Measuring Sharpness and Resolution
March 2022

Agenda

1. Definition
2. Methods
3. Challenges
4. Solutions
5. Development

Definitions

and questions

Resolution

The smallest interval measurable by a scientific (especially optical) instrument; the resolving power.

- **the degree of detail visible in a photographic or television image.**

  "a high-resolution monitor"

(Oxford Language)

Difficult to translate to a single objective measurement

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Sharpness

How much spatial information is reproduced across all frequencies

Sharp

Blurred

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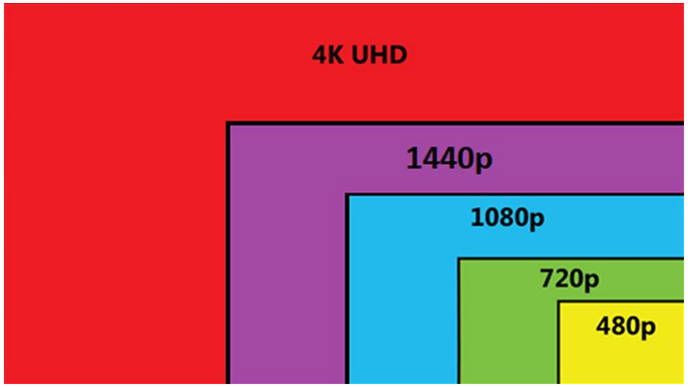
Sensor Resolution: Necessary but not sufficient

.

Just because you have a lot of pixels doesn't mean they are:

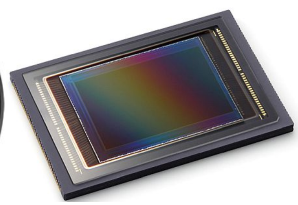
- sensitive
- free from noise
- isolated from other pixels

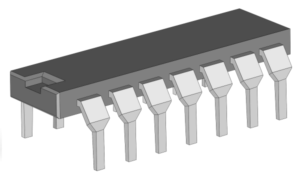


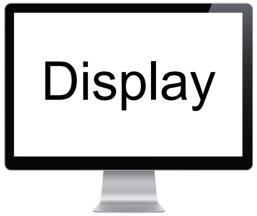
What is an imaging system?

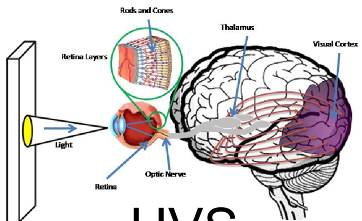

Scene


Lens

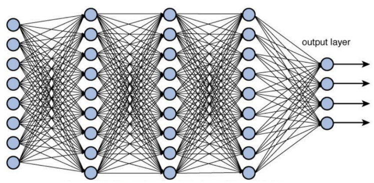

Sensor


Signal Processor





HVS



Neural Network

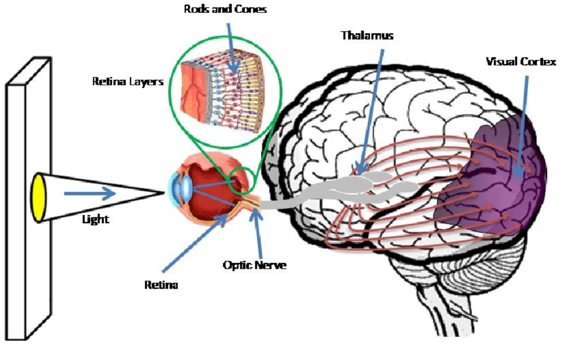
Who do we care can resolve?

Human, Machine, Both?

What are we trying to resolve?

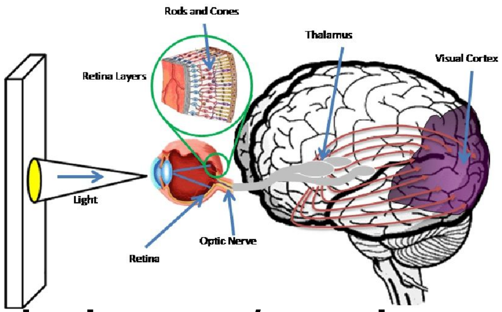
- Distance?
- Location in image?
- Angle?
- Spectral properties of the object and background?
- Atmospheric properties?

What is Visible?



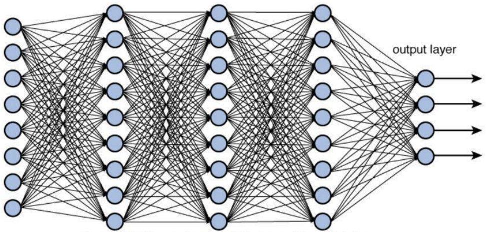
Is this visible?	0% contrast loss	
Is this visible?	50% contrast loss	MTF50
Is this visible?	65% contrast loss	MTF35
Is this visible?	70% contrast loss	MTF30
Is this visible?	75% contrast loss	MTF25
Is this visible?	80% contrast loss	MTF20
Is this visible?	85% contrast loss	MTF15
Is this visible?	90% contrast loss	MTF10
Is this visible?	99% contrast loss	MTF01

Limits



Humans:

- Limited by display, image size, viewing distance/angle
- Limited by spatial/temporal/contextual contrast sensitivity of HVS



Machines:

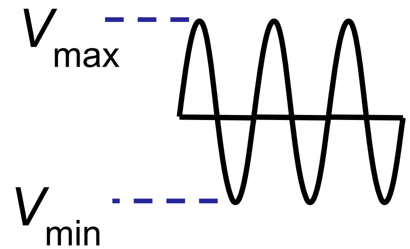
- Limited by algorithm design
- Limited by computation power, energy consumption

SFR (Spatial Frequency Response)
MTF (Modulation Transfer Function)

The ***contrast*** of a sine pattern at **spatial frequency *f*** relative to contrast at low spatial frequencies.

Contrast

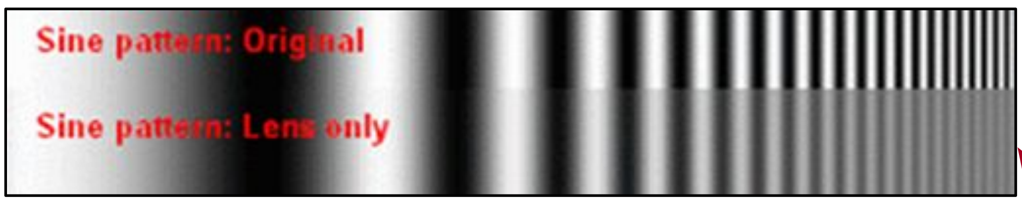
$$C(f) = \frac{V_{max} - V_{min}}{V_{max} + V_{min}}$$



Sine pattern

in

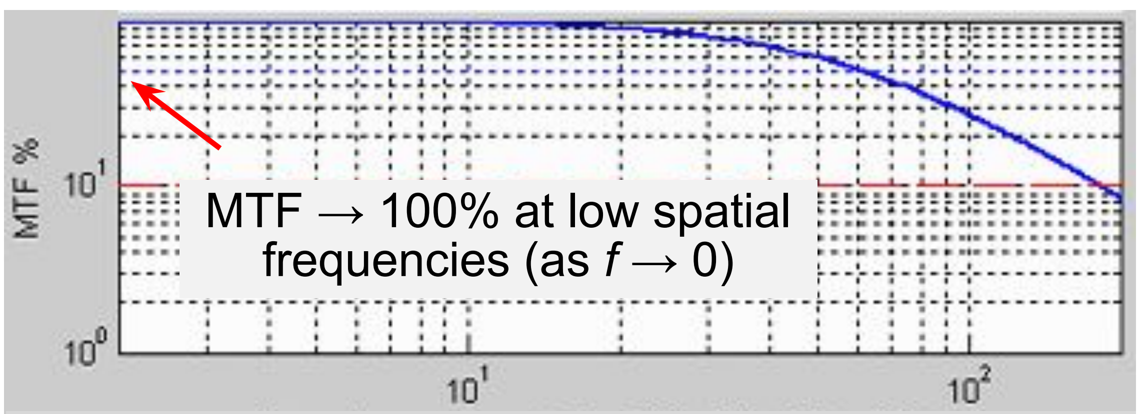
out



Original (constant contrast)

with losses

MTF(*f*)



Spatial frequency *f* (increases logarithmically)

MTF usually drops with frequency

$$MTF(f) = 100\% \times \frac{C(f)}{C(0)}$$

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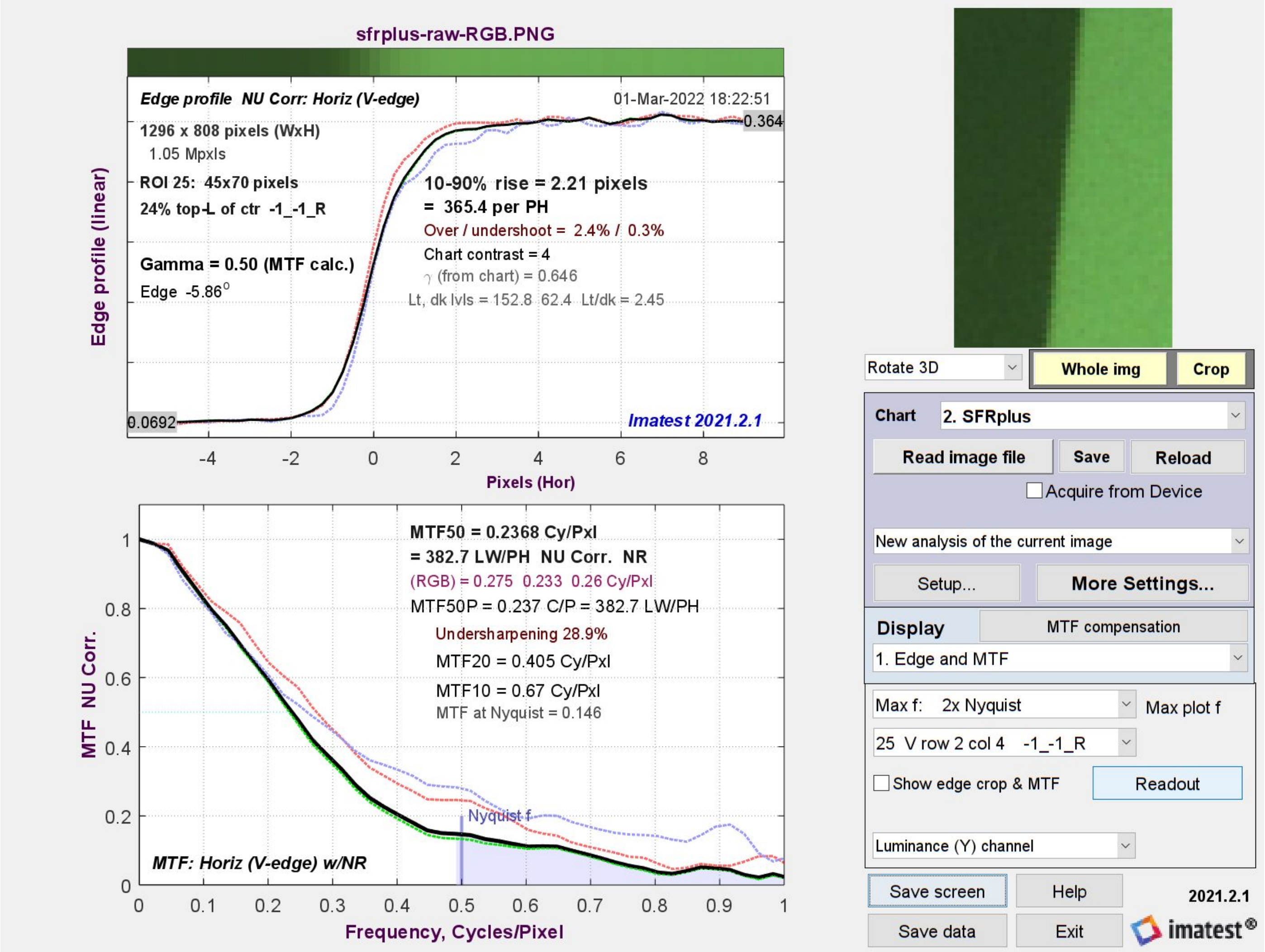
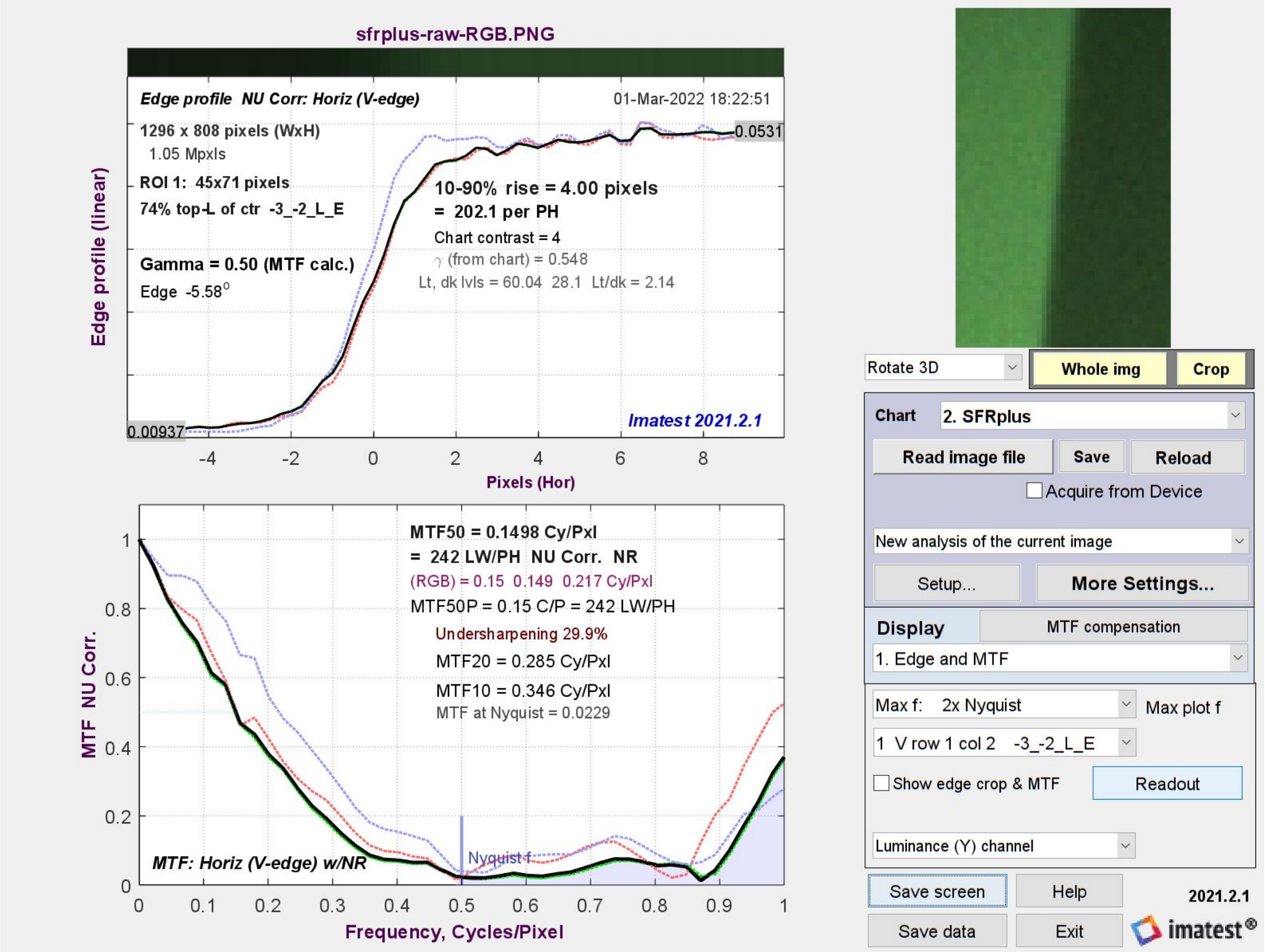
Example MTF plot (OK)



Example MTF plot (worse)



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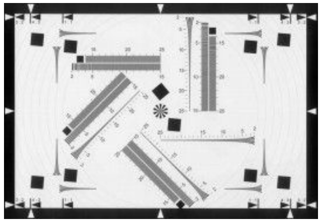
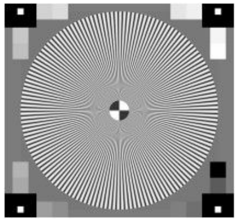
Methods

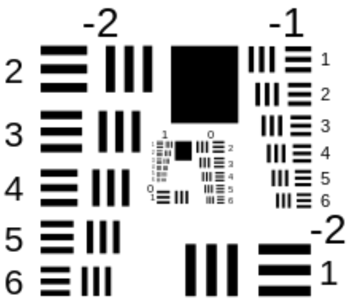
History of Resolution Targets

CIPA

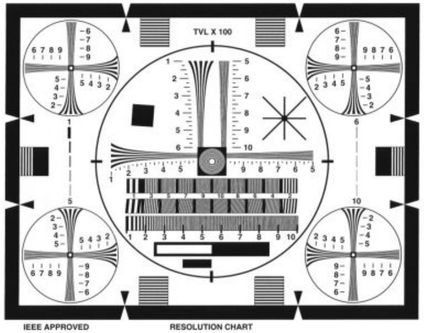


Sinusoidal Star

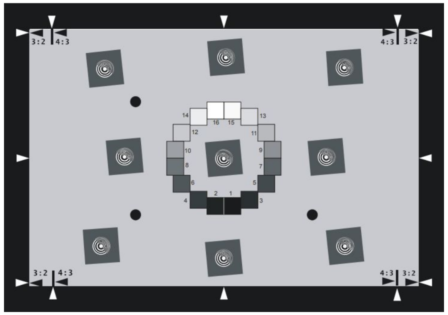




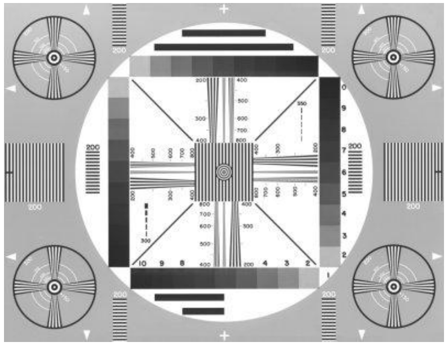
USAF 1951



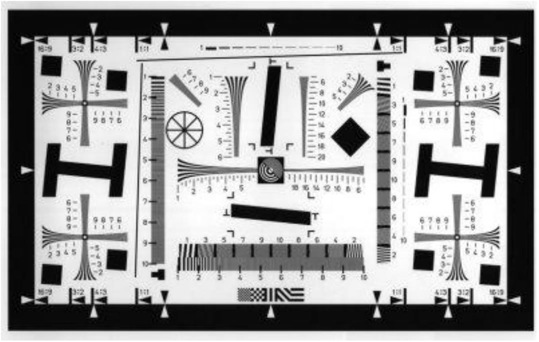
IEEE 1995



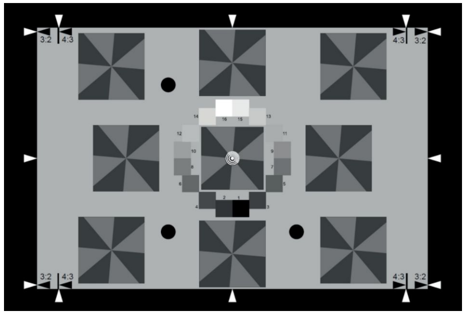
ISO 12233 2014



EIA 1956

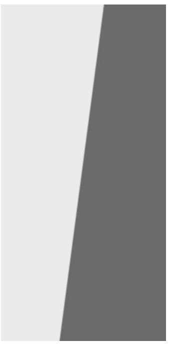


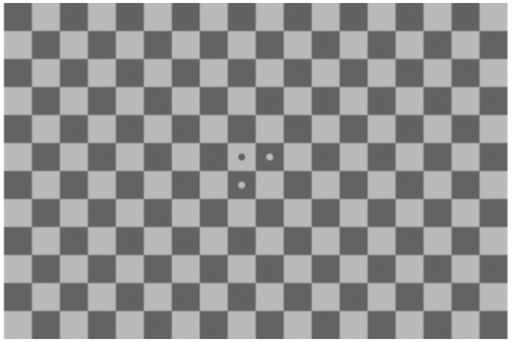
ISO 12233 2000

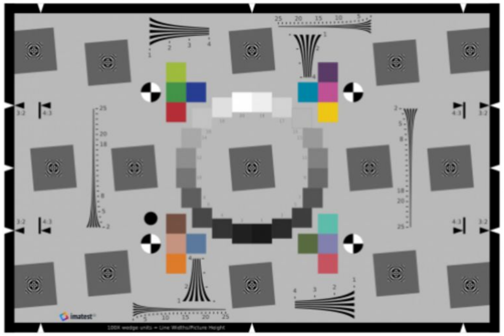


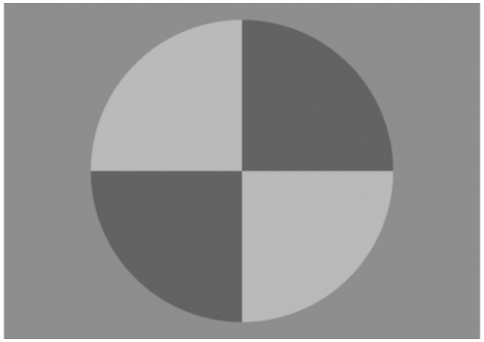
ISO 12233 2022

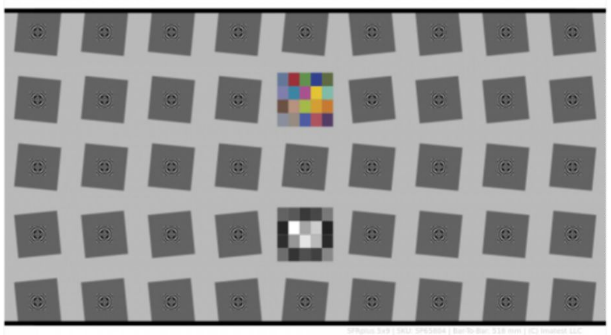
Imatest Sharpness / Resolution Targets

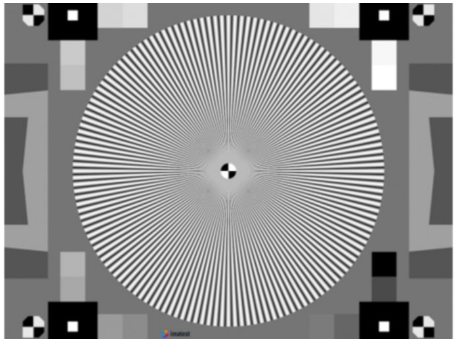


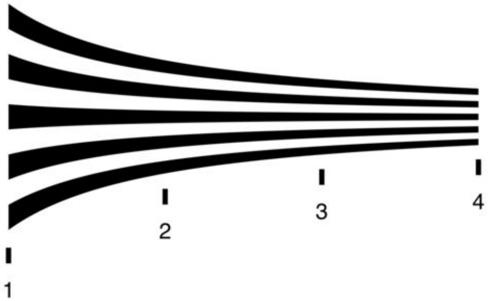


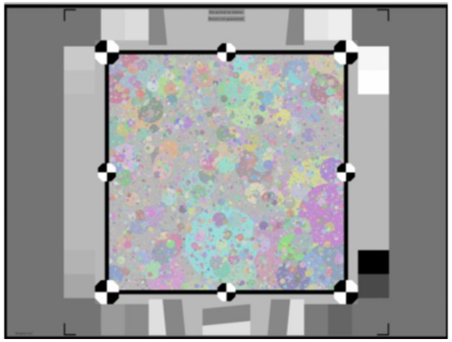


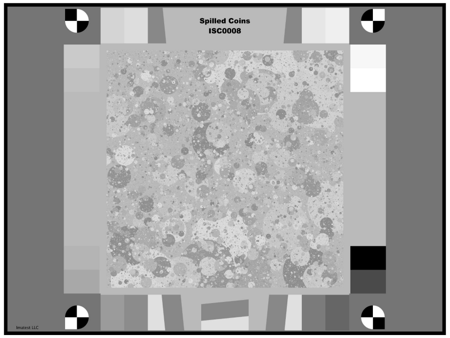


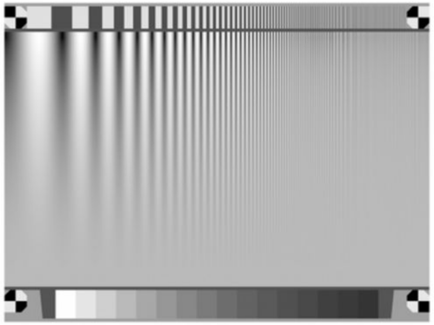












Slanted-edge Resolution

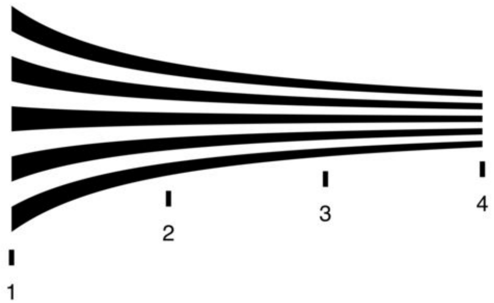
- Introduced with ISO 12233:2000
- Disable sharpening or use RAW image to test resolution

Advantages

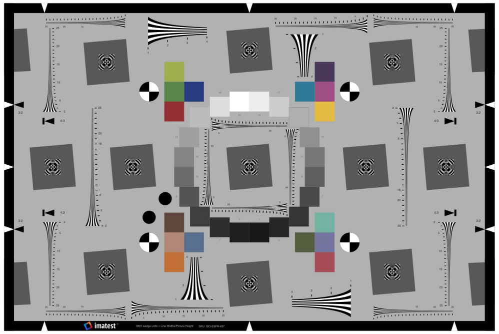
- Spatial precision
- Fast calculation

Disadvantages

- Only one angle of MTF per edge
- Very impacted by sharpening



Wedge Resolution



Introduced with ISO 12233:2014 standard
Used for “TV Lines” measurement similar to Line Widths / Picture Height (LW/PH) MTF units

Advantages

- Less impacted by signal processing than slanted edge

Disadvantages

- Only one angle
- Long target means low spatial precision
- Used for subjective analysis which reduces precision
- Poor precision for sharp systems at fractions of nyquist frequency

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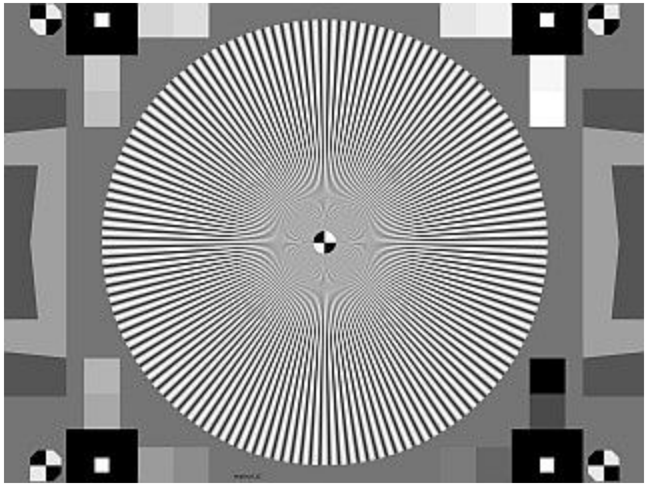
Sinusoidal siemens star (S-SFR)



Introduced with ISO 12233:2014 standard

Advantages

- All angles of MTF
- Less impacted by signal processing than slanted edge

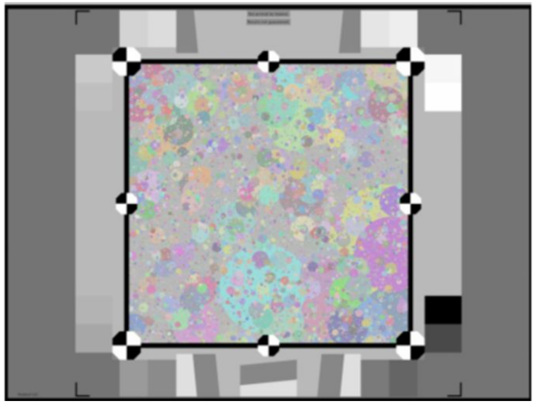
Disadvantages

- Large target means low spatial detail
- Calculation speed

Texture Analysis From Random Pattern

Target known as “Spilled Coins” or “Dead Leaves.

ISO TS/19567-2:2019



Advantages

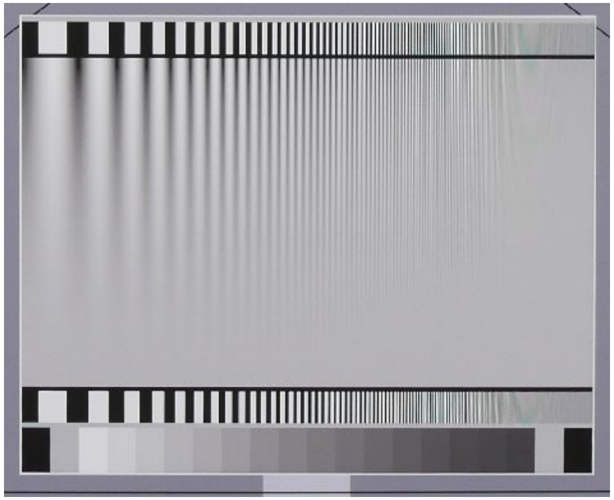
- Measure how well your system preserves fine detail

Disadvantages

- Noise reduction will remove texture
- Low light accuracy issues

see imatest.com/docs/random/

Log Frequency Contrast



Sinusoidal pattern with many different contrasts and frequencies

Advantages

- See how signal processing handles different spatial content

Disadvantages

- Only one angle
- Low spatial precision

Challenges

Measurement Precision & Accuracy

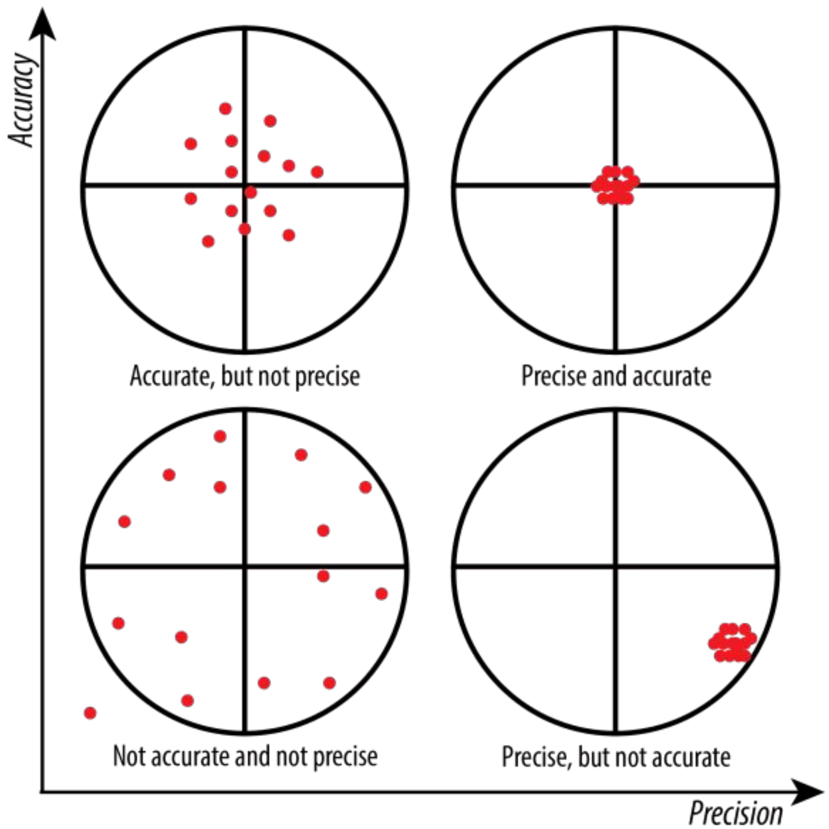
Precision:

signal to noise ratio

algorithmic stability

Accuracy:

saturation	(+)
signal processing	(+)
nonuniformity	(+-)
chart quality	(-)

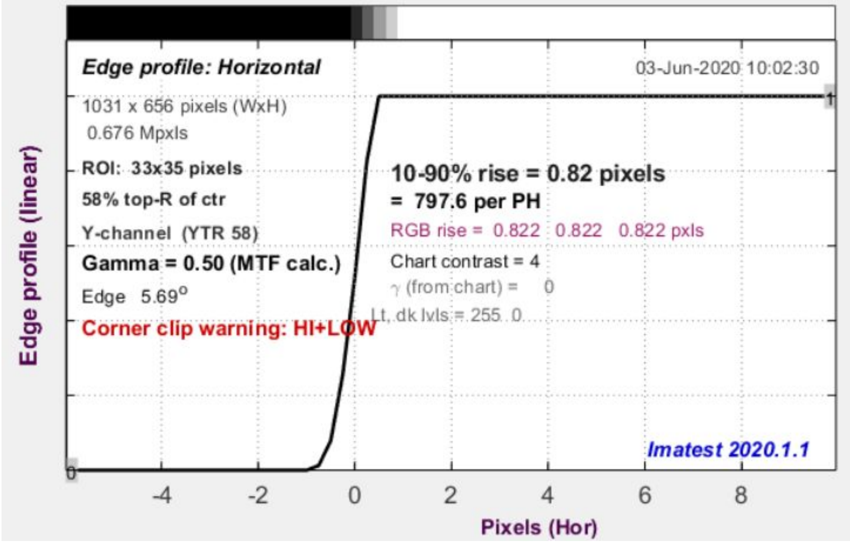


Saturation Degrades Accuracy (+)

May be caused by:

- High contrast targets
- Low dynamic range
- improper exposure
-

This wrongfully increases measured sharpness and resolution



see: [High-contrast edge-SFR test targets produce invalid MTF results]

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Effects of Signal Processing

If you care only about your lens and sensor

→ use a RAW or minimally processed image

Are you unable to obtain a RAW image?

→ Be aware of the impact of signal processing

Care more about the full system performance?

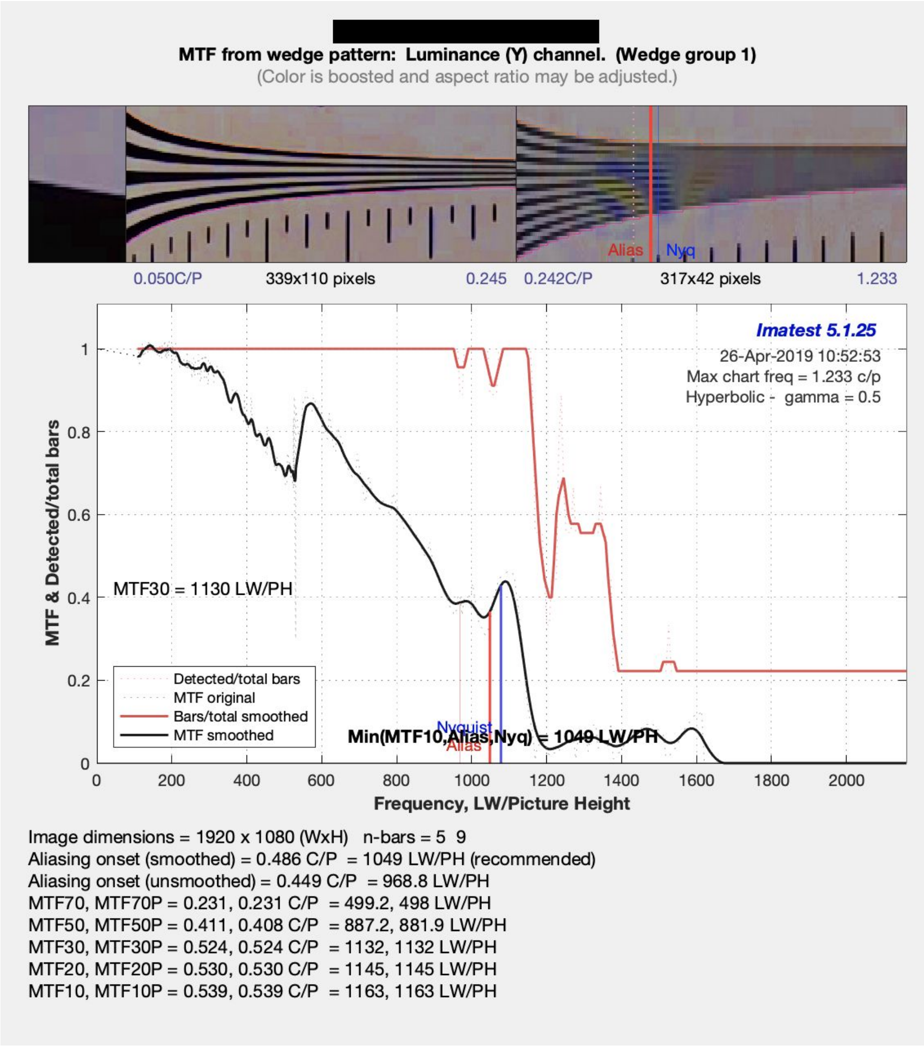
→ Use the processed image

Wedge MTF issues

- For sharp lenses, If the bars are in phase with the pixel array, you will get fantastic response

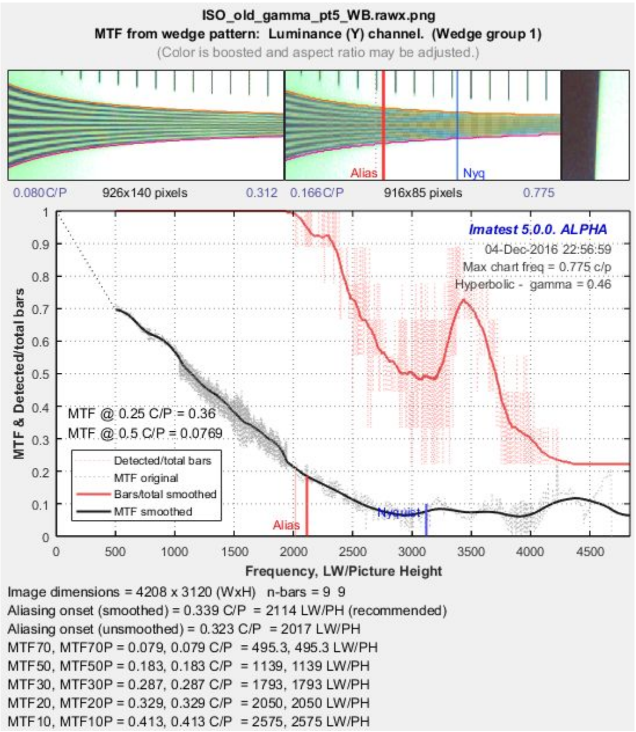
- If the bars are out of phase with the pixel array they will disappear

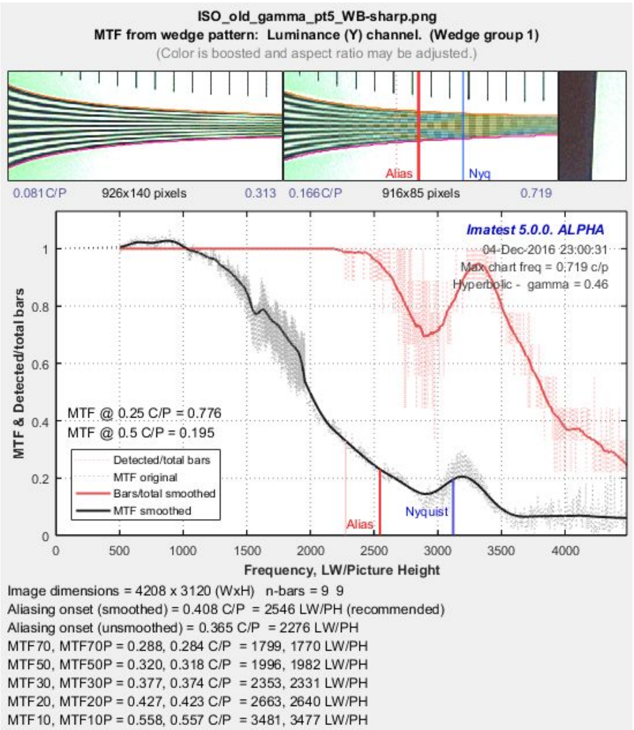
- This is most problematic at fractions of Nyquist frequency



https://www.imatest.com/2017/01/measuring-mtf-with-wedges-pitfalls-and-best-practices/

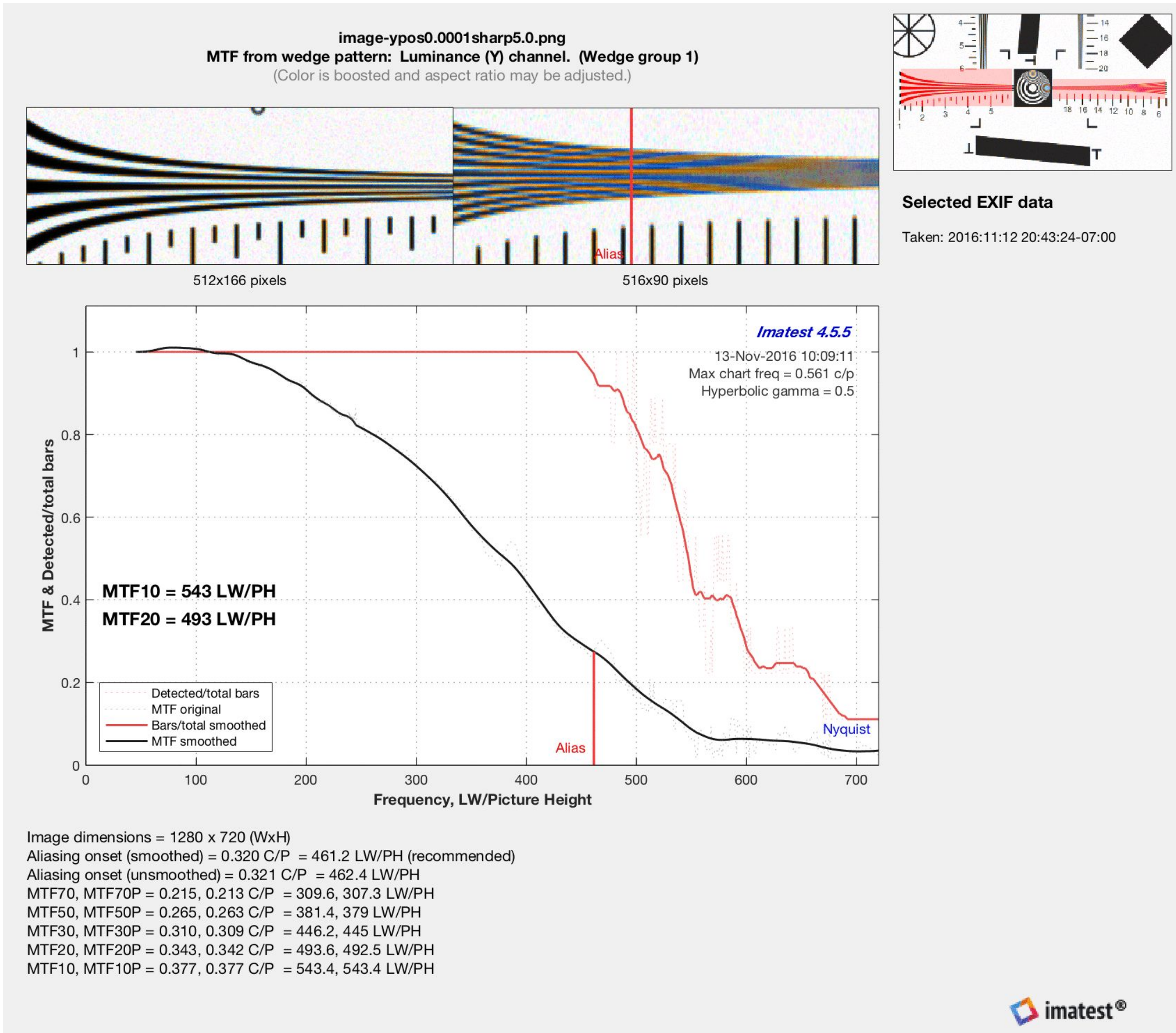
Wedge measurement





MTF often flattens out around the 10% level, making MTF10 very susceptible to noise, sharpening

Wedge Issue: Microposition Changes



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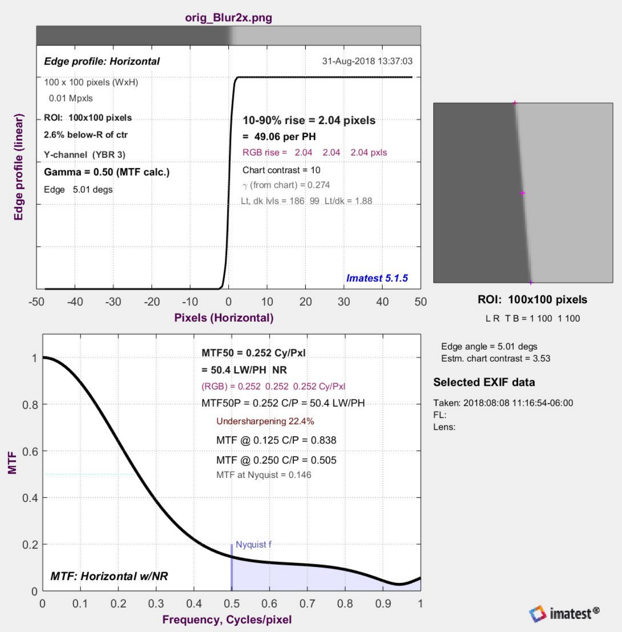
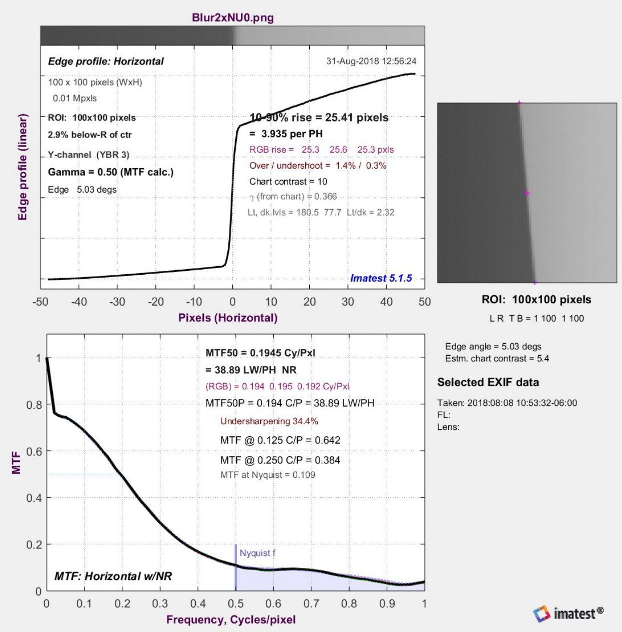
Slanted Edge Nonuniformity

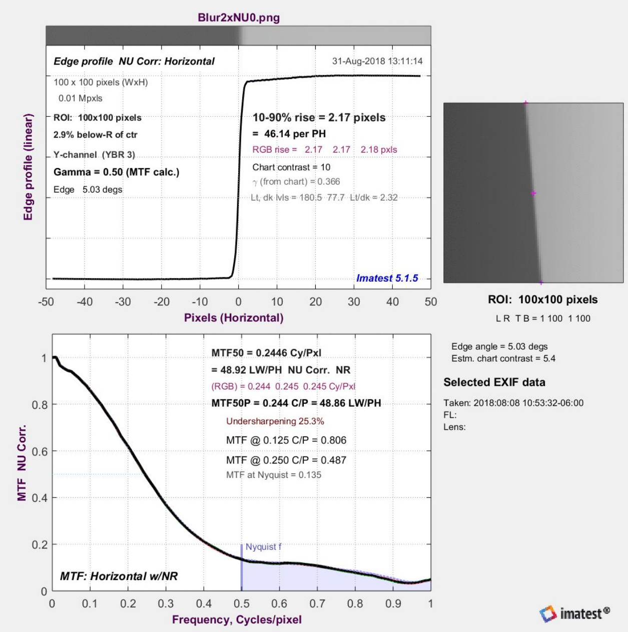
- Nonuniformity introduces error in edge-SFR
- with transition increases, against transition reduces
- Correction introduced in Imatest 4.5 (2016)
- Coming to ISO 12233 standard in 2022

see: Correcting nonuniformity in slanted-edge MTF measurements

Uniform: **Nonuniform:** **Corrected:**



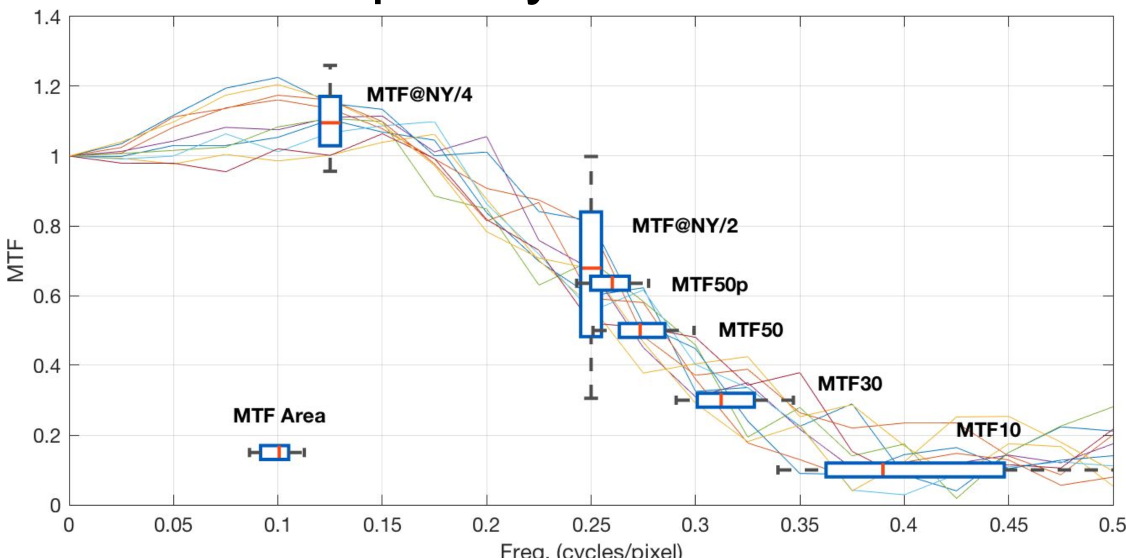




Measurement Repeatability

Higher frequency measurements are more impacted by noise.

- Maximize your samples
  - Adequate sized ROI's
  - Signal averaging
- Ensure adequate signal level
  - Chart contrast
  - Exposure
- Consider using more stable low-frequency metrics



see: [Increasing the Repeatability of Your Sharpness Tests]

Solutions

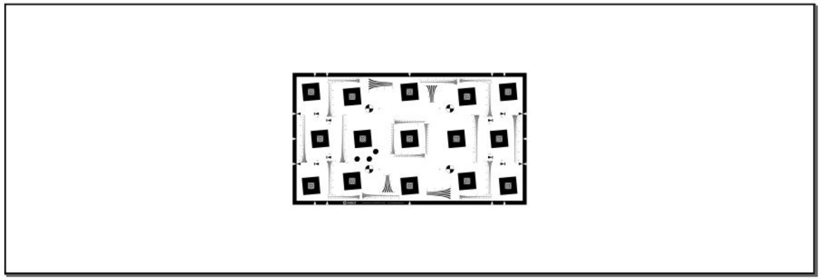
Imatest measurement systems

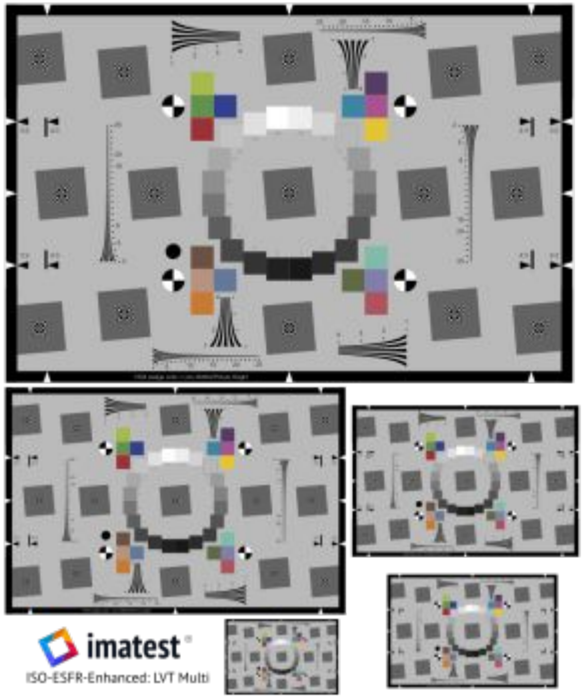
Test setup goals

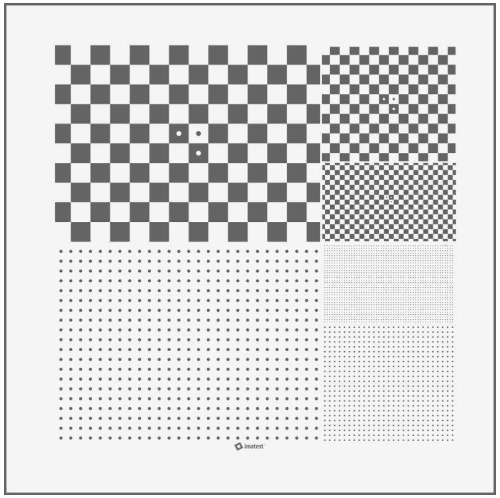
- Place target at a working distance
  - Beyond minimum focus distance
  - Up to hyperfocal distance
- Chart sharper than imaging system
- Fill field of view out to the corners
- Uniform illumination of target

Close Range Targets

High precision targets for Endoscopes, Microscopes, or macro autofocus







Imatest Modular Test Stand

Facilitates repeatable camera, target and light source positioning

Includes

- Custom rail system
- Ruler & laser rangefinder
- Stable camera mount
- Adjustable chart holder
- Motorized version available

MTS: Wide Field-of-View Module

Add-on to the Modular Test Stand

- Test up to 200º FOV
- Polar-coordinate system for four reflective SFRReg targets
- Distance, angle, and height are easily adjusted.
- Sliding light post for mounting Kino Flo LED panels

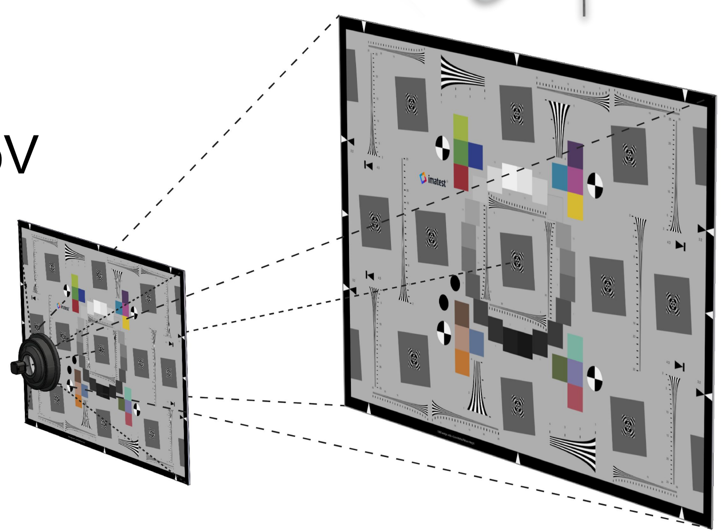
imatest.com/mts-wfov

Imatest Collimator Fixture

Relay lens system for simulating large test distances

- Collimator lenses create a virtual image at a longer working distance up to infinity
- Target projectors include chart + light source
- Mechanical stages to align UUT and virtual target distance
- Cover between 5°- 120° FoV

imatest.com/collimator



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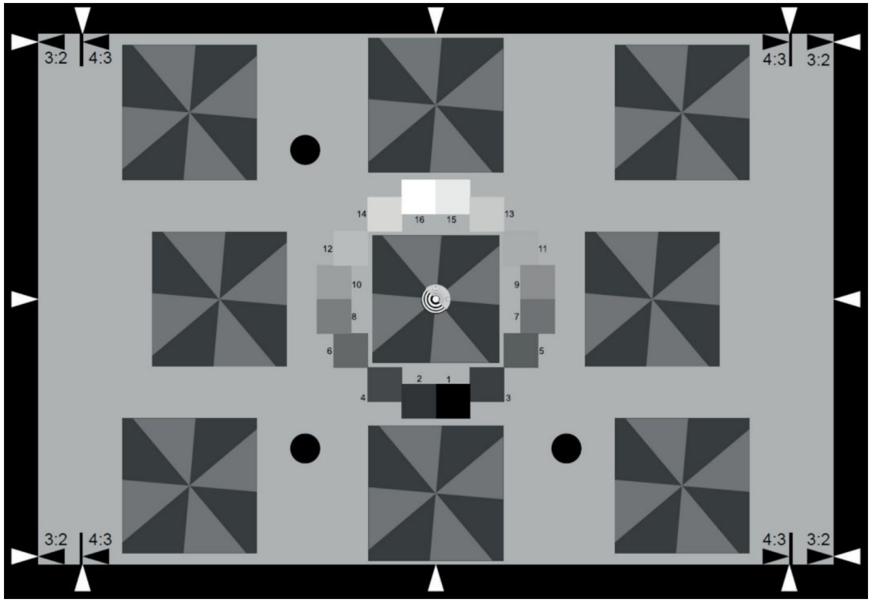
In Development

New ISO 12233 2022 Standard

- Slanted star edge-SFR chart enabling sagittal tangential measurements closer to the corners
- 5th-order polynomial curve fitting
- Tukey window for improved stability
- Nonuniformity correction



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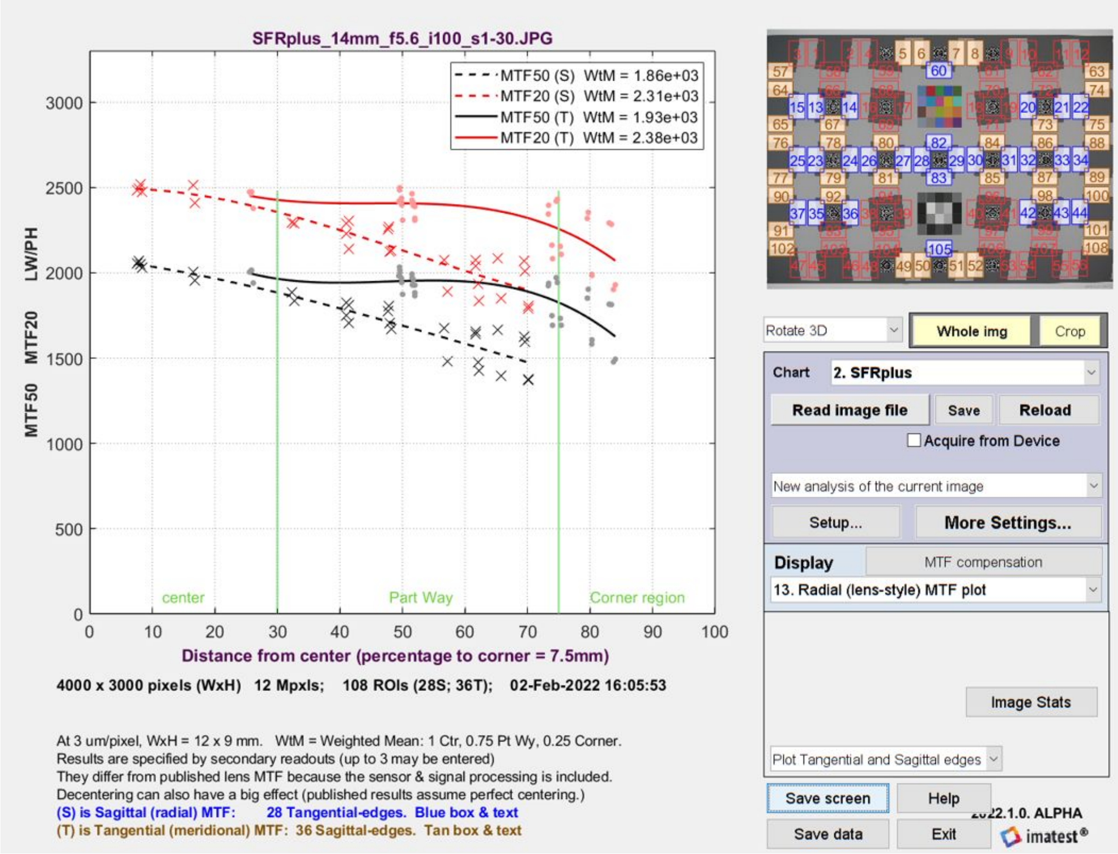
Sagittal & Tangential Radial Plots in Imatest 22.1

- Before the plots were always vertical and horizontal

- Sagittal & Tangential sharpness are closer to the max/min performance



Thank You!

Follow up questions?

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