Bringing dreams about contrast down to earth

Contrast values of 1 million ?

The contrast of display screens based on emission of light (e.g. CRTs, PDPs) are often specified with extremely high values. The contrast of e.g. Sony's "XEL-1" OLED TV-set is specified with a value of 1.000.000 (one million, see e.g. http://www.sonystyle.com).

- Under which conditions can such contrast values be measured ?
- How relevant are these contrast values for the actual performance of TV-screens ?

These are the questions we try to *illuminate* in this article.

What is the definition of contrast ?

The visual contrast of a display-screen is defined as the (dimensionless) ratio of the *luminance* of a lighter optical state, L_H, and the *luminance* of a darker optical state, L_L. The luminance (specified in cd/m^2) is the physical quantity corresponding to the perception of *brightness*. This quotient is often called "contrast ratio" (CR) and specified as *number:1* to indicate that it is without dimension.

In most cases the **maximum contrast** that can be achieved with a display screen is specified in the data-sheet. The maximum contrast is given by the luminance of the full white state (R=G=B=100%) and the luminance of the full black state (R=G=B=0). The minimum luminance of display screens based on light-emitting technologies (e.g. CRT, PDP) is very low (theoretically exactly zero) and thus the quotient yielding the contrast becomes quite high (theoretically infinite).

In the case of LCDs light is generated by the backlight unit and the LCD-panel in front of the backlight acts as a spatial modulator for the light via electrically controllable transmission. The range of transmission of LCD-cells with color filters is limited by the technology and in the range from 5% to 0.005%. If the luminance of the brightest state is supposed to be 200 cd/m^2 the backlight luminance has to be a factor of 1/0.05=20 higher which means it must amount to 4000 cd/m^2. The darkest state of the LCD-screen is then at a luminance of 0.2 cd/m^2 and the resulting contrast value is CR=1000.

There are two problems emanating in that context:

- it turns out to be difficult to measure luminance < 1 cd/m^2 in a reproducible way, and
- it is difficult to keep a room that dark that no ambient light will corrupt the measurement.

How is contrast measured ?

The luminance of the light state of a television screen is (depending on the state of adaptation of the eye of the observer) typically in the range of 100 cd/m^2. If this luminance is set too high the observer may experience that unpleasantly as *glare*.

In order to be able to measure a contrast of 1 million in a laboratory it must be assured that no ambient light (from e.g. LEDs on the operating panel of instruments) are corrupting the dark state of the object of measurement at a luminance of 10^{-4} cd/m^2 (10^{+2} / 10^{-4} = 10^{+6}). It turns out to be not easy to realize this condition.

Moreover, luminance values below 10^{-3} cd/m^2 can be measured accurately only with special and thus more expensive instruments.

When the above mentioned conditions are fulfilled, the luminance of the display under test is first measured in the full-white state and then in the full-black state. The contrast evaluated from these measurements under the specified conditions is called ***full-screen***

sequential dark-room contrast. This contrast is relatively easy to measure but it does not correlate with the contrast that is relevant for the visual experience of a human observer.

Implications for the dark laboratory

In order to avoid corruption of the black-state of the display under test at a luminance of 10^{-4} cd/m^2 during the measurement the walls of the room must be painted with low reflectance paint (~5% reflectance) and/or be far away from the object of measurement.

Sony OLED TV "XEL-1"

Scenario 1: The TV-screen with a diagonal of 11" is located in a **completely dark room**. The screen shows a black square (0 cd/m^2) of 50mm x 50mm on a white background (100 cd/m^2). The screen is 3 m away from a wall with a (diffuse) reflectance of 18% (photographic gray-chart). The screen is assumed to have a specular reflectance of 5%.

Which contrast does the black square have with respect to the white background ?

An 11" screen with an aspect ration of 16:9 has a surface area of

$$244mm \times 137mm = 33{,}428\ 10^{-3}\ m^2$$

The light emitting surface thus is $33{,}428\ 10^{-3}\ m^2 - (0{,}05\ m)^2 = 30{,}93\ 10^{-3}\ m^2$

The illuminance E of the wall in 3m distance becomes

$$E = (L*A) / d^2 = 100\ cd/m^2 * 30{,}93\ 10^{-3}\ m^2 / 9\ m^2 = 0{,}34364\ lux$$

The luminance L of the wall then becomes

$$L = E\ \rho/\pi = 0{,}019689\ cd/m^2 \sim 0{,}02\ cd/m^2$$

The luminance reflected from the screen at the location of the black spot then is

$$L_R = 0{,}02 * 0{,}05 = 1\ 10^{-3}\ cd/m^2$$

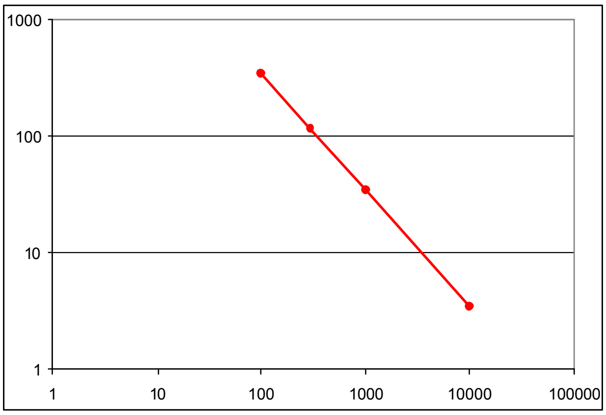
The contrast then becomes

$$C = 100\ cd/m^2 / 1\ 10^{-3}\ cd/m^2 = 10^{+5}$$

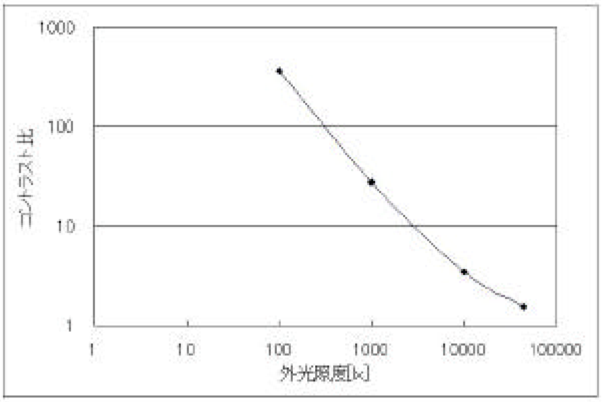
This means that the contrast under such severe darkroom conditions is reduced from 10^{+6} to 10^{+5} by the illumination of the wall caused by the TV-screen.

Scenario 2: The same TV screen now is in a dim room at an illuminance of 100 lux (home theater conditions in the living room). This illuminance (we can neglect here the effect from the white TV-screen) causes the wall to have a luminance of 5,7 cd/m^2 (please note that most white wall papers have a reflectance of 70% - 80% instead of the 18% used here !). The luminance of the wall reflected from the black spot on the TV-screen then becomes 0,285 cd/m^2 and thus the contrast 349 !!!

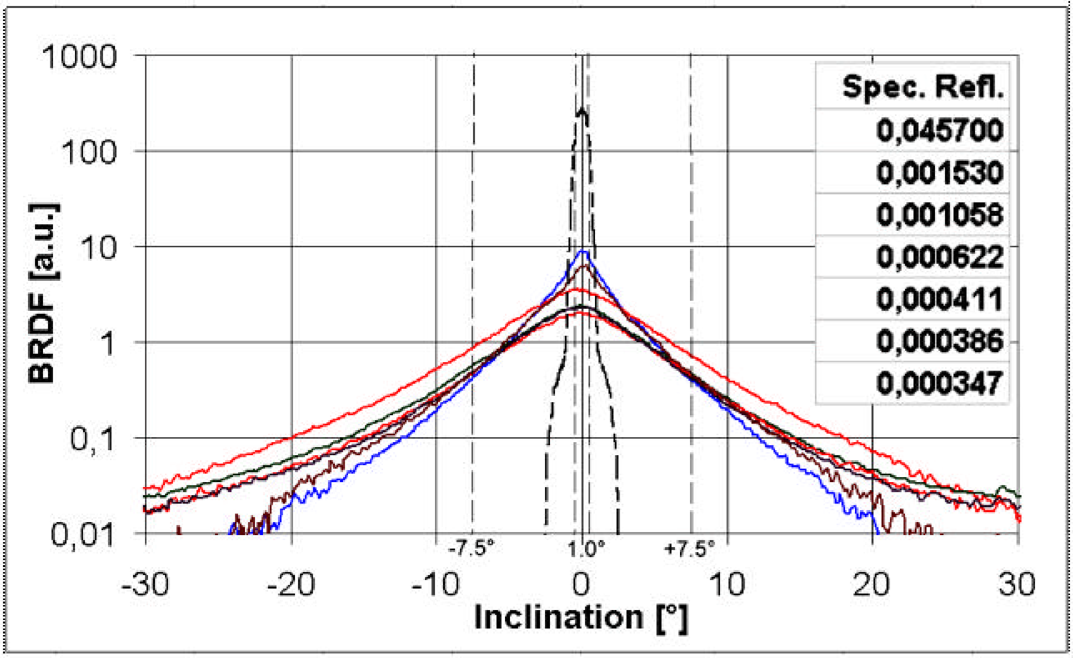
Scenario 3: The same TV screen now is in a room at an illuminance of 300 lux (minimum for office work). This illuminance (we can neglect here the effect from the white TV-screen) causes the wall to have a luminance of 17,2 cd/m^2 (please note that most wall papers have a reflectance of 70% - 80% instead of the 18% used here !). The luminance reflected from the black spot on the TV screen then becomes 0,86 cd/m^2 and thus the contrast 116 !!!



contrast values versus illuminance (lux) calculated according to the scenarios described above.



contrast values versus illuminance (lux) according to measurements published at http://techon.nikkeibp.co.jp.



Bidirectional reflectance distribution function of a range of LCD-screens showing specular reflectance values in the range of 0.1% - 0.2% for scattering anti-glare coatings (AG), and in the range of 0.04% to 0.03% for combined AG and dielectric anti-reflection coatings [3].

Conclusion

Contrast values used for specification and demonstration of the performance of display devices in data sheets are assessed under special conditions and thus often meaningless for actual application situations.

In order to assure good visual performance outside of the dark-room condition of optical laboratories, i.e. under non-vanishing ambient illumination, effective treatment of the surface of the display-screen to reduce reflections is most important.

References

[1] http://www.sonystyle.com
[2] http://techon.nikkeibp.co.jp/english/NEWS_EN/20071127/143111/
[3] M. E. Becker: "Display Reflectance: Basics, measurement, and rating", J SID, November 2006, Volume 14, Issue 11, pp. 1003-1017