Using SFRplus Part 1

The SFRplus chart: features and how to photograph it

Imatest SFRplus performs highly automated measurements of several key image quality factors using a a specially-designed test chart that may be purchased from the Imatest store (recommended) or printed on a high-quality inkjet printer. Unlike other modules, the user does not need to manually select Regions of Interest (ROIs). Image quality factors include

- **Sharpness**, expressed as Spatial Frequency Response (SFR), also known as Modulation Transfer Function (MTF),
- **Noise**,
- **Lateral Chromatic Aberration**,
- **Distortion** (with less detailed output than the Distortion module), and
- **Tonal response** (again, with less detail than Stepchart; no noise statistics)
- **Color accuracy**, when used with an SFRplus chart that contains the optional color pattern, located above the central square.
- **ISO sensitivity** (Saturation-based and Standard Output Sensitivity), when incident lux is entered.

SFRplus operates in two modes.

- **Interactive/setup mode** (run in Rescharts or by pressing in the Imatest main window), which allows you to select settings and interactively examine results in detail.
- **Auto mode** (run by pressing **SFRplus auto** in the Imatest main window), which runs automatically with no additional user input. ROIs are located automatically based on settings saved from the interactive/setup mode. This allows images of different sizes and framing to be analyzed with no change of settings. Auto mode works with large batches of files, and is especially useful for automated testing, where framing may vary from image to image.

This document introduces ***SFRplus*** and explains how to obtain and photograph the chart. Part 2 shows how to run SFRplus inside Rescharts and how to save settings for automated runs. Part 3 illustrates the results.

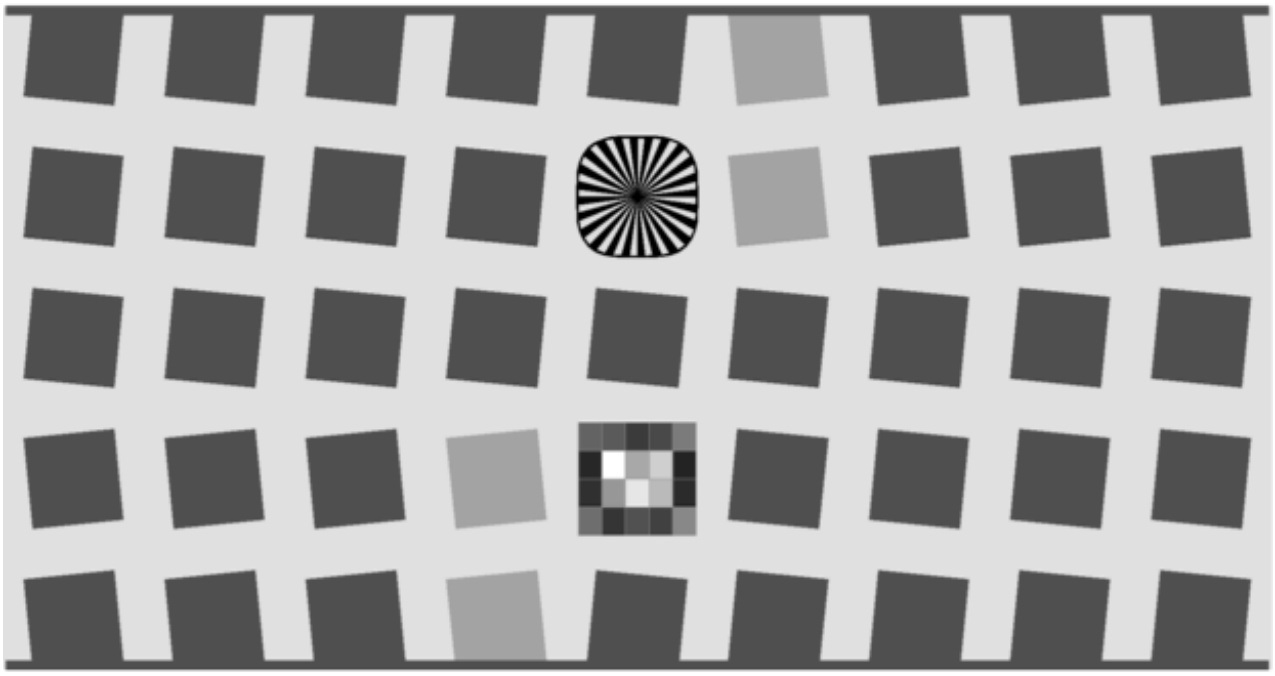
New in Imatest 3.9 SFRplus can be run without including the top and bottom bars by setting the row detection to Auto – no bars. Pre-distorted SFRplus charts are available for testing fisheye (extremely barrel-distorted) lenses.

New in Imatest 3.6 The Lens-style MTF plot is similar to MTF displays on the Canon, Nikon, and Zeiss websites.
New in Imatest 3.5.1 Several geometrical alignment and field of view (FoV) results are displayed in the Image & geometry plot.

Click on any of the thumbnails below (or on the image itself, repeatedly) to explore the many capabilities of SFRplus. Note the description below the image. Results are described in more detail in Part 3.

The SFRplus test chart

A standard SFRplus test chart is shown below.



Standard SFRplus test chart: 5×9 grid, 10:1 and 2:1 contrasts,
20-step 4×5 stepchart (0.1 density increment), and focus star.

Sharpness is derived from light/dark slanted edges at the boundaries of the squares, as described in Sharpness: What is it and how is it measured? SFRplus can handle a wide range of camera aspect ratios; the left and right sides of the chat can extend beyond the frame or be inside the frame.

The essential features of the SFRplus chart are

- Bars at the top and bottom used for measuring distortion and facilitating edge detection.

- A grid of slanted squares with contrasts no greater than 10:1. 4×7, 5×7, 5×9 and 7×11 (row x columns) grids are available. The tilt of the squares facilitates measurement of Lateral Chromatic Aberration using vertical edges (which are near-tangential) near the corners. This orientation also helps with the Lens-style MTF plots, which are similar to MTF displays on the Canon, Nikon, and Zeiss websites.
- The squares above and below the middle square are reserved for non-spatial measurements. In the standard chart, the square below the middle is a 4×5 grayscale stepchart with density steps of 0.1 used to measure tonal response and gamma, and the square above the middle square contains either a fine star pattern (used as a focusing aid; not for analysis) or a 4×5 color pattern (with 18 of the 20 colors similar to the industry-standard 24-patch color chart) for measuring color accuracy.
- A small number of low contrast (typically 2:1) squares for measuring the effects of nonlinear/nonuniform signal processing. Charts may optionally have squares of a single contrast. This is helpful for 3D plots that map the performance over the image surface.

SFRplus chart options (can be selected when ordering)

	Standard	Options & notes
Grid	5×9 or 5×7	5×9 is best suited for HDTV (16:9 aspect ratio) and DSLRs (3:2 aspect ratio). 5×7 is best suited for compact digital cameras and camera phones (4:3 aspect ratio). 4×7 and 7×11 are available on special request.
Contrast level(s)	10:1 – only	40:1 through 1.2:1 are available in the Test Charts module, but contrast > 10:1 is not recommended. 40:1, which was used in the old ISO 12233 chart, produced unreliable results because images were frequently saturated (clipped).
	10:1 (primary), 2:1 (secondary)	Most squares have 10:1 contrast; a few (typically 4) have 2:1 contrast to show the effects of nonlinear/nonuniform processing.
	4:1 – only	4:1 contrast will be specified in the new ISO 12233 standard, to be released in 2012. May give lower MTF numbers than the 10:1 chart due to nonuniform signal processing.
Grayscale stepchart	Included (below center)	Not available in chrome on opal or glass charts
Focus	The focus star is	The focus star is used as a focus aid (not for Imatest

star or Color chart (above center)	normally included.	analysis). Omitted if color chart is included.
	A 20-patch color chart is optional	Replaces focus star if selected. L*a*b* values will be sent in a CSV file. 18 of the 20 patches are close to the industry-standard 24-patch test chart.
Pre-distorted chart	(The standard chart is undistorted.)	Two levels of pincushion distortion distortion are available for use with fisheye (strongly barrel-distorted) lenses. Available in matte surface only.
Surface	Matte or semigloss	Semigloss is slightly sharper and has a more accurate grayscale in the deep tones (print densities > 1.4), but is more susceptible to glare (specular reflections), especially with wide angle lenses. **Matte surface is recommended for wide angle lenses**

Advantages of the SFRplus chart over the old ISO 12233 chart

- Much less wasted area. About 90% of the ISO chart is covered with patterns that have little value for computer analysis.
- You can produce a map of sharpness (MTF) over the image surface. This cannot be done with the ISO chart because there are not enough suitable edges— and they are not well-located.
- 10:1 (or lower) contrast edges are less likely to clip than the edges in the (soon-to-be-obsolete) ISO chart, whose contrast is specified at ≥ 40:1. The camera operates in a more linear region, and hence results are more consistent and accurate— less affected by overexposure, underexposure, or incorrect gamma estimate. Also, 10:1 or lower contrast edges are more representative of real edges that affect perceived image sharpness. SFRplus charts are available in 4:1 contrast, which is consistent with the soon-to-be released (we hope) revision to the ISO 12233 standard.
- The low contrast edges (2:1 contrast in a few edges in the standard SFRplus chart) provide additional information about signal processing in the camera under test. Although Imatest SFR is relatively insensitive to chart contrast (MTF is normalized to 100% at low spatial frequencies), measured SFR is often affected by chart contrast due to ***nonlinear and nonuniform signal processing*** in cameras, as described in the box below.
- The SFRplus chart is well-suited for automated testing with the Imatest SFRplus module. With the ISO chart, regions of interest (ROIs) must be selected carefully whenever the image framing changes.
- The measurement is ISO-compliant. *ISO-compliant measurements do not require the standard ISO chart.* The upcoming (2013?) revision to the ISO standard will recommend an entirely different pattern with 4:1 contrast, which is fully supported by SFRplus.
- It can measure additional image quality factors, including lateral chromatic aberration, distortion, gamma (contrast), tonal response, and color accuracy (in charts that have the optional color pattern).

Nonlinear and nonuniform signal processing SFR (MTF) measurements are often affected by chart contrast due to ***nonuniform signal processing***, i.e., processing that depends on the contents of neighboring pixels, and hence may vary throughout an image. Nonuniform processing is almost universal in consumer digital cameras. It improves pictorial quality but complicates measurements. You can avoid it for Imatest measurements by decoding RAW images (if available) with dcraw. It takes two primary forms.

- **Sharpening**, applied near contrasty features like edges. Boosts response at high spatial frequencies.
- **Noise reduction**, applied in the absence of contrasty features. Attenuates response at high spatial frequencies, i.e., removes fine, low contrast detail (texture), which is interpreted as noise. Many cameras increase noise reduction at high ISO speeds.

The signal processing algorithms are proprietary; they are a part of a manufacturer's "secret sauce" for producing pleasing images. Though they vary a great deal, the following generalizations can be made.

> ***Most cameras do NOT apply noise reduction and sharpening uniformly throughout an image.***
> ***Contrasty edges tend to have better MTF than low contrast edges.***

For this reason it is sometimes useful to photograph a chart that has both relatively high and low contrast edges: 10:1 and 2:1 in the table above.

Nonuniform signal processing can be analyzed in depth in the Log F-Contrast module.

SFRplus slanted-edge algorithm The algorithms for calculating MTF/SFR were adapted from a Matlab program, sfrmat, written by Peter Burns () to implement the ISO 12233 standard. SFRplus incorporates numerous improvements, including improved edge detection, better handling of lens distortion, and far more detailed output. A description can be found here. The original Matlab code is available on the I3A ISO tools download page by clicking on ISO 12233 Slant Edge Analysis Tool sfrmat 2.0. In comparing sfrmat 2.0 results with Imatest, keep the following in mind: If an OECF (tonal response curve) file is not entered into sfrmat, it assumes that there is no tonal response curve, i.e., gamma = 1. In Imatest, the default gamma is 0.5, which is typical of digital cameras. To obtain good agreement with sfrmat, you must set gamma to 1.

pdburns@ieee.org

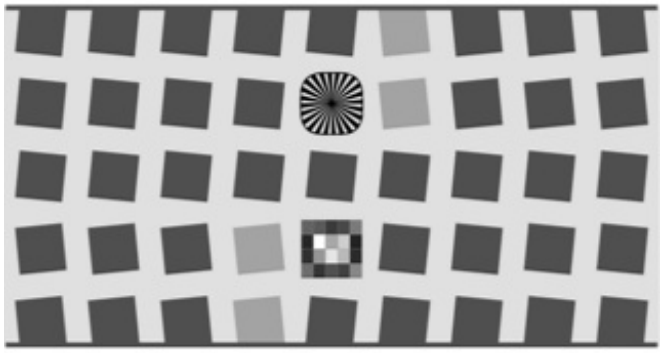
Obtaining and photographing the chart

Summary

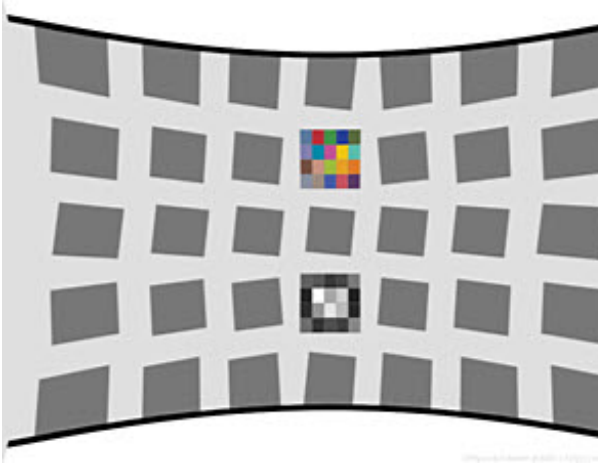
- Obtain a test chart (Purchase or print)
- Mount the chart.
- Photograph the chart.

- **Tips:** Lighting | Distance | Exposure | Tips on photographing

Obtain a test chart.



Standard 5×9 SFRplus chart, 10:1 & 2:1 contrast, focus star.

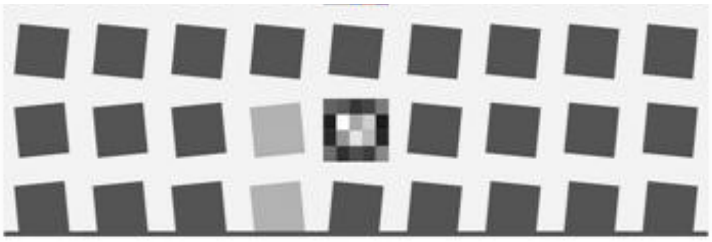


Pre-distorted 5×7 chart, 4:1 contrast, color. (An even more distorted chart is available.)

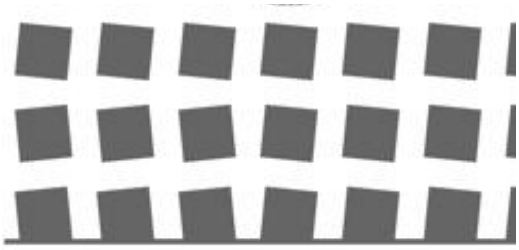
The standard SFRplus test chart consists of a 5×7 or 5×9 grid of squares, all but four of which have a 10:1 contrast ratio. The contrast ratio of the remaining four (one column off the center) is 2:1. A small 4×5 patch stepchart (densities in steps of 0.1 from 0.05 to 1.95) is located below the central square and a focus star (not analyzed by SFRplus) is located above the center.

The chart can be purchased from the Imatest store. It should be mounted on 32×40 or 40 x60 inch sheets of 1/2 inch (12.5 mm) thick foam board with a spray adhesive (such as 3M™ 77 or Photo Mount) or double-sided tape (such as 3M™ #568 Positionable Mounting Adhesive). 1/2 inch foam board stays flatter than standard 1/4 or 3/8 inch foam board. PVC board is also very promising: it may be more durable and it comes in a variety of sizes.

Charts are available with a variety of options. The chart on the left below contains a color pattern (an L*a*b* reference file is included with purchase). The single-toned chart on the right below contains a star pattern, which can be used as a focus aid (not for analysis). It be produced as a chrome-on-glass transmission target in very small sizes Details here. Charts can be printed on widebody inkjet printers, but you must have fine materials, skill, and a knowledge of color management. We strongly recommend that you purchase a chart.



5×9 SFRplus chart with color pattern

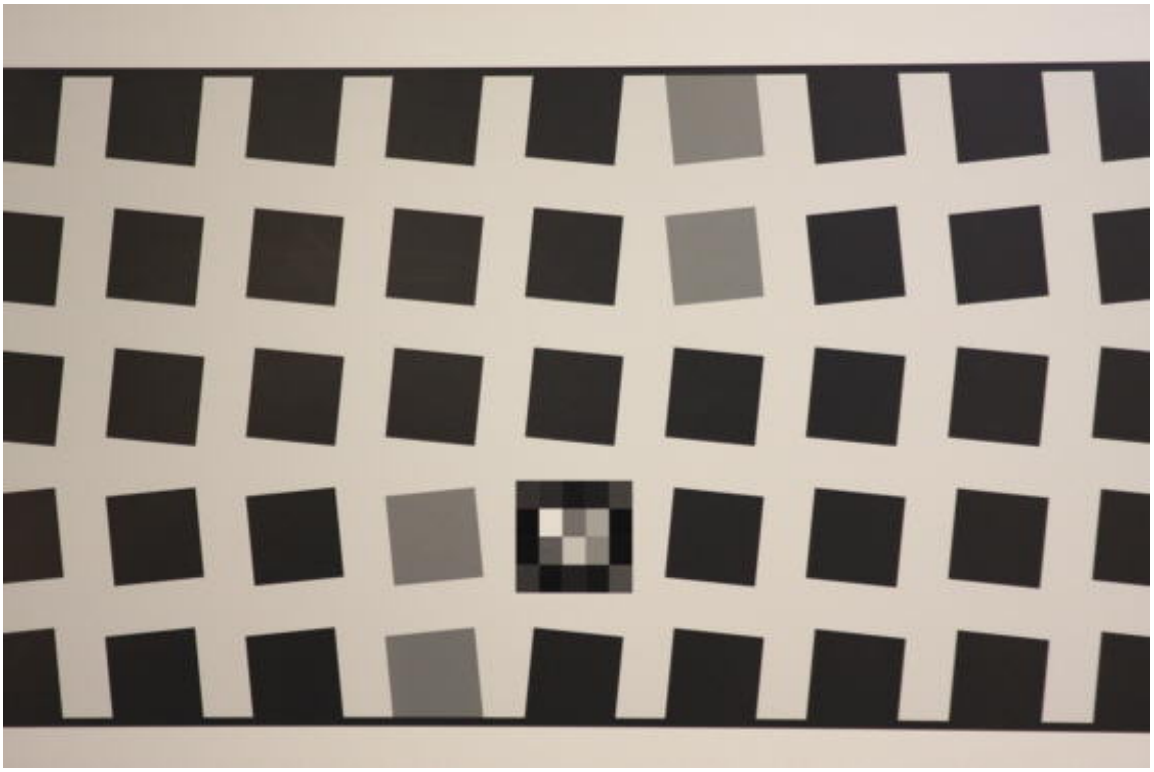


Single-toned 5×7 SFRplus chart with focus star

Photograph the chart.

Framing requirements:

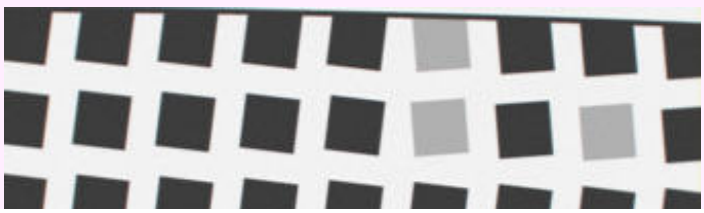
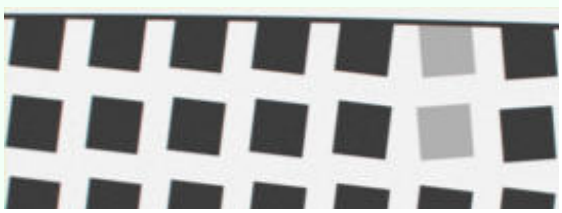
- There should be white space above and below the bars (used to measure distortion) at the top and bottom of the images. The white areas should be at least 0.5% and no more than 25% of the total image height. Ideally the white space should be ~1-6% of the image height. The chart should be vertically centered if possible, but this is not necessary for SFRplus to run successfully.
    - Starting with Imatest 3.9 the bars may be omitted if row detection in the SFRplus setup window is set to **Auto – no bars**. Some care should be taken with framing since region selection acts as if there were bars at the top and bottom of the image.
- The stepchart pattern should be centered horizontally.
- ***The sides of the chart may extend beyond the image*** (as shown below) ***or*** be well within the image. The software is designed to accommodate a wide variety of framing and aspect ratios. Edges near the left and right boundaries will be properly located. If the left and right sides of the chart are inside the image, there should be no interfering patterns in the image that could be mistaken for chart features. Chart surroundings included within the image should be or light gray if possible; if that's not possible you can crop the image in the SFRplus setup window.

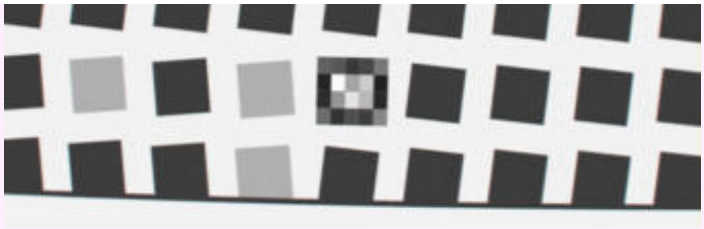


Well-framed SFRplus image (somewhat more top, bottom white space than needed)
It's OK (quite commonplace) for the sides of the chart to run off the image.

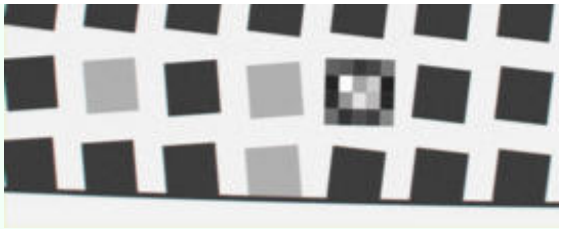
- The chart should be aligned using techniques shown in Building a Low-Cost Test Lab. SFRplus tolerates moderate misalignment: a tilt of 1-2 degrees, some perspective (keystone) distortion, etc., but every effort should be made to align the chart properly. Moderate barrel or pincushion distortion (<8% SMIA) is also well tolerated, but a pre-distorted chart should be used with extreme Fisheye lenses (with high, intentional barrel distortion).
- The image can be cropped (starting with) to remove interfering features near the edges, using the Crop borders button in the SFRplus setup window.

If exposure compensation is available, increasing exposure by +1 f-stop often produces a better exposure, especially on the grayscale stepchart pattern.

Bad framing Interfering patterns near borders (Can be cropped.)	**Good framing** Same pattern; interfering patterns mask
	



Missing white space above top distortion bar



Some tilt, distortion tolerated
OK for sides of chart to run off imag

Starting with ***Imatest 3.9***, the top and bottom bars may be omitted if **Auto – no bars** is selected in the row detection menu in the SFRplus setup window. Region selection will behave as if the bars were located at the top and bottom of the image.

No bars

Lighting

The chart below summarizes lighting considerations. The goal is even, glare-free illumination. Lighting angles between 25 and 45 degrees are ideal in most cases. At least two lights (one on each side) is recommended; four or six is better. Avoid lighting behind the camera, which can cause glare. Check for glare and lighting uniformity before you expose. Matte charts are recommended for wide angle lenses; it's very difficult to control glare with semigloss surfaces.

A detailed description of the recommended lighting setup, which uses six high quality (CRI > 98) 4700K (near-daylight) 50W SoLux quartz-halogen lamps, can be found in Building a Low-Cost Test Lab. The BK Precision 615 Light meter (Lux meter) is an outstanding low-cost instrument (about $100 USD) for measuring the intensity and uniformity of illumination.

Simplified lighting diagram

Distance

Distance and field of view

The camera must be far enough from the chart so you are measuring the sharpness of your

camera and lens, ***not*** the chart. But remember,

It's the field of view, not the chart-to-camera distance, that counts.

A *rough* rule of thumb: For an inkjet-printed chart the field of view should be at least

24 inches (60 cm) for a 6-megapixel camera;
40 inches (90 cm) for a 16 megapixel camera.

Details below. For a high-quality photographically-printed chart (such as the charts from Applied Imaging) you can get quite a bit closer.

A letter-sized (8.5×11 inch) chart printed on Premium Luster paper on the Epson 2200 (a high quality pigment-based inkjet photo printer) was analyzed for MTF using the 6.3 megapixel Canon EOS-10D. There was no change when the image field was at least 22 inches (56 cm) wide— twice the length of the chart. Performance fell off slowly for smaller fields.

Choose a camera-to-target distance that gives at least this image field width. The actual distance depends on the sensor size and the focal length of the lens. The minimum image field is illustrated on the right.

Cameras with more pixels, and hence higher potential resolution, should have a larger image field width, hence printed chart width.

Distance/field width guidelines for high quality inkjet charts (You can get closer with photographically-printed charts.)

The camera-to-target distance is not critical as long as it is greater than a reasonable minimum.

Image field width (in inches) > 8.8 × sqrt(megapixels)
Image field width (in cm) > 22 × sqrt(megapixels) — or —There should be no more than 140 sensor pixels per inch of target or 55 sensor pixels per centimeter of the target. — or —The distance to the target should be at least 40X the focal length of the lens for 6-10 megapixel digital SLRs.(25X is the absolute minimum for 6 megapixel DSLRs; 40X leaves some margin.) For

Sensor sizes			
Desig-nation	Diagonal mm.	Width mm.	Height mm.
1/3.6″	5.0	4.0	3.0
1/3.2″	5.68	4.54	3.42

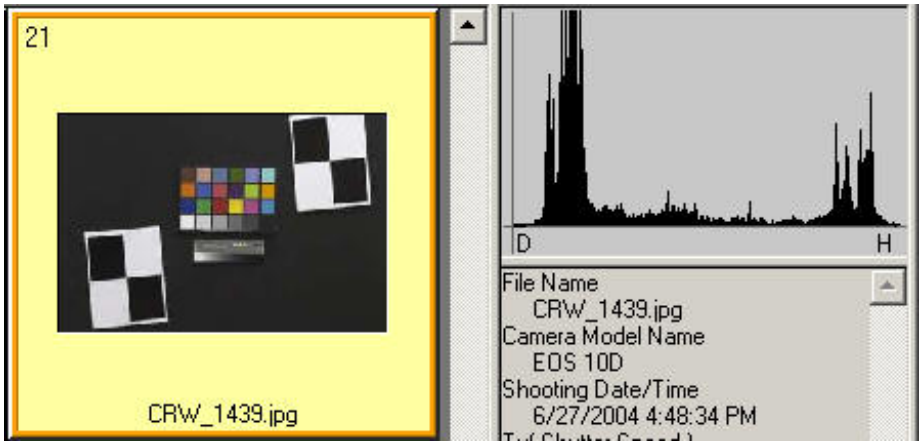
compact digital cameras, which have much smaller sensors, the distance should be at least 100X the actual focal length: the field of view is about the same as an SLR with comparable pixel count. The recommended distance is described in more detail in Chart quality and distance, below.

There is some confusion about lens focal lengths in compact digital cameras. They are often given as the "35mm-equivalent," which many photographers can relate to viewing angle. 35-105mm or 28-140mm are typical "35mm-equivalent" numbers, but they are ***not*** the true lens focal length, which is often omitted from the specs. What is given is the sensor size in 1/*n* inches, a confusing designation based on the outside diameter of long-obsolete vidicon tubes. It The table on the right relates the 1/*n*designation to the diagonal dimension of the sensor. **True focal length = "35mm-equivalent" × (diagonal mm.) / 44.3**

1/3″	6.0	4.8	3.6
1/2.7″	6.59	5.27	3.96
1/2″	8.0	6.4	4.8
1/1.8″	8.93	7.18	5.32
2/3″	11.0	8.8	6.6
1″	16.0	12.8	9.6
4/3″	22.5	18.0	13.5
35mm	44.3	24.0	36.0

Exposure

Good exposure is important for accurate SFRplus results. Neither the black nor the white regions of the chart should ***clip***— have substantial areas that reach pixel levels 0 or 255. The best way to ensure proper exposure is to use the histogram in your digital camera. Blacks (the peaks on the left) should be above the minimum and whites (the peak(s) on the right) should be below the maximum.



The above image (taken from the Canon File Viewer Utility) is close to a perfect exposure. Some exposure compensation, typically around +1 f-stop, may be helpful.

Tips on photographing the chart

Distance doesn't matter as long as the target far enough from the camera so sharpness is limited by the camera and lens, ***not*** by the target. A Wide body printer (capable of printing images at least 24 inches high) are required to print the SFRplus chart.
The target should be evenly lit and free of glare.
White balance should be approximately neutral.
Use a sturdy tripod and a cable release. For DSLRs, use the mirror lock if possible. You can use Imatest SFR to find the difference made by a good tripod or mirror lock— to sharpen your technique, literally (*pun intended*).
Be sure to expose the image so detail is maintained in both light and dark areas. Neither should be blocked (clipped). Use your camera's histogram. If more than 0.5% of the pixels are at levels 0 or 255, Imatest SFR will assume that clipping has taken place and issue a warning message. This has no effect on the calculations— it's just a warning that accuracy may be compromised.
Be sure the camera is correctly focused on the chart.
Place slanted-edge images near the corners of the field as well as near the center.
You may find it instructive to photograph the slanted edge target along with a target from Lens testing, but there's no need to do so.

Save the image as a RAW file or maximum quality JPEG. If you are using a RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression, which is not supported), or PNG. If you are using film, develop and scan it.

If the folder contains meaningless camera-generated file names such as IMG_3734.jpg, IMG_3735.jpg, etc., you can change them to meaningful names that include focal length, aperture, etc., with the View/Rename Files utility, which takes advantage of EXIF data stored in each file.

You are now ready to **run Imatest SFRplus**.

Links

How to Read MTF Curves by H. H. Nasse of Carl Zeiss. Excellent, thorough introduction. 33 pages long; requires patience. Has a lot of detail on the MTF curves similar to the Lens-style MTF curve in SFRplus. Even more detail in Part II. Their (optical) MTF Tester K8 is of some interest.

Understanding MTF from Luminous Landscape.com has a much shorter introduction.

Understanding image sharpness and MTF A multi-part series by the author of Imatest, mostly written prior to Imatest's founding. Moderately technical.

Bob Atkins has an excellent introduction to MTF and SQF. SQF (subjective quality factor) is a measure of perceived print sharpness that incorporates the contrast sensitivity function (CSF) of the human eye. It will be added to Imatest Master in late October 2006.

Optikos makes instruments for measuring lens MTF. Their 64 page PDF document, How to Measure MTF and other Properties of Lenses, is of particular interest.