Image quality perception

Evaluating real-world image quality performance

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Factors affecting image quality perception

Many interrelated factors combine to create what people perceive as a quality image. Although much attention is given to absolute brightness in a display system, other factors have at least as great an effect on perceived image quality. Among these factors are: contrast ratio, which defines the dynamic range of the display system; and resolution, the system's ability to display fine detail.

Contrast ratio

Contrast ratio is often under-emphasized, even though it has a tremendous effect on perceived image quality. Poor contrast ratio usually means the system exhibits a poor black level performance. This is characterized as either an inability to display dark enough blacks – resulting in "washed out" images – or a loss of fine detail in the dark areas of the image.

Resolution

Resolution of a digital display is specified as the number of horizontal and vertical pixels. For instance, an SVGA imaging device is 800 pixels wide and 600 pixels tall. A larger number of pixels means the system can display images with finer detail. This is also referred to as the spatial frequency of an image. Areas of fine detail have high spatial frequency content.

Brightness

Brightness, contrast and resolution are interrelated in their contributions to image quality. The human ability to resolve fine detail is affected by both the brightness and the contrast of the image. So simply selecting the brightest display with the highest native resolution is not necessarily the best choice for overall perceived image quality. While brightness is important to *capture attention*, contrast performance is most critical for *conveying information*. The concept of maximizing the amount of conveyed information, and its relationship to perceived image quality is the focus of this paper.

A new metric for evaluating image quality

Although both brightness and contrast have an effect on image quality, their contributions are not easily measured. Brightness and contrast performance must be characterized over the full range of spatial frequencies. Only then can the image quality performance of different display systems be rigorously compared.

However, most display manufacturers publish only a low frequency brightness and contrast specification. What is needed is a simple way to compare different display systems that is based on information widely specified by manufacturers, and has good correlation to perceived image quality.

Clarity uses a combination of brightness and contrast as a more revealing metric for evaluating image quality. This metric, the Quality Viewing Metric (QVM), is the product of brightness times contrast in ambient light. Incorporating the effects of ambient light is key. How the display's screen handles ambient light has a large impact on overall contrast ratio.

Importance of contrast ratio performance

Modulation Transfer Function

Contrast is often defined as the ratio of the brightest white image a system can generate (I_{max}) divided by the darkest black image (I_{min}). Here I_{max} and I_{min} are screen brightness measurements in foot Lamberts or candelas per square meter. What this simple definition fails to address is how contrast ratio varies with spatial frequency (f). Contrast performance over a spatial frequency range is characterized by the Modulation Transfer Function (MTF):

$$M(f) = \frac{I_{max}(f) - I_{min}(f)}{I_{max}(f) + I_{min}(f)}$$

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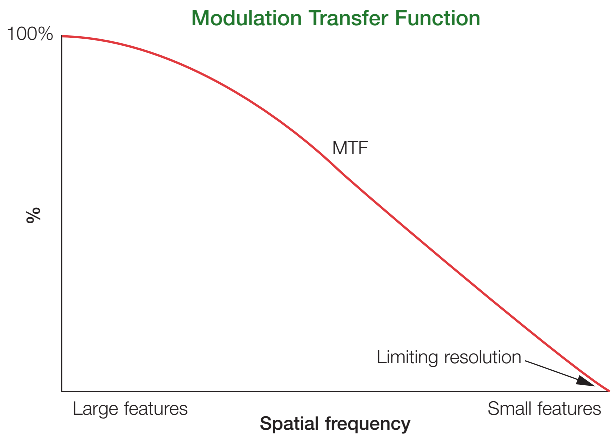
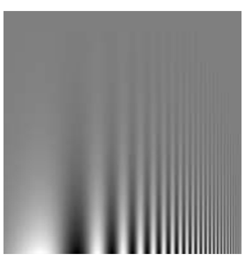


Small aberrations in the imaging devices and optical elements cause the MTF to decrease with increasing spatial frequency. The overall number of pixels in the imaging device sets the limiting resolution point.

MTF is similar to frequency response of an electrical system. The MTFs of individual elements in an optical system (e.g. imaging device, lenses, screen) multiply together to yield the overall system MTF.

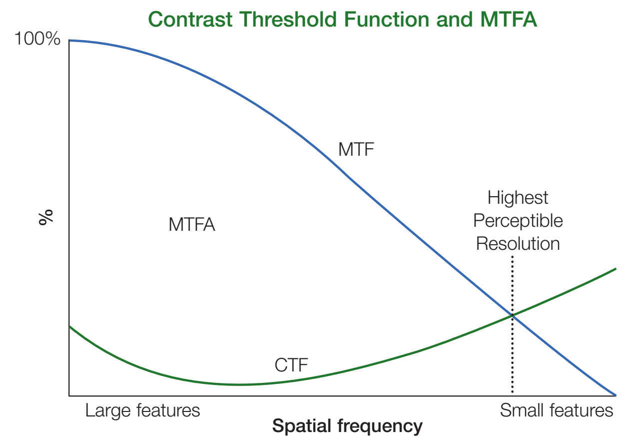


Contrast Threshold Function

While the MTF deals with the contrast performance limitations of an imaging system, there are also limitations associated with *human vision*. Our ability to discern low contrast patterns varies with the size of the pattern, or its spatial frequency. The Contrast Threshold Function (CTF) is a measure of the minimum contrast needed for images to become distinguishable. Each individual has a different CTF curve. Relatively speaking, higher amounts of minimum contrast are needed at extremely low and extremely high spatial frequencies.

This effect is illustrated by the image above.[1] In this image, spatial frequency increases from left to right, and contrast varies from 100 percent at the bottom to less than one percent at the top. If human perception of contrast were frequency independent, the alternating bars in the image would appear to have equal height. However, the bars in the middle appear taller. Moreover, the apparent position of the peak changes as one moves closer and farther from the image, indicating that the inverted U-shaped envelope seen is not in the image itself, but is an artifact of the human visual system.

When plotted together, the MTF of an imaging system and the CTF of human vision combine to determine the highest useable resolution. At a certain spatial frequency, the imaging system's contrast performance will fall below the minimum needed to distinguish a pattern from a uniform field. This crossover point determines the highest perceptible resolution.



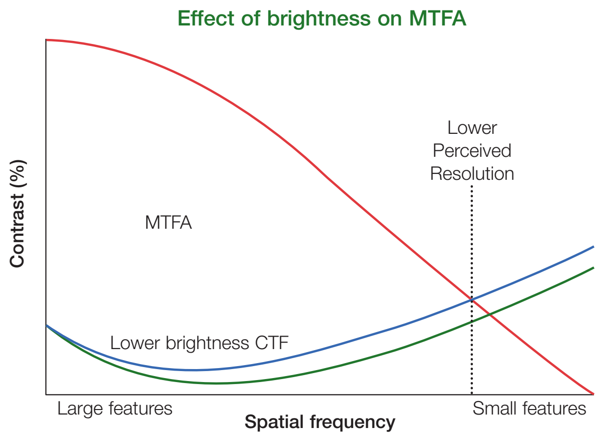
The area on the graph between the two curves is referred to as the Modulation Transfer Function Area (MTFA).[2] This area represents the amount of image content that is conveyed to the viewer. By maximizing this area, perceived image quality performance is maximized as well.

Effects of higher brightness and contrast

Using the concept of MTFA, the effects of brightness and contrast on overall image quality are better understood. The average brightness of an image changes the position of the CTF. Darker images shift the curve up and to the left. In other words, if an image has less average brightness, the minimum contrast needed at any given frequency tends to be more. The net effect is a slightly smaller MTFA.

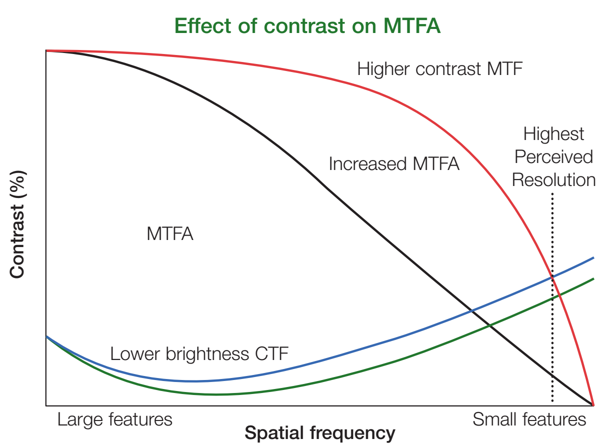
[1] Campbell, F.W. and Robson, J.G. (1968) Application of Fourier analysis to the visibility of gratings. *Journal of Physiology* (London) 197: 551-566

[2] MTFA concept first proposed by Charman and Olin in 1965.



Contrast affects the MTFA in a fundamentally different way. If peak brightness performance of a display system is traded off for increased contrast performance, two simultaneous effects occur on the graph. In the following example, assumptions are a slightly smaller I_{max} value (decreased brightness) but a much smaller I_{min} value resulting in a larger I_{max}/I_{min} (increased contrast).

The reduced brightness shifts the CTF curve up and to the left. However, the improved contrast performance changes the shape of the MTF curve. The overall result is a significant increase in both the maximum perceived resolution, as well as the MTFA. Here we can see the tremendous impact that contrast ratio has on overall image quality. Higher contrast significantly increases the amount of image content conveyed to the viewer.



Summary and conclusion

Many factors combine to create excellent perceived image quality. In comparing brightness, contrast and resolution specifications for rear projection displays, it is important to have a thorough understanding of how these different factors affect image quality. Simply selecting the display with the highest brightness and the highest native resolution can lead to disappointing results.

Although our perceptions of brightness, contrast and resolution are quite complex, we have seen that contrast ratio has a tremendous effect on perceived image quality. Any metric for comparing the performance of different display systems should ideally include all factors affecting image quality. However, as a practical matter, we must use metrics that are typically specified by most manufacturers. Using QVM, the simple product of brightness times contrast in ambient light, gives a more meaningful indication of image quality than brightness alone. Using the QVM as an *objective* measure exhibits good correlation to *subjective* image quality evaluations.[3]

Clarity Visual Systems understands the importance of contrast ratio and its effect on image quality. Our Advanced Performance Liquid Crystal Display (AP/LCD™) technology, combined with Jenmar's BlackScreen™ technology, yields outstanding contrast and brightness performance. The superior QVM rating of Clarity displays makes them the best choice for most applications.

[3] See *Image Quality Series: Part III* ***Quality Viewing Metric***

Clarity Visual Systems, Incorporated
9025 S.W. Hillman Court, Suite 3122
Wilsonville, Oregon, 97070, USA
Phone: 503-570-0700
Fax: 503-682-9441
http://www.clarityvisual.com

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