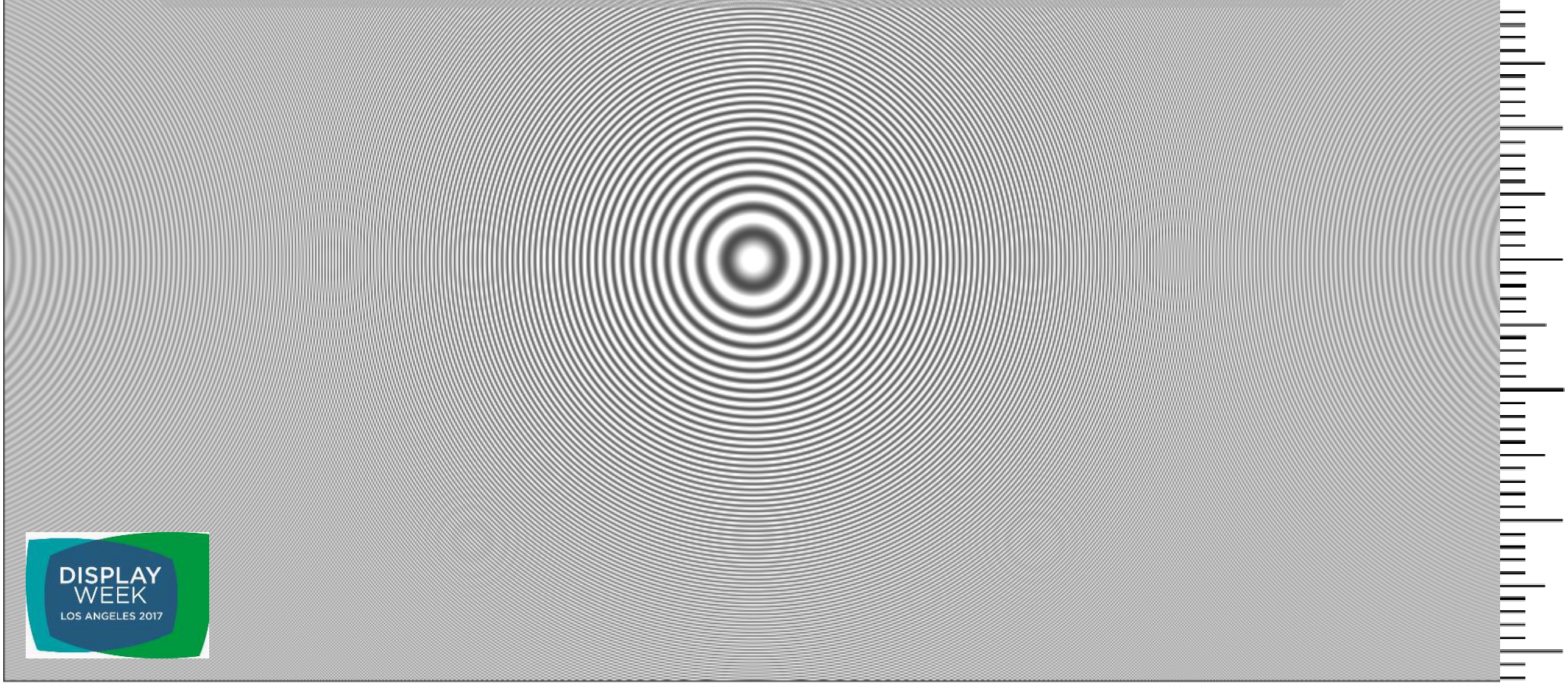
Measurement of Visual Resolution of Display Screens



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Campbell-Robson Contrast Sensitivity Chart

Resolution

on display side:

the "ability to reproduce" smallest image details,

on detector/observer side:

the "ability to distinguish" smallest image details.

??? "ability" ???

??? "smallest image details" ???

Resolution Test-Chart for the Observer

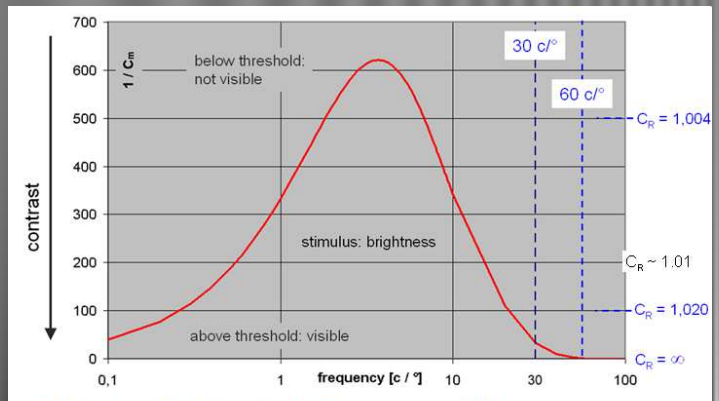
Campbell-Robson Contrast Sensitivity Chart

http://ohzawa-lab.bpe.es.osaka-u.ac.jp

frequency

contrast

contrast vs. size



Contrast sensitivity function ($1/C_m$) versus spatial frequency according to a **Barten model** for $L_{Display}$ = 200 cd/m² and 30° subtended visual angle, sinusoidal luminance modulations. The frequency of 30 c/° corresponds to a visus of one.

Contrast

Contrast is a property of the border between two areas with different optical properties (luminance, chromaticity)

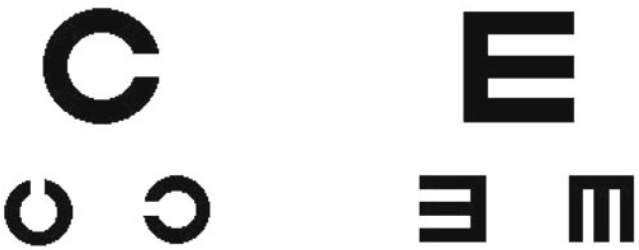
Definition	Designation	Unit	Min.	Max.	Comment
$C_R = L_H - L_L$	contrast = luminance ratio	1	1	∞	quotient of luminance levels no contrast: $C_R = 1$
$C_R = (L_H - L_L) / L_L$	contrast	1	0	∞	
$C_M = (L_H - L_L) / (L_H + L_L)$	Michelson contrast = luminance modulation	1	0	1 100%	used for small contrast values $C_R = 100 \rightarrow C_M = 0.98$ $C_R = 1000 \rightarrow C_M = 0.998$

$$C_M = \frac{C_R - 1}{C_R + 1} \qquad C_R = \frac{1 + C_M}{1 - C_M} \qquad C_M = C_W / 2 \quad C_W = 2 \cdot C_M$$

L_H = luminance of lighter state
L_L = luminance of darker state

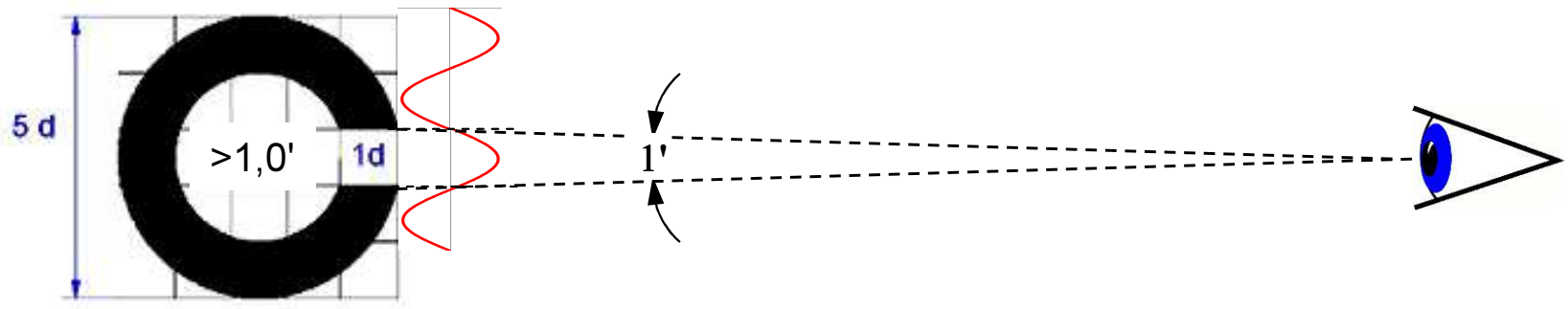
CIE-S017-ILV

Contrast in the perceptual sense: Assessment of the difference in appearance of two or more parts of a field seen simultaneously or successively (hence: brightness contrast, lightness contrast, colour contrast, simultaneous contrast, successive contrast, etc.).



Visual Acuity:
the ability of the eye to distinguish small features of visual targets.

@ good contrast, photopic adaptation, etc.

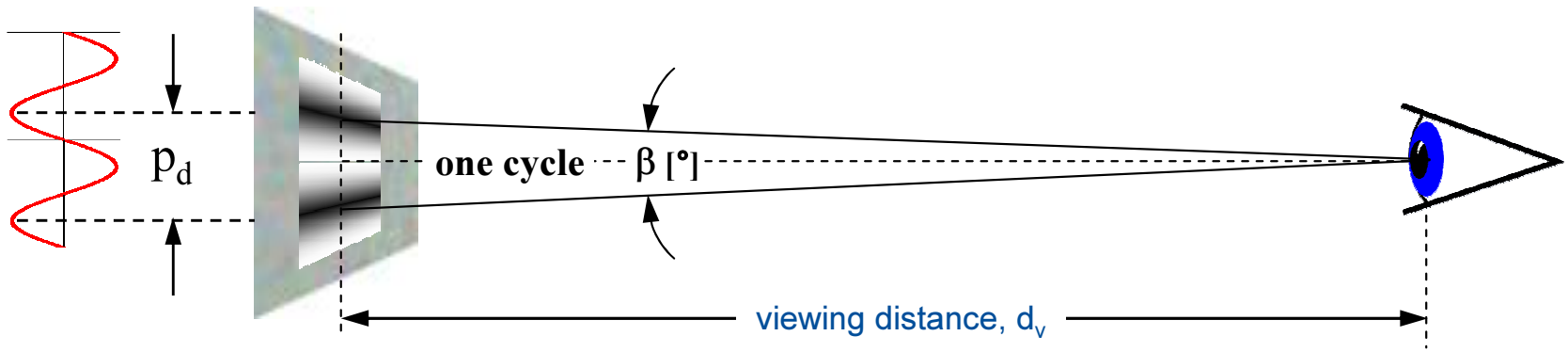


A ***visus of 1*** means a visual target feature subtending an angle of 1 minute of arc (1' = 1°/60) can ***just be recognized*** (~73 μm @ 250 mm).

Visus = 1 / limit angle [minute of arc]

The eye performs a summation / integration over an angle of 1' = 1°/60.

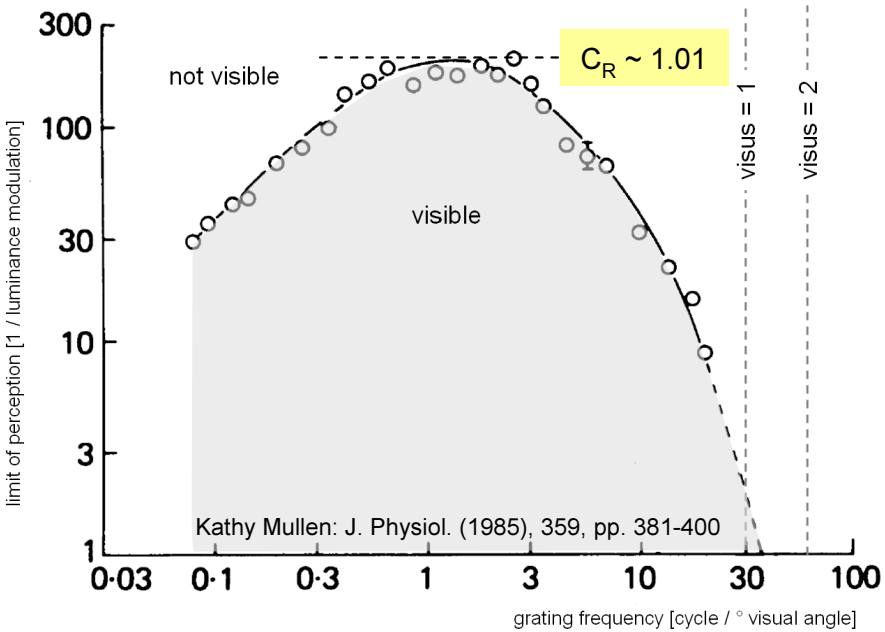
Spatial Frequencies



Observation condition

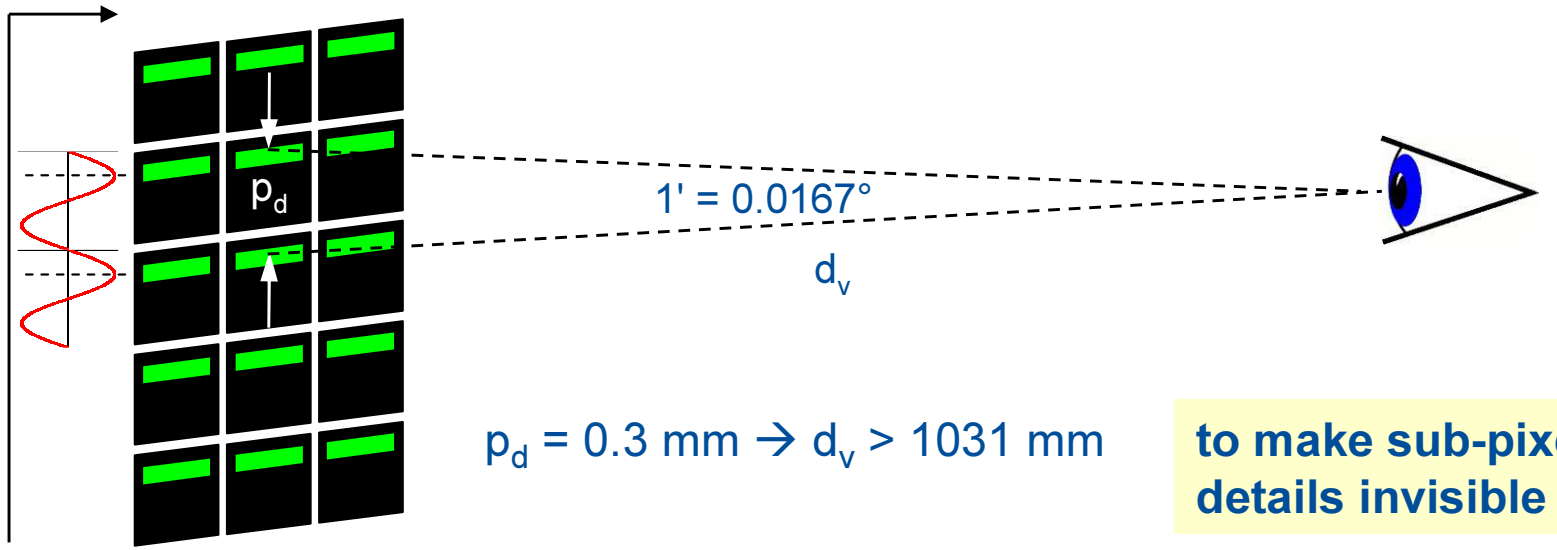
Adjustment of viewing distance

to make pixel pattern disappear



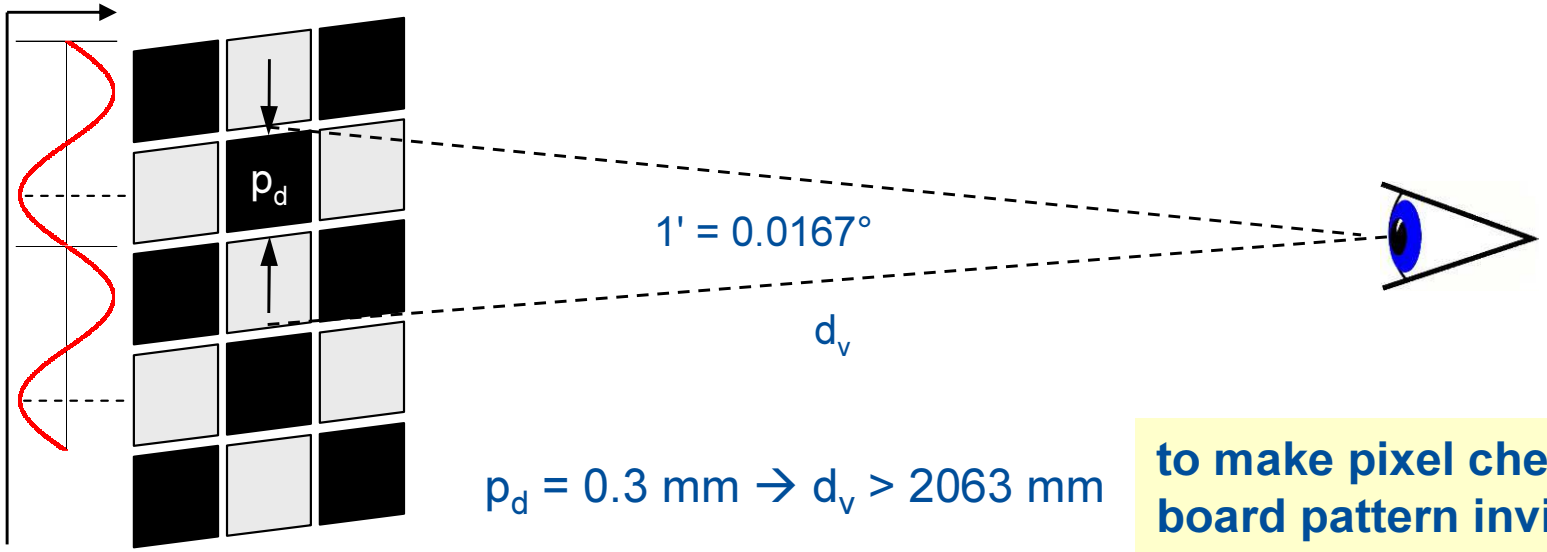
$$f_{vis,0}[\text{cycles}/°] = 1/\arctan\left(p_d / d_v\right)$$

Adjustment of viewing distance to make details invisible



p_d = 0.3 mm → d_v > 1031 mm

to make sub-pixel details invisible



p_d = 0.3 mm → d_v > 2063 mm

to make pixel checker-board pattern invisible

Lateral Averaging

Gala contemplating the Mediterranean Sea - which at a distance of 20 meters - is transformed into the portrait of Abraham Lincoln, Salvator Dali, 1976

Smallest Image Details

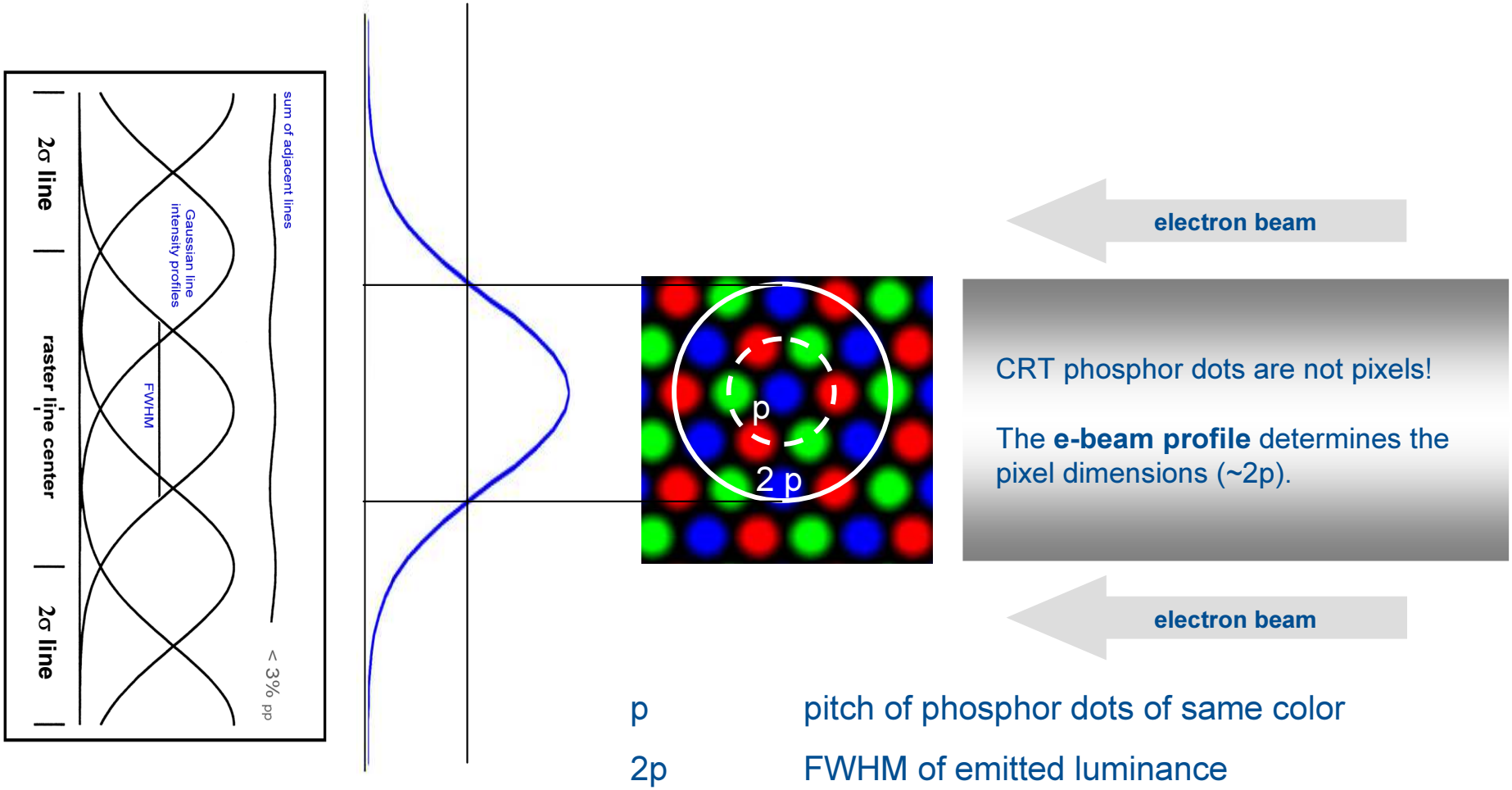
The **smallest details that can be shown on a display** are of similar size as the smallest entities of the display that can be **electrically controlled.**

In the case of **flat-panel displays with fixed matrix structures** the smallest entity able to reproduce the full range of luminance and chromaticity is called **pixel** (short form for "picture element").

The smallest individually controllable elements are **subpixels**.

In CRT monitors however, the pixels were not rigidly coupled to the individual phosphor dots, but they were rather determined by the diameter and the profile of the electron beam and its timing. So the width of lines (with Gaussian profile) and their spacing could be controlled electrically in CRTs, but these are both fixed in flat-panel displays by the manufacturing process.

Finest Image Details

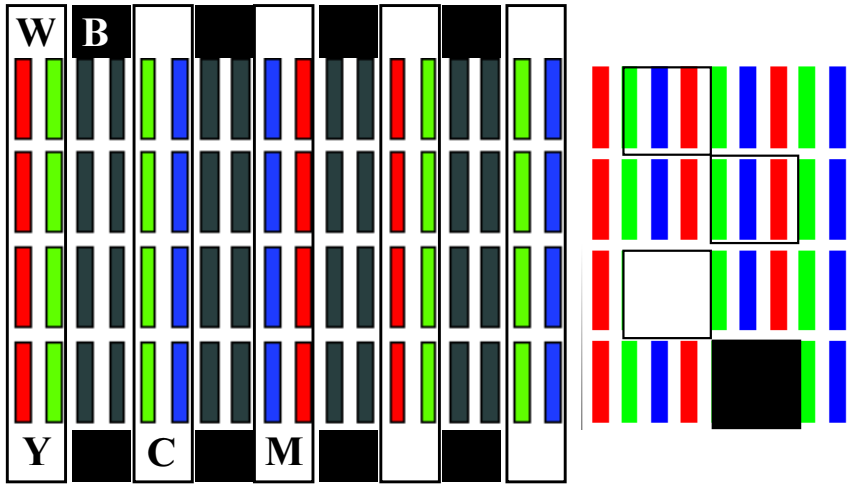


p	pitch of phosphor dots of same color
2p	FWHM of emitted luminance

Conflict in CRT screens:

sharpness of lines vs. uniformity of areas.

Achromatic Grille Patterns



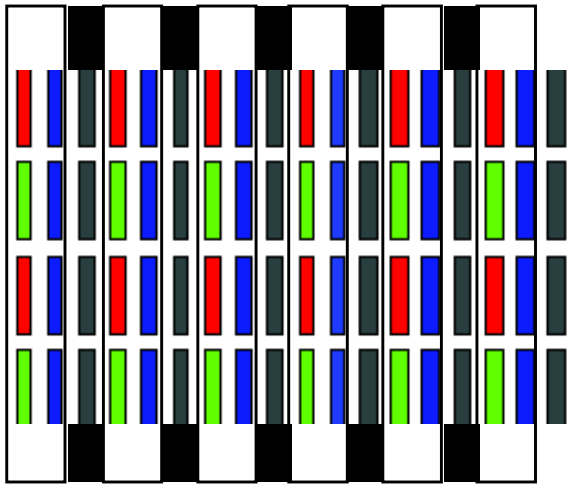
Visual resolution:
6 SubPixel = 3 SubPixel (horizontal)
2 SubPixel (vertical)

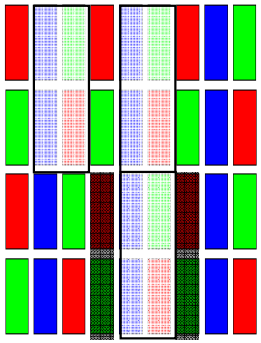
square elements

B/W line-pairs with 4 SubPixel / Periode ⇨ **not achromatic**.

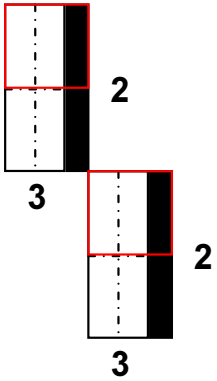
B/W line-pairs with 3 SubPixel / period - achromatic.

The Visual resolution of a display **(h/v):**
number **B/W-line-pairs (horiz./vertical)**,
that can be rendered achromatically
i.e. without chromaticity artefacts.





PenTile™ 1A

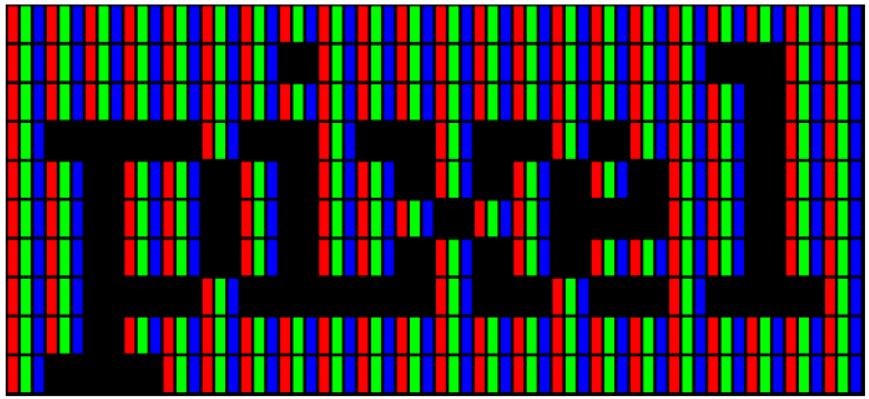


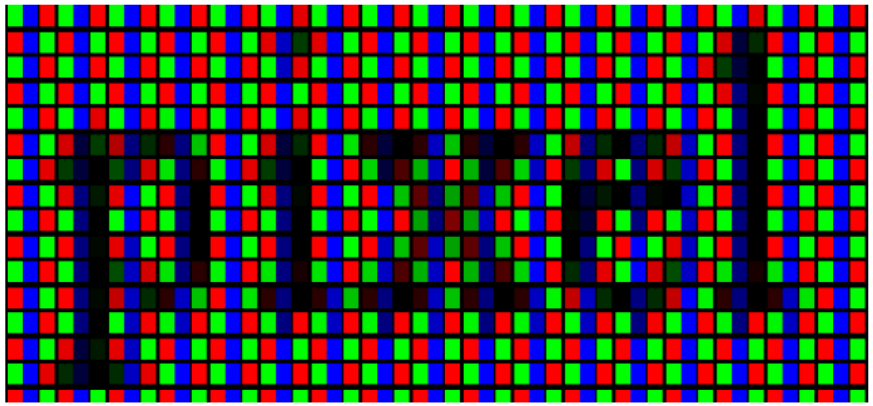
Visual resolution:
3 SubPixel (horizontal)
2 SubPixel (vertical)

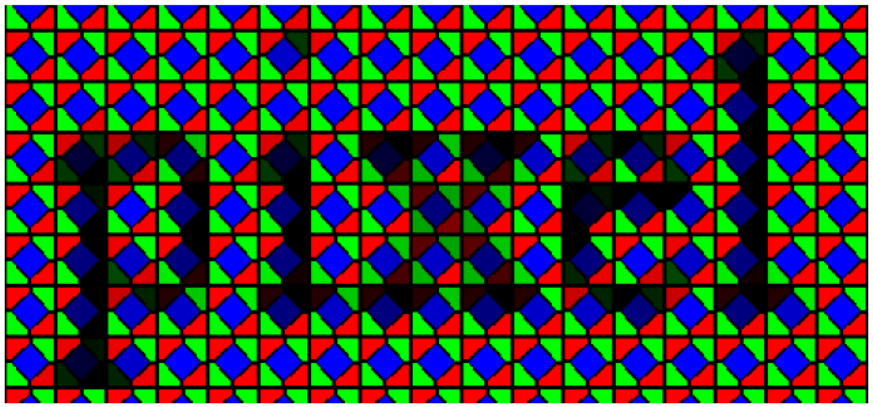
rectangular elements

after: Candice Brown-Elliot, Clairvoyante Inc.

Alternative Pixel Layouts



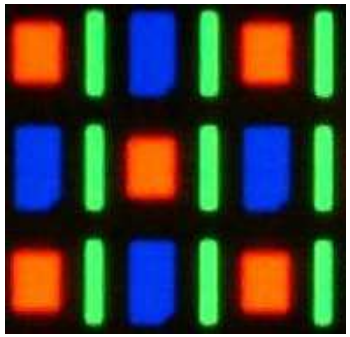


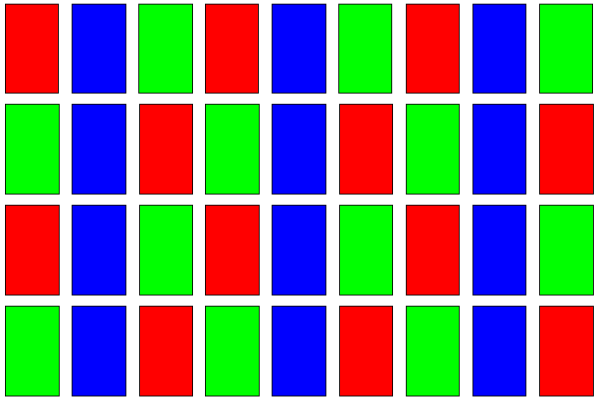


New Pixel Layout:
PenTile Matrix™ Architecture

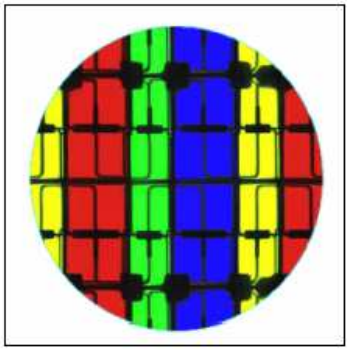
ClairVoyante Laboratories, Inc. / www.nouvoyance.com

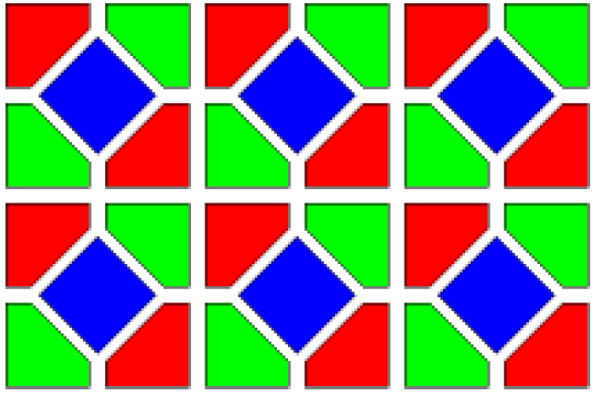
Exploiting the difference in bandwith (spatial resolution) of the visual channels (L, B/Y, R/G).





Sharp Quattron





Smallest Image Details

The independent control of individual pixels and their subpixels may be limited

- by ***electrical effects*** (***crosstalk***) and
- by **scattering of light** from one subpixel to an adjacent one (***halation***).

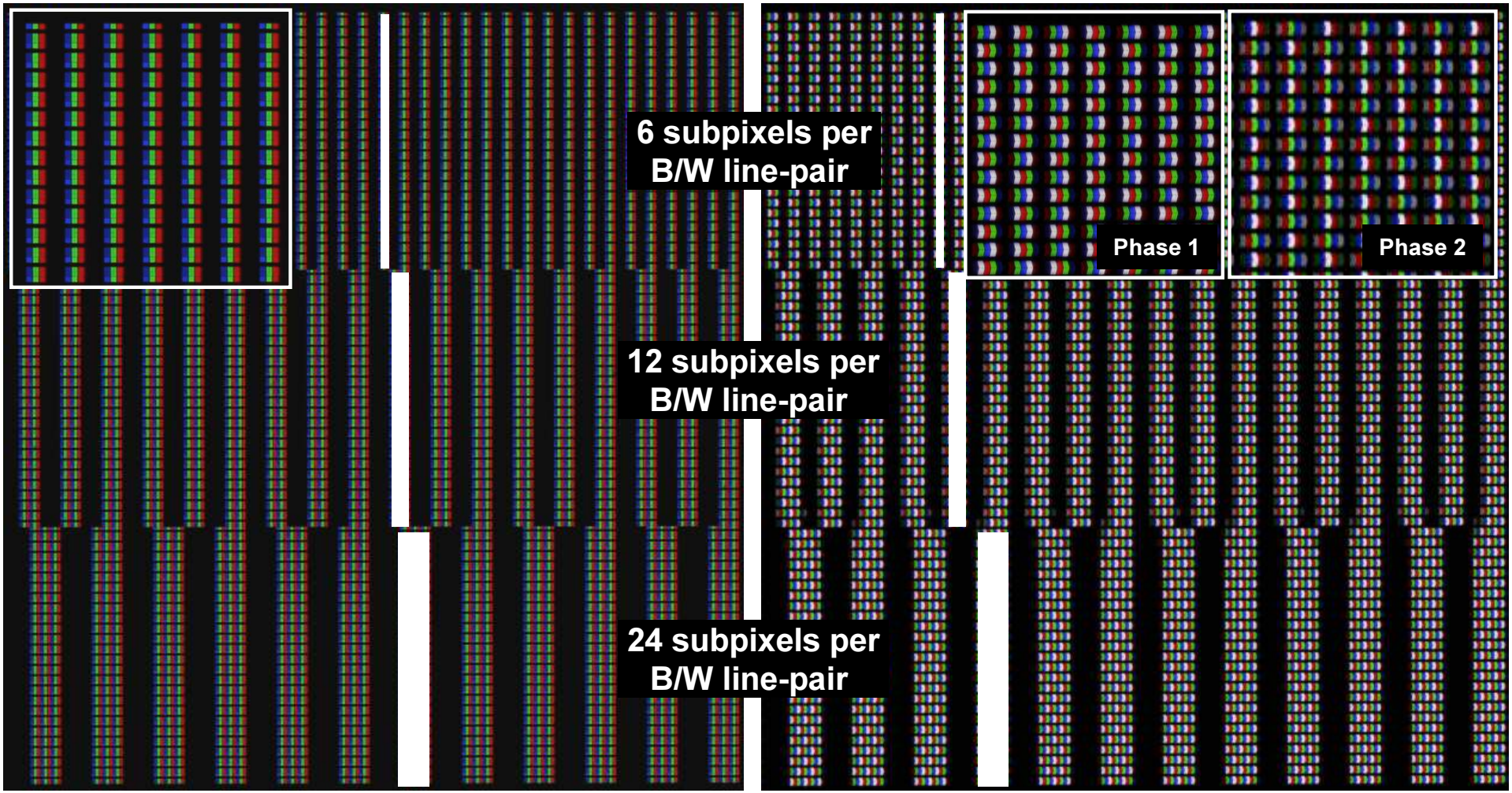
The visual resolution of flat-panel display screens is not directly given by the ***addressability*** which is commonly specified as the dimension of the subpixel matrix (e.g. 1920x1080x3 for HD and 3840x2160x3 for UHD).

Alternative subpixel architectures (e.g. RGBY, RGBW, PenTile®) recently complement the traditional way of composing square-shaped pixels from three stripe-shaped subpixels, each providing one of the primary colors, R, G and B.

New techniques are available for grouping subpixels in the process of presenting image information (subpixel rendering).

Alternative Pixel Layouts

How many pixels does/should a UHD TV-screen have?



3840 x RGB = 11 520 subpixels

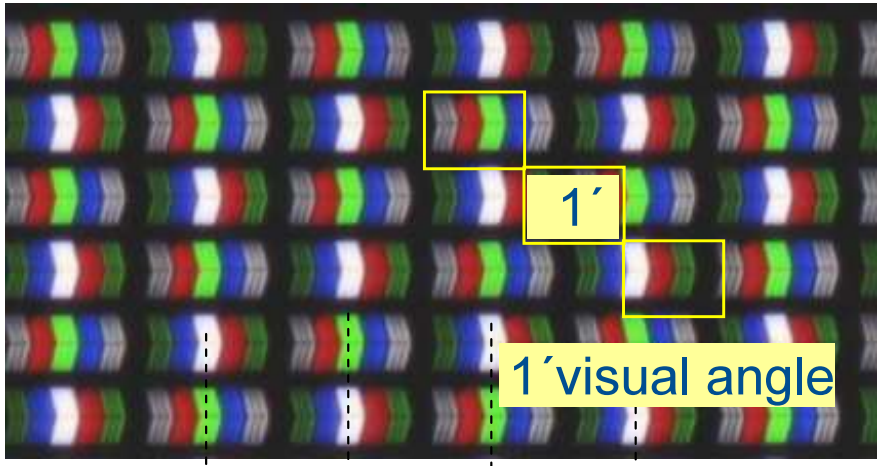
2880 x RGBW = 11 520 subpixels

How many ***pixels*** does that make ?

Procedure according to IDMSv1p03b, 2012

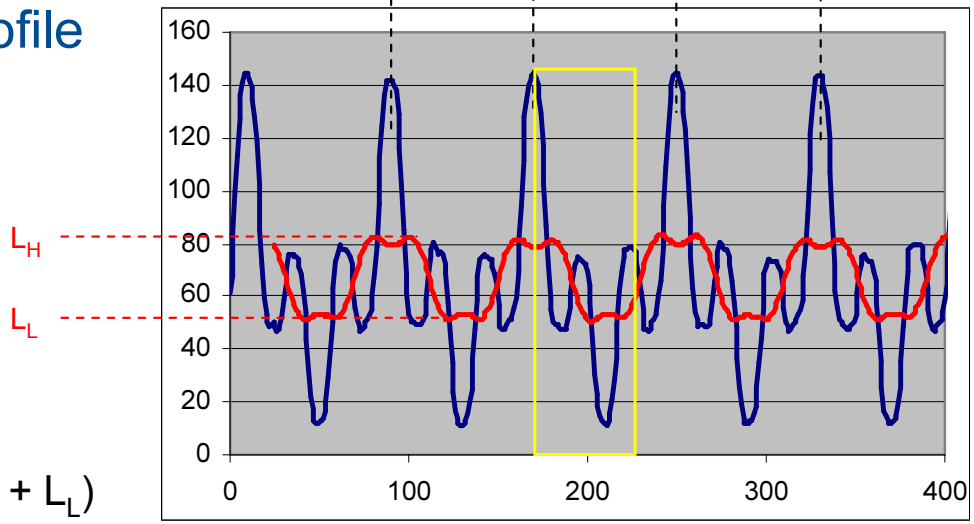
Luminance image

averaging



Phase 2

Luminance profile



Assumption:

RGBW = 1 Pixel

MAW width = 4 subpixel

$C_M = 21\%$

$C_M = (L_H - L_L) / (L_H + L_L)$

$C_M = 21\%$ ➔ FAIL

integration over 1´visual angle

Problem with RGBW sub-pixel structures

Width of the averaging window set to "1 pixel = 4 subpixels" in the RGBW case

→ luminance modulation decreases and may drop below the target **threshold**.

? What is a pixel ?

That 2012 version of the IDMS had been written for **computer monitors with a distinct fixed relation between subpixels and pixels** of the display. For that class of devices a pixel is defined as the smallest unit that can display the full range of luminance and chromaticity.

There are display screens whithout fixed relation between the subpixels and the pixels,

e.g. displays with e.g. **PenTile subpixel architectures**.

The 2016 Updates of the IDMS

The **basic principles laid down in the IDMSv1p03b can be successfully applied to measurement of the resolution of displays with alternative pixel layouts**.

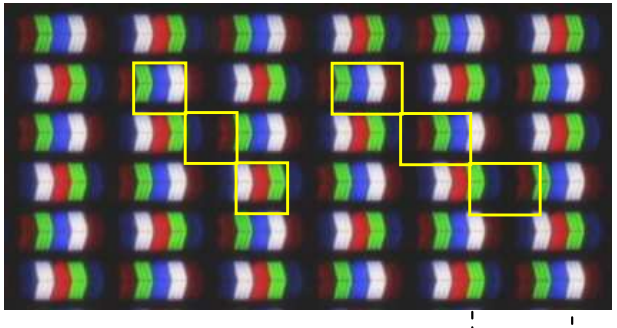
Give up thinking in terms of pixels,

start thinking in terms of subpixels instead.

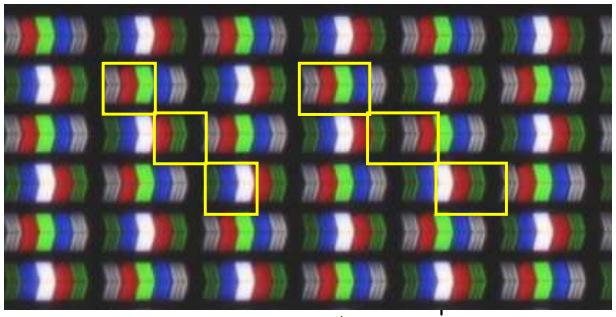
The width of the moving window used for averaging of luminance profiles is determined from the measured luminance profiles,

➲ **the procedure for determination of visual display resolution becomes straightforward and transparent.**

Effect of Averaging Window Width

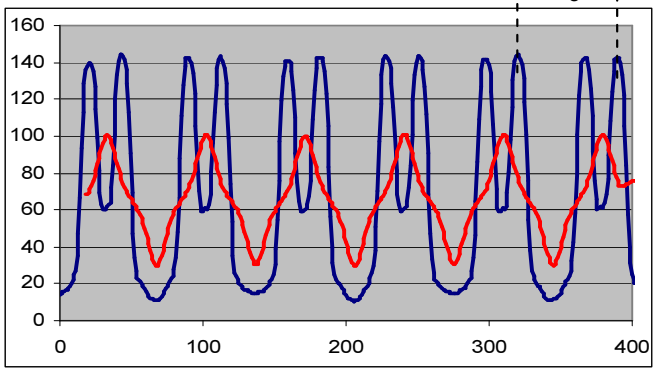


Sub-pixel pattern - phase 1



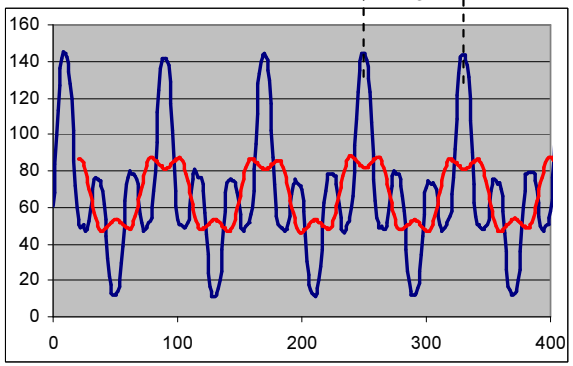
Sub-pixel pattern - phase 2

p_0



C_M = 54%

p_0

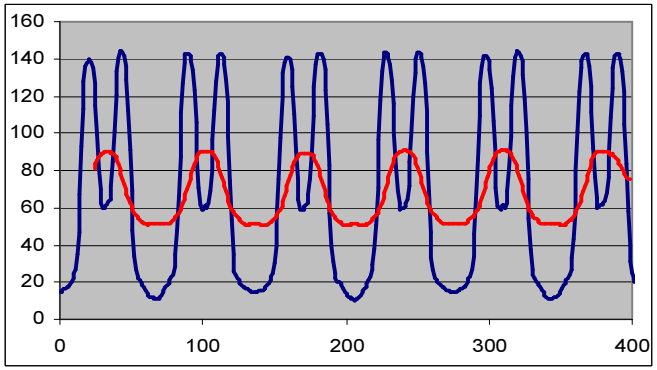


C_M = 30%

PASS

$p_0/2$

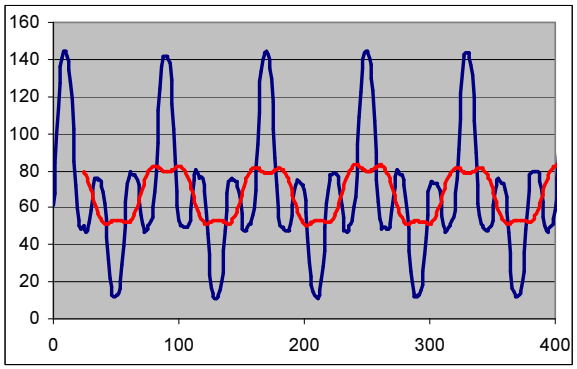
ability



C_M = 29%

C_M = 25%

$2p_0/3$



C_M = 21%

FAIL

The 2016 Updates of the IDMS

The ICDM on May 24, 2016 accepted a series of editorial comments and explanations (7p0-01-20160524.pdf, 7p2-01-20160524.pdf, 7p8-01-20160524.pdf) to remove the problems.

- The updated procedures are based on evaluation of the luminance modulation of achromatic grille test-patterns (both phases) starting with the smallest grille line width (highest number of lines or line-pairs).

- **The width of the averaging window is obtained from the measured luminance profile and in case of different modulations for both phases of the grille pattern, the average value has to be used and reported.**

- The updated section 7.2 requires **reporting of the Michelson contrast for the smallest grille line width to avoid obfuscation by application of thresholds for pass/fail decisions.**

The updates also suggest that version 2 of the IDMS will comprise the following details for even more complete specification of the visual resolution of display screens:

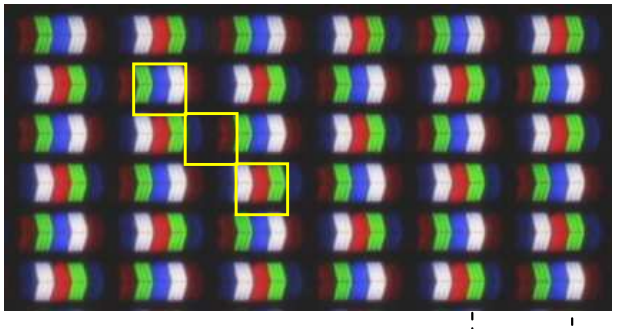
1 Replacement of the modulation thresholds by specification of the luminance modulation as a function of achromatic grille line width.

2 Extension to grille patters of primary colors in combination with black.

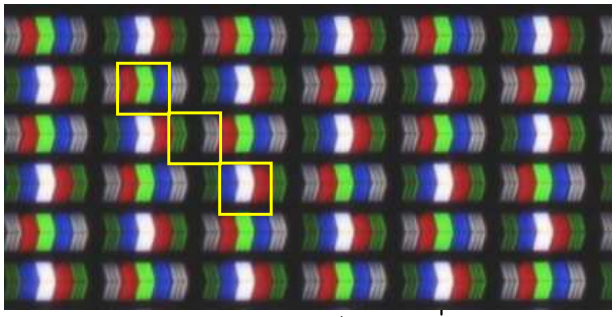
Effect of Averaging Window Width

Luminance image

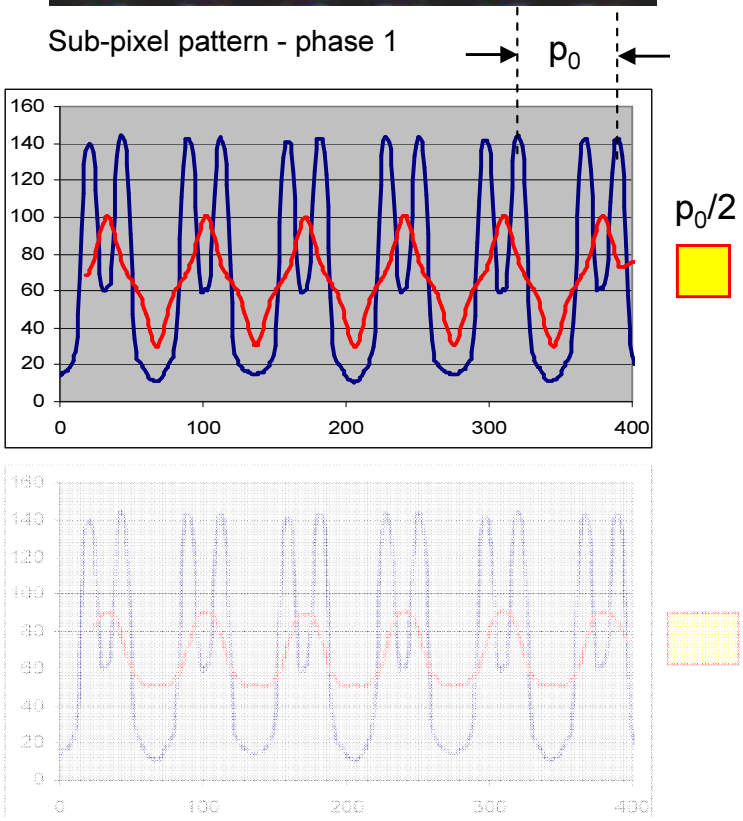
Luminance profile

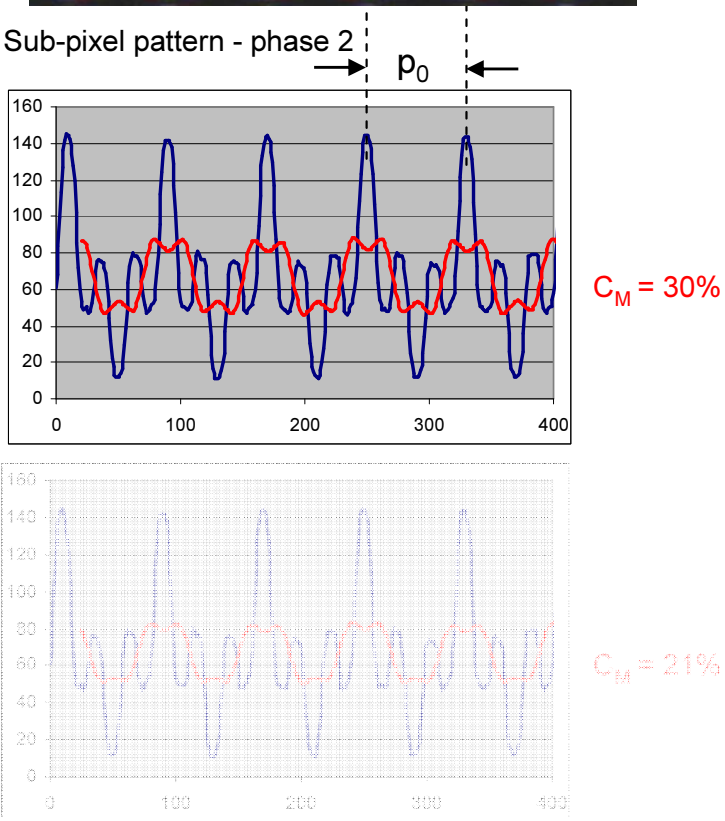


Sub-pixel pattern - phase 1



Sub-pixel pattern - phase 2





Grille-patterns of achromatic vertical lines (top) displayed on the RGBW-screen and the corresponding luminance profile (bottom, blue curve). The period corresponding to the lowest fundamental frequency, p_0, is the same for both phases of the grille pattern. The red curve is obtained by application of a *moving window average* with a window dimension of $p_0/2$.

? Interpolation ?

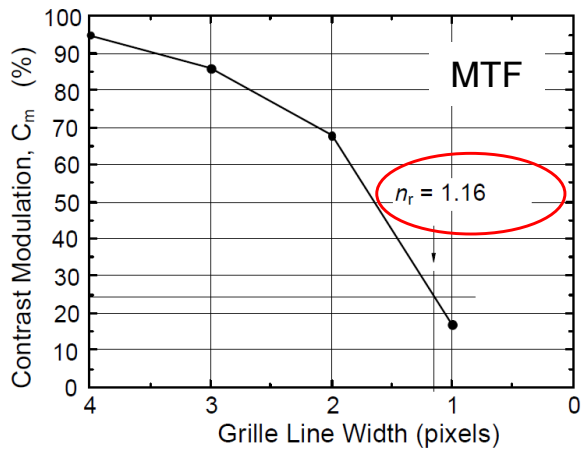


Fig. 1. Use linear interpolation to determine the value of n_r from contrast modulation measurements. An example of n_r = 1.16 is shown.

Calculate the resolution in number of resolvable pixels:

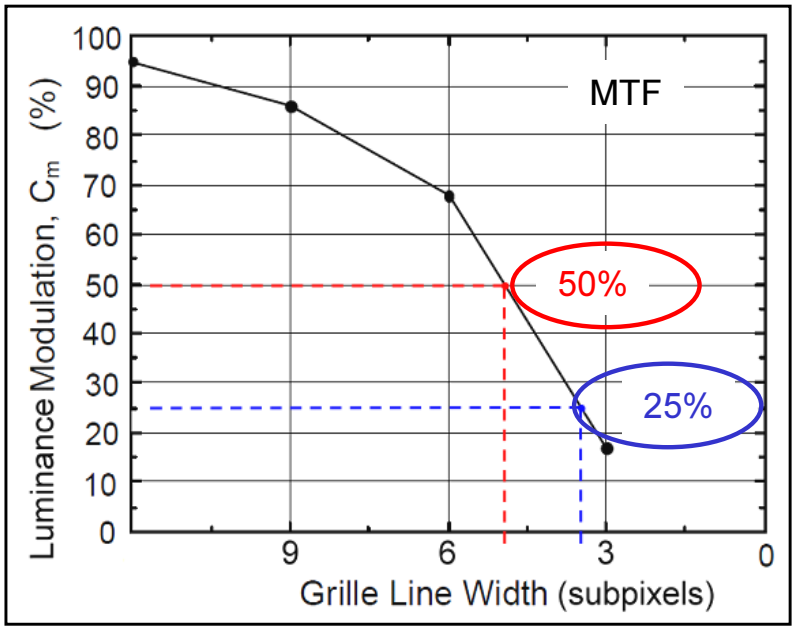
$$\text{Resolution} = \frac{\#\text{ of Addressable Lines}}{n_r}$$

"Resolution" = 1920 x 2 / 1.16 = 3 310.35 ???

This number (3 310.35) indicates that the addressable matrix (3 840 x 1160) cannot display the grille pattern with sufficient contrast.

The resolution obtained via interpolation from the MTF is only a theoretical (i.e. hypothetical) one, since no achromatic grille pattern with that "resolution" can be rendered by the display.

This specification has no practical relevance.

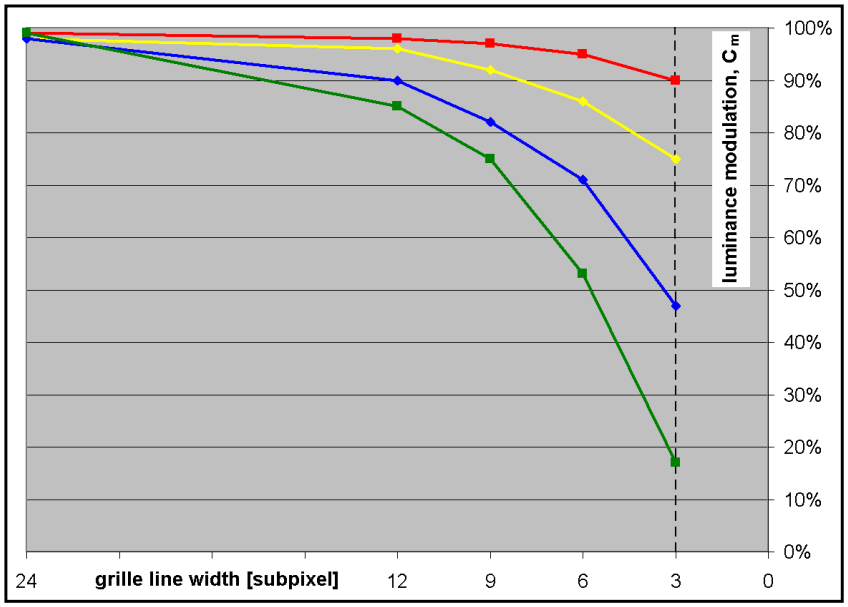


! The logical alternative !

Do not interpolate the MTF to obtain a hypothetical "resolution", just specify the luminance modulation, C_M, at the **target resolution**, e.g. UHD:

1920 ***achromatic line pairs*** horizontal / display width @ C_{M1}
1080 ***achromatic line pairs*** vertical / display height @ C_{M2}

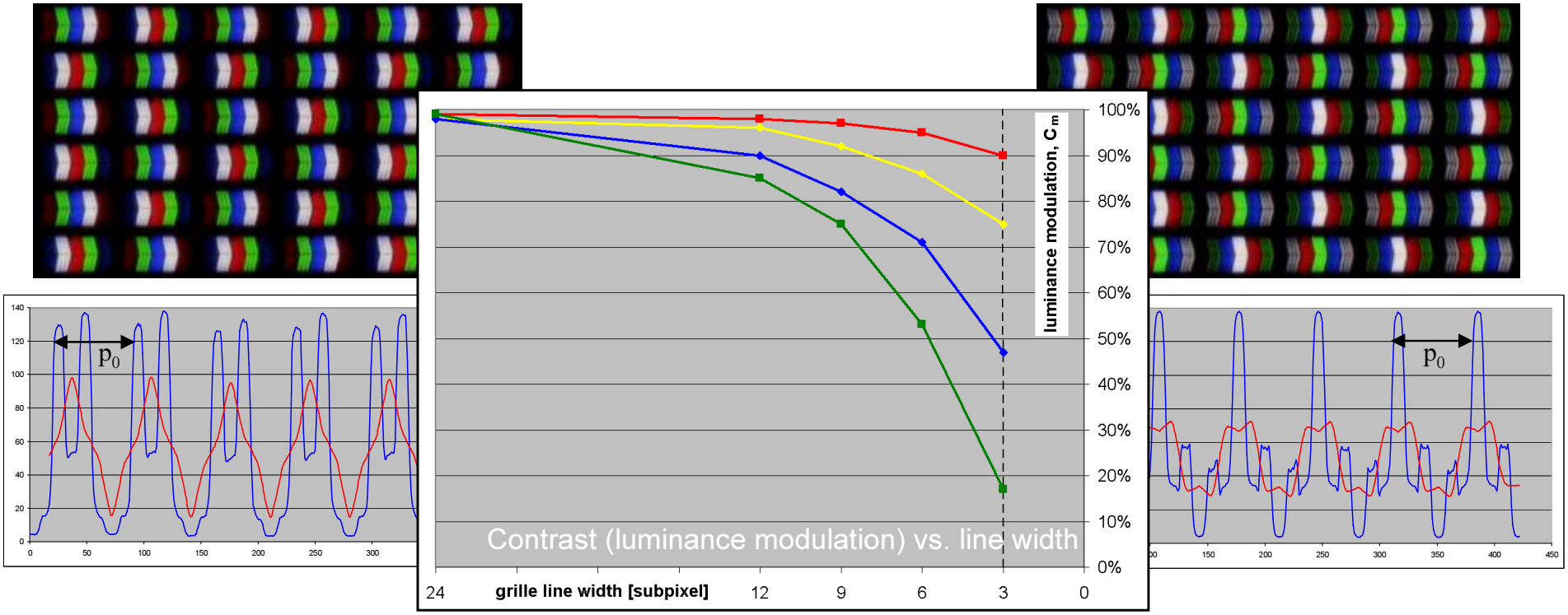
➲ UHD resolution @ $C_M = (C_{M1} + C_{M2}) / 2$



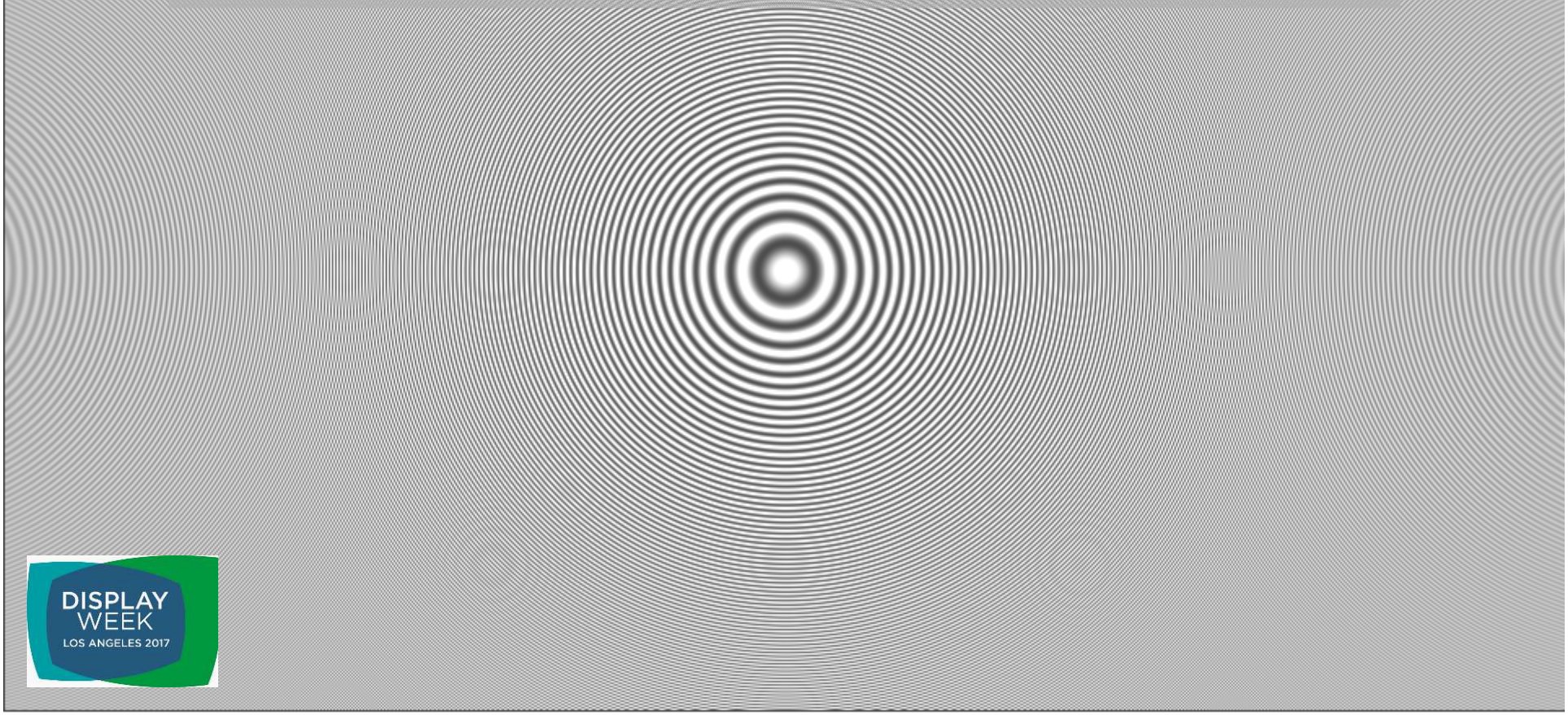
UHD resolution @ C_M = 18%
UHD resolution @ C_M = 90%

Visual Resolution Measurement

- Display an ***achromatic*** grille pattern (horizontal, vertical, phase 1+2) with the smallest possible line widths (i.e. max. number of line-pairs).
- Evaluate the corresponding luminance profile (follow precautions of the IDMS).
- Evaluate the lowest frequency of the luminance modulation, or the respective period, p_0.
- Perform a moving average with window dimension, $p_0/2$.
- Determine the modulation of the averaged luminance profile, C_M.
- Report the contrast, C_M for the smallest line widths.



Measurement of Visual Resolution of Display Screens



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