IMAGE QUALITY: MEASUREMENTS AND DEFINITION

Alan Dragon, Field Applications Engineer

INTRODUCTION

This application note will explain image quality of displays by defining commonly used measurement terminology and by describing the visual capabilities of the observer. In understanding image quality, it is important that the limits of the display and that of the human-eye system are comprehended. For a display to "look acceptable" there are many intangibles that come into play such as aesthetic taste, cultural conditioning, intelligence, attentiveness, and patience. In order to equally assess different displays and display technologies, image quality must be carefully defined in tangible and measurable terms. When characterizing a display, sensory qualities such as luminance, contrast, color, and spatial frequency depend and interact with each other. Although the focus will be on flat panel displays (LCDs and ELs), all of these terms and measuring techniques can be applied to any display technology.

It is well known that many terms used in our everyday technical discussion are often misused, such as brightness vs. luminance and resolution vs. display format. Although it is often hard to break habits, this application note will define all of these terms so there is at least an understanding of the technically correct definition.

HUMAN VISUAL RESPONSE

It is important to understand how we process and perceive visual stimulus to understand how image quality is defined. The human eye is composed of two photoreceptors; rods and cones. These photoreceptors are distributed in different parts of the retina and have different sensitivities to light energy. The cones are concentrated in the center of the eye and the rods are concentrated 18-20° off center, linearly decreasing their density out to approximately 80°. Rods and cones have the following characteristics:

- Rods have greater sensitivity to light than do cones.
- Cones are differentially sensitive to the wavelengths of light (i.e., can "see" colors) whereas rods can only "see" shades of gray.
- Cones have greater resolving capabilities than do rods, thus provide greater discrimination of details.
- Rods are more sensitive to temporal changes in luminance levels and are more likely to see flicker. This is why we can see flicker more readily in our peripheral vision.

Based on these attributes, the human eye processes visual information with the following characteristics:

- When the intensity of a multi-color display or image is lowered, the colors will drop out sequentially into gray levels. The first colors to shift to gray are blues and reds with the last being greens. This shifting of colors to gray is known as the Purkinje shift.
- The ability to detect resolution depends on the size of the object, luminance of the object, luminance of the background and ambient, and the color of the object.
- Lower luminance levels on a display require greater contrast for equal discriminability (i.e., a high-contrast low-light output LCD can look as good as a lower-contrast high-light output LCD).
- The human eye is sensitive to the color spectrum between the wavelengths of 380 and 720 nm. This sensitivity shifts based on ambient lighting conditions. There is approximately a 50 nm shift of the sensitivity curve, lower in wavelength, from daytime to nighttime vision.
- As the human eye-brain system is differential input, the eye is very sensitive to luminance and color differences. However, as the average luminance level increases on a display, the eye is less sensitive to absolute luminious differences.

The two primary measurements used in display image quality characteristics are luminance and spectral radiance. Resolution is also important in defining the interaction between the information density on the display and the resolving capability of the human visual system.

LUMINANCE

Luminance is the psycho-physical measure of perceived radiant power under carefully controlled and defined conditions. Luminance can also be defined as the quantitative measure of brightness and is measured in English units as footlamberts (fL) and in SI (International System) units as candela/m^2 (nit).

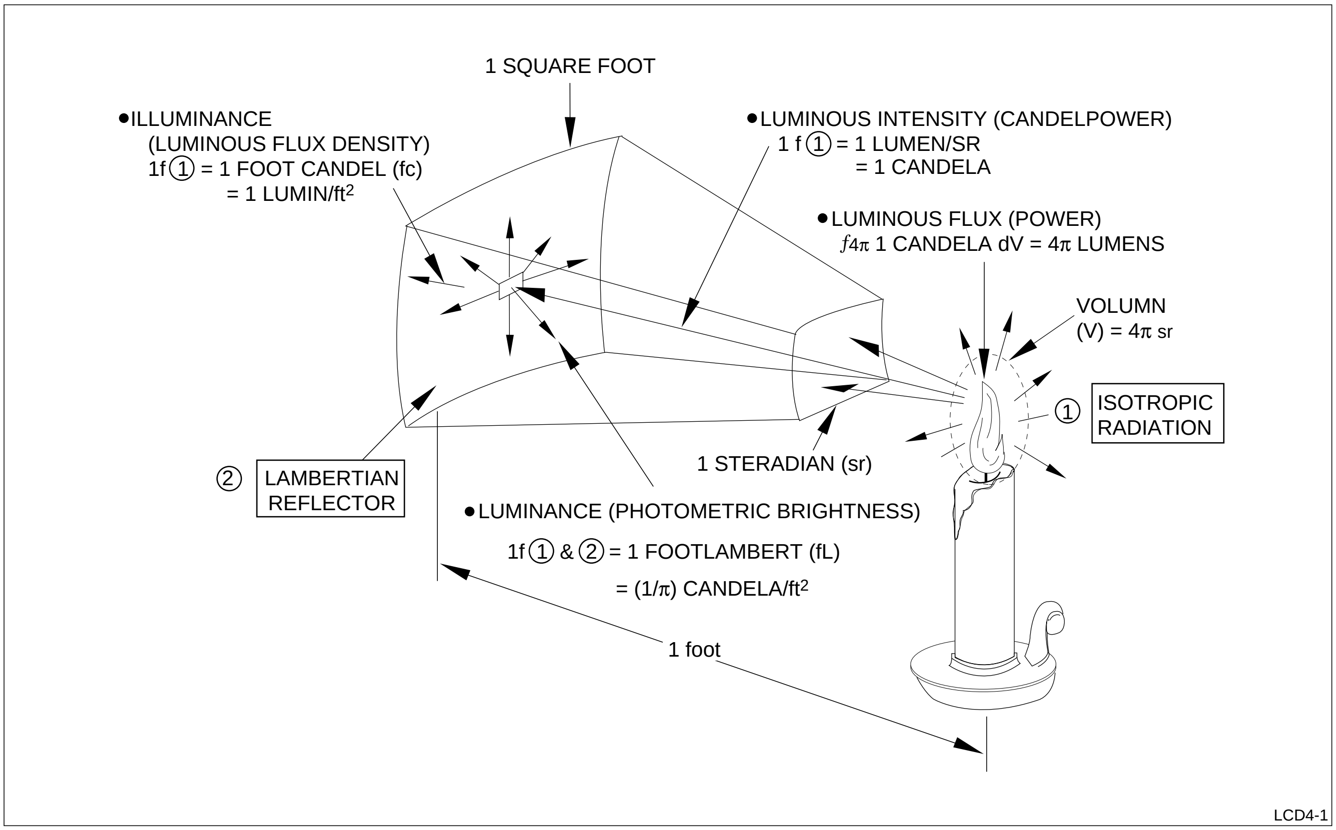

Fig. 1. Footlambert

A footlambert is the luminance reflected off a 1 square foot Lambertian (perfectly diffusing) reflector illuminated by 1 foot candle (fc) (Figure 1). Figure 2 shows the same setup in SI units. Table 1 gives the conversion factors between the two systems along with a chart (Figure 3) to show the electrical equivalent term.

BRIGHTNESS

Brightness is a term that is commonly misused when specifying light output levels. Brightness is purely a psycho-physiological attribute; the subjective response to electromagnetic energy that occurs when the human eye system has adapted to a particular radiation level. To put it in simple terms, a radiance and intrinsic luminance. BRIGHTNESS IS NOT A MEASURABLE VISUAL PARAMETER.

RADIANCE

Radiance is a measure of the rate of energy flow from an electromagnetic source usually measured in power units; watts or joules/second. All colormetric analysis requires the use of radiance measurements as a function of wavelength (spectral radiance) and subsequent conversion to luminance or chrominance values. Chrominance is the physical combination of the dominant wavelength (hue) and purity (saturation).

Hue is the dominant wavelength of the color as subjectively perceived by the human eye system. Saturation is the degree to which the hue of a color subjectively appears to be undiluted by its complimentary color to form white. If there is no trace of apparent white in the color, it is said to be fully saturated.

When explaining about color it is important to understand how the human eye processes color. Figure 4 shows the human eye response to radiant power. This clearly indicates the eye does not have the same sensitivity to all colors. Our eyes are much more sensitive to green wavelengths of light. In order to get the same perceived luminance (sensory response) for all colors, the radiance power levels (lumens/watt) are different. It is important to note that lumen of red, green, or blue light has the same sensory response, only the amount of radiant power to get to that level is different.

When describing white light, it is EQUAL LUMINANCE levels across the visible spectrum that gives white its color. EQUAL RADIANCE levels across the visible spectrum however, will give a magenta color. A sometimes confusion concept, but as long as radiance and luminance levels of wavelengths are kept separate, there shouldn't be any comprehension problems.

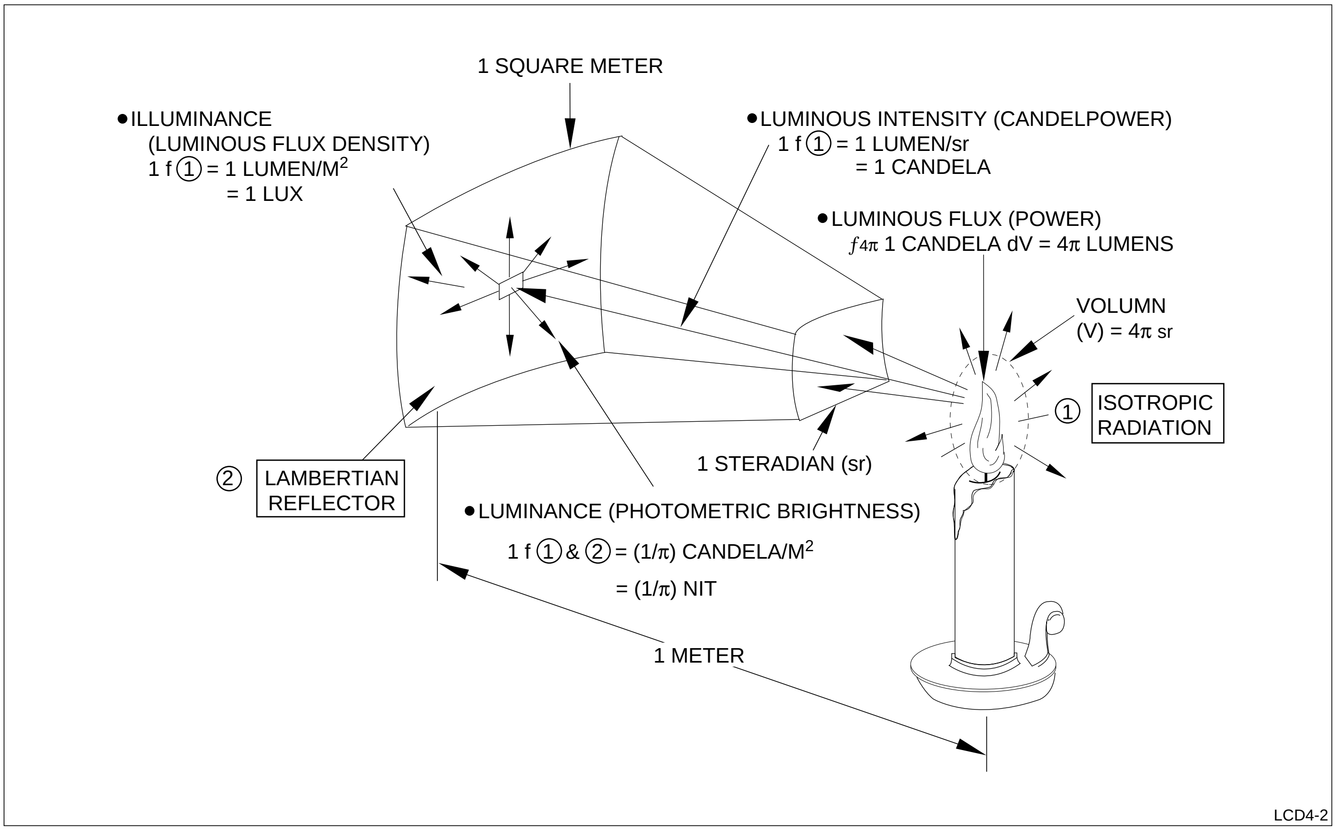

Fig. 2. Footlambert in SI Units

Table 1.
Conversion Factors and Electrical Equivalents

NO. OF MULTIPLIED BY EQUALS NO. OF	FOOTLAMBERT	CANDELA/m^2	MILLILAMBERT	CANDELA/in^2	CANDELA/ft2	STILB
Footlambert	1	0.2919	0.929	452	3.142	2,919
Candela/m^2 (nit)	3.426	1	3.183	1,550	10.76	10,000
Millilambert	1.076	0.3142	1	487	3.382	3,142
Candela/in^2	0.00221	0.000645	0.00205	1	0.00694	6.45
Candela/ft^2	0.3183	0.0929	0.2957	144	1	929
Stilb	0.00034	0.0001	0.00032	0.155	0.00108	1

ELECTRICAL	LUMINOSITY TERM	LUMINOSITY UNIT
Power (rate of energy flow)	Luminous Flux	Lumen = 1/680 watt/Luminosity Function
Power-source Output	Intensity (Power-Source)	Candela = Lumen/Steradian
Delivered Power	Luminance (Surface)	Nit = Lumen/Steradian/meter^2 = Candela/m^2
Power-transfer Efficiency	Transmittance	Transmittance Factor = 0.0 to 1.0
	Reflectance	Reflectance Factor = 0.0 to 1.0

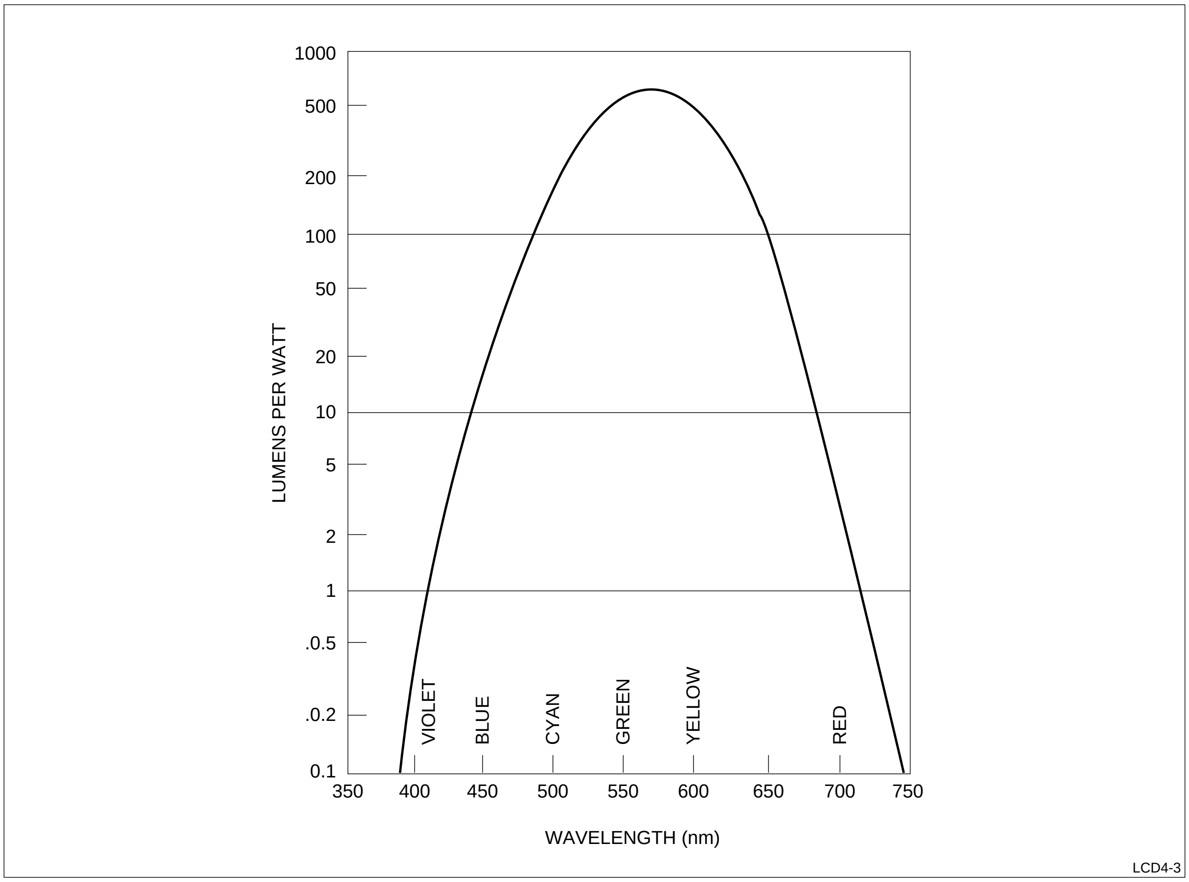

Fig. 3. Electrical Equivalent Term

COLOR

One of the best ways to describe the three dimensional color characteristics (luminance, hue, and saturation) in a two dimensional chart is by using the CIE (Commission Internationale de L'Eclairage) System. (Figures 4 and 5) The original 1931 chart revised in 1955 by the NBS (Nation Bureau of Standards) and adopted by the EIA (Electronic Industries Association) is also called the Kelly Chart and can be used today for any type of color characterization. The chart is based on the supersaturated primaries of red, blue, and green. Any color can be characterized by its x and y coordinates. The chart assumes all colors are generated by equal radiance sources, which puts white at the center of the chart. Color temperature can also be readily specified by this chart. Color temperature is often used to specify white balance. The color temperature of a source is the temperature in Kelvins at which an ideal black-body radiator would emit the same spectral power distribution. Any set of primaries can be plotted and aligned to any reference white. The compliment of every primary color is a combination of the other two primaries on the chart. Two colors are considered compliments if they connect thru the center white point on the chart.

SHADES OF GRAY

Specifying shades of gray is often a game of specmanship. The industry standard has been to assume the detectable increment in luminance between two levels is the square root of 2 or 1.41. When calculating gray level, the original luminance level, size and shape of the object, number of objects, and adapting luminance should all be taken into account. As this can be very difficult, it is sometimes better to define dynamic range (maximum-minimum luninance) to determine performance.

UNIFORMITY

Uniformity, or the absence of, called nonuniformity, is the gradual change of luminance and chrominance from one display area to the next. It can be broken down into large-area and small-area nonuniformity. Large-area nonuniformity is usually a luminance change over the entire display (i.e., edge-to-edge, edge-to-middle). Because these changes are very gradual, a 50% change from edge to edge sometime can not be noticed. At low display luminance levels though, even these gradual changes may be seen. Small-area nonuniformity is often referred to as pixel to pixel changes in luminance or chrominance.

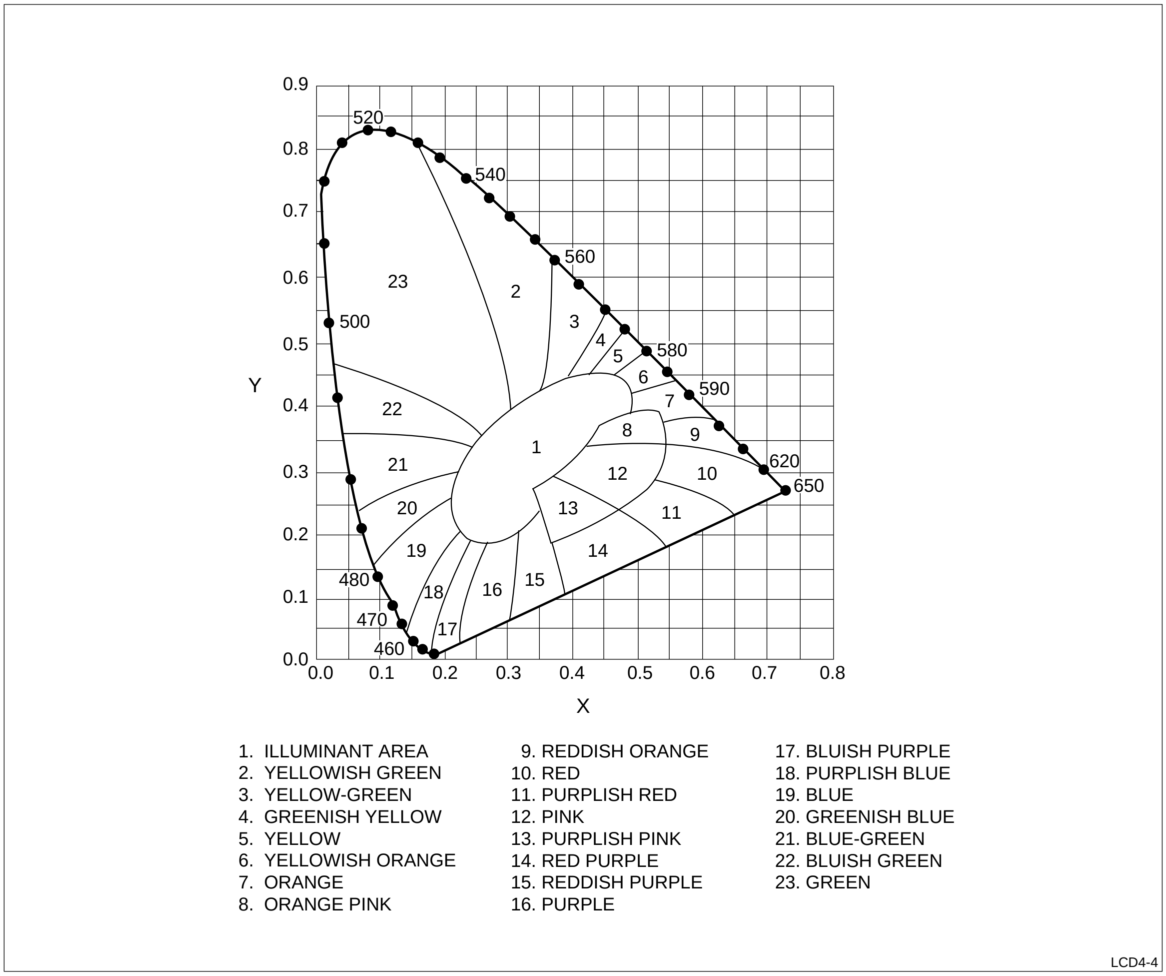

Fig. 4. Three-Dimensional Color Characteristics

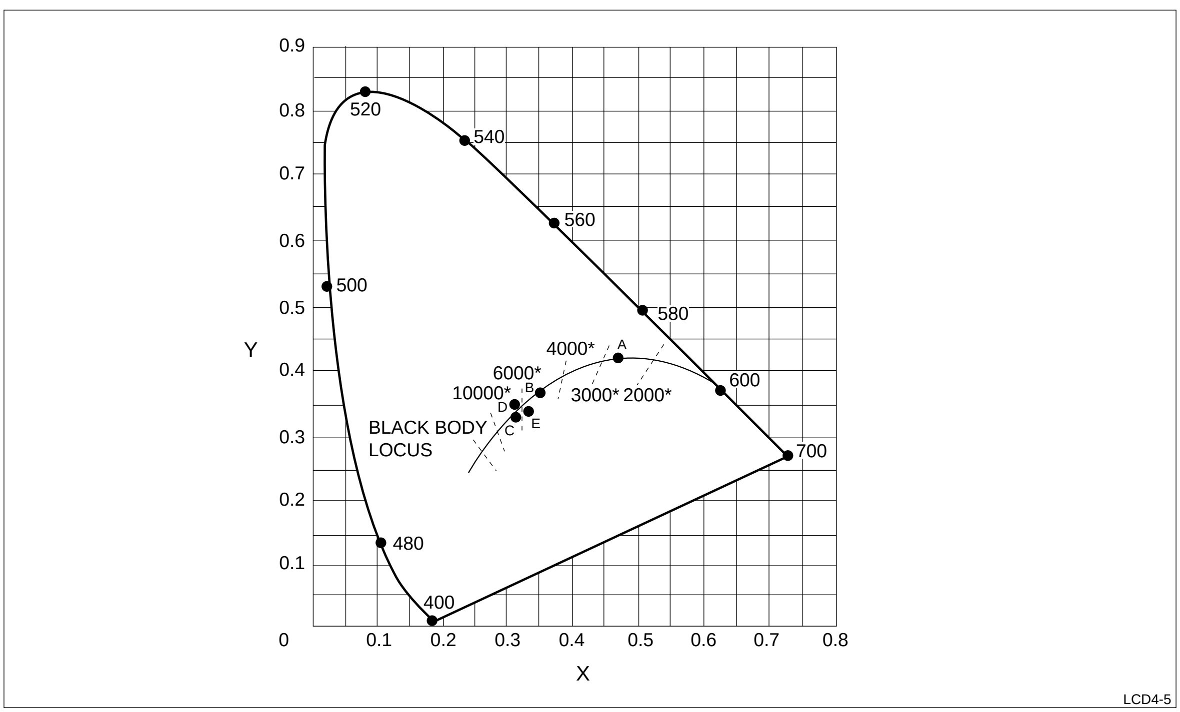

Fig. 5. Three-Dimensional Color Characteristics

These changes are usually very visible due to the sensitivity of the human eye to changes in luminance in close proximity.

PIXEL

The smallest resolvable spatial-information element on any display is called a pixel. The pixel can be subdivided further to achieve color. Each red, green, and blue element is referred to as a subpixel (Figure 6). The spatial dimension of pixel can be defined by the pixel size and pixel pitch (Figure 7). Fill factor (Figure 8) is another parameter used when image quality measurements are taken over an area (more than one pixel).

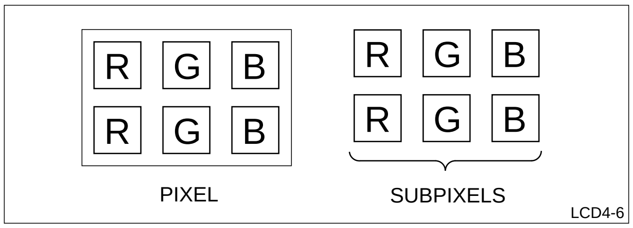

Fig. 6. Subpixel

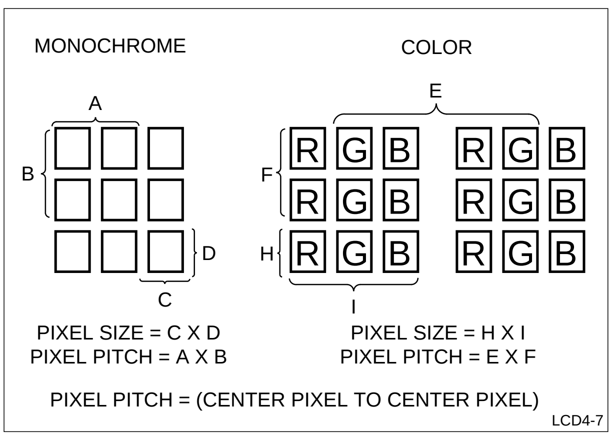

Fig. 7. Spatial Dimension of a Pixel

RESOLUTION

Resolution is probably the most misused term when describing image quality. For example, when describing a LCD, 640 x 480 is not the resolution. This should be referred to as the display format. Resolution is a very complicated measurement which deals with both the display and the human eye. For discretely addressed displays such as LCDs, resolution is usually measured in resolvable elements per unit measurement (i.e., pixels (dots)/inch). For analog addressable displays such as CRTs, resolution can be defined as above or more accurately as the spatial frequency (lines/inch) at which an observer can no longer discriminate the light and dark bars of a square wave pattern. There are numerous methods to measure resolution, so it is important that whatever method is used, it is consistent when comparing two display to each other.

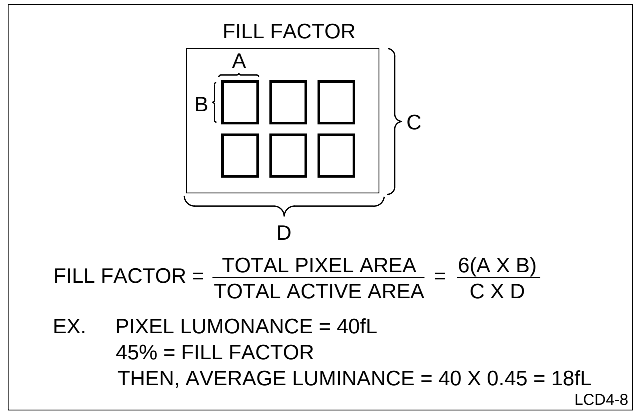

Fig. 8. Fill Factor of a Pixel

CONTRAST RATIO

$$\text{Contrast Ratio} = \frac{\text{Maximum Luminance}}{\text{Minimum Luminance}}$$

Although this is a simple formula, many factors must be taken into consideration. All ambient and display parameters must be defined in order to calculate a meaningful ratio. As is shown in Figure 9, if ambient conditions are not taken into account, the contrast ratio can vary significantly. Another factor is the area for the measurement. It can be on-pixel ("white") to off-pixel ("black") or on-area ("white") to off-area ("black"). In LCDs the angle of measurement to the display surface should be defined as the contrast ratio varies over the angle. Again, as long as all conditions are controlled and noted, an accurate comparison of displays can be made.

VIEWING ANGLE

Viewing angle is an important parameter to define in non-emissive display such as a LCD. Because there are limitations inherent to the technology, the viewing angle can help characterize the display more accurately. LCDs usually have their viewing angle defined as minimum contrast ratio over a certain angle. This angle is specified by its x and y direction on the face of the display.

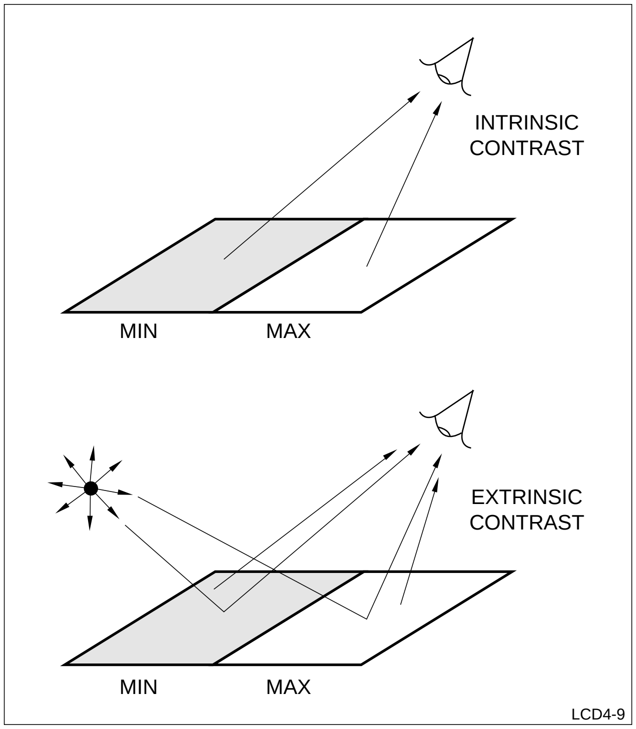

Fig. 9. Contrast Ratio

RESPONSE TIME

Response time is the time it takes a pixel to change state from on to off ("black" to "white"). This time includes all electrical and physical delays. It is defined as the transition time from the 10% level to the 90% level of luminance output (Figure 10). In LCDs, because the rise and decay times are usually unequal, both are specified; $\tau\gamma$ (10%-90%), τd (90%-10%). Rise and decay times may be combined to give a total response time.

CONCLUSION

As has been explained, image quality is characterized by a close interaction between the display and human eye system. Both must be understood to fully comprehend how to perform accurate and meaningful measurements. In order to compare displays of the same technology or even different technology, carefully controlled conditions and techniques must be implemented to get comparable results. Unfortunately, sometimes in the end, it may be a subjective visual response that determines the choice of the display, contrary to measured data. With the understanding of the terminology used in image quality analysis, it is hoped subjective decisions can be kept to a minimum.

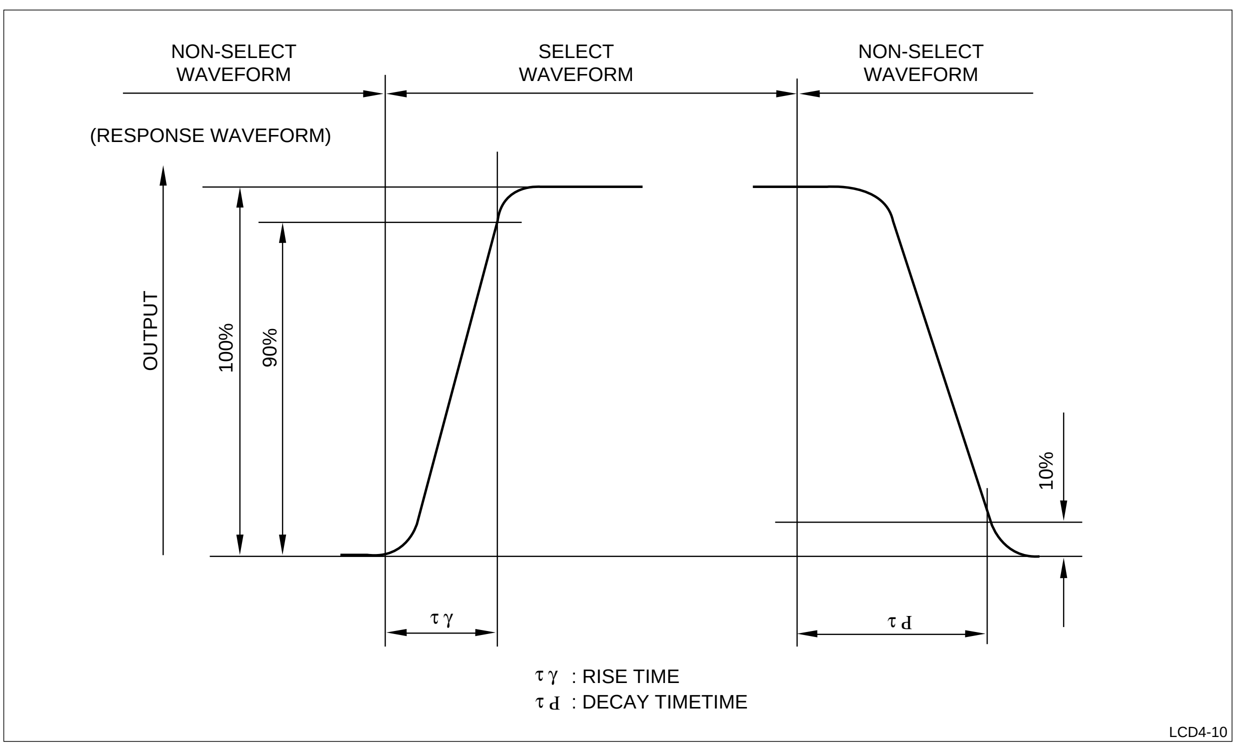

Fig. 10. Response Time

LIFE SUPPORT POLICY

SHARP components should not be used in medical devices with life support functions or in safety equipment (or similiar applications where component failure would result in loss of life or physical harm) without the written approval of an officer of the Sharp Corporation.

SHARP reserves the right to make changes in specifications at any time and without notice. SHARP does not assume any responsibility for the use of any circuitry described; no circuit patent licenses are implied.

NORTH AMERICA

SHARP Electronics Corporation
Microelectronics Group
5700 NW Pacific Rim Blvd., M/S 20
Camas, WA 98607, U.S.A.
Phone: (360) 834-2500
Telex: 49608472 (SHARPCAM)
Facsimile: (360) 834-8903

EUROPE

SHARP Electronics (Europe) GmbH
Microelectronics Division
Sonninstraße 3
20097 Hamburg, Germany
Phone: (49) 40 2376-2286
Telex: 2161867 (HEEG D)
Facsimile: (49) 40 2376-2232

ASIA

SHARP Corporation
Integrated Circuits Group
1, 2613-banchi, Ichinomoto-cho
Tenri-shi, Nara Pref. 632, Japan
Phone: (07436) 5-1321
Telex: LABOMETA-B J63428
Facsimile: (07436) 5-1532

Editions: No. 1, 1993
Printed and bound in the U.S.A.

Ref. No. SMT92023