3.1: Invited: What Do the Specifications Mean?

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Abstract
Specifications and "specsmanship" continue to confuse people despite the fact that a solid metrological basis exists for communicating display performance. We review some of the misunderstandings encountered in the display industry and encourage uniformity in expressing measurement of light and reporting display performance.

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1. Introduction
On an exhibition floor we might see two large displays both claiming a contrast of 500:1, but one looks much better (contrast wise) to our eye than the other. Why? "Specsmanship" can be a factor. "Specsmanship" amounts to reporting a measured value that is deliberately intended to mislead or where the display is measured in a configuration in which it would never be used but provides better reporting values. In either case, the intention is to hide a deficiency for competitive purposes. However, specsmanship is not always the reason for confusion in specifications. Another factor might be an ignorance of existing measurement standards that describe how to quantify performance: A manufacturer may have its own and different way of measuring the contrast and did not follow any standard. Another reason for misleading specifications is that existing measurement methods are inadequate to properly characterize a display property that the manufacturer deems important, yet a common name is used to describe the result.

In addition to confusion over what the specifications mean, there can be confusion over what the quantities are and what their units mean. Luminance and brightness are often confused, for example. The unit of illuminance can be confused with the unit of luminous flux when discussing projectors. Sometimes the units used to quantify a property of a display can be entirely wrong. For example, a projector's illuminance is incorrectly called luminance, and brightness is incorrectly claimed to be measured in luminance units. For such a projector, the quantity of interest may be the luminous flux, but to speak of "ANSI lumens" is incorrect (ANSI is American National Standards Institute). ANSI is not the "keeper" of the lumen. We are not measuring the lumen; we are measuring the flux in units of lumens. "ANSI flux" would be a correct term for the measurement of projector flux using the ANSI method.

In the following we try to address some of the above problems by placing our specifications upon a solid bedrock of display metrology. We do this by referring to the FPDM—the Flat Panel Display Measurements Standard offered by the Video Electronics Standards Association in version 2.0 (version 2.0 is specifically referred to as FPDM2). [1] Currently, the FPDM2 is a 322-page document that is very reasonably priced so it can be readily obtained for wide distribution and ease of use. The FPDM provides a buffet of measurement procedures that can be selected as needed to quantify display performance. Each measurement method has a unique name and number so that confusion between measurement results is prevented. The measurement result to be reported shares the name of the measurement method. The users of the FPDM are encouraged to maintain the nomenclature in their reporting to avoid confusion and specsmanship.

2. Unit Confusion
Tutorials are provided in the FPDM (A200 Technical Discussion Section) to assist the reader with understanding the units of photopic light measurements. The fundamental metrics most often used in the display industry to quantify light are found in Table 1 (see FPDM sections A201, 2, 3, etc.). For further discussion and conversions to non-SI units see FPDM A201 (SI is Systéme International d'Unités [International System of Units]). [2]

The unit of luminance, cd/m^2, at one time had a name, the "nit"; but such use is no longer considered proper. The nit is a deprecated unit (see FPDM2 p. 23). There are a number of other units employed to quantify light, but they are rarely used in display measurements. Further, the above considers only photometric measurements. Radiometric measurements are also possible where attention is given to the spectrum of the light. For a full discussion, see FPDM A201 as well as other texts. [3]

Luminance is not equivalent to brightness. Brightness is a psycho-visual response of the vision system and can change depending upon the environment. In fact, one color may appear brighter to the eye but have less luminance. To illustrate this, we can place a bright (fully saturated) green box within a larger white box using graphics software on a computer monitor. To most, the green box seems brighter to the eye than the surrounding white. However, the white has a greater luminance (obviously, because it includes the same green strength plus both the red and blue added). Thus, if we use the term "brightness" we need to be sure that we don't mean "luminance." We don't want to confuse the terms. Our luminance meters measure luminance, not brightness.

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Table 1. Fundamental metrics for display measurements.

Quantity	Symbol	Unit	Comment
luminous flux (or just flux)	Φ	lumen (lm)	Often used in describing the light from a projector or in determining efficiency.
luminous intensity (or just intensity)	I	candela (cd) = lm/sr	Rarely used to describe displays. Used often in calculations and derivations.
luminance	L	cd/m^2	Often used to characterize displays. Confused with brightness.
illuminance	E	lux (lx) = lm/m^2	Often used in front projector measurements to estimate the flux.
Note that luminous exitance M refers to the flux per unit area emanating from a surface and has units of lm/m^2 but is *not* called a lux. The unit lux is used only for illuminance. Luminous exitance is not commonly used in display characterization.			

3. Metrology Bedrock

In writing specifications, a solid basis of metrology needs to be in place before the specifications are meaningful. Participants have to agree to use the measurement procedures upon which such specifications can be based, and they must adhere to the proper nomenclature in reporting values. The FPDM is designed to meet many of these needs by providing well-defined metrology to accommodate the display industry as well as an unambiguous specification language. [4] The FPDM is a methods document that is not concerned with the values of measurement results (acceptance criteria) but *is* concerned with *how* those results are obtained. If people will uniformly employ the FPDM or other similar standard in writing specifications, then the mystery surrounding specsmanship would be reduced.

Consider the case of contrast. The term "contrast" is not uniquely defined, in general, because it has several different definitions. In the FPDM there are 11 different methods to measure a contrast:

- 302-3 Darkroom Contrast Ratio of Full Screen
- 303-1 Line Contrast Ratio
- 303-2 Grille Contrast Ratio
- 303-5 Intracharacter Contrast Ratio
- 304-1 Luminance and Contrast Ratio of Centered Box
- 304-2 Centered Box On-Off Contrast Ratio
- 304-3 Transverse Contrast Ratio of Box
- 304-9 Checkerboard Contrast Ratio
- 304-10 Highlight Contrast
- 306-3 Sampled Uniformity of Contrast Ratio
- 308-2 Ambient Contrast Ratio

Future editions of the FPDM will expand upon this list in order to accommodate the uses and needs of the display industry.

For emissive displays, the FPDM requires that the darkroom contrast ratio of full screen be reported in addition to any other contrast metric that is employed — see Section 300-4. If no description is used and only "contrast" is used to describe the measurement result, then it *must* be this darkroom contrast (some call this dynamic range). For example, one manufacturer may quote a "contrast" that is 500:1 and represents a darkroom contrast of full screen. Another manufacturer may quote a "contrast" that is 500:1, but it represents what amounts to a highlight contrast. (A highlight contrast is the luminance of a small white square at the center of the screen [30×30 pixels in size as defined in 304-10] compared to the luminance of full-screen black.) That same display may exhibit a full-screen darkroom contrast of only 150:1. However, we have no way of knowing that the full screen performance is very different between the two displays unless we ask for a detailed explanation of the methods used to measure the contrasts.

Regarding measurements of white, one manufacturer may give a screen luminance of 200 cd/m^2 when measuring a full-screen white, and the other may also give 200 cd/m^2 but be referring to a highlight luminance rather than full-screen luminance, which might be much lower than the highlight luminance. Thus, although in writing the specification, only a white luminance value is reported, we don't know how that white is measured.

All of these problems can be avoided if we employ a specific terminology based upon an existing standard such as the FPDM. Each unambiguous measurement method we use has a specific name, and that same name is used for reporting the measurement result. If specification writers require that a certain specification be met based upon the metrology in the FPDM, the confusion of what is expected vs. what is delivered is eliminated.

Suppose the above two manufacturers employed the FPDM standard to declare their specifications. We might find the specifications to read as in Table 2. Because Display 1 does not change its contrast for a highlight measurement, the manufacturer reports only the full-screen values. The manufacturer of Display 2 wants to emphasize that the highlight performance is considered important, but the full-screen values must also be reported because of the FPDM requirements. Thus, there is no longer any confusion. However, the manufacturer of Display 2 may not be happy about letting people know of the lower full-screen values. On the other hand, those who want to use such displays in their equipment or their homes might be thankful for the more complete understanding of performance. (The FPDM

Table 2 Reporting based upon the FPDM2.

	L_W (cd/m^2)	C	L_H (cd/m^2)	C_H
Display 1 *	200	500	NR	NR
Display 2 *	60	150	500	1250

* All measurement compliant with FPDM2.

C = full-screen darkroom contrast, C_H = highlight contrast, L_W = luminance of full-screen white, L_H = luminance of 30 px × 30 px highlight white, NR = not reported (no change) requires that if highlight contrast is measured, then the full-screen darkroom contrast must also be measured and reported. Note the statement relating to highlight contrast in FPDM2, Section 304-10, page 98: “It [the highlight contrast] must never be substituted for a full-screen darkroom contrast. Full-screen darkroom contrast must always be included with any reporting of a highlight contrast so the highlight contrast will not be unethically confused with the full-screen darkroom contrast.”)

Another example of specsmanship might be found in efficiency ratings. Luminous efficacy of a source is defined by the CIE [5] and is the kind of quantity that is specified to be measured in the FPDM: 402-2 Luminous Efficacy (symbol η). Some have *unfortunately* attempted to choose this term to mean something quite different. For what should be called by some other entirely different name, we will use the symbol ι, which is the luminous flux Φ_W of a full-white screen divided by the difference in electrical power between driving the screen at full white, P_W, and full black, P_K; or

$$\iota = \Phi_W/(P_W - P_K). \tag{1}$$

However, people have been tempted to try to call this differential or incremental luminous efficacy (or efficiency), which it is not. If the “differential” or “incremental” gets dropped, they then avoid distinguishing efficiencies and enable confusion of such a quantity with luminous efficacy. Could this be a specsmanship problem? Certainly! If a display were to require so much power that it gets hot, you can hide such a problem by using the calculation for ι but avoid naming it properly so that the reader of the specification is led to think that the display is quite efficient. Such a specification will appear much better when compared with displays of other technologies.

Clearly, Eq. (1) is an unsatisfactory way of characterizing an overall efficiency metric to compare display technologies. If it were to happen that the power used to create black is greater than that needed to create white, then ι becomes negative. If the powers are the same, ι is infinite. And if the display did require 5000 W for white and 4999 W for black with a luminous flux for white of 1000 lm, then ι = 1000 lm/W; this sounds very efficient and would be an extraordinarily attractive number—and misleading—for a display upon the surface of which we might cook an egg!

Viewing angle is another specification that is surrounded with confusion. Many simply state a viewing angle without describing, in some way, what criteria are used to establish that viewing angle. The FPDM lists six viewing-angle measurements, all with different names and parametric descriptions.

Black luminance is also confusing. Some will adjust the controls on the display to obtain the darkest black in a darkroom or dimly lit room and then measure the luminance of the black screen. Never mind that the display could never be used with such an adjustment of its controls. The FPDM specifies that the display must be adjusted to adequately show the task information and that usually requires that the levels near black and white be simultaneously visible—see Section 301-3A. Similar maladjustments can be made for white. In either case, unrealistic values for white or black are obtained and reported.

The whole point of this discussion is this: If we need to characterize a certain type of quality for our display that distinguishes it in some way, and a suitable metric doesn’t yet exist, then we create a new metric with a new name to distinguish it from existing metrics. We don’t simply “borrow” the name of an established metric and slap it on a new metric. To create fair and appropriate metrics that don’t confuse is the purpose of standards committees and working groups. It is what the FPDM attempts to do. If more metrics are needed, then appropriate additions can be quickly made to the FPDM via an update document (see FPDM2: 101-7, p. 3).

4. Reflection Characterization

The darkroom performance of a display may be very different from its performance in ambient light. Simple models of reflection include specular (or regular) reflection and Lambertian reflection. The specular reflectance ζ can be expressed in terms of the luminance L_s of the source and the luminance L of the observed distinct virtual image of the source, where the source and detector are placed on opposite sides of the normal to the display surface:

$$L = \zeta L_s. \tag{2}$$

Thus, the luminance of the virtual image of the source is proportional to the luminance of the source. This kind of specular reflection is mirror-like in that it produces a distinct (non-hazy) virtual image of the source. Lambertian reflection is characterized by

$$L = \rho E/\pi, \tag{3}$$

where L is the reflected luminance, E is the illuminance, and ρ is the diffuse reflectance. The luminance of a Lambertian material (either source or sample) is the same no matter from what direction that luminance is observed. Also, for a Lambertian surface, the luminance does not depend upon the direction from which the illuminance comes. These two simple models, adequate for old television sets, are often inadequate to deal with many modern display surfaces. They are oversimplifications, and measurement methods based upon the thinking that lies behind these simple models are often found to be irreproducible when applied to many modern displays.

Adding to the complexity, many people confuse diffuse reflection with Lambertian reflection and apply the formula in Eq. (3) with impunity; doing so will often lead to erroneous results. Diffuse means scattering light energy out of the specular beam (the specular beams would be found from using a perfect mirror). Many displays, such as used in laptops, exhibit a substantial diffusion about the specular direction and are far from Lambertian. Thus, when a small light source is observed in a reflection, if there is a fuzzy ball of light surrounding the virtual image of the source (if a distinct virtual image is even visible), then there is a component of reflection that has been called haze. Haze is a diffuse reflection that follows the specular direction but is proportional to the illuminance. Haze is a reflection property somewhat intermediate between specular and Lambertian. [6] Whenever haze is nontrivial, then the measurement of reflection can become very sensitive to the geometry of the apparatus used to make the measurement. [7] Unless a robust measurement apparatus is employed, the measurement result will often be found to be irreproducible.

Of the three most robust reflection measurement apparatus in common usage, [7] probably the most robust and reproducible apparatus uses a uniform diffuse illumination. [8] Such an apparatus is employed in FPDM reflection measurements 308-1 and 308-2. Ambient contrast (308-2) is a useful metric that has been avoided to date because it provides low contrast values. However, it is a contrast metric that permits the comparison of reflective and emissive displays. We can define $C_A(E)$ to be the ambient contrast for diffuse illuminance E expressed in lux. Different illuminance levels can be used for different tasks. We might use $E = 5000$ lx for diffuse daylight, 500 lx for bright office, 100 lx for a living room, and 5 lx for a dark living room. In this way the ambient-contrast metric can be tailored to the application. A $C_A(500) = 10$ is a reasonably good value to obtain.

5. Composite Metrics

In the future, we can expect that “bang-for-the-buck” metrics or composite metrics will become more common in order to address task-oriented needs. Such composite metrics are the products of powers of basic metrics that are either fundamental or derived metrics (examples of fundamental metrics are luminance, flux, size, power, etc.; examples of derived metrics are contrast, luminous efficacy, etc., that amount to simple and intuitive combinations of fundamental metrics). Consider a number N of basic metrics Q_n that characterize the quality of a display in different ways, each with a threshold or minimally acceptable or desired value T_n and a possible offset q_n. A composite metric G—a quality or goodness metric—may be composed via a product of powers of the basic metrics normalized to their acceptable values:

$$G = G_0 \prod_{n=1}^{N} \left(\frac{Q_n - q_n}{T_n} \right)^{m_n} , \qquad (4)$$

where m_n are powers selected to emphasize ($m_n > 1$) or de-emphasize ($m_n < 1$) the relevant contribution of each component base metric Q_n , and where G_0 is a scaling factor, if needed. This formalism could be obviously extended to a large number of base metrics that all combine to yield a quality metric G that is tailored to suit each task. If the thresholds T_n are included then the quality metric G is unitless; if they are not included, then G will have physical units unless eliminated by the scaling factor G_0.

Consider, for example, the contrast $C = L_W/L_K$, where we feel that a contrast of 100 is good (a threshold). Another base metric is the luminance L_W of full-screen white, where the threshold of acceptability might be 150 cd/m^2. If an ambient contrast (with an illuminance of 500 lx) of $C_A = 10$ is considered desirable, then we might write a composite metric based upon these three basic metrics as

$$G_1 = \left(\frac{C-1}{100} \right)^{1/2} \left(\frac{L_W}{150} \right)^{1/3} \left(\frac{C_A(500)}{10} \right)^{2} , \qquad (5)$$

where the contrast offset is 1. (This example is for illustration purposes only. It is not intended to be employed in practice.) The 1/3 power associated with the luminance is borrowed from the CIE lightness. [3] (See FPDM A200) The exponent of 2 associated with the ambient contrast would be used to emphasize an extreme importance of good ambient contrast for the task for which the G_1 metric is to be applied. Each task could have a composite metric associated with it based upon a different set of base metrics as needed.

6. References

[1] *Flat Panel Display Measurements Standard*, Video Electronics Standards Association, Version 2.0, 322 pp., June 1, 2001. Current chair of the DMC is Joseph Miseli of Sun Microsystems, CA, and the author currently serves as the editor of the document.

[2] Barry N. Taylor, Guide for the Use of the International System of Units (SI), NIST Special Publication 811, 1995 Edition.

[3] For example, see: Günter Wyszecki and W. S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, 2nd Edition (1982, John Wiley & Sons).

[4] E. F. Kelley, "Plotting the Course of the Next VESA Flat Panel Display Measurements Standard," 2004-SID International Symposium Digest of Technical Papers, Society for Information Display, Invited Paper 7.1, Vol. 35, Book 1, pp. 78-81, Seattle, WA, May 25, 2004. To be republished in the Journal of the SID in greater detail.

[5] CIE Publication No. 17.4, International Lighting Vocabulary, Commission Internationale de l'Eclairage (International Commission on Illumination), 1987. A joint publication with the International Electrotechical Commission: IEC Publication 50(845), International Electrotechnical Vocabulary, Chapter 845: Lighting, 1987.

[6] E. F. Kelley, G. R. Jones, and T. A. Germer, "Display Reflectance Model Based on the BRDF," Displays, Vol. 19, No. 1, pp. 27-34, June 30, 1998.

[7] E. F. Kelley, "Sensitivity of Display Reflection Measurements to Apparatus Geometry," 2002-SID International Symposium Digest of Technical Papers, Society for Information Display, Boston, MA, pp. 140-143, May 19-24, 2002.

[8] E. F. Kelley, "Proposed Diffuse Ambient Contrast Measurement Methods for Flat Panel Displays," NISTIR 6738, 6 pp., April 2001.