Chapter 6. Guidelines for Specific Displays

In this chapter are presented guidelines specific to each of the displays selected for the handbook. General guidelines applicable to all the electronic displays in the handbook are in chapter 5.

Analog Indicators

158. WHEN TO USE:

Analog indicators should be used in preference to digital readouts when the data displayed are of qualitative as well as quantitative value (i.e., when trends, direction of movement, and more-than/less-than relationships are of value as well as the specific numeric value), or of qualitative value only. Analog indicators should not be used when the primary purpose is readout of precise quantitative information.[14]

159. PREFERRED TYPE:

The preferred type of analog indicator for most applications has a moving pointer and a fixed scale. (The scale may be circular, curved [arc], horizontal-straight, or vertical-straight.) With a moving pointer, fixed scale indicator, both the scale progression and control movement are compatible with user expectancies. Avoid a fixed pointer, moving scale indicator.[14] (See guideline 40.)

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

160. SCALE GRADUATION TYPE:

Scales should be graduated linearly even if the function being controlled is nonlinear. If the nonlinearity of the function causes too much scale compression, making readout or adjustment difficult, another type of device such as a moving-tape indicator would be preferred over use of a nonlinear scale. Logarithmic scales should be avoided unless needed to display a large range of values.[14,48]

163. COLOR OF MARKINGS:

Instrument faces for use when night or dark adaptation is not critical are more easily seen if the markings are black on a light colored face. Even though the instrument may have to be illuminated at night (e.g., an automobile speedometer), the lighter background can still be dimly lit and provide a more readable display.[10]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

164. LUMINANCE CONTRAST:

A luminance contrast of at least 0.75 should be provided between the scale face and the markings and pointer. (Luminance contrast, C, is:

$C \approx \frac{L_1 - L_2}{L_2}$**, where L_1 is the higher luminance and L_2 is the lower luminance.)[14]**

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

165. CHARACTER HEIGHTS FOR FIXED SCALE INDICATORS:

On a fixed scale indicator, the heights of numbers, control and switch markings, and emergency instructions should be as follows:

a. **For low luminance (0.1 to 3.4 cd/m² [0.03 to 1 fl]):**

$$\text{height} = \frac{(\text{viewing distance})(0.38)}{71} \text{ to } \frac{(\text{viewing distance})(0.76)}{71}, \text{ where}$$

height and viewing distance are in centimeters.

b. **For high luminance (>3.4 cd/m² [1 fl]:**

$$\text{height} = \frac{(\text{viewing distance})(0.25)}{71} \text{ to } \frac{(\text{viewing distance})(0.51)}{71}, \text{ where}$$

height and viewing distance are in centimeters. (Based on reference 25.)

Comment: Approximately 3 cd/m2 (0.9 fl) marks a break point between scotopic vision (low-light, night vision) and photopic vision. Visual acuity and color discrimination are reduced in scotopic conditions, requiring larger characters.[41]

This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

166. STROKE WIDTH OF NUMBERS:

The stroke width of numbers should be from one-sixth to one-eighth of the number height.[25]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.

- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

167. WIDTH OF NUMBERS:

The width of all numbers should be three-fifths of the height, except for the 4, which should be one stroke width wider than the others, and the 1, which should be one stroke width wide.[25]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

168. SPECIFICATIONS FOR GRADUATION MARKS:

Graduation marks should conform to the specifications shown in table 24. (Based on references 14,48.)

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

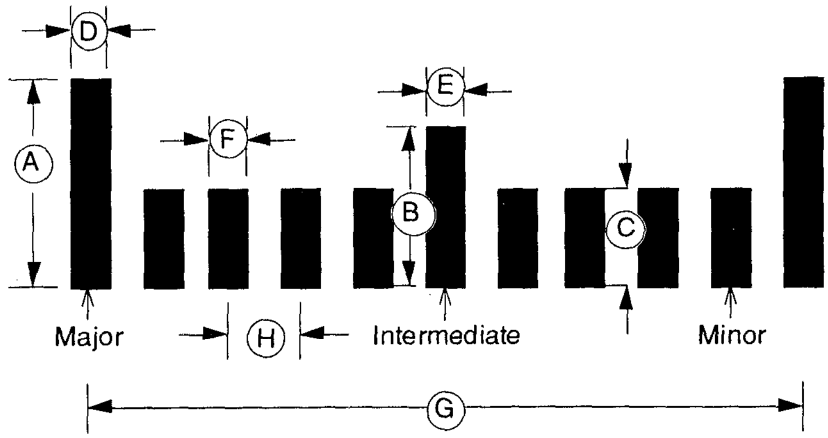


Figure 23. Reference figure for graduation mark specifications.

Table 24. Specifications for graduation marks. (See figure 23 for reference letters.)

	Viewing Distance	
	≤ 45.7 cm (1.5 ft)	> 45.7 cm (1.5 ft)
Graduation Mark Height Major (A)	.56 cm (.22 in)	viewing distance/91.3, where height and viewing distance are in centi-meters
Intermediate (B)	.41 cm (.16 in)	viewing distance/l28.5, where height and viewing distance are in centimeters.
Minor (C)	.23 cm (.09 in)	viewing distance/212.0, where height and viewing distance are in centimeters
Graduation Mark Width Major (D)	(.00125) (viewing distance), where width and viewing distance are in centimeters.	(.00125) (viewing distance), where width and viewing distance are in centimeters.
Intermediate (E)	(.00107) (viewing distance), where width and viewing distance are in centimeters.	(00107) (viewing distance), where width and viewing distance are in centimeters.
Minor (F)	(.0009) (viewing distance), where width and viewing distance are in centimeters.	(.0009) (viewing distance), where width and viewing distance are in centimeters.
Separation Between Midpoints Between major marks (G)	(.025) (viewing distance), where separation and viewing distance are in centimeters.	(.025) (viewing distance), where separation and viewing distance are in centimeters.
Between major and minor marks; between intermediate and minor marks; between two minor marks (H)	(.0025) (viewing distance), where separation and viewing distance are in centimeters.	(.0025) (viewing distance), where separation and viewing distance are in centimeters.

169. GENERAL GUIDELINES FOR SCALE MARKINGS:

Scale markings should conform to the following:

a. Graduation marks should be limited in number to the accuracy required.

b. No more than three sizes of graduation marks should be used on any scale.

c. Major, intermediate, and minor graduation marks should be used if there are five or more graduations between numbers.

d. Major and minor graduation marks should be used if there are up to four graduations between numbers.

e. The number of graduation marks between numbered marks should not exceed nine.

f. Scale graduations should be in increments of one, two, or five, or decimal multiples thereof.

g. Display scales should start at zero, except where this would be inappropriate for the function involved.[14,29,48]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

170. ORIENTATION OF NUMBERS:

On a fixed scale, numbers should be vertically oriented.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

171. DIRECTION OF NUMBERS INCREASE:

Numbered scales should increase clockwise, from left to right, or from bottom to top, depending on the scale layout (circular or arc, horizontal-straight, or vertical-straight, respectively).(14)

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

172. TYPE OF NUMBER FOR GRADUATION MARKS:

Except for measurements that are normally expressed in decimal fractions, whole numbers should be used for major graduation marks. Intermediate graduation marks should ordinarily not be numbered.(14)

Comment: It is assumed that minor graduation marks should also not ordinarily be numbered.

This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

173. GRADUATION MARKS AT SCALE START AND END:

Scales should start and end on major graduation marks, even if this puts either or both ends beyond the usable range of the scale. For example, if the maximum speed that can be read on a speedometer is 82 mi/h, the scale should go to at least 85 mi/h, where there could be a major graduation mark.(14)

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

174. INTERPOLATION:

Ordinarily, scales should be designed so that interpolation between graduation marks is not necessary; but when space is limited, it is better to require interpolated readings than to clutter the dial with crowded graduation marks.[25]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

175. POINTER SHAPE:

For best legibility, indicators with scales should have pointers that are relatively wide at the pivot, tapering gradually to a fine tip, arrowhead, or teardrop that is the same width as the smallest graduation mark (see figure 24 for preferred shapes). If a pointer has a tail on it, the observer can judge slight movements of the pointer better than if the pointer does not have a tai1.[14,48]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.

- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

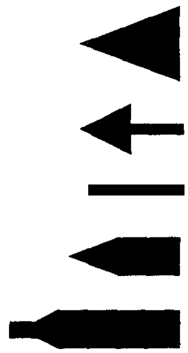


Figure 24. Preferred pointer tip shapes.

176. POINTER LENGTH:

Pointers should meet, but not overlap, the shortest scale graduation mark.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

177. POSITION OF ZERO ON SCALES WITH POSITIVE AND NEGATIVE NUMBERS:

When positive and negative values around zero are being displayed:

a. **On circular and arc indicators, locate the zero at 9 o'clock or 12 o'clock.**

b. **On horizontal-straight indicators, locate the zero at 12 o'clock.**

c. **On vertical-straight indicators, locate the zero at 9 o'clock.** (Based on references 14,24.)

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

178. POINTER PIVOT LOCATION:

Pointers should be pivoted at the right for vertical scales, and at the bottom for horizontal scales.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

179. POINTER MOUNTING:

The pointer should be mounted as close as possible to the face of the dial to minimize parallax.[14]

180. POINTER COLOR:

Pointer color from the tip to the center of the dial should be the same as the color of the graduation marks. The tail of the pointer should be the same color as the dial face unless the tail is used as an indicator itself or unless the pointer is used for horizontal alignment.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.

- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

181. METHODS FOR IMPROVING DUAL POINTER VISIBILITY AND DISCRIMINABILITY:

Except for clocks or watches (which often have three hands), not more than two coaxial pointers should be used on a single-dial indicator. Methods for improving the visibility and discriminability of dual pointers include:

a. The two pointers should be different colors.

b. The tails on the two pointers should be different lengths.

c. Each of the pointer tips should be close to the graduation marks.[10,14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

182. POINTER TAIL LENGTH:

The tail on a pointer should not be more than one-third the length of the pointing segment.[10]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

183. DOUBLE-ENDED POINTERS:

With reciprocal (double-ended) pointers, it should be made easy to distinguish the end that indicates the reading.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

184. USE IN MAKING SETTINGS:

If the indicator is used for making settings, such as tuning a particular channel, it is usually desirable to cover the unused portion of the dial face. The open window should be large enough to show at least one numbered graduation on each side of any setting.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

185. ZONE MARKINGS:

Zone markings should be used to show the operational implications of various readings such as the operating range, upper and/or lower limits, and danger range. In addition:

a. **Zone markings should be conspicuous and distinctly different for different zones.**

b. **Zone markings should not interfere with the reading of quantitative markings.**

c. **If color is used for coding, the following conventions should be followed:**

- **Red should be used to indicate an alarm condition, alerting the user that the system or a portion of the system is inoperative.**
- **Yellow should be used to indicate a caution condition, advising the user that a condition exists that is marginal.**
- **Green should be used to indicate a normal, in-tolerance condition.**
- **White should be used as a neutral color, indicating a system condition that does not have right or wrong implications. (See** references 14, 41, 48, 49.)

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

186. WHEN AN OPERATING CONDITION ALWAYS FALLS WITHIN A LIMITED RANGE OF THE SCALE:

When a certain operating condition (such as normal operating temperature) always falls within a limited range of the total scale, that range should be made readily identifiable by means of pattern, color, or shape coding applied to the face of the instrument.[14]

Comment: This guideline also applies to analog indicators represented *on* the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

187. WHEN LESS THAN A FULL ROTATION OF THE POINTER COVERS THE SCALE:

When less than a full rotation of the pointer is required to cover the entire scale, scale end-points should be indicated by a break in the scale. The break should be at least one numbered interval in length, and should be oriented at 6 o'clock.[48]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

188. MULTIREVOLUTION POINTER MOVEMENT:

When multirevolution pointer movement is involved (e.g., on a clock), zero should be at 12 o'clock and there should be no break between scale ends.[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

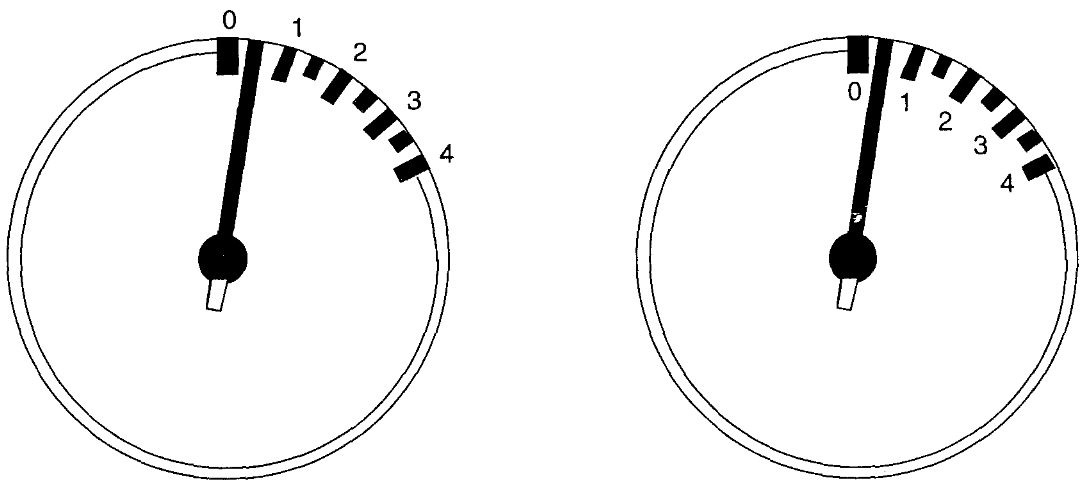
- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

189. LOCATION OF NUMBERS:

Numbers should be located on the side of the graduation marks opposite the pointer. Exception 1: If readout accuracy is not critical, such as when the gross relationship between the pointer and the number is all that is required, the numbers may be located inside the graduation marks (see figure 25). Exception 2: If space is limited (for curved or arc scales), numbers may be placed inside the graduation marks to avoid undue constriction of the scale (see figure 25).[14]

Comment: This guideline also applies to analog indicators represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.



(a) Normal number location (b) Acceptable number location

Figure 25. Normal number location and acceptable number location when readout accuracy is not critical or space is limited.

Cathode Ray Tube (CRT) Displays

DEFINITION:

A cathode ray tube (CRT) display produces light by bombarding a phosphor-covered face plate with one or more electron beams. On a raster CRT display, the electron beam sweeps across the entire display on each refresh cycle, illuminating appropriate points as it comes to them. On a stroke writing CRT display, the electron beam is directed to only those points on the display that are to be illuminated. Some CRT's may use both raster and stroke writing, although raster CRT's are by far the most common commercialized form of the CRT. Cathode ray tube image color is controlled by the selection of phosphors, and a variety of

phosphor colors is available for monochrome as well as full-color CRT's in both stroke and raster formats.

These guidelines apply to both raster and stroke-written CRT's, but do not apply to developmental flat-panel CRT's such as field-emitter array displays.

190. WHEN TO USE:

A CRT should be used for text and graphics applications where display visibility from multiple viewer positions, high display brightness, high display mean time between failures, high display resolution, and a large range of display colors are more important than the display power consumption and physical display volume. Stroke CRT's should be selected over raster CRT's when high symbol luminance is more important than the need to display filled or shaded objects and backgrounds.

191. USE OF GENERAL DISPLAY GUIDELINES:

The design and use of CRT displays should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

192. IMAGE QUALITY:

The image on a CRT display should appear to be stable and free of geometric distortion.[39]

Comment: Sources of CRT instability include flicker and jitter. Flicker is associated with the following display attributes:

- Low refresh rate.
- Short phosphor persistence.
- High luminance.
- Wide field of view.

Jitter is independent of these attributes and is an artifact of imperfect control of the electron beam.[41]

193. REFRESH RATE:

CRT's should use a noninterlaced refresh rate of at least 70 **Hz.** (Based on reference 40.)

Comment: *Noninterlaced* means that the entire picture is drawn each time the electron beam moves across the display. The guideline assumes that display luminance will at times exceed 100 cd/m2 (29.2 fl). Display flicker will become more noticeable as display luminance increases.

194. LINES PER SYMBOL HEIGHT:

CRT's should use a minimum of 16 lines per symbol height. (Based on reference 50.)

195. MISCONVERGENCE:

In no case should misconvergence cause a line, symbol, or character color or form to be ambiguous. (Based on reference 51.)

Comment: The perceptual consequence of misconvergence is the apparent separation of color primaries that should ordinarily overlap to form a single pixel. Misconverged CRT's present white lines as partially overlapped red, green, and blue lines.[14]

Counters

196. WHEN TO USE:

Counters should be used for presenting large ranges of quantitative data when users must make quick, precise readings but need not keep track of continuous trends.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

197. HOW NUMBERS SHOULD CHANGE:

The numbers on a counter should change by snap action rather than continuously. Exception: When numbers on right-hand drums do not need to be read accurately, they may move in a continuous motion. In such cases, at least two of the numbers should be visible (see figure 26[d]).[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.

- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

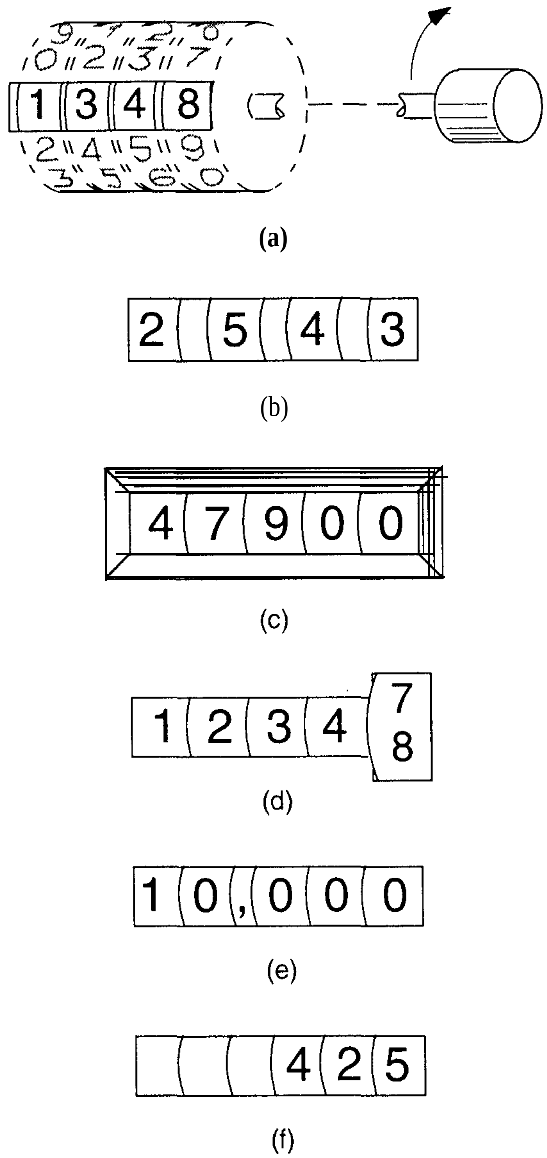


Figure 26. Counter design features.

198. FINISH ON DRUM SURFACE AND SURROUND:

The surface of the drums and surrounding areas on a counter should have a matte finish to minimize glare.[48]

199. RATE OF NUMBERS CHANGE:

If the user must read numbers consecutively, numbers on a counter should not change faster than twice per second. Odometers and hour meters are exceptions to this rule.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

200. RESETTING COUNTERS USED TO INDICATE SEQUENCING OF EQUIPMENT:

Counters used to indicate sequencing of equipment should be designed so they reset automatically when the sequence is completed. Manual resetting should also be provided, and it can be accomplished in one of two ways:

a. With a knob, which should rotate clockwise to reset the counter.

b. With a pushbutton. Actuating force required should not exceed 16.7 N (3.8 **lbf).[14]**

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

201. LAYOUT OF NUMBERS:

Numbers on counters should read horizontally, from left to right, rather than vertically.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

202. SPACING BETWEEN NUMBER DRUMS:

Large horizontal spacing between number drums on a counter should be avoided. Normal spacing should be between one-fourth and one-half the numeral width.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

203. COUNTER FRAME COLOR:

When only a small area of the counter drum is visible around each number, the counter frame should be the same color as the drum.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

204. SPECIFICATIONS:

Counters should conform to the specifications shown in table 25.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

Table 25. Character sizes and separations for counters.

Viewing Distance	Number Height[1]	Number Width	Number Stroke Width	Minimum Separation Between Numbers
NORMAL ILLUMINATION. ABOVE 3.4 CD/M^2 (1 FL)				
710 mm (28 in)	3.8 mm (.15 in)	3.8 mm (.15 in)	.94 mm (.04 in)	.64 mm (.03 in)
910 mm (35 in)	4.8 mm (.19 in)	4.8 mm (.19 in)	1.2 mm (.05 in)	.81 mm (.03 in)
1525 mm (59 in)	7.9 mm (.31 in)	7.9 mm (.31 in)	1.3 mm (.05 in)	1.3 mm (.05 in)
LOW ILLUMINATION: .1 TO 3.4 CD/M^2 (.03 TO 1 FL)				
710 mm (28 in)	5.6 mm (.22 in)	5.6 mm (.22 in)	.94 mm (.04 in)	.94 mm (.04 in)
910 mm (35 in)	7.1 mm (.28 in)	7.1 mm (.28 in)	1.2 mm (.05 in)	1.2 mm (.05 in)
1525 mm (59 in)	13.0 mm (.51 in)	13.0 mm (.51 in)	2.1 mm (.08 in)	2.1 mm (.08 in)

[1] For viewing distances less than 710 mm (28 in), numbers should be at least 3 mm (0.12 in) high.

205. COUNTER DRUMS NUMBERING:

Counter drums should be numbered so that a clockwise rotation of the drums and/or reset control produces increasing numerical values (see figure 26[a]).[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.

- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

206. NUMBER HEIGHT-TO-WIDTH RATIO:

The number height-to-width ratio on a counter should be within the range of 5:3 to 1:1, with 1:1 being preferred except for the number 1.[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

207. BETWEEN-NUMBERS SPACING:

Spacing between adjacent numerals on a counter should not exceed one-fourth the width of wide numerals or one-half the width of narrow numerals when several numbers are to be read as a total value (see figure 26[b]).[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

208. MOUNTING OF COUNTER DRUMS:

Counter drums should be mounted as close to the front panel surface as practical and the edges of the viewing window should be beveled to provide at least a 45° off-angle view of the display (see figure 26[c]).[14]

209. DECIMAL POINTS AND COMMAS:

Decimal points on a counter may be inserted within the viewing window, or placed on the panel when the position remains constant. Commas should not be used unless more than four numbers appear in the window (see figure 26[e]).[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

210. NUMBERS WITH MORE THAN FIVE DIGITS:

Numbers on a counter having more than five digits should have groups of three digits separated by either blank space equivalent to one-half the width of one character or by commas. Grouping should start from the right.[49]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

211. LEADING ZEROS:

If left-hand numbers on a counter are seldom used, a blanking system should be provided rather than presenting several leading zeros. The blanking device should expose left-hand drums only when a nonzero number is displayed (see figure 26[f]).[14]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

212. CONTRAST BETWEEN CHARACTERS AND IMMEDIATE BACKGROUND:

Contrast between characters and the immediate background should always be maximized. Black on white provides maximum visibility under normal illumination conditions.[29]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

213. NUMBER OF DIGITS IN AN OPEN WINDOW:

No more than one digit should appear in an open window at one time. Exception: When numbers on right-hand drums do not need to be read accurately, they may move in a continuous motion. In such cases, at least two of the numbers should be visible (see figure 26[d]).[14,29]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

214. DIGITAL DISPLAY ILLUMINATION:

Digital displays should be self-illuminated when used in an area in which ambient illumination will provide display luminance below 3.5 **cd/m^2 (1 fl).**[49]

Comment: This guideline also applies to counters represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

Electroluminescent (EL) Displays

DEFINITION:

An electroluminescent (EL) display produces light through the application of an electric field to a polycrystalline phosphor. Readily available EL displays are monochromatic, with a typical color being yellow on a black background; EL displays with limited color capability are also available. EL displays are most commonly used as matrix-addressed graphics displays and backlights for liquid crystal displays; the latter use is not covered by this handbook.

215. WHEN TO USE:

A matrix-addressed EL display should be used for graphics applications where display visibility from multiple viewer positions, high display uniformity, high display resolution, low physical display volume, and low power consumption are more important than the display of high-brightness images, the luminance half-life of the display, or sunlight readability of the display.

216. USE OF GENERAL DISPLAYS GUIDELINES:

The design and use of EL displays should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

217. MATRIX ANOMALIES:

A matrix-addressed EL display should not display any matrix anomalies that cause distraction or erroneous interpretation. (Based on reference 47.)

Comment: Since the display is an array of discrete elements, symbols will have spatial and color anomalies. These phenomena are different in static and dynamic symbols; matrix anomalies are especially visible in dynamic images. The extent of the anomaly is dependent on many factors, including the size, shape, and arrangement of the elements; construction of the symbol; rate, direction, and increment of motion; and luminance control of the elements.[47]

218. PIXEL SHAPE:

A monochrome matrix-addressed EL display should use square rather than rectangular pixels. (Based on reference 52.)

219. FAILURE RATES FOR PIXELS AND LINES:

A matrix-addressed EL display should have fewer than 1 percent of pixels failed "on," fewer than 2 percent failed pixels total, and no failed lines. (Based on references 53,54.)

Comment: Not all pixels in a matrix-addressed display perform **as** designed. For monochrome displays, failures are either "on" (matching the symbol luminance) or "off" (matching the background luminance). Failures that are on have a more significant impact on performance measures such as reading time, search speed, and errors than do failures that are off. When all the pixels in a single row or column fail, a failed "line" is said to occur. While failed lines typically have a less significant effect on user performance, they are much more visible and distracting to users. Even a single line failure can often be highly visible.

When individual color elements and lines can fail in a full-color, matrix-addressable display, attention should be given to resulting errors in color perception (e.g., a normally white line could appear yellow if the blue component of the line were to fail).

Head-Up Displays (HUD's)

DEFINITION:

A head-up display (HUD) includes an image source, projection optics, and a combiner. The image is generated on the image source and then projected via collimation optics onto the combiner, where it is viewed as an image overlaid on the forward visual scene. The automotive HUD image source is typically monochromatic, either a vacuum fluorescent display or a stroke-written cathode ray tube. The automotive HUD combiner is typically the forward windshield of the vehicle.

220. WHEN TO USE:

A HUD should be used in either of two circumstances. First, if there is a need to present an electronic image conformal with (precisely overlaid on) the outside scene, HUD's are the most obvious way to address, this need. Second, a properly placed and collimated HUD may be used to decrease visual transitions from head down displays to the outside, forward scene. Information presented on a head-up display should be limited to critical data that the user is required to monitor while simultaneously performing some primary visual task.[13]

221. USE OF GENERAL DISPLAYS GUIDELINES:

The design and use of head-up displays should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

222. FACTORS TO CONSIDER IN SELECTING AN IMAGE SOURCE:

Selection of a HUD image source for automotive applications should consider output brightness, resolution limitations, packaging considerations, power dissipation, and the recurring costs associated with the display source and the drive electronics. (Based on reference 55.)

Comment: The display technology selected for most of the automotive HUD systems in use today is the vacuum fluorescent display. High brightness CRT's have not been used in automotive HUD's because of the high cost of stroke-writing electronics and because of the low display brightness inherent in raster CRT's. (Based on reference 55.)

223. HEAD MOTION BOX (EYE BOX) SIZE:

A HUD head motion box, or eye box, is a three-dimensional region in space surrounding the eye reference point in which the display can be viewed with at least one eye. This head motion box should be as large as possible to allow maximum head motion without losing the display. The minimum desired size of the head motion box, independent of the optical system technology, is as follows:

a. Width: 11.4 cm (4.5 in).

b. Height: 6.4 cm (2.5 in).

c. Depth: 15.2 cm (6.0 in). [55]

Comment: Head-up displays are typically designed to accommodate a single user from a single design eye reference point. The head motion box would have to be considerably larger to accommodate multiple viewers, which in turn would lead to unrealistic demands on the optical design of the HUD.

224. TRANSMISSION THROUGH THE WINDSHIELD:

If the automobile windshield is modified for use as a HUD combiner, the total transmission through the windshield must not fall below the Federal requirement of 70 percent. (Based on reference 55.)

Comment: To increase the display brightness and improve the contrast ratio, the windshield reflectivity can be increased by introducing a holographic element into the windshield or by adding a wavelength-selective conventional coating to the inner surface of the windshield.[56]

225. IMAGE IMPACT ON NORMAL VEHICLE OPERATION:

If the automobile HUD image is not conformal with (precisely overlaid on) the outside scene, it should be positioned such that it does not interfere with the normal operation of the vehicle. (Based on reference 55.)

226. COMBINING GLASS ASSEMBLY DESIGN:

The combining glass assembly should be designed so that the user will not be injured by contact with the combiner.[51]

Comment: The windshield is typically used as the combiner for automotive HUD applications. If a separate combiner is used, it must be designed and placed with consideration of uncontrolled body movements under positive and negative vehicle accelerations.

227. ANGULAR DISPLACEMENT OF REAL-WORLD OBJECTS:

The combining glass assembly should not cause the angular location of real-world objects, as they appear through the combining glass assembly, to deviate by more than 1.72 arcmin. (Based on reference 51.) **This translates to:**

> **displacement = viewing distance/1998.69, where displacement and viewing distance are in centimeters.**
>
> **Example: At a viewing distance of 10 m (32.8 ft), the allowed displacement is 1000 cm/1998.69 = .5 cm (.2 in).**

228. SALIENCE OF VISIBLE EDGES AROUND THE COMBINER:

Efforts should be made to minimize the salience of visible edges around a HUD combiner. (When the combiner is the windshield, this is not an issue. When the combiner is some other glass, it may be supported by some type of framework, and the edges of the framework are to be made as nearly invisible as possible.)[38]

Comment: Any kind of salient visual detail attracts convergence (and accommodation). Placing the HUD image adjacent to, e.g., a window post, may interfere with a driver's ability to visually accommodate to the image at the intended image distance.[38]

229. CHARACTER HEIGHTS:

The minimum heights for HUD alphanumeric and nonalphanumeric characters that need to be identified or distinguished from other characters are shown in table 26. The recommendation does not apply to pointers, scale markings, and the like. (Based on reference 38.)

Table 26. Minimum character sizes for head-up displays.

	For Alphanumeric Characters	For Nonalphanumeric Characters
Minimum size on the retina, arcmin	28	34
Minimum height, centimeters[a]	Focal distance/l 22. 78, where focal distance is in centimeters[b]	Focal distance/ 101.11, where focal distance is in centimeters[b]

[a] The formula for determining character height (h) upon which the table is based is as follows:

$$h = 2\left(\tan\left(\frac{\text{character size on the retina}}{2}\right)\right)(\text{focal distance})$$, where h and focal distance are in centimeters, and character size on the retina is in degrees.[41]

Retinal character size is used because it is independent of focal distance. Thus, one can tell whether a character that subtends 30 arcmin (its retinal size) can be read without knowing the focal distance, but one could not tell whether a 0.3-cm- (0.12-in-) high character could be read without knowing the focal distance.

Example of determining character height (in centimeters) using the formula shown in the table: For alphanumeric characters, what is the minimum character height needed at a focal distance of 101.6 cm (40 in)? Character height = 101.6/122.78 = 0.83 cm (0.33 in).

[b] In a collimated system, focal distance is the distance at which the image appears to be. It is analogous to viewing distance when looking at a real-world object.

230. RASTER LINES PER SYMBOL HEIGHT:

In head up raster displays, a 16-lines-per-symbol-height minimum should be used for labels and alphanumeric characters. For nonalphanumeric characters and all moving symbols, a 20-lines-per-symbol-height minimum should be used.[38]

231. STROKE WIDTH TO SYMBOL HEIGHT RATIO:

The minimum stroke width to symbol height ratio for a stroke-written HUD is between 1:5 and 1:8. (Based on reference 38.)

232. SYMBOL WIDTH:

The minimum HUD symbol width should be 75 percent of the symbol height.[38]

233. BETWEEN-CHARACTERS SPACING:

The minimum HUD between-characters spacing should be 50 percent of character height for grouped letters.[38]

234. BETWEEN-WORDS SPACING:

The minimum HUD between-words spacing should be 100 percent of character height.[38]

235. CHARACTER MATRIX SIZE:

The minimum HUD character matrix size is 7 by 9 (width by height). The preferred HUD character matrix size is 9 by 11.[38]

236. USE OF COLOR:

Color should not be used for HUD symbology. A monochromatic HUD with a narrow-band phosphor is preferred (P-43 phosphor is often chosen).[38]

Comment: Although color coding has been shown to be advantageous over shape coding in conventional display use, this advantage has not been demonstrated for HUD's. The continually changing background makes the perception of color more difficult, and chromatic (colored) symbols will be harder to discriminate (lack of chromatic contrast with the background) and will serve as a poor coding scheme (lack of color constancy) under certain environmental circumstances. Reference 54 failed to find a performance advantage for including color in HUD's. Perhaps more significantly, image source technology constraints limit the luminance of color displays and therefore make them less attractive for HUD applications.

237. SYMBOL LUMINANCE:

For daytime use, HUD symbol luminance for automotive applications should be a minimum of 3000 cd/m2 (876 fl). It should be significantly lower for nighttime use. (Based on reference 56.)

Comment: It is assumed that this requirement should be interpreted as a minimum luminance at the eye rather than at the display. Higher HUD symbol luminances may be required to meet HUD contrast requirements.

238. IMAGE (FOCUS) DISTANCE:

The image (focus) distance of the HUD should not be infinity, but rather the approximate distance of **the bumper of the vehicle.** (Based on reference 55.)

Comment: This is a compromise distance designed to eliminate driver confusion potentially originating from having a display distance greater than real-world obstacles (e.g., traffic). Drivers are already experienced at focusing from outside of the vehicle to inside to view conventional dashboard displays. Therefore, "focusing in" slightly to see the HUD display is a practical and natural action. A display image at the distance of the front bumper minimizes the focus change, yet still keeps the driver's attention outside. An image distance closer than 2.5 m (8.2 ft) may, however, lead to response time penalties for older drivers.(56)

239. VERGENCE ANGLE:

The vergence angle for a head-up display should be between 0.0° and 0.14°.(57) (Vergence angle is the angle between the lines of sight of the two eyes. For collimating displays such as HUD's, it is used to specify apparent image distance.)

Comment: Divergent viewing (vergence angles less than 0.0°) will lead to viewing discomfort and possibly double vision. A vergence angle of 0.0° corresponds to a HUD image distance of infinity. Vergence angle is given by:

$$\text{vergence angle} = 2 \arctan\left(0.5\left[\frac{\text{interocular separation}}{\text{focus distance}}\right]\right), \text{ where}$$

vergence angle is in degrees, and interocular separation and focus distance are in millimeters.

Example: For an interocular separation of 6.4 mm (0.25 in) and a focus distance of 2.6 m (8.5 ft), what is the vergence angle? First, convert the focus distance to millimeters: 2.6 m = 2600 mm. Then, vergence angle = 2 arctan (0.5 [6.4/2600]) = 0.14°.

240. FIELD OF VIEW:

An automotive HUD should have the following minimum fields of view with respect to the user's eye position:

- **a. 6° above the horizontal.**
- **b. 5° below the horizontal.**
- **c. 12° to the left of straight ahead.**
- **d. 11° to the right of straight ahead.** (Based on reference 56.)

Indicator Lights (Simple)

241. WHEN TO USE:

Indicator lights should be used to indicate system, equipment, and/or control condition. They should be used to display qualitative information when an immediate reaction by the user is needed, or to draw attention to an important system status.[14]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

242. USE OF A LIGHT-EMITTING DIODE (LED) AND GENERAL DISPLAYS GUIDELINES:

The design and use of LED's as simple indicator lights should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

243. STATE INDICATIONS:

Generally, an indicator light should be used to indicate equipment state rather than to control position or condition. In addition:

a. Equipment state should always be continually displayed.

b. Control actuation should be transiently displayed.

c. Control setting should be continuously displayed if it can be at variance with equipment state. An in-transit condition should remain ON until the system state is consistent with the control state (except for in-transit durations shorter than the user's response time).[14]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.

- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

244. USE UNDER VARIED AMBIENT ILLUMINATION:

When an indicator light is used under varied ambient illumination, a dimming control should be provided. It should be capable of providing multiple step or continuously variable illumination. Dimming to full OFF may be provided in noncritical operations, but not if inadvertent failure to turn on an indicator could lead to a critical user failure, i.e., failure to detect or perform a critical step in an operation.[13]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

245. BETWEEN-LIGHTS SPACING:

The spacing between adjacent edges of simple, round indicator light fixtures should be sufficient to permit unambiguous labeling and signal interpretation, and convenient bulb replacement.[13]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

246. LABELING LOCATION:

Indicator labeling should be provided close to the indicator, imparting the message intended by the light's illumination.[49]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

247. MEANING OF CHANGES IN LIGHT STATUS:

Changes in indicator light status should signify changes in functional status rather than the results of control actuation alone.[13]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

248. MEANING OF ABSENCE OR EXTINGUISHMENT OF A LIGHT:

The absence or extinguishment of an indicator light should not be used to denote a malfunction, no go, or out-of-tolerance condition; however, the absence of a power-ON signal should be acceptable to indicate a power-OFF condition for operational displays only (i.e., not for maintenance displays). The absence or extinguishment of an indicator light should not be used to indicate a ready or in-tolerance condition, unless the status- or caution-light filament and its associated circuitry can be easily tested by the user and user perception of such events is not time critical.[13]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

249. INFERRING SYSTEM OR EQUIPMENT STATUS:

System or equipment status should be inferred from the illumination of an indicator light, not by the absence of its illumination.[(49)]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

250. LOCATION OF AN INDICATOR ASSOCIATED WITH A CONTROL:

When an indicator is associated with a control, the indicator light should be so located as to be immediately and unambiguously associated with the control and visible to the user during control operation.[(14)]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

251. LOCATION OF A CRITICAL FUNCTION INDICATOR:

A critical function indicator (safety-related master warning light) should be located horizontally within ±15° of a line of sight straight ahead and vertically between the horizontal line of sight and 30° below it, except as indicated in guideline 250.[14]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

252. USE OF AN LED:

An LED may be used as a simple indicator light only if it is bright enough to be readable in the intended environment.[13]

253. LAMP REMOVAL AND REPLACEMENT:

Where possible, lamps should be removable and replaceable from the front of the display panel. The procedure for lamp removal and replacement should not require the use of tools and should be easily and rapidly accomplished.[13]

254. INDICATORS ON A CONTROL PANEL:

When indicator lights using incandescent bulbs are installed on a control panel, a master lamp-test control should be incorporated. When applicable, the design should allow testing of all control panels at one time. Panels containing three or fewer lights may be designed for individual press-to-test lamp testing. Circuitry should be designed to test the operation of the total indicator circuit. An LED indicator light with less than 100,000 h mean time between failures should require a lamp testing capability.[13,49]

255. PREVENTION OF INDICATOR LENS INTERCHANGING:

Provisions (design or procedural) should be made to prevent interchanging indicator lenses.[48]

256. LUMINANCE:

Luminance of the illuminated indicator should be at least 10 percent greater than that of the immediate mounting surface. Where glare should be reduced, the luminance should not exceed 300 percent of the surrounding luminance.[14]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

257. BRIGHTNESS OF A WARNING OR CAUTION SIGNAL:

When used as a warning or caution signal, an indicator light should be at least three times brighter than the other indicators on the panel.[49]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

258. FALSE INDICATIONS:

An indicator light should not appear to be illuminated when in fact it is off, or vice versa.[48]

259. INCANDESCENT LAMP COLOR CONVENTIONS:

Color of an incandescent lamp indicator light may be provided by a tinted cover glass or by a layer of colored material inside the cover. The color of the light should be clearly identifiable, and should conform to the following scheme:

a. **Red should be used to indicate an alarm condition, alerting the user that the system or a portion of the system is inoperative.**

b. **Flashing red should be used to indicate an emergency condition that requires immediate user action.**

c. **Yellow should be used to indicate a caution condition, advising the user that a condition exists that is marginal.**

d. **Green should be used to indicate a normal, in-tolerance condition.**

e. **White should be used as a neutral color, indicating a system condition that does not have right or wrong implications (e.g., alternative functions).**

f. **Blue may be used as an advisory color.** (Based on references 14, 43,48,49.)

Comment: The part of the guideline stating that the color of the light should be clearly identifiable and the color scheme in parts a through f of the guideline also apply to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

260. LIGHT-EMITTING DIODE COLOR CONVENTIONS:

Color coding for an LED used as an indicator light should conform to guideline 259. Note: Red LED's used in a matrix-addressed display should not be located in the proximity of indicator lights that are coded red.[13]

261. SIZE CODING:

Size coding of indicator lights should conform to the specifications in table 27.[14]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.

- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

Table 27. Size coding of indicator lights.[1]

Diameter and Type	Red	Yellow	Green	White
≤13 mm (.5 in) Steady Light	Malfunction, action stopped, failure, stop action	Delay, check, recheck	Go ahead, in tolerance, acceptable, ready	Functional or physical position, action in progress
≥25 mm (1 in) Steady Light	Master summation	Extreme caution (impending danger)	Master summation	–
≥25 mm (1 in) Flashing Light	Emergency condition (impending personnel or equipment disaster)	–	–	–

[1] Actual sizes may be less important than relative sizes, given at least equal luminances. (Based on reference 13.)

262. FLASHING:

The use of flashing lights should be minimized. Flashing lights should be used only when it is necessary to call the user's attention to some condition requiring immediate action. The flash rate should be 3 to 5 Hz with approximately equal on and off times (i.e., a 50 percent duty cycle). Flashing lights which could be simultaneously active should have synchronized flashes. If the indicator is energized and the flasher device fails, the light should illuminate and burn steadily.[(14)]

Comment: This guideline also applies to simple indicator lights represented on the following electronic displays that are included in this handbook:

- Cathode ray tube.
- Electroluminescent.
- Head-up display.
- Light-emitting diode: matrix addressed.
- Liquid crystal display: transflective, matrix addressed; and transmissive, matrix addressed.
- Vacuum fluorescent display: matrix addressed.

Light-Emitting Diode (LED) Displays

DEFINITION:

An LED produces light through electron injection in a solid state semiconductor. LED's are available in red, yellow, green, and blue, and graphics displays have been produced for avionic applications that incorporate large matrices of LED's. Common uses of LED's include:

a. Indicator lights.

b. Matrix-addressed graphics displays.

c. Segmented character displays (not addressed in this handbook).

263. WHEN TO USE:

Matrix-addressed LED's should be used for graphics applications when display visibility from multiple viewer positions, low physical display volume, and high display mean time between failures are more important than high resolution, high brightness, low power consumption, and sunlight visibility.

264. USE OF GENERAL DISPLAYS GUIDELINES:

The design and use of LED displays should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

265. MATRIX ANOMALIES:

Matrix-addressed LED's should not display any matrix anomalies that can cause distraction or erroneous interpretation. (Based on reference 45.)

Comment: Since the display is an array of discrete elements, symbols will have spatial and color anomalies. These phenomena are different in static and dynamic symbols; matrix anomalies are especially visible in dynamic images. The extent of the anomaly is dependent on many factors, including the size, shape, and arrangement of the elements; construction of the symbol; rate, direction, and increment of motion; and luminance control of the elements.[47]

266. PIXEL SHAPE:

Monochrome matrix-addressed LED's should use square rather than rectangular pixels. (Based on reference 52.)

267. FAILURE RATES FOR PIXELS AND LINES:

Matrix-addressed LED's should have fewer than 1 percent of pixels failed "on," fewer than 2 percent failed pixels total, and no failed lines. (Based on references 45,53.)

Comment: Not all pixels in a matrix-addressed display perform as designed. For monochrome displays, failures are either "on" (matching the symbol luminance) or "off" (matching the background luminance). Failures that are on have a more significant impact on performance measures such as reading time, search speed, and errors than do failures that are off. When all the pixels in a single row or column fail, a failed "line" is said to occur. While failed lines typically have a less significant effect on user performance, they are much more visible and distracting to users. Even a single line failure can often be highly visible.

When individual color elements and lines can fail in a full-color, matrix-addressable display, attention should be given to resulting errors in color perception (e.g., a normally white line could appear yellow if the blue component of the line were to fail).

Liquid Crystal Displays (LCD's)

DEFINITION:

Unlike the other electronic displays addressed in this handbook, a liquid crystal does not produce light, but rather acts as a light valve. The alignment of liquid crystal molecules is altered by applying an electric field. Their alignment is used to control the polarization of light passing through the liquid crystal material, either blocking the light or allowing the light to pass through. Liquid crystal displays are generally transmissive (backlighted), reflective (relying only on ambient light), or transflective (a combination of transmissive and reflective). Typical LCD backlights include fluorescent, electroluminescent (EL), light-emitting diode, and incandescent lamp. For transmissive LCD's, cold cathode fluorescent lamps generally provide the best maximum luminance and luminance half-life, while EL backlights provide the best luminance uniformity and thickness. Liquid crystal displays may present either dark images on light backgrounds or light images on dark backgrounds. Monochrome LCD's are available with a variety of colored backgrounds and colored backlights. Full color LCD's are available in larger graphics displays, but generally are not available in character displays. A wide variety of display addressing techniques has been devised for LCD's. The most satisfactory off-axis contrast is obtained with thin-film-transistor active-matrix LCD's. The LCD's addressed in this handbook are:

a. Transflective, segmented-character displays.

b. Transflective, matrix-addressed displays.

c. Transmissive, matrix-addressed displays.

268. WHEN TO USE:

A transflective LCD should be used where sunlight visibility, low power consumption, and display visibility from multiple viewer positions are more important than a multicolor, high resolution display. A transmissive LCD should be used where display brightness, display resolution, and multicolor display are more important than sunlight visibility, low power consumption, and display visibility from multiple viewer positions. Seven-segment displays should be used only for applications requiring numeric information.[13]

Comment: Seven-segment displays are assumed to have insufficient addressability to adequately display an alphabetic character set.

269. USE OF GENERAL DISPLAYS GUIDELINES:

The design and use of LCD's should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

270. COLOR DISCRIMINABILITY:

Colors, especially red, amber, and yellow, should remain discriminable at all angles from which the LCD is likely to be viewed. (Based on reference 47.)

Comment: Color shifts and even color reversals are commonly seen in LCD's at viewing angles deviating from perpendicular to the display surface.

271. DAYTIME USE OF TRANSFLECTIVE, SEGMENTED LCD's:

For daytime use, a transflective, segmented LCD should be backlighted. The minimum reflectance of the "on" or active segment areas of these displays should be 25 percent. (Based on reference 47.)

Comment: Such displays should also be backlighted for nighttime use, although at a lower luminance.[41]

272. LUMINANCE OF TRANSMISSIVE LCD's:

A transmissive LCD should be capable of displaying white symbol lines at a luminance of at least 168 cd/m^2 (49 fl). (Based on reference 47.)

Comment: The measurement of symbol line luminance requires the use of proper instrumentation and measurement technique. In particular, it is important that the background area does not occupy a large portion of the measurement field.

273. MATRIX ANOMALIES:

A matrix-addressed LCD should not display any matrix anomalies that can cause distraction or erroneous interpretation. (Based on reference 47.)

Comment: Since the display is an array of discrete elements, symbols will have spatial and color anomalies. These phenomena are different in static and dynamic symbols; matrix anomalies are especially visible in dynamic images. The extent of the anomaly is dependent on many factors, including the size, shape, and arrangement of the elements; construction of the symbol; rate, direction, and increment of motion; and luminance control of the elements.[47]

274. PIXEL SHAPE:

A monochrome matrix-addressed LCD should use square rather than rectangular pixels. (Based on reference 52.)

275. FAILURE RATES FOR PIXELS AND LINES:

A matrix-addressed LCD should have fewer than 1 percent of pixels failed "on," fewer than 2 percent failed pixels total, and no failed lines, (Based on references 45,53.)

Comment: Not all pixels in a matrix-addressed display perform as designed. For monochrome displays, failures are either "on" (matching the symbol luminance) or "off" (matching the background luminance). Failures that are on have a more significant impact on performance measures such as reading time, search speed, and errors than do failures that are off. When all the pixels in a single row or column fail, a failed "line" is said to occur. While failed lines typically have a less significant effect on user performance, they are much more visible and distracting to users. Even a single line failure can often be highly visible.

When individual color elements and lines can fail in a full-color, matrix-addressable display, attention should be given to resulting errors in color perception (e.g., a normally white line could appear yellow if the blue component of the line were to fail).

Plasma (Gas Discharge) Displays

DEFINITION:

A plasma (gas discharge) display produces a cathode glow by electrical excitation of small pockets of gas. Both direct current- and alternating current (ac)-power plasma displays are available. The plasma display color is typically orange on a black background. Color ac plasma displays have been demonstrated, but are not yet commercially available. Display filters may be used to change the color of monochrome displays, but at the expense of lowering the display luminance. Common plasma display applications include:

a. Matrix-addressed graphics displays.

b. Segmented character displays (not addressed in this handbook).

276. WHEN TO USE:

A matrix-addressed plasma display should be used for graphics applications when display visibility from multiple viewer positions, low physical display volume, low power consumption, and high display mean time between failures are more important than high resolution, high brightness, the display of multicolored objects, and sunlight visibility.

277. USE OF GENERAL DISPLAYS GUIDELINES:

The design and use of plasma displays should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

278. MATRIX ANOMALIES:

A matrix-addressed plasma display should not display any matrix anomalies that can cause distraction or erroneous interpretation. (Based on reference 47.)

Comment: Since the display is an array of discrete elements, symbols will have spatial and color anomalies. These phenomena are different in static and dynamic symbols; matrix anomalies are especially visible in dynamic images. The extent of the anomaly is dependent on many factors, including the size, shape, and arrangement of the elements; construction of the symbol; rate, direction, and increment of motion; and luminance control of the elements.[47]

279. PIXEL SHAPE:

A monochrome matrix-addressed plasma display should use square rather than rectangular pixels. (Based on reference 52.)

280. FAILURE RATES FOR PIXELS AND LINES:

A matrix-addressed plasma display should have fewer than 1 percent of pixels failed "on," fewer than 2 percent failed pixels total, and no failed lines. (Based on references 45,53.)

Comment: Not all pixels in a matrix-addressed display perform as designed. For monochrome displays, failures are either "on" (matching the symbol luminance) or "off" (matching the background luminance). Failures that are on have a more significant impact on performance measures such as reading time, search speed, and errors than do failures that are off. When all the pixels in a single row or column fail, a failed "line" is said to occur. While failed lines typically have a less significant effect on user performance, they are much more visible and distracting to users. Even a single line failure can often be highly visible.

When individual color elements and lines can fail in a full-color, matrix-addressable display, attention should be given to resulting errors in color perception (e.g., a normally white line could appear yellow if the blue component of the line were to fail).

Vacuum Fluorescent Displays (VFD's)

DEFINITION:

A vacuum fluorescent display (VFD) produces light through electron bombardment of phosphor in a vacuum under the control of a grid. So-called "front-luminous" VFD's are available that may provide better display visibility (luminance and contrast) than conventional VFD's. The VFD color is typically blue-green on a black background, but filters are often used to produce other colors such as green, yellow, and red. Full-color VFD's have been demonstrated, but at resolutions and luminance levels too low to be of practical value in a road vehicle. Even monochrome graphics VFD's are of limited resolution. VFD's are most commonly used as:

a. Segmented character displays.

b. Matrix-addressed graphics displays.

281. WHEN TO USE:

A VFD should be used for character display and graphics applications when display visibility from multiple viewer positions, high display brightness, low physical display volume, and high display mean time between failures are more important than the display of high resolution, multicolored objects. Seven-segment displays should be used only for applications requiring numeric information.[13]

Comment: Seven-segment displays are assumed to have insufficient addressability to adequately display an alphabetic character set.

282. USE OF GENERAL DISPLAYS GUIDELINES:

The design and use of VFD's should conform to the applicable general guidelines for electronic visual displays that are in chapter 5.

283. MATRIX ANOMALIES:

A matrix-addressed VFD should not display any matrix anomalies that can cause distraction or erroneous interpretation. (Based on reference 47.)

Comment: Since the display is an array of discrete elements, symbols will have spatial and color anomalies. These phenomena are different in static and dynamic symbols; matrix anomalies are especially visible in dynamic images. The extent of the anomaly is dependent on many factors, including the size, shape, and arrangement of the elements; construction of the symbol; rate, direction, and increment of motion; and luminance control of the elements.[47]

284. PIXEL SHAPE:

A monochrome matrix-addressed VFD should use square rather than rectangular pixels. (Based on reference 52.)

285. FAILURE RATES FOR PIXELS AND LINES:

A matrix-addressed VFD should have fewer than 1 percent of **pixels failed "on," fewer than 2 percent failed pixels total, and no failed lines.** (Based on references 45,53.)

Comment: Not all pixels in a matrix-addressed display perform as designed. For monochrome displays, failures are either "on" (matching the symbol luminance) or "off" (matching the background luminance). Failures that are on have a more significant impact on performance measures such as reading time, search speed, and errors than do failures that are off. When all the pixels in a single row or column fail, a failed "line" is said to occur. While failed lines typically have a less significant effect on user performance, they are much more visible and distracting to users. Even a single line failure can often be highly visible.

When individual color elements and lines can fail in a full-color, matrix-addressable display, attention should be given to resulting errors in color perception (e.g., a normally white line could appear yellow if the blue component of the line were to fail).

Nonspeech Auditory Displays

DEFINITIONS:

The following definitions are used in the guidelines for nonspeech auditory displays:

a. An alerting signal is used when there is a requirement for an immediate response to a situation outside the user's normal task sequence, when some system function needs attention on an irregular basis, or when there is a minor component failure.

b. A caution signal is used to capture the attention of the user so as to direct him/her to a potentially destructive condition requiring immediate awareness. There is no immediate threat to life or major property damage, but there may be incipient threat to either, or there may be a possible threat of a major system malfunction or abort. A caution signal may be either a single-element or a two-element signal (see item d in this guideline).

c. A warning signal is used to alert the user in hazardous or emergency situations that immediate action is required. A warning signal may be either a single-element or a two-element signal (see item d in this guideline).

d. A single-element signal consists of an alert only; it indicates that there is a problem but not exactly what it is. A two-element signal consists of an alert followed by an identifying (or action) signal, the latter indicating the specific nature of the problem.[14]

286. WHEN TO USE:

Use nonspeech auditory displays under the following conditions:

a. The information that is to be processed is short, simple, and transitory, requiring an immediate or time-based response.

b. The visual display is restricted by:

- **Overburdening.**
- **Ambient light variability or limitation.**
- **User mobility.**
- **Degradation of vision (e.g., due to vibration).**
- **Other environmental considerations.**
- **Anticipated user inattention.**

c. It is desirable to capture the user's attention.

d. **Custom or usage has created the anticipation of an auditory display.**

e. **An auditory presentation is desirable to reinforce a visual presentation.**[14]

287. WHEN TO USE A NONSPEECH AUDITORY DISPLAY VS. A SPEECH DISPLAY:

A nonspeech auditory display should be used rather than a speech display under the following circumstances:

a. **When listeners are trained to understand coded signals.**

b. **For designating a point in time that has no absolute value.**

c. **When immediate action is desired.**

d. **In conditions unfavorable for receiving speech messages.**

e. **If speech will mask other speech signals or annoy listeners for whom the message is not intended.**[25]

288. STRENGTHS AND WEAKNESSES:

Nonspeech auditory displays are either simple tones or complex sounds. Their strengths and weaknesses with respect to use for various functions are presented in table 28.[14]

Table 28. Strengths and weaknesses of nonspeech auditory displays.

Function	Simple Tones	Complex Sounds
Quantitative Indication	**Poor:** A maximum of five to six tones are absolutely recognizable.	**Poor:** Interpolation between signals is inaccurate.
Qualitative Indication	**Poor to Fair:** It is difficult to judge the approximate value and direction of deviation from a null setting unless the tones are presented in a close temporal sequence.	**Poor.** It is difficult to judge the approximate deviation from the desired value
Status Indication	**Good.** Start and stop timing can be used. Continuous information can be provided when the rate of change of the input is low.	**Good:** Especially suitable for irregularly occurring signals (e.g., alarms).
General	• Good for the automatic communication of limited information. • Their meanings must be learned. • They are easily generated.	• Some sounds are available that have a common meaning (e.g, a fire bell) • They are easily generated.

289. OPERABILITY TEST:

Nonspeech auditory displays should be equipped with circuitry test devices or other means of testing operability.[14]

290. CODING PRINCIPLES:

If nonspeech auditory displays are to be coded (e.g., to prioritize signals), the following principles should be employed:

a. **Coding methods should be distinct and unambiguous, and should not conflict with other auditory signals.**

b. **Pulse coding by repetition rate may be used, but the number of codes should be limited to two or three. Repetition rates should be sufficiently separated to ensure user discrimination**

c. **If modulation of signal frequency denotes information, center frequencies should be between 500 and 1,000 Hz.**

d. **If discrete frequency codes are used, frequencies should be broad band (±l00 Hz) and widely spaced within the 200 to 5,000 Hz range. No more than five separate frequencies should be used.**

e. **Coding by intensity is not recommended.[48]**

291. USE OF UNIQUE CODES:

Once a particular nonspeech auditory display code is established for a given operating situation, the same code should not be designated for some other display.[10]

292. WHEN A FAILURE CAN RESULT IN SUSTAINED ACTUATION OF THE DISPLAY:

An interlocked, manual-disable control should be provided if there is any failure mode that can result in the sustained actuation of a non-speech auditory display.[49]

293. TRANSMISSION SYSTEM:

Systems used to transmit nonspeech auditory signals should be used for only that purpose.[48]

294. DIRECTION OF SOUND:

Sound sources (e.g., speakers) should direct sound toward the center of the primary operating area.[48]

295. WHEN THE SIGNAL IS TO BE QUANTIFIABLE:

When the tonal signal information is to be quantifiable, provide a reference tone (e.g., a baseline loudness or pitch) against which the primary signal can be compared.

296. TIME TO CONTAIN ESSENTIAL INFORMATION IN A SINGLE-ELEMENT SIGNAL:

A single-element signal should contain all essential information in the first 0.5 s.[10]

297. FREQUENCY RANGE:

The frequency range for nonspeech auditory displays should be between 200 and 5,000 Hz, with a preferred range of 500 to 3,000 Hz.[14]

298. PROMINENT FREQUENCY COMPONENTS AND HARMONICS:

The prominent frequency components for nonspeech auditory displays should be in the range from 1,000 to 4,000 Hz. At least 4 of the first 10 harmonics should be present.[58]

299. INTENSITY:

Nonspeech auditory displays should be presented at ≥ 20 dB(A) above the background noise level. Their intensity should not be greater than 90 dB(A).[14,58]

300. ONSET RATE:

The onset rate for nonspeech auditory displays should be less than 1 dB/ms.[58]

301. WHEN USING MULTIPLE FREQUENCIES:

When using multiple frequencies, simple multiples of other frequencies should be avoided.[25]

302. ATTENTION-DEMANDING SIGNAL:

An intermittent (1 to 8 beeps/s) or frequency-modulated signal should be used to demand attention.[25]

303. SIGNAL BURST DURATION:

The minimum duration signal burst should be at least 100 ms.[58]

304. SIGNAL TYPES TO AVOID:

The types of signals listed below should not be used where possible confusion might exist because of the operational environment:

a. **Steady signals that resemble hisses, static, or sporadic radio signals.**

b. **Trains of impulses that resemble electrical interference, whether regularly or irregularly spaced in time.**

c. **Signals similar to random noise generated by air conditioning or any other equipment.**

d. **Signals that resemble sounds likely to occur accidentally under operational conditions.**[14]

305. FALSE ALARMS:

Alerts, cautions, and warnings should be designed so that false alarms are avoided.[48]

306. VOLUME CONTROL:

The volume (loudness) of an alerting, caution, or warning signal should be designed to be controlled by the user, the sensing mechanism, or both, depending on the operational situation and personnel safety factors. User control actions should not be allowed to reduce the volume to an inaudible level. Full volume should be automatically restored upon initiation of the subsequent signal. (Based on references 13,14.)

307. DISCRIMINABILITY AMONG SIGNALS:

When several different nonspeech auditory displays are to be used to alert the user to different types of conditions, either beats and harmonics should be used or there should be a discriminable difference in intensity or pitch. If absolute discrimination is required, the number of signals to be identified should not exceed four.[49]

308. WHEN AN ALERTING SIGNAL CONSISTS OF A GLISSANDO:

When an alerting signal consists of a glissando (a series of notes forming a nearly unbroken change of pitch), the audible signal should remain at least 100 ms in each octave band from the lowest to the highest frequency.[10]

309. ALERTING SIGNAL REPETITION, PERSISTENCE, AND RESET:

An alerting signal may be momentary or continuous in nature, as appropriate:

a. **If it is momentary, it should be repeated periodically until either proper action is taken or the signal is turned off.**

b. **If it is continuous, it should persist until initiation of proper action or signal turn off.**

In either case, after the signal is terminated it should be automatically reset to respond to the next initiating condition.[14]

310. WHEN THE TOTAL NUMBER OF CAUTION SIGNALS IS SMALL:

When the total number of caution signals is small, a two-element caution signal should be used.[14]

311. WHEN USING A SINGLE-ELEMENT CAUTION SIGNAL:

A single-element caution signal should be accompanied by a visually presented message that identifies the specific nature of the caution situation.[14]

312. CAUTION SIGNAL PERSISTENCE AND RESET:

A caution signal should persist intermittently until restoration of normal conditions or manual shut off. Upon termination, it should be automatically reset to respond to the next initiating condition.[14]

313. WHEN THE TOTAL NUMBER OF WARNING SIGNALS IS SMALL:

When the total number of warning signals is small, a single element warning signal should be used.[14]

314. USE OF A SINGLE-ELEMENT WARNING SIGNAL:

A single-element warning signal should be accompanied by a visual annunciation that defines the condition.[13]

315. TIME TO CONTAIN INFORMATION IN A TWO-ELEMENT WARNING SIGNAL:

A two-element warning signal should convey the full meaning of the signal within 2.5 s of initiation.[14]

316. AUTOMATICALLY INITIATED WARNING SIGNAL PERSISTENCE AND RESET:

An automatically initiated warning signal should persist until either automatically or manually terminated. Completion of a corrective action by the user or by other means should automatically terminate the signal. Provision for manual termination should also be provided. Automatic reset for the next initiating condition should be provided.[14]

317. SIMULTANEOUS WARNING SIGNALS:

No warning signal should preclude hearing any other warning signa1.[14]

318. WARNING SIGNAL POWER SOURCE:

A warning signal should be provided with a separate, emergency power source.[29]

319. WARNING SIGNAL FAILURE:

Nonspeech auditory display devices and circuits should be designed to preclude warning signal failure related to system or equipment failure

and vice versa. A positive and attention-demanding indication should be provided if failure occurs.[49]

320. NUMBER OF WARNING SIGNAL FREQUENCY COMPONENTS:

Warning signals should have at least four prominent frequency components.[58]

321. ALERT AND WARNING SIGNAL AUDIBILITY:

Alerts and warning signals should be audible in all parts of the vehicle.[48]

322. ALERT AND WARNING SIGNAL DISTINCTIVENESS:

The first 0.5 s of an alert or warning signal should be discriminable from the first 0.5 s of any other signal that may occur. (Based on reference 49.)

Speech Displays

323. WHEN TO USE:

A speech display should be used in situations where the user's eyes are busy or mobility is required. Avoid using a speech (or other auditory) display when frequency of use is high, when multiple messages must be displayed simultaneously, or when the user would be expected to remember a series of instructions.[31]

324. WHEN TO USE A SPEECH DISPLAY VS. A NONSPEECH AUDITORY DISPLAY:

Use a speech display rather than a nonspeech auditory display under the following circumstances:

a. **Flexibility is required.**

b. **The user has no special training in coded signals.**

c. **The message deals with a future time, requiring preparation.**

d. **In situations of stress, which might cause the user to forget the meaning of a coded signal.**[59]

325. OUTPUT RATE:

Use an output rate of approximately 150 to 180 words/min.[31,33]

326. STRUCTURE OF UNPREDICTABLE MESSAGES:

When output messages are unpredictable, begin a speech display with a small number of noncritical words to provide context, to allow the user

to pick up the speech cadence and quality, and to allow the user to get oriented to the subject matter. Critical information should occur at the end of the message.[31]

327. OPERABILITY TEST:

Speech displays should be equipped with circuitry test devices or other means of testing operability.[14]

328. FALSE ALARMS:

Speech alarm systems should be designed so that false alarms are avoided.[48]

329. WARNING SIGNAL FAILURE:

Speech display devices and circuits should be designed to preclude warning signal failure related to system or equipment failure and vice versa. A positive and attention-demanding indication should be provided if failure occurs.[49]

330. WHEN A FAILURE CAN RESULT IN SUSTAINED ACTUATION OF THE DISPLAY:

An interlocked, manual-disable control should be provided if there is any failure mode that can result in a sustained actuation of a speech display.[49]

331. ORDER OF INFORMATION IN AN INSTRUCTIONAL PROMPT:

In a speech display used as an instructional prompt to the user, put the goal first and the action last. For example, use "To confirm your destination, press one" rather than "Press one to confirm your destination."[31]

332. REPEAT CAPABILITY:

Provide the capability for the user to have a speech display repeated.[31]

333. APPROPRIATE USE:

Use a speech display to announce discrete events, not to present readings of continuously changing variables.[33]

334. PRESENTING LONG MESSAGES OR STAND-ALONE INFORMATION:

Do not use a speech display to present long, detailed messages or to present information that must be remembered by the user without benefit of a concurrent visual display.[33]

335. DIGITIZED VS. SYNTHETIC SPEECH:

Use digitized (recorded) speech instead of synthetic speech (made from the concatenation of basic speech sounds) whenever possible. Use synthetic speech only when a technical or practical barrier prevents the use of recorded voice.[34]

336. SYNTHETIC-SPEECH INTELLIGIBILITY:

When synthetic speech must be used, intelligibility can be improved through these steps:

- **a. Ensure the listener is familiar with all possible interpretations of the message.**
- **b. Provide the listener with training.**
- **c. Begin any synthesized message with redundant words to allow the user to pick up the speech cadence and quality.[34]**

337. ALERTING SOUNDS WITH MACHINE-QUALITY WARNINGS:

When machine-quality speech displays are used exclusively for warnings, do not put any alerting nonspeech auditory display before the speech warning message.[33]

338. ALERTING WITH MACHINE-SOUNDING WARNINGS:

When machine-sounding speech displays are used for warnings and other functions (e.g., advisories), responses to user queries, and so forth, incorporate an alerting characteristic into the speech warnings.[33]

Comment: Possible alerting features might include a higher pitched voice, a "prefix" that is either speech or a nonspeech auditory display, or some other feature that makes the warning message distinctive and can be shown (presumably experimentally) to increase message detectability without increasing user response time.[33] A speech alarm display must consist of two segments:

- a. An initial, nonspeech auditory display to attract attention and to designate the general problem.
- b. A brief, standardized speech display that identifies the specific condition and optionally suggests appropriate action.[26]

339. INTENSITIES OF CAUTIONS AND WARNINGS:

Speech displays for caution conditions should be at least 10 dB(A) above the noise level at the operating position of the intended receiver, and for warnings should be at least 20 dB(A) above the noise level[14]

340. INTERVAL BETWEEN SUCCESSIVE WARNINGS:

For speech warning displays, the length of time between successive presentations of the same message should depend upon the severity of the consequences of the user not correcting the problem.[33] Critical speech warning displays should be repeated with not more than a 3-s pause between messages until the warning state is terminated, either automatically or manually.[14]

341. MESSAGE PRIORITY SYSTEM:

When there could be the possibility of simultaneous presentation of automatically initiated messages, a message priority system should be provided such that the most critical message overrides for initial presentation any messages occurring lower on the priority list. Following initial presentation of the top priority message, other messages should be presented in the priority order, except that no caution messages should be presented until all warning messages are terminated.[14]

342. NUMBER OF SYLLABLES IN WARNINGS:

For speech warning displays, use a minimum of four syllables to provide sufficient linguistic context for warning comprehension after first enunciation of the message.[33]

343. CAPABILITY TO CANCEL WARNINGS:

For speech warning displays, provide the user with a means to cancel the message once it has been presented.[33]

344. RULES FOR RECORDING MESSAGES:

When recording speech displays, either digitized or synthesized:

a. Use a professional voice with the following characteristics:

- **It should be agreeable and assertive.**
- **It should be clear in enunciation, free from regional dialects, authoritative, and confident, and should sound concerned but not detached or anxious.**

b. All prompts and messages should be recorded by the same speaker.

c. If possible, record all messages during a single session to ensure voice homogeneity. This is especially important for systems with concatenated (synthetic) speech.

d. When recording spoken digits, such as vehicle speeds, the digits must be recorded for each position in which that digit will occur because, depending on position, the intonation of the utterance will be different.

e. Do not change voices during a dialogue unless there is a purposeful reason for doing so.[14,60,61]

345. USE OF SINGLE LETTERS AS CODES:

Avoid using single letters as codes where noise is present.[62]

346. WHEN TO REPEAT PROMPTS:

Repeat a prompt after a 10-s period of inactivity or after a command from the user.[63]

347. PHRASING OF PROMPTS:

When phrasing prompts, consider the following:

a. Adopt terminology consistent with how users think about the task, and use that terminology consistently.

b. Use simple, explicit, and concise language.

c. Avoid passive voice or negative conditionals

d. For keypad entries, use the term “press” for prompting selections from menus (e.g., “To confirm your destination, press one”).[61]