Fulldome Display Specifications: A Proposal

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Abstract. General standards are proposed for specifying fulldome displays. Proposed specifications include brightness, brightness uniformity, color uniformity, contrast, resolution and update rate. A methodology for measuring edge-blend uniformity is proposed, and suggestions are made for approaching more difficult parameters such as color gamut.

In today's marketplace there are a variety of fulldome display technologies, each with their own unique visual and functional properties. Display technologies currently in use include cathode ray tube (CRT), digital light processor (DLP), liquid crystal on silicon (LCoS) and laser-based displays including 2-dimensional scanning (Zeiss) and the new grating light valve (GLV from E&S). The technical trade-offs involved in selecting an appropriate technology are enough to boggle a display engineer, much less an aspiring fulldome theater owner. While there is no substitute for actually seeing the various technologies in action, a common technical language is required if we are to make display technology selection comprehensible to all interested parties.

This paper proposes that the industry voluntarily adopts standard language for expressing basic display system characteristics, and standard methods for measuring these characteristics. Such practices will go a long way towards helping fulldome customers understand what specific display options can and cannot provide. Armed with a basic understanding of the display characteristics through vendor system specifications, it is hoped that the customer would then be freed to spend more time assessing the more subtle variables involved in system selection, such as maintenance costs, vendor performance and ease of use. In the end, this would result in a more satisfied client whose expectations are more closely aligned with the final delivered theater.

Proposed Specifications

The table below lists the proposed IPS specifications. These specifications are, as much as possible, system level specs that are independent of the specific display technology and dome screen properties, thereby allowing direct comparison between competing systems regardless of the specific installation site and enabling display technologies. The desire is to create a user experience that is similar to shopping for a single video projector where specifications are independent of the screen size and reflectance properties.

It should be noted that this list of specifications is a proposal only, and is expected to be subject to review and revision. This is necessarily only an initial step in display system specification development, which in fact excludes image quality factors related to the specific image generation means. A complete system specification would include image generator characteristics including pixel bit depth, spatial color bandwidth (4:4:4 versus 4:2:0, for instance), image compression options and/or image bit rate. Also, a complete interface specification would be expected for display systems that were being sold independent of an image generator. Such specifications are beyond the scope of this current effort.

Display Parameter	Measurement	Unit
IPS Light Output	Full-white (over entire dome) luminous flux actually delivered to dome surface, accounting for projector masking, overlaps, blending, and color matching. Uses ANSI lumens technique.	lumens (l)
IPS Peak Light Output	Same as above, except the measurement is made with a small area of white rather than full-white which can drive CRT projectors into current limiting.	lumens (l)
IPS Brightness (30/50 method)	Average full-white brightness produced on 30-foot diameter dome screen with 50% reflectivity.	foot lamberts (fL)
Brightness Uniformity	Peak-to-peak variation in brightness across the entire display, with respect to the average brightness. Specification must hold for all three primary colors in addition to white.	percent (%)
IPS Blend Uniformity	Worst-case peak-to-peak variation of brightness measured at three points along a line perpendicularly intersecting the blend region (points measured at center of and on either side of blend region). Specification must hold for all three primary colors in addition to white.	percent (%)
IPS Resolution	Minimum number of pixels projected per degree of arc on the spherical surface, assuming a nominal angular projection (180-degree hemispheric projection for fulldome systems). For non-digital displays a 50% MTF criterion is used.	pixels/degree
IPS Contrast	Instantaneous contrast ratio of typical system (not individual projectors) using IPS test pattern.	N:1 (ratio)
IPS Sequential Contrast	Frame-sequential (full white/full black) contrast ratio of typical system (not individual projectors) using IPS test pattern.	N:1 (ratio)
Color Gamut	CIE 1931 x, y values	numeric x,y
Frame Rate	Maximum, minimum and/or typical number of frames displayed per second, and whether the frame rate is progressive or interlaced.	Frames/second
Gamma	(Your specification here)	

Brightness. All too often, fulldome display brightness is expressed in terms of individual projector light output. Even in the case of fisheye projectors, however, the full 4:3 frame never makes it to the dome screen. Only a circular cutout from the image frame is actually received by the dome, resulting in an image brightness that is 60% of the full projector specification. Additional losses are common in edge-blended systems where brightness compromises are often made to color-balance and blend all projectors. The IPS brightness specification is a system parameter and refers to actual light delivered to the dome surface under normal operating conditions, regardless of the delivery means. It is independent of (or accounts for) projector masking, projector overlaps, edge blending, color matching, lens loss and other device and system-related light losses.

Strictly speaking, brightness is best expressed by luminance, or the luminous intensity per unit area projected in a given direction. In practice, brightness would be measured on the screen surface, typically in the (admittedly arcane) units of foot-lamberts. However, the measurement is meaningless for display system comparison unless a screen area and screen reflectance is specified. By specifying a nominal dome screen diameter and reflectance, we can generate a number that is valid for comparison. I suggest using a 30/50 method where we assume a nominal 30' diameter dome (units of feet to match the foot-lambert units) with a 0.5 reflectance (50% reflectivity).

Alternately, a more universal (and preferred) parameter that can easily be used to compute display brightness is light output (technically known as luminous flux), measured in lumens. This measure is entirely independent of the projection surface. Actual display brightness for a given dome screen can therefore be found by:

Display Brightness (fL) = Screen Reflectance * Light Output (lumens)/Screen Area (sq. ft.)

In the case of light output or brightness, the ANSI technique of using a full-white field is employed. In the case of CRT projectors, a full-white field will force the projectors into current limiting resulting in a lower-than-expected brightness value. In this case, a "peak" brightness and light output parameter may be employed alongside the standard ANSI measure. Peak brightness is measured while projecting a small area of white instead of a full-field white.

Brightness Uniformity. Brightness uniformity refers to the peak-to-peak range of luminance values across the entire display surface, expressed as a percentage of the average brightness. Peak-to-peak brightness Bpp is found by:

Bpp (%) = (Bmax – Bmin)/Bavg * 100

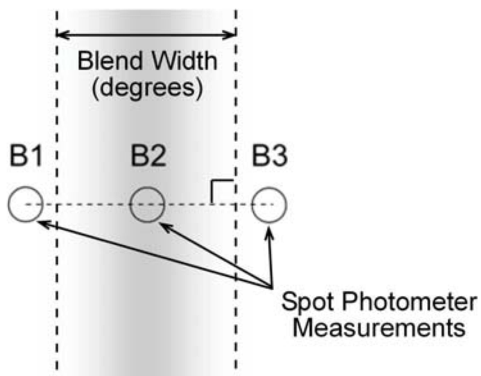
Where Bmax is the highest brightness measured in the set, Bmin is the lowest measured value, and Bavg is the average of all measurements. In theory this would include local luminance variations within blend regions as well as projector-to-projector variations. It is conceptually and empirically easier, however, to break these measurements into two separate categories – Brightness Uniformity and Blend Uniformity. Single-projector systems are exempt from the latter specification.

Flexibility is called for in brightness uniformity measurements. A rigorous method would be to make spot photometer measurements at fixed, equally spaced azimuth and elevation coordinates over the entire display. Such an approach would be overly burdensome, however, requiring perhaps hundreds of points to achieve an accurate measurement. Certain factors often dictate a specific set of measurement points. For instance, in a multi-projector system we might measure brightness at the center and four corners of each individual projector frame (avoiding the blend regions themselves). For a single-projector system, measurements might be made in four quadrants at a lower and higher elevation. Since it is intended to be a worst-case specification, then wherever the measurements are conducted the specification should still hold true.

Blend Uniformity. In edge-blended systems it is useful to have a measure of how seamlessly the projectors are blended. This may be accomplished by taking three measurements along a line that cuts through a blend region perpendicularly. One measurement (B2) is made at the center of the blend. The other two measurements (B1, B3) are made on either side of the blend. Blend brightness uniformity is therefore the peak-to-peak percent luminance variation through this region, given by:

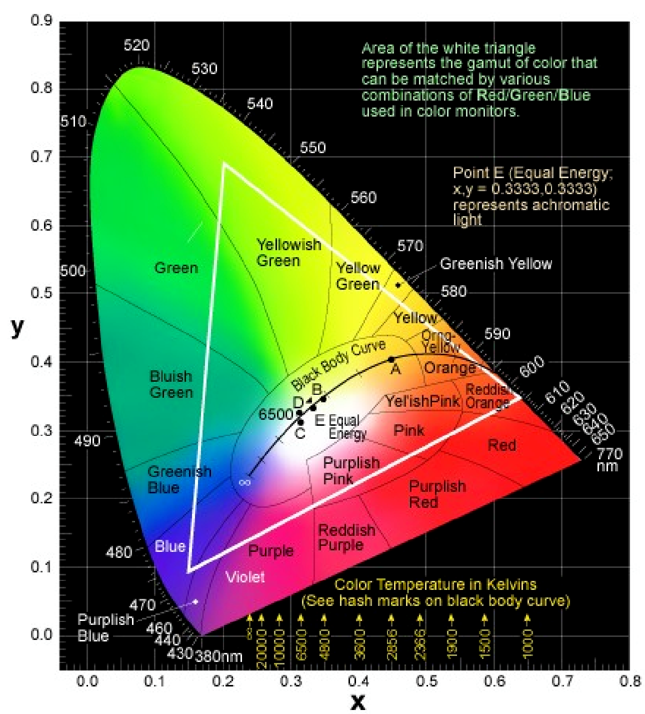
$$Bpp = (Bmax – Bmin)/Bavg.$$

Blend uniformity of approximately 5% or better typically results in a near-seamless blend, but this figure also depends on the angular width of the blend, which should be specified for completeness.



Edge-blend uniformity measurement using three spot photometer readings.

Color Gamut. Color gamut is a function of the color values used in the red, blue, and green primaries within the projector optics. The most commonly used color space for specifying gamut is the 1931 CIE Chromaticity diagram. Each unique color value can be expressed using two coordinates (x,y). Three color values would have to be specified to define a color gamut for a given projector technology. It should be noted that, in practice, projector manufacturers rarely specify these values, and color space measurements are not generally well understood. Nevertheless, with the advent of laser projector technologies that vastly expand color gamut, the CIE chromaticity diagram would provide a useful means to compare and contrast the differences between various projection technologies and is therefore

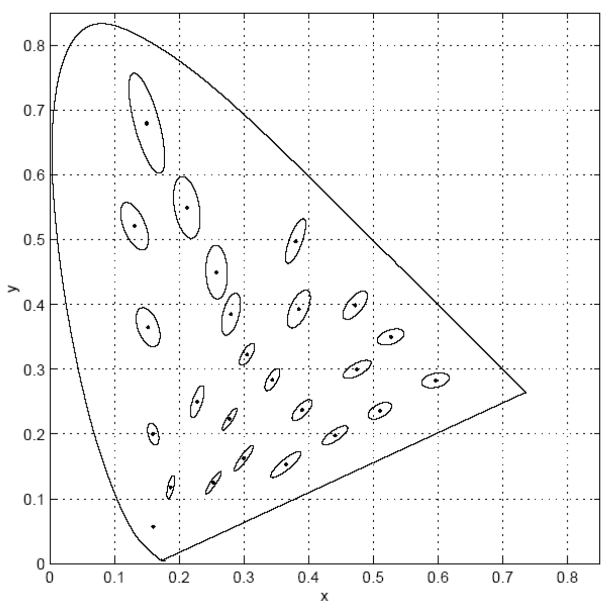


1931 CIE Chromaticity Diagram & Color Gamut
Image courtesy of LEDtronics, Inc. www.ledtronics.com

included in this specification.

Color Uniformity. Perhaps the most difficult parameter to measure and specify is color uniformity. Again, the spatial parameter is crucial, with a given difference in color across a small region of the dome being more perceptible than the same difference spread over a larger area.

Instruments are available to measure color, and can compute color differences based on scales that account for the human eye's sensitivity to color shifts as a function of where that particular color lies in color space. This is illustrated by the MacAdam ellipses on the CIE 1931 (x,y) chromaticity diagram that represent how far one can stray from a given color before the average human observer will notice a shift. This led to the MacAdam unit (FMC II dE), which has largely been superceded by the CIE76 dE and CIE94 dE systems. In these systems, one delta E represents the detectable threshold difference between two colors.

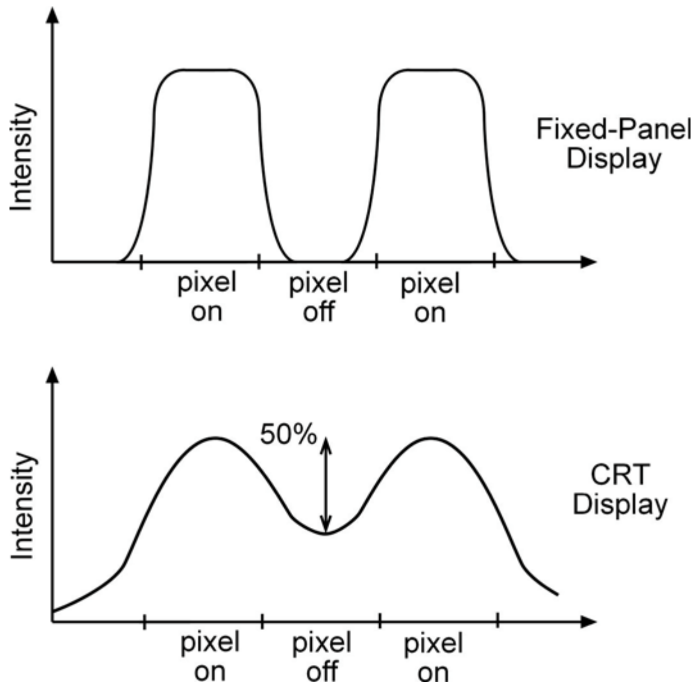


MacAdam ellipses shown on the CIE 1931 (x,y) chromaticity diagram at 10x magnification [Wyszecki 1982]

While delta E measurements could yield an acceptable means of specifying and measuring color, this is currently far from industry practice. To be effective, standards should exemplify common industry practices rather than attempt to force practices that require the purchase of hitherto unnecessary equipment and burdensome measurements. The fulldome industry is probably not yet ready for the imposition of delta E color standards, although they may well be used in-house by projector manufacturers to match individual projectors together. The utility of delta E measurement must first be demonstrated in practice prior to being proposed and adopted. I therefore recommend an alternate approach that involves an extension of common brightness measurements and reasonable assumptions regarding the projection systems.

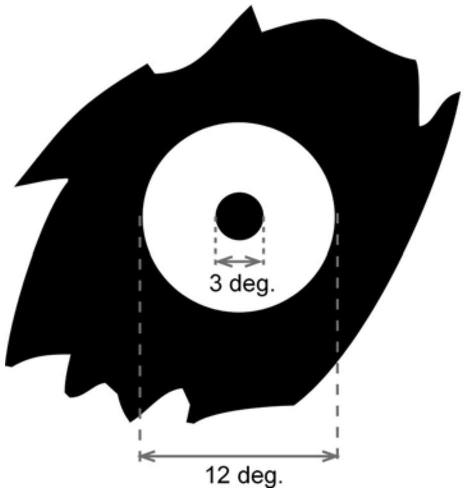
Almost without exception, video projectors utilize additive color mixing with red, green and blue primaries. If we assume that the inherent color of each primary is well matched from projector-to-projector, we can simply repeat the brightness uniformity measurements on a per-color basis to verify color uniformity across the display. This method would provide three brightness uniformity values – one for red, blue and green. The test patterns required would therefore by full-field red, blue and green, and the measurement would be a percent. However, for the purposes of a functional specification, it is sufficient to require that the same Brightness Uniformity and Blend Uniformity peak-to-peak values apply for both full white and for individual colors.

IPS Resolution. It is proposed that display resolution be expressed in resolvable pixels per angular degree (measured with respect to spherical dome coordinates). This measurement is easily understood and is especially compatible with newer digital projector technologies where pixels are nearly always individually resolvable. In the case of non-fixed panel displays such as CRT projectors, resolution would be the number of addressed pixels per degree provided that a 50% MTF (Modulation Transfer Function) is achievable at this pixel density. That is, when successive pixels alternate between white and black, the contrast ratio between the two shall be at least 50% at the highest pixel resolution.



50% MTF Requirement for Defining CRT Resolution

IPS Contrast Ratio. Projector contrast ratio is commonly measured using a 16x16 checkerboard pattern according to the American National Standards Institute (ANSI) standard. This method must be modified somewhat for the dome screen, resulting in a unique IPS contrast ratio specification. In a traditional neutral-density dome screen environment, the cross-dome scatter typically reduces the contrast ratio to 10:1 or less when used with a fulldome checkerboard pattern – a figure that varies from theater-to-theater depending on dome reflectivity, dome geometry, and theater finishes. In fact, the ANSI method would effectively measure the properties of the dome screen and not the display system itself, as typical display contrast ratio would be masked by the light scattered by a large checkerboard pattern on the dome.



IPS Contrast Ratio Test Pattern

To achieve a theater-independent measure of contrast I recommend the adoption of a standard test pattern consisting of a white circle against a full black background with a small black cutout area within the circle. The overall circle is 12-degrees in width with respect to dome coordinates, while the smaller cutout is three degrees in width. A one-degree spot photometer is then used to measure the brightness within the center black region, which will largely be a measure of how much light from the surrounding disk scatters into the center region. This pattern is not based on a calculation of the actual scattered light produced in the center region due to cross-dome scatter – it is instead based on the need to accommodate a typical spot photometer. Ideally the entire pattern would be made as small as possible to nearly eliminate "measurement noise" produced by cross-dome scatter. I would welcome such a calculation for typical dome reflectivity's to verify the maximum contrast ration able to be measured by this method.

Frame Rate. Finally, frame rate is of interest when comparing systems. This parameter is typically fixed, although some systems do allow a variable update rate. Frame rate is expressed in frames or fields per second, and is designated as either progressive scan (p) or interlaced scan (i).

References

[Wyszecki 1982] G. Wyszecki & W.S. Stiles, Color Science: Concepts and Methods, Quantitative Data and Formulae, John Wiley & Sons, New York, 1982

[Halsted 1993] Charles P. Halsted, "Brightness, Luminance, and Confusion," Society for Information Display, March 1993, http://www.crompton.com/wa3dsp/light/lumin.html