Image quality measurement: real world challenges

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www.imatest com

- **Background: Predicting image quality; *Imatest* structure**
- **Image quality factors and how they are measured**
- ***Imatest* modules: review**

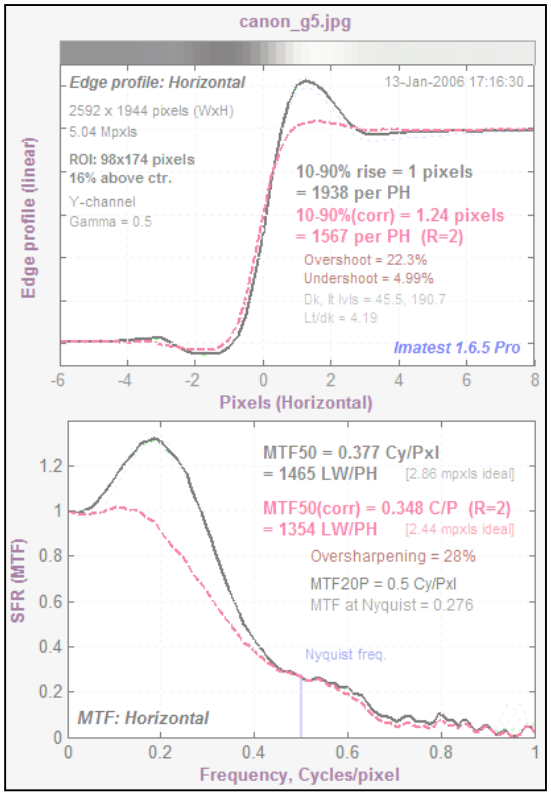
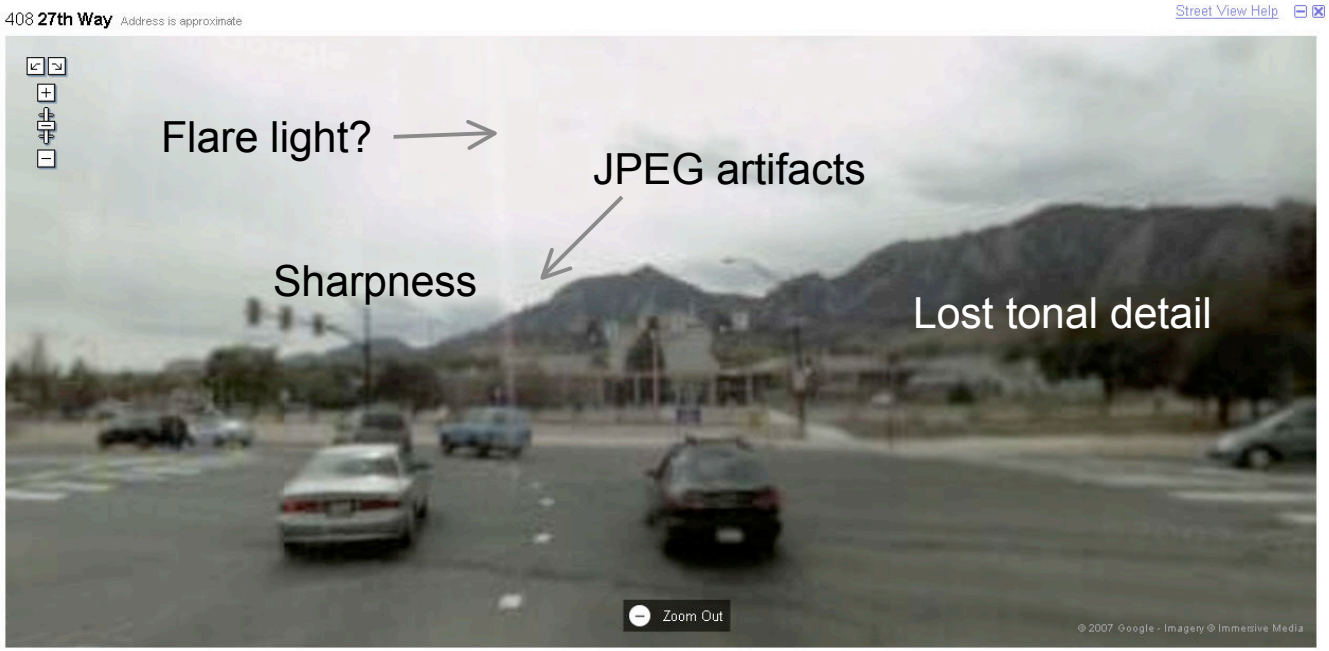


Image quality example



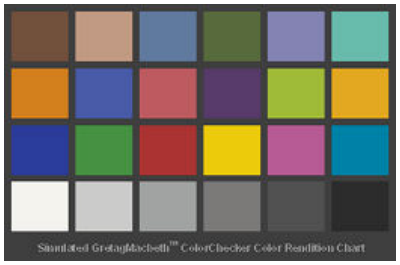
DOC/NIST building in Boulder (atomic clock): Street view boundary

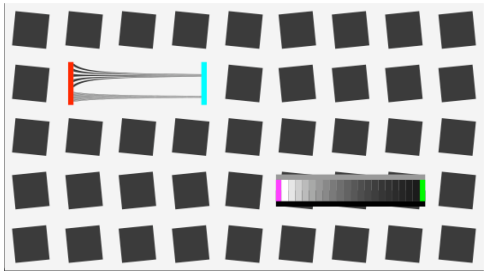
Poor sharpness, smudged shadow detail, JPEG artifacts, flare light(?)

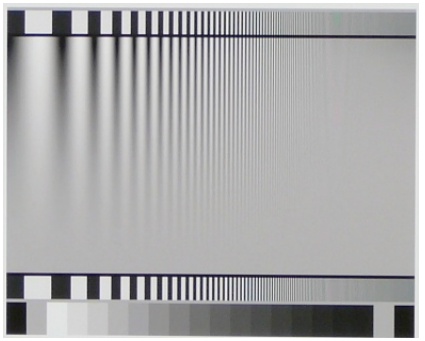
***Imatest* was created to predict imaging system performance.**

Imatest: Basics

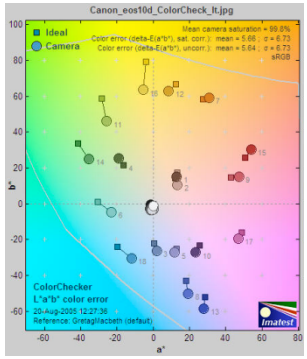
- **Photograph** test chart (standard or user-created) in controlled environment or as part of a scene.

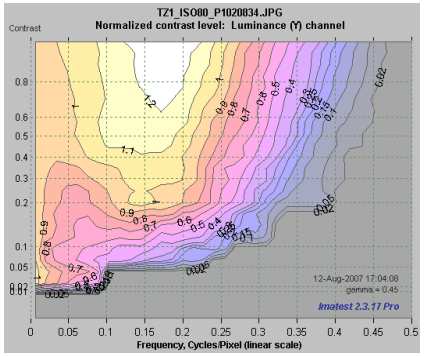


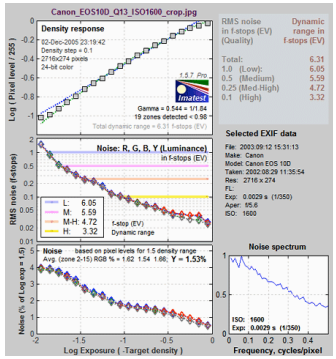


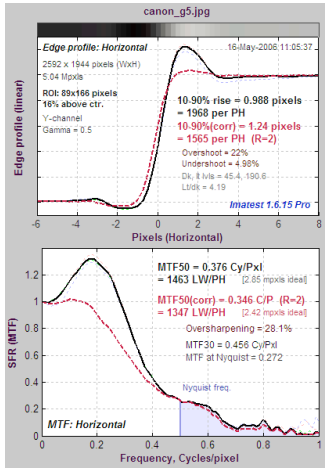


- **Analyze** image for relevant quality factor.





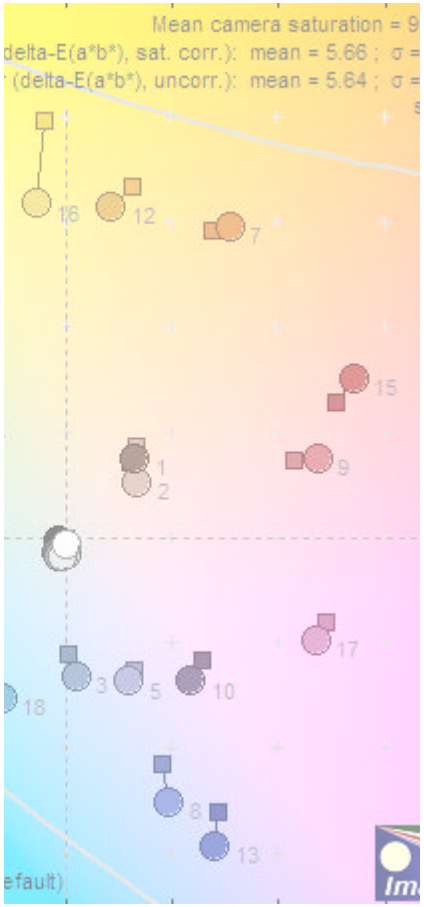




- Cannot separate lens, sensor, signal processing.

Imatest: Background

- Created to enable individual photographers to test lenses and cameras.
  - Lens sharpness?
  - Camera dynamic range?
  - Color reproduction accuracy?
- Widely adopted by industry: mobile imaging and many others.
- Compiled Matlab.
- Downloaded from www.imatest.com.
- Modules analyze images of standard targets.



Tour of image quality factors

with examples of ***Imatest*** analysis

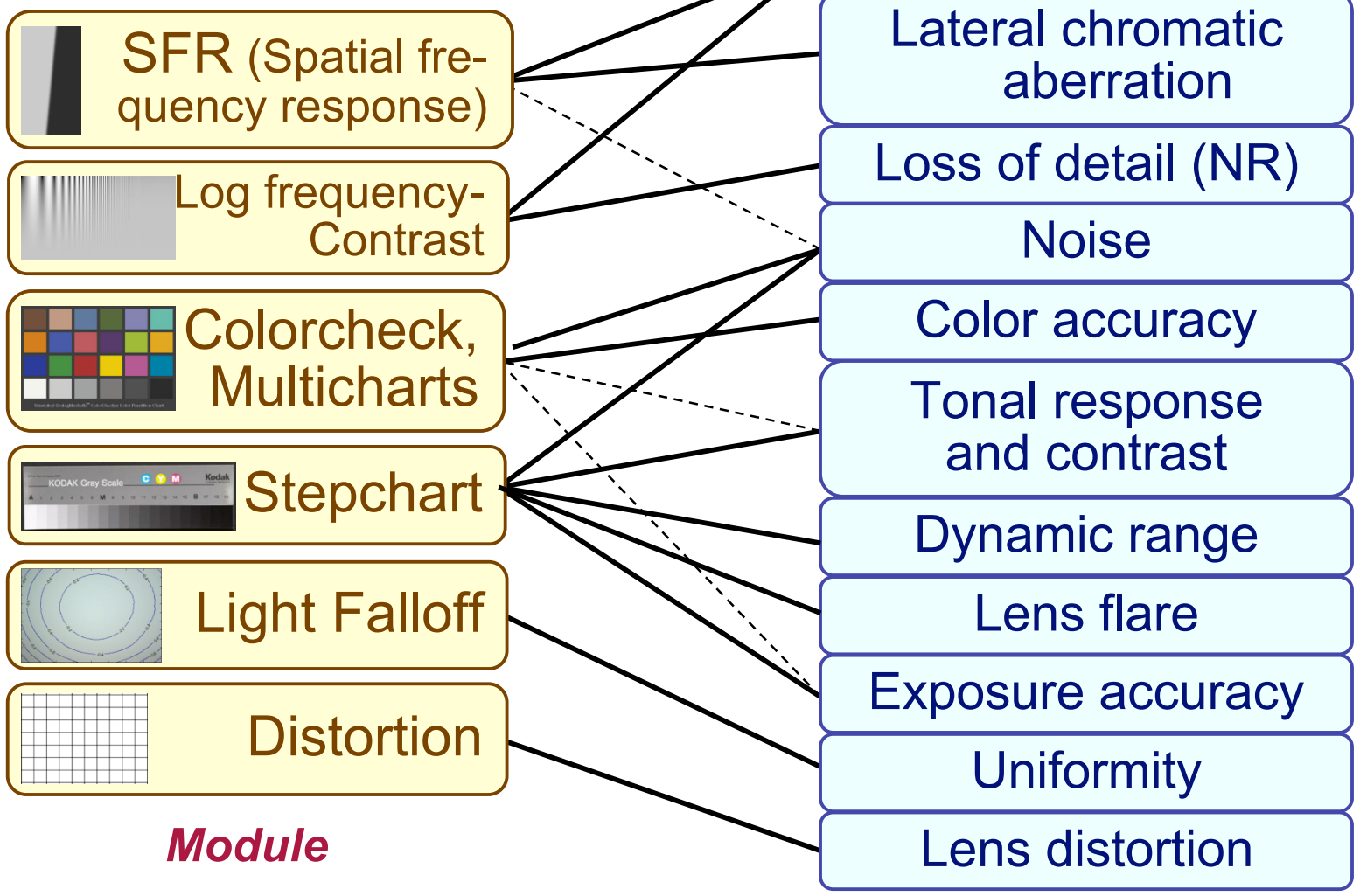
Monument Valley/Hunt's Mesa image illustrates image quality factor degradations.

Issues to think about:

- Capture vs. post-processing
- Objective measurements vs. subjective judgment

Original on left | Degraded on right

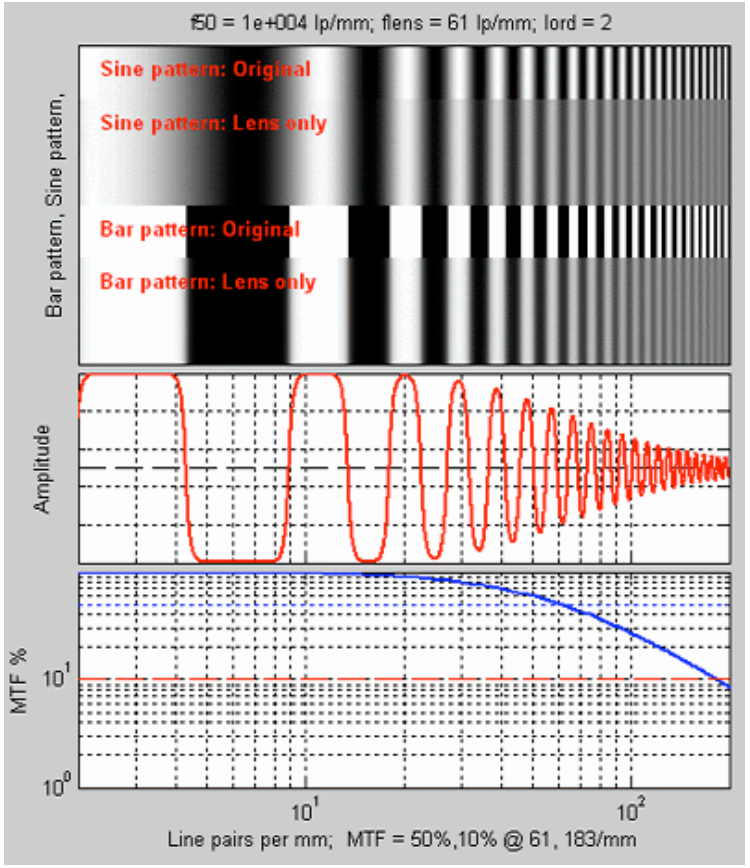
Module summary



Measuring sharpness

Spatial frequency response (SFR); Modulation transfer function (MTF)

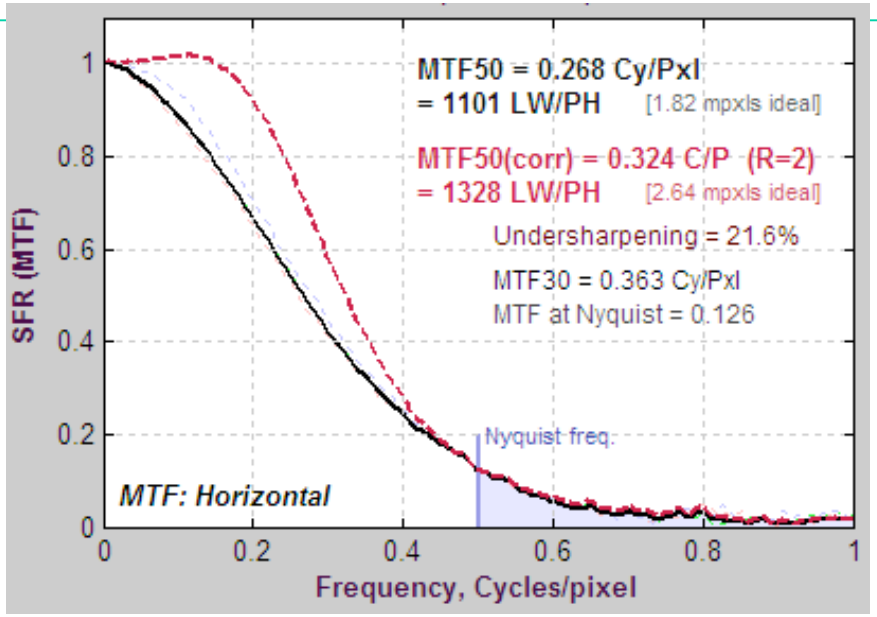
- **Upper:** Sine and bar patterns: original and blurred.
- **Middle:** Level of the blurred bar pattern (**red** curve). Contrast decreases at high spatial frequencies.
- **Lower:** the corresponding MTF (SFR) curve (**blue** curve).
- Low frequency MTF is defined to be 1 (100%). MTF can be larger than 1.
- Strongly affected by signal processing (sharpening).



Spatial frequency

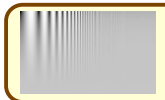
Sharpness (loss)

- Arguably the most important factor
- Determines how much detail can be conveyed
- Affected by the lens, sensor, and digital signal processing (sharpening)
- Measured by Spatial frequency response (SFR), AKA Modulation Transfer Function (MTF)



original | blurred

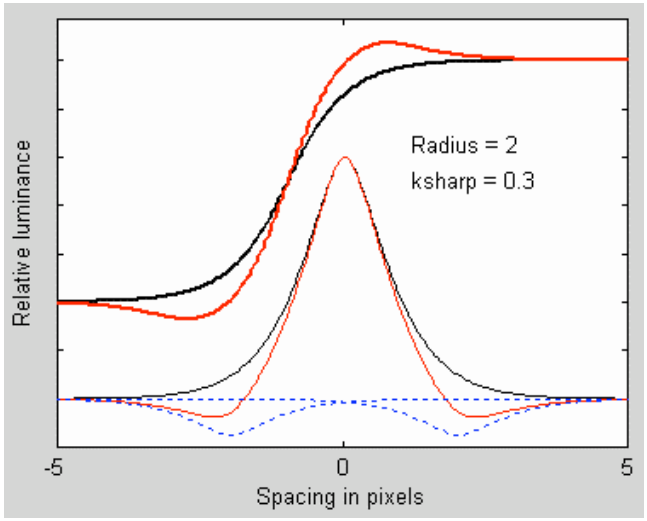

SFR (Spatial frequency response)


Log frequency-Contrast

Sharpening

- Most digital images look soft without sharpening.
- Subtracts a fraction of neighboring pixels from each pixel.
- Boosts contrast & MTF at high spatial frequencies.
- Applied to virtually all digital camera images—in the camera, RAW converter, and/or image editor.

Black– unsharpened
Red: sharpened

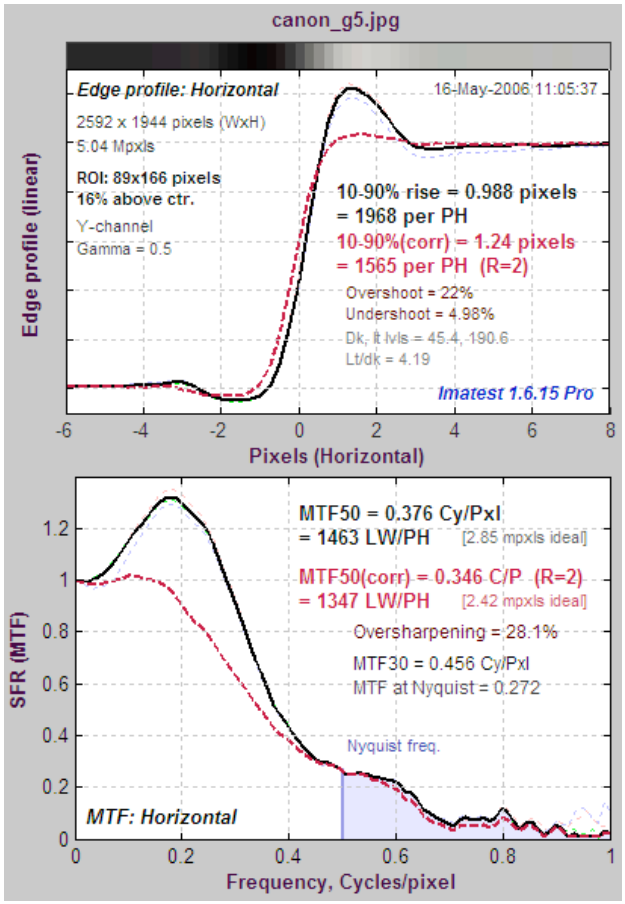


- ***Different amounts of sharpening in different cameras makes comparisons challenging.***

Transfer function: $MTF_{sharp}(f) = (1 - k_{sharp}\cos(2\pi f V))/(1-k_{sharp})$
where V = Sharpening radius / pixel spacing

Sharpness (oversharpening)

- Too much digital sharpening causes severe “halos” at edges.
- Peak in MTF response.
- Boosts MTF50.
- Common in compact digital cameras.
- Looks OK in small images; bad enlarged.



original | oversharpened

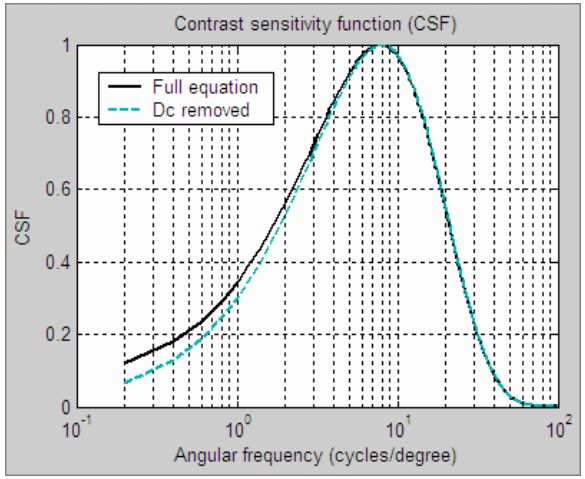
SFR (Spatial frequency response)

Log frequency-Contrast

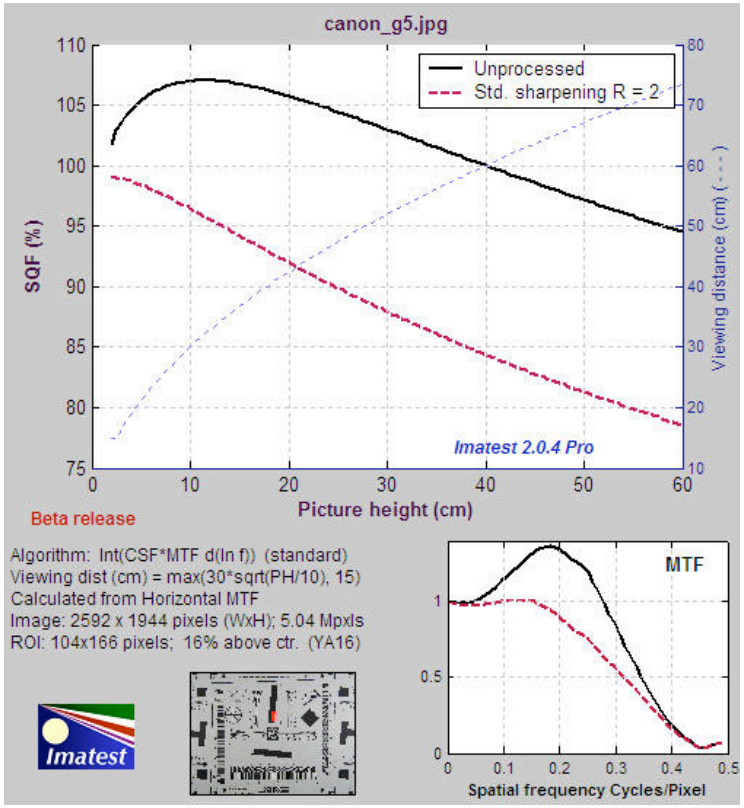
SQF: Subjective Quality Factor

A measure of subjective (perceptual) sharpness, optionally displayed in SFR, that combines

- MTF,
- The human eye's Contrast sensitivity function (CSF) (peaks at 6-8 cycles/degree),
- Image height,
- Viewing distance



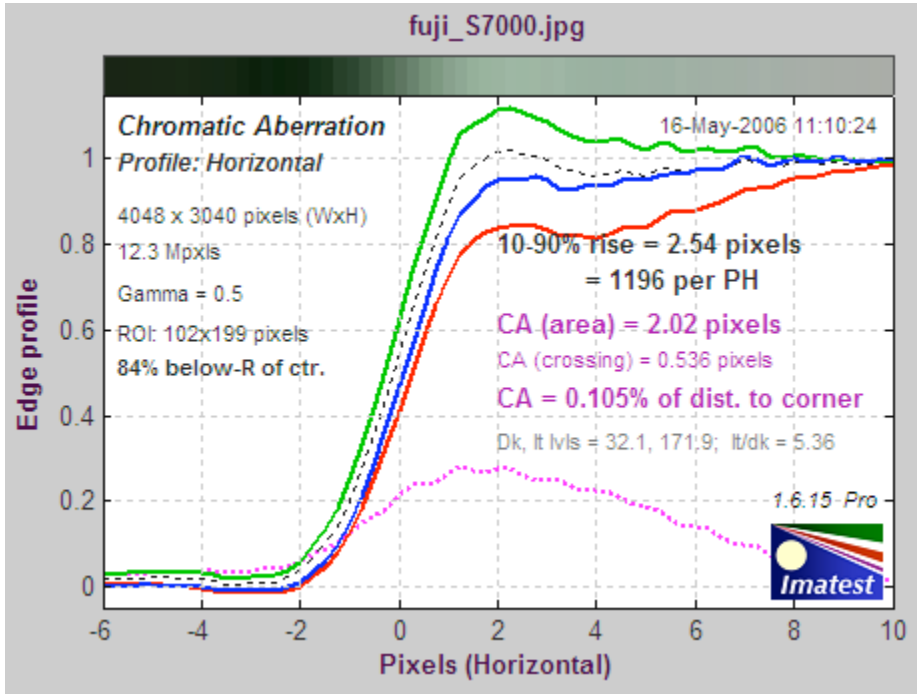
CSF of the human eye



A+	A	B+	B	C+	C	D	F
94-100	89-94	84-89	79-84	69-79	59-69	49-59	Under 49

Lateral chromatic aberration

- Seen as “color fringing” near corners.
- Can be digitally corrected.

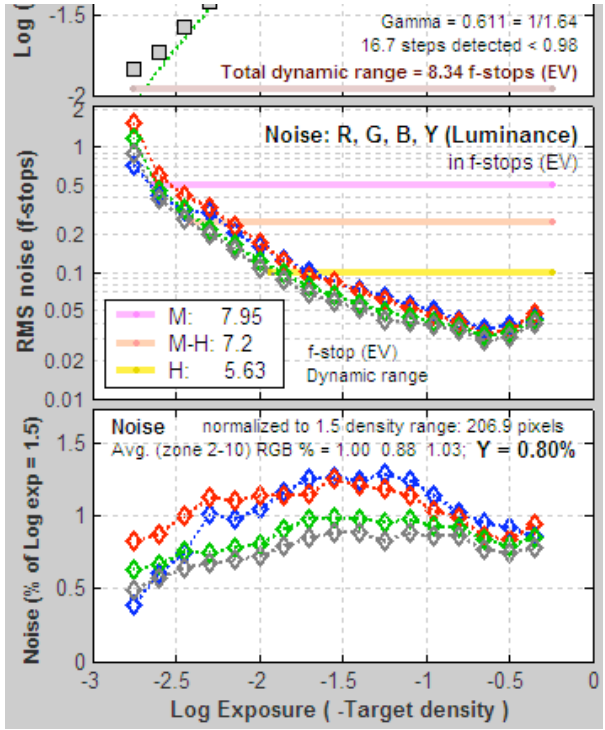


original | with CA

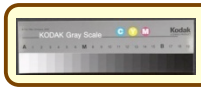
SFR (Spatial frequency response)

Noise

- A serious degradation; corresponding to grain in film.
- Software noise reduction can remove fine detail.



original | noisy

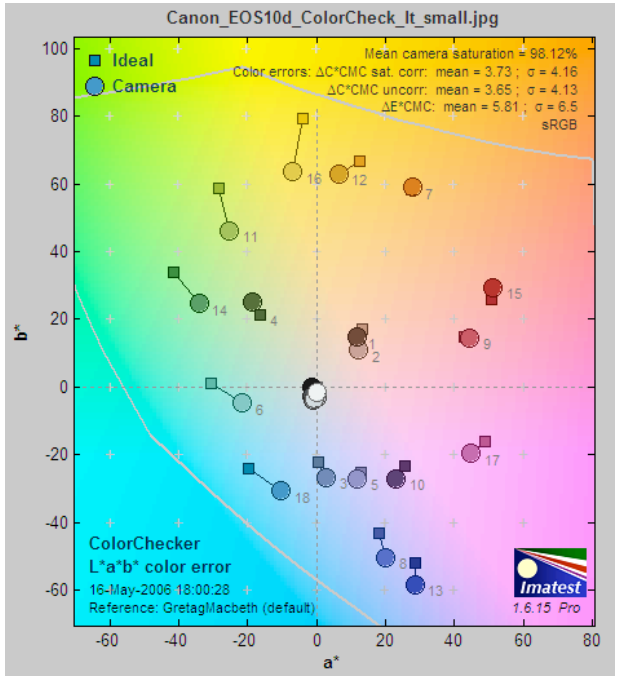


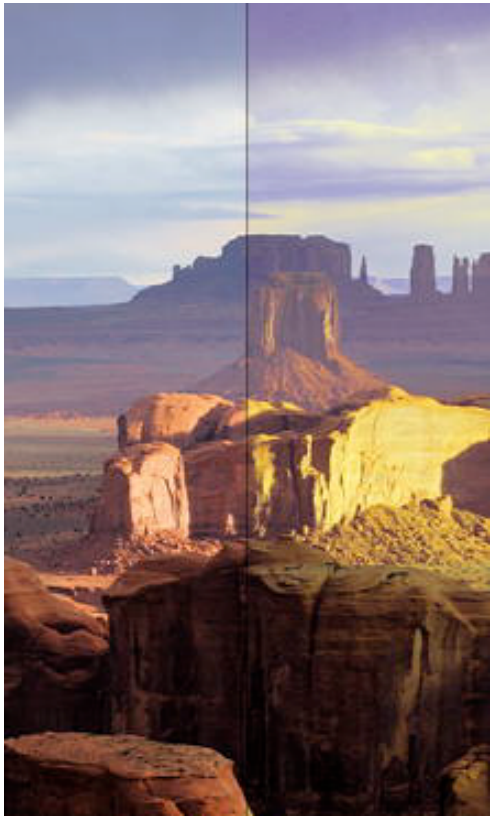
Stepchart

Colorcheck

Color accuracy

- Uses the GretagMacbeth ColorChecker (in ***Colorcheck***; other charts in ***Multicharts***).
- Errors displayed in L*a*b* space.
- Several color difference metrics can be selected.
- Reference colors can be selected to be *accurate* or *pleasing*.



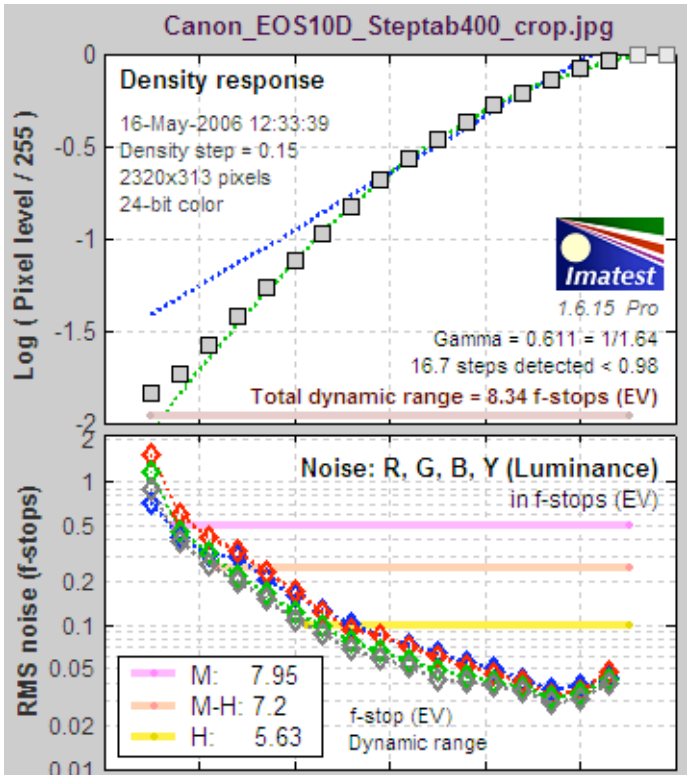


original | color-shifted

Colorcheck

Tonal response and Contrast

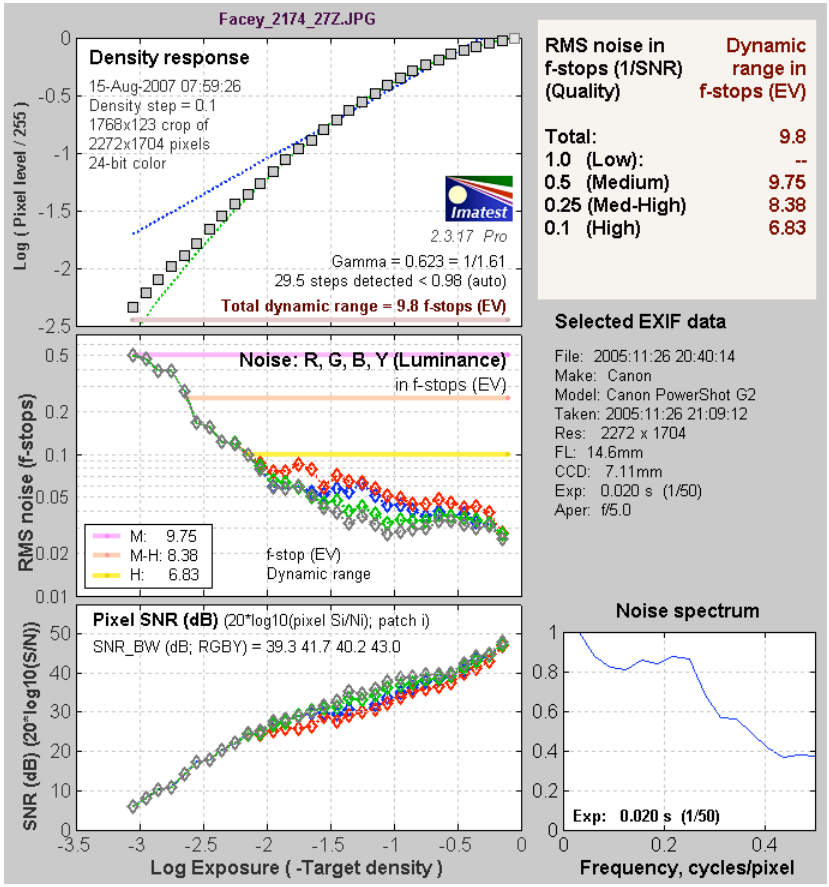
- Pixel level ≈ luminance$^{\gamma}$ (γ is gamma = contrast); S-curve often superimposed.
- Image contrast is gamma (γ) in mid-tones.



original | clipped

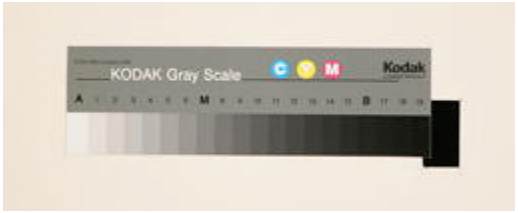
Dynamic range

- The exposure range a camera can record at a quality level specified by max noise or min SNR. Units of f-stops.
- Reflected step charts have insufficient range; trans-mission chart recommended (Stouffer T4110 with D_{max} = 4.0 shown).



Lens flare (veiling glare)

- Stray light bouncing between lens elements or off lens barrel (interior). Important when lighting is uncontrolled.
- Overall fogging of image (loss of shadow detail): can be measured
- “Ghost” imaging: difficult to measure, predict.
- Measured using a “black hole” (cavity) with white surround next to step chart.



- Veiling glare = *V* = 100% (*L*(black hole) / *L*(white surface))

original | with flare

Exposure accuracy

- Important in cameras with auto-exposure
- Affected by history: may change after exposure to very bright or dim light.
- Calculated from reference values for step chart or ColorChecker and gamma (γ).

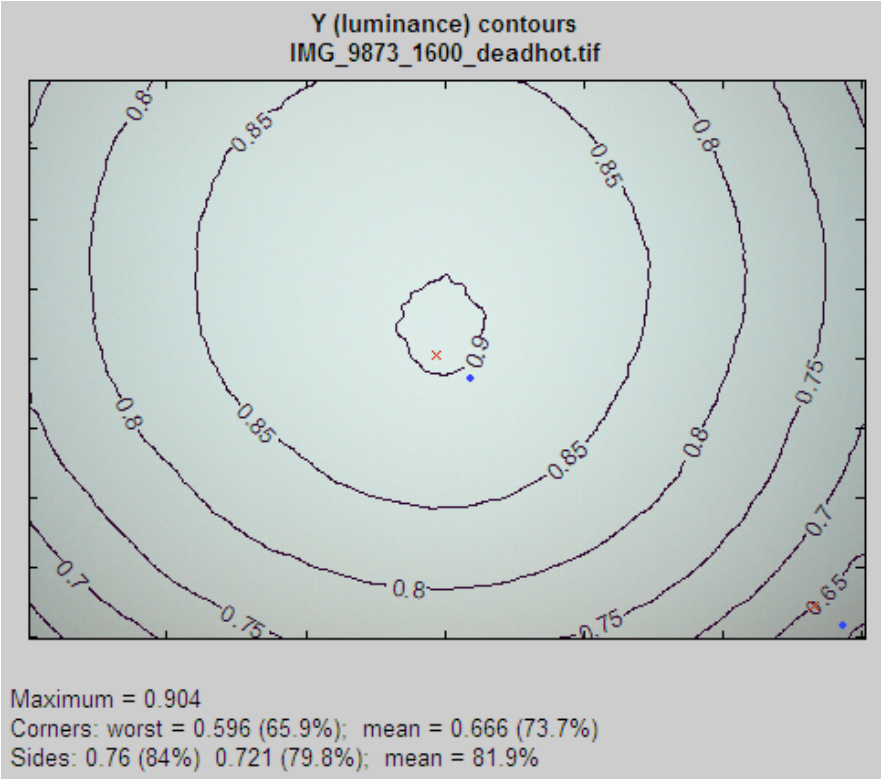
original | overexposed


Stepchart

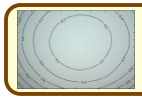

Colorcheck

Light falloff

- Measures light falloff due to lens and sensor, as well as color shifts due to “pixel shading” at sensor.

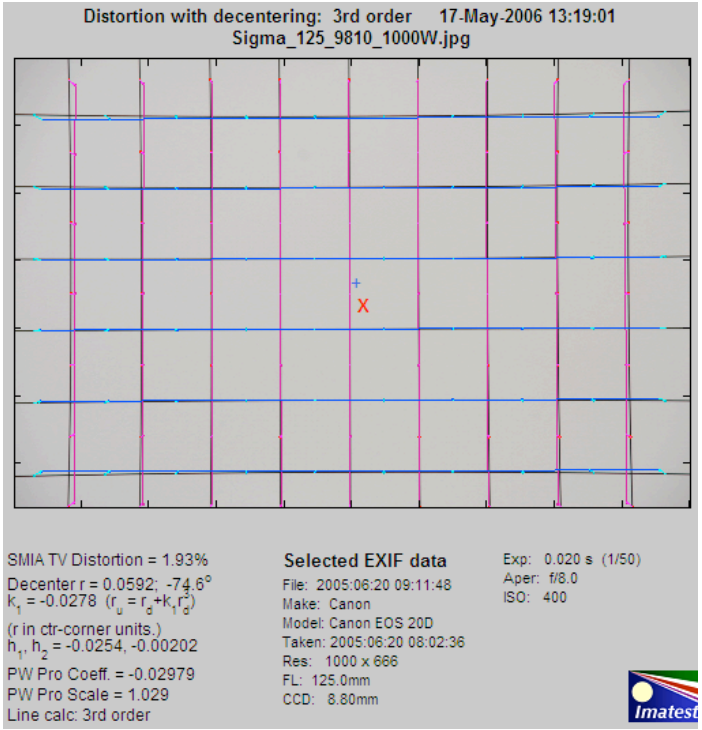


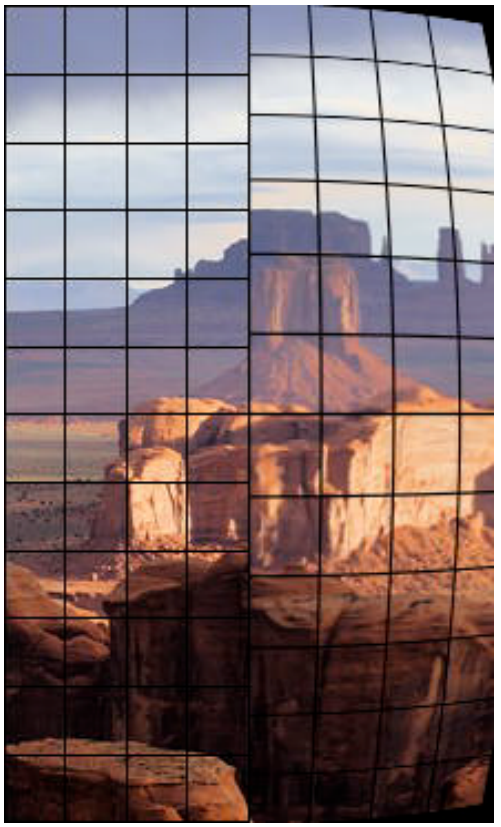
original | vignetted


Light Falloff

Lens distortion

- Can be measured using a grid or a single line near the image boundary.
- Several correction coefficients calculated.

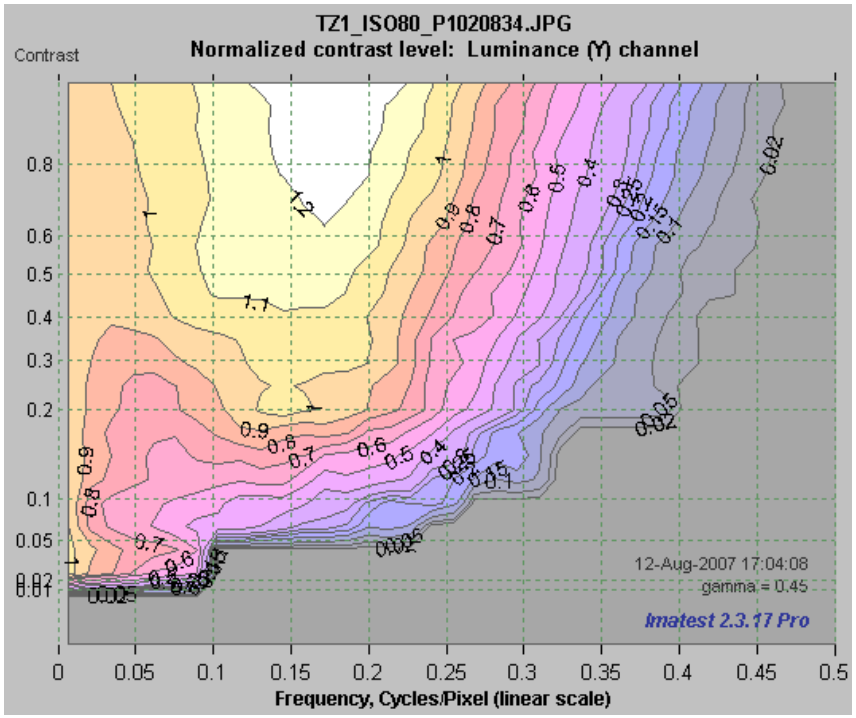




original | barrel distortion

Loss of detail from Signal processing (ISO 80)

Measure contrast loss as a function of spatial frequency and chart contrast. boundary.

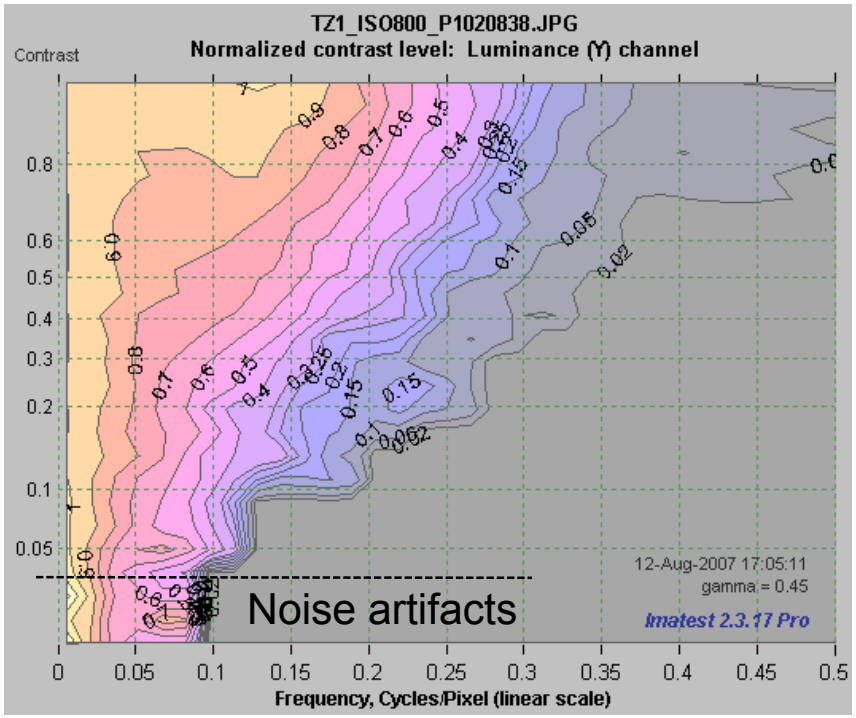


Compact digital camera, ISO 80

original | lost detail

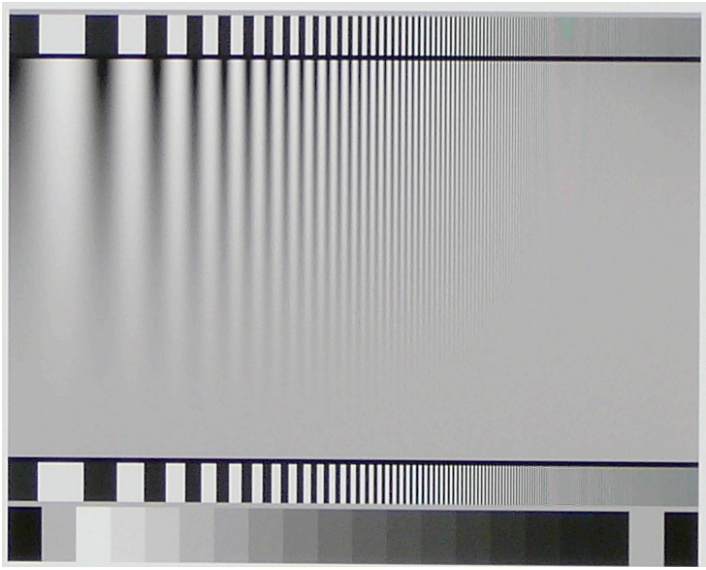
Loss of detail from Signal processing (ISO 800)

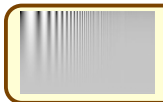
More noise reduction at higher ISO speed results in more contrast loss at high spatial frequencies, especially at lower contrasts.



Compact digital camera, ISO 800

Test chart




Log frequency-Contrast

Imatest modules: *Stepchart*

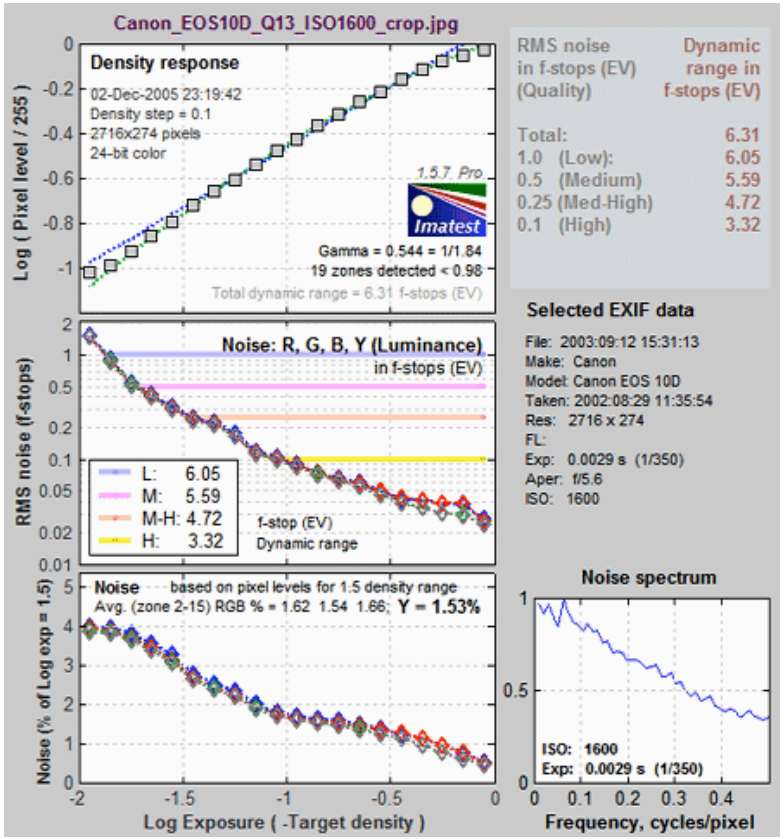
Photograph a step chart:

reflective (Kodak Q-13/Q-14, etc.),

transmission (Stouffer T4110, etc.)

Measure

- Tonal response,
- Gamma (contrast; average and instantaneous),
- Noise (or SNR),
- Dynamic range (transmission charts only),
- Exposure error (reflective charts only).

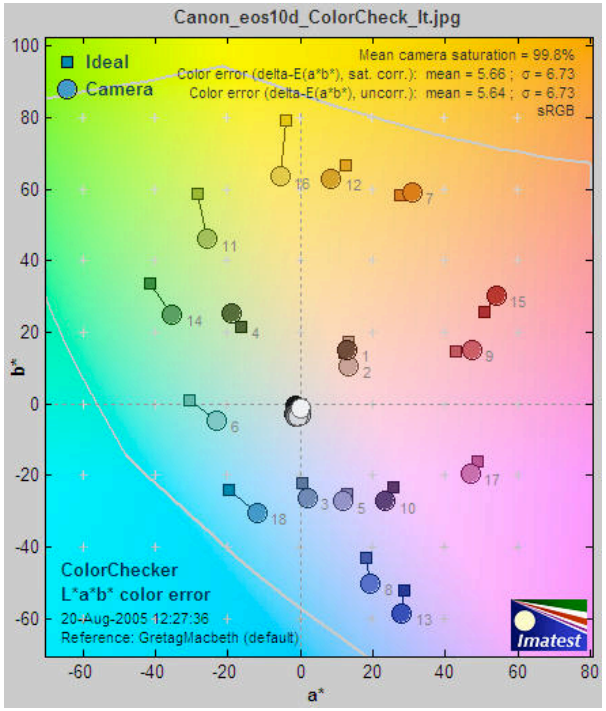


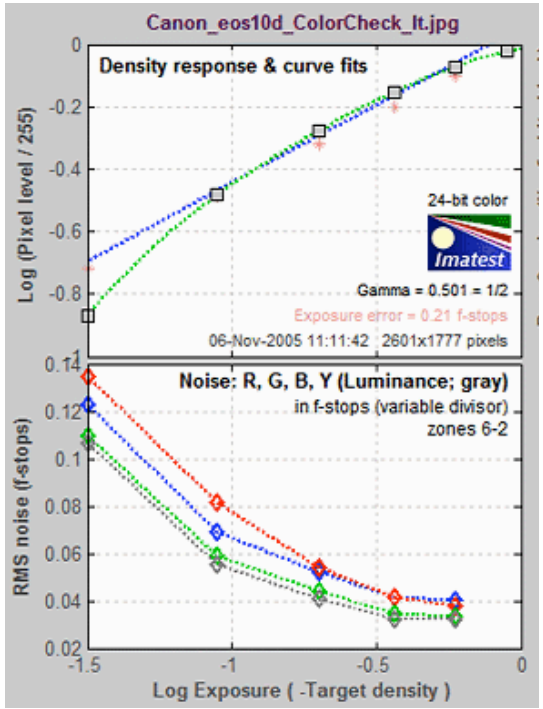
Imatest modules: *Colorcheck*

Photograph the GretagMacbeth Color checker.

Measure

- Color accuracy (various lighting conditions),
- Tonal response,
- Gamma,
- Noise,
- Exposure error.

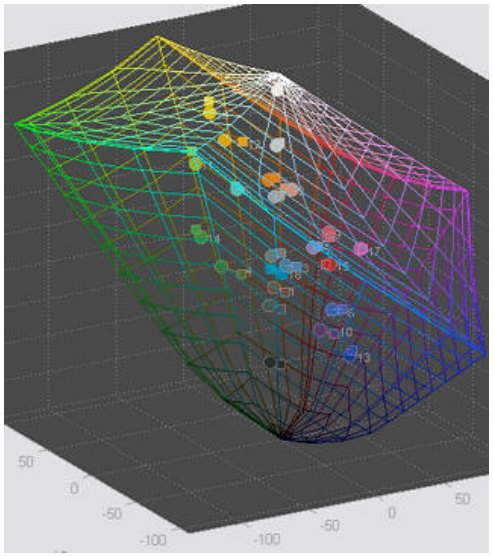




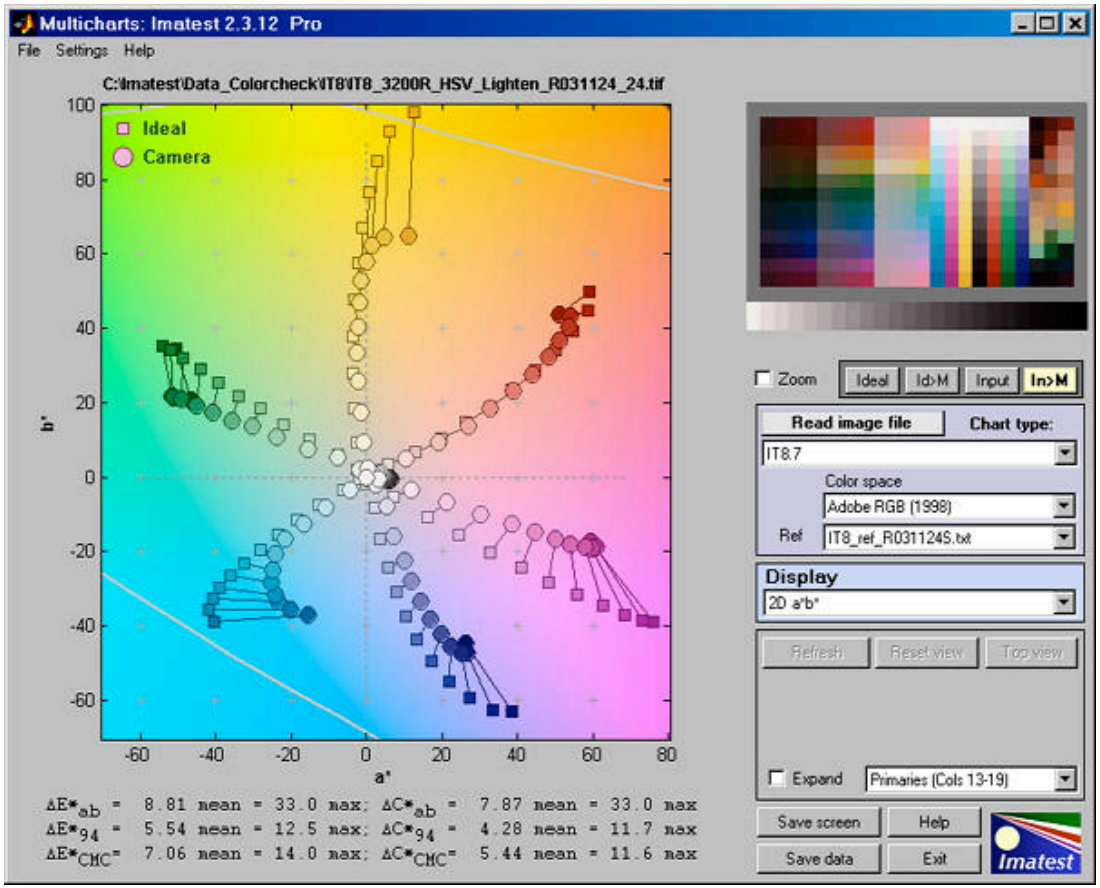
Imatest modules: *Multicharts*

Measure

- Color accuracy (various lighting conditions),
- Tonal response,
- Gamma.



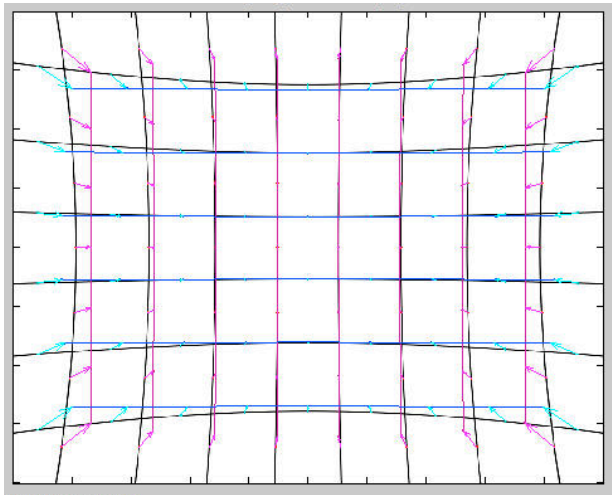
Photograph the test chart (many charts are supported). Highly interactive interface.



Imatest modules:

Distortion

Photograph a grid.

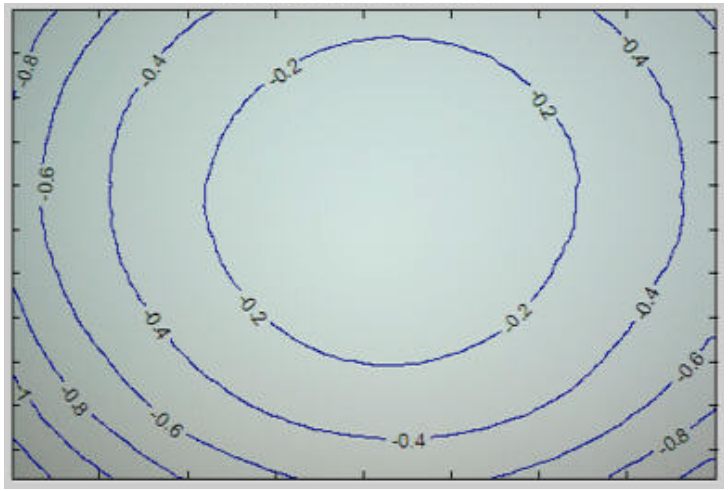


Measure Distortion and correction coefficients in several models:

- 3rd and 5th order,
- Tangent/arctangent,
- SMIA TV distortion.

Light Falloff

Photograph a uniform white or gray region.



Measure

- Light falloff (vignetting; uniformity),
- Sensor noise detail,
- Dead and hot pixels.

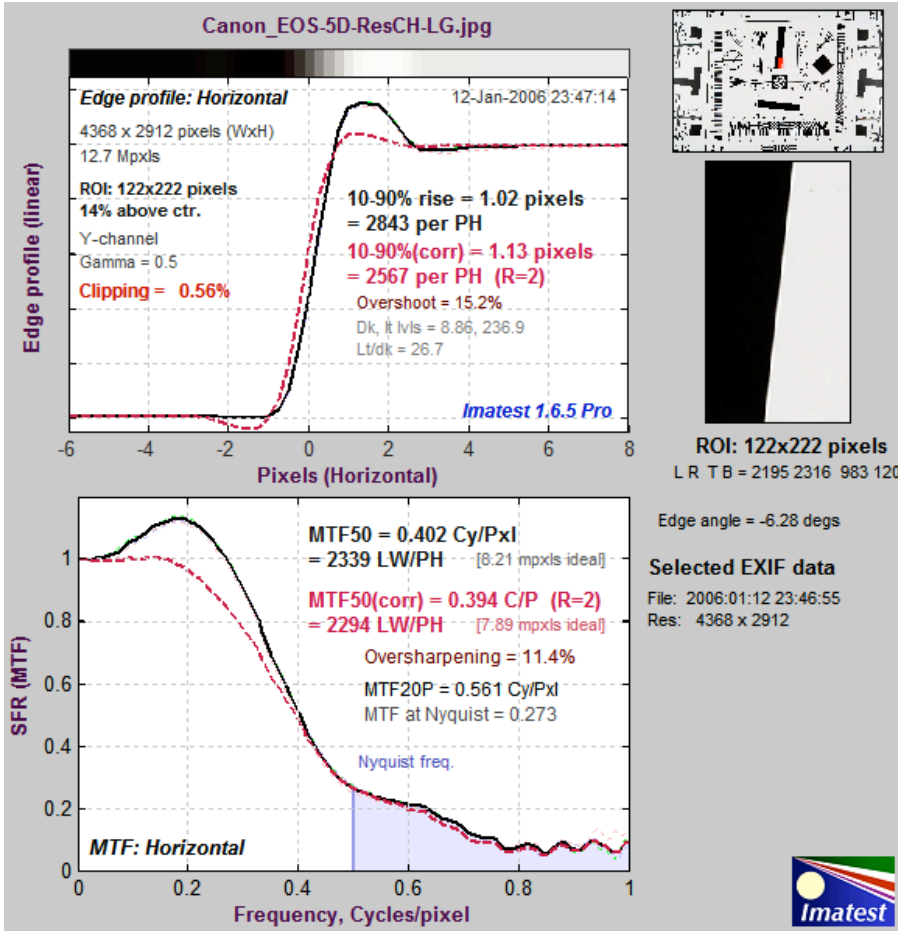
Imatest modules: *SFR*
(Spatial frequency response: SHARPNESS)

Photograph a slanted-edge target. Can be printed on a high quality inkjet printer or be a part of the ISO 12233 chart.

Measure

- Average edge response (upper plot); 10-90% rise distance,
- SFR (spatial frequency response = MTF); MTF_{50} (an excellent metric for image sharpness)
- Lateral chromatic aberration.

Dashed red lines (- - -) are for standardized sharpening.



Imatest summary

Image quality is determined by several factors.

Imatest analyzes

Sharpness	Tonal response and contrast	Light falloff
Noise	Lateral chromatic aberration	Lens distortion
Dynamic range	Exposure accuracy	Flare light
Color accuracy		Data compression loss

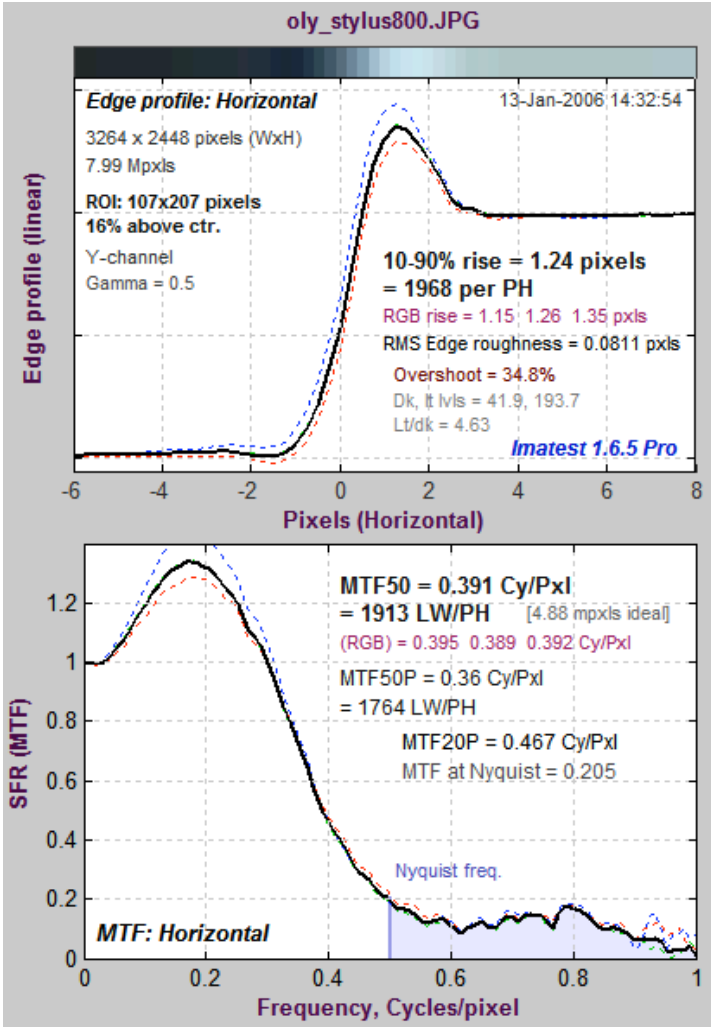
- Some more affected by capture; others by post-processing.
- Many can be improved with post-processing.
- Weighting of each factor depends on individual preference, application.
- Difficult to define a single measure of image quality.

Oversharpened image

5 MPXL compact digital camera

Peaks in both domains. “Halo” (overshoot) at the edge.

MTF_{50} is unrealistically high.



Undersharpened image

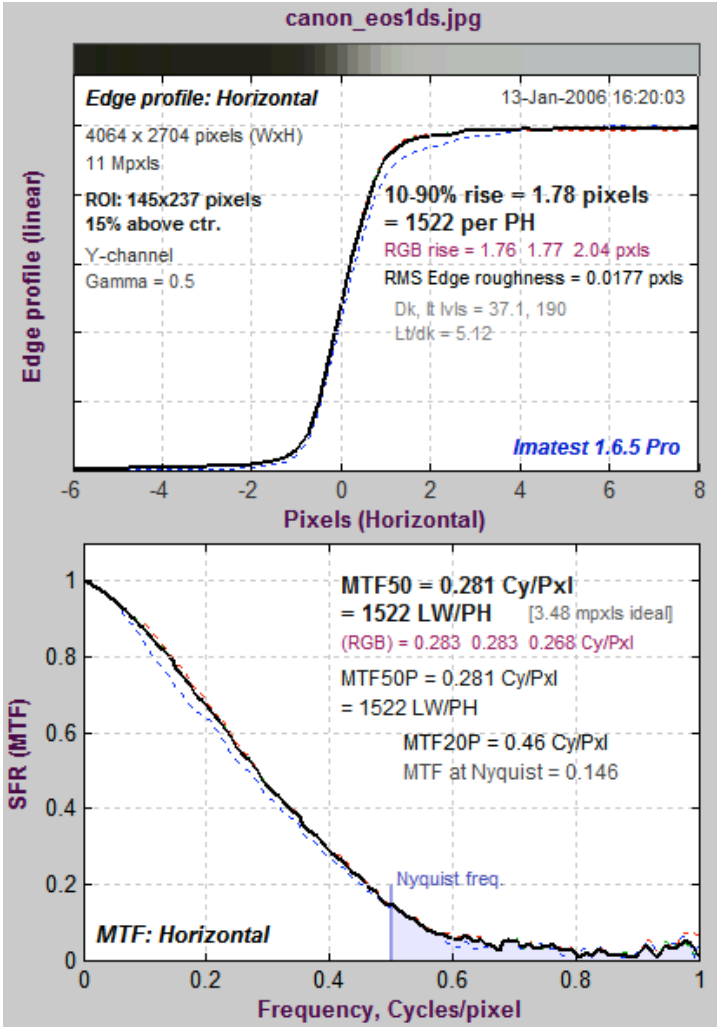
11 MPXL DSLR

Edges are rounded; no overshoot.

Image can benefit from additional sharpening.

MTF_{50} is lower than it would be with a reasonable amount of sharpening. MTF_{50} (LW/PH) is lower than the 5 MPXL camera.

It is difficult to make a fair comparison between under- and oversharpened images.



Standardized sharpening I

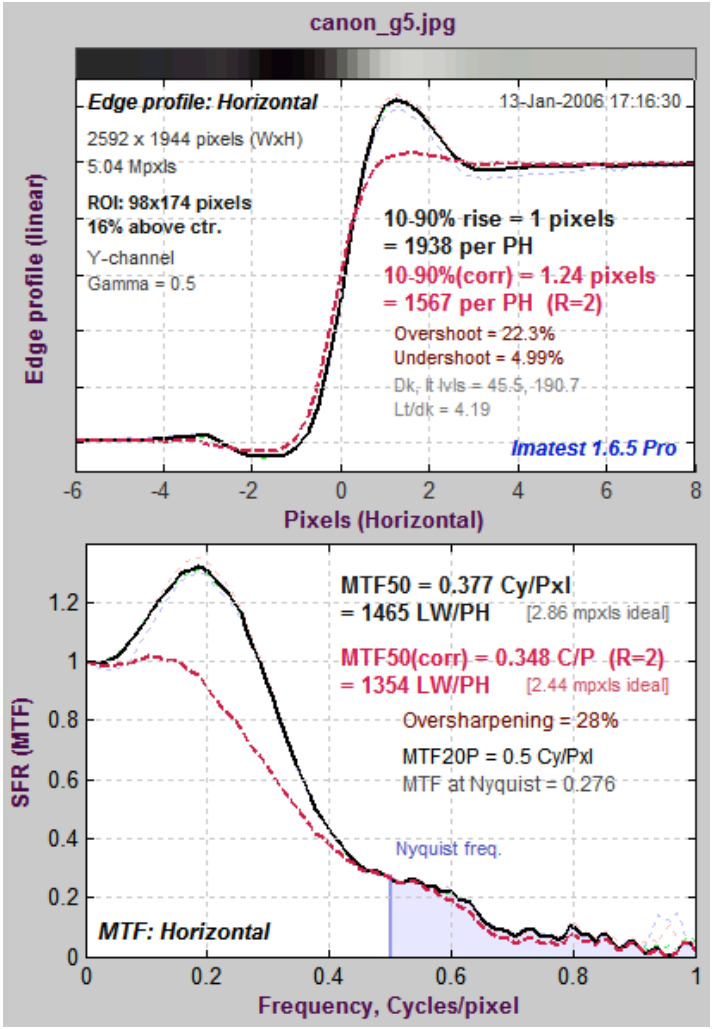
Standardized sharpening is a strategy for comparing camera performance in the presence of differences in sharpening.

Algorithm:

Sharpen (or de-sharpen) the image with a fixed radius *R* (usually between 1 and 2; the value used in most compact digital cameras) so MTF at *f* = 0.3 * Nyquist (0.15 cycles/pixel) is equal to MTF at *f* = 0.

The response with standardized sharpening is shown by the dashed (– – –) red curves.

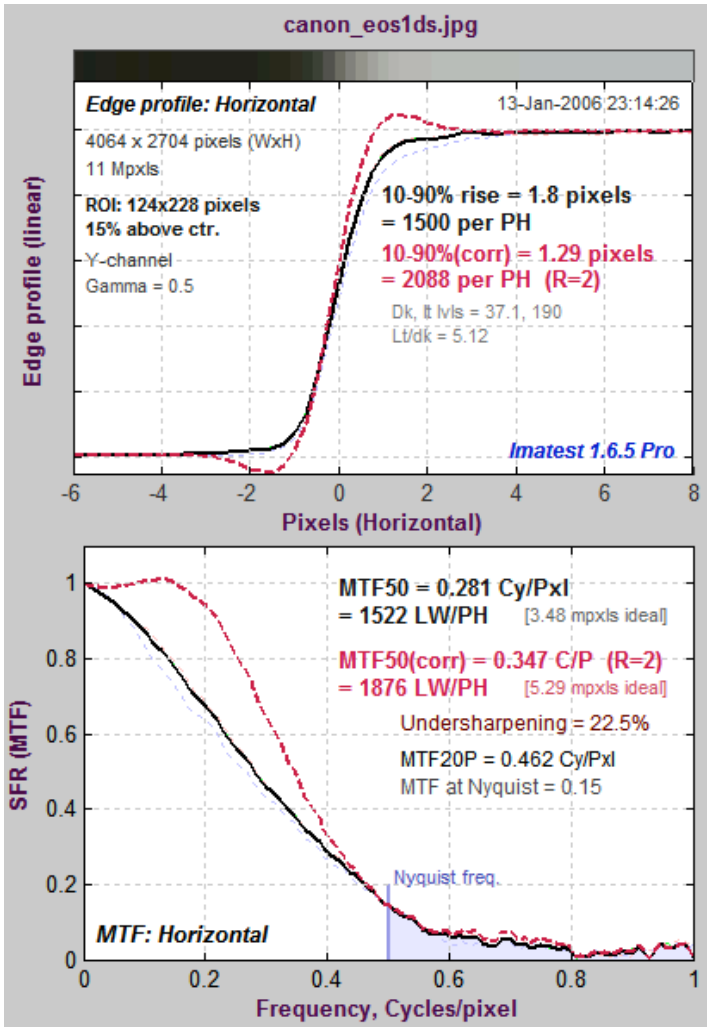
MTF50(corr) indicates sharpness.



Standardized sharpening II

Standardized sharpened edges have a small amount of overshoot: typical for manual sharpening.

Thus undersharped 11 MPXL DSLR image has been Standardized sharpened with *R* = 2. *MTF*50 (LW/PH) is higher than the 5 MPXL camera.



Standardized sharpening equations:

$$MTF_{stdsh}(f) = \left| \frac{\left(1 - k_{sharp} \cos(2\pi f R / d_{scan})\right) MTF_{orig}(f)}{1 - k_{sharp}} \right|$$

where

$$k_{sharp} = \frac{1 - 1/MTF_{orig}(f_{eql})}{\cos(2\pi R f_{eql}) - 1/MTF_{orig}(f_{eql})}$$

Standardized sharpening radius *R*

Same pulse (11 MPXL DSLR), Standardized sharpened with *R* = 1:

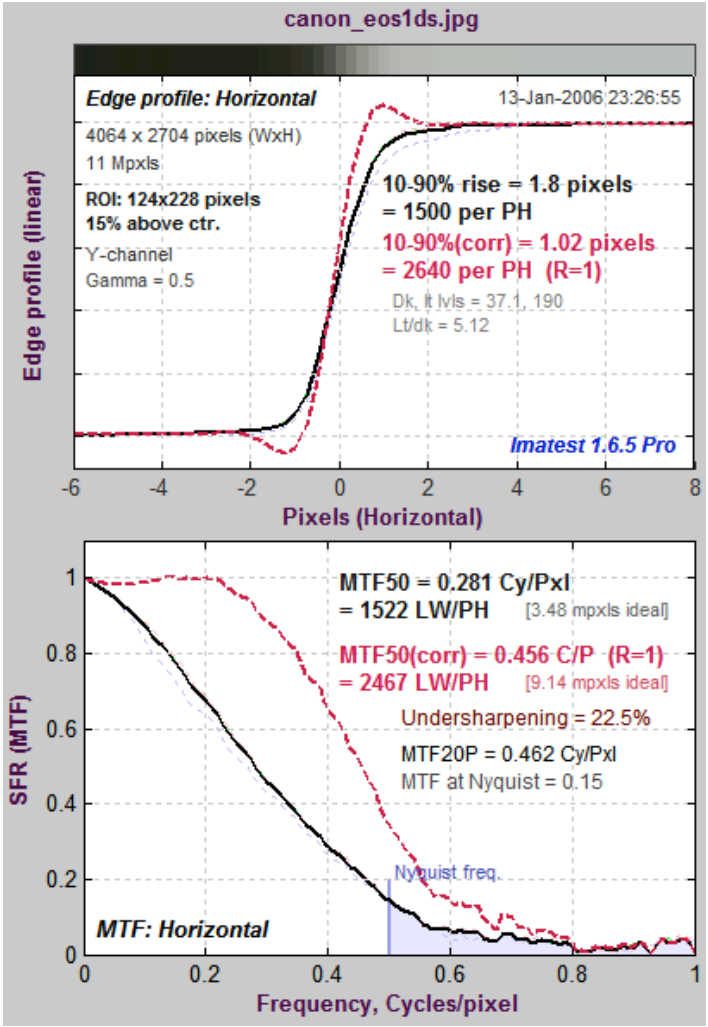
Sharper (higher MTF_{50}) than *R* = 2.

***R* = 1 often gives best results for undersharpened DSLRs.**

Larger *R* is appropriate systems with poor sharpness (low MTF_{50}).

***R* = 2 usually works better for de-sharpening compact digital cameras, typically (over)sharpened with *R* = 2.**

No general algorithm for selecting *R*



Standardized sharpening
Conclusions

- Useful for comparing performance of different cameras with light to moderate signal processing.

but

- Can be fooled by sophisticated signal processing (complex sharpening & noise reduction with thresholds)
  - Almost any response curve can be replicated with sufficient sharpening, *but*...
  - Excessive sharpening boosts noise & other artifacts. Can worsen appearance.
- Additional tests needed.

Slanted-edge measurements
Conclusions

- Excellent for measuring sharpness:
  Convenient, accurate, valid well beyond Nyquist frequency.
- Affected by in-camera sharpening. Best with no or known sharpening.
- Cannot distinguish between response above Nyquist caused by weak anti-aliasing filter and sharpening; does not indicate potential seriousness of Moiré fringing.
- Additional tests will be added to fully characterize system quality, e.g., CIPA DC-003 & Siemens Star, which can measure the onset of aliasing.