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5 Displays and printers

This section presents information on different means of presenting output information to the user visually. In particular, this chapter covers different types of monitors (also known as Video Display Terminals (VDTs), Video Display Units (VDUs), or Cathode Ray Tubes (CRTs)), projection displays, stereoscopic displays, printers and plotters.

5.1 Displays

This section covers visual displays used for information output. It does not address touch screen displays or visual indicators such as LED displays and lights accompanying switches and controls. Touch screen displays are in the input devices chapter (Chapter 9) and visual indicators are addressed in the chapter on controls and visual indicators (Chapter 6).

5.1.1 General

- **5.1.1.1 Make displays function under operational conditions.** Visual displays should function under any circumstance corresponding with the operational and use philosophies of the system. [Source: Department of Defense (MIL-STD-1472F), 1999]

- **5.1.1.2 Make displays legible under all conditions.** Visual displays shall be legible under all anticipated viewing conditions. [Source: MIL-STD-1472F, 1999]

  Discussion. Factors affecting the **legibility** of a display include the nature and characteristics of the display itself, ambient lighting, and viewing distance.

- **5.1.1.3 Avoid unnecessary markings.** Trademarks, company names, and other markings not needed to identify a display or aid in performing tasks should not be displayed on a panel face. [Source: MIL-STD-1472F, 1999]

- **5.1.1.4 Ensure adequate refresh rate.** Displays that require refreshing of information such as CRTs, heads up displays, and collimated displays, shall be refreshed at a rate that insures that the displayed information is sufficiently current for the users to perform their tasks. [Source: MIL-STD-1472F, 1999]

  Definition. Refresh rate is the rate in cycles per second (Hz) at which the displayed contents of a computer screen are periodically regenerated.

- **5.1.1.5 Provide adjustable contrast and brightness.** Visual displays should provide users with the capability of adjusting contrast and/or brightness. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.1.1.6 Controls should conform to Chapter 6.** Controls for displays should conform to the design criteria contained in Chapter 6, Controls and visual indicators.

5.1.2 Location and arrangement

- **5.1.2.1 Locate displays to be readable without assuming uncomfortable positions.** Displays shall be located so that a user can read them to the degree of accuracy required without having to assume an uncomfortable, awkward, or unsafe position. [Source: MIL-STD-1472F, 1999]

  Discussion. Locating visual displays so that the users can see the information can include positioning the displays so they are readable to users in wheelchairs. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.1.2.2 Make readable without special equipment.** A user should be able to read a visual display without the use of a ladder, a flashlight, or other special equipment. [Source: MIL-STD-1472F, 1999]

- **5.1.2.3 Locate directly in front of user** A screen should be directly in front of the user when the user is in his or her normal working position. [Source: Department of Energy (DOE-HFAC 1), 1992]

  Discussion. Locating the screen off-center can cause the user to adopt uncomfortable or awkward positions, leading to pain. Exceptions to this rule are when the users look at the monitor infrequently.

- **5.1.2.4 Place the top of the screen below eye level.** The top of the screen should not be above the viewer's eye level. [Source: DOE-HFAC 1, 1992]

  Discussion. By placing the top of the screen below eye level, the user can view the information on the screen using a downward gaze. When people view the displays at eye level, they tend to blink less and eyes can get dry and irritated. A downward gaze exposes less of the eye to the atmosphere, preventing dry eyes. [Source: Tsubota & Nakamori, 1993].

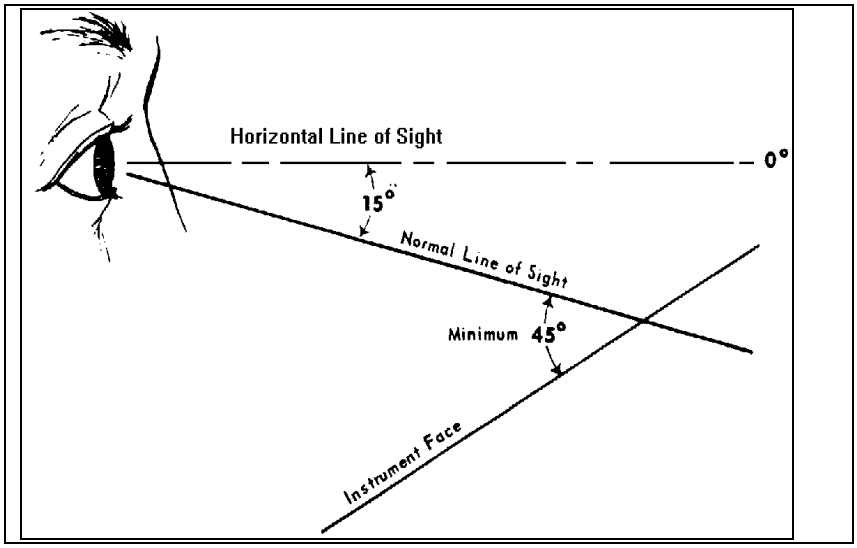
- **5.1.2.5 Make line of sight below horizontal.** The line of sight from the viewer's eyes to the center of the screen should be between 10° and 60° below horizontal, preferably allowing the user to set the angle most comfortable for him or her within this range. [Source: DOE-HFAC 1, 1992; Balci & Aghazadeh, 1998; MIL-STD 1472F, 1999, American National Standard Institute (ANSI), 1988]

  Discussion. The resting position of the eyes, considered to be the most comfortable position, is 15° below the horizontal. However, a lower monitor position improves the ability to accommodate and facilitates convergence (the turning in of eyes to focus on a nearby object), particularly for persons over 40 years old. Additionally, a monitor location 40° below horizontal can reduce discomfort in the neck, shoulders, forearms, and wrists for users wearing bifocals. [Source: Balci & Aghazadeh, 1998; Krimsky, 1948; Morgan, Cook, Chapanis & Lund, 1963; Ripple, 1952; Tyrrell & Leibowitz, 1990;]

- **5.1.2.6 Orient perpendicular to line of sight.** Display screens should be positioned so that the face is perpendicular to the user's line of sight whenever feasible. [Source: DOE-HFAC 1, 1992]

  Discussion. Tilting the monitor downward can lead to increased discomfort both physically and visually, particularly in the neck area, versus a monitor tilted back a little. [Source: Ankrum, Hansen, & Nemeth, 1995; Ankrum & Nemeth, 1995]

Exhibit 5.1.2.7 Display face not tilted more than 45° to user's line of sight [Source: MIL-STD-1472F, 1999]



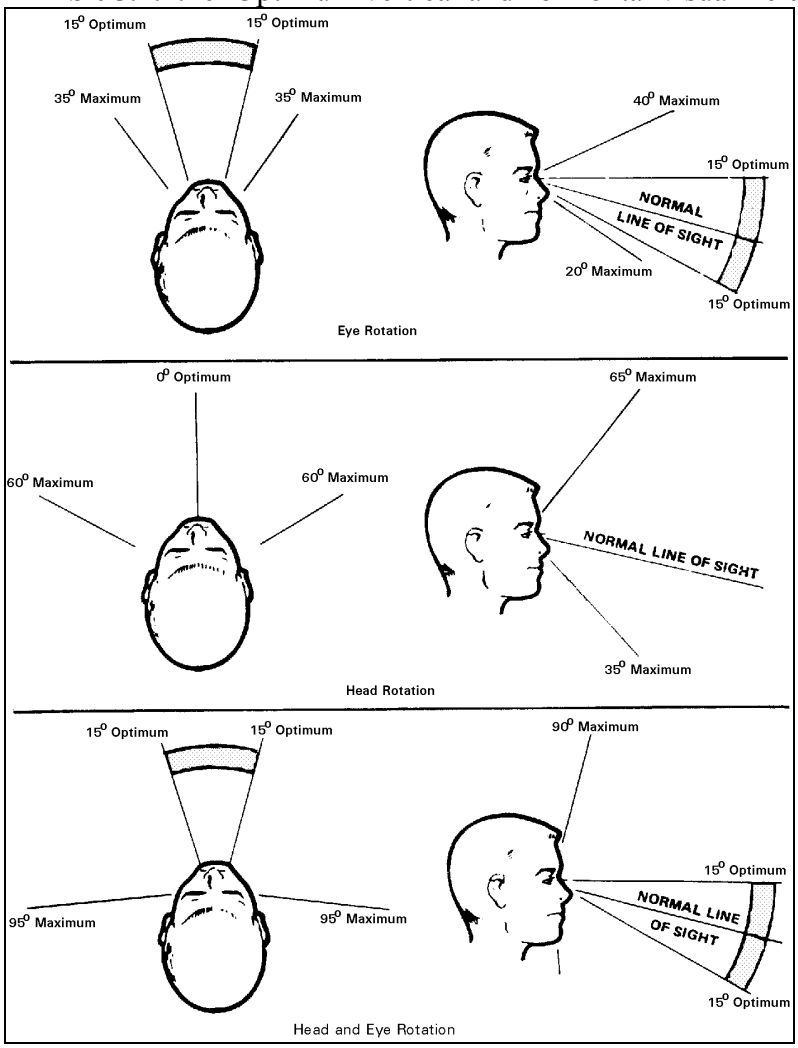
- **5.1.2.7 Avoid excessive tilt.** The display face shall not be tilted more than 45° from the normal line of sight as illustrated in Exhibit 5.1.2.7. [Source: MIL-STD-1472F, 1999]

- **5.1.2.8 Group task-related displays together.** All displays necessary to support a user's activities or sequence of activities should be grouped together. [Source: MIL-STD-1472F, 1999]

- **5.1.2.9 Arrange according to function and sequence.** Displays shall be arranged in relation to one another according to their sequence of use or the functional relations of the components they represent. [Source: MIL-STD-1472F, 1999]

  Discussion. In general, it is beneficial if displays are arranged sequentially within a functional group so that they provide a left-to-right or top-to-bottom information flow within the group because this is how people read.

Exhibit 5.1.2.10 Optimum vertical and horizontal visual fields



- **5.1.2.10 Locate critical displays in central visual field.** Critical or frequently used displays shall be located in the **central visual field**, as illustrated in Exhibit 5.1.2.10, and occupy a privileged position in that field (e.g., the top or left-most position). [Source: MIL-STD-1472F, 1999]

  Discussion. Focal vision is the central 30° of the visual field, pictured as the shaded area in the top panel of the Exhibit 5.1.2.10, (along with the range of eye movements with the head stationary). This is the area that people use to look at objects in the world, moving their eyes as needed to bring images of the object on to the **fovea**, which is the area of highest acuity. When an object is outside of the focal area, a person will usually turn the head rather than simply move the eyes. The range of head rotation is illustrated in the second panel of Exhibit 5.1.2.10. The combined range of combined head and eye movement is illustrated in the third panel of Exhibit 5.1.2.10. By locating frequently used displays in the central 30° of visual field, the user is not required to move his or her head to bring the information into the focal area, presumably minimizing neck strain.

- **5.1.2.11 Arrange displays consistently.** The arrangement of displays within a system shall be consistent from application to application. [Source: MIL-STD-1472F, 1999]

- **5.1.2.12 Distance for monitors with controls.** If there is a control associated with a display, the viewing distance from the eye reference point of a seated user to the associated display and control shall not exceed 635 mm (25 in). [Source: MIL-STD-1472F, 1999]

  Discussion. The reach distance for a 5th percentile female is 26 inches, so setting the distance at 25 inches insures that the 5th percentile female can reach the controls. The 5th percentile female measurements and reach ranges represent the customary minimal design criteria. Designing to accommodate the minimal reach range will increase the likelihood that the entire user population can reach the controls.

▪ **5.1.2.13 Maintain at least a minimum viewing distance.** The viewing distance from the eye to a display shall not be less than 330 mm (13 in), unless the periods of viewing will be short or if dim signals must be detected, in which case the minimum can be 250 mm (10 in). [Source: MIL-STD-1472F, 1999]

Discussion. In general, a further viewing distance is preferred. Earlier recommendations were to locate the monitor at the same viewing distance as the distance for reading hard copy 307 mm- 410 mm (12-16 inches). However, new research has found that eyestrain is not increased when the document and monitor were viewed at different distances. Less eyestrain is reported for 980 mm (38 in) viewing distances than 660 mm (26 in). Users judged 50 cm (20 in) as too close for computer work and performance suffered at this distance over a 100 cm (40 in) distance. Users with presbyopia (common in people over 40) may require corrective lenses to view displays further than 16 in from the eye. [Source: ANSI, 1988; Owens & Wolf-Kelly, 1987; Jaschinski-Kruza, 1990]

▫ **5.1.2.14 Determine maximum viewing distance by legibility.** Maximum viewing distance for displays should be determined by the legibility of the displayed information. [Source: MIL-STD-1472F, 1999]

Discussion. The further the screen is from the viewer, the more difficult it is for the eyes to resolve fine detail. This can often be fixed by displaying screen items at larger resolution.

▫ **5.1.2.15 Modify displayed information when viewing distance exceeds 20 inches.** Information on displays that are located at viewing distances greater than 20 in should be appropriately modified in aspects such as display size, symbol size, brightness ranges, and resolution to ensure legibility of displayed information. [Source: MIL-STD-1472F, 1999]

Discussion. A general rule of thumb is that items viewed at twice the distance will appear half as large. As the preferred character size for readability is 20-22 arc minutes, the size of the characters on the display will need to be larger to maintain the preferred character size at greater distances. [Source: ANSI, 1988]

- **5.1.2.16 Allow users to set viewing distance where possible.** Although there may be a set normal viewing distance, workplace design should not restrict observers from viewing a CRT from other distances. [Source: MIL-STD-1472F, 1999]

  Example. The set distance between the viewer's eye and the CRT screen may be 20 in, but the viewer may occasionally want to lean forward to take a closer look at the information displayed on the screen.

  Discussion. Users have individual differences in their preferred viewing distances. Particularly for workstations with a single user, it is preferable for users to adjust the viewing distance to their preferred distance. Users report more visual strain when they are forced to work at a distance shorter than their preferred distance. [Source: Jaschinski, Heuer, & Kylian, 1998]

- **5.1.2.17 Do not allow vibration to interfere with tasks.** Vibration of visual displays shall not hinder users in the performance of their tasks. [Source: MIL-STD-1472F, 1999]

5.2 Cathode ray tube displays

A **Cathode Ray Tube** or CRT is the tube of a television or computer monitor in which rays of electrons are beamed onto a phosphorescent screen to produce images. CRT is often used as a generic term for a computer monitor. Three key specifications for a CRT are the maximum resolution it will display (determined by dot pitch and resolution), the refresh rate, and whether it is interlaced or non-interlaced. An **interlaced** display produces a video image by displaying alternate scan lines. A **non-interlaced** display produces a video image by displaying all lines in a frame in one pass from top to bottom before the next frame appears. Non-interlaced displays are preferred to reduce the perception of flicker. (**Flicker** is the appearance of flashing or wavering light that occurs in a computer display.) Negative aspects of CRTs are that they use a lot of electricity and take up a lot of space.

5.2.1 General

- **5.2.1.1 Refresh rate.** CRT displays shall be refreshed at a rate of at least 65 Hz, preferably more than 100 Hz to avoid the perception of flicker on monitors for photosensitive users. [Source: ANSI, 1988; Bauer & Cavonius, 1980; Cardosi & Murphy 1995, DOE-HFAC 1, 1992; Vanderheiden & Vanderheiden, 1991]

  Discussion. A refresh rate of 100 Hz on a non interlaced monitor is considered sufficient to ensure that flicker is well beyond the threshold of perception even in the peripheral vision where sensitivity is higher. (A 100 Hz refresh rate on an interlaced monitor refreshes a given line only 50 times a second, causing noticeable flicker.) Individual differences exist in flicker sensitivity. The perception of flicker increases in the peripheral vision, so the bigger the monitor is, the higher the refresh rate will need to be to ensure flicker is not a problem. [Source: Bauer & Cavonius, 1980]

- **5.2.1.2 Avoid display induced seizures.** Displays shall be designed to maximize the number of people who can view them without experiencing a seizure. [Source: Vanderheiden & Vanderheiden, 1991]

  Discussion. Seizures may be induced by flashing screen cursors or by flickering displays, particularly when the flash rates are between 10 and 25 Hz, with peak levels occurring between 15-20 Hz. Flicker sensitivity becomes greater with increases in light intensity and the proportion of the visual field that is flickering. Some users experience seizure responses when exposed to flicker rates of 15-20 Hz even when their eyes are closed. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.2.1.3 Flicker.** CRT displays shall have no apparent flicker to at least 90 % of a sample of the user population when viewed under the expected conditions of use. [Source: ANSI, 1988; DOE-HFAC 1, 1992; Cardosi & Murphy, 1995]

  Discussion. The refresh rate is one of several factors that can cause the user to perceive flicker. The perception of flicker increases in the peripheral vision, so the bigger the monitor is, the higher the refresh rate will need to be to ensure flicker is not a problem.

  Ambient illumination, display contrast, colors used, and the **phosphor** persistence of the monitor also contribute to the perception of monitor flicker. One of the traditional ways of minimizing flicker is by keeping the screen as dark as possible.

  A longer decay rate on the phosphor (high persistence phosphor) decreases the flicker perception but can produce trails or after images behind moving elements. There are also individual differences and age differences in the ability to perceive flicker, with younger people generally being more sensitive.

- **5.2.1.4 Use medium persistence phosphors.** General purpose CRTs should use medium-persistence phosphors. [Source: DOE-HFAC 1, 1992]

  Discussion. High-persistence phosphors tend to produce trails or after images behind moving elements, and low-persistence phosphors are more likely to result in a perceptible flicker. [Source: DOE-HFAC 1, 1992]

- **5.2.1.5 Ensure color fringes do not affect performance.** Color fringes on images on CRT displays, if perceptible, shall not have an adverse effect on a user's perception or performance. [Source: MIL-STD-1472F, 1999]

  Definition. Color fringes are the pixels along the border of an object that contain a combination of the selection and background colors.

- **5.2.1.6 Avoid jitter.** Deviations in the location of a displayed element shall be equal to or less than .0002 mm per mm of viewing distance over the period of a second. [Source: ANSI, 1988]

  Definition. Jitter is a departure from geometric stability. It occurs when pixels in displayed objects move instead of remaining in a fixed position.

- **5.2.1.7 Maintain uniform element size.** The size of a display element (for example, an alphanumeric character or symbol) should not vary by more than 10 % regardless of its location within the display. [Source: ANSI, 1988]

  Discussion. If you type the capital letter E such that it fills the screen, all of the Es, from the ones in the center to those on the outer edge, should appear to be the same size.

- **5.2.1.8 Minimize element displacement.** The displacement of a single display element's position shall vary by less than 5 % of the display element box height relative to those above and below, or right and left of it. [Source: ANSI, 1988]

- **5.2.1.9 Maintain column and row linearity.** Rows and columns shall be parallel and orthogonal to each other with the linearity of any column or row not varying by more than 2 % of the length of the column or row. [Source: ANSI, 1988]

5.2.2 Luminance and contrast

- **5.2.2.1 Minimize luminance variation across the display.** Luminance shall not vary by more than 50 % from the center to the edge of the display. [Source: ANSI, 1988]

  Definition. Luminance is the physical measure of the amount of light emitted by or reflected in a given direction from the display. Luminance is expressed in candela per meter squared or foot lamberts. **Foot lamberts** is a measure that has been corrected for the visual system's differential sensitivity to different wavelengths, giving an approximation to perceived brightness. [Source: Murch, 1987]

- **5.2.2.2 Luminance.** Either characters or their background, whichever has higher luminance, shall have a luminance of at least 35 cd/m^2 (10 fL). [Source: MIL-STD-1472F, 1999]

  Discussion. Increasing luminance reduces pupil diameter, reducing distortions and improving speed of accommodation and depth of field, especially for users over 40 who tend to lose some of their ability to accommodate. However, higher luminance increases sensitivity to flicker. [Source: Bauer & Cavonius, 1980]

- **5.2.2.3 Screen luminance.** The ambient screen illumination shall not contribute more than 25 % of screen brightness through diffuse reflection and phosphor excitation. [Source: MIL-STD-1472F, 1999]

- **5.2.2.4 Provide a control for adjusting luminance.** A control shall be provided to vary the CRT luminance from 10 % of minimum ambient luminance to full CRT luminance. [Source: MIL-STD-1472F, 1999]

- **5.2.2.5 Provide a control for adjusting contrast ratio.** A control shall be provided to vary the foreground-background contrast ratio. [Source: MIL-STD-1472F, 1999]

  Definition. Contrast ratio is the luminance of the foreground divided by the luminance of the background. It indicates how much brighter a pure white output would be than a pure black output. The greater the contrast, the sharper the image will be. Also called luminance ratio, contrast ratios for CRTs are generally better than those for active matrix LCDs, which are better than those for passive matrix LCDs.

- **5.2.2.6 Facilitate detection of faint signals.** When the detection of faint signals is required, and when the ambient illumination may be above 2.7 lux (0.25 ft-c), CRTs shall be hooded, shielded, or recessed. [Source: MIL-STD-1472F, 1999]

- **5.2.2.7 Ensure CRT luminance exceeds adjacent surfaces.** With the exception of emergency indicators, no light source in the immediate surrounding area shall be of greater luminance than the CRT signal. [Source: MIL-STD-1472F, 1999]

- **5.2.2.8 Provide adequate ambient illumination.** The ambient lighting levels in areas of the CRT shall be appropriate for other visual functions such as setting controls, reading instruments, and maintenance, but shall not degrade the visibility of signals on the CRT display. [Source: MIL-STD-1472F, 1999]

  Discussion. Automatic adjustment of CRT brightness may be used if the adjustment is a function of ambient illumination and the range of adjustment is adequate for the full range of ambient illumination. [Source: MIL-STD-1472F, 1999]

- **5.2.2.9 Provide controls to modulate ambient lighting.** If ambient illumination in an area where a CRT display is used is variable, controls shall be provided to dim all light sources, including illuminated panels, indicators, and switches in the immediate vicinity of the CRT. [Source: MIL-STD-1472F, 1999]

5.2.3 Glare control

Glare may be of two types, diffuse or specular. **Diffuse glare** is caused by the general environmental illuminance, which effectively reduces the display contrast. **Specular glare** is the appearance of unwanted images (reflections) on the display surface. The most effective method of glare control is to design the workplace so that neither type is produced. Other methods include screen meshes placed over the display surface, etched faceplates, anti-reflective coatings, and bonded quarterwave filters. All of these degrade both contrast and resolution to some degree.

- **5.2.3.1 Minimize or eliminate glare.** Glare shall be eliminated or minimized.

  Discussion. Some of the methods that can be used to eliminate or minimize glare are

  a. proper placement of the CRT relative to light sources,

  b. use of an anti-glare treatment, such as a diffusing surface or an optical coating, or

  c. filter control of the light sources. [Source: ANSI, 1988; MIL-STD-1472F, 1999]

  Hoods are often unacceptable for this purpose because they tend to restrict the viewing angle of screens. Do not allow the use of anti-glare treatments to violate the requirements for luminance, contrast, and resolution contained in this section. [Source: ANSI, 1988; MIL-STD-1472F, 1999]

- **5.2.3.2 Make adjacent surfaces matte.** Surfaces adjacent to the CRT shall have a dull, matte finish. [Source: MIL-STD-1472F, 1999]

- **5.2.3.3 Minimize reflections.** Displays shall be constructed, arranged, and mounted to prevent interference from reflections of illumination sources, windows, and other visual displays. [Source: MIL-STD-1472F, 1999]

  Discussion. If necessary, shields, filters, or other techniques may be used to ensure that system performance is not degraded. [Source: MIL-STD-1472F, 1999]

5.2.4 Resolution

- **5.2.4.1 Allow discrimination of similar characters.** When presenting alphanumeric characters, displays shall allow discrimination of similar characters. [Source: MIL-STD-1472F, 1999]

  Example. The letter "l" and the number "1", or the letter "Z" and the number "2" are easily confused.

- **5.2.4.2 Resolution for CRTs.** CRTs for displaying simple alphanumeric text shall have a resolution of at least 0.8 resolution elements per mm (20 per in). [Source: DOE-HFAC 1, 1992]

- **5.2.4.3 Minimum resolution for alphanumeric characters.** Alphanumeric characters should have at least 10 resolution elements per character height. [Source: DOE-HFAC 1, 1992]

- **5.2.4.4 Resolution for high reading speed.** When high reading speed is required, high resolution monitors with at least 35 pixels per mm (90 dpi) shall be used. [Source: DOE-HFAC 1, 1992]

  Discussion. Higher resolution displays (greater than 90dpi) are associated with increases in visual performance and decreases in visual fatigue in visual search tasks. [Source: Ziefle, 1998]

- **5.2.4.5 Resolution for complex symbols.** CRTs for displaying complex symbols and graphic detail should have at least 100 resolution elements per inch. [Source: DOE-HFAC 1, 1992]

5.3 Flat-panel displays

In flat-panel displays, images are formed from discrete, nonoverlapping, rectangular pixels. These images can differ from images on CRTs in character-to-character spacing, interline spacing, character and symbol design, the effect of ambient illumination, image polarity, and failure mode. [Source: Avery & Bowser (DOE HFDG ATCCS V2.0), 1992]

- **5.3.1 Character formation -- vertical orientation.** Characters in a vertical orientation should be formed from a matrix of at least 9 by 13 pixels. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.3.2 Minimum character formation for nonvertical orientation.** Characters in a nonvertical orientation should be formed from a matrix of at least 8 by 11 pixels, preferably 15 by 21 pixels. [Source: DOE HFDG ATCCS V2.0, 1992]

▫ **5.3.3 Character stroke width.** Character stroke width should not exceed the minimum and maximum values given in Exhibit 5.3.3. [Source: DOE HFDG ATCCS V2.0, 1992]

Definition: Stroke width is the thickness of the lines used to make up the number or letter.

Exhibit 5.3.3 Stroke width for pixel-generated characters. All numbers are in pixels.

Upper case character height	Minimum stroke width	Maximum stroke width
7 to 8	1	1
9 to 12	1	2
13 to 14	2	2
15 to 20	2	3
21 to 23	2	4

▫ **5.3.4 Minimum and preferred character height-width relationship.** The width of characters of a given height should not exceed the minimum and maximum values given in Exhibit 5.3.4. The exhibit also includes the preferred values. [Source: DOE HFDG ATCCS V2.0, 1992]

Exhibit 5.3.4 Height-width relationship for upper case pixel-generated characters. All numbers are in pixels.

Character height	Minimum width	Preferred width	Maximum width
7	4	5	5
8	4	6	7
9	5	6	8
10	5	7	9
11	6	8	10
12	6	9	11
13	6	9	12
14	7	10	13
15 or 16	8	11	14

▫ **5.3.5 Image formation time when motion artifacts are unimportant.** If motion artifacts are not important, image formation time should not exceed 55 msec. [Source: DOE HFDG ATCCS V2.0, 1992]

Definition. Motion artifacts are the after images (made up of the previously drawn object that have not yet decayed enough to disappear) that one sees that appear to follow a moving display object. They often look like the tail of a comet following the object in motion.

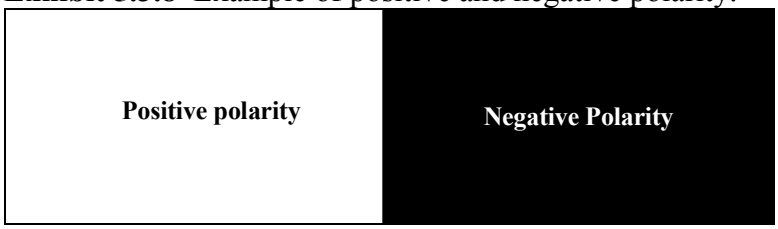
- **5.3.6 Image formation time when motion artifacts are important.** If motion artifacts are important, image formation time should not exceed 10 msec. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.3.7 Minimize pixel failure rate.** Displays should be selected and maintained so that the pixel failure rate does not exceed 1%. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.3.8 Use positive polarity when all else is equal.** If character stroke width, modulation, and luminance values are approximately equal for both polarities, the positive polarity (dark characters on a light background) should be used. (see Exhibit 5.3.8). [Source: DOE HFDG ATCCS V2.0, 1992]

  Discussion. Reflections are less visible on a bright background than on a dark background.

  Exhibit 5.3.8 Example of positive and negative polarity.



- **5.3.9 Treat displays to minimize reflections.** All flat panel displays should incorporate a first-surface treatment to diminish specular reflections. [Source: DOE HFDG ATCCS V2.0, 1992]

5.4 Liquid crystal displays

Liquid crystal displays (LCDs) are a type of flat-panel display that works by suspending liquid crystals between two transparent sheets of polarizing material. An electric current passes through the liquid causing the crystals to act like a shutter, either permitting light to pass through or blocking the light so that it cannot pass through. Most LCDs are backlit to make them easier to read in bright environments. LCDs are especially suited for information display in environments where ambient illumination is high. Their advantages include excellent contrast, long life, rugged design, low voltage, and low power consumption (except when backlit). Their disadvantages include slow speed, limited color capability, limited temperature range, and manufacturing problems for larger panels with higher resolution. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.4.1 Use only with adequate illumination.** LCDs should be used only with adequate levels of ambient illumination. [Source: DOE HFDG ATCCS V2.0, 1992]

  Discussion. LCD reading performance improves as ambient illumination increases over the range 20 to 1500 lx. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.4.2 Polarity.** For reflective LCDs, the image should be light characters on a dark background; for backlighted (transmissive) LCDs, the image should be dark characters on a light background. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.4.3 Minimize backlighting.** The amount of backlighting used should be minimized. [Source: DOE HFDG ATCCS V2.0, 1992]

  Discussion. LCD reading errors increase as backlighting increases over the range of 0 to 122 cd/m^2. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.4.4 LCDs used in low ambient illumination.** If LCDs are used in the presence of low ambient illumination, users should be able to adjust the viewing angle and the amount of backlight. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.4.5 Minimize off-axis viewing of backlit LCDs.** If used, backlit LCDs should be located so that off-axis viewing is minimized. [Source: DOE HFDG ATCCS V2.0, 1992]

  Discussion. The readability of many LCD screens drops off considerably as does the brightness particularly with a 45 degree off axis viewing angle. This may not be as much of a problem with newer LCD technology that claims a higher off axis viewing angle.

- **5.4.6 Incident illumination.** The incident illumination on the surface of LCD displays should be at least 35∏/R lux, with R equaling reflectivity of the display at its most reflective state. [Source: ANSI, 1988]

5.5 Gas plasma displays

A **gas plasma display** is a type of flat-panel display that works by placing neon gas between one plate coated with vertical conductive print and another plate coated with horizontal conductive print to form a grid. A point of light (pixel) is created at the intersection of a horizontal and vertical line that has been charged with an electric current. A major advantage of gas plasma displays is the availability of very bright, high-resolution displays, some of which can be viewed in direct sunlight. Other advantages are uniformity, high resolution, large size, long life, ruggedness, excellent viewing angle, and the absence of flicker. Some disadvantages are high voltage and power requirements, complex drive circuits, low luminous efficiency, relatively large pixel size, and limited color capability.

5.6 Electroluminescent displays

Electroluminescent displays (ELD) may be used where display visibility from multiple viewer positions, high display uniformity, high MTBF, high resolution, low display volume, low heat dissipation, and low power consumption are more important than display of multicolored objects, high brightness images, or sunlight readability. They are also lightweight, and provide display flexibility, therefore, they may be used instead of mechanical instruments. They may also be used where sudden lamp failure could result in catastrophic consequences. [Source: MIL-STD-1472F, 1999]

- **5.6.1 Alphanumeric character and symbol size.** The height of alphanumeric characters and geometric or pictorial symbols shall subtend a visual angle of at least 15 min. [Source: MIL-STD-1472F, 1999]

  Definition. Visual angle is the angle subtended by objects measured in minutes of arc. It represents an apparent size of an object based on the relationship between an object's distance from the viewer and its size (perpendicular to the viewer's line of sight). For example, if an object that is size h is at a distance d from the retina, the visual angle subtended (x) is equal to arctan (h/d).

- **5.6.2 Evaluate through prototyping.** The use of ELDs should be evaluated through prototyping before being incorporated in a new system. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.6.3 Verify acceptability by users.** The acceptability of ELDs should be verified by the expected users. [Source: DOE HFDG ATCCS V2.0, 1992]

5.7 Large-screen displays

The selection or design of a large-screen display, especially a projection display, may be more complex than that of other workstation displays. The effects of ambient illumination, observer location, type of data to be displayed, visual acuity for symbol size and contrast, screen size, screen format, symbol luminance, and screen gain are all important factors.

5.7.1 General

▫ **5.7.1.1 When to use.** Large-screen displays should be used when

a. more than one user needs to refer to the same displayed information, but space or other constraints make the use of a single, common display preferable to many, individual displays.

b. one or more members of a team of users need to be able to move about, yet still need access to displayed information. [Source: MIL-STD-1472F, 1999]

▪ **5.7.1.2 When not to use.** Large-screen displays shall not be used if the spatial and environmental conditions do not allow all users to have appropriate visual access in terms of viewing distance, angle, and lack of interference from intervening objects, personnel, and ambient lighting. (If the display is optically projected, see Paragraph 5.9.2). [Source: MIL-STD-1472F, 1999]

▪ **5.7.1.3 Viewing distance.** The display shall be near enough that the most distant viewers can resolve the critical details presented, but not closer to any viewer than 1/2 the display width or height, whichever is greater. [Source: MIL-STD-1472F, 1999]

▪ **5.7.1.4 Locate so that view is not obscured.** A large-screen display shall be located so that its critical users do not have their view of it obscured by persons moving about in their normal traffic patterns. [Source: MIL-STD-1472F, 1999]

▪ **5.7.1.5 Ensure critical information cannot be deleted.** Control of large-screen group display systems shall ensure that critical information cannot be modified or deleted inadvertently or arbitrarily. [Source: MIL-STD-1472F, 1999]

- **5.7.1.6 Place display changes in control of users.** Changes in the group display shall be under the control of designated users who operate according to pre-established procedures, on command of a person in charge, or both. [Source: MIL-STD-1472F, 1999]

- **5.7.1.7 Separate display.** When a user must make changes that are of interest only to him or her, a separate, remote display shall be provided. [Source: MIL-STD-1472F, 1999]

5.7.2 Large-screen optical projection displays

- **5.7.2.1 When to use.** When ambient light can be properly controlled, optical projection displays shall be used for applications requiring group presentation, pictorial and spatial information, past history versus real-time presentation, synthetically generated pictures, simulation of the external world, or superimposition of data from more than one source. [Source: MIL-STD-1472F, 1999]

- **5.7.2.2 When to use rear projection.** Rear projection shall be used where physical obstructions to front projection result in poor visibility, or where work areas require high ambient illumination for other activities. [Source: MIL-STD-1472F, 1999]

- **5.7.2.3 Viewing distance and screen size.** The ratio of viewing distance to screen size (measured diagonally) shall be not more than 8:1 and not less than 2:1. The optimum ratio is 4:1; the preferred range is not less than 3:1 or more than 6:1. [Source: MIL-STD-1472F, 1999]

- **5.7.2.4 Viewing angle for groups.** The angle off center-line for viewing a large-screen display shall not be greater than 30° for groups. The optimum viewing angle is 0°; and the preferred limit is 20°. [Source: MIL-STD-1472F, 1999]

- **5.7.2.5 Viewing angle for individuals.** The angle off center-line for viewing a large-screen display shall not be greater than 10° for individuals. [Source: MIL-STD-1472F, 1999]

- **5.7.2.6 Image luminance with no film in the projector.** The image luminance with no film in the operating projector shall be not less than 17 cd/m^2 (5 fL), and not more than 70 cd/m^2 (20 fL). [Source: MIL-STD-1472F, 1999]

- **5.7.2.7 Luminance ratio across the screen.** The ratio of maximum to minimum luminance across the screen shall be not greater than 3:1. The optimum ratio of maximum to minimum luminance across the screen is 1:1, and the preferred limit is 1.5:1. [Source: MIL-STD-1472F, 1999]

- **5.7.2.8 Luminance ratio as a function of viewing location.** The ratio of maximum to minimum luminance as a function of viewing location shall be not greater than 4:1. The optimum ratio of maximum to minimum luminance as a function of viewing location is 1:1, and the preferred limit is 2:1. [Source: MIL-STD-1472F, 1999]

- **5.7.2.9 Luminance ratio of ambient light to brightest image.** The ratio of ambient light to the brightest part of an image shall not be greater than 1:10 for black and white images and 2:10 for images with gray scale or color, while maintaining optimum image luminance. The optimum ratio of ambient light to the brightest part of the image is 0:1, and the preferred range is 1:100 to 1:500. [Source: MIL-STD-1472F, 1999]

  Discussion. The optimum image luminance is 35 cd/m2 (10 fL), and the preferred range is from 27 to 48 cd/m2 (8 to 14 fL).

- **5.7.2.10 Luminance of screen center at the maximum viewing angle.** The luminance of the screen center at the maximum viewing angle shall be at least half its maximum luminance. [Source: MIL-STD-1472F, 1999]

- **5.7.2.11 Luminance ratio.** Under optimal ambient lighting conditions, the luminance ratio for optically projected displays should be 500:1. [Source: MIL-STD-1472F, 1999]

  Definition. Luminance ratio is the ratio of the luminance of an object to that of its surrounding field or background. [Source: MIL-STD-1472F, 1999]

- **5.7.2.12 Minimum luminance ratio for viewing charts and text.** The minimum luminance ratio for viewing charts, printed text, and other line work shall be 5:1. [Source: MIL-STD-1472F, 1999]

- **5.7.2.13 Minimum luminance ratio for images with limited range of detail.** The minimum luminance ratio for images that contain limited shadows and detail with a limited luminance range, such as animation or photographs, shall be 25:1. [Source: MIL-STD-1472F, 1999]

- **5.7.2.14 Minimum luminance ratio for images with a full range.** The minimum luminance ratio for images that contain a full range of colors, or grays in black-and-white photographs, shall be 100:1. [Source: MIL-STD-1472F, 1999]

- **5.7.2.15 Minimize distortion.** Distortion of the projected image shall be minimized by ensuring that the screen is as nearly as possible perpendicular to the light beam from the projector. [Source: MIL-STD-1472F, 1999]

5.8 Stereoscopic displays

Stereoscopic displays generate the sensation of three dimensions, height, width and depth within the human visual system. Three-dimensional display technology may be "stereoscopic," which requires that users wear special glasses that provide different images to the two eyes, or "auto stereoscopic," which does not require any special viewing aids. There are situations in which three-dimensional images can enhance user performance or increase the "naturalness" of the presentation of complex spatial data. Emerging technology in this area is likely to have the disadvantages of limiting the field of view, the number of viewers, and the nature of data that can be displayed. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.1 Use only if third dimension is meaningful.** Three-dimensional displays shall be used only if the third dimension conveys a real benefit to the user. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.2 Do not slow system performance.** The three-dimensional presentation of information should not slow information display, degrade image quality, or degrade other aspects of system performance. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.3 Avoid interocular crosstalk.** There should be no interocular crosstalk, that is, the left eye should not see the images intended for the right eye, and vice versa. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.4 Avoid saturated primary colors.** Secondary colors should be used in coding stereoscopic images; saturated primary colors should be avoided. [Source: DOE HFDG ATCCS V2.0, 1992]

  Discussion. Saturated primary colors can produce depth perceptions by themselves, which might interfere with the stereoscopically produced depth perceptions. **Primary colors** for light emitting displays such as CRTs are Red, Green, and Blue (RGB) and **secondary colors** are Cyan, Magenta, and Yellow (CMY). This is different than the primary colors for subtractive color mixture (like mixing paints), which are Yellow, Red, and Blue. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.5 Temporal modulation for dynamic displays.** If dynamic three-dimensional displays are used, the temporal modulation of stereopsis should be approximately 1 Hz to ensure the most accurate perception of stereo motion. [Source: DOE HFDG ATCCS V2.0, 1992]

  Definition. Stereopsis (also called stereoscopic vision) is three dimensional depth perception based on retinal disparity. As the eyes are slightly separated, each eye sees a slightly different image, when these images are fused in the brain. The result is a perception of depth or stereoscopic vision.

- **5.8.6 Separate depth-coded objects.** Depth-coded objects should be separated spatially to eliminate disparity averaging, crowding, and repulsion. [Source: DOE HFDG ATCCS V2.0, 1992]

  Definition. Disparity is the computation of depth values based on the lateral distance between corresponding picture elements in both image planes of stereo vision.

- **5.8.7 Scale images according to disparity.** Image size should be scaled according to the disparity of the image. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.8 Provide individual size scaling if critical to task performance.** If accurate size perception is critical to task performance, size scaling should be done for each observer. [Source: DOE HFDG ATCCS V2.0, 1992]

- **5.8.9 Co-modulate luminance and stereopsis.** Luminance should be co-modulated with stereopsis. [Source: DOE HFDG ATCCS V2.0, 1992]

  Discussion. Brightness is also a depth cue, with brighter objects being perceived as nearer. [Source: DOE HFDG ATCCS V2.0, 1992]

5.9 Printers

- **5.9.1 When to use.** Printers should be used if a visual record of data is necessary or desirable. [Source: MIL-STD-1472F, 1999]

- **5.9.2 Minimum contrast.** A minimum luminance contrast of 3.0 shall be provided between the printed material and the background on which it is printed. [Source: MIL-STD-1472F, 1999]

- **5.9.3 Provide illumination where needed.** If the printed matter would not be legible in the planned operational ambient illumination, the printer shall be provided with internal illumination. [Source: MIL-STD-1472F, 1999]

- **5.9.4 Provide a take up device.** A take-up device shall be provided for printed material. [Source: MIL-STD-1472F, 1999]

- **5.9.5 Allow for annotation.** If applicable, printers should be mounted so that the user can write or mark on printed matter easily while it is still in the printer. [Source: MIL-STD-1472F, 1999]

- **5.9.6 Ensure legibility.** The print shall be free from character line misregistration, character tilt, and smear. [Source: MIL-STD-1472F, 1999]

- **5.9.7 Ensure readability of printed tapes.** If information is printed on tapes, the information on tapes shall be printed in such a manner that it can be read as it is received from the machine without requiring the cutting and pasting of tape sections. [Source: MIL-STD-1472F, 1999]

- **5.9.8 Controls, feedback, and normal operations.** Printers shall conform to the rules in this standard with respect to

  a. the controls and displays used to start, stop, and adjust the machine and its critical operating elements,

  b. giving a positive indication of the remaining supply of materials such as paper and ink,

  c. operations performed by the user, such as inserting, adjusting, removing, replenishing, and replacing supplies and materials without requiring disassembly or special tools, and

  d. operations performed on site by a technician, such as adjustments and replacements not ordinarily performed by the user. [Source: MIL-STD-1472F, 1999]

- **5.9.9 Locate printed outputs within reach.** Printed output should be located within easy reach of those who need it. [Source: Vanderheiden & Vanderheiden, 1991]

  Discussion. Improperly located printouts may not be reachable to users in a wheelchair because of the location of the printer. [Source: Vanderheiden & Vanderheiden, 1991

5.10 Plotters and recorders

- **5.10.1 When to use.** Plotters or recorders should be used if a visual record of continuous graphic data is necessary or desirable. [Source: MIL-STD-1472F, 1999]

- **5.10.2 Do not obscure critical graphics while plotting or recording.** Critical graphics (those points, curves, or grids that must be observed while a recording is being made) shall not be obscured by the pen assembly, arm, or other hardware elements. [Source: MIL-STD-1472F, 1999]

- **5.10.3 Provide adequate contrast.** Luminance contrast between a plotted function and the background on which it is drawn shall be at least 1.0. [Source: MIL-STD-1472F, 1999]

- **5.10.4 Provide a take up device.** If necessary or desirable, a take-up device shall be provided for plotted material. [Source: MIL-STD-1472F, 1999]

- **5.10.5 Provide an overlay if needed.** If it is critical to the proper interpretation of graphic data as they are being generated, a graphic overlay shall be provided. [Source: MIL-STD-1472F, 1999]

- **5.10.6 Do not obscure data.** Graphic overlays shall not obscure or distort the data. [Source: MIL-STD-1472F, 1999]

- **5.10.7 Resist smudge and smear.** Output from plotters shall be resistant to smudging and smearing under operational use. [Source: MIL-STD-1472F, 1999]

- **5.10.8 Allow annotation.** If applicable, plotters and recorders shall be designed or mounted so that the user can write on or mark the paper while it is still in the plotter or recorder. [Source: MIL-STD-1472F, 1999]

- **5.10.9 Controls, feedback, and normal operations.** Plotters and recorders shall conform to the rules in this standard with respect to

  a. the controls and displays used to start, stop, and adjust the machine and its critical operating elements,

  b. giving a positive indication of the remaining supply of materials such as paper and ink,

  c. operations performed by the user, such as inserting, adjusting, removing, replenishing, and replacing supplies and materials without requiring disassembly or special tools, and

  d. operations performed on site by a technician, such as adjustments and replacements not ordinarily performed by the user. [Source: MIL-STD-1472F, 1999]

5.11 Accommodating people with disabilities

Accessibility in design extends general design principles to cover those individuals who are faced with either temporary or permanent limitations in some dimension of human ability (sight, hearing, physical mobility, etc.). Although these rules are meant to make systems more accessible and thus make systems available to an increased number of users, it is not possible to design everything for use by everyone. However, there are often adaptations that can significantly increase system accessibility and usefulness. The goal of this section is to make systems more accessible and thus maximize the number of potential users.

- **5.11.1 Maximize the number of people who can see output.** Visual displays intended to be accessible should be designed to maximize the number of people who can clearly see the presented output. [Source: Vanderheiden & Vanderheiden, 1991]

  Discussion. For instance, users with decreased visual abilities may have difficulty seeing small output or complex fonts and graphics. Other users may have difficulty seeing objects if there is insufficient contrast between the object and the background or may be especially sensitive to glare. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.11.2 Ensure that visual outputs are not missed.** Equipment intended to be accessible should be designed to minimize the number of people who will miss important information if they cannot see. [Source: Vanderheiden & Vanderheiden, 1991]

  Discussion. Visual output, for example, information presented on screens, paper printouts, warning lights, and dials, may not be seen at all by some users. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.11.3 Provide connection points for alternative output devices.** Computers and computer systems should provide a point to which an alternative output device can be connected. [Source: Scadden & Vanderheiden, 1988]

  Discussion. The connection point might be a standard serial or parallel port. Alternative output devices include speech synthesizers and Braille display devices. [Source: Scadden & Vanderheiden, 1988]

- **5.11.4 Provide speech output compatibility.** Computers and computer systems should provide a built-in speech output capability or provide a point to which a speech synthesizer can be connected. [Source: Scadden & Vanderheiden, 1988]

- **5.11.5 Facilitate the manipulation of printouts.** The manipulation of printouts should be facilitated by providing reaching and grasping devices such as reachers, artificial hands or hooks, and mouthsticks with clasps attached if the printouts are not within easy reach of the user. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.11.6 Provide redundant auditory output.** Redundant auditory output should be provided in addition to a visual display if the visual display cannot be made physically accessible to a person in a wheelchair. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.11.7 Attach larger displays or accommodating assistive devices.** If a visual display is not sufficient for users with difficulty seeing small output, a means should be provided of either attaching larger-image displays or utilizing other special assistive devices, such as an electronic magnifier, a voice synthesizer or a braille printer. [Source: Vanderheiden & Vanderheiden, 1991]

- **5.11.8 Provide redundant visual information.** A system should provide warnings, cues, and all other critical visual information redundantly in audible or tactile form if it is intended for use by a visually impaired person or a user who may have their attention focused elsewhere. [Source: Vanderheiden & Vanderheiden, 1991]

Glossary

Cathode Ray Tube (CRT) - A vacuum tube of a television or computer monitor in which the inner surface is coated with phosphors which glow and produce light when hit by an electron beam. CRT is often used as a generic term for a computer monitor.

Central visual field - Central visual field (sometimes referred to as the focal area) is the central 30° of the visual field. This is the area that people use to look at objects in the world, moving their eyes as needed to bring images of the object on to the fovea, which is the area of highest acuity. When an object is outside of the focal area, a person will usually turn their head rather than simply move their eyes.

Color fringes - Are the pixels along the border of an object that contain a combination of the selection and background colors.

Contrast - The range between the lightest tones and the darkest tones. The lower the number value, the more closely the shades will resemble each other. The higher the number, the more the shades will stand out from each other.

Contrast ratio - The luminance of the foreground divided by the luminance of the background. It indicates how much brighter a pure white output would be than a pure black output. The greater the contrast, the sharper the image will be. Also called luminance ratio.

CRT - See Cathode Ray Tube

Diffuse glare - A type of glare caused by the general ambient luminance, which effectively reduces the display contrast without producing significant specular reflection.

Disparity - The computation of depth values based on the lateral distance between corresponding picture elements in both image planes of stereovision.

ELD - See electroluminescent displays.

Electroluminescent displays (ELD) - A flat-panel display, the type typically used for laptop computers, that works by placing a thin phosphorescent film between one plate coated with vertical wires and another plate with horizontal wires, to form a grid. When an electrical current passes through a horizontal and a vertical wire, the phosphorescent film at this intersection glows, creating a point of light (pixel).

Flicker - The appearance of flashing that occurs in a computer display when the display is not refreshed frequently enough causing the phosphor to begin to decay prior to being refreshed.

Focal vision - The central 30° of the visual field. It is the area that people use to look at objects in the world, moving their eyes as needed to bring images of the object on to the fovea, which is the area of highest acuity.

Foot lamberts - Is a measure that has been corrected for the visual system's differential sensitivity to different wavelengths, giving an approximation to perceived brightness.

Fovea - The small central region of the retina that exhibits the greatest sensitivity to detail and color.

Gas plasma displays - Is a type of flat-panel display that works by placing neon gas between one plate coated with vertical conductive print and another plate coated with horizontal conductive print to form a grid. A point of light (pixel) is created at the intersection of a horizontal and vertical line that has been charged with an electric current.

Interlaced - A display that produces a video image by displaying alternate scan lines.

Interocular crosstalk - When the left eye can see the images intended for the right eye, and vice versa.

Jitter - A departure from geometric stability, which occurs when pixels in displayed objects move instead of remaining in a fixed position.

LCD - See liquid crystal display.

Legibility - The extent to which the user can decipher or read alphanumeric characters or text.

Liquid crystal display (LCD) - Is a flat-panel display that works by suspending liquid crystals between two transparent sheets of polarizing material. An electric current passes through the liquid causing the crystals to act like a shutter, either permitting light to pass through or blocking the light so that it cannot pass through.

Luminance - Is the physical measure of the amount of light emitted by or reflected in a given direction from the display. Luminance is expressed in candela per meter squared or foot lamberts.

Luminance ratio - The luminance of the foreground divided by the luminance of the background. It indicates how much brighter a pure white output would be than a pure black output. The greater the contrast, the sharper the image will be. It is also called contrast ratio.

Motion artifacts - The after images made up of the previously drawn object that have not yet decayed enough to disappear that one sees that appear to follow a moving display object. They often look like the tail of a comet following the object in motion.

Non interlaced - A display that produces a video image by displaying all lines in a frame in one pass from top to bottom before the next frame appears.

Phosphor - A luminescent substance, used to coat the inside of a CRT, which emits visible light when illuminated by electrons within an evacuated glass tube.

Polarity - The relationship between the brightness of the background and an image. A bright image on a dark background is negative polarity and a dark image on a bright background is positive polarity.

Primary colors – Primary colors for displays are Red, Green, and Blue (RGB) for light emitting displays such as CRTs. This is different than the primary colors for subtractive color mixture (like mixing paints), which are Yellow, Red and Blue.

Refresh rate - The rate (in cycles per second or Hz) at which the displayed contents of a computer screen are regenerated.

Resolution - The number of pixel elements per square inch.

Secondary colors – Secondary colors are Cyan, Magenta, and Yellow (CMY) for light emitting displays such as CRTs.

Specular glare - The appearance of unwanted images (reflections) on the display surface.

Stereopsis - (also called stereoscopic vision) Three dimensional depth perception based on retinal disparity. As the eyes are slightly separated, each eye sees a slightly different image, when these images are fused in the brain. The result is a perception of depth or stereoscopic vision.

Stereoscopic display - A method used to generate the sensation of three dimensions within the human visual system. Three-dimensional display technology may be "stereoscopic," which requires that users wear special glasses that provide different images to the two eyes, or "auto stereoscopic," which does not require any special viewing aids.

Stereoscopic vision - See Stereopsis.

Stroke width - The thickness of the lines used to make up the number or letter.

Viewing angle - The angle off the center line from which a displayed will be viewed

Visual angle - The angle subtended by objects measured in minutes of arc. It represents an apparent size of an object based on the relationship between an object's distance from the viewer and its size (perpendicular to the viewer's line of sight). For example, if an object that is size $\boldsymbol{h}$ is at a distance $\boldsymbol{d}$ from the retina the visual angle subtended, $\boldsymbol{x}$, is: $\boldsymbol{x}$ = arctan ($\boldsymbol{h}$/$\boldsymbol{d}$).

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