Imatest - Using Stepchart

Stepchart measures the tonal response, noise, dynamic range, and ISO sensitivity of digital cameras and scanners using

- **Reflection step charts** such as the Kodak/Tiffen Q-13 and Q-14 Gray Scales, which have a single row of patches (a linear arrangement), or
- **Transmission step charts** such as the Imatest 36-patch Dynamic Range Chart or charts from Stouffer, Applied Image, Kodak, DSC Labs, and Danes-Picta. Transmission charts, which have higher maximum densities than reflective charts, are required for measuring dynamic range from a single image.
- **Additional ISO charts** such as ISO-14524 and ISO-15739, with non-linear (multiple rows; may be circular) patch arrangements, shown below. (Imatest Master only)

Stepchart can also measure veiling glare (lens flare).

New in Imatest 3.7 Temporal noise can be calculated from two identical Step chart images.
New in Imatest 3.5 ISO sensitivity is calculated when the incident lux level is entered.

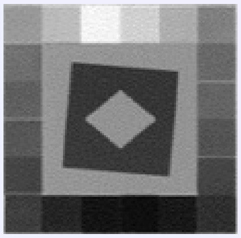
New in Imatest 3.1 Highly distorted images can be analyzed if automatic patch location is turned off. Several images can be combined (averaged) to facilitate fixed pattern noise measurement.

The Kodak/Tiffen Q-13 Gray Scale* is an inexpensive 8 inch long chart consisting of 20 zones, labeled 0-19, which have optical densities from 0.05 to 1.95 in steps of 0.1 (reflectance from 0.891 to 0.011). The Q-14 is identical, except that it’s 14 inches long. The chart is printed on a luster (semigloss) surface. *The Q-13/Q-14 charts were formerly sold under Kodak’s name. It is now usually sold as a Tiffen’s chart. (Tiffen was apparently the manufacturer all along.) The Q-13 image on the right was photographed slightly out of focus to minimize noise.

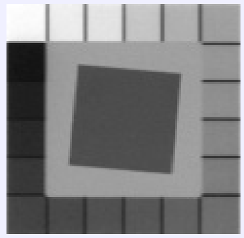
Additional (multiple-row or circular) charts for Imatest Master

Several monochrome targets, shown below, can be analyzed with Imatest Master. To run them, ope
the approximate region of interest for the key features in the target, following the instructions in Ste

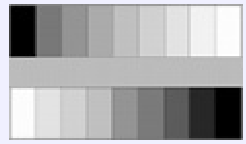
[Image/ISO targets](). Additional dialog boxes allow you to specify the target type and refine the crop.



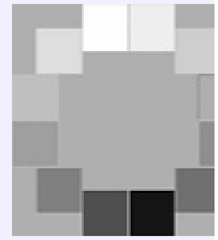
QA-61 ISO-16067-1 Scanner



QA-62

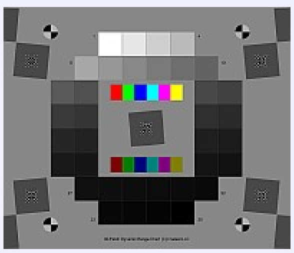


ST-51 EIA Grayscale

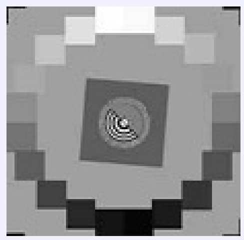


ST-52 ISO-14524 12-patch OECF target

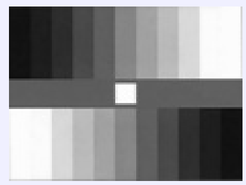
Imatest 36-patch



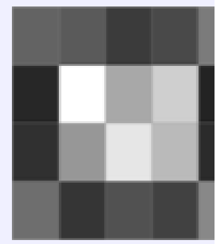
DR target



20-patch OECF targets



ITE Grayscale



SFRplus 20-patc stepchart

Photographing the chart

- ***Light.*** Be sure the light is even and free of glare. Lighting uniformity can be measured with an illuminance (Lux) meter. A variation of no more than ±5% is recommended. As little as possible should come from behind the camera— it can cause glare and flatten image tones. For reflective charts, at least two lamps with an incident angle of about 20-45° are recommended. Lighting recommendations can be found in Building a Low-Cost Test Lab. Be especially careful to avoid glare in the dark zones on the right of the Q-13/Q-14 charts; it can hard to avoid with wide angle lenses. The light should not emphasize the texture of the chart, which would cause erroneous noise measurements. If possible, the surroundings of the Step chart should be gray or black to minimize flare light (unless you are measuring flare light). An 18% gray surround is recommended for cameras with auto-exposure.
- ***Focus.*** The chart may be photographed ***slightly*** out of focus to minimize noise measurement errors due to texture in the patches. ***Slightly*** is emphasized— the boundaries between the patches must remain distinct.
- ***Distance.*** Distance is not critical. The width of the chart image should be no more than about

2/3 of the total image width to minimize vignetting (light falloff, which can be serious with wide-angle lenses). The noise analysis will be most accurate if each patch is 50 pixels wide, but fewer are adequate for low resolution cameras. Increasing the size improves the accuracy of the noise measurement up to a point, but there is little improvement for patches over 100 pixels wide. Tonal response can be measured with very small images, as long as the zones are distinctly visible.

- ***Photograph*** the chart.
- ***Save the image*** as a RAW file, TIFF, or high quality JPEG, then load it on your computer. Raw images can be converted using dcraw. If you are using another RAW converter, convert to JPEG (maximum quality), TIFF (without LZW compression), or PNG.

Running Stepchart

- ***Run*** Imatest.
- ***Click*** on the button in the Imatest main window.
- ***Open the input file*** using the dialog box. Imatest remembers the directory name of the last input file opened (for each module, individually).

Multiple file selection Several files can be selected in Imatest Master using standard Windows techniques (shift-click or control-click). Depending on your response to the multi-image dialog box you can combine (average) several files or run them sequentially (**batch mode**).

Combined (averaged) files are useful for measuring fixed-pattern noise (at least 8 identical images captured at low ISO speed are recommended). The combined file can be saved. Its name will be the same as the first selected file with _comb_n appended, where n is the number of files combined.

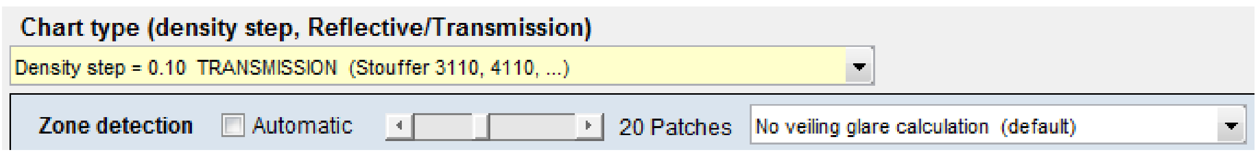
Temporal noise (noise representing the difference between images) can be measured by selecting 2 files of identical (but separately acquired) step chart images, then selecting **Read two files for measuring temporal noise** in the **Multi image file list** dialog box.

Batch mode allows several files to be analyzed in sequence. There are three requirements. The files should (1) be in the same folder, (2) have the same pixel size, and (3) be framed identically.

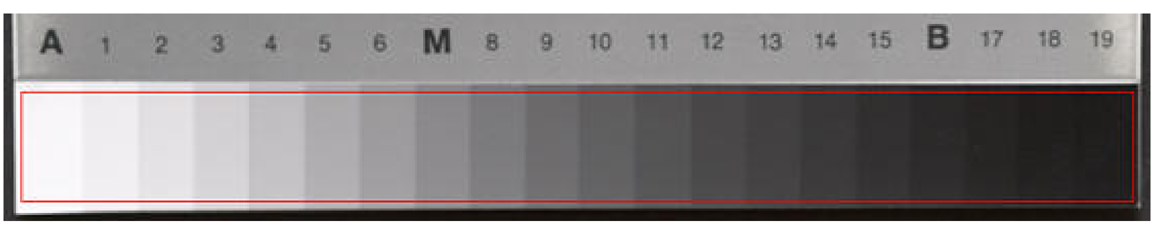
The input dialog box for the first run is the same as for standard non-batch runs. Additional runs use the same settings. Since no user input is required they can run extremely fast.

One caution: Imatest can slow dramatically on most computers when more than about twenty figures are open. For this reason we recommend checking the **Close figures after save** checkbox, and saving the results. This allows a large number of image files to be run in batch mode without danger of bogging down the computer.

- ***Crop the image***. For linear (single-row) charts, the Zone detection setting shown below determines how regions are selected, and hence how you crop. For multiple-row charts Automatic is implicitly unchecked. When Automatic is unchecked, small blue rectangles for each of the patches will be displayed in the Fine Adjustment window. For linear charts you need to enter the number of patches. When it is checked, the patches are located automatically: no rectangles are shown during the region selection. To measure veiling glare, make the appropriate selection in the dropdown menu on the right and (for the Q14) select 21 regions.



Typical crops (for Automatic zone detection are shown below, indicated by **red** rectangles. Click ***outside*** the image for no crop. The orientation does not need to be correct; Imatest will rotate the image to the correct orientation. To display the exposure error correctly (reflective targets only), select the entire chart, including any clipped highlight patches that may be present. If the aspect ratio (length:width) of the crop is less than 4:1, a dialog box for one of the additional (multiple-row or circular) charts will appear (for Imatest Master). If you plan to use manual Zone detection (selected in the Stepchart input dialog box, below), the selection can be approximate: a **Fine adjustment** window that opens after the **Stepchart settings** window will enable you to refine the crop.



Crop of a Kodak/Tiffen Q-13 chart

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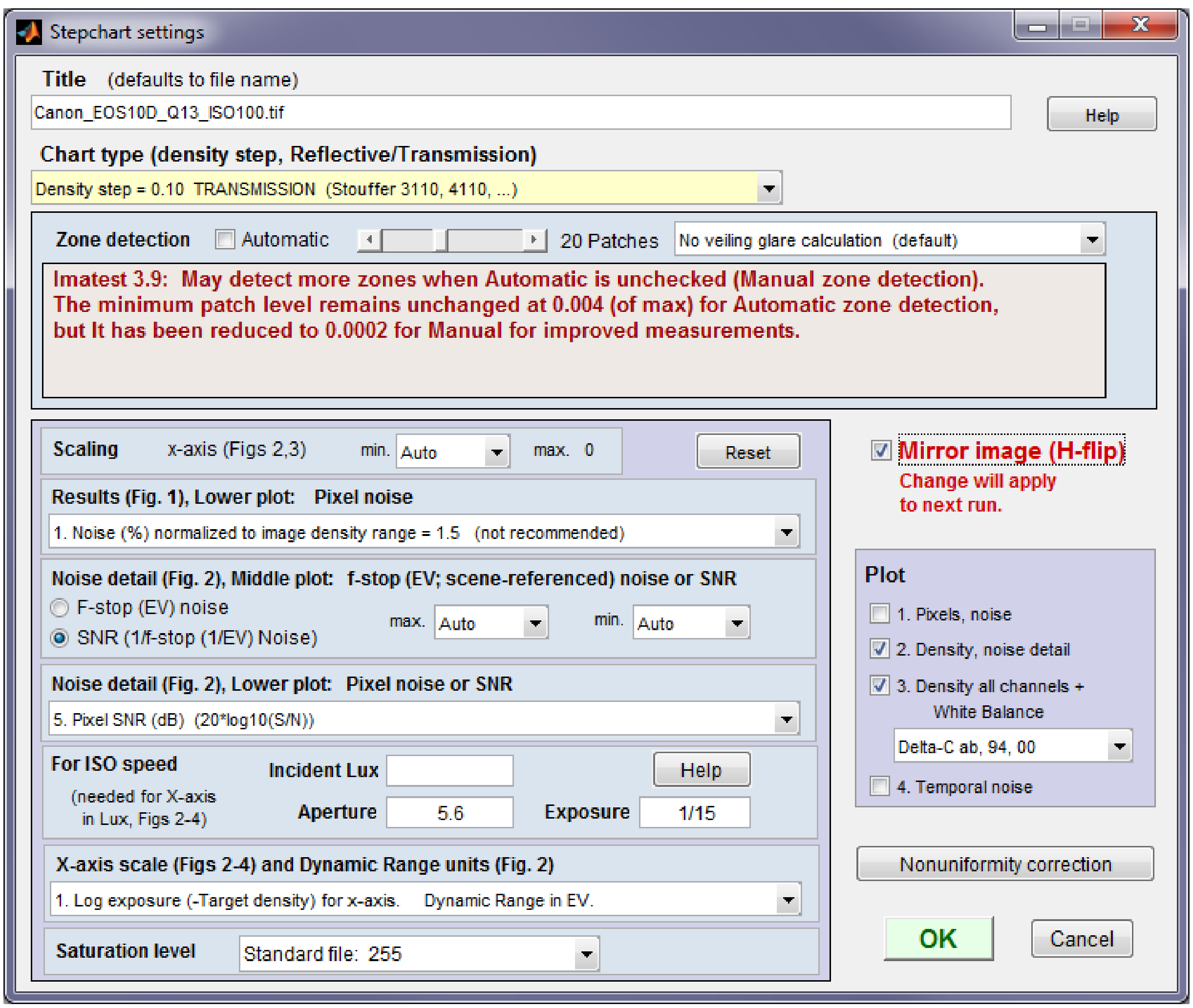
Crop of a Stouffer T4110 chart (better without the tilt).

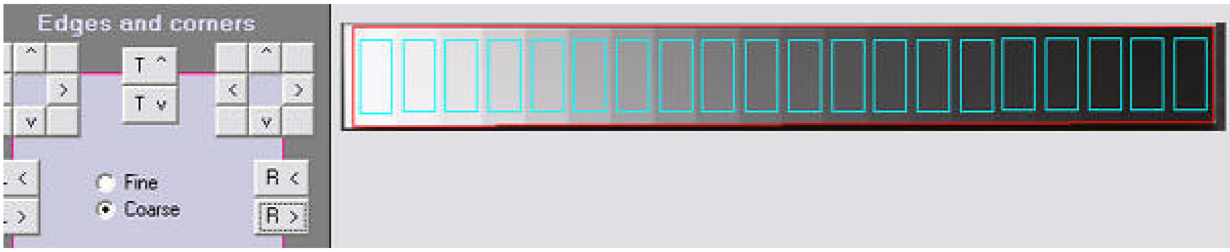
- ***Make any needed changes*** to the Stepchart input dialog box.

> *Chart type   A reflective target with density steps of 0.10 (the Q-13/Q-14) is selected by default. If you are using a transmission target, be sure to choose the correct target type. In Imatest Master you can enter a table of densities from an ASCII file (one density per line). **Automatic (default)** must be unchecked to enable [Veiling glare](#) measurements. (See [Dynamic range](#), below.) Click to continue.*



Stepchart settings window

Zone detection For linear (single-row) charts you can toggle between Automatic and Manual Zone detection with the **Automatic (default)** checkbox. If it is unchecked, a fixed number of patches (6-41) can be selected with the slider for Stepchart analysis, and a fine ROI adjustment box appears after is pressed. This option is useful when high noise in dark regions confuses the automatic ROI detection, or when veiling glare is to be calculated. (Zone detection can also be set from in the Imatest main window.)



Fine ROI selection (dialog box detail): Details here.

Scaling You can select the minimum value of the x-axis for figures 2 and 3. This setting defaults to Auto. Setting it manually allows several successive runs to be scaled identically, which can clarify comparisons between different cameras.

Results (Fig. 1), Lower plot: Pixel noise Three noise displays are available for the lower-left plot in first figure.

Noise (%) normalized to image density range = 1.5 (not recommended)	Values 0-1. (This setting is an approximation to scene-referenced noise, and is no longer recommended.)
Noise (%) normalized to 255 pixels (max of 100)	Values 0-1. Noise will be worse for higher contrast cameras (affected by the gamma encoding)
Noise in pixels (maximum of 255)	Values 0-255.

Noise Detail (Fig. 2), Middle plot: f-stop noise or SNR Two types of display are available for the middle-left plot of the second figure. The effects of gradual illumination nonuniformities have been removed from the results.

f-stop noise	Scene-referenced noise, based on f-stops (factors of 2 in exposure or illumination)
SNR (based on f-	Scene-references Signal-to-Noise Ratio, based on f-stops. Note that there are many ways of defining SNR. Most are image (or pixel)-referenced. Results are different from S/N in the lower plot (which is more standard).

stops)	

The scaling (minimum and maximum values) can be set in the dropdown menus to the right of the radio buttons. Most of the time these should be left at **Auto**. The values are inverted when the display is toggled between F-stop noise and SNR. For example, the minimum value of the x-axis in both Figures 2 and 3 can be set between -4 and -1.5.

Noise Detail (Fig. 2), Lower plot: Pixel noise or SNR Five types of display are available for the lower-left plot of the second figure. The first three are the same as the lower plot of Fig. 1. The effects of gradual illumination nonuniformities have been removed from the noise results. All displays are derived from Noise in pixels (the third selection below). In the notation below N_i is RMS noise and S_i is signal (pixel) level for patch i.

Noise (%) normalized to image density range = 1.5	100% * (Noise in pixels) divided by (the difference in pixel levels between light and dark patches that have a density difference of 1.5). This difference is close to the 1.45 White-Black difference in the ColorChecker. Useful because it references the noise to the scene: noise performance is not affected by camera contrast.
Noise (%) normalized to 255 pixels (max of 100)	100% * (Noise in pixels) / 255 = N_i/2.55. Values 0-100. This noise measurement will be worse for higher contrast cameras. (It is affected by the gamma encoding.)
Noise in pixels (maximum of 255)	Noise in pixels (N_i). Values 0-255.
Pixel S/N (Signal in patch/RMS noise) dimensionless	Noise in pixels (N_i). Values 0-255.
Pixel SNR (dB) (20*log10(S/N))	20 Log10(signal/noise) for each patch (where signal = pixel level). Units of dB (decibels). Doubling S/N increased dB measurement by 6.02.
	For this selection, SNR_BW is also displayed. SNR_BW is an average SNR based on White-Black patches (density difference = 1.5, close to the W-B difference in the ColorChecker).

	SNR_BW = 20 $\log_{10}((S_{WHITE}-S_{BLACK})/N_{mid})$, where N_{mid} is the noise in a middle gray patch (closest to nominal chart density = 0.7).

The Plot box on the right allows any of the figures to be turned off or on. Two files must be read in to obtain the Temporal noise plot.

Incident lux (for ISO Sensitivity calculations) When a positive value of incident light level (not blank or zero) in lux is entered in this box, ISO sensitivity is calculated and displayed in the Stepchart noise detail figure. More details are on the ISO Sensitivity and Exposure Index page. Also required if Lux is selected for the X-axis scale (figs 2-4).

Aperture and **Exposure** must be entered for the x-axis of Figures 2-4 to be displayed in units of Lux. They are normally obtained from the EXIF data, but they may be entered manually if needed.

X-axis scale (Figs 2-4) and Dynamic Range units (Fig. 2) Several choices are available, including Density units, EV, Lux (if incident Lux, Aperture, and Exposure are available) and dB (decibels: 20*density units). DR units may or may not be the same as the scale units. The old default was scale in Log exposure and Dynamic Range in EV (the first selection). Note: 1 Density unit = 3.322 EV = 20 dB; 1 EV = 6.02 dB. Selections:

> *Log exposure (-target density) for x-axis. Dynamic Range in EV.*
> *Lux (incident Lux / 10^density) for x-axis. Dynamic Range in EV.*
> *Exposure in dB (-20*Target density) for x-axis. Dynamic range in dB.*
> *Log exposure for x-axis. Dynamic Range in Density units.*
> *F-stops (EV) for x-axis. Dynamic Range in EV (F-stops).*

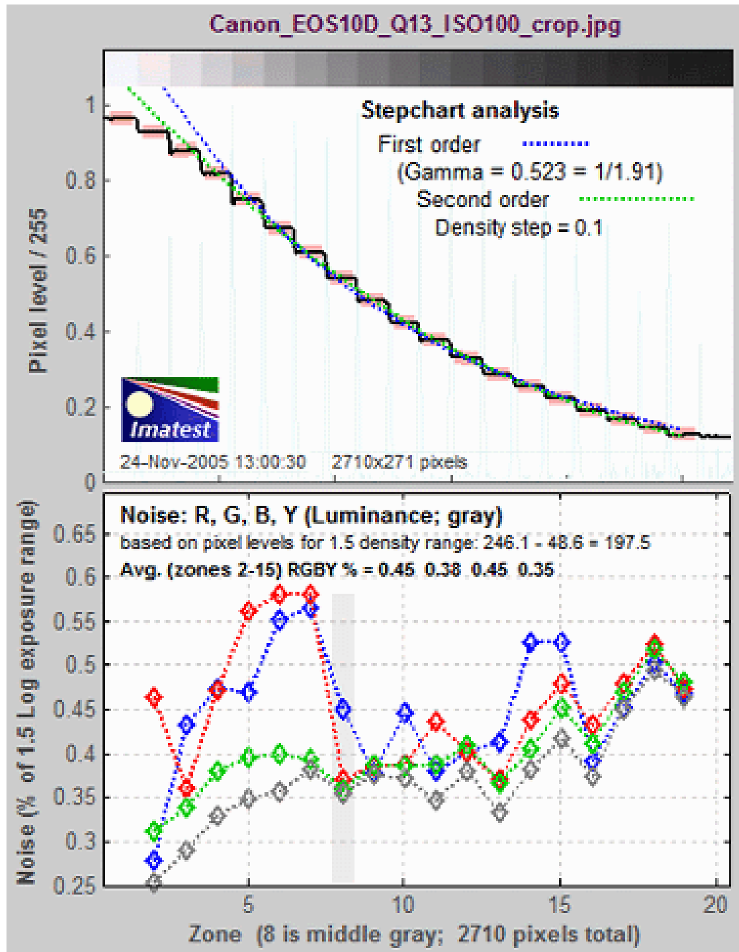
> ***Saturation level*** *The maximum pixel level for Dynamic range measurements. Selections:*
>
> > *Standard file: 255*
> > *ITU-R REc. 501 (BT.601): 235*
> > *Maximum detected patch level*

Output

The example was photographed with the Canon EOS-10D at ISO 100 and converted from RAW format using Capture One with default settings (no curves applied).

The results include tonal response and noise. Colorcheck produces a similar result, but with less tonal detail. Three figures are produced for color images; two for B&W.

First Figure: Stepchart results



The upper plot shows the average density of the grayscale patches (**black** curve) and first and second order density fits (dashed **blue** and **green** curves). The horizontal axis is the distance along the target. A portion of the patches themselves are shown just above the plot. The equations for the density fits are given in the Algorithm section, below. The second order fit closely matches the patches. The light cyan spikes are the differentiated and smoothed steps used to find the boundaries between zones.

The lower plot shows the RMS noise for each patch: R, G, B, and Y (luminance). In this plot it is expressed as the percentage of the pixel level difference corresponding to a target density range of 1.5: the same as the white – black patches on the GretagMacbeth ColorChecker. For this camera, the pixel difference is 197.5. For this display, noise measured in pixels can be calculated by multiplying the percentage noise by 197.5.

Noise can also be normalized to 255 pixels or expressed in pixels (maximum of 255). Options are described above.

The high levels of Red and Blue noise in zones 3-6 may be due to imperfections in the target which are completely swamped by the noise at ISO 1600, shown below. Noise is largest in the dark areas because of gamma encoding: In the conversion from the sensor’s linear output to the color space (sRGB, here) intended for viewing at gamma = 2.2, the dark areas are amplified more than the light areas and the noise is boosted as well.

See Noise in photographic images for a detailed explanation of noise: its appearance and measurement.

Second figure: Stepchart noise detail

The second figure (Noise detail) contains some of the most important results:

- the tonal response curve (displayed on a log scale, similar to film response curves),
- noise expressed as either a fraction of an f-stop (or EV or zone), or f-stop Signal-to-Noise Ratio (SNR = S/N = 1/f-stop noise),
- noise or SNR (signal-to-noise ratio), based on pixel levels, expressed in one of several ways, and
- dynamic range (for transmission step charts).

The horizontal axis for the three plots on the left is Log Exposure, which equals (minus) the nominal target density (0.05 – 1.95 for the Q-13 chart). This axis is reversed from Figure 1.

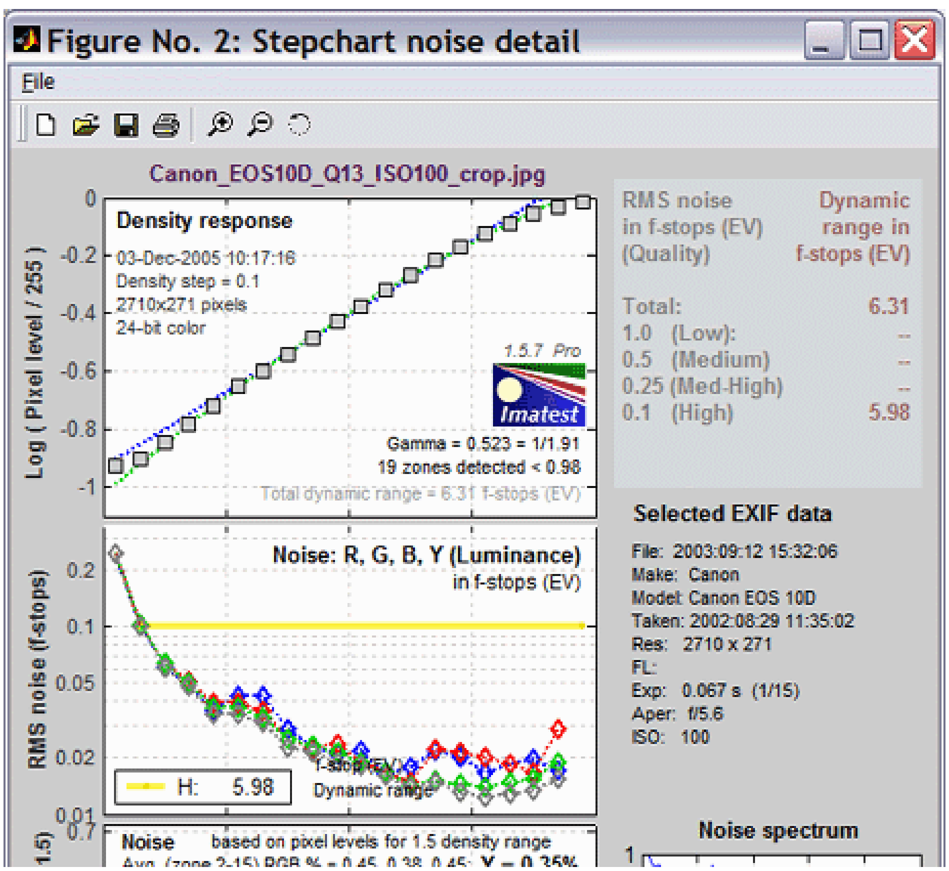
The upper left plot shows the density (tonal) response (gray squares), as well as the first and second order fits (dashed **blue** and **green** lines). It resembles a traditional film density response curve. Dynamic range is grayed out because the reflective Q-13 target has too small a density range to measure a camera's total dynamic range. See Dynamic range, below. This curve is closely related to the Opto-Electronic Conversion Function (OECF), which is a linear curve of exposure vs. pixel level.

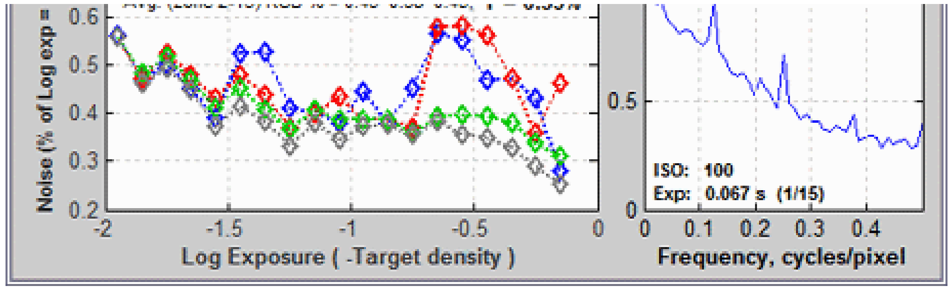
The upper right box contains dynamic range results: total dynamic range and range for several quality levels, based on luminance (Y) noise. Details below. It is shown in gray when a reflective target is selected.

Second figure: noise detail

The x-axis (log exposure) is reversed in direction from Figure 1, which shows the chart zone (from light to dark)

The f-stop (scene-referenced) Signal-to-Noise Ratio (SNR_f = 1/f-stop noise) can be displayed in the middle-left figure in place of RMS noise (in f-stops)



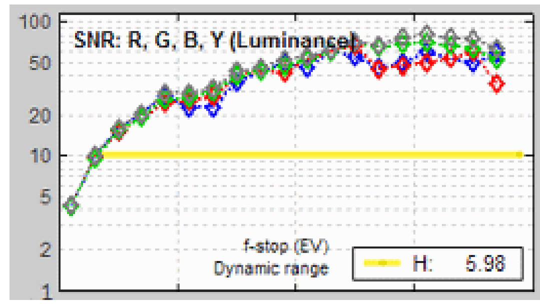


The middle left plot shows [noise in f-stops (or EV)](), i.e., noise scaled to (divided by) the difference in pixel levels between f-stops, which decreases as brightness decreases. **Noise measured this way is the *inverse* of the signal-to-noise ratio (N/S), which we will call SNR_f**(to distinguish it from other SNR measurements). The darkest levels have the highest noise. This measurement corresponds to the workings of the eye and has important consequences for the calculation of practical dynamic range. The vertical axis is logarithmic to display low noise levels clearly. Dynamic range information is displayed when the range for a specific quality level (defined by maximum f-stop noise or minimum S/N) is within the range of the plot. It is omitted if noise or SNR_f is better than the specified level for all patches: it is not reported for quality levels lower than H in the above plot because the noise level never reaches 0.25 (the M-H level).

The bottom left plot shows pixel noise or SNR scaled in one of [several different ways](). The above illustration shows pixel noise normalized to the difference in levels between lightest patch and the patch corresponding to a density of 1.5—close to the 1.45 density range as the GretagMacbeth [Colorchecker](). (The normalization is discussed in Fig. 1, above.)

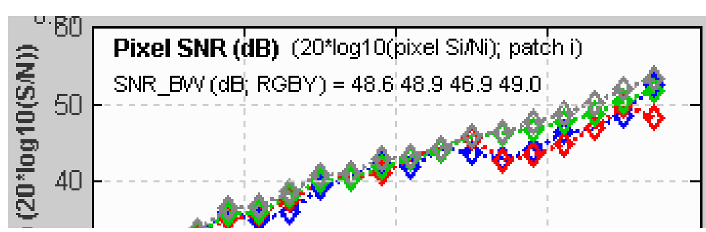
EXIF data is shown in the middle right region.

The lower right plot shows the noise spectrum. Digital camera images with excessive noise reduction will have an unusually rapid falloff of the noise spectrum.

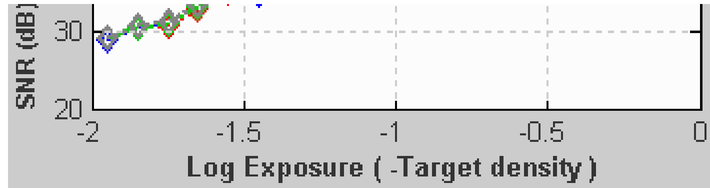


The bottom left plot has several display options, listed [above](). **Pixel SNR (dB)** is shown on the left.

SNR (dB) = 20 $\log_{10}(S_i/N_i)$, where S_i is the signal

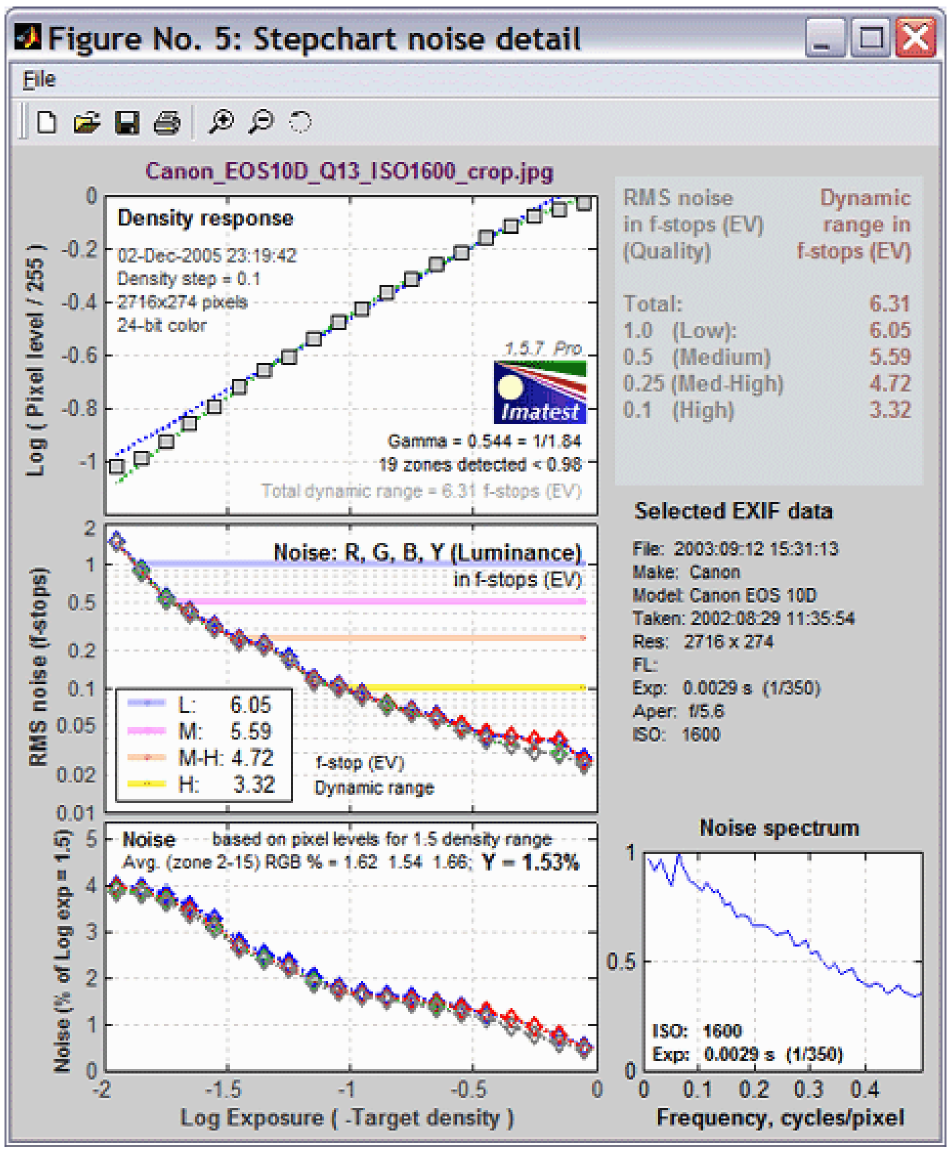


(mean pixel level) of patch i and N_i is the noise (standard deviation of the pixel level, with slow variations removed) of patch i.



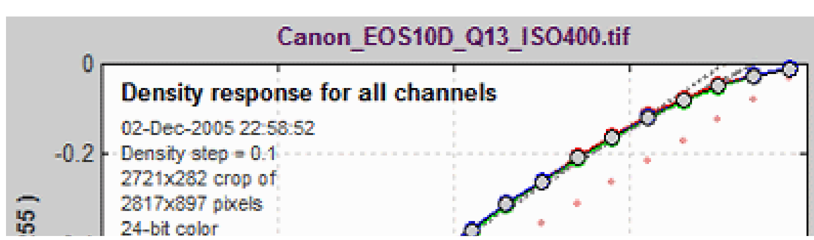
SNR_BW is an average SNR based on white-black patches (density difference = 1.5)
SNR_BW = 20 $\log_{10}((S_{WHITE}-S_{BLACK})/N_{mid})$, where N_{mid} is the noise in a middle level patch (closest to nominal chart density = 0.7).

Here are the results for ISO 1600. Tonal response is similar to ISO 100, but the noise is greatly increased— enough to swamp out any imperfections in the target. The noise is highly visible. It wouldn't be suitable for portraits and other high quality work, but it would be acceptable when a grainy "Tri-X" or "available light" look is desired. [Neat image]() can do an excellent job of reducing it. The middle-left plot displays dynamic range for several quality levels, specified by the maximum noise within the range. The dynamic range for low quality (L; blue) has a maximum noise of 1 f-stop; the dynamic range for high quality (H; yellow) has a maximum noise of 0.1 f-stop.

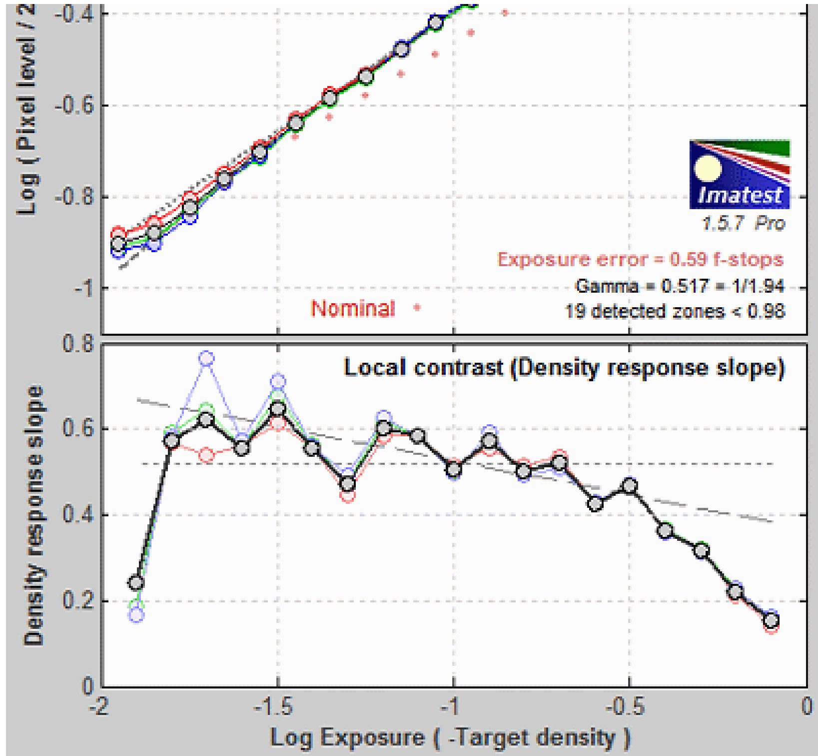


Third Figure: Density and contrast response

The upper plot shows the [density]() response (small circles) of the luminance (Y), red, green, and blue channels, as well as the first and second order fits (dotted and dashed **gray** lines). It



resembles a set of traditional film density response curves. The R, G, and B curves are displayed in Imatest Master only.



For reflection step charts only, the nominal exposure is shown as pink dots (•), and the exposure error in f-stops is displayed. Exposure error is less critical than for ColorCheck, where it strongly affects the a*b* color values: that's why it isn't displayed in the other figures. The equation for nominal exposure is similar to equation that calculates the grayscale pixel levels of the ColorChecker:

pixel level = 255 * $(10^{-\text{density}}/1.01)^{(1/2.2)}$

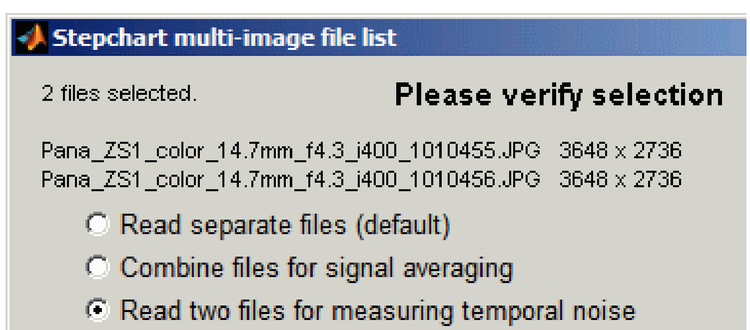
The lower plot shows the slope of the density curve, which can also be regarded as the local contrast or gamma. This curve is the derivative of the density, *d*(Density) / *d*(Log Exposure).

Lens flare (stray light that bounces between lens elements and off the barrel) can be measured by photographing a reflective step chart (a Q-13 or Q-14) against dark and white backgrounds. When flare light is present (white background) it will reduce the slope of the density response in dark regions of the step chart (on the left of the plot). This curve makes it easy to measure the decrease in the slope.

The fourth figure: Temporal noise

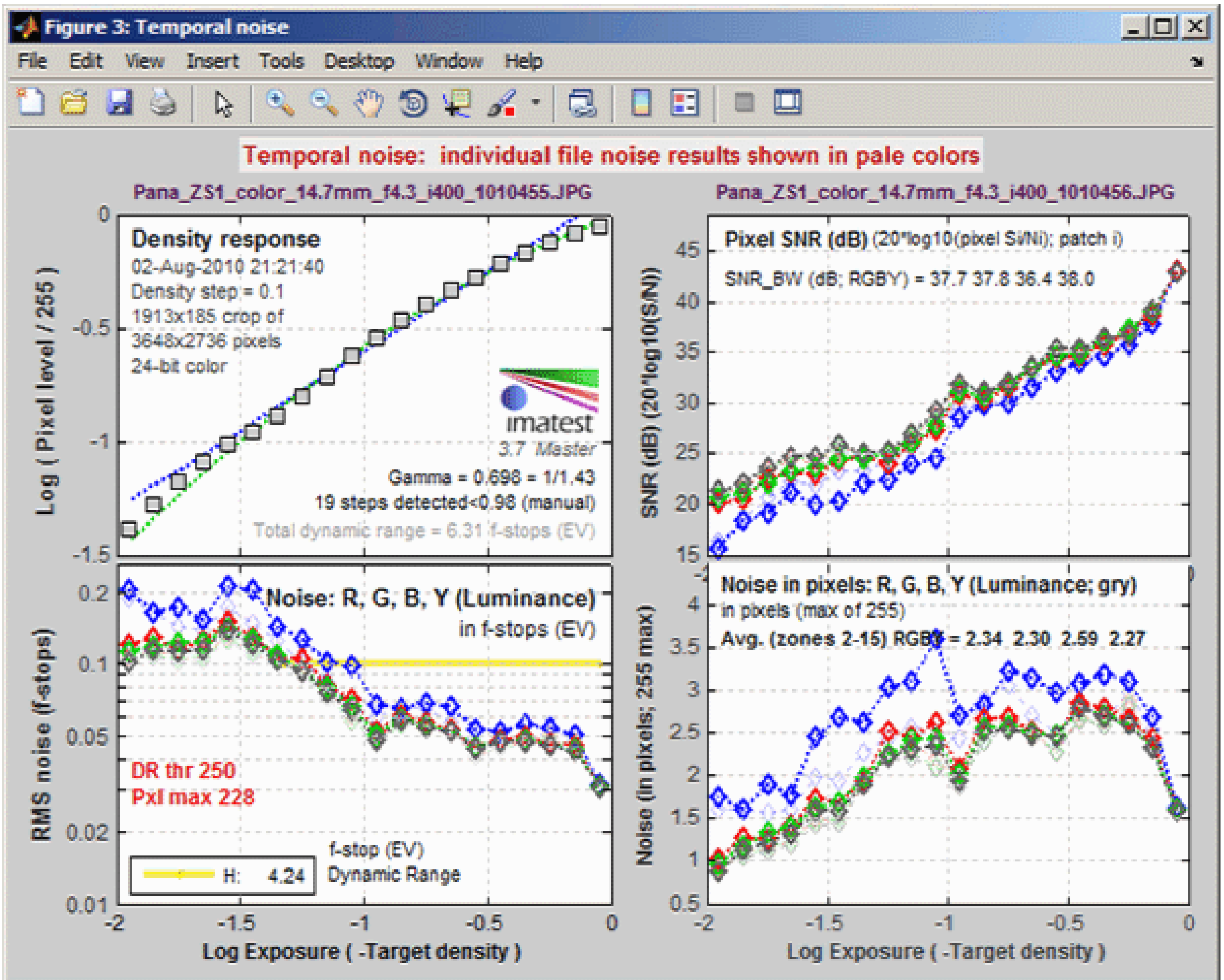
Temporal (time-varying) noise is the random difference between otherwise identical images. It is measured as the noise (standard deviation) of the difference two identical test chart images divided by the square root of 2 (1.414).

> $N_{temporal} = Noise(Image_1 - Image_2) / 1.414$



Subtracting two images removes fixed pattern noise. The square root of 2 is needed because noise powers add, even though image pixels are subtracted. Dividing by the square root of 2 scales temporal noise to be the same as noise measured in an individual image.

To measure temporal noise, select two images for analysis. In the dialog box shown on the right, select **Read two files for measuring temporal noise**. The analysis proceeds normally (for the first file), but a fourth figure, displayed if **4. Temporal noise** is checked in the input dialog box **Plot** area, contains the temporal noise analysis. This figure is intended to be self-contained, hence repeats some features of previous plots.



Temporal noise display

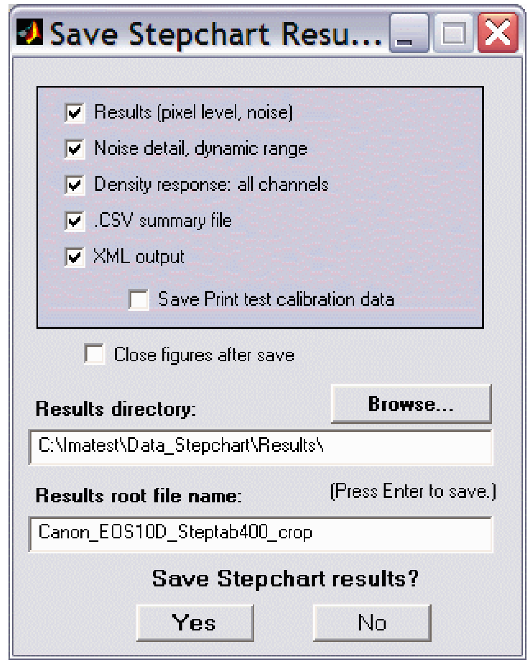
- The upper-left plot displays the density response, similar to the upper-left plot of Figure 2.
- The lower-left plot (RMS noise (f-stops)) displays scene-referenced noise or SNR using the same scale as the middle-left plot of Figure 2. In these plots, noise (or SNR) for a single image is shown as a pale curve.
- The upper-right plot (Pixel SNR (dB)) displays noise or SNR using the same scale as the lower-left plot of Figure 2.
- The lower-right plot (Noise in pixels) displays pixel noise scaled the same as the lower plot of Figure 1 (for the vertical axis; the x-axis is different).

Saving the results

When the Stepchart calculations are complete, the **Save Stepchart Results?** dialog box appears. It allows you to select figures to save and choose where to save them. The default is subdirectory Results in the data file directory. You can change to another existing directory, but new results directories must be created outside of Imatest— using a utility such as Windows Explorer. (This is a limitation of this version of Matlab.) The selections are saved between runs. You can examine the output figures before you check or uncheck the boxes.

Figures, CSV, and XML data are saved in files whose names consist of a root file name with a suffix and extension. The root file name defaults to the image file name, but can be changed using the **Results root file name** box. Be sure to press enter.

Checking **Close figures after save** is recommended for preventing a buildup of figures (which slows down most systems) in batch runs. After you click on or , the Imatest main window reappears.



Save dialog box

Dynamic range of cameras and scanners

The Dynamic Range module calculates dynamic range from the CSV output of several differently-exposed stepchart images (usually reflective, but transmissive may also be used). Reflective images are often easier to work with than transmissive step charts.

Dynamic Range (DR) is the range of tones over which a camera responds. It is usually measured in f-stops, or equivalently, zones or EV (factors of two). (It can also be measured in density units, where one density unit = 3.322 f-stops.) It can be specified in two ways:

The most straightforward way to measure a camera's (or scanner's) dynamic range is with a transmission step chart illuminated from behind by a lightbox. Reflection step charts such as the Kodak/Tiffen Q-13 or Q-14 are inadequate because their density range of around 1.9 is equivalent to 1.9 * 3.32 = 6.3 f-stops, well below that of digital cameras (though they can be used with multiple exposures and the Dynamic Range postprocessor for Stepchart).

Transmission step chart

The table below lists several transmission step charts, all of which have a density range of at least 3 (10 f-stops). Kodak Photographic Step Tablets can be purchased calibrated or uncalibrated. Uncalibrated is usually sufficient. The Stouffer charts are attractively priced.

Product	Steps	Density increment	Dmax	Size
Imatest 36-patch Dynamic Range test chart	36	~0.10 (1/3 f-stop); Reference file included	3.4	8×10″
Kodak Photographic Step Tablet No. 2 or 3	21	0.15 (1/2 f-stop) Linear pattern	3.05	1x5.5″ (#2) larger (#3)
Stouffer Transmission Step Wedge T2115	21	0.15 (1/2 f-stop) Linear pattern	3.05	0.5x5″
Stouffer Transmission Step Wedge T3110	31	0.10 (1/3 f-stop) Linear pattern	3.05	3/4x8″
Stouffer Transmission Step Wedge T4110	41	0.10 (1/3 f-stop) Linear pattern	4.05	1x9″
Danes-Picta TS28D (on their Digital Imaging page)	28	0.15 (1/2 f-stop) Linear pattern	4.2	10x230 mm (0.4x9″)
DSC Labs 72-dB 13-step Greyscale	13	0.30 (1 f-stop) Linear pattern	3.7	(large)
Esser Test Charts TE 241	20	from table; large in dark regions Circular pattern of squares	4.1	(large)

The Stouffer T4110 (13.3 f-stops range), Danes-Picta TS28D (13.6 f-stops range), or TE 241 (13.6 f-stops range) are often used for Digital SLRs, which can have dynamic ranges over 10 f-stops. Charts with Dmax = 3.05 = 10 f-stops are adequate for compact digital cameras with small pixel sizes (≤2 microns).

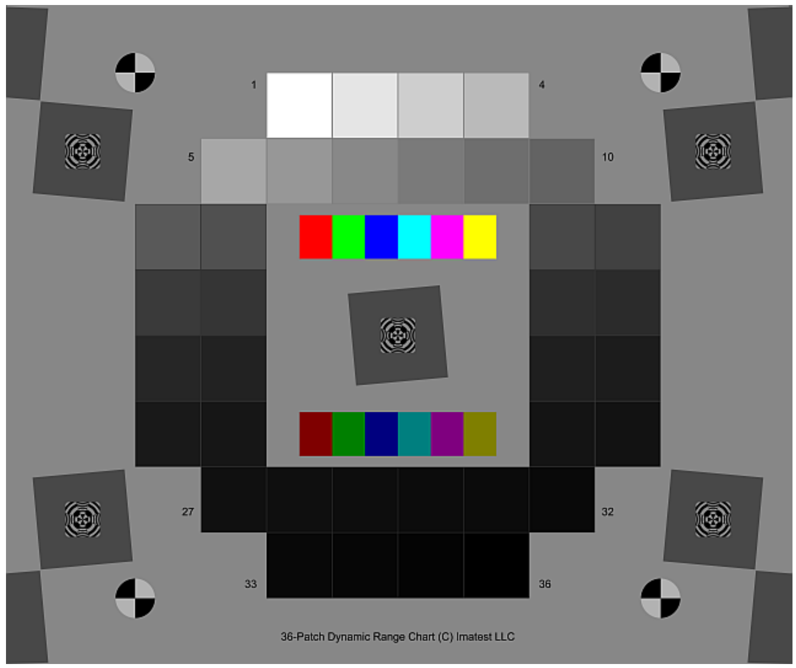
Stouffer T4110, inexpensive with Dmax = 4.0, but difficult to frame, difficult to expose properly with auto-exposure cameras, and susceptible to light falloff due to its linear arrangement.

The Imatest 36-patch Dynamic Range test chart, which has density steps of approximately 0.1, ranging from base density to base+3.4 (an 11.3 f-stop range), is strongly recommended. A nearly circular patch arrangement ensures that vignetting has minimal effect on results. A CSV reference file with actual densities is supplied. the chart has an active area of 7.75×9.25 inches on 8×10 inch film.

It also contains slanted edges in the center and corners with 4:1 contrast for measuring MTF. The edges have an MTF50 >= 16 cycles/mm, which is about 3 times better than the best inkjet charts. Registration marks make the regions easy to select. A neutral gray background helps ensure that the chart will be well-exposed in auto exposure cameras (compared to charts with black backgrounds, which are sometimes strongly overexposed).

It can be used with the Dynamic Range postprocessor if several manual exposures are available. Dmax = 3.4 is sufficient for camera phones and digital cameras with small pixel sizes, but high-end DSLRs generally have higher dynamic ranges (and also manual exposure), which makes them well suited for Dynamic Range.

Imatest 36-patch Dynamic Range chart on 8×10 film



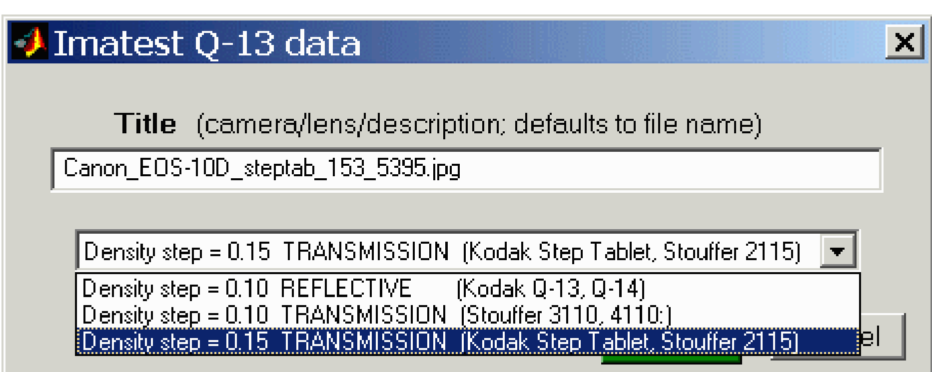
This chart is produced with a high-precision LVT film recording process for the best possible density range, low noise, and fine detail.

Lightbox

You'll need a lightbox that can evenly illuminate the transmission step chart. 8x10 inches is large enough. Avoid thin or "mini" models, which may not have even enough illumination. The Logan Tru-View 810/920 is inexpensive and quite adequate. Light boxes are widely available, though they may be hard to find on dealers' websites. On Adorama, click on Filing/Storage | Mounting & Viewing Equipment | Lightboxes & Loupes. On B&H, click on Projection & Viewing | General Presentation Equipment | Lightboxes, Loupes & Slide Viewers | Lightboxes & Slide Viewers | **Lightboxes & Light Tables. T** he Kyoritsu calibrated light sources, especially the pattern light boxes, available in the North America from C.R.I.S., are worth checking out.

To measure dynamic range,

- Prepare a fixture for mounting the the step chart. It should be large enough to keep stray light out of the camera. **Stray light can reduce the measured dynamic range; it should be avoided at all costs.** I made a fixture out of scrap mat board held together with Scotch magic tape and Elmer's glue. (That old mainstay, duct tape, wasn't quite right for the job.)
- Place the fixture and step chart on top of the lightbox— or any other source of uniform diffuse light.
- Photograph the chart in a darkened room. ***No*** stray light should reach the front of the target; it will distort the results. The surroundings of the chart should be kept as dark as possible to minimize flare light. An example is shown above. The density difference between the darker zones is not very visible, but it shows up clearly in the measurements. I used a Kodak step wedge (density steps of 0.15) that I purchased in 1969!
- Use your camera's histogram to determine the minimum exposure that saturates the lightest region of the chart. Overexposure (or underexposure) reduces the number of useful zones. The lightest region should have a relative pixel level of at least 0.98 (pixel level 250 or 255); otherwise the full dynamic range of the camera will not be detected. If the lightest zone is below this level, and a transmission chart is selected, a Dynamic range warning is issued.



-

For flatbed scanners with transparency units (TPUs, i.e., light sources for transparencies), you can simply lay the step chart down on the glass. Stray light shouldn't be an issue, though there is no harm in keeping it to a minimum. 35mm film scanners may be difficult to test since most can only scan 36mm segments. (Most transmission targets are longer.) For scanners specified as having Dmax greater than 3, the charts of choice are the [Stouffer Transmission Step Wedge T4110] or [Danes-Picta TS28D], which are too large to be tested easily with 35mm film scanners.

- Follow the remainder of instructions in [Photographing the chart and running Stepchart, above]. Be sure to select the correct chart type from the Stepchart input dialog box (right).

The Imatest algorithm for finding dynamic range is remarkably accurate. Imatest detects chart zones using the smallest density step that results in uniformly spaced detected zones (see [Algorithm]). For smaller steps, noise can be mistaken for zone boundaries. For larger steps, fewer zones are detected.

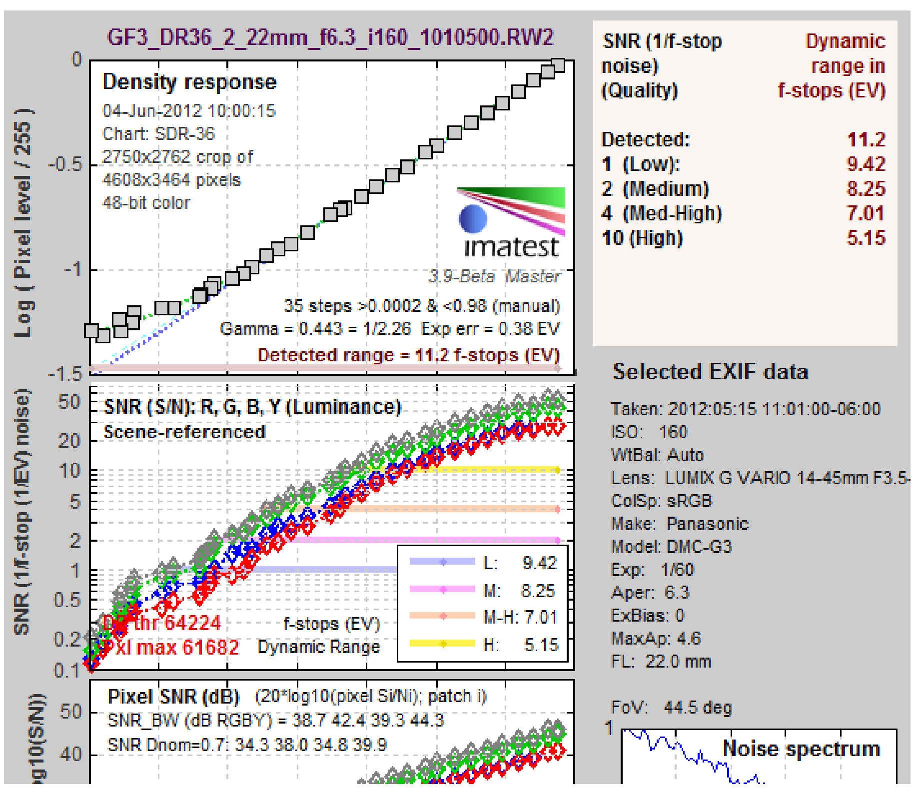
The dynamic range is the difference in density between the zone where the pixel level is 98% of its maximum value (250 for 24-bit color, where the maximum is 255), estimated by interpolation, and the darkest zone that meets the measurement criterion. The repeatability of this measurement is better than 1/4 f-stop.

Here is a result for the Panasonic G3 (a Micro Four-Thirds camera with 3.75 micron pixel pitch) at ISO 160, converted from raw using [dcraw] with the following settings: **Demosaicing:** Normal RAW conversion (demosaiced), **Output gamma:** 2.2, **White Balance:** Camera, **Output color space:** 48-bit, **Quality:** Default.

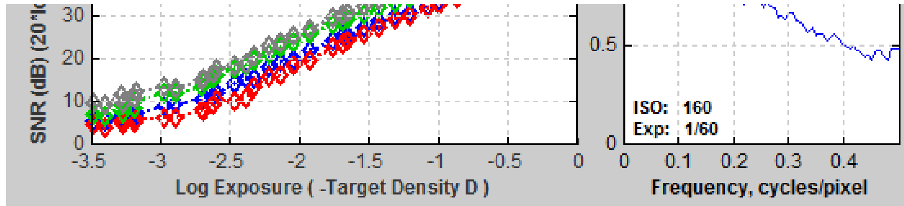
Panasonic G3, ISO 160, Converted with dcraw.

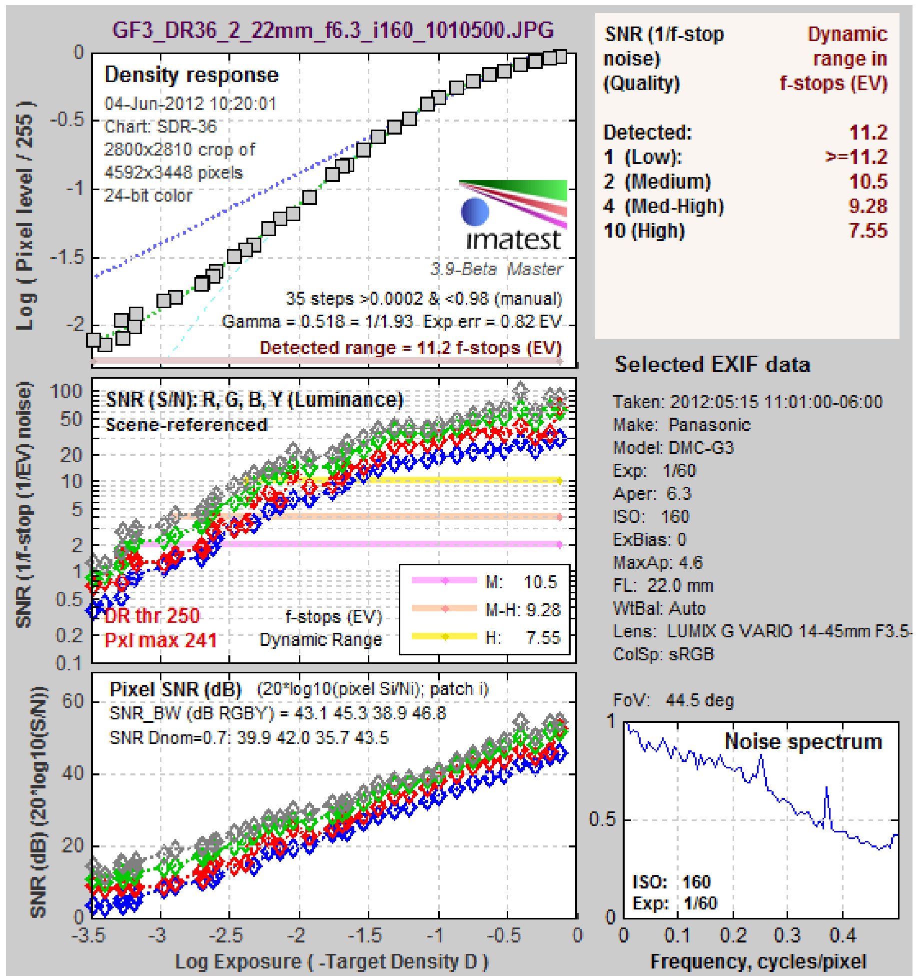
The detected patches have a density range of 11.2 f-stops (this should ***not*** be interpreted as the camera's Dynamic Range). The Dynamic Range at low quality level (scene-referenced SNR = 1) is 9.42 f-stops, decreasing to 5.15 f-stops at high quality level (SNR = 10). These results are unchanged for 24-bit raw conversion.

The shape of the response curve is a strong function of the conversion software settings. The



plot below is for the same exposure, saved as a JPEG file inside the camera. Note that the transfer curve is quite different: it has a “shoulder” in the highlights, which improves pictorial quality by reducing the tendency of highlights to saturate (“burn out”). Dynamic Range is improved due to software noise reduction (absent in the dcraw conversion).





Panasonic G3, ISO 160, in-cemera JPEG. Note the “shoulder.”
Dynamic range is improved due to software noise reduction.

Units for displaying Dynamic Range can be set in the **X-axis scale (Figs 2-4) and Dynamic Range units (Fig. 2)** dropdown menu. To convert dynamic range from f-stops into decibels (dB), the measurement normally given on sensor data sheets, multiply the dynamic range in f-stops by 6.02 ($20 \log_{10}(2)$). The dynamic range for low quality (f-stop noise = 1; SNR = 1) corresponds most closely to the number on the data sheets. Measured dynamic range is normally somewhat lower than specified dynamic range because of lens flare and other factors.

Summary .CSV and XML files

An optional .CSV (comma-separated variable) output file contains results for Stepchart. Its name is [*root name*]_summary.csv. An example is Canon_EOS10D_Q13_ISO400_crop_summary.csv.

The format is as follows:

Module	SFR, SFR multi-ROI, Colorcheck, or Stepchart.

File	File name (title).
Run date	mm/dd/yyyy hh:mm of run.
(blank line)	
Tables	Tables are separated by blank lines.
	The first table contains measured and ideal pixel levels and densities.
	The second table contains density = -log(exposure) and Y, R, G, and B densities (-log(pixel level/255)), assuming 8 bits/pixel.
	The third table contains the density differences (slopes) between the Y, R, G, and B patches.
	The fourth table contains two sets of Y, R, G, and B noise measurements for the the patches in the bottom two rows, described above. – Noise (%) normalized to image density range = 1.5 – f-stop noise
	The fifth table contains S/N and SNR (dB) for the Y, R, G, and B channels, described above.
(blank line)	
Additional data	The first entry is the name of the data; the second (and additional) entries contain the value. Names are generally self-explanatory (similar to the figures).
(blank line)	
EXIF data	Displayed if available. **EXIF data** is image file metadata that contains important camera, lens, and exposure settings. By default, Imatest uses a small program, jhead.exe, which works only with JPEG files, to read EXIF data. To read detailed EXIF data from all image file formats, we recommend downloading, installing, and selecting Phil Harvey's ExifTool, as described here.

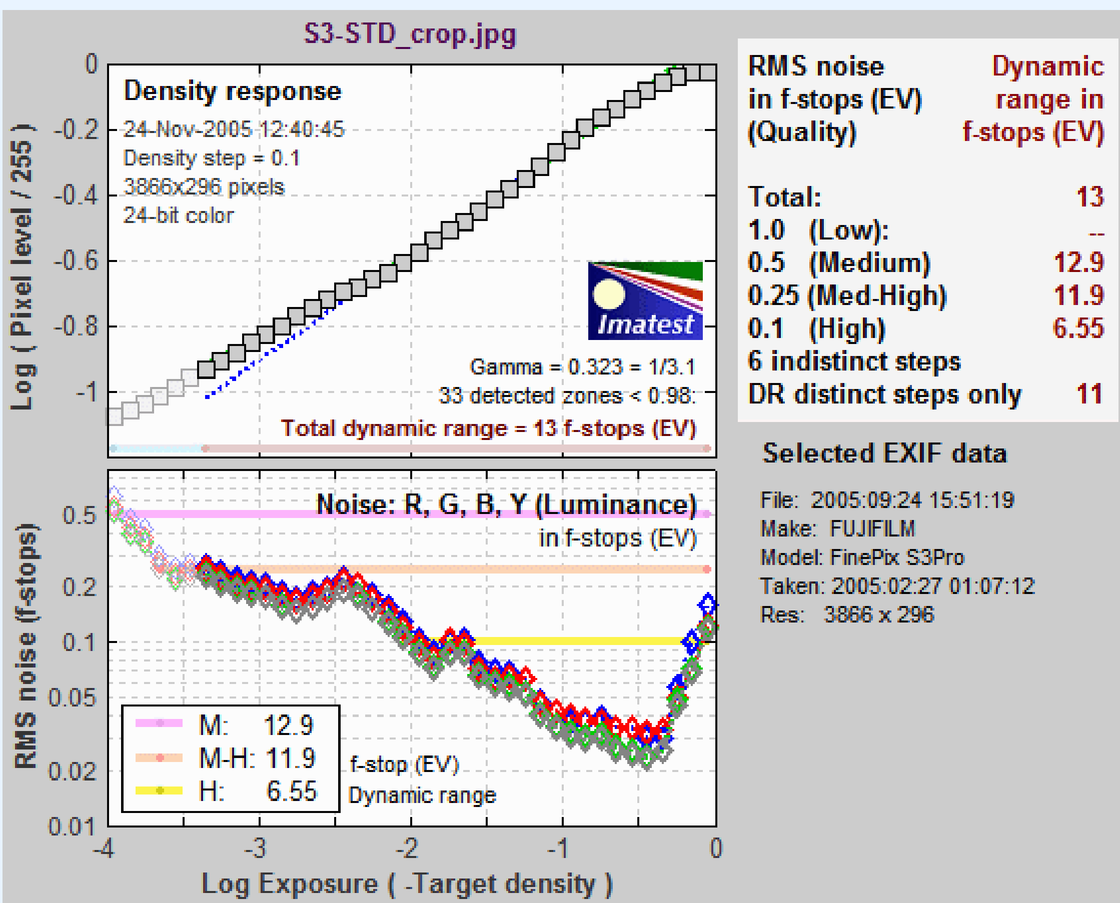
This format is similar for all modules. Data is largely self-explanatory. Enhancements to .CSV files will be listed in the Change Log.

The optional XML output file contains results similar to the .CSV file. Its contents are largely self-explanatory. It is stored in [*root name*].xml. XML output will be used for extensions to Imatest, such as databases, to be written by Imatest and third parties. Contact us if you have questions or suggestions.

Indistinct zones in the Stouffer T4110 test chart

The Stouffer T4110 test chart is particularly valuable because its maximum density of 4.0 (corresponding to 13 f-stops or a 10,000:1 brightness range) makes it uniquely suitable for measuring the dynamic range of digital SLRs. But the original Stepchart algorithm, which depended on sharp boundaries between zones, sometimes failed to detect zones in the darkest regions. This problem first appeared in dark zones (D > 3.3) of images taken by Max Penson of D-spot (a leading Hebrew language digital photography website) with the Fuji S2 Pro and S3 Pro (which claims an extended dynamic range).

To correct this problem, Stepchart now ***extrapolates***— infers zones in dark areas within the crop, as long as the density in each zone is less than that of the previous zone by at least 0.2 times the average density difference between detected zones. These “indistinct” zones are indicated by light graphics on the left of the plots below. For the Fuji S3 Pro with a “Standard” setting, there are 6 “indistinct” zones, representing 2 additional f-stops, for a total dynamic range of 13 (***huge***; better than negative film). These numbers are real, and starting with Imatest 1.5.5 (November 2005) they are included in the definition of Total Dynamic Range. The number of indistinct steps (and DR based on distinct steps only) is still displayed, but its significance has been downplayed.



Algorithm

- (*Automatic zone detection only*) Locate the distinct zones in the image. This is done by taking the derivative of the pixel level averaged vertically, then smoothing it, illustrated by the light cyan spikes in the upper left plots in the above figures. A boundary between zones is detected if this function goes above a threshold. The threshold is adjusted to the lowest value that gives evenly spaced, regular intervals. This is an ***optimum*** detection algorithm: a lower threshold detects false boundaries (i.e., noise), while a higher threshold can miss valid zones.
- Find regions of interest (ROIs) for each zone, which comprises the central 2/3 of the zone.
- Calculate statistics for the ROIs, including the average pixel level and a second-order polynomial fit to the pixel levels inside the ROIs— this fit is subtracted from the pixel levels for calculating noise. It removes the effects of nonuniform illumination.
- Calculate the noise in each ROI. The noise is the standard deviation of the pixel level, after the second-order polynomial has been subtracted. Noise display options are given above. The noise spectrum is calculated for the seventh zone (middle gray) by lining up the pixels (with the second-order polynomial subtracted) into a 1D array and taking the Fourier transform (FFT). The independent axis is displayed in Cycles/pixel, where 0.5 is the Nyquist frequency.
- Using the average pixel values of the regions whose value is 10% below the maximum and above theminum, the average pixel response is fit to a mathematical function (actually, two functions). This requires some explanation.
- Using the average pixel values of grayscale zones for densities between approximately 0.1 and 0.9 (omitting the extremes near white and black), the average pixel response is fit to two mathematical functions to find gamma (contrast: first-order equation) and also a second order qeuation. This requires some explanation.

A simplified (first-order) equation for a capture device (camera or scanner) response is,

normalized pixel level = (pixel level/255) = k_1 exposure^{gamc}

Gamc is the ***gamma*** of the capture device. Monitors also have gamma = gamm defined by

monitor luminance = (pixel level/255)^{gamm}

Both gammas affect the final image contrast,

System gamma = gamc * gamm

Gamc is typically around 0.5 = 1/2 for digital cameras. Gamm is 1.8 for Macintosh systems; gamm is 2.2 for Windows systems and several well known color spaces (sRGB, Adobe RGB 1998, etc.). Images tend to look best when system gamma is somewhat larger than 1.0, though this may not hold for contrasty scenes. For more on gamma, see Glossary, Using

Imatest SFR, and Monitor calibration.
Using the equation, **density = – $\log_{10}$(exposure) + k**,

$$\log_{10}(\text{normalized pixel level}) = \log_{10}(k_1\ \text{exposure}^{gamc}) = k_2 - gamc * \text{density}$$

This is a nice first order equation with slope gamc, represented by the **blue** dashed curves in the figure. But it's not very accurate. A second order equation works much better:

$$\log_{10}(\text{normalized pixel level}) = k_3 + k_4 * \text{density} + k_5 * \text{density}^2$$

k_3, k_4, and k_5 are found using second order regression and plotted in the **green** dashed curves. The second order fit works extremely well.