Midlands Vision Group Meeting, Keele, April 1998

Calibration issues in monochrome raster scan displays

Andrew Schofield

THE UNIVERSITY OF BIRMINGHAM

School of Psychology

Note: Some slides have been altered from the original talk

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Raster scan CRT artifacts

Interactions Between	Space	Time	Intensity / colour
Space	Spatial frequency Jagged edges line orientation-width interaction	Stroboscopic effects **Time and screen location**	Inter-pixel interactions (B) Screen in-homogeneity Large bright stimuli overload power supply (A) Bright stimuli blurred
Time		Temporal resolution (B)	Phosphor decay Phosphor aging Warm up time
Intensity / colour			(A) (B) Gamma non-linearity limited DAC resolution Limited colour gamut colour gun interactions

——————— = Areas covered in talk

– – – – – – = Area covered here but not in talk

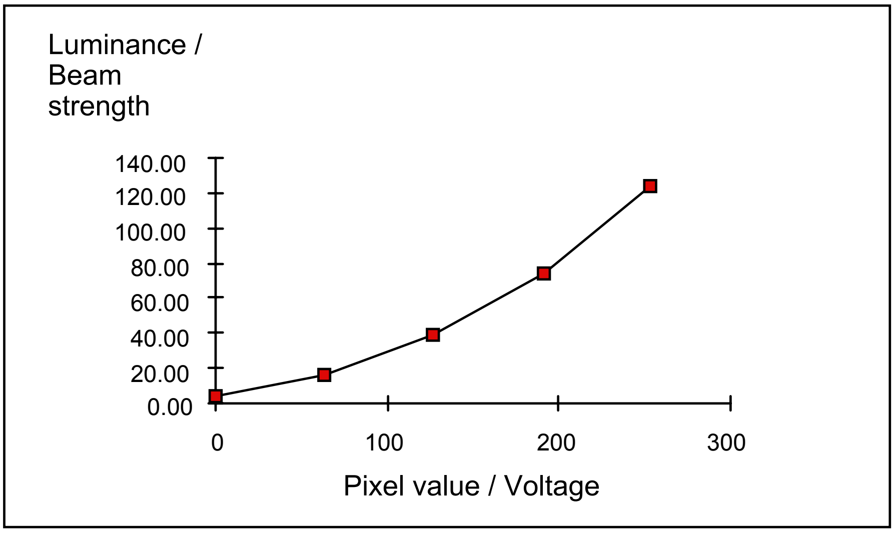
(A) (B) = Related issues

Items in bold type were covered at a talk given at Birmingham University

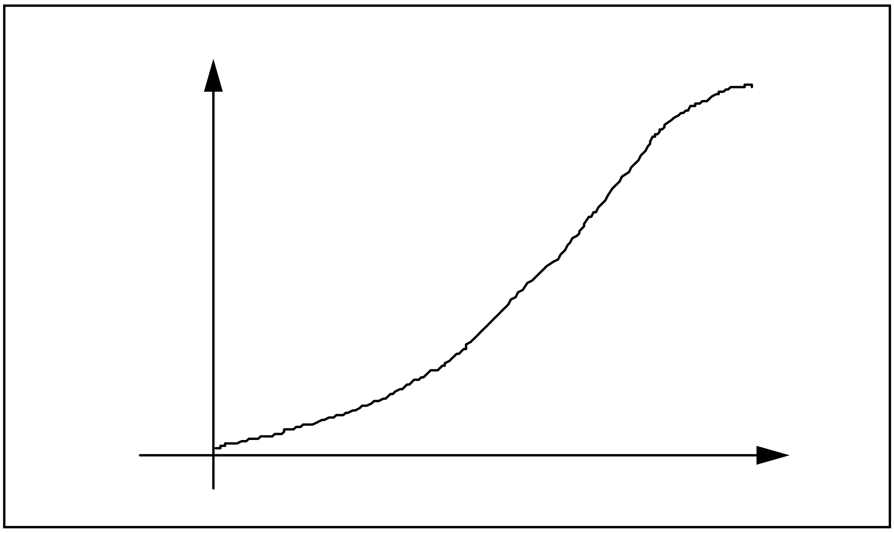
After Bach, Meigen and Strasburger, Spatial vision, Vol 10 pp403-414

Gamma γ

Gamma non-linearity is due to the valve characteristic of the cathode ray tube



$$L=a+(bI)^{\gamma}$$



Estimating Gamma - Method 1 γ

Variable mean luminance

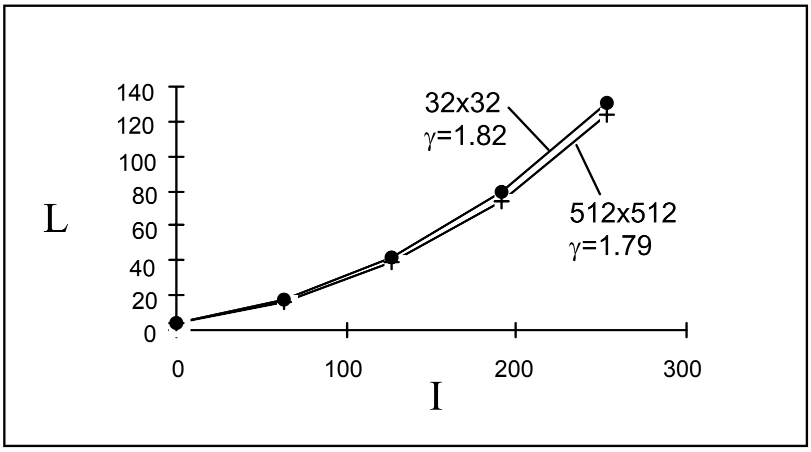
Draw a dot or square on the screen at various pixel values, measure the luminance and do a curve fit to find Gamma.

Problems: Observed Gamma depends on load placed on power supply and so changes with size of dot and intensity.

So: Estimated Gamma will good for one object size only.
Will not be a good estimate at low contrasts (low luminance).

How big are these effects:

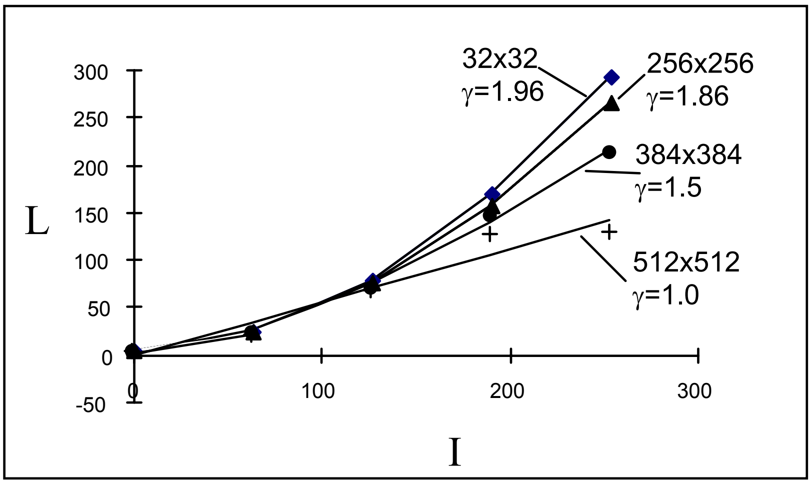
Good screen set up for low Gamma



Eizo 6500M
Mono
110Hz
21"
110Hz
512x512 =
7.9" square

Brightness and contrast set for low gamma

Old screen not well tuned



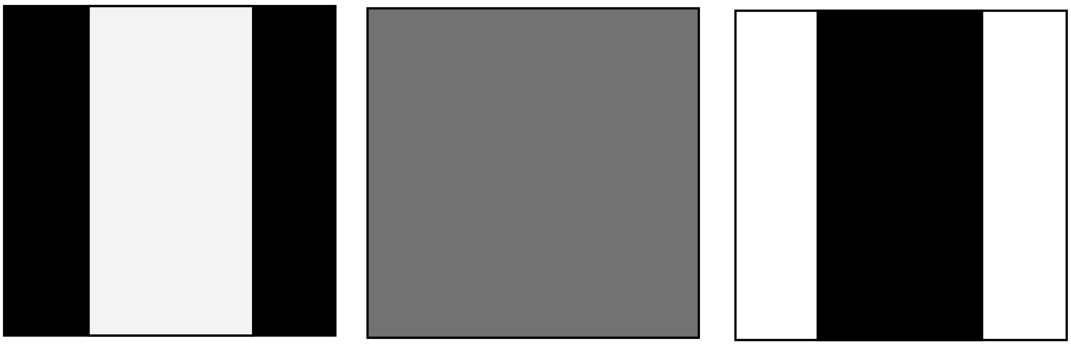
Eizo 9060S
RGB
14"
60Hz
512x512 =
7.9" square

Brightness low contrast high

Estimating Gamma - Method 2 γ

Fixed mean luminance

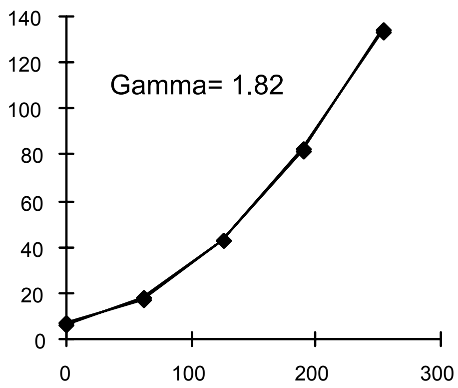
Draw one cycle of a square wave (even) at various contrasts (positive and negative) and measure luminance of central area



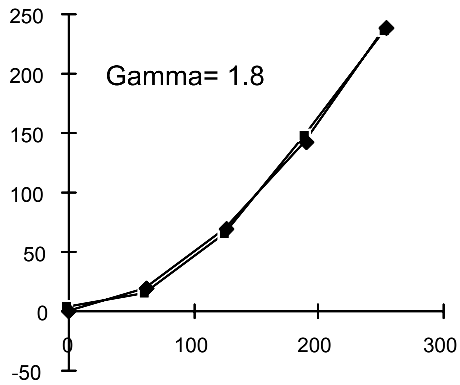
Mean luminance is always the same so load is constant and estimate of Gamma is true

Problems: Load still varies with image size Gamma only valid for stimuli with mean pixel value = 128

Good screen



Bad Screen



Estimating Gamma - Method 3 γ

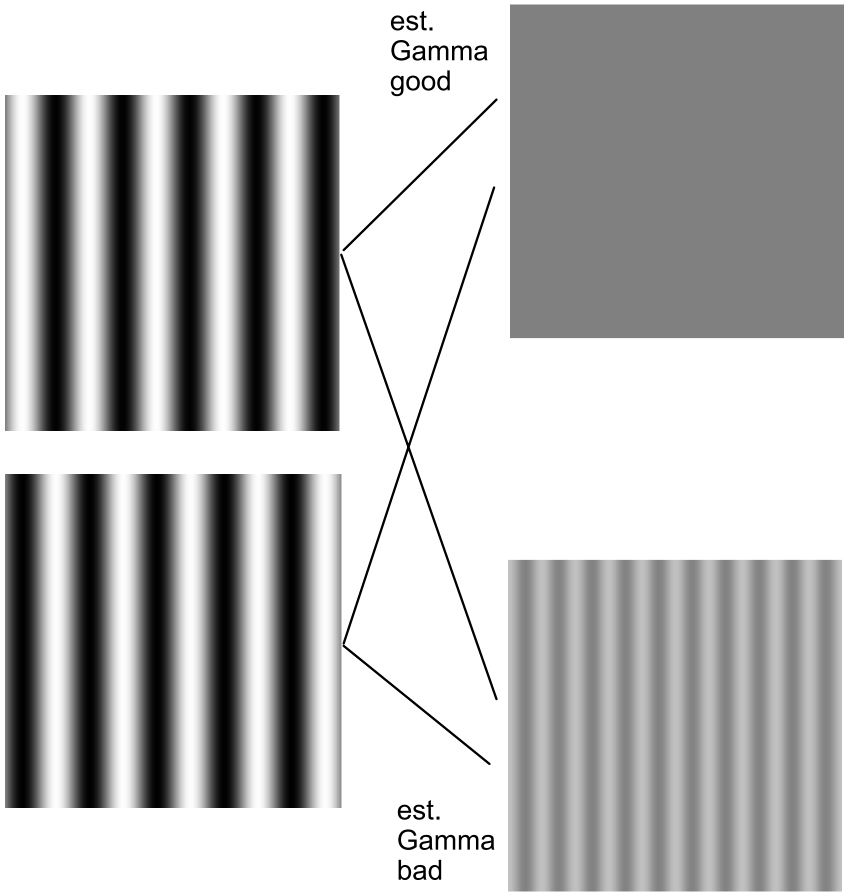
By eye

Display two sinusoids of equal frequency but opposite phase in alternate frames of the video sequence.

Apply some Gamma correction

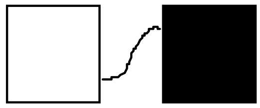
When estimated Gamma = true Gamma stimuli are undistorted and cancel to mean grey
When estimated Gamma <> true Gamma stimuli are distorted and a beat pattern is observed.

Simply adjust estimate until the beat disappears



Good screen -- easy to do, chosen Gamma 1.8 - 1.82
Bad screen -- difficult to do, chosen Gamma 1.9 - 2.0

Inter-pixel interactions

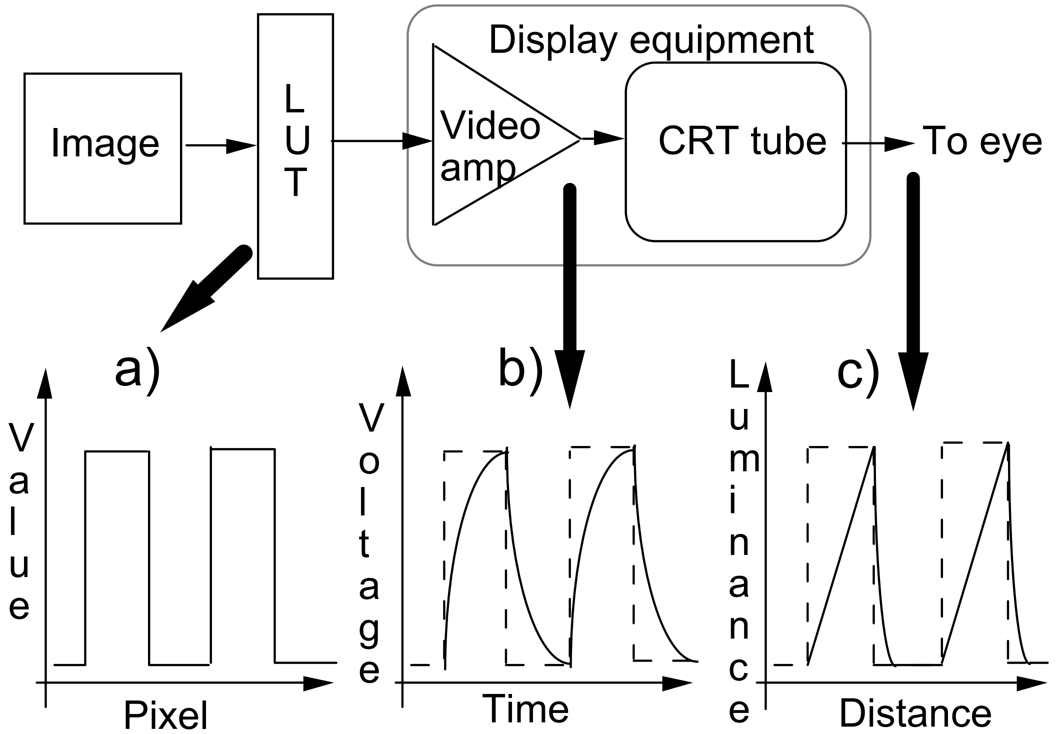


Adjacent Pixel Non-Linearity

The luminance of a pixel is dependent upon the luminances of adjacent pixels.

Why?

(Mulligan and Stone, JOSA-A, 6, pp 1217-1227, 1989)



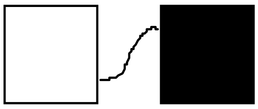
a) High frequency image variations after gamma correction.
b) Bandwidth limitations in the video amplifier smooth the waveform.
c)Rising and falling edges are distorted by gamma transformation.

APNL is only a problem for signals that vary along the direction of travel of the electron beam. (That is across the raster of a raster scan screen)

APNL is worst when:

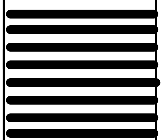
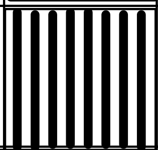
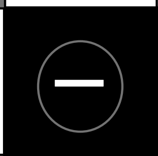
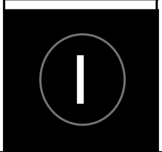
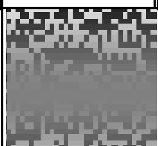
- Image contrast is high.
- Screen gamma is high.
- Video bandwidth is low.

APNL -- Consequences

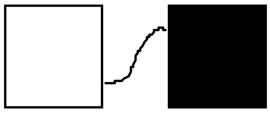


1) High frequency image components are attenuated.
2) Mean luminance is reduced in high frequency, high contrast images.
3) On a raster screen - vertical edges, lines or gratings will have a lower contrast and mean luminance than their horizontal counterparts.
4) Second-order contrast variations of high resolution carriers will produce first-order variations in mean luminance.

Magnitude of problem -- Good screen

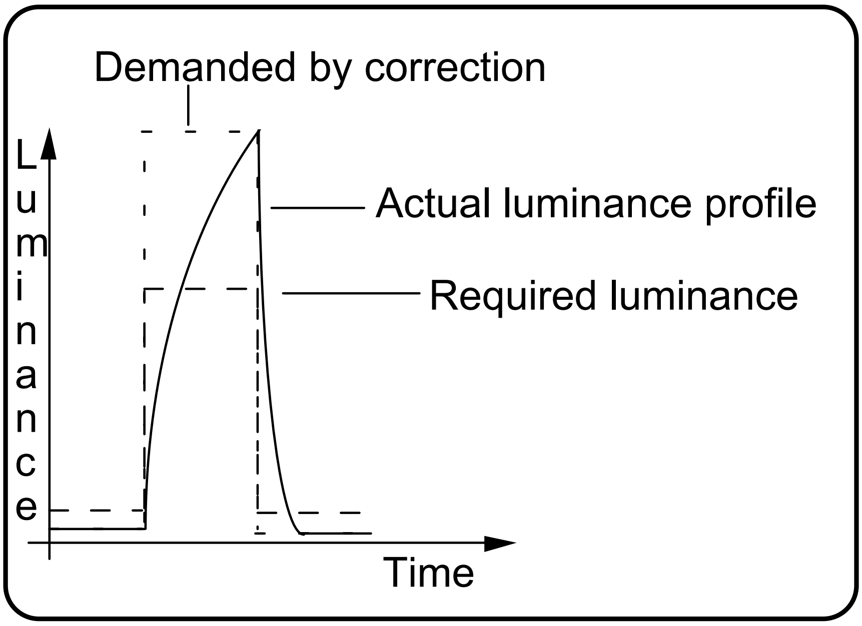
Description	Image	Mean luminance
12.8 c/cm Horizontal squarewave grating		59.2 cdm^{-2}
12.8 c/cm Vertical squarewave grating		48.5 cdm^{-2}
1.5mm wide horizontal white line on black background		7.0 cdm^{-2} at 1.7m (Averaged over RF of meter)
1.5mm wide vertical white line on black background		5.9 cdm^{-2} at 1.7 m (Averaged over RF of meter)
Low contrast noise		← 57 cdm^{-2}
High contrast noise		← 53 cdm^{-2}

APNL -- Full correction



Over shoot the target!

(Due to Kline, Hu and Carney, Vis Res, 36, pp3167-31811996)



- Voltage waveform is given by

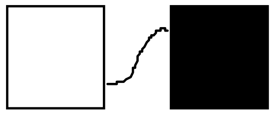
$$V(t) = V_a + (V_i - V_a)\exp(-1(t-t_0)/\tau)$$

- Luminance waveform is given by:

$$L(t) = A((V(t) - V_0)/255)^{\gamma} + L_0 \qquad V(t) > V_0$$
$$= L_0 \qquad V(t) < V_0$$

- Create at table of L_{ave} for all values of V_i and V_a
- Invert this table to give V_a for all values of V_i and L_{ave} - This then becomes a double entry LUT
- Re-construct image pixel by pixel, finding V_a for the current pixel from V_i for the previous one and L_{ave}, the desired luminance.

APNL --

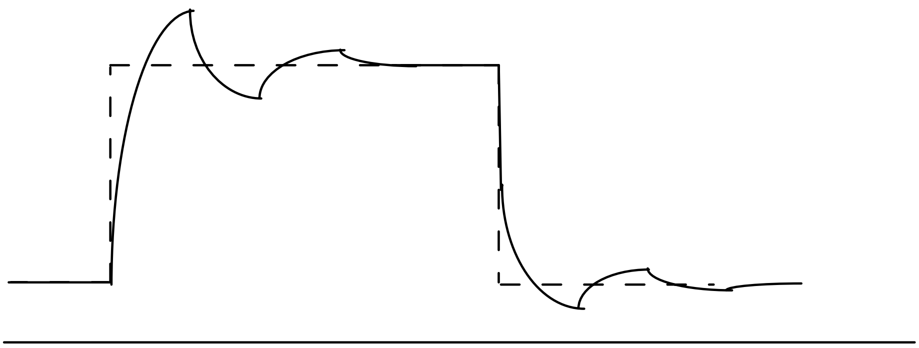


Problems with full correction

1) Computational overhead
As pixel values must be re-calculated on a pixel by pixel basis the method is relatively time consuming and while useful when images are created entirely off-line is impractical when some image property such as contrast is varied at display time.

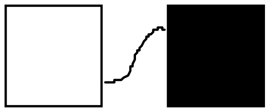
2) Reduction in available contrast
Over- and under-shoots have to be accommodated within
the contrast range of the CRT and hence the maximum contrast available is reduced.

3) Ringing
Over-shoots can introduce a ringing effect at large changes in luminance.



Problems 2 and 3 can be reduced by smoothing the original image. The smoothing process can be included in the double entry LUT

APNL -- Quickie corrections



1) Damage Limitation

The impact of APNL can be reduced by choosing a display with a large video bandwidth and by setting up the CRT to minimise Gamma. Gamma correct as normal.

2) Limit the maximum frequency

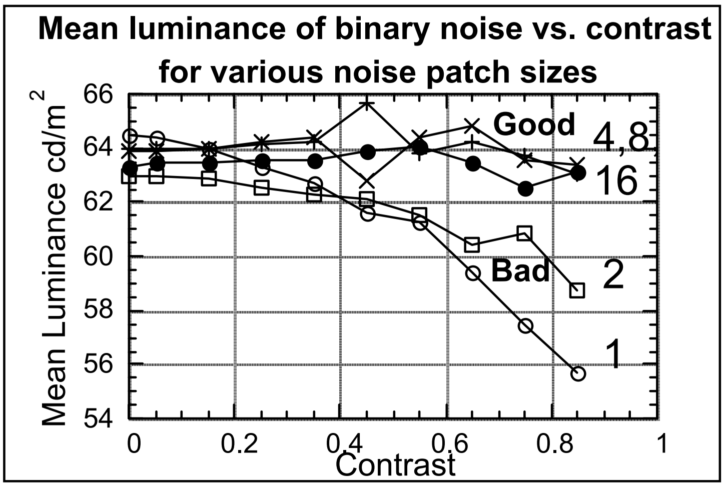
Use only low frequency sinusoids. Use only low-passed or band-passed noise. Frequency content at eye can be increased by increasing viewing distance

3) Compensate for orientation

In the case of oriented lines one can measure the 'luminance' of a horizontal line at a pixel value that is (say) 75% of the maximum and then adjust the pixel values of lines at other orientations such that their 'luminances' match.

4) Measure mean luminance

In the case of binary noise limit the resolution such that the mean luminance (averaged over repeated measurements stays constant) with increased contrast.



Accuracy depends on integration area of luminance meter. Can be improved by using a slit or hole.

APNL -- Quickie corrections

6) Tilt screen

So that things are oriented either side of screen vertical

7) Mean luminance comparison by eye

With normal Gamma correction in place. Frame interleave the image to be calibrated with its own negative. Compare the result with a mean luminance field. Errors due to APNL will show up either as a drop in mean luminance or as localised dark patches. Correct for APNL by adjusting some parameter of the image (ie max frequency) until mean luminance is OK and artifacts disappear.

8) False Gamma

Adjust Gamma until the mean luminance of the stimulus (measured by 4 or 5) remains fixed with contrast. The resulting false Gamma can be used to simultaneously correct Gamma and APNL non-linearities, but only for images similar to the one used in calibration. For example horizontal and vertical gratings would required different Gammas. The impact of the shape of the waveform is unclear.

Summary

All methods for correcting APNL are prone to some error and/or introduce some artifact. Method 5 seems about the best as it has the potential to produce images that have no observable artifacts.

The main thing is to calibrate for each type of stimulus.

Specification for EIZO 6500M

In choosing a monitor when APNL might be an issue you should look for one with a high video bandwidth and low rise time.

The EIZO has a bandwidth of 120MHz and rise time of 5.0ns

Note that τ does not equate to the rise time.

Rise time is measured by applying a step input to the amplifier and measuring the time taken for its output to vary from 10% to 90% of the target value.

τ=rise-time/2.2

Beware however that manufacturers specifications are the norms for the model and may not be accurate for an individual device. Kline, Hu and Carney suggest a method fro estimating τ.

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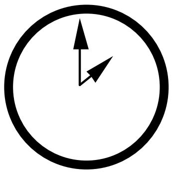
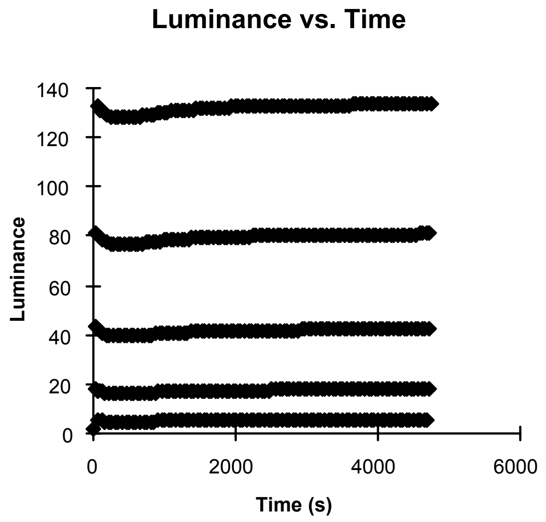
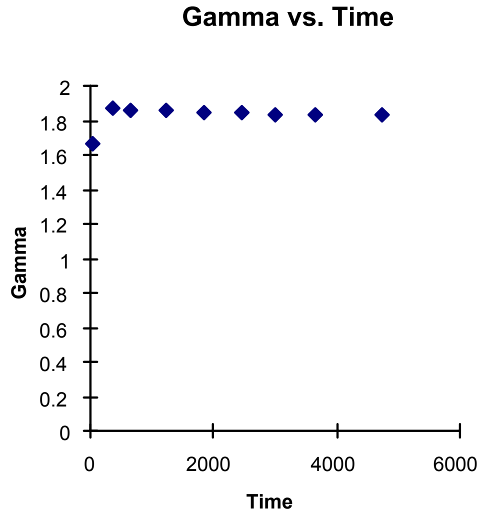
Warm - Up time

Does it really take an hour for a display to warm up?

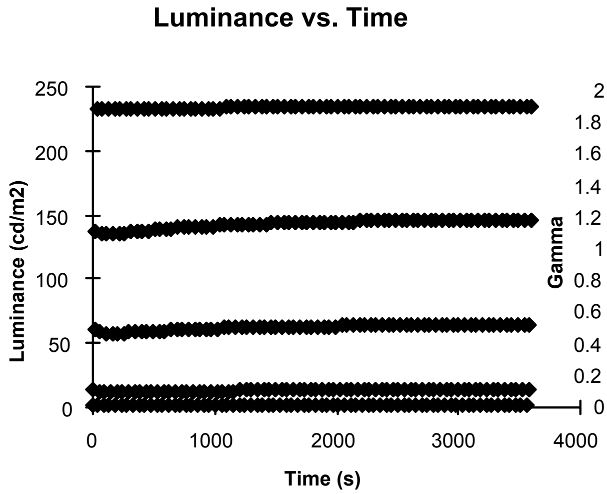


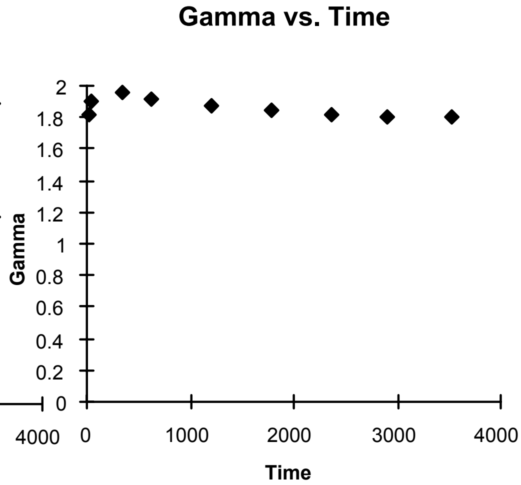
Good screen



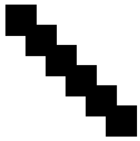


Bad screen





Jagged Edges - Aliasing



Pixels

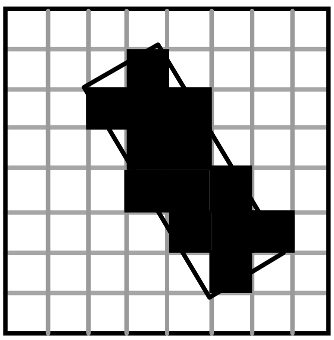
Scan lines. The video signal and raster scan screens are inherently digital in the vertical dimension. The signal is however analogue in the horizontal dimension as are mono displays.

Shadow mask. For colour screens digitisation extends to the horizontal as well.

Bit mapped images. In any case most graphics cards produce the screen image from bit mapped or digitised sources and thus digitise the horizontal dimension anyway.

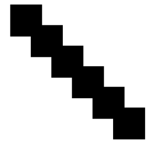
Drawing lines

Smooth curves and lines drawn onto bit mapped images become pixilated.



Algorithms for drawing such lines vary in their sophistication one (simplistic) way is to plot an imaginary boundary and then colour in any pixel whose centre lies within the boundary.

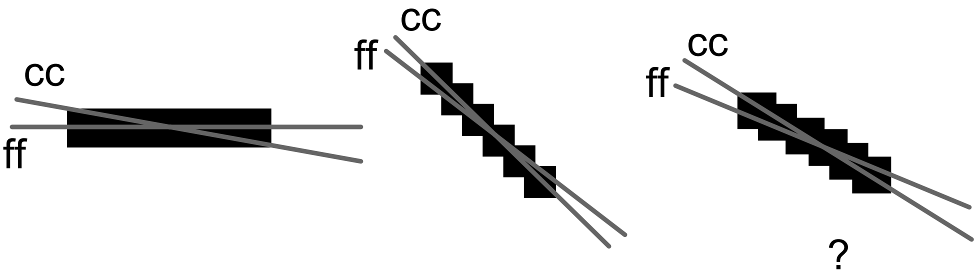
Jagged Edges - Aliasing



So what's the problem?

If the pixels are small (in degrees of arc) then the pixilation of lines may go unnoticed. But what is the orientation of such a line?

1) The orientation passed to the line plotting function?
2) The orientation of the line joining the extreme corners?
3) Or the orientation of the line joining the mid points of the end faces?



90Þ, face - face   45Þ, corner - corner

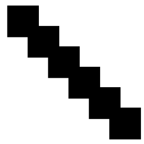
Keeble, Moulden and Kingdom (Vis Res 35, pp 2759-2766, 1995) show that neither the 'ff' or the 'cc' metric gives a good estimate of perceived orientation. The errors are bigger than a JND.

♌ The orientation of a least-squares fit to pixel centres is a better metric.

♌ When anti-aliasing is used the perceived orientation is close to that orientation supplied to the plotting function.

Residual errors are small (<=1JND) and vary with the circumstances of the test.

Jagged Edges - Aliasing



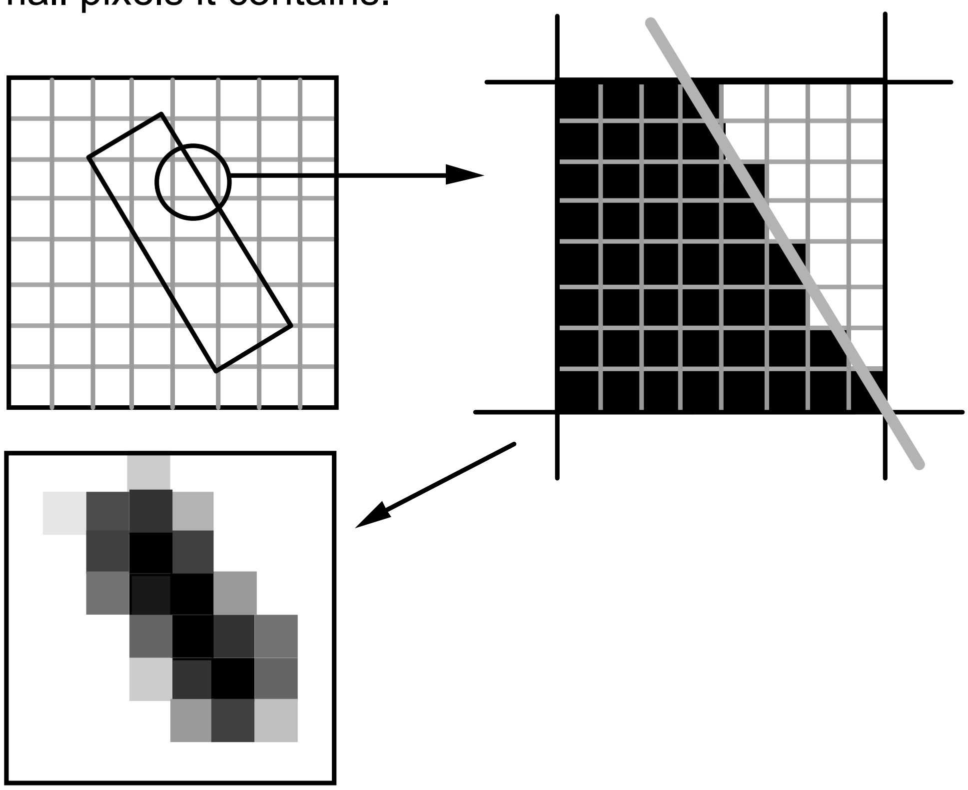
Anti-aliasing

Use the available grey levels of soften the edges

There are many methods.

In the one used by Keeble et al an ideal line is drawn at a high resolution, low pass filtered and then sampled at the true resolution.
(Due to Gupta and Sproull, Computer Graphics 15, pp1-5, 1981)

Another method is to draw the line at a high resolution and the re-sample at the lower resolution assigning each large pixel a grey level in proportion to the number of filled small pixels it contains.



Grey Level Resolution

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Most graphics systems have 8 bit digital to analogue converters. This means that there are only 256 grey levels between min and max luminance. When contrast is low the image may contain very few grey levels this can cause blocking and a loss of detail.

Hardware solutions

1) Achieve low contrast by adjusting CRT controls. (Watch out for Gamma)
2) Optically mix images from two monitors.
3) Mix two images by frame interleaving.
4) Use a graphics card with 12 bit (or more) DAC's. (increasingly available at low cost)
5) Attenuate video signal. Watch out for bandwidth of attenuating amplifier (thought should be very good).

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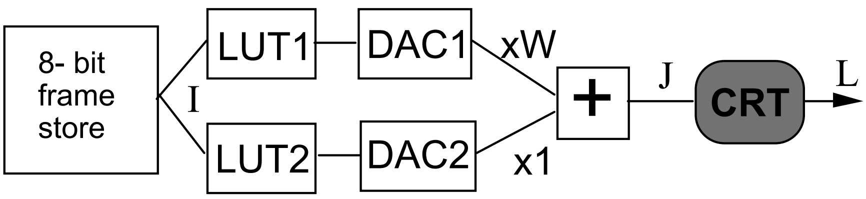
6) Cascade DAC's. Use 2 8-bit DACs and add their outputs with an appropriate scaling factor applied to one.

(Pelli and Zhang, Vis Res 31, pp1337-1350, 1991)



The maximum number of grey levels is still 256 but this can be achieved over a greater range of contrasts.

At low contrast: DAC! determines the minimum luminance and DAC2 carries the information.

At high contrast: DAC1 carries the information and DAC2 has a minor role.

Grey Level Resolution

8

Software solutions

1) Dithering

Luminance and colour resolution can be improved at the cost of spatial resolution by dithering. There are three types of dithering but the essence of the method is to work out the error between the actual luminance of a pixel and the requested and then disperse the error onto the neighbouring pixels. (Mulligan and Stone ibid)

2) Bit stealing

This variant of dithering exchanges colour resolution for luminance resolution. The luminance resolution is improved by making sub-threshold adjustments to the hue of each pixel.

For example a pixel with RGB values 254,255,254 has a slightly higher luminance than 254,254,254 but it is also very-very slightly green.

(Tyler, Spatial Vision, 10, pp369-377, 1997)