Imatest - Wedge

Analysis of hyperbolic or trapezoidal wedge patterns

Introduction

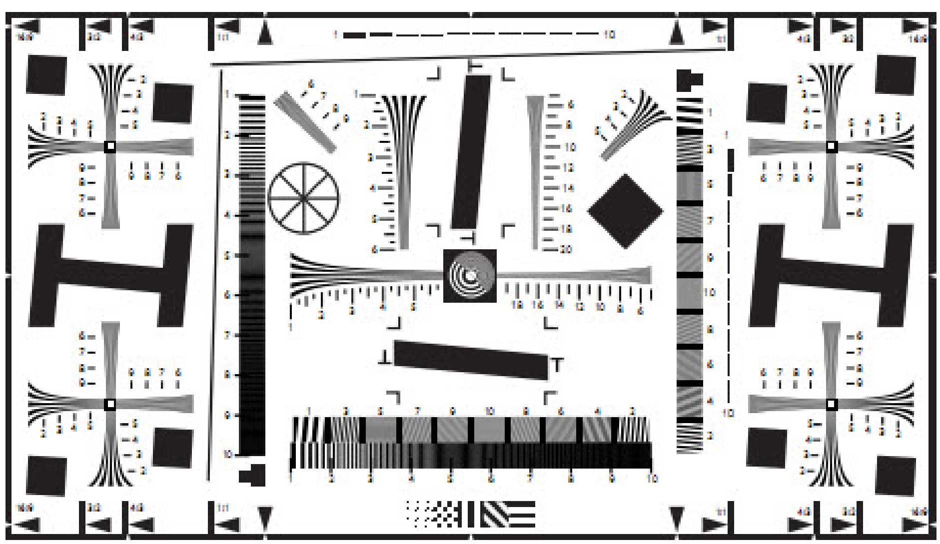
Wedge , which is opened from the Rescharts interface (Imatest Master -only), measures the the MTF (Modulation Transfer Function) and the onset aliasing (related to the vanishing resolution) from converging bar Patterns On called "wedges", which are a PArt of Charts of several well-known resolution test. "Hyperbolic" (linear in. frequency) wedge patterns are central to the CIPA DC-003 Standard for digital camera resolution measurement, which will be Incorporated in a revision of the ISO 12233 RESOLUTION measurement STANDARD.

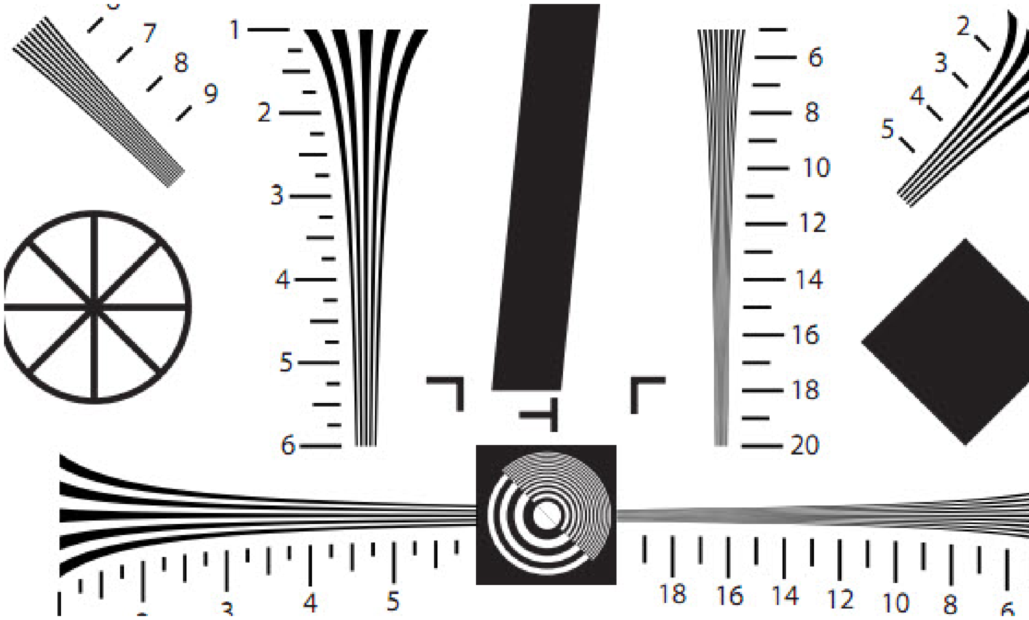
The wedges the Wedge can analyze vertical content horizontalCompare (but not Diagonal) To the best of our kNoWlEdGe Imatest Wedge is the only software that can the calculate the MTF from wedge Patterns, but there is a significant limitation - with the calculation: the results at the the Nyquist FREQuency (and also around 2/3 Nyquist) are highly sensitive to the phase of the bars relative to the pixels, ie, the sub-pixel positioning, which is difficult to control in practice.

The best-known chart that contains wedge patterns is the ISO 12233 resolution test chart. It contains 22 hyperbolic wedges: 10 vertical, 10 horizontal, and 2 diagonal.

ISO 12233 resolution test chart

Here is a crop of the chart that Illustrates several of the hyperbolic wedges. The the Wedge the supports content horizontalCompare and content verticalCompare wedges, but not diagonal wedges.



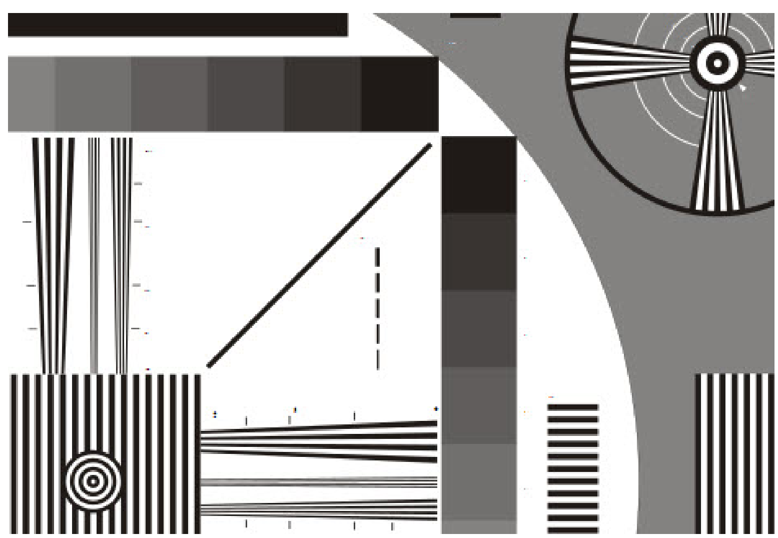


ISO 12233 resolution test chart crop, showing hyperbolic wedges

Hyperbolic wedges are found in a number of other test Charts the Video test CharT including the of the CIPA resolution CharT and the IEEE Std 208 (replacement for the EIA-1956 CharT below).

On Trapezoidal wedges (linear in SPACing) are found in fewer is Charts, the most notable being the EIA-1956 video resolution test CharT The range of spatial FREQUENCIES in this Chart is quite narrow. A crop of the upper-right is shown BELOW.

EIA 1956 test chart (crop of upper-right)



Testing recommendations

If you are starting an image quality / resolution testing distribution PROGram, we strongly recommend that you consider the SFRplus MODULE, which offers AUTOMATED region selection, maps resolution (MTF) over the image surface, and measures several image The quality factors from a single image.

Operation of Wedge is somewhat fussier; it to requires special care in region selection (Described below) To get reliable MTF measurements from Standard test Charts, at least ***two*** regions must be selected. These regions tend to cover a relatively large portion of the image The so there is little possibility of mapping the response over the image surface. Nevertheless Wedge has a few unique attributes:

- Wedge measures color moiré fringing that results from aliasing This can not be done with slanted-edge measurements, though it can be MEASURED (the using a different algorithm that the Produces mynewly different results) with the Log Frequency MODULE.
- The onset of aliasing (the spatial frequency where the number of detected bard drops below the number of bars in the chart) is relatively independent of signal processing (sharpening, noise reduction, etc.), Making it potentially useful for comparing cameras with differing amounts This FREQuency is called the "vanishing resolution" in the CIPA STANDARD of signal processing.

The measurement of the MTF from Anon wedge Patterns is an entirely new feature of the of Imatest Wedge MODULE. To our kNoWlEdGe, no other software has the this capability.

Instructions

Select the test CharT On The ISO 12233 resolution test CharT and its VARIANTS are by far the best-know charts with wedge Patterns, but there are many others, including the EIA-1956 CharT. The SVG Squares and the Wedges CharT , which is the a Scalable Vector the Graphics file that can be printed from Imatest Test Charts , contains very nice Wedge Patterns.

Photograph the test chart a using reasonably even (± 10%) glare-free Lighting A low-cost lighting the setup is described in The Imatest Test Lab Save the image in a standard the format (TIFF, BMP, PNG, high quality JPEG, etc. .)

The distance to the CharT, is not critical. The *The CALibration NUMBERs next to the wedge Patterns are not used by Imatest which calculates spatial FREQUENCIES automatically. the* The CALibration numbers are only valid when the arrowhead Patterns at the top and bottom of the CharT are aligned with the top and bottom of the image The (They represent spatial frequency in LW / PH when multiplied by 100.) If Possible, the highest spatial FREQuency in the wedge patterns should be above the the Nyquist FREQuency (0.5 cycles / pixel) This may be be difficult to achieve when the original ISO 12233 chart is used with high resolution cameras.

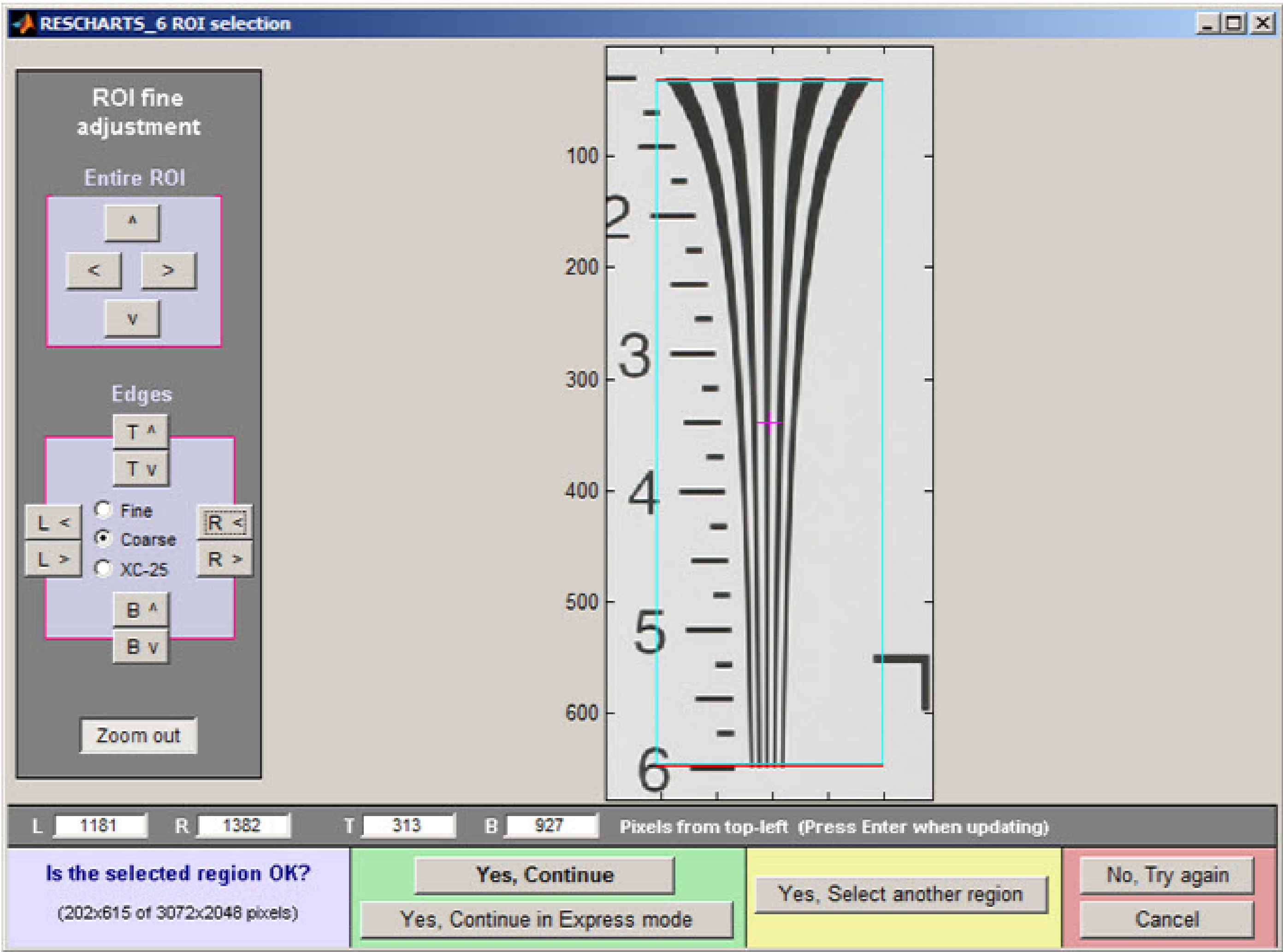
Open of Imatest , the Press the left, then the select **Wedge pattern** in the **Chart type** box, below the button on the right (the If **6 Wedge pattern** has already been selected, simply the click on .)

Open the file to be analyzed.

Select the regions of interest Interest (ROIs)) to be analyzed. Read this section carefully: Poor region selection can lead to unreliable results!

In most cases you'll NEED to select more than one region. Only content verticalCompare, and content horizontalCompare (but not Diagonal) wedges can be analyzed at this time.

Select the first region. Using the the STANDARD Imatest in rough selection window After you've made the selection, the fine adjust window opens.



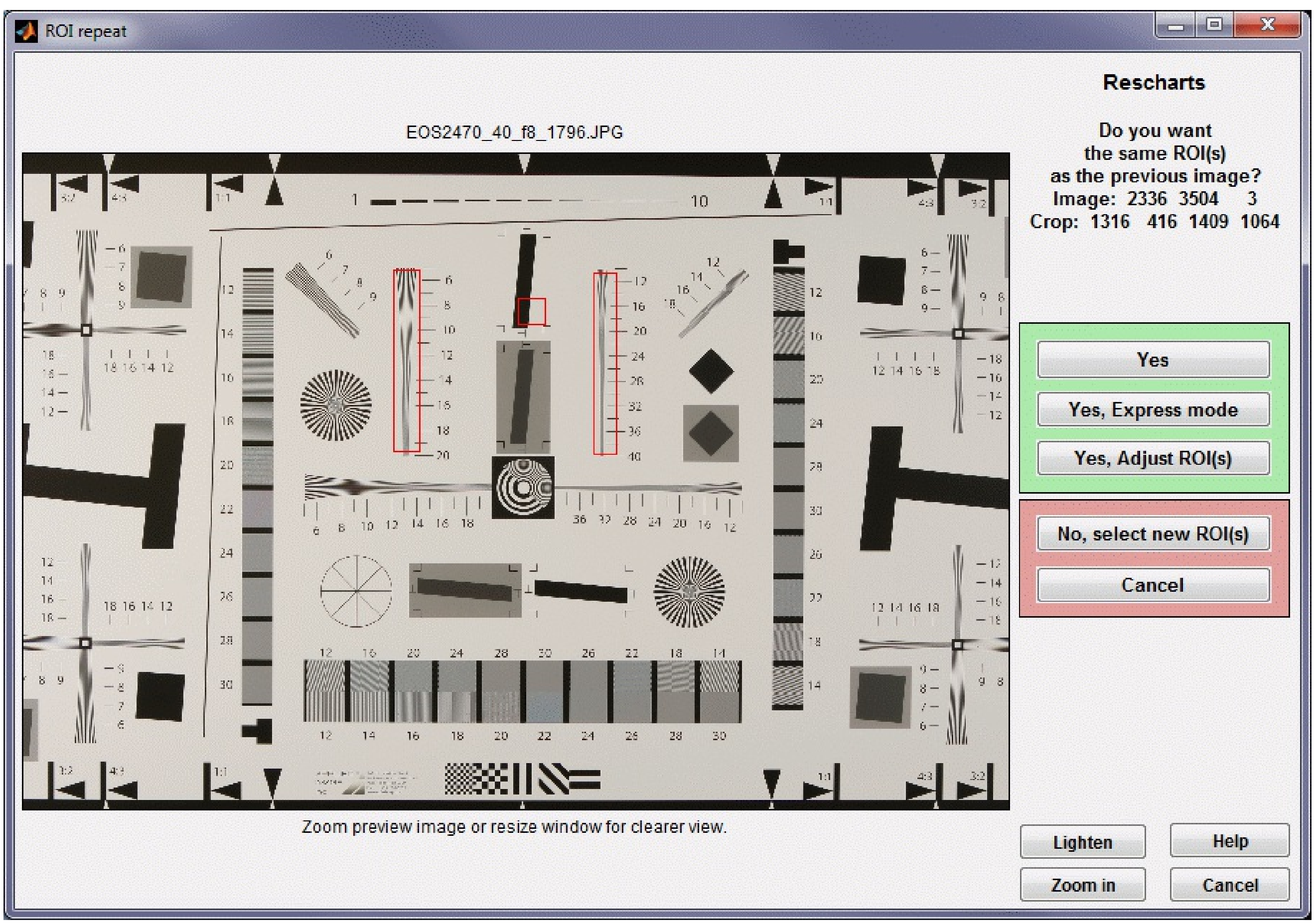
ROI Fine adjustment window

The boundaries of the selected region should be ***inside*** the ends of the wedge. Wedge may work the if the boundaries are outside, but some bad rows (or columns for content horizontalCompare wedges) may be detected., if the image is unsharp The boundaries of the selected region would be ***outside*** the sides of the wedge (the outer bars), allowing a little breathing room. "There should be no problem if the selected region includes interfering Patterns (of mostly content horizontalCompare lines in the above image). Wedge employs a very robust algorithm for ignoring them.

Usually more than one region needs to be selected because most wedges have a-Limited FREQuency range (100-600 LW / PH in the above image Assuming it was framed according to the ISO recommendations-UNNECESSARY for Imatest) To select another region, the click (in the yellow region, bottom-center) pleasure in giving to the [test chart crop](#) image The [ISO 12233 RESOLUTION](#) , above, the first region (5 bars labeled 1-5 with Relatively low spatial FREQUENCIES) was located to the left of center. The second region should be the narrower region (9 bars, labelled 6-20, with higher spatial frequencies) to the right of the center.

In some cases two regions will be sufficient, but in the [Applied Image QA-77](#) test CharT, which is a revised version of the ISO 12233 chart with added low contrast edges the the lowest spatial FREQuency in the the Hyperbolic wedges is Labeled 5, which corresponds to 500 Line Widths / Picture Height when the chart is framed according to specification. This compares to 1 (~ 100 LW / PH) for the old standard ISO chart. Unfortunately 500 LW / PH is not a low enough spatial frequency to reliably normalize the MTF, which is by definition 1 (100%) at low spatial frequencies. (100 LW / PH is low enough in most practical situations.)

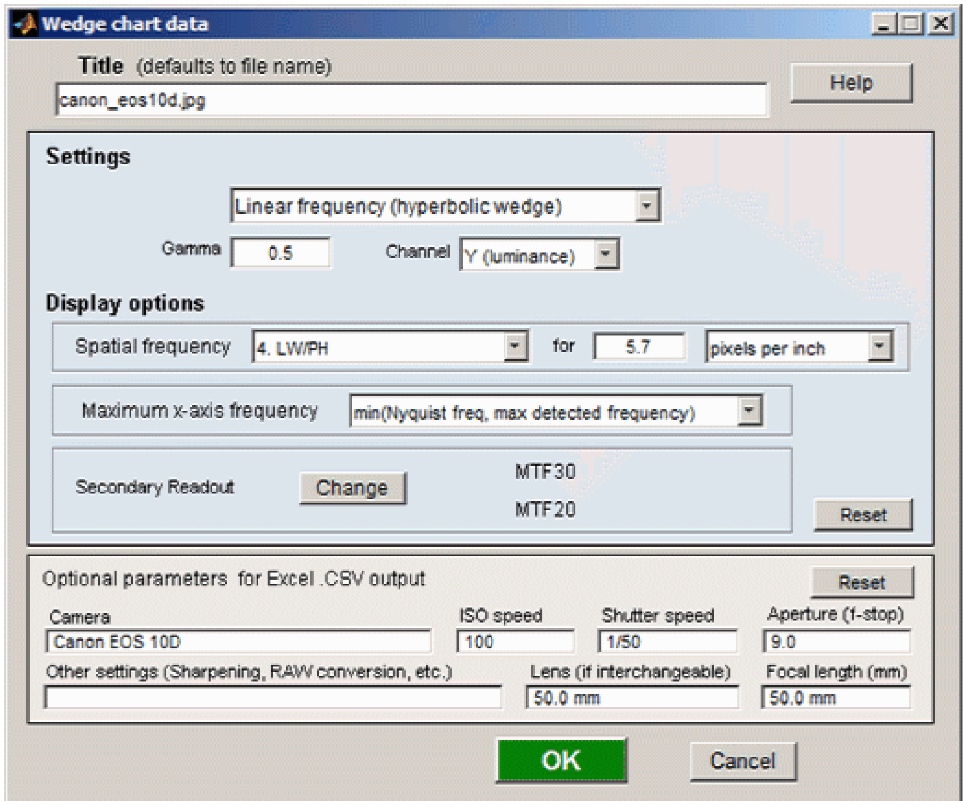
To provide the low frequency reference needed for properly normalized MTF measurements, you can enter a square region (defined by aspect ratio = height / width between 0.7 and 1.4) that contains a single edge, half light and half dark. The edge should reasonably close to the lowest frequency portion of the wedges.



The ROI repeat dialog box (appears the when you read an image The with the same pixel size as the

previous image),
showing three selected regions including a square for low frequency MTF normalization.

When you have selected "regions, press **Yes, Continue** or **Yes, the Continue in Express mode** at the bottom of the ROI Fine Adjustment box If **Express mode** is ***not*** selected, the input dialog box shown on the right appears. This box is also opened when you press .



Input dialog box

Settings

Do not worry about getting all settings correct: You can always open this dialog box by clicking on in the Rescharts window.

Chart type: Either **Linear Frequency: Hyperbolic wedge** or **Linear SPACing: the trapezoidal wedge** (straight lines). the Select the appropriate type.

The Gamma is USED to the linearize the test CharT. It can be is measured by Stepchart, Colorcheck, or Multicharts. 0.5 is a typical value for color Spaces intended for display at gamma = 2 (sRGB, Adobe RGB, etc.).

The Channel is at the R, G, and B, or Y-(Luminance; the default).

Display options

The Spatial frequency Selects spatial frequency units for display (cycles / pixel, cycles / mm, cycles / in LW / PH (Line Widths per Picture Height, the where 2 Line Widths = 1 cycle or line pair), LP / PH, cycles / milliradian , or cycles / degree). If Cycles / mm, Cycles / in, or Cycles / angle are selected, the pixel spacing (pitch) in pixels per inch, pixels per mm, or microns per pixel should be entered.

The Maximum the x-axis FREQuency Baizen the maximum the display FREQuency.

The Secondary readout allows up to the two secondary redouts (MTFnn, MTFnnP, or MTF at a specified spatial frequency) to be DISPLAYED on the MTF plot. Details here .

After you press , CALCULATIONS are performed and the most recently-selected display appears.

Results

The **Display** box in the Rescharts window, shown below, allows you to the select one of two DISPLAYS Display options are set in boxes BELOW the Display All DISPLAYS have a channel selection option in (Red, Green, Blue, or Luminance (Y) (0.3 R + 0.59G + 0.11B).

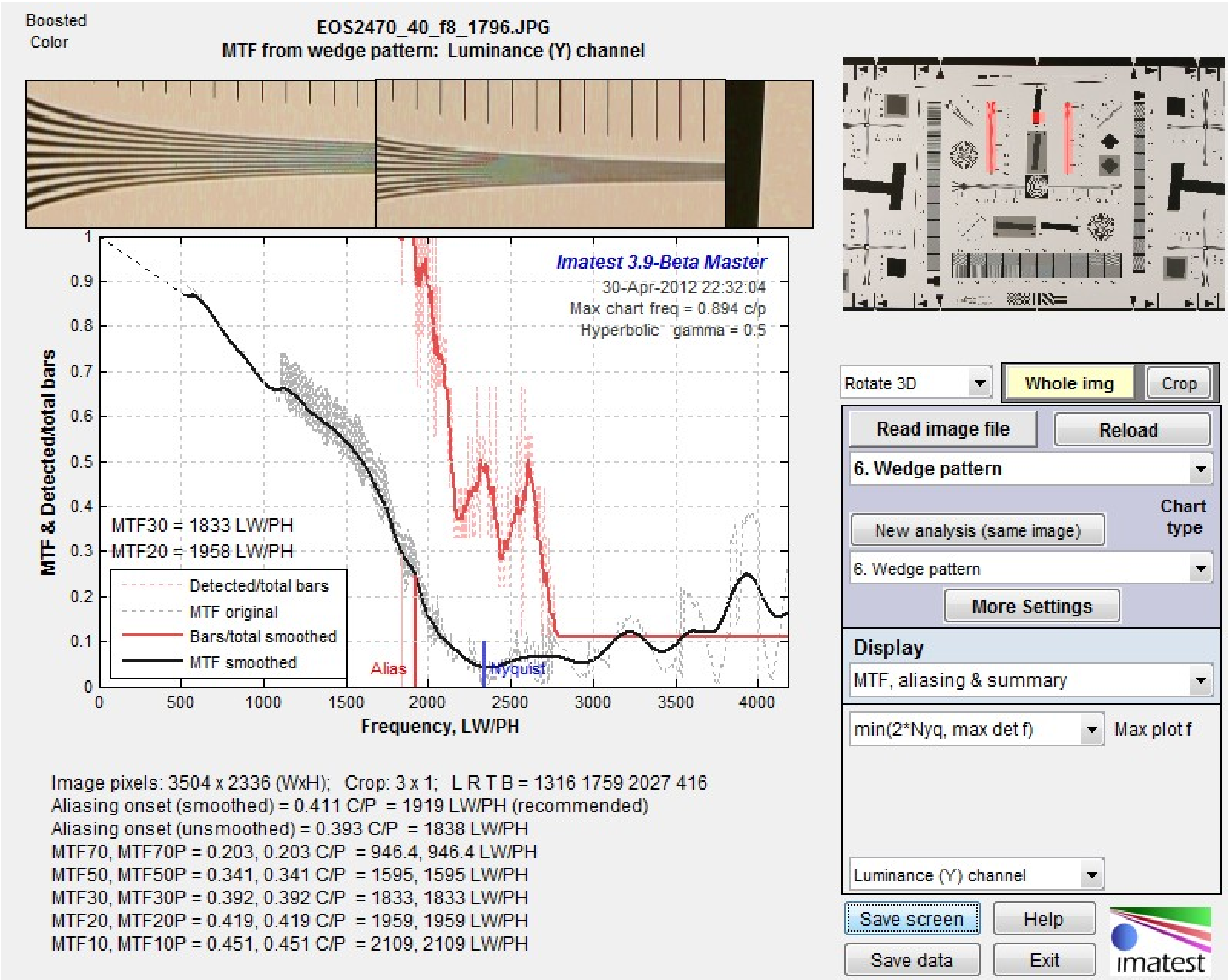
Display	Description
MTF, Aliasing, and Summary	Display the MTF and the onset of aliasing (called "vanishing resolution" in the CIPA DC-003 standard).
EXIF data & Moire	Displays color Moiré and EXIF data, if available.
> ***In addition to the DISPLAYS, two BUTTONS allow you to save results .***	
	Saves an image of the Starchart window as a PNG file. If you check Display screen in the Save screen dialog box , the image will be opened in the editor / viewer of your choice. (Irfanview works well, and it's free.)
	Saves detailed results in a CSV file that can be opened by Excel and also in an XML file.

The spatial frequency is automatically calculated from the image under the assumption that

- frequency INCREASES linearly with distance when **Linear frequency (hyperbolic wedge)** is selected, or
- the spacing (1/frequency) INCREASES linearly with the distance when **Linear SPACing (trapezoidal wedge)** is selected.

MTF and Aliasing

The image The BELOW shows results for the Canon EOS-40D, 24-70 f/2.8 lens set at 40mm, f / 8, JPEG OUTPut, Standard picture style. A sequence of images were taken at different focal lengths and apertures. Rename FILEs was used to add the key information (focal length, aperture) to the file name.



MTF and Aliasing onset results

The jagged sawtooth pattern in the original (unsmoothed) MTF plot (the thin gray dotted lines which look like a gray blur in the above image) arises from differences in MTF between the two wedges, which have overlapping spatial frequencies. The wedges are in different Portions of the image, and hence have mynewly different MTF When Wedge is run with a simulated image that has uniform signal processing, the sawtooth pattern does not appear.

The Detected / total bars Smoothed (thick red line) shows the onset of aliasing The unsmoothed line is On not used because it is susceptible to noise The smoothed line is calculated from 15 adjacent (equally-weighted) values The onset of aliasing (" vanishing resolution ") is where the smoothed line drops BELOW 0.95 It is displayed as a VERTICAL **red** line of at the bottom of the plot.

Algorithm: Spatial FREQUENCIES are calculated directly from the image The using a fit classes to the FREQuency VARIATION (linear with distance for hyperbolic WEDGES) The MTF results for the two wedge Images are concatenated, then Sorted The smoothed results to obtain the pale gray dashed line. (the **black** line) is On the best MTF calculation; it removes some of the strong numerical Artifacts of the original unsmoothed calculation.

Color moiré

Color moiré on fabric
(Canon Rebel XT with kit lens)

Color moiré is artificial color banding that can appear in images with repetitive patterns of high spatial frequencies, like fabrics or picket fences. The example on the right is a detail of a shirt captured by the Canon Rebel XT with its excellent kit lens.

Color moiré is the result of aliasing in Image Sensors that employ Bayer of color filter ARRAYS, as explained below
Key POINts:

- Color moiré can appear when there is a significant image energy above the sensor the Nyquist Frequency for the red and green channels (0.25 cycles / pixel; half the image the Nyquist FREQuency of 0.5 cycles / pixel).
- It is affected by lens sharpness, the anti-aliasing (lowpass) filter (which softens the image), and demosaicing software. It tends to be worst with the sharpest lenses.
- It is most noticeable in the red and blue channels.
- Color moiré should be measured near the center of the image, where lenses tend to be sharpest and lateral chromatic aberration (which can mimic color moiré) is minimal.

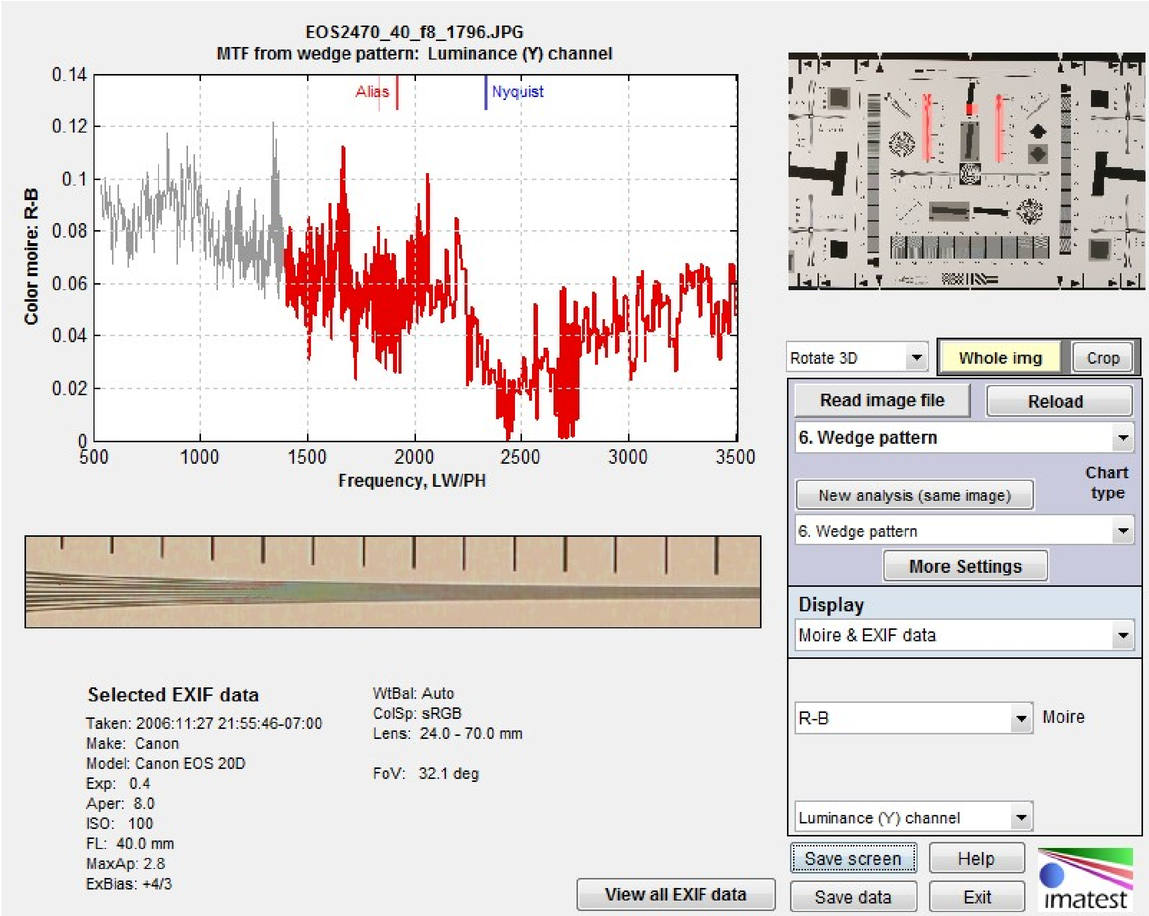
To the best of our kNoWlEdGe there is no well-established Standard for measuring color moiré. The measurement depends on the test pattern, and as a result we've had to use a mynewly different measurement from the Log Frequency MODULE. One of the parameters shown on the right, selected "by the Moire box in the Plot settings area of the Rescharts window is plotted immediately BELOW MTF in the MTF & Moire DISPLAYS., The two parameters shown in boldface, **RB** and **L * a * b * chroma (sqrt (a * ^{2} + b * ^{2}))** have proven to be the most useful. the A color moiré plot is shown BELOW.

The Correct for color density checkbox, which corrects for tonal imbalances in the image, should normally be checked. The lowest frequency where moiré can be visible with Bayer sensors is 0.25 cycles / pixel, half the image Nyquist frequency. This is so because the sensor the red and blue channels the

RB	The most useful of the color differences
(RB) / (R + B)	
RG	
(RG) / (R + G)	

pixel SPACing for is *Twice* that of the (final demosaiced) image pixel SPACing of The total the moiré the for a selected parameter is the variation of that parameter above 0.3 cycles / pixel, shown in **bold red** in the plot. the For the PLOT below, it is at the maximum - Minimum L * a * b * Chroma (√ (a * ^{2} + b * ^{2})) is above 0.3 c / p = 14.9 (L a * b * Units).

GB	
(GB) / (G+ B)	
S (HSL)	Saturation in HSL color
S (HSV)	Saturation in HSV color
Chroma (sqrt (a * ^{2} + b * ^{2}))	Chroma in L * a * b * space
Color moiré measurements	

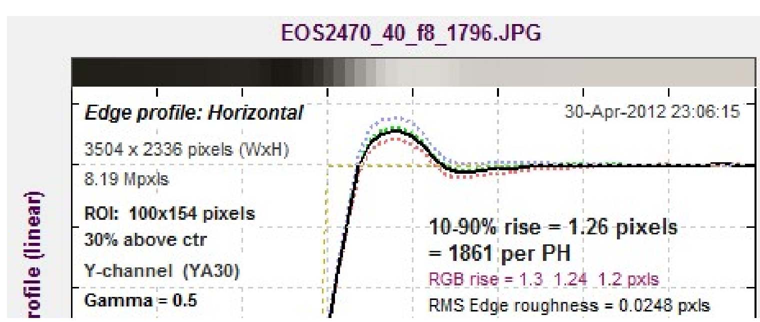


Color moiré and EXIF data

Limitations and Comparisons

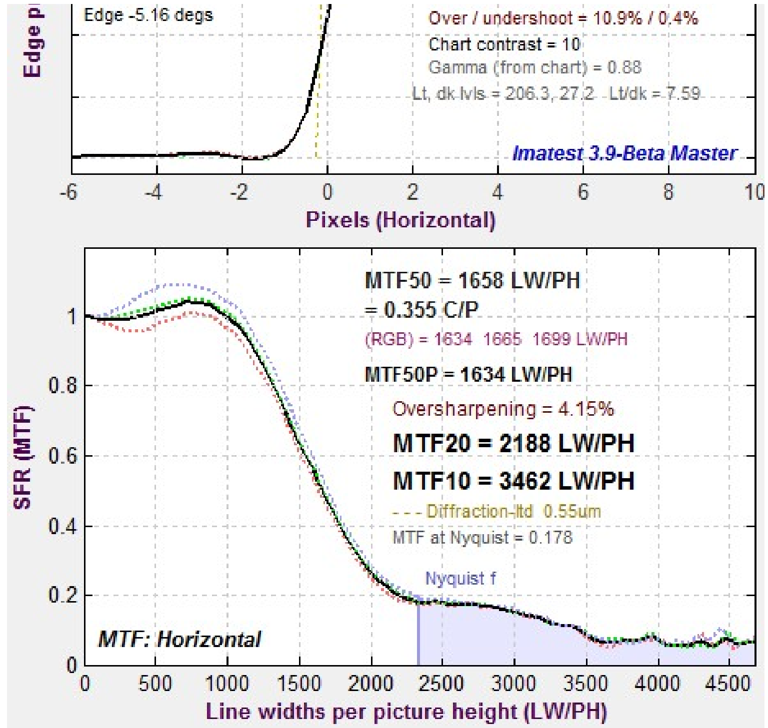
A key limitation to the Wedge the MTF measurement is that the results at the [the Nyquist FREQuency]() (and also 2/3 Nyquist) are highly sensitive to the PHASe of the Bars to the precise sub-pixel POSITIONING relative to the pixels, ie, the which is difficult to control. It can be visualized as follows: At the Nyquist frequency, there are exactly two pixels per bar spacing (where by "bar spacing" we mean a complete cycle composed of a (dark) bar and the (light) interval) . If the bar boundary is in the middle of a pixel, half of each pixel will be covered by the bar and half will be covered by the region between bars-MTF will be zero. If the bar boundaries corresponds to the pixel boundaries, alternate pixels will be dark and light-there will be a strong MTF. In practice this sub-pixel spacing is impossible control, so MTF at Nyquist will vary randomly from one measurement to the next.

Slanted-edge results for Edge between the two wedges



> *The beauty of the [slanted-edge algorithm]() is used in. [SFR]() and [SFRplus is]() that is contains a*

> *distribution of sampling phases, so that the average (correct) MTF is On measured at any spatial Frequency* ***Results are not sensitive the to Edge location.***



An was obvious to Question is, how do Wedge results compare with Slanted-edge SFR? The comparison is easy to make because the test target the contains slanted-edge charts as well as hyperbolic wedges To make the comparison, all you NEED to do is CLICK **Slanted-edge SFR** under **New analysis (same image)** , and select the appropriate region (a high contrast edge in this case). Results are shown on the right.

The most notable difference is On that the the Sharpening bump, between about 600 and 1700 LW / PH, seems to be attenuated in the Wedge OUTPut, This result is quite common We do not entirely understand the cause.

On s Some differences are expected because of the ***nonlinear signal processing*** , which is widespread in digital Cameras: most Digital Cameras, especially compacts, process the signal differently in the presence or absence of contrasty edges In the presence of a contrasty to edge the image The is sharpened: spatial frequencies are boosted. In the absence of a contrasty edge noise reduction is applied, ie, the image is blurred; high spatial frequencies are attenuated. Because nonlinear processing is part of manufacturer's "secret sauce", it's difficult to predict exactly how the different methods will compare.

Here is a summary of reasons why the different charts may give different results.

- **Nonlinear (nonuniform) signal processing** can a major cause of the differences. Sharpening is boosted in the presence of contrasty edges; noise. hate reduction the (lowpass Filtering; the OPPOSITE of Sharpening) is often applied in the absence of contrasty edges.
- **Noise** can cause errors in Wedge results, but smoothing helps. It is averaged out more effectively in the slanted-edge algorithm.
- **Sampling phase errors** cause irregularities in Wedge results, particularly at the the Nyquist FREQuency and sub-multiples of 2 * the Nyquist (1 / *N* cycles / pixel for *N* an integer) The irregularities are too broad to be helped by smoothing.

Despite these factors, a reasonable match between the different methods can be obtained if nonlinear signal processing is not strong.

Calculation details

MTF is defined as the relative modulation of a sine pattern (a pattern of pure spatial FREQuency) To the calculate the MTF from the wedge, the which is a bar pattern, it is treated as a us square wave , which can be broken down to a FUNDAMENTAL FREQuency and harmonics by means of fourier transform the analySIS. (Only the fundamental is significant for MTF.) Here is the algorithm:

- Each selected region (ROI) is scanned line by line (where the scans are perpendicular to the wedge lines), and the outer limits of the wedge are detected. Interfering patterns (bars, calibration numbers, etc.) Are ignored.
- The number of bars and the mean spacing between bars (and hence frequency, which is the inverse of spacing) of each line is detected. The spacing is a "noisy" number.
- The frequency for all lines is determined from a first-order polynomial fit of of the mean spacings or frequencies (depending on the type of wedge) for lines where the number of detected bars equals the total (ie, at frequencies below the onset of aliasing).
- The Modulation M is at each Scan Copyright (c) EC21 calculated for the using Equations based on Fourier Transform analySIS If y is the the AMPLITUDE, x is Distance across the Scan, and f is the Spatial FREQuency, $a = \int Y(x) \cos(2\pi xf)$; b $C = \text{sqrt}(a^2 + b^2)$; $M = c / (2$ MEAN (Y)) Special care is at $= \int Y(x) \sin(2\pi xf)$; taken with the Integration LIMITS so that exactly N-1 Complete Cycles is used for N bars total.

- MTF is derived from M , which may be taken from several wedges and normalized to 1 at low spatial FREQUENCIES If a square the ROI has been selected (which should have a single edge, ie, low. spatial FREQUENCIES), it is used to the normalize the MTF . If more than one wedge region is selected (two is frequent), the spatial frequency and MTF results are concatenated, sorted by frequency (merged in the overlap region), then smoothed to remove numerical artifacts.

Smoothing. The MTF & Aliasing results consist of *two* curves: On unsmoothed (thin dashed lines) and Smoothed (thick solid lines). The smoothed curves are the emphasized because the Roughness in the unsmoothed curves is entirely an artifact of the CALCULATIONS resulting from the sampling PHASe and noise-irregularities can result from noise on a *single* scan line It is important to variously realize that the features of the unsmoothed CURVE have *no physical meaning* .

The Nyquist sampling theorem, aliasing, and color moiré

(This

The Nyquist SAMPLING theorem states that if a signal is On sampled the at a rate *dscan* and is strict higher than *dscan* / 2, the original analog signal can be *exactly* reconstructed The FREQuency f_N = d definition f_N is On always 0.5 cycles / pixel.

Of The first sensor null (the FREQuency the where a complete cycle of the signal COVERS one SAM ***Twice*** the the Nyquist FREQuency. The sensor's AVERage sensitivity (the AVERage of all SAMPLIN quite large.

Signal energy above f_N is ***aliased*** - it appears as artificially low frequency signals in. repetitive Patt repetitive Patterns aliasing appears as JAGGED Diagonal lines-"the jaggies" (a less severe form of how response above the Nyquist frequency leads to aliasing.

Example of aliasing

Signal (3 f_N / 2)					
Sensor pixels	**1**	**2**	**3**	**4**	**5**
Response (f_N / 2)					

In this simplified example, sensor pixels are shown as alternating pink and cyan zones in the middle r 2 pixels = 0.5 cycles / pixel. The signal (top row; 3 cycles in 4 pixels) is 3/2 the Nyquist FREQuency, b Nyquist the FREQuency (1 cycle in 4 pixels) - the ***Wrong*** FREQuency It is ***aliased*** .

> ***The sensor Responds to signals above the Nyquist-MTF is nonzero, but because***

In digital Cameras with ***the Bayer color filter ARRAYS*** - Sensors covered with alternating rows o GBGBGB filters-the problem is compounded because the SPACing between pixels of like color is larger than the SPACing is between pixels in the final image, especially for the Red and Blue chann Nyquist FREQuency is ***half*** that of the final image. This can result in ***color moiré*** , which can be HIG repetitive Patterns such as FABRICS. Demosaicing programs (programs that the fill in the missing image) use sophisticated algorithms to infer missing detail in each color from detail in the other co algorithms can have a significant effect on color moiré.

The Many Digital camera sensors have *anti-aliasing* or *lowpass* the filters to reduce response above
mynewly, ie, the they the reduce resolution Sharp cutoff filters do not exist in optics as they do in the e
especially with very sharp lenses. The design of anti-aliasing filters involves a tradeoff between sharp

Extreme aliasing. The now-discontinued 14-megapixel Kodak DCS 14n, Pro N, and Pro C, had the no anti-aliasing filter. With sharp LENSES, the MTF response extended well beyond the the Nyquist FREQuency The 14n behaved ***very*** badly in the Vicinity of the Nyquist (63 lp / mm), as shown in this MTF test CharT image supplied by Sergio Lovisolo. This is about as bad as it gets.

The Foveon sensor used in Sigma DSLRs is sensitive to all three colors at each pixel site. It also has
aliasing is far less visible because it is monochrome, not color.