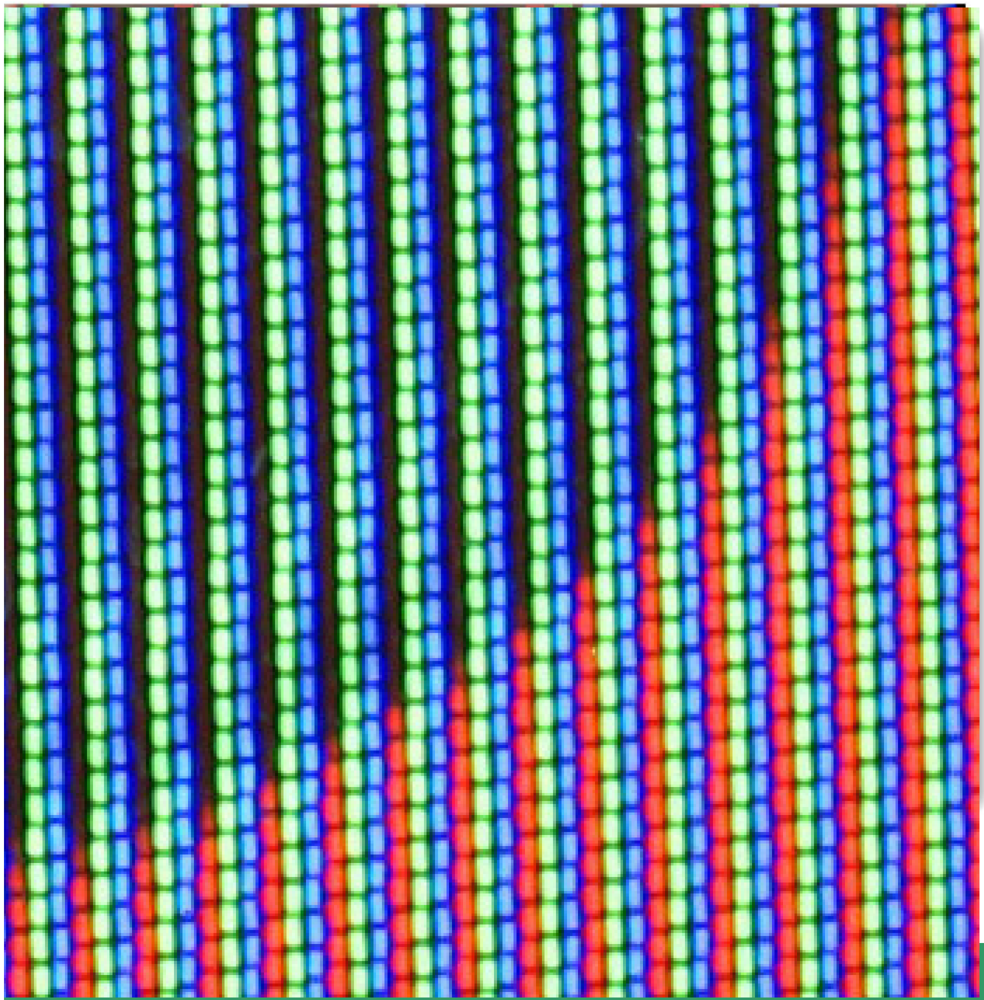


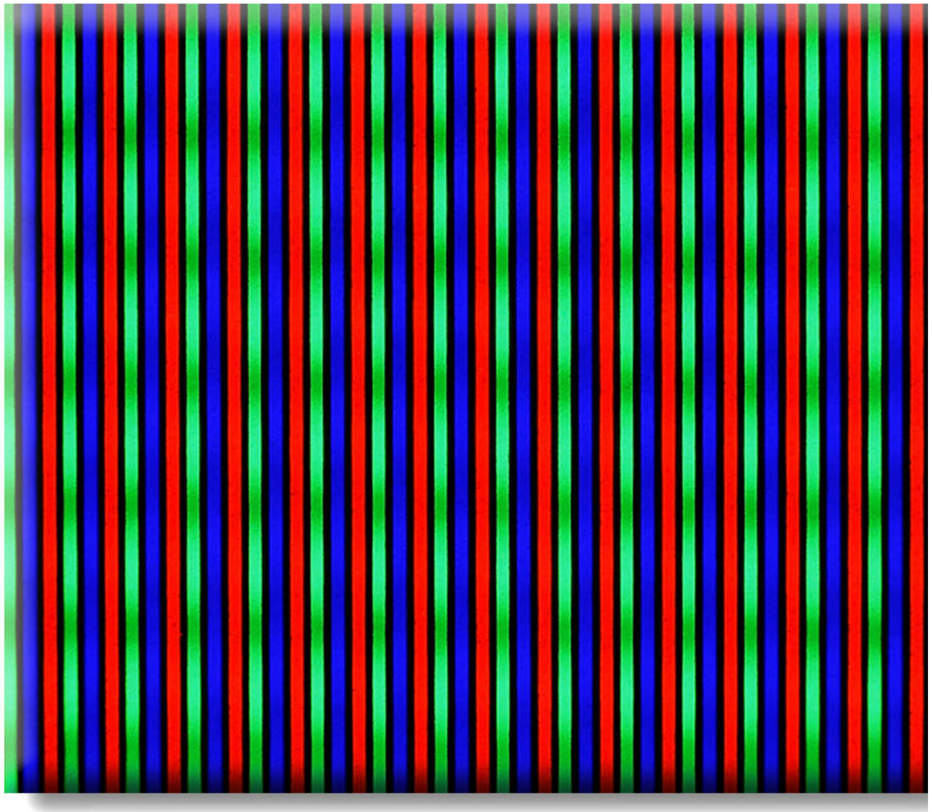


21” TV CR

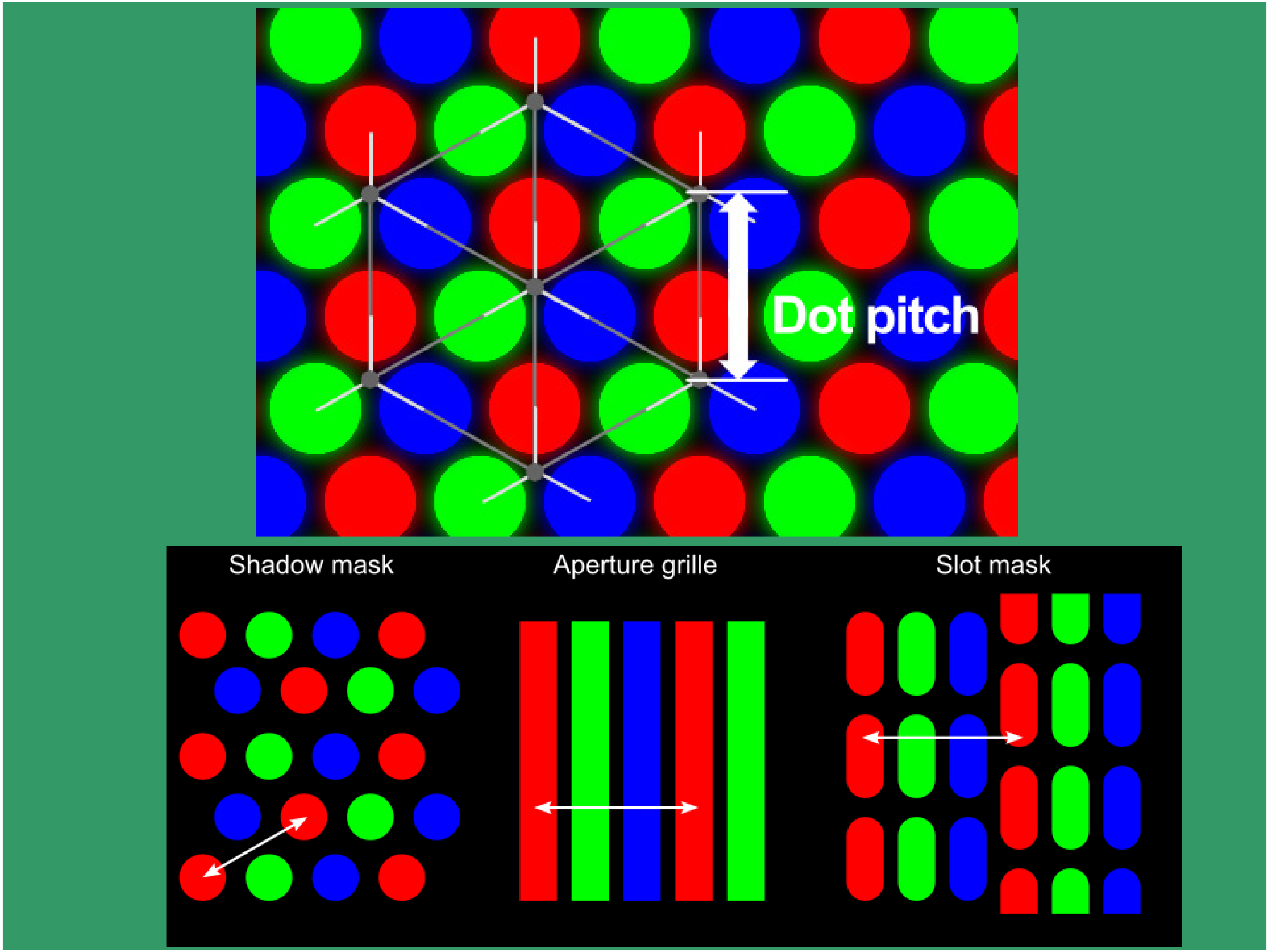
C CRT Display

Shadow mask arrangements





Aperture Grille


Dot pitch
Shadow mask
Aperture grille
Slot mask

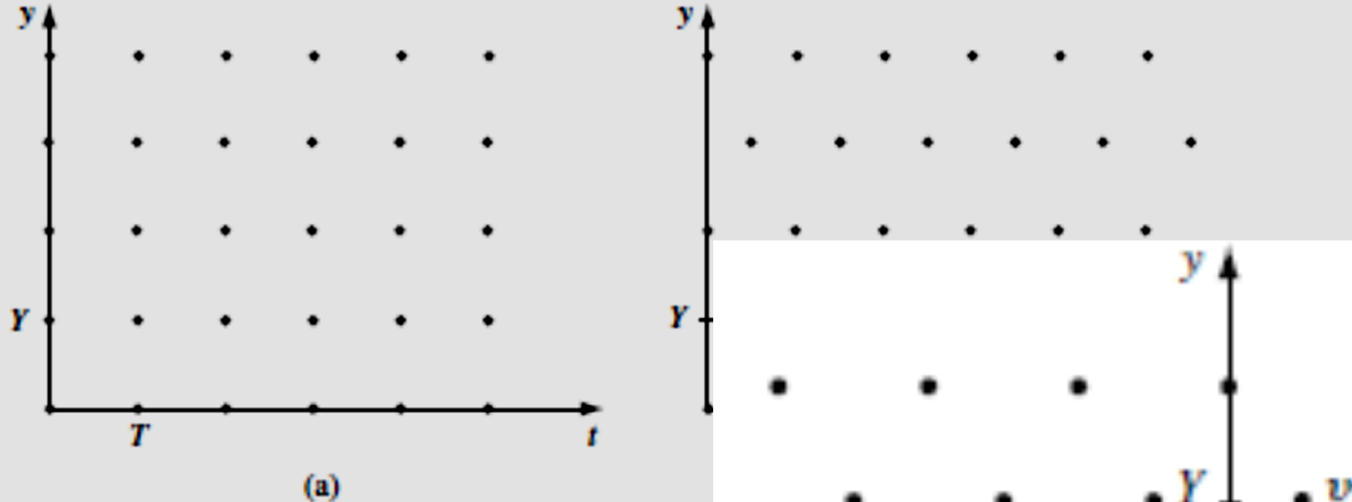
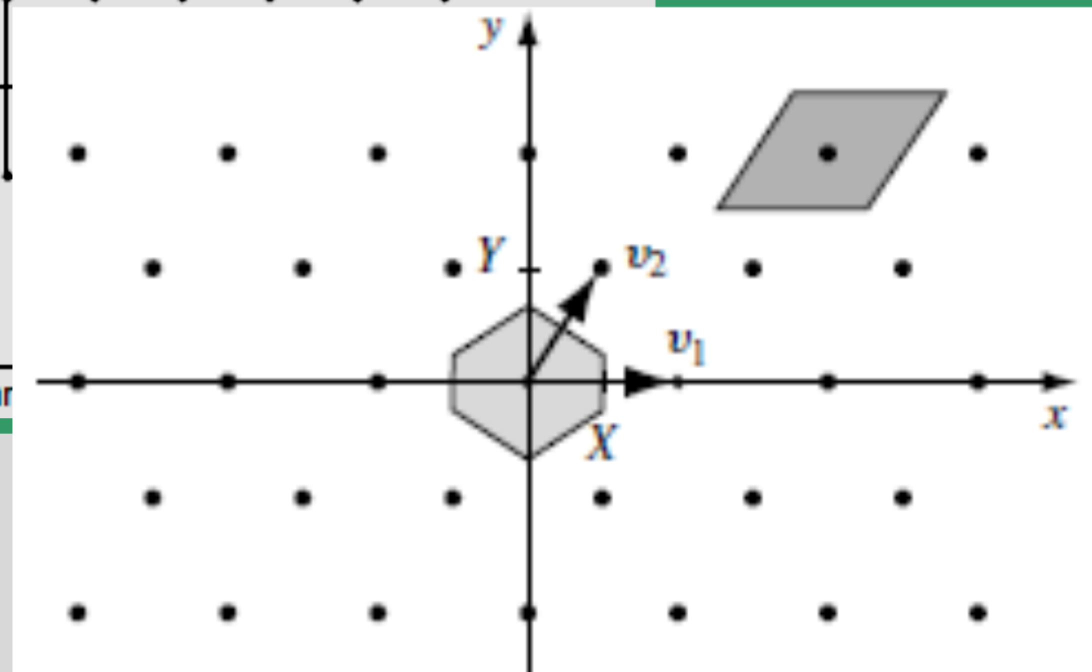


FIGURE 2.2

Two-dimensional vertical-temporal lattices. (a) Rectar



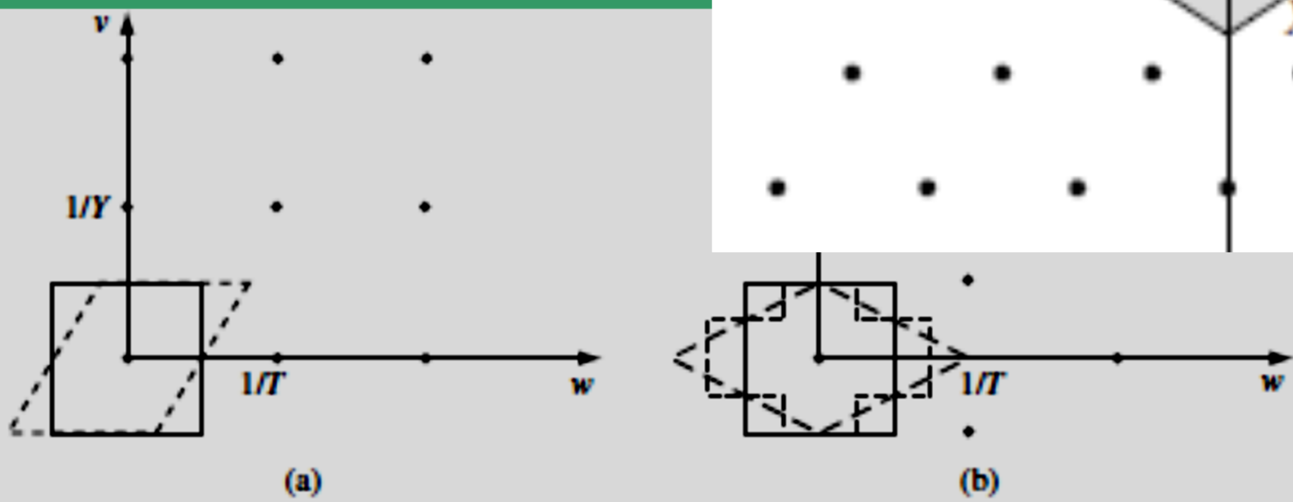
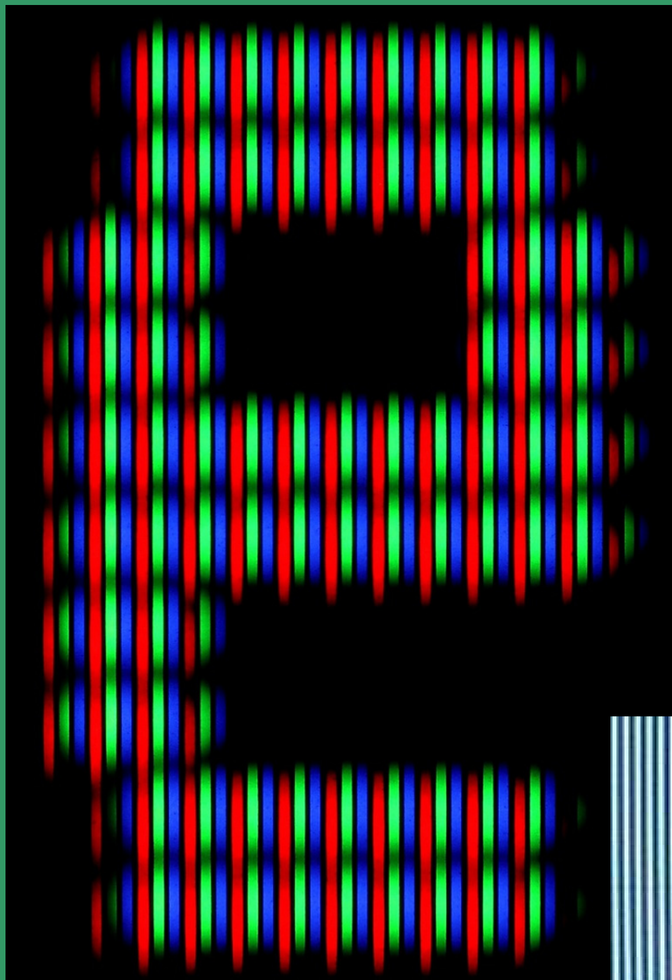


FIGURE 2.3

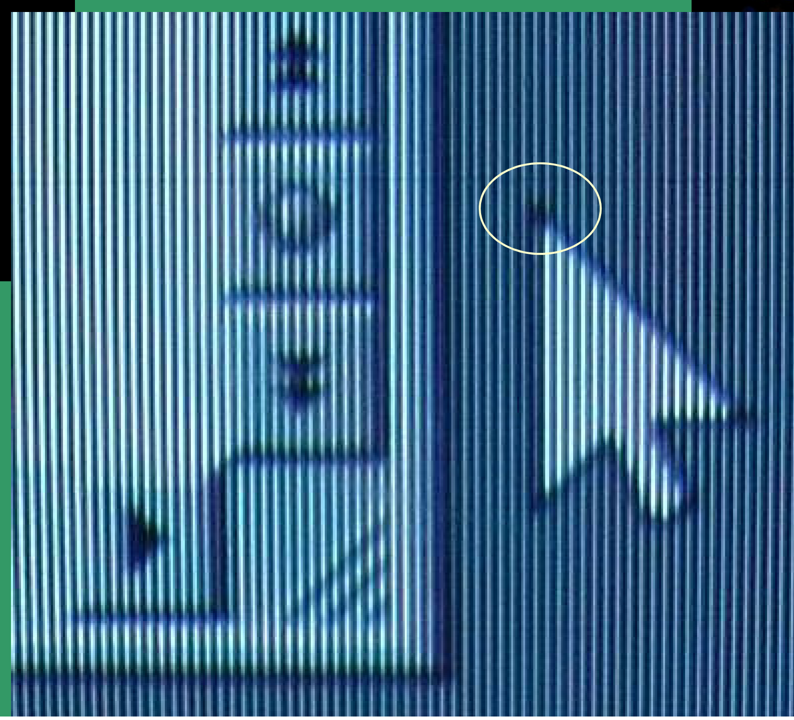
Reciprocal lattices of the two-dimensional vertical-temporal lattices of Fig. 2.2 with several possible unit cells. (a) Rectangular lattice Λ_R^*. (b) Hexagonal lattice Λ_H^*.

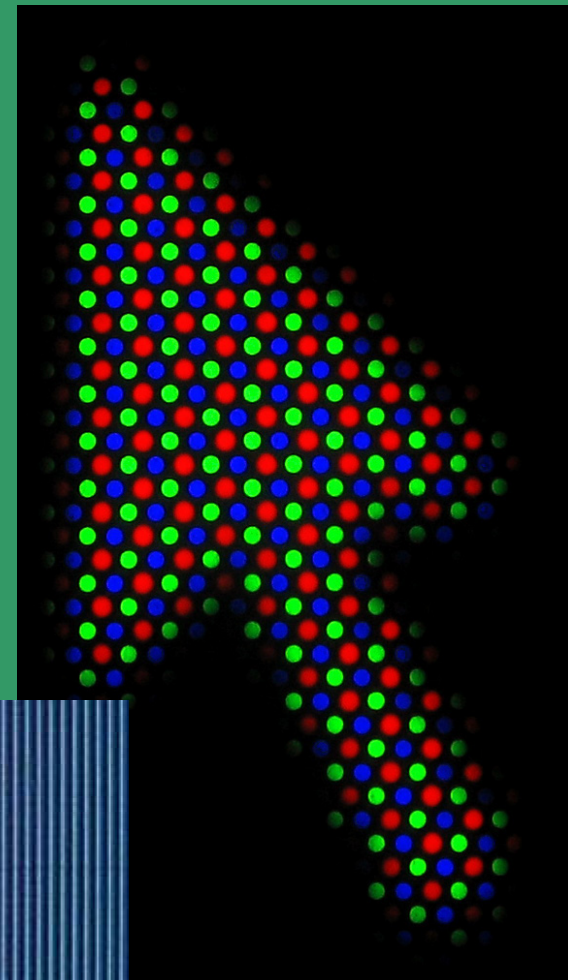
Computer Standard	Resolution	Ratio	Dot Pitch (mm)	Pixels	Pixels per inch
QWXGA	2048×1152	16:9	0.249	2.4M	102.2
QXGA	2048×1536	4:3		3.1M	
WQXGA	2560×1600	16:10	0.25	4.1M	101.6
QSXGA	2560×2048	5:4		5.2M	
WQSXGA	3200×2048	25:16		6.6M	
QUXGA	3200×2400	4:3		7.7M	
WQUXGA	3840×2400	16:10	0.125	9.2M	203.2

The dot pitch of FLC displays (Ferro Liquid Crystal) can be as low as 0.012 mm



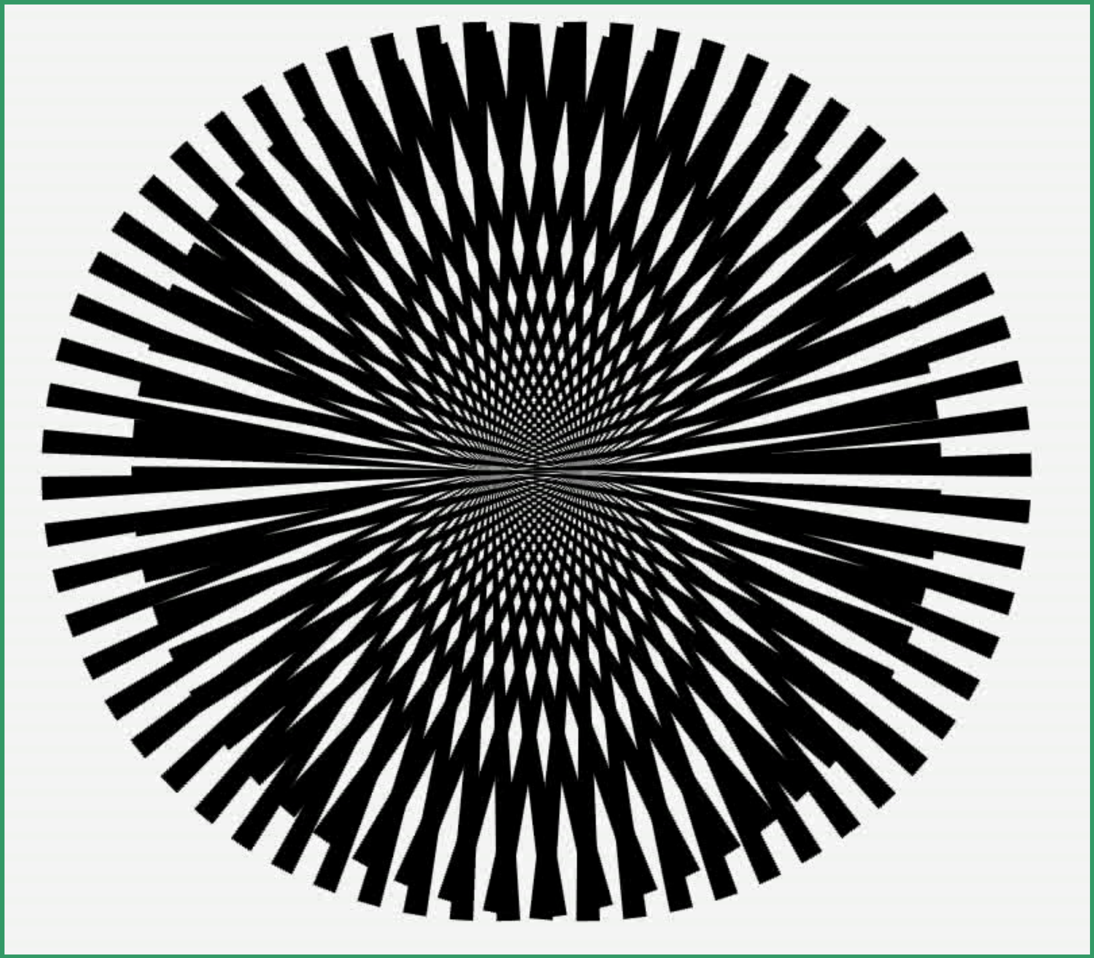
Aperture-grille-based CRT



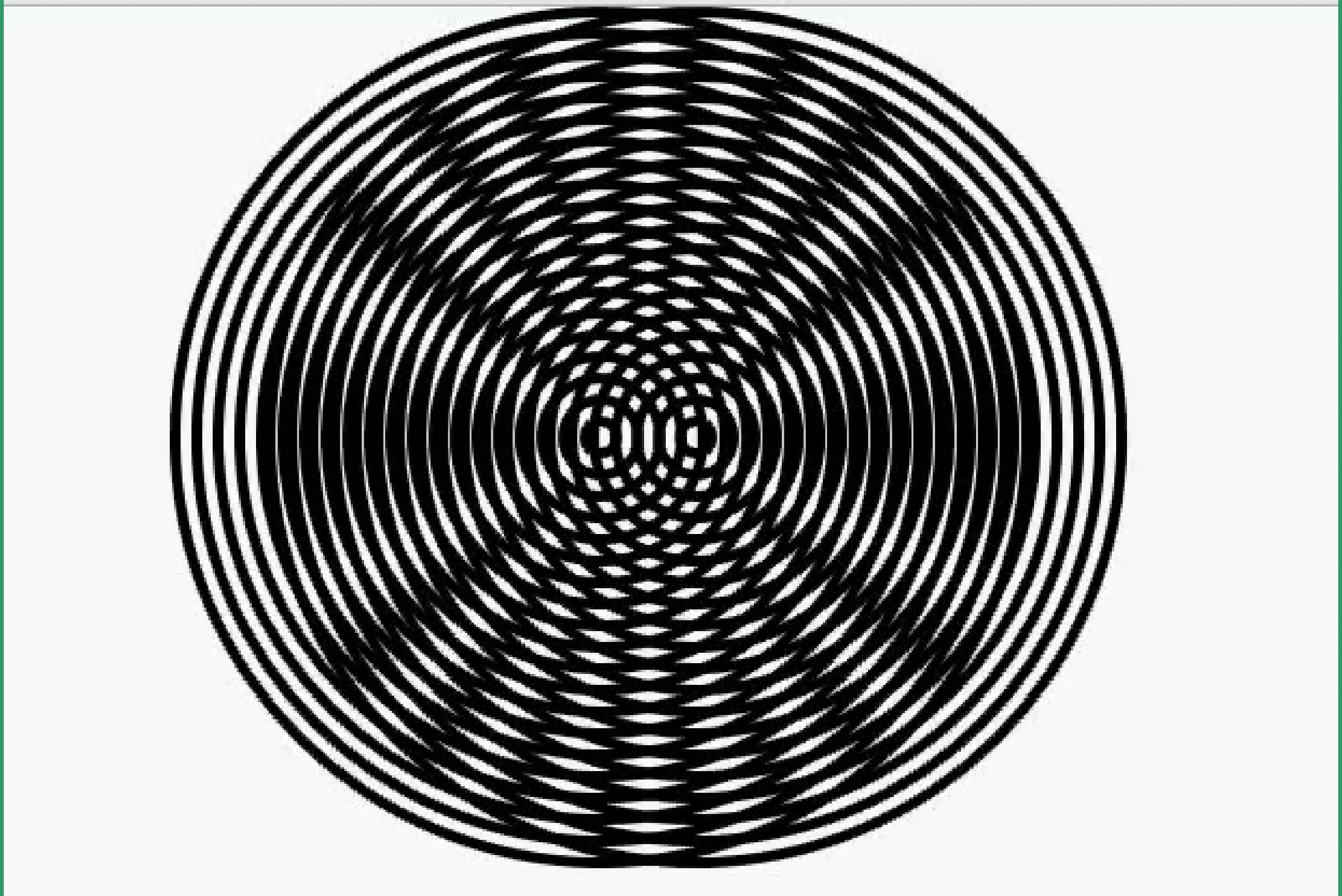


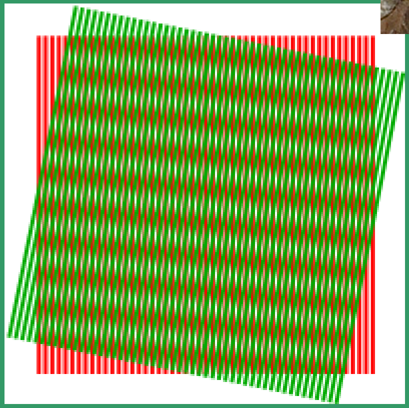
Shadow Mask

Moire Lines



Moire Circle



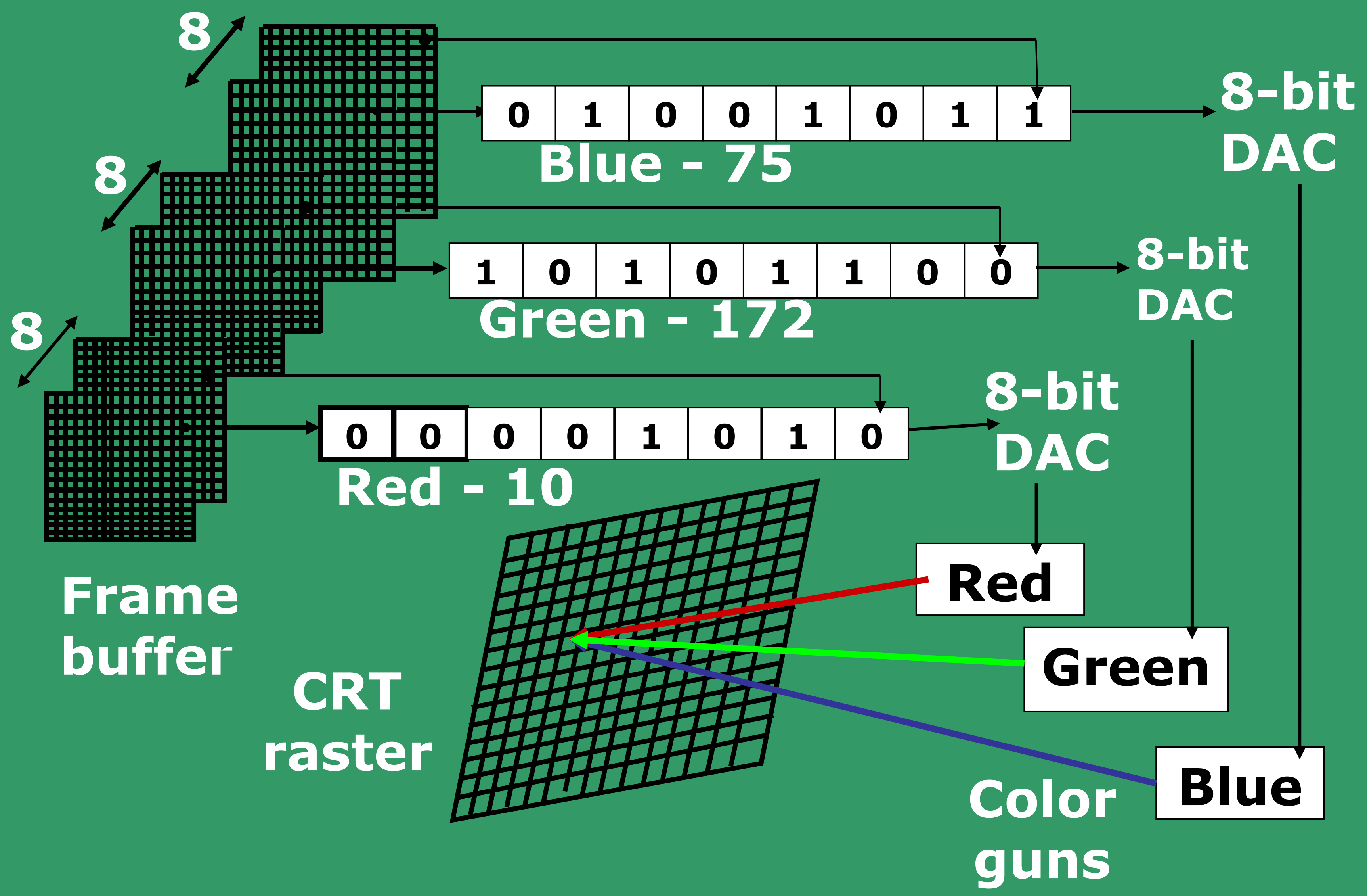


Moire Patterns on screens

N-bit plane gray level Frame buffer (Contd.)

- Typically 8-bit planes per color is used, which gives a 24-bit plane frame buffer
- Each group of bit-planes drives an 8-bit DAC
- Each group generates 256 shades of intensities of red, green or blue
- Hence we obtain 2^{24} = 16,777,216 possible colors.
- This is called a **FULL COLOR FRAME BUFFER**

A 24-bit-plane color frame buffer



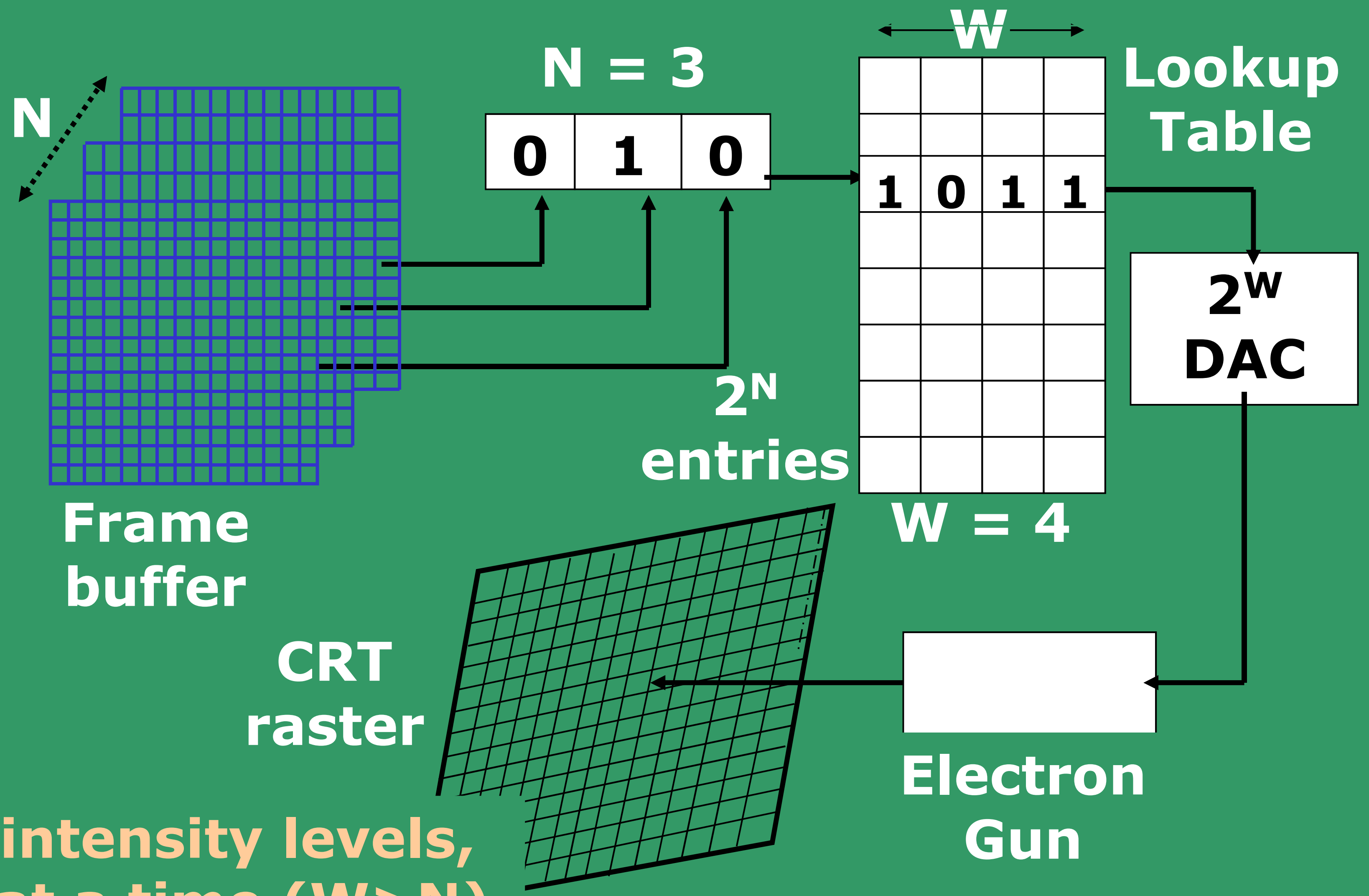
N-bit plane gray level Frame buffer (Contd.)

Use of

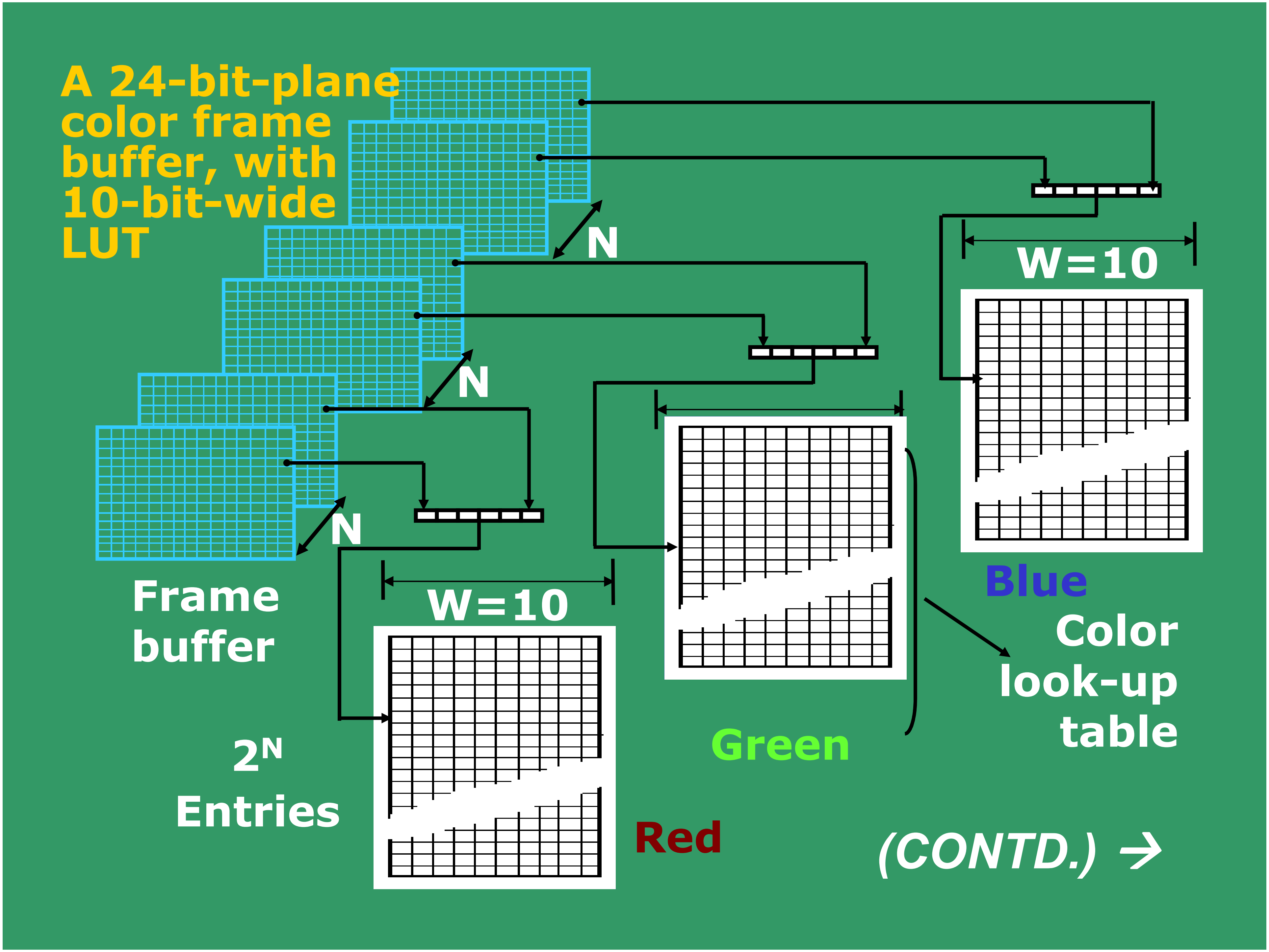
- **LUT (Look-up-table)**

- **N-bit plane gray level/color frame buffer with W-bit wide LUT**
- **Typically W > N**
- **The N-bit register content acts as an index into the lookup table**
- **Thus out of 2^W possible intensities, that are available, only 2^N different intensities are usable at any time**
- **The programmer must choose 2^N different intensities, based on his requirement, and load the LUT (addressable in memory) before use**

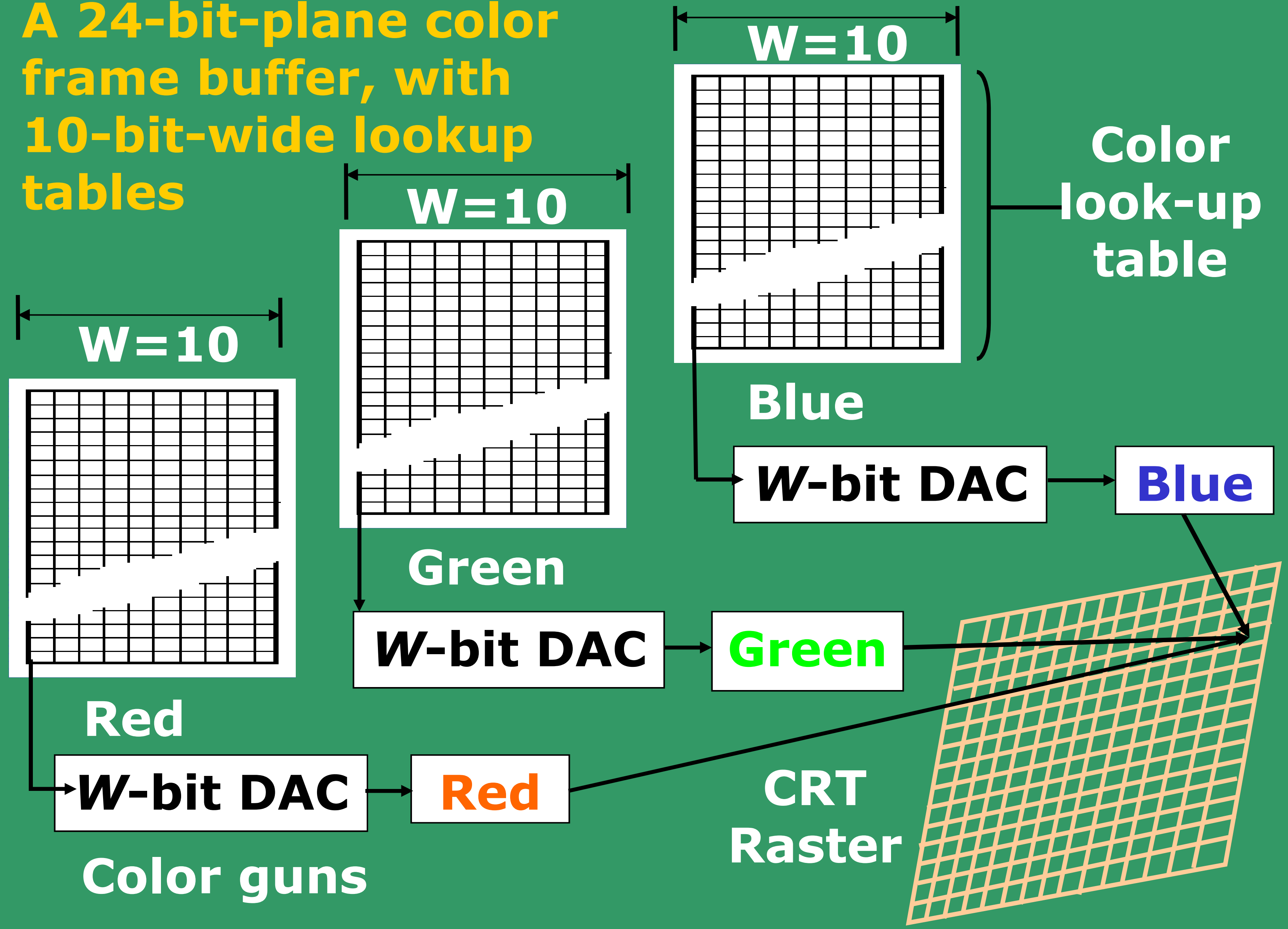
An N-bit-plane gray level frame buffer with a W-bit-wide lookup table.



2^W intensity levels, 2^N at a time (W>N)


A 24-bit-plane color frame buffer, with 10-bit-wide LUT
N
N
N
W=10
W=10
Frame buffer
Blue
Color look-up table
Green
2N Entries
Red
(CONTD.) →

A 24-bit-plane color frame buffer, with 10-bit-wide lookup tables



LCD and FLAT PANEL DISPLAYS

- LCD is made up of 6 layers – vertical polarizer plane; layer of thin grid wires; layer of LCDs; layer of horizontal grid wires; horizontal polarizer; and finally a reflector.
- LCD material is made up of long crystalline molecules; When the crystals are in an electric field, they all line up in the same direction.
- Active matrix panels have a transistor at each grid point (X, Y). Crystals are dyed up to provide color. Transistors act as memory, and also cause the crystals to change their state quickly.
- LCD displays are low cost, low weight, small size and low power consumption

LCD and FLAT PANEL DISPLAYS

- The display contains two polarizers, aligned 90^0 to each other.
- With the display in its OFF (or twisted) state, light entering the display is plane polarized by the first polarizer.
- This polarized light passes through the liquid crystal sandwich and then through the second polarizer and is reflected back to the display.
- Turning the pixel ON (by applying and electric field) causes the crystal to untwist.
- Light now passing through the liquid crystal sandwich is now absorbed by the second polarizer. The pixel now appears dark.

LCD and FLAT PANEL DISPLAYS

- Displays are of two types – plasma/gas discharge or Electroluminescent.
- All flat panel displays are raster refresh displays.
- A flat CRT is obtained by initially projecting the beam parallel to the screen and then reflecting it through 90^0.
- Reflection of the electron beam reduces the depth of the CRT bottle and hence the display.
- Plasma displays like LCDs are also called active matrix displays.
- The required voltage or current to control the pixel illumination is supplied using a thin-film transistor or diode.

Some questions and take-home tasks - I

- **What are the drawbacks of DVST displays ?**

- **List a few non-CRT based display devices.**

- **What is the difference between Phosphorescence and Phosphor's Fluorescence.**

- **Let the average time to execute an instruction in the display list be 33.33 μsec. If the frame rate is 30 fps, obtain the maximum number of instructions that may be present in the display list (for random-scan displays).**

- **Learn about flat-panel displays, mouse, scanners, track ball and keyboard.**

Some questions and take-home tasks- II

- Use a graph paper to illustrate the staircase effect of a line drawn on a screen.

- Consider three different raster systems with resolutions of 640x480, 1280x1024 and 2560x2048. Obtain the size of the frame buffer necessary in each system to store (a) 12 bits and (b) 32 bits per pixel.

- Consider a display area of a video monitor to be 12”x9.6”. If the resolution of the monitor is 1280x1024, what is the diameter of each pixel (assume aspect ratio = 1)?

Some questions and take-home tasks- III

- **Compute the access time per pixel, for systems with resolutions (a) 640x480 and (b) 1280x1024. Assume a refresh rate of 60fps.**

- **Consider a single field refresh scan display system with just two(2) horizontal scan lines. Let the vertical retrace start when the beam is at the bottom-right of the screen. Draw both the horizontal and vertical deflection voltages (combined plot) as a function of time, for a single refresh cycle.**

- **Use a graph paper to plot pixel points to draw a character A. Try to enlarge the character by a factor of 2, by multiplying the pixel coordinates by the same factor. What do you get?**

Some questions and take-home tasks-IV

- **Assuming a transfer rate of 0.1 MB/sec, how much time would be necessary to load pixmaps with resolutions:** (a) 512x512x1, (b) 1024x1280x1.
- We require large refresh rate mainly due to the short persistence of the phosphor. Why not use a long persistence instead, to reduce the frame rate ?
- Obtain the percentage of time (per frame) when the beam does not trace any image, in these cases:

Visible Area	FPS	Inter lace	Retrace Time (VER)	Retrace Time (HOR)
640x485	30	No	1250 μs	11 μs
1280x1024	60	No	1250 μs	7 μs
1280x1024	60	Yes	600 μs	4 μs

End of

Lectures on

CRT Display Devices