Measuring MTF with wedges: pitfalls and best practices

We discuss sharpness measurements in the ISO 16505 standard for mirror-replacement Camera Monitor Systems.

We became aware of ISO 16505 when customers experienced difficulty with measurements.

Key features:

- **Uses high-contrast wedges instead of slanted-edges for MTF/resolution, even though MTF is not defined for wedges in ISO 12233:2014.**
- **Uses MTF10 (spatial frequency where MTF is 10%) for pass/fail**

Reference (definitive): Handbook of Camera Monitor Systems — The Automotive Mirror-Replacement Technology based on ISO 16505, Anestis Terzis *Editor*

Measuring MTF with wedges: pitfalls and best practices

The problem: ISO 16505 calls for

-wedges for MTF (resolution) measurements, and

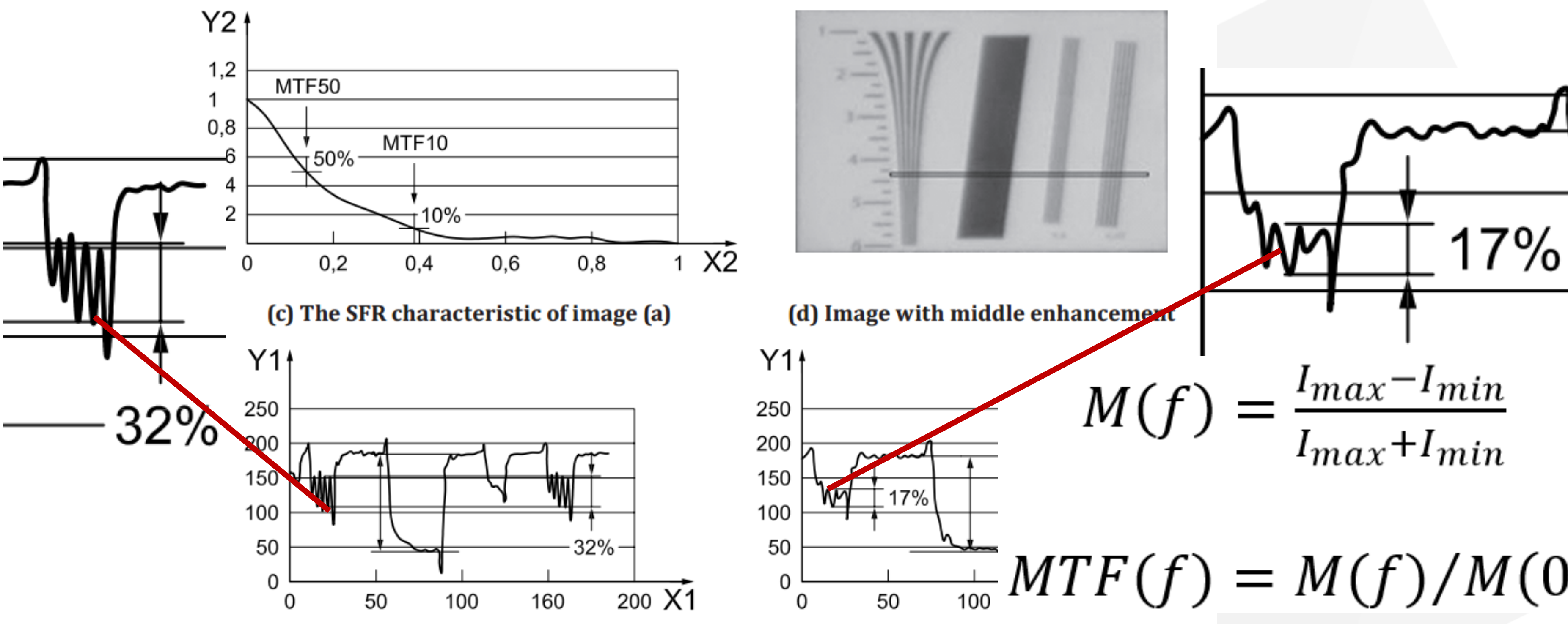
-*MTF10* (the spatial frequency where MTF = 10%) as the pass/fail criterion.

"Edge enhancement is a well-known technology … but such a processing will strongly affect the reproducibility of the *SFR** measurement. Along the discrete sampling of image; the *SFR* measurement improperly used can lead to incorrect results of limit resolution measurement. … Therefore, a traditional resolution measurement method using black and white hyperbolic resolution chart is advised to be used to evaluate the resolution (*MTF*) performance of the CMS." **SFR* implies a slanted-edge measurement.

***MTF10* cannot always be measured, and low quality cameras may have high *MTF10*.**

WRONG! The wedge is equally sensitive to errors caused by signal processing (sharpening). Black and white (high contrast) edges are especially bad, particularly when compared to low-contrast slanted-edges (ISO 12233:2014).

Amplitude for wedge MTF calculation (I_{max}-I_{min} from the standard)



(c) The SFR characteristic of image (a)

(d) Image with middle enhancement

(e) The signal amplitude along horizontal upper line, frequency point 4,25

(f) The signal amplitude along horizontal lower line, frequency point 4,8

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

$$MTF(f) = M(f)/M(0)$$

Amplitudes (I_{max}-I_{min}) used to estimate MTF are arbitrarily selected: neither repeatable nor robust. From ISO 16505, E.3.

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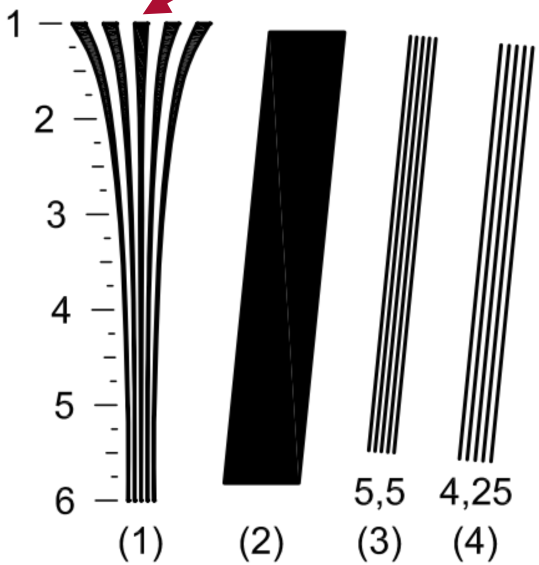
Square wave 4/π MTF error

This approach to wedge-based MTF is incorrect because the wedge is a *square wave*. MTF is based on *sine waves*.

$$x_{\text{square}}(t) = \frac{4}{\pi} \sum_{k=1}^{\infty} \frac{\sin\left(2\pi(2k-1)ft\right)}{2k-1}$$

$$= \frac{4}{\pi}\left(\sin(2\pi ft) + \frac{1}{3}\sin(6\pi ft) + \frac{1}{5}\sin(10\pi ft) + \cdots\right)$$



MTF derived from square wave amplitude is high by a factor of 4/π.

A better MTF equation for wedges

A more accurate solution:

Find *M*(*f*) from sine wave (Fourier) coefficients, C_{cos} & C_{sin}.

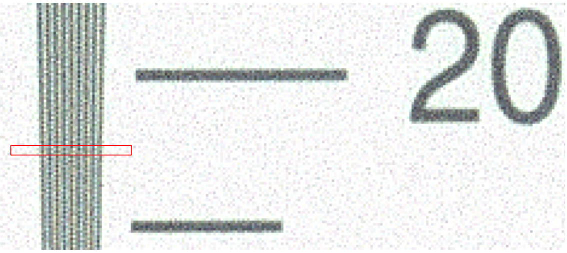
- **Accurate (uses sine components)**
- **Stable, relatively repeatable, fast**

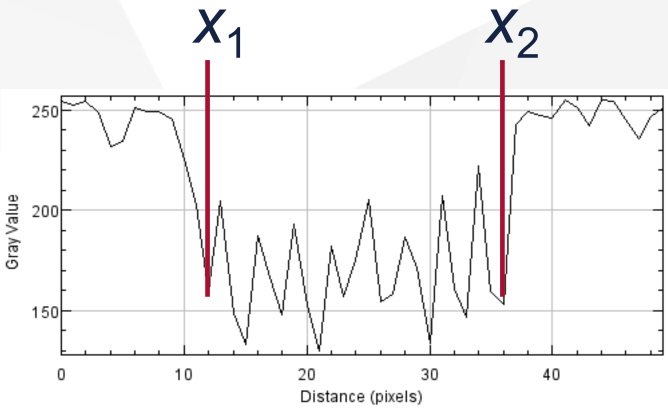
$$C_{cos} = \int_{x_1}^{x_2} I(x)\cos(2\pi f(y))\,dx/(x_2 - x_1)$$

$$C_{sin} = \int_{x_1}^{x_2} I(x)\sin(2\pi f(y))\,dx/(x_2 - x_1)$$

$$M(f) = \sqrt{C_{cos}^2 + C_{sin}^2}$$

$$MTF(f) = M(f)/M(0)$$

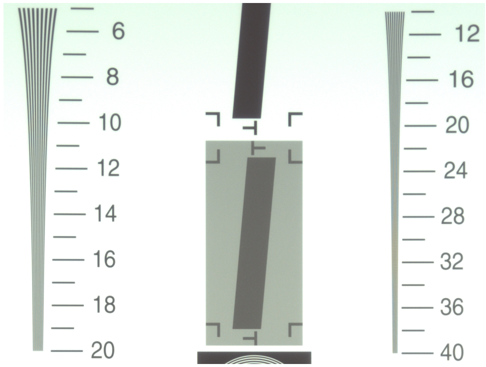


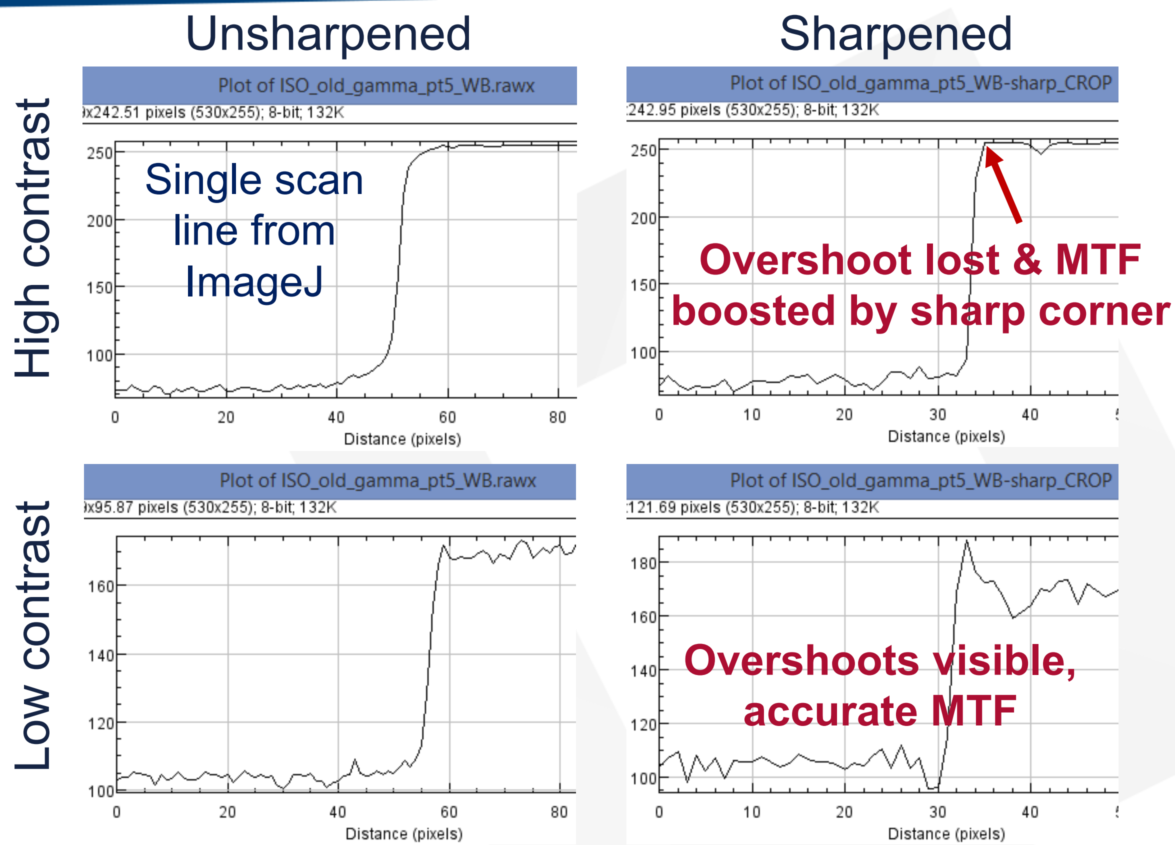


Saturation
a problem with high contrast charts

The image saturates (clips) when the brightest areas reach the maximum digital value (255 for 8-bit ima-ges). “Halos” near sharp-ened high-contrast edges may saturate strongly.

The image below, without and with sharpening, illustrates saturation.



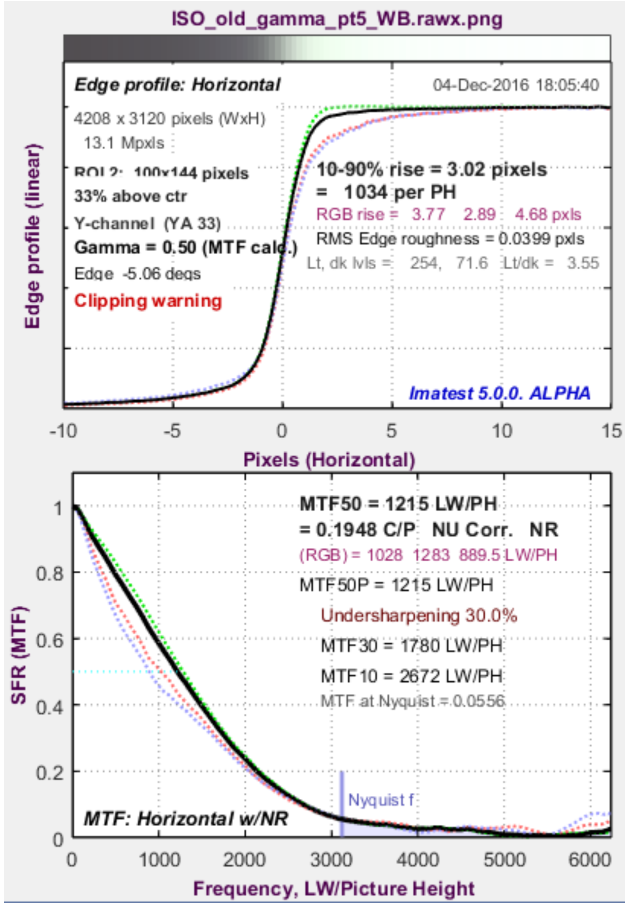


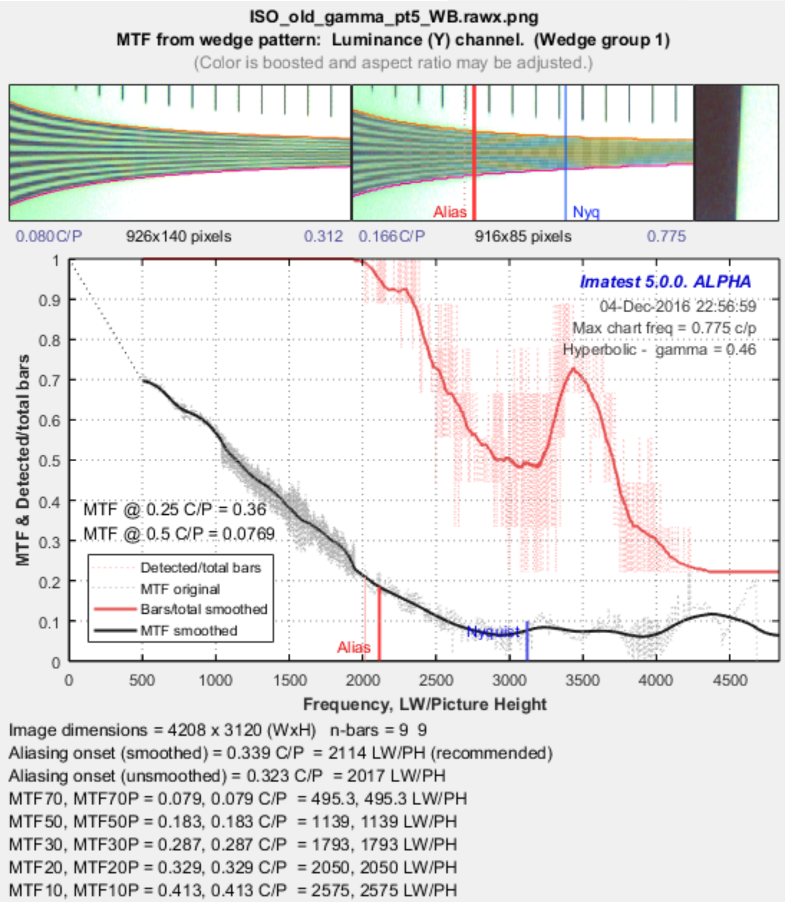
Information is lost when image clips: Measurements become inaccurate. Lower contrast features (edges & wedges) are recommended.

Comparing Edge and Wedge MTF

for high contrast edge & wedge

MTF curves are very similar for **unsharpened** edge and wedge images.
Saturation has little effect.



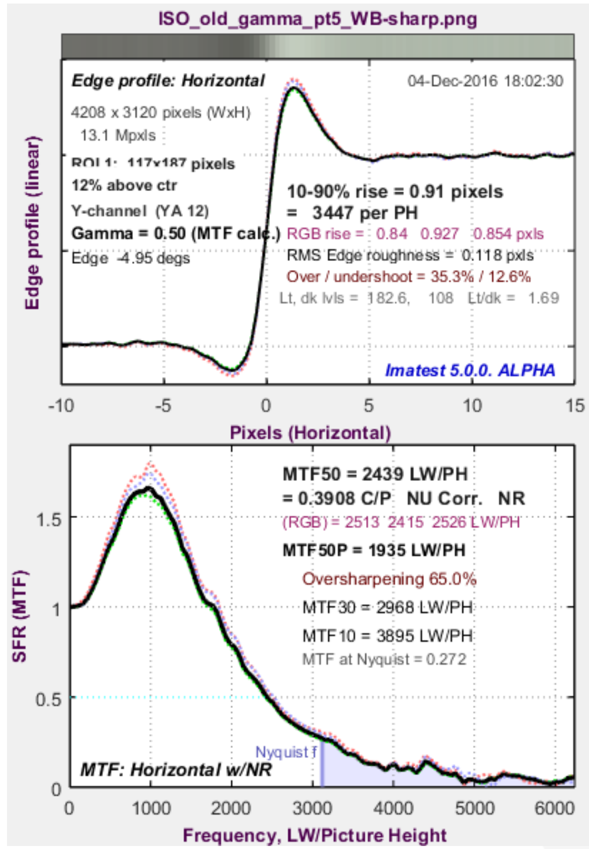


Sharpened image: low vs. high contrast edge

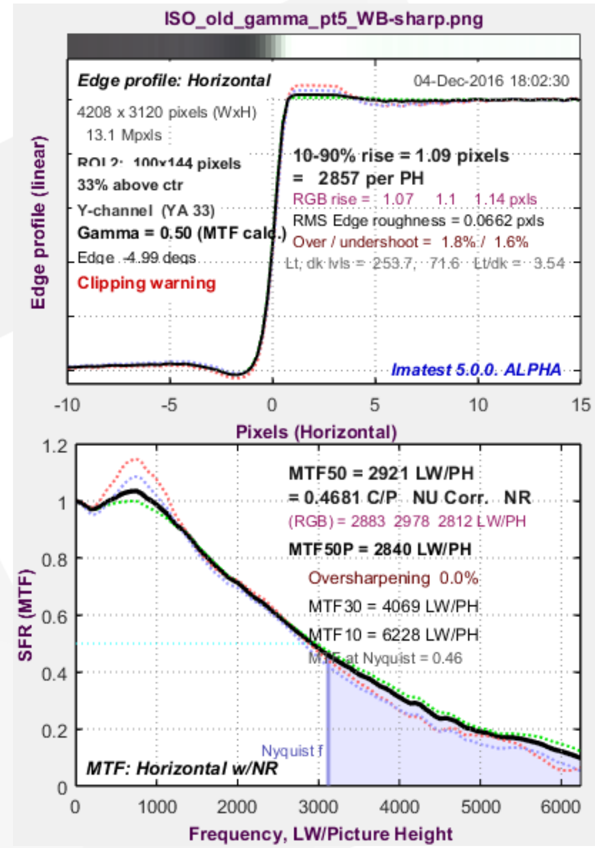
Low and high contrast edges have *very* different spatial and MTF response in sharpened images.

The overshoot in the low contrast edge represents a real artifact (halos near edges) that can affect image interpretation. (Some overshoot is OK for visual display.)

Overshoot is suppressed and MTF is inaccurate (too high) in the clipped high contrast image.



Low contrast– shows edge overshoot

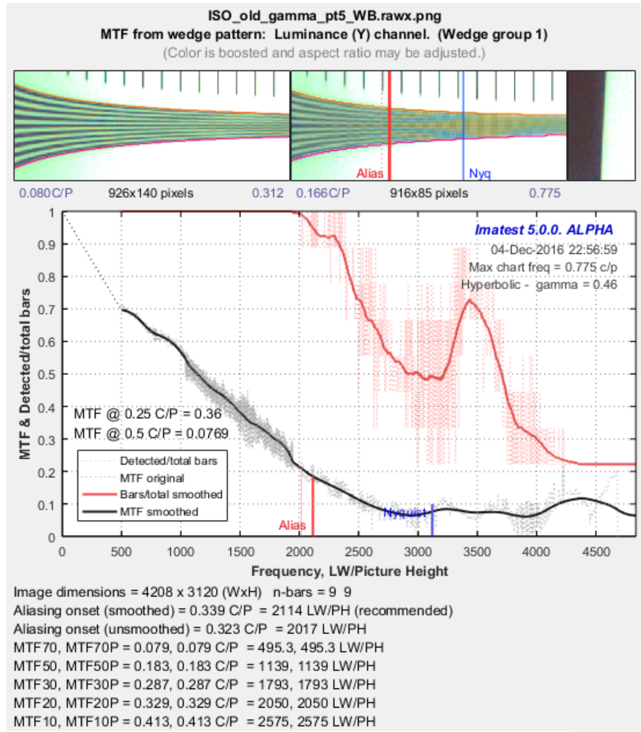


High contrast– clipped! *MTF10 >> f_{nyq}*

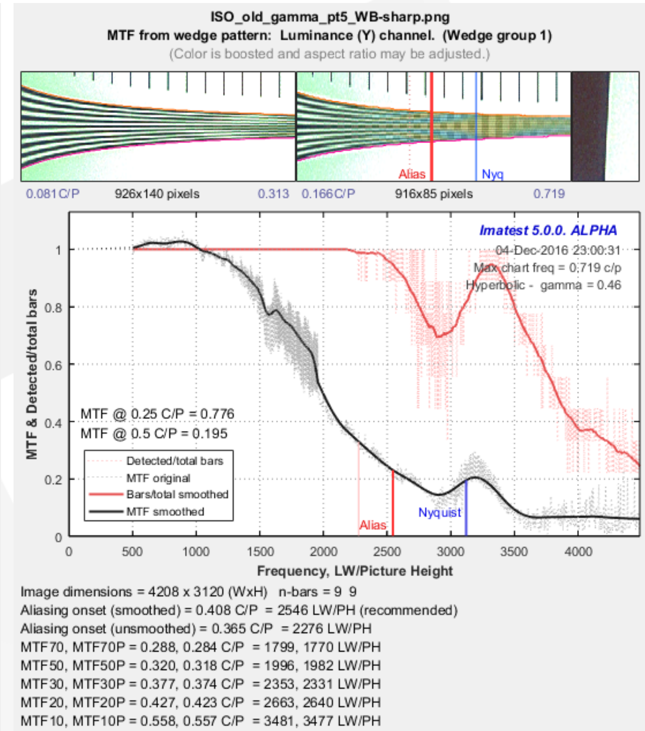
Unsharpened vs. sharpened wedge measurements

The sharpened edge shows better MTF, as expected. Overshoot is suppressed.

MTF50 is a better indicator of perceived sharpness, and more stable because d*MTF*/d*f* is much larger at the 50% level.



Unsharpened wedge response.



Sharpened wedge response. Note MTF bump near f_{nyq} (from sampling phase) and large increase in *MTF10* (>> f_{nyq}).

MTF often flattens out around the 10% level, making *MTF10* very susceptible to noise, sharpening, and other perturbations.

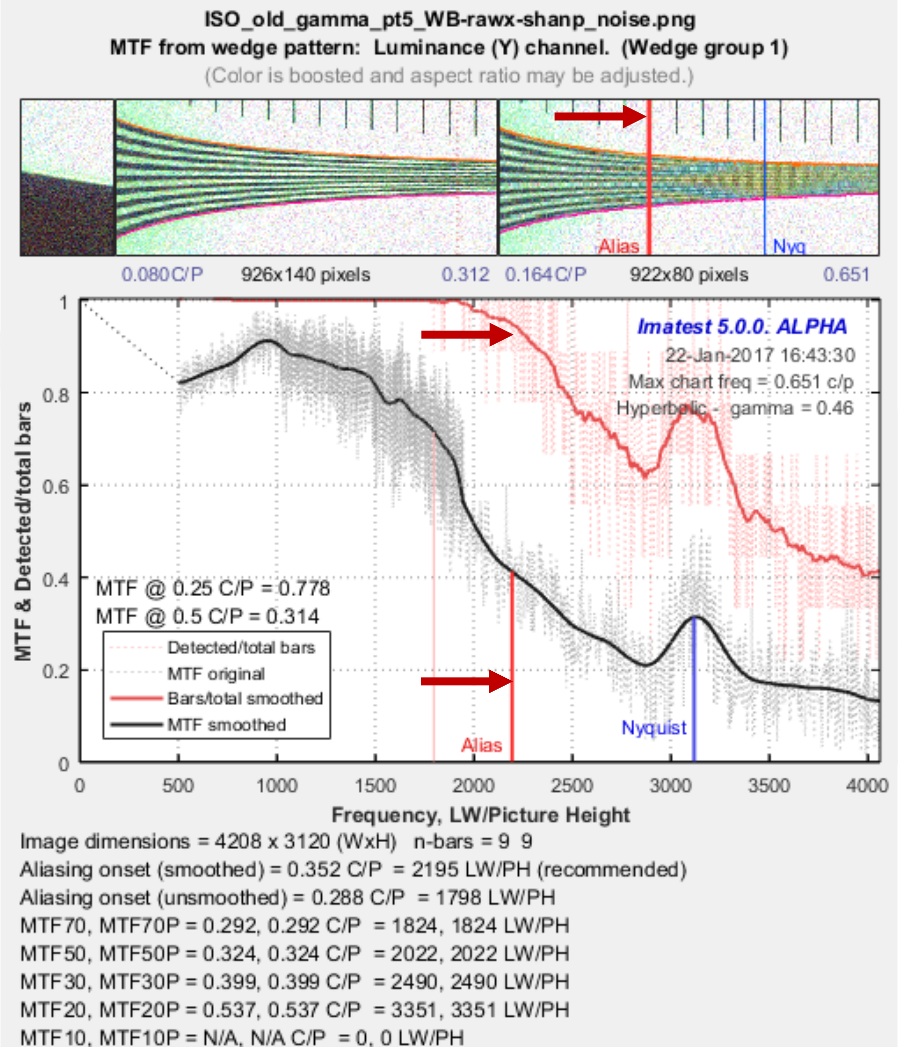
Image where MTF10 is undefined and “Onset of Aliasing”

Example of image where MTF never drops to the 10% level. *MTF10* is undefined.

The primary cause is noise, but we have seen this with images that have less-than-obvious artifacts.

The wedge has a saving grace: It counts the numbers of detected bars.

The frequency were the number of bars (the count has to be smoothed) drops below 95% if the maximum is a good indicator of the resolution limit. For sharp images this is called the “Onset of aliasing” ⟶ on the right.



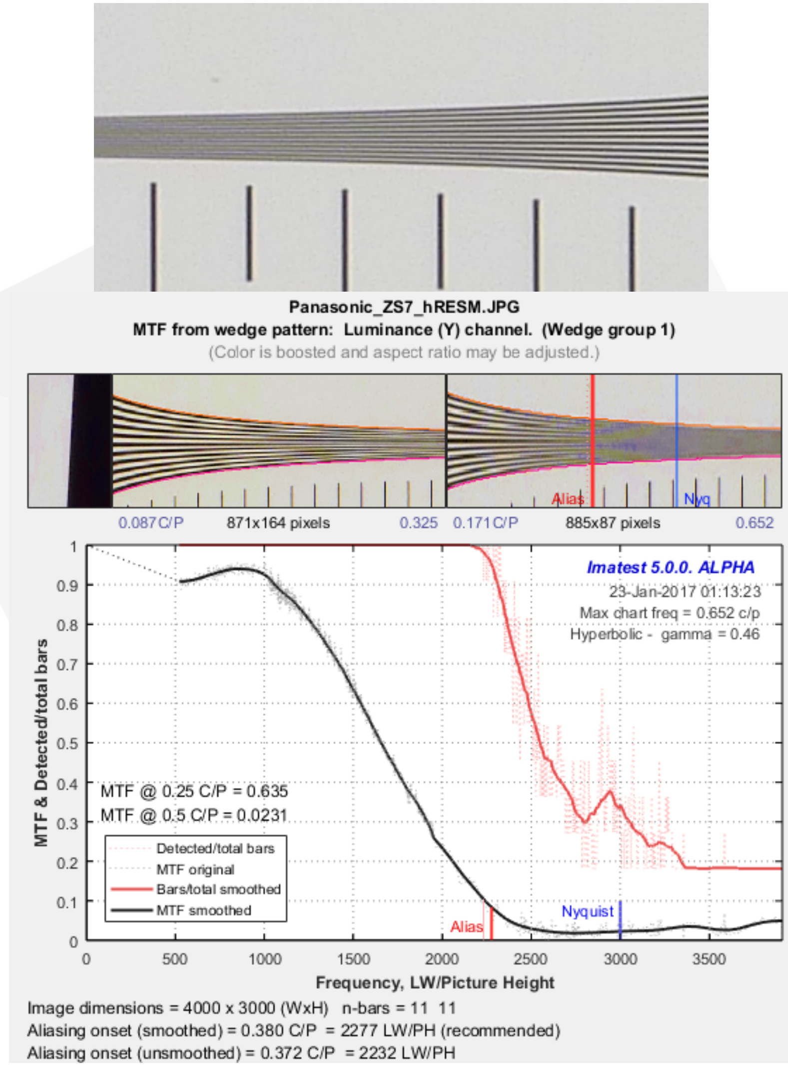
Recommended measurement

Because *MTF10* is not reliable– and is subject to strong variations from signal processing, noise, and artifacts, we recommend the following measurement criterion.

$$\boldsymbol{MTF\ limit = \min(MTF10,\ f_{alias},\ f_{nyq})}$$

f_{alias}, is relatively stable. It is much less affected by sharpening, noise, and clipping than *MTF*10.

f_{nyq} is fixed at 0.5 Cycles/Pixels. Information above f_{nyq} is not useful (is aliased to lower spatial frequencies),



General comments 1

- Saturation (clipping) affects both high contrast slanted-edge and wedge measurements. (Slanted-edges come off somewhat worse, but ISO 12233:2014 recommends low contrast (4:1) slanted-edges, which avoids this issue.)
- We recommend reducing wedge contrast (from Black and White, typically ≥40:1). 10:1 would work well to reduce clipping.
- *MTF50* (or *MTF50P*) is generally a better measurement than *MTF10*: more stable and better correlated to perceived sharpness.
- Since *MTF10* is *not* a robust measurement and is often >> f_{nyq}, we recommend *MTF limit* = min(*MTF10*, f_{alias}, f_{nyq}).
- Sharpening artifacts, best measured with a low-contrast (4:1) slanted edge, are strongly recommend for fully characterizing imaging systems.

Standards issues

- Many standards are being developed that are related to image quality. We would like to see better coordination with groups familiar practical measurement techniques.
- Many companies familiar with practical measurements are already involved with several standards groups (ITO TC42, CPIQ, etc.), all of which involve time and travel costs. Adding more committees might not be feasible.