Research on Raw Capture – Methodology

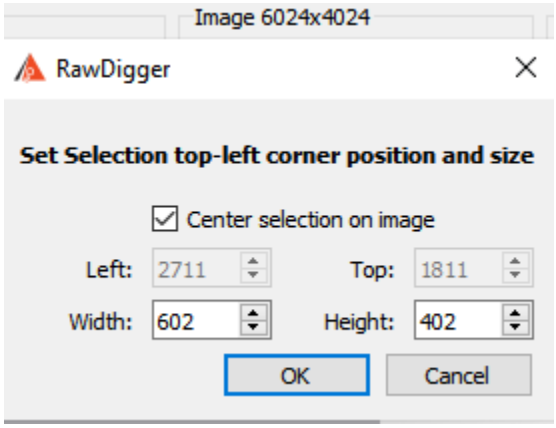
The initial purpose of this research was to study the relationship between the raw values captured by the camera and the onset of highlight warnings (or Zebra warnings with Sony). These warnings (blinkies) are based on the raw information (more on this shortly). They can be examined with the help of RawDigger.

The camera's histograms are based on the JPEG and can be affected by settings like Active D-Lighting and other algorithms used to create the camera's JPEG.

The initial tests involved a brief series of captures at base ISO to locate the first image with warnings as the exposure is increased in 1/3 stop increments.

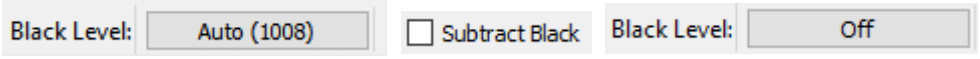
The target is a white screen displayed on a monitor calibrated to 120cd/m^2, the default brightness recommended by Datacolor for calibrating a monitor in normal ambient lighting. The images are captured from close to the screen with manual focus at infinity to minimize any noise due to the screen's individual pixels.

To adjust for different sensor resolutions we can select 1% of the pixels at the center of the image. For a 24MP image the sample size is about 242k pixels.



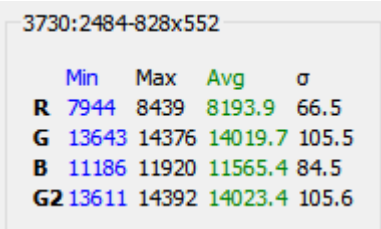
This accounts for the different MP captures for different cameras since they can be used to make images with the same final dimensions. The small selection also eliminates the vignette that can be seen in the full image.

For reasons to be apparent shortly, the Black Level adjustment is turned off in the bottom left corner of the main RawDigger display by clicking on Auto (xxxx) and unselecting Subtract Black on the next page to get.



This lets us to see the actual raw values with a maximum limit of 16383 for a 14-bit file and 4095 for a 12-bit file.

For a Bayer array the two green channels contain 50% of all the luminance information. The data from the two green channels overlap:



The value recorded in the **Avg** column is entered in the spreadsheet as =AVERAGE(14019.7,14023.4) and the standard deviation in the **σ** column as =AVERAGE(105.5,105.6). The minimum is 13611 and the maximum 14392 which are often in different green channels.

An X-trans array makes this easier since the green channel (more than 55.5% of the luminance data) has a single row of values. A monochrome raw file has only a gray channel.

The highlight warnings at base ISO start before the maximum raw value reaches the raw limit. The gap between the maximum raw value and the raw limit about a ½ stop for the Nikon Df, less than 1/6 stop for the Fuji X100T and about 1/5 stop for the Nikon Z7. These gaps decrease as the ISO is increased. The numbers might change slightly for different camera models but the onset of highlight warnings is probably consistent for a particular brand.

Here are the results for a Nikon Z7:

A	B	C	D	E	F	G	H	I	J	K	L	M
	ISO	raw	log(raw)	S.D.	log(S/N)	log(SD)	Max	log(max)	raw limit	log(limit)	**Gap(max)**	**Gap(avg)**
Z7	64	14007.20	13.77	77.9	7.490	6.284	14332	13.807	16383	14.000	**0.193**	**0.226**
Uncompressed	800	13638.55	13.74	218.5	5.964	7.771	14645	13.838	16383	14.000	**0.162**	**0.265**
	6400	13501.85	13.72	568.2	4.571	9.150	15833	13.951	16383	14.000	**0.049**	**0.279**

It would be a good idea to avoid the blinkies for three of the cameras tested unless the blinkies are flashing over highlights you don't care about. Once the blinkies start to flash there is very little room for additional exposure before the raw file reaches its maximum.

The exception is the A7 II. The A7 II can set Zebra to "100+" and they start start more than a stop below the raw limit. That changed starting with with the A7 III which can be set to "109+" to get closer to the raw limit.

Are blinkies based on raw or JPEG

At the level where we expect to see highlight warnings both the raw and the JPEG values are very close to their limit, ususally within a third stop or less. This is not easily apparent until you capture an image using a white balance setting for the JPEG that is not appropriate for the color of the highlights.

For example, in broad daylight a Daylight white balance the brightest highlights (white clouds, white bird feathers, sea foam, snow, etc.) will be rendered white (neutral) in the JPEG image.

Under tungsten or incandescent lighting the brightest highlights might be white paint, paper or other materials. With a tungsten or incandescent white balance setting these highlights will also be render as white. The same thing happens with flourescent or other artificial lighting. If the white balance is set to Daylight the blinkies may show up in the wrong place relative to the raw limit.

Even Auto WB might throw the blinkies off a little if it does not render the highlights as neutral.

In broad daylight with the white balance set to UniWB (which renders a washed out green JPEG) the blinkies can show up as much as two stops *after* the JPEG limits but close to the raw limit. If the blinkies were based on the JPEG alone they would be useless. If they were based strictly on the raw data they would actually not show up soon enough to prevent the raw limits from being exceeded.

Nevertheless, if the brightest highlights have a strong magenta hue like the one used to set up a custom UniWB white balance:

UniWB would render those hghlights neutral gray JPEG and the blinkies would behave normally.

So the blinkies are useless in broad daylight if you are using UniWB or any white balance setting other than Daylight.

Nikon's Higlight Weighted Metering

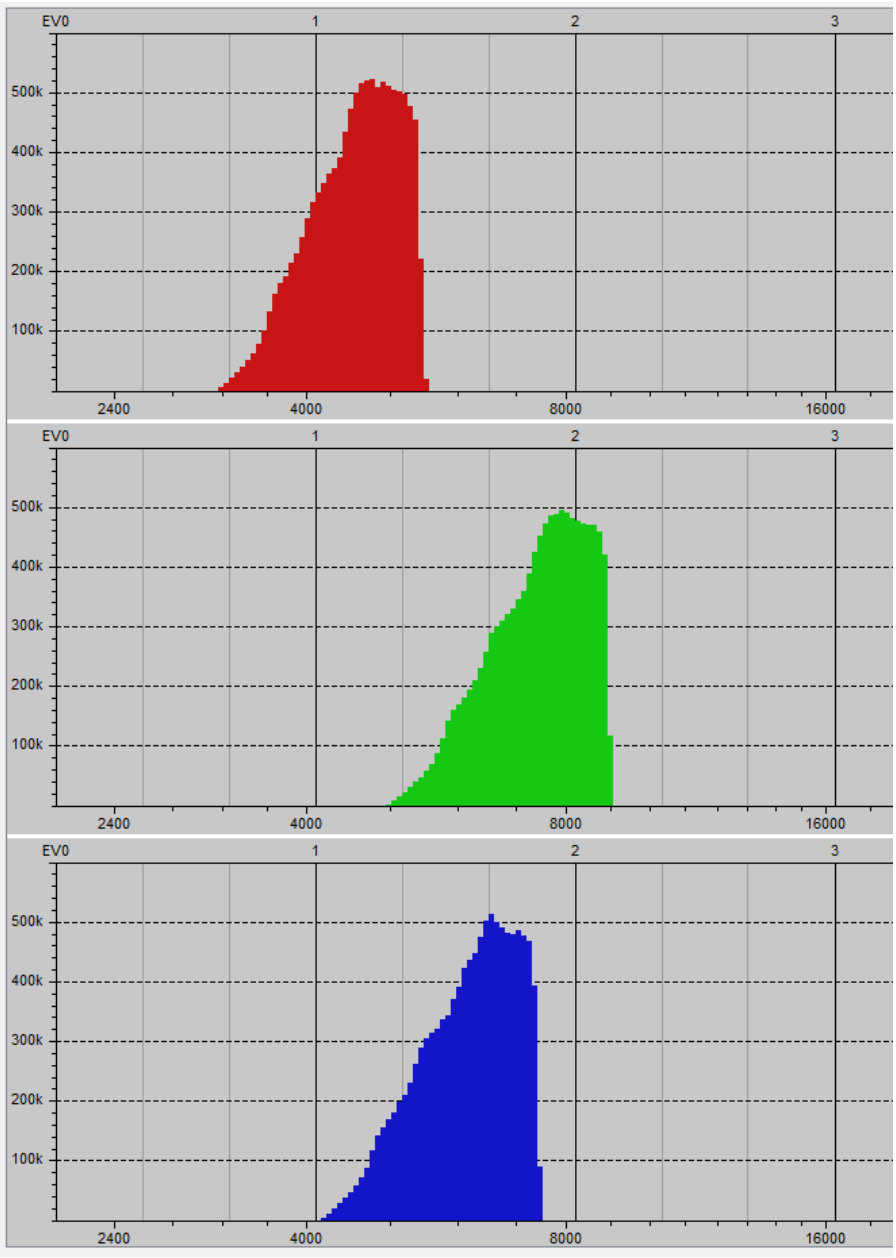
This is another way to avoid blown raw highlights but it can sometimes be too aggressive if there are any specular highlights or light sources in the scene. The blinkies make it easier to control which highlights should be allowed to blow out.

Dynamic Range (DR)

For a source on the DR performance of your camera at different ISO settings, see [Photons to Photos].

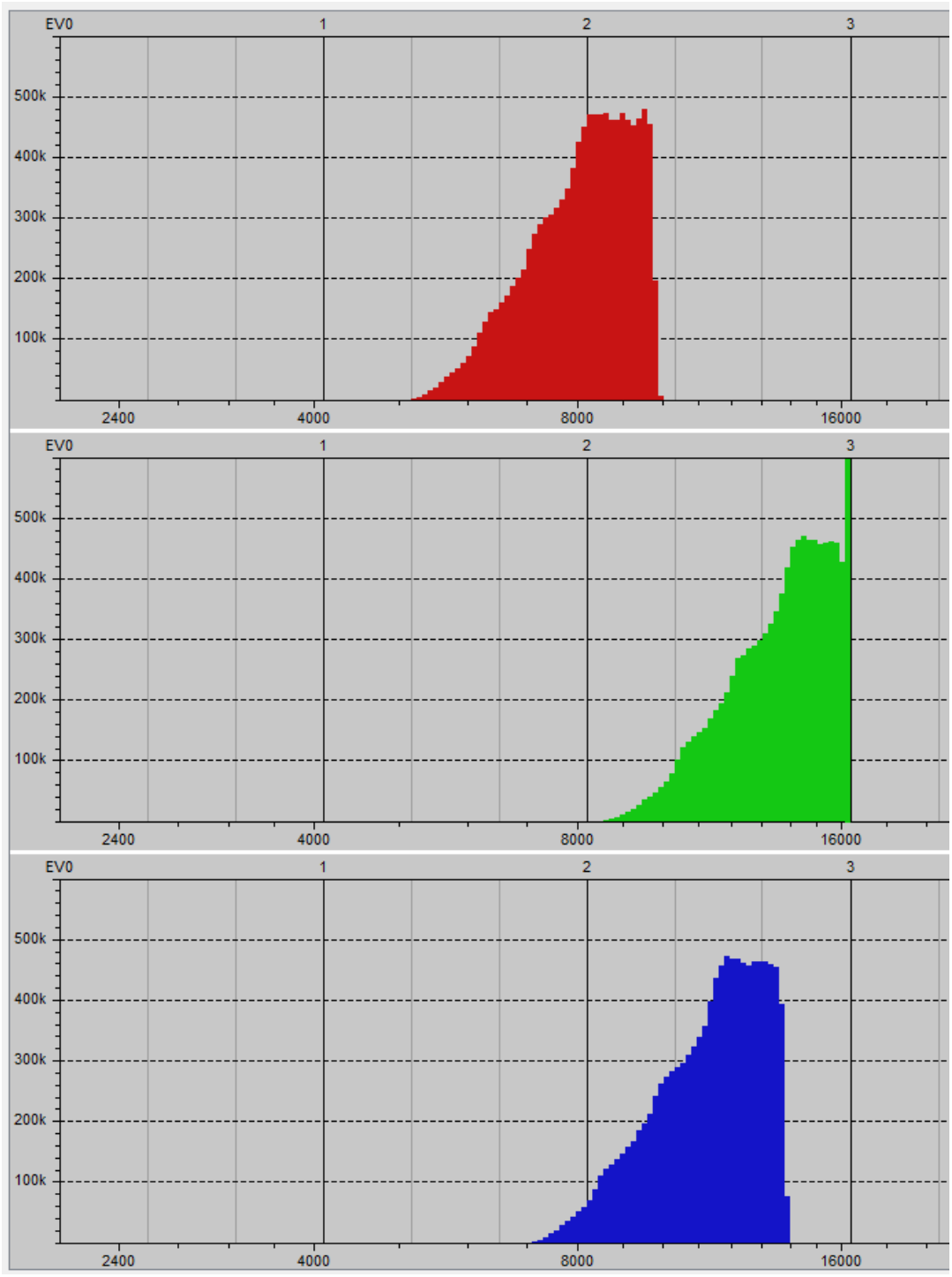
The following might shed some light on what happens to the DR as you change the ISO exposure or ISO.

Here is what happens with a Nikon Z7 at abase ISO 64 for a neutral (gray) target near the top of its range.

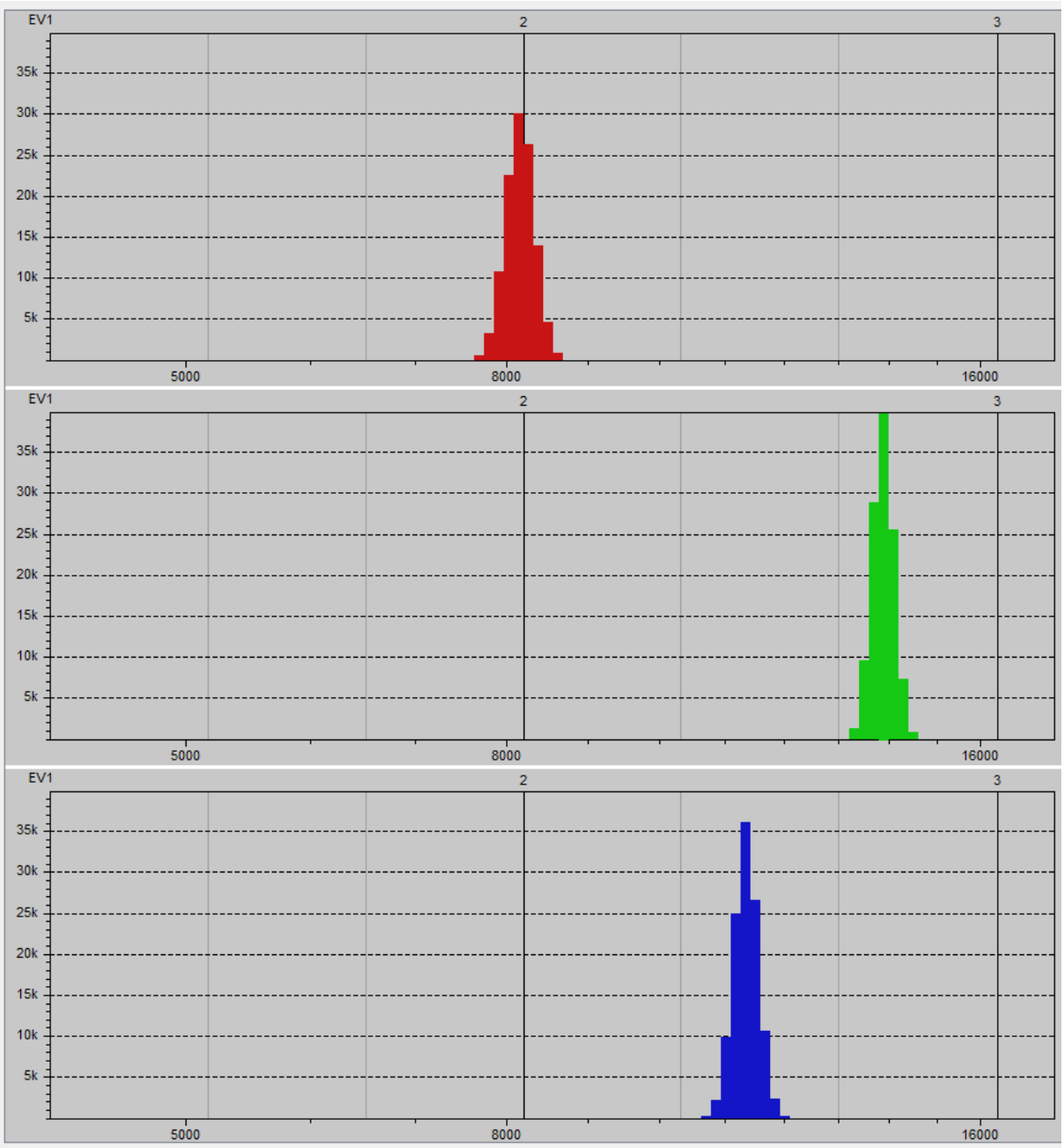


The green plot appears to the right of the blue and red plots. Since it has not reached the limit all three still looks like normal distributions. The center of each plot is the location of the average raw value in the sample. The maximum value of the disribution is at the right end of the green plot just beyond the 16000 level.

If it does not get completely “blown out” some of the values will end up as a spike and the rest will plot normally. The green channel will be compromised even if only the maximum value excedes the raw limit. Part of the green channel in this case is blown out and the colors start to degrade.



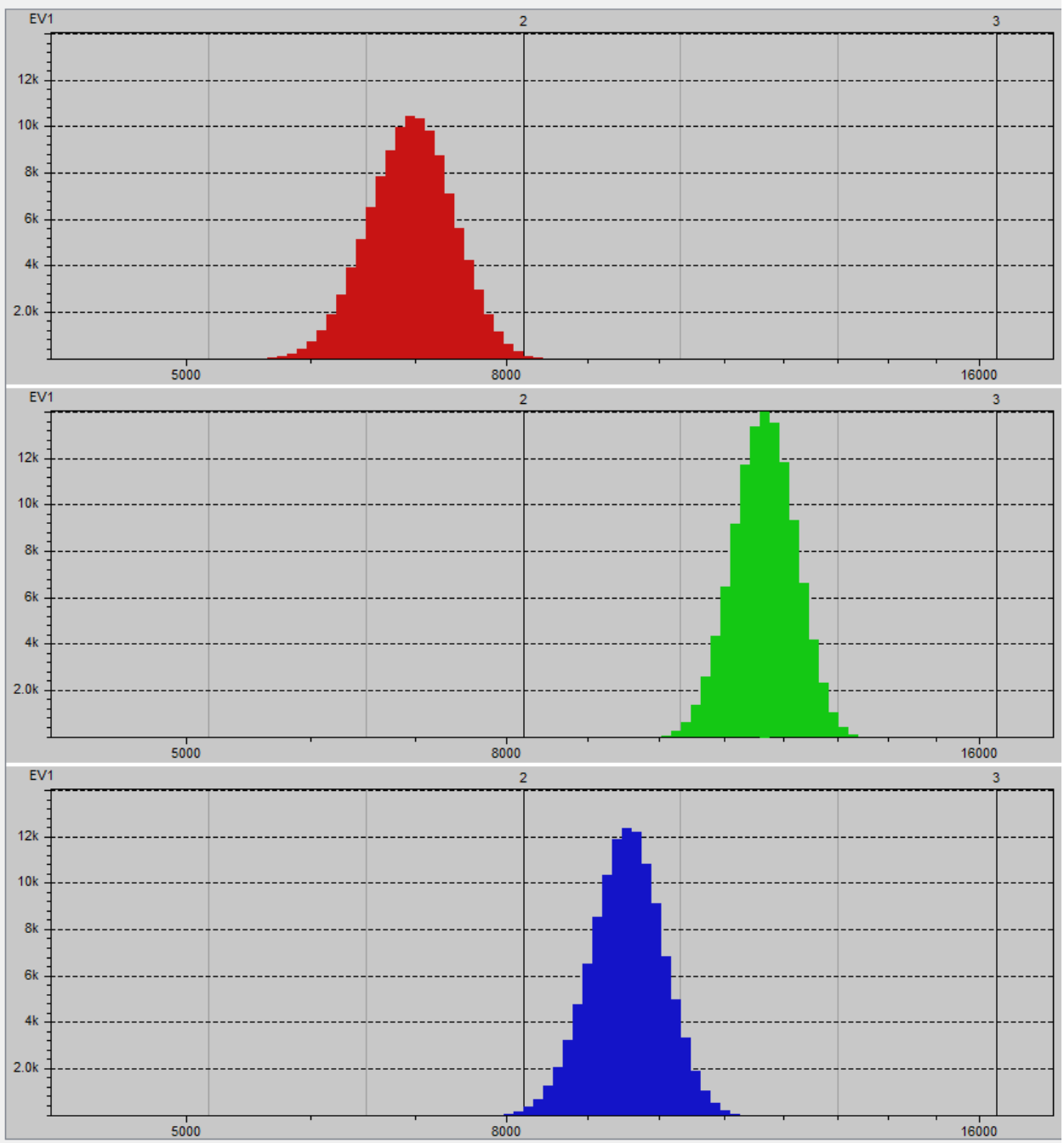
Changing the ISO can affct the location where the blinkies begin and something else happens – at ISO 800 the plots spread out.



Note that, as a group, the right end of the green channel shows the maximum raw value and the left end of the red channel the minimum value. In this case they cover a full stop.

The consequence is that, although the average values might record close to the same level after the exposure has been adjusted to match the increase in ISO, the upper and lower ends of the full range are farther apart – closer to the upper and lower raw limits.

At ISO 6400.



There is more amplification of the raw values and the plots spread out more, in this case more than a full stop. The center of each plot will move back and forth slightly with each change of ISO.

The DR should be based on the range where the darkest capture does not drop to the raw minimum (0) and the lightest capture does not reach the maximum raw value. A modern full frame cameras using 14-bit raw files the actual dynamic ranges at base ISO is between 9 and 12 stops. Some medium format cameras can do better than that and use a 16-bit raw file.

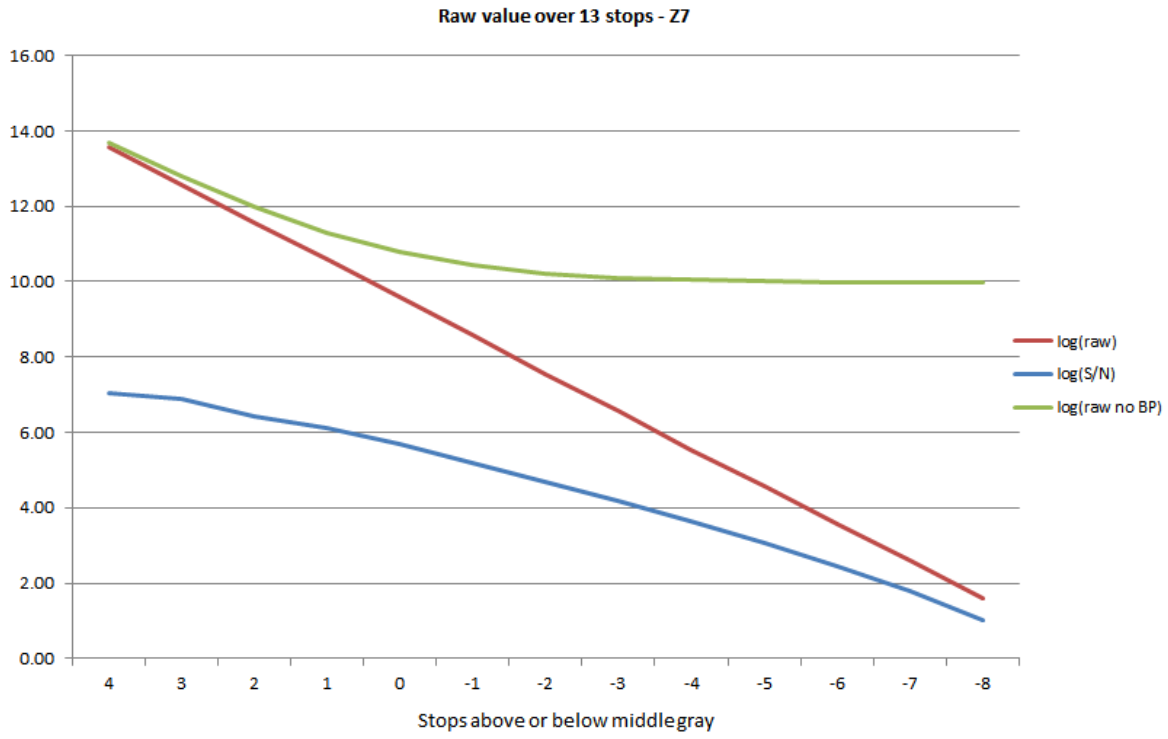
Testing for Exposure Variation

Another experiment shows what happens as exposure is reduced over a range starting with 1 second through 1/4000s. This test was performed at base ISO.

This series of 13 captures should be perfectly linear since the exposure increments are deliberately one stop apart. Changing the exposure is a proxy for capturing a scene with a very wide DR. In order to achieve this we need to turn the Black Level back on by checking the Subtract Black checkbox.

The value in parentheses (512 for the A7 II, 0 for the Df and D610, 1020 for the X100T and 1008 for the Z7) will be subtracted from all of the raw values in the raw file to achieve a linear result.

As the exposure is dropping the signal drops faster than the standard deviation of the recorded values resulting in a loss of DR (this is an indicator, not strictly a measure of noise).



The green line represents the actual raw values stored in the raw file for each exposure when the Black Level checkbox is off. The red line results from subtracting 1008 from those raw values. It is clearly linear.

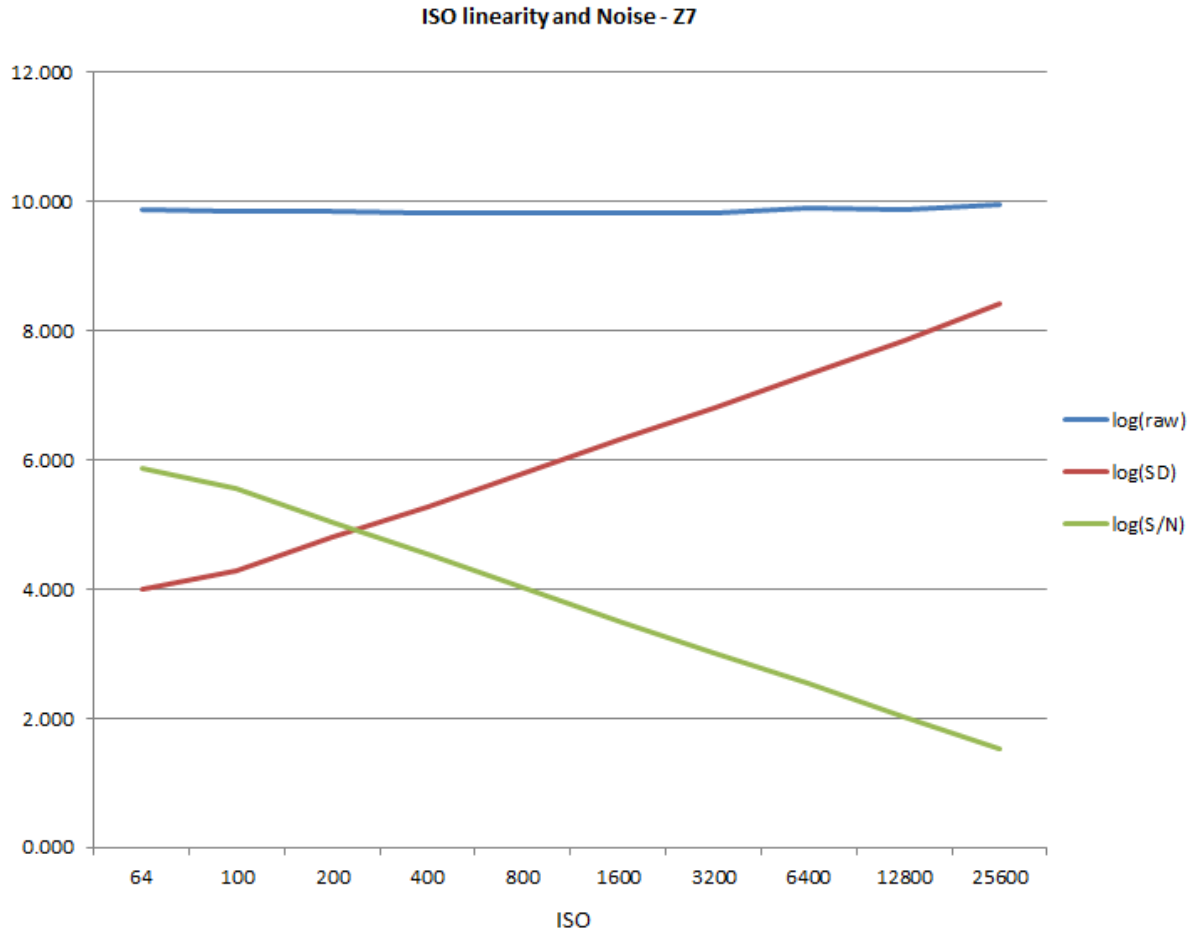
The blue line shows the decline in S/N, a measure of signal to noise. The log(S/N) is calculated as the base 2 log of the raw values divided by the base 2 log of the standard deviations.

The number of stops from the log(raw) line and the log(S/N) line is close to 7 stops at +4 but at -4 it's only about 2 stops.

Testing for ISO and Shutter Speed Linearity

Another series of tests looks for variations in shutter speed and the effect of increasing the ISO from the base to a high value, excluding any extended ranges.

These tests were performed using the camera's meter to select a shutter speed while maintaining a log(raw) value close to 10.



The log(raw) line is not perfectly straight. It's not clear whether this is due to a lack of precision in the shutter or variations in the process converting the analog signal at the sensor into a digital value.

The log(SD) and log(S/N) lines appear to be very straight except for the ISO 64 point which is not a full stop below ISO 100.

At ISO 12800 the raw minimum values are unexposed and record as 0. This also happened with the A7 II. It did not happen with the X100T because its top ISO is 6400. It also did not happen with the Df because its pixels are much larger than those in either of the cameras with higher MP sensors.

Afterword

The Nikon Df and Z7 results are compatible with the results previously found with a D610. The recommendations regarding blinkies probably apply to other Nikon models.

The behavior of the A7 II and X100T may not be representative of other Sony and Fuji models. You should test your own cameras to determine how close the beginning of the blinkies comes to the raw limit. Turning off the Black Level adjustment will help since you can compare the results to a standard limit like 16383 for a 14-bit file.

The other tests described above are not critical but they provide some background into the raw files.

Noise levels and dynamic range are difficult to quantify. We are not likely to see noise in the shadows and highlights as easily as we can see them in the mid-tones. It is more visible where there is smooth tonality and not a lot of detail.

Pixel peeping (looking for noise at 100% or more magnification) is misleading. The image should be viewed at a normal magnification from an appropriate viewing distance – about the same as the longest dimension of the image.

There are simple steps you can take in post processing to mitigate noise.