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Luminous Contrast and Sunlight Readability of the HCMS-235X Series LED Alphanumeric Displays for Sunlight Viewable Applications

Application Note 1029

Contents

Introduction

Military specifications for avionics and other kinds of electronics that require readability in sunlight use specific definitions for luminous contrast. The concept of chrominance contrast and the theory of Discrimination Index (see Agilent Technologies Application Note 1015, *Contrast Enhancement Techniques for LED Displays*) are not used by the military as a means of determining readability in sunlight. Thus, the military requirements for readability in sunlight are based solely on luminous contrast measurements.

This application note discusses the luminous contrasts used by military specifications, describes anti-reflection/circular polarized filters designed for use with the HCMS-235X series sunlight viewable LED displays, and presents luminous contrast data for various HCMS-235X display/ filter combinations.

Luminous Contrast

In this application note, luminance refers to luminous intensity per unit area, which is luminous sterance in units of foot-lamberts, fL, or candelas per square meter, cd/m^2.

Definition of Luminous Contrast

Luminous contrast (C) is a comparison of the average luminance of a display pixel, illuminated and non-illuminated, with the average luminance of the area immediately surrounding the pixel. The luminance of the illuminated pixel is determined by the light output of the LED. The luminance of the non-illuminated pixel is due to the ambient light reflected off the pixel. The luminance of the area immediately surrounding the pixel is due to reflected ambient light off the background. The purpose of a contrast enhancement filter is to increase contrast between the illuminated pixel and the background by reducing the amount of reflected ambient light in relationship to the amount of display emitted light.

The luminous contrasts discussed in this application note are exclusive of specular reflections off the filter window, the situation where the image of the sun is reflected into the eye of an observer.

The Military's Definition for Luminous Contrast

Military documents and specifications, such as MIL-P-7788F, MIL-S-22885D, MIL-S-

38039B, and MIL-L-85762A may use up to three definitions for luminous contrast: on-pixel to background, on-pixel to off-pixel, and off-pixel to background, Equations 1, 2 and 3:

On-pixel to background (C_1):

$$C_1 = \frac{L_2 - L_1}{L_1} \quad (1)$$

On-pixel to Off-pixel (C_2):

$$C_2 = \frac{L_2 - L_3}{L_3} \quad (2)$$

Off-pixel to background (C_3):

$$C_3 = \frac{|L_3 - L_1|}{L_1} \quad (3)$$

Where:
L1 = Average luminance of the background area immediately surrounding the pixel due to reflected ambient light.
L2 = Average luminance of the ON (illuminated) pixel.
L3 = Average luminance of the OFF-pixel due to reflected ambient light.

Military Requirements for Sunlight Readability

The military requirements for luminous contrast for sunlight readability of alphanumeric LED displays, as defined by Equations 1, 2, and 3 and specified in MIL-L-85762A are:

On-Pixel to Background
(C_1) $\geq$ 2.0:1 Minimum
On-Pixel to Off-Pixel
(C_2) $\geq$ 2.0:1 Minimum
Off-Pixel to Background
(C_3) $\leq$ 0.25:1 Maximum

Alphanumeric LED Display/Filter Combinations that meet Military Requirements for Sunlight Readability

Sunlight Viewable Alphanumeric LED Displays

The HCMS-235X family of alphanumeric LED displays are glass window, ceramic package devices especially suited for use with circular polarizing filters. With effective filtering, the HCMS-235X series of sunlight viewable alphanumeric LED displays produce sufficient light output to meet military luminous contrast requirements for readability in sunlight. For this reason, the HCMS-2351/2352/2353 displays were used to make the contrast measurements contained within this application note.

Contrast Enhancement Filters

Antireflection coated, circular polarized, AR/CP, optically tinted bandpass glass filters are used with the HCMS-235X series sunlight viewable LED displays to achieve sufficient luminous contrast for readability in sunlight. The construction of these filters is a sandwich, as illustrated in Figure 1, with the circular polarizer (and an EMI screen, if required) placed between two sheets of glass. The front sheet of glass has an anti-reflective quarter wave coating to reduce front surface reflections.

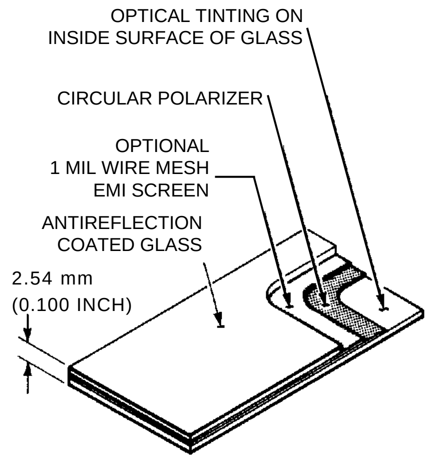

Figure 1. Construction of an Antireflection Coated/Circular Polarized Glass Filter.

Figures 2, 3, and 4 present optimal relative transmission characteristics for bandpass AR/CP glass filters. Figure 5 presents the relative transmission characteristic for a neutral density AR/CP filter. The optimum transmission for maximum luminous contrast is 14% (tolerance 11% to 17%) at the LED peak wavelength as shown in Figure 6. Luminous contrast decreases as the filter transmission increases above or decreases below the 14% value. The bandpass filters provide the best luminous contrast as they fully attenuate all wavelengths of light in the blue green and blue regions and have minimal transmission in the deep red region.

The antireflection coating on the front face of the glass filter reduces front surface reflections from 4% to a nominal 0.25%, for off-axis viewing angles up to 30 degrees. Front surface reflections increase proportionately with off-axis viewing angles greater than 30 degrees.

The circular polarizer reduces specular surface reflections off the face of the display package, LED, and IC chips to a level less than 1%.

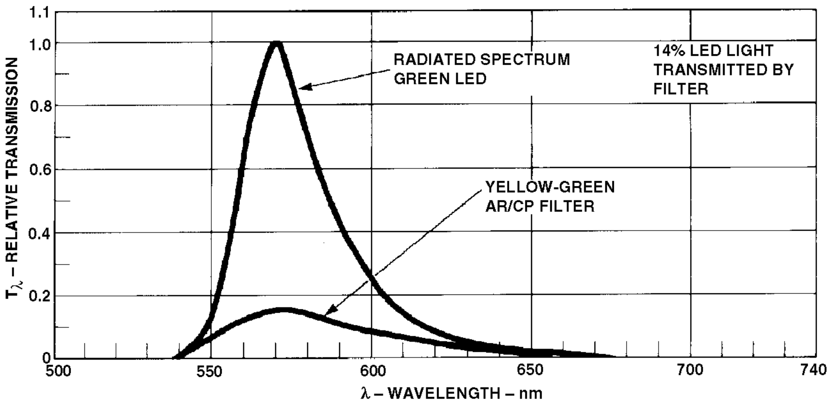

Figure 2. Relative Transmission Characteristic for Yellow-Green AR/CP Glass Filter.

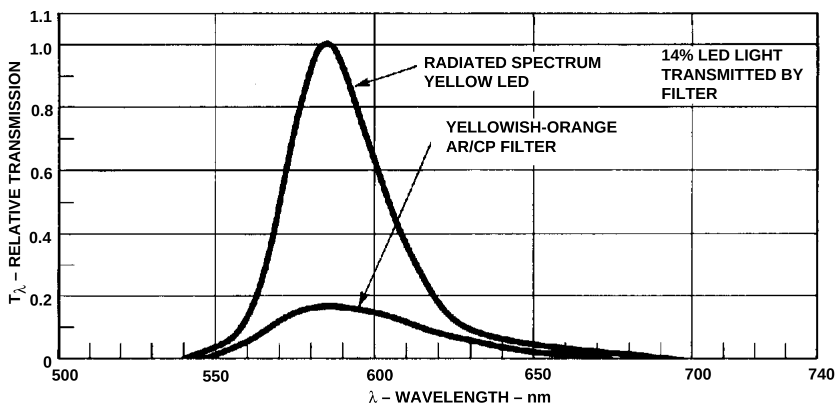

Figure 3. Relative Transmission Characteristic for Yellowish-Orange AR/CP Glass Filter.

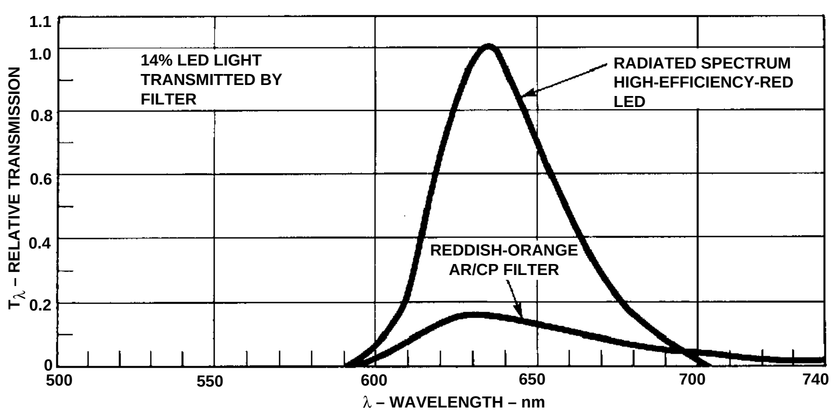

Figure 4. Relative Transmission Characteristic for Reddish-Orange AR/CP Glass Filter.

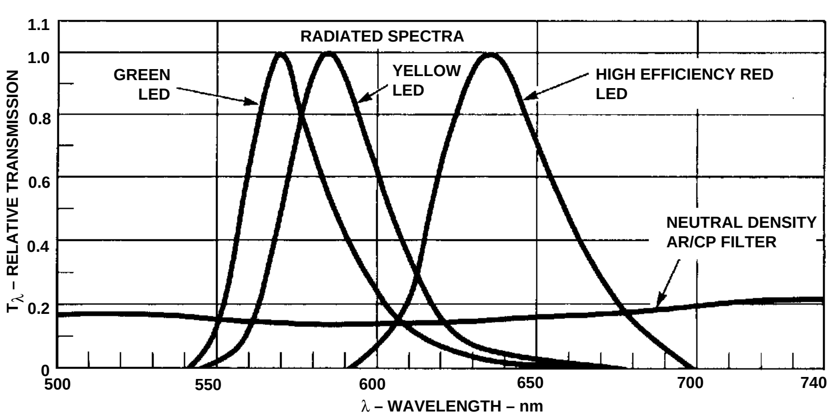

Figure 5. Relative Transmission Characteristic for Neutral Density AR/CP Glass Filter.

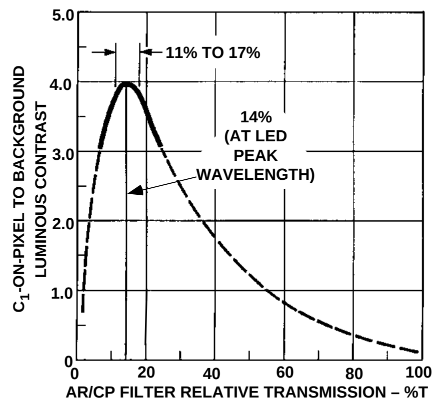

Figure 6. Luminous Contrast vs. Filter Transmission.

List of Filter Manufacturers

The following are two AR/CP glass filter manufacturers:

HOYA Optics, Inc.
960 Rincon Circle
San Jose, CA 95131
Tel: 1-408-435-1450
Fax: 1-408-435-1536

Marks Polarized Corporation
275-D Marcus Blvd.
Hauppauge, NY 11788
Tel: 1-516-273-8900
Fax: 1-516-273-1198

Luminous Contrast Measurements

Agilent Technologies has made luminous contrast measurements on the HCMS-235X series LED displays under simulated 10,000 footcandle sunlight in combination with AR/CP glass filters. The results of those measurements are presented in this section.

Contrast Measurement Setup and Procedure

Measurement Setup: The measurement setup is illustrated in Figure 7. A Photo Research Spectra Pritchard spot photometer Model 1980A with a Macro

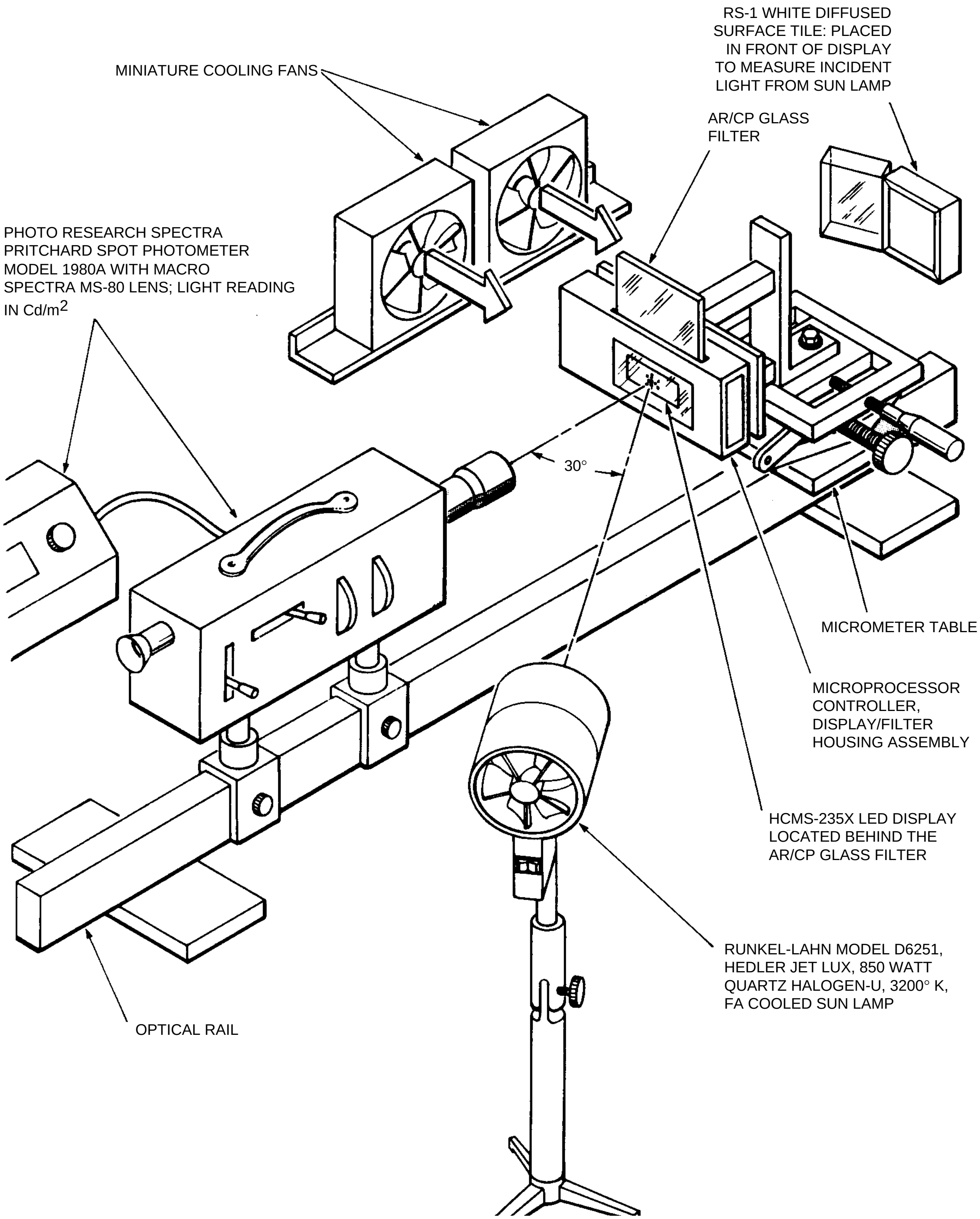

Figure 7. Luminous Contrast Measurement Set-up.

Spectar MS-80 lens and a micrometer table were mounted to an optical rail. A micro-processor controller was used to drive the displays under test at an LED on time duty factor of 16.25% to simulate the operation of a 16 character display. The displays were mounted on a display PC board and supported by the micrometer table. Simulated sunlight was provided by a Runkel-Lahn Model D6251, Hedler Jet Lux, 850 watt quartz halogen-U lamp with a color temperature of 3200°K. The lamp was set at an incident angle of 30° off axis and at a distance to provide 10,000 footcandles of incident light. Cooling fans were used to prevent overheating of the displays under test due to the close proximity of the sun lamp.

Measurement Procedure: Before measurements were taken, the Pritchard photometer amplifier offset was set to zero and the gain set to a calibration factor of 5.36 ±0.20. The Pritchard photometer was used to set the incident simulated sunlight at 10,000 footcandles by measuring the light reflected off a Photo Research RS-1 white, diffused surface tile placed in front of the display PC board assembly.

All measurements were made using the Pritchard photometer's 2 minute angle, 0.102 mm (0.004 inch) diameter spot, the sun lamp on and an AR/CP glass filter placed in front of the display under test.

Luminous Contrast Data

Display light output: The data presented were obtained from displays of each color. The data sheet peak luminous intensity per LED pixel and light output categories are listed below as combined averages for the displays that were measured:

HCMS-2353 Green:
4300 µcd/LED; Light Output Category "U"
HCMS-2351 Yellow:
3700 µcd/LED; Light Output Category "T"
HCMS-2352 HER:
4100 µcd/LED; Light Output Category "U"

Note: Light output categories for the HDSP-235X displays are identified on the back of the display packages by letters of the alphabet, with "S" identifying the minimum brightness category and subsequent letters identifying higher brightness categories. The data sheet minimum peak luminous intensities, Iv PEAK, for category "S" displays are: 2400 µcd peak for the HCMS-2353 green and HCMS-2351 yellow displays and 1920 µcd peak for the HCMS-2352 high efficiency red display.

Selected pixels: Figure 8 shows the pixels that were selected for contrast measurement from the two inboard digits of each display under test. The asterisk (*) was used as the illuminated character to obtain two pixels of opposite contrast conditions. Pixel A was selected because it has four illuminated pixels surrounding it and pixel B was selected because it has four non-illuminated pixels surrounding it. Measurements from these two pixels were combined to obtain data that would be representative of a typical pixel in any given character.

Measurement points: Figure 9 shows the measurement points selected for each pixel. The measurement points were selected to obtain luminance data from the LED chip, gold die attach pad, ceramic substrate and the gold trace between pixels.

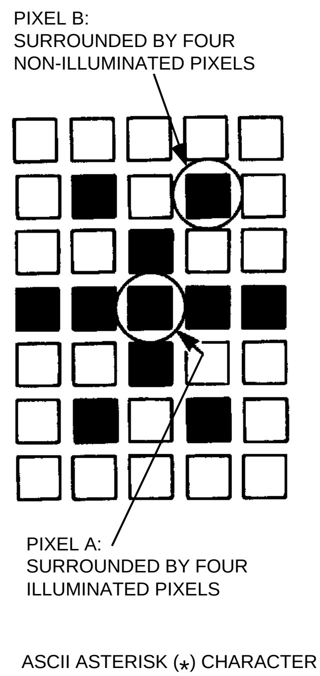

Figure 8. Pixels Selected for Contrast Measurement.

Measurement data: Luminance measurements from pixels A and B of characters 2 and 3 for each of the display/filter combinations were combined into measured representative data for a typical pixel. This representative data is presented in Table 1 for the HCMS-2353 green displays, Table 2 for the HCMS-2351 yellow displays and Table 3 for the HCMS-2352 high efficiency red displays.

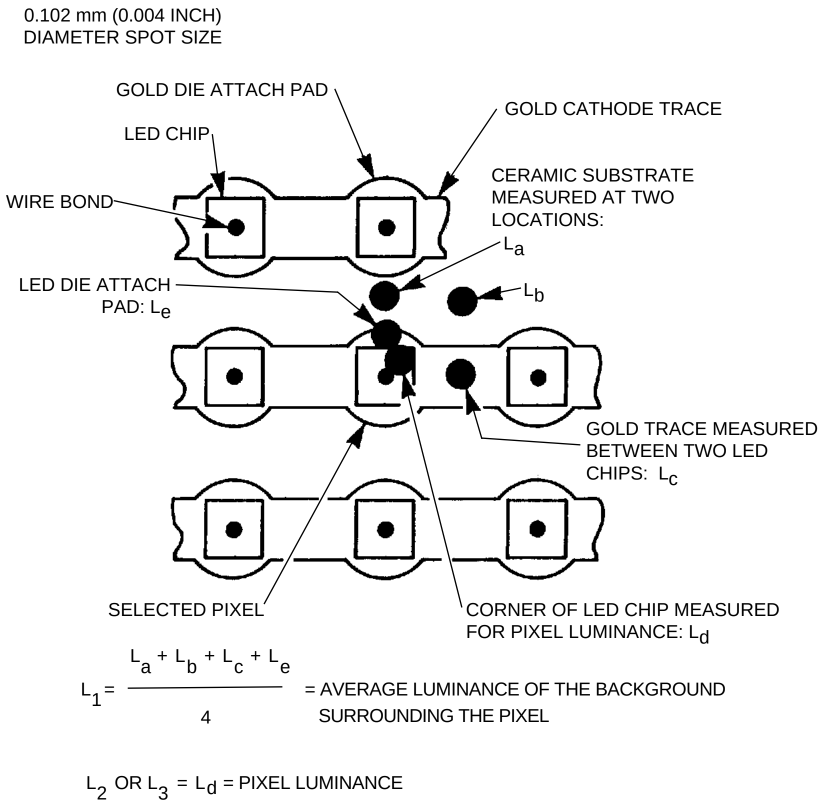

Figure 9. Luminous Stearance, Lv, Points for Luminous Contrast Measurements.

Luminous Contrast Calculations

The following calculations use the data in Tables 1, 2, and 3 to determine luminous contrast in simulated 10,000 footcandle sunlight using Equations 1, 2, and 3.

Equations 4 and 5 define the terms of equations 1, 2, 3 in terms of the pixel luminance values presented in Tables 1, 2, and 3.

Example calculations are given for the luminous contrast values for the two HCMS-2353 green LED display/filter combinations. Similar calculations give the luminous contrast values for the HCMS-2351 and HCMS-2352 display/filter combinations.

$$L_1 = \frac{L_a + L_b + L_c + L_e}{4} = \text{Average luminance of the background surrounding the pixel, fL} \quad (4)$$

$$L_2 \text{ or } L_3 \text{ or } = L_d = \text{Pixel luminance, fL} \quad (5)$$

Table 1. Representative Luminance Data for a Typical Pixel in Two HCMS-2353 Green LED Display, AR/CP Glass filter Combinations.

	Yellow-Green Bandpass Filter		**Neutral Density Filter**	
Data Point	Pixel Off	Pixel On	Pixel Off	Pixel On
L_a	7.7 (26.5)	11.6 (39.7)	13.7 (46.8)	18.6 (63.6)
L_b	6.4 (21.9)	8.9 (30.4)	11.2 (38.4)	15.1 (51.8)
L_c	12.4 (42.4)	30.0 (102.9)	30.8 (105.4)	57.2 (195.8)
L_d	7.9 (27.0)	122.1 (418.3)	15.5 (53.1)	173.6 (594.6)
L_e	10.4 (35.7)	40.7 (139.3)	26.6 (91.1)	70.4 (241.1)

Data = fL (cd/m^2)

Table 2. Representative Luminance Data for a Typical Pixel in Two HCMS-2351 Yellow LED Display, AR/CP Glass filter Combinations.

	Yellowish-Orange Bandpass Filter		**Neutral Density Filter**	
Data Point	Pixel Off	Pixel On	Pixel Off	Pixel On
L_a	9.4 (32.3)	14.1 (48.2)	14.7 (50.3)	17.4 (59.7)
L_b	6.6 (22.7)	9.0 (30.7)	9.8 (33.6)	11.9 (40.9)
L_c	16.6 (56.7)	43.5 (148.9)	33.3 (114.2)	56.3 (193.0)
L_d	10.0 (34.3)	115.4 (392.5)	14.6 (50.1)	127.0 (435.2)
L_e	15.4 (52.6)	40.4 (138.3)	27.5 (94.2)	52.5 (180.0)

Data = fL (cd/m^2)

Table 3. Representative Luminance Data for a Typical Pixel in Two HCMS-2352 High-Efficiency Red LED Display, AR/CP Glass filter Combinations.

	Reddish-Orange Bandpass Filter		**Neutral Density Filter**	
Data Point	Pixel Off	Pixel On	Pixel Off	Pixel On
L_a	8.3 (28.4)	12.1 (41.3)	13.0 (44.4)	15.8 (54.1)
L_b	6.7 (22.8)	9.2 (31.4)	10.1 (34.7)	12.3 (42.3)
L_c	13.1 (44.8)	50.6 (173.3)	23.2 (79.5)	57.3 (196.2)
L_d	9.5 (32.4)	195.1 (668.5)	15.4 (52.9)	176.6 (604.9)
L_e	12.3 (42.1)	33.7 (115.3)	21.1 (72.4)	39.1 (134.1)

Data = fL (cd/m^2)

Example Calculations for the HCMS-235X/Filter Combinations

Luminance values are determined from the data in Table 1 and Equations 4 and 5:

Representative luminance values for the HCMS-235X with a yellow-green bandpass AR/CP filter:

$$L_1\,(ON) = \frac{11.6 + 8.9 + 30.0 + 40.7}{4} = 22.8\ fL$$

$$L_1\,(OFF) = \frac{7.7 + 6.4 + 12.4 + 10.4}{4} = 9.2\ fL$$

$$L_2 = 122.1\ fL$$

$$L_3 = 7.9\ fL$$

$$C_1 = \frac{122.1 - 22.8}{22.8} = 4.4$$

$$C_2 = \frac{122.1 - 7.9}{7.9} = 14.5$$

$$C_3 = \frac{|\ 7.9 - 9.2\ |}{9.2} = 0.14$$

Representative luminance values for the HCMS-235X with a neutral density AR/CP filter:

$$L_1\,(ON) = \frac{18.6 + 15.1 + 57.2 + 70.4}{4} = 40.3\ fL$$

$$L_1\,(OFF) = \frac{13.7 + 11.2 + 30.8 + 26.6}{4} = 20.6\ fL$$

$$L_2 = 173.6\ fL$$

$$L_3 = 15.5\ fL$$

$$C_1 = \frac{173.6 - 40.3}{40.3} = 3.3$$

$$C_2 = \frac{173.6 - 15.5}{15.5} = 10.2$$

$$C_3 = \frac{|\ 15.5 - 20.6\ |}{20.6} = 0.25$$

Calculated Luminous Contrast Values for HCMS-235X Displays

The luminous contrast values presented in Table 4 are representative for a typical pixel in a character that can be achieved when designing for readability in sunlight.

Table 4. Representative Luminous Contrast Values for HCMS-235X, AR/CP Glass Filter Combinations in 10,000 fc Sunlight.

HCMS-2353 Green LED Display with a Yellow-Green Bandpass AR/CP Glass Filter C_1 = 4.4 C_2 = 14.5 C_3= 0.14	**HCMS-2353 Green LED Display with a Neutral Density AR/CP Glass Filter** C_1 = 3.3 C_2 = 10.2 C_3= 0.25
HCMS-2351 Yellow LED Display with a Yellowish-Orange Bandpass AR/CP Glass Filter C_1 = 3.3 C_2 = 10.4 C_3= 0.16	**HCMS-2351 Yellow LED Display with a Neutral Density AR/CP Glass Filter** C_1 = 2.7 C_2 = 7.7 C_3= 0.31
HCMS-2352 HER LED Display with a Reddish-Orange Bandpass AR/CP Glass Filter C_1 = 6.4 C_2 = 19.6 C_3= 0.06	**HCMS-2352 HER LED Display with a Neutral Density AR/CP Glass Filter** C_1 = 4.7 C_2 = 10.4 C_3= 0.08

Luminous Contrast vs. LED On-time Duty Factor

Figure 10 presents graphs of the representative on-pixel to background luminous contrast, C_1, vs. LED on-time duty factor for the HCMS-235X LED display, AR/CP glass filter combinations measured in simulated 10,000 footcandle sunlight for this application note. Table 5 shows the following minimum LED on-time duty factors to meet the minimum value of 2.0 for luminous contrast C_1.

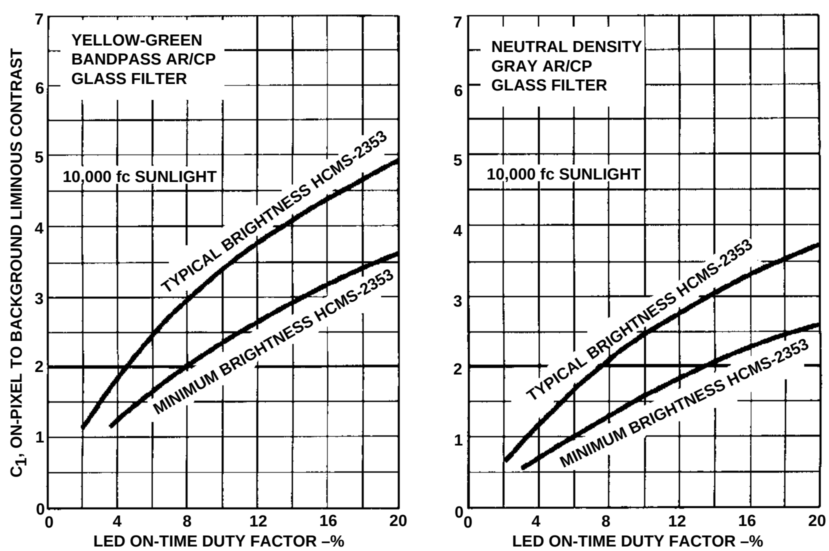

Figure 10a. Representative Luminous Contrast vs. LED On-time Duty Factor for HCMS-2353 Green LED Display, AR/CP Glass Filter Combinations in 10,000 fc Sunlight.

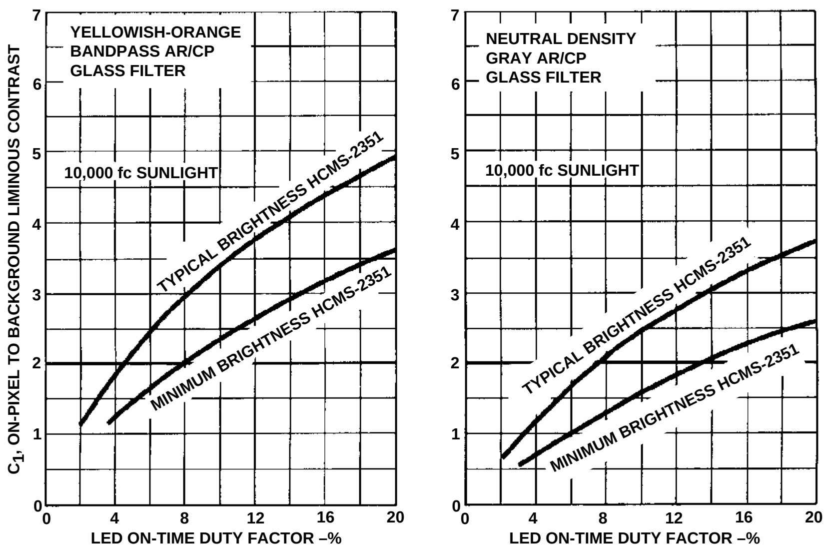

Figure 10b. Representative Luminous Contrast vs. LED On-time Duty Factor HCMS-2351 Yellow LED Display, AR/CP Glass Filter Combinations in 10,000 fc Sunlight.

Display on-time duty factor is a function of display character string length, decreasing with increasing character count as shown in Figure 11. For example, a character string length of 256 characters will have an LED on-time of 8% or higher, when the column refresh rate is 100 Hz and the data is loaded into the display shift registers at a clock rate of 1.5 MHz or faster. For an explanation of LED on-time duty factor see Agilent Technologies Application Note 1016, *Using the HDSP-2000 Alphanumeric Display Family*.

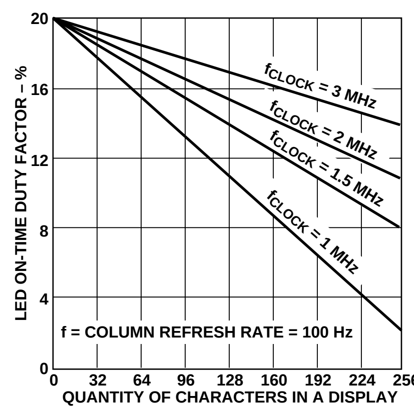

Figure 11. LED On-time Duty Factor vs. Display Character String Length.

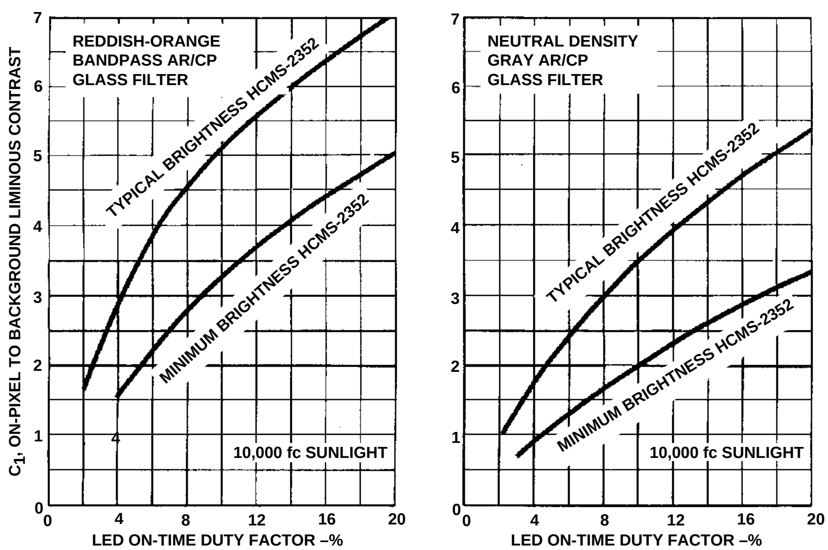

Figure 10c. Representative Luminous Contrast vs. LED On-time Duty Factor for HCMS-2352 High-Efficiency Red LED Display, AR/CP Glass Filter Combinations in 10,000 fc Sunlight.

Table 5. Minimum LED On-time Duty Factors for HCMS-235X, AR/CP Glass Filter Combinations to Achieve an On-Pixel to Background Luminous Contrast Value of C_1 = 2.0 in 10,000 fc sunlight.

HCMS-2353 Green Display
Yellow-Green Bandpass Filter:
Minimum Brightness Display = 8% Minimum LED On-time Duty Factor
Typical Brightness Display = 5% Minimum LED On-time Duty Factor

Neutral Density Gray Filter:
Minimum Brightness Display = 14% Minimum LED On-time Duty Factor
Typical Brightness Display = 8% Minimum LED On-time Duty Factor

HCMS-2351 Yellow Display
Yellowish-Orange Bandpass Filter:
Minimum Brightness Display = 11% Minimum LED On-time Duty Factor
Typical Brightness Display = 7% Minimum LED On-time Duty Factor

Neutral Density Gray Filter:
Minimum Brightness Display = 17% Minimum LED On-time Duty Factor
Typical Brightness Display = 11% Minimum LED On-time Duty Factor

HCMS-2352 High-Efficiency Red Display
Reddish-Orange Bandpass Filter:
Minimum Brightness Display = 6% Minimum LED On-time Duty Factor
Typical Brightness Display = 3% Minimum LED On-time Duty Factor

Neutral Density Gray Filter:
Minimum Brightness Display = 10% Minimum LED On-time Duty Factor
Typical Brightness Display = 5% Minimum LED On-time Duty Factor

Conclusions and Summary

Conclusions

The HCMS-235X series displays, with a light output category of “S” or better, used in combination with an AR/CP glass filter, can achieve sufficient luminous contrast to meet military requirements for sunlight readability.

When an HCMS-235X series LED display is combined with the proper AR/CP glass filter in a 10,000 fc ambient, the on-pixel to background and the on-pixel to off-pixel luminous contrasts, C_1 and C_2, exceed the minimum value of 2.0. The off-pixel to background luminous contrast, C_3, although typically within specification, may exceed the maximum limit of 0.25 when a neutral density filter is used.

The luminous contrast obtained with a bandpass AR-CP glass filter in sunlight is superior to that obtained with a neutral density AR/CP glass filter, and thus is preferred for a single color LED display. For multi-color LED displays, a neutral density AR/CP glass filter is best, and provides sufficient luminous contrast to assure readability of the green, yellow and high efficiency red LED colors.

To assure meeting the military requirements for luminous contrast in 10,000 fc sunlight, the LED on-time duty factor must be set at or above a minimum value depending upon the display light output. Each LED display, AR/CP glass filter combination will dictate the minimum acceptable LED on-time duty factor as listed in Table 5.

Summary

Representative data for a typical pixel in a character, obtained from luminous contrast measurements, show that the HCMS-235X series sunlight viewable LED displays used in combination with an AR/CP glass filter do meet the military requirements for sunlight readability.

Bandpass and neutral density AR/CP glass filters are available from two manufacturers to provide sufficient luminous contrast for readability of the HCMS-235X series LED displays in sunlight.

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