Examples of Computer Graphics Devices:

CRT, EGA (Enhanced Graphic Adapter)/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**

- A slow moving electron beam draw a line on the screen
- Screen has a storage mesh in which the phosphor is embedded
- Image is stored as a distribution of the charges on the inside surface of the screen
- Limited interactive support
- Storage Tube- it is a CRT with a long persistence phosphor i.e..
- Provides flicker-free display
- No refreshing necessary

Operation of an Electron gun with an accelerating **anode**

- Heating filament used to heat up the cathode to generate the electron for the display on the phosphor coated surface.
- Electron is guided by the set of devices which are:
Control Grid: eg. When you examine the picture on the screen you can see that some picture may be bright and some picture may be dark. Such brightness and darkness and the luminance and intensity on the screen are controlled by the intensity of the beam by the strike on the particular point on the screen. This intensity of the screen is controlled by the controlling the intensity of the electron beam, which is coming out of the cathode.

- Control Grid control the intensity of the Electron beam which are generate by the Electron gun, where Electrons are negatively charged. Control Grid is a cylindrical device which is also negatively charged with high negative voltage, which is apply to the control grid.
- Now the Electron and Control Grid is also negatively charged. Both of them are ripple to each other.
- So the amount of the voltage in control grid is essentially allow a certain amount of the electron of the electron beam to pass straight i.e. controlled by the negative voltage of control grid.
- If you reduce the amount of the control grid (i.e. –ve voltage) the electron beam intensity will be higher and amount of the intensity on the screen will be higher
- Whereas increase the voltage of the control grid you are allowing to less amount of the electron pass through. The intensity of the electron beam which is passing through the control grid will now be less and you will have less brightness on the screen

- Focusing Anode:
- Accelerating Anode:

Focusing Anode and Accelerating anode is positively charged. Control grid is negatively charged because it needs to stop or resist some electrons if necessary to control the intensity of the beam on the screen surface. Focusing Anode is responsible to focus the electron beam on the particular point of the screen. That is similar to lens focusing point on some solid surface. In this Technology we are not focusing light instead of light we are focusing some electron beams on the phosphor coated surface of the CRT. It is also called electrostatic lens.

Accelerating Anode is required to electrons to strike the screen with very high speed to emit the light.
Basic Design of a Magnetic Deflection CRT

Electrostatic Deflection of the electron beam in a CRT

DVST- Drawback

- 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.
- The Display must be refreshed at regular intervals – minimum of 30Hz (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

- The display processor sends digital and point coordinate values to a vector generator
- Point value used to draw a line in X,Y coordinate system
- Digital value for the intensity of the line
- 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 40-50Hz
- Scope of animation with the segmentation – mixture of static and dynamic parts of a picture

Phosphor’s **fluorescence** is the light emitted as electrons (unstable) lose their excess energy while the phosphor is being struck by electrons. Electrons lose their energy by two form
- Heat energy
- Light energy: it is very short time emitted the light and goes off, while the beam comes back to refresh that point.

- **Phosphorescence** 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 **Persistence** 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 **Point-Plotting device**
- Raster displays store the display primitives (lines, characters, shaded and patterned areas) in a refresh buffer
- Refresh Buffer (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](attachment:image.png)
• 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 is causes the effect of ‘Aliasing’, ‘Jaggies’, or ‘Staircase’ Effect
• Refresh/Frame Buffer is also called Bit-Plane

Rasterization: (a) General Line; (b) Special Cases
• 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 refreshes operations*
Architecture of a raster display

Raster scan with outline primitives
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:

<table>
<thead>
<tr>
<th>N</th>
<th>Size in KB</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>96</td>
</tr>
<tr>
<td>8</td>
<td>256</td>
</tr>
<tr>
<td>24</td>
<td>768</td>
</tr>
</tbody>
</table>

Refresh rate to avoid flickering – 60 Hz

If one uses a 1024x1024 high resolution CRT:

<table>
<thead>
<tr>
<th>N</th>
<th>DISPLAY COLOR</th>
<th>MEMORY SIZE</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Black and White</td>
<td>128 KB</td>
</tr>
<tr>
<td>8</td>
<td>256 Color</td>
<td>1 MB</td>
</tr>
<tr>
<td>24</td>
<td>16 Million Color</td>
<td>3 MB</td>
</tr>
<tr>
<td>32</td>
<td>16 Million Color</td>
<td>4 MB</td>
</tr>
</tbody>
</table>
Even 32 bits per pixel with 1280x1024 pixels raster are available.

- 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

**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**

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.

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
• 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.
• Let the time available for each scan line be T.
• Thus, we have: T * 525 * 30 = 1 sec.
• Thus, T = 63.5 * s/scan-line
• 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):
$T' = 0.83 \times T = 53 \, \text{s}.$

- Considering 4:3 aspect ratio, the number of pixels per scan line = $483 \times 4/3 = 644$
- Thus, time available for the beam to access and display a pixel = 82.3 ns (nano-second).

Some examples of pixel access times:

<table>
<thead>
<tr>
<th>Frame Rate</th>
<th>Display Resolution</th>
<th>Pixel Access Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>512 x 512</td>
<td>105 ns</td>
</tr>
<tr>
<td>25</td>
<td>500 x 625</td>
<td>105 ns</td>
</tr>
<tr>
<td>60</td>
<td>1000 x 1000</td>
<td>26 ns</td>
</tr>
<tr>
<td>60</td>
<td>1024 x 1024</td>
<td>24 ns</td>
</tr>
</tbody>
</table>

QXGA, or Quad eXtended Graphics Array, display standard

WQUXGA, or Wide Quad Ultra eXtended Graphics Array

<table>
<thead>
<tr>
<th>Computer Standard</th>
<th>Resolution</th>
<th>Ratio</th>
<th>Ratio (Decimal)</th>
<th>Pixels</th>
</tr>
</thead>
<tbody>
<tr>
<td>QWXGA</td>
<td>2048 x 1152</td>
<td>16:9</td>
<td>1.78</td>
<td>2.4M</td>
</tr>
<tr>
<td>QXGA</td>
<td>2048 x 1536</td>
<td>4:3</td>
<td>1.333</td>
<td>3.1M</td>
</tr>
<tr>
<td>WQXGA</td>
<td>2560 x 1600</td>
<td>16:10</td>
<td>1.6</td>
<td>4.1M</td>
</tr>
<tr>
<td>QSXGA</td>
<td>2560 x 2048</td>
<td>5:4</td>
<td>1.25</td>
<td>5.2M</td>
</tr>
<tr>
<td>WQSXGA</td>
<td>3200 x 2048</td>
<td>25:16</td>
<td>1.5625</td>
<td>6.6M</td>
</tr>
<tr>
<td>QUXGA</td>
<td>3200 x 2400</td>
<td>4:3</td>
<td>1.333</td>
<td>7.7M</td>
</tr>
</tbody>
</table>
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
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 CRT

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

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

- 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 $224 = 16,777,216$ possible colors.
- This is called a FULL COLOR FRAME BUFFER.

**A 24-bit-plane color frame buffer**

- 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.**
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
• The display contains two polarizers, aligned 900 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.
• 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 900.
• 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.