Boosting Sensitivity

In this series of articles, we’ll explore this topic in more detail and show you how to boost the light sensitivity of your digital high-speed camera when required by an application. And, we’ll discuss the trade-offs you will make by doing so. We will tackle this topic at a high level and even make a few simplifying assumptions. But, don’t worry; the results will be meaningful and relevant to your everyday use of a digital high-speed camera.

We’ll cover a number of key concepts in this series.

**Topic #1**

**Photo Site / Pixel:**

The sensor used in today’s digital high-speed cameras is typically a CMOS technology integrated circuit comprised of millions of pixels. Each pixel (or photo site) converts photons that strike it into electrons that accumulate charge at the pixel. Think of the pixel as having a bucket that holds the electrons. The more photons that hit the pixel in a given time, or the longer we wait under a constant illumination, the more electrons that will accumulate in the bucket. This bucket is called a “well”. And, the number of electrons that the well can hold before it reaches saturation is called the Full Well Capacity (FWC) of the pixel.

In normal use, a pixel will “count” photons, turning them into electrons and accumulating a proportional charge during the image exposure time. If only a few electrons accumulate, that pixel will have a very small charge. If a lot of electrons accumulate the charge will be proportionally larger. If the pixel well fills up with accumulated electrons and starts to “overflow” it will saturate.

At the end of the exposure time, the accumulated charge in each pixel is read out and converted into a digital number representation of the charge by an analog-to-digital converter (A/D). The resulting number represents the charge that accumulated during the exposure time. A low number represents black and a large number represents white. In a 12-bit sensor, a value of 0 would be pure black (no charge accumulated) and a value of 4095 would represent pure white. And every digital number between 0 and 4095 would represent a different scale of gray in-between pure black and pure white. Because this is now a
digital number representation of the charge at the pixel, it is easily stored in camera memory and represents the “raw” value of that pixel.

There are several factors that determine how well a photo site will do at capturing photons and converting them to electrons. While not really essential to our discussion, it is worth your time to further investigate some of these factors if you are finding this discussion interesting:

- **Fill factor**: the percentage of the pixel surface area that is actually able to capture photons. Conductive metallic layers will block some of the pixel area, for example.

- **Quantum efficiency (QE)**: the effectiveness of the pixel at converting photons that hit the active area into electrons.

- **Microlenses**: tiny lenses on each pixel that can redirect some photons that would not hit the active area of the pixel onto the active area. The effect can never be greater than a 100% fill factor.

The raw value of a pixel is further manipulated before you view it on a monitor or computer screen. The manipulations are often stored as metadata attached to the raw file. That way, the actual pixels values are always preserved and the images can be manipulated in a non-destructive way. Typical image processing steps are: application of offsets and gains from a calibration image to remove the effects of differences between pixels (the calibration image is a totally dark frame); for color cameras, separate gains are applied to the red, green and blue pixels to normalize them to a proper white balance; color interpolation will take place on a color camera; gamma is applied to adapt the linear response of a sensor to the nonlinear response of the human eye; etc.

From this first article, you should have a good idea how a pixel on a sensor works. And, you should understand the concept of a photo site “well” and that the Full Well Capacity is the number of electrons it can hold before saturation. You should also understand that the charge accumulated in the well is turned into a digital number representation of the charge by an A/D converter and stored in memory as a raw value that is later manipulated to provide a visible image.

---

**Topic #2**

**ISO 12232**: This is the name of the standard for measuring the sensitivity of a Digital Still Camera (DSC) that most camera vendors use when specifying light sensitivity of a high-speed camera. It specifies the methodology for several different ISO measurements. Two are called noise-based measurements. One is called a saturation-based measurement.

The noise-based measurements yield the ISO value when the signal-to-noise ratio (SNR) is either 10 or 40. The saturation-based measurement yields the ISO value when the sensor is just reaching saturation and is the most conservative measurement. Typically, the SNR will be the highest at saturation, so the image quality (at least as far as noise in the image is concerned) will be the best.
At Vision Research, we use the ISO saturation-based methodology, usually called ISO_{sat}.

Here is how the measurement works:

1. Illuminate the sensor under test with a constant and prescribed light source. The illumination can be Daylight or Tungsten (the specific spectrum for each of these is described in the standard).
2. Measure the lux value of the illumination.
3. Start exposing the (uncharged) sensor to the light and measure the time it takes to reach saturation.
4. Do some math with the lux value and exposure time as variables in this equation:

   \[
   \text{ISO}_{\text{sat}} = \frac{78}{\text{exposure} \times \text{lux}}
   \]

Pretty simple!

For a given illumination level (lux), the less time it takes to reach saturation (exposure in seconds), the higher the ISO value.

The standard then allows the resulting ISO value to be rounded up to the next standard ISO number. The standard ISO numbers range between 10 and 8000. There is a pattern to these numbers that you can see in the last 10 valid numbers from the spec:

\[
\text{1000, 1250, 1600, 2000, 2500, 3200, 4000, 5000, 6400, 8000}
\]

While the spec doesn’t call out any valid numbers above 8000, we in the high-speed industry have assumed it is okay to use this sequence, but multiply each valid number by 10. So, for modern-day high-speed cameras you will likely see ISO specs with values of:

\[
\text{10000, 12500, 16000, 20000, 25000, 32000, 40000, 50000, 64000, or 80000}
\]

So, a measured value of 34000 will be rounded up to 40000 for the purposes of specifying the camera sensitivity. This means that two cameras with the same specification may actually have somewhat different native sensitivities.

Why round up? Besides the convenience of a set of standard values, the rounding up of a base measured value helps ensure that when ISO values are used to judge/calculate proper lighting and exposure, nothing in the image will saturate. (Alternatively, if light and exposure are fixed, a light meter will tell a photographer what ISO rating to use to get a good shot without the risk of saturation.) Remember, the standard is written for digital still cameras. It provides an analog to the ASA / ISO ratings for film that photographers relied upon for proper film selection for a given scene.

An ISO value that is measured using Daylight illumination will sometimes be marked with a “D”. If there is no specific illumination noted in the value, then you can assume it is the Daylight value. A value measured under Tungsten illumination must be marked with a “T” in its value.

Tungsten lighting will have more light with a spectrum toward the “infrared” wavelengths (typically, wavelengths between about 700nm and 1100nm). Assuming the sensor is sensitive to those wavelengths (and most monochrome sensors are), there will be more photons available to the
Boosting Sensitivity

sensor over any given exposure time. This is good to know when using a monochrome camera in a light-starved application. You can effectively boost the sensitivity of the camera by using Tungsten illumination.

It turns out that the ISO 12232 standard wants us to filter out this extra spectrum of light before making the ISO measurement under Tungsten illumination! Doing so will make the ISO value of a monochrome sensor appear to be much less that it really is capable of. So, what is going on?

Remember, the ISO 12232 specification is written for measuring the ISO value of Digital Still Cameras. And, probably 99.99% of them are color cameras. Turns out, you don’t want that extra spectrum in a color camera. It causes what is called IR contamination, which results in false colors on a color camera. So, an IR cut filter is used to restrict the offending light spectrum and prevent IR contamination.

But, with a monochrome camera, that extra spectrum is advantageous, as we’ve discussed.

So, when we at Vision Research measure and specify a Tungsten-based ISO value for a monochrome camera, we do not use the prescribed IR cut filter resulting in a value that is more representative of the way the camera will be used in real-world applications.

In this second article in our series on Boosting Sensitivity, you’ve learned, at a high level, how the ISO 12232 specification for measuring ISO of a Digital Still Camera works. A key point is that for a given amount of illumination, shorter exposure times to saturation result in higher ISO values. We’ve also covered the two lighting methods allowed, and explained why VRI does not conform to the measurement standard when using Tungsten illumination with a monochrome sensor.

---

**Topic #3**

**Gain**

In the previous topic we discussed the ISO 12232 method for measuring ISO. At Vision Research, we make this measurement with camera gain and gamma set to a value of “1”. That is, no gain and a linear gamma. We call that “native” ISO because it is the base ISO of the camera without any manipulations to boost ISO that might cause undesired side effects (such as a decrease in signal-to-noise ratio or dynamic range—we’ll get into those topics more in part 5).

If you have a light-starved application that needs more sensitivity, you can increase the effective sensitivity by adding gain to the image. Our customers do it all the time.

There are really three ways to add gain, but only one is typically available to the user. The camera designers may add gain to the analog value of the photo site charge before sending it to the A/D. This is a normal design practice to match the charge of the full well to the range of the A/D and helps get maximum performance from the camera. It has trade-offs, but they are generally good for the end user.

---

**#3a THREE WAYS TO BOOST GAIN**

1. **TIME**
2. **A/D**
3. **MEMORY**
4. **DATA IN**
5. **VISUALIZATION OF DATA**

---

4
A second place to add gain is to the digital number output from the A/D before storing the pixel value as raw data in the camera. Doing this means that some of the digital numbers that represent white will be pushed beyond the bit-depth limit of the camera (i.e. numbers greater than 4095 for a 12-bit camera) and those pixels will appear saturated. The user can then adjust either the lens aperture or the digital exposure time so that there is no longer saturation and a nice image results. This sounds like a great solution to increase sensitivity, but there are some downsides. Most notably you now have fewer digital numbers representing the full swing of the camera from black to saturation. This means less dynamic range in the image. We will also soon learn that boosting gain is equivalent to lowering the full-well capacity (FWC). And, that means a lower signal-to-noise ratio (SNR). Finally, the amplified values of the pixels are stored in the raw image data. So, the full dynamic range and SNR of the image is now lost. Forever.

The third way is to use image-processing controls to manipulate the raw image data for presentation. Adding gain in this way does pretty much the same thing as the second method above, but the gain is only added to the visualization of the data. There is the same boost in apparent sensitivity. There is the same effective lowering of the FWC with a resulting decrease in SNR and dynamic range. But, the full range in the raw data is protected. Only the visualized version is changed and that can be analyzed or saved with the gain added. And, if you ever need to go back to the original raw data, it is available in the raw file. (In a Phantom camera, any image processing done to the live image prior to recording will be saved as meta-data with the raw file. This means that you will always “see” the manipulated image because the meta-data will be applied when you view it or save it. But, the raw data does not change and the visualized image can be further manipulated with image-processing controls at any time, including removal of gain and recovery of the full dynamic range and SNR of the image.)

The new value of ISO obtained by adding gain is called the Exposure Index or EI. Anyone with a modern digital still camera has probably had the opportunity to increase the EI setting on their camera in low light situations to boost the sensitivity. The result, however, is often an unsatisfactory, noisy image.

Earlier, I mentioned that boosting gain to boost ISO is equivalent to lowering the full-well capacity of the sensor. Here is the logic behind that claim. Refer back to the description of how ISO is measured and formula used from part two of this series.

Under constant illumination at some lux value, you increase the exposure of the camera until the sensor “just saturates”. It “just saturates” when it reaches the FWC.

If I add gain to boost sensitivity, then the effective ISO value goes up. We have not magically created any more incoming photons by adding gain, and it takes less exposure time to saturate, so the well must be smaller. Another way to say it: we reach saturation with fewer electrons, so by definition the well is smaller.

Higher gain means an effectively smaller FWC. And, the relationship is linear. If I had a FWC of 20,000 electrons (e-) with a gain value of “1” (remember, a value of “1” means “no gain” because whatever is coming into the gain equation is simply multiplied by 1), and I increase the gain to a value of “2”, my effective FWC is now 10,000 e-.

I’d really like to discuss the side effects of using gain to boost ISO, but that requires a discussion about noise first. So that is the topic of part 4 of this series. Stay tuned.
NOTES

Boosting Sensitivity

Topic # 4

Noise

There are many potential sources of noise in a CMOS sensor. At a high level, they break down into two types: temporal and fixed-pattern.

Fixed Pattern Noise (FPN) is noise that does not change with time. There is a fixed pattern to the noise, perhaps a moiré pattern, streaks or lines. Obviously, all vendors work hard to minimize visible FPN. FPN can be reduced using flat-field correction techniques such as a Current Session Reference (CSR) also called a “Black Reference”, or Correlated Double Sampling (CDS).

FPN may become more visible when adding gain to boost ISO, so it is something you want to look for when evaluating a camera for purchase. Since it does not vary over time we don’t consider it when calculating signal-to-noise ratio or dynamic range. (In other words, to those metrics of image quality FPN just looks like part of the image since it does not change over time.)

Temporal noise is noise that varies over time. And, there are three main kinds of temporal noise: dark noise, readout noise, and shot noise.

Dark noise is the charge that accumulates with no light stimulus over long exposure times.

Readout noise is really just the dark noise over very short time periods. It is the noise in an otherwise perfectly black frame and is an intrinsic noise in CMOS sensors. Since a high speed camera is generally running at high frame rates, the difference between readout noise and dark noise is negligible and we will consider them to be the same. Readout noise is measured in electrons (e-). It is specified as a root-mean-square (RMS) value and it varies according to a Gaussian distribution. The design of the sensor and camera can affect readout noise.

Shot noise is the noise that accumulates during exposure. In fact, it accumulates at a rate proportional to the square root of the charge. It is also specified in electrons as an RMS value and varies according to a Poisson distribution. Since shot noise accumulates proportional to the square root of the charge, the maximum possible shot noise is the square root of the full-well capacity. There is nothing that can be done in the sensor or camera design to affect shot noise. It is dependent only on the number of photons collected.

If all this sounds a bit techy, well it is. There is a lot of physics at work here. But, there is a simple way to think about it. When you start exposing a frame you start with some “built in” noise in the image. That is called readout noise and it is the noise in a perfectly black image.

As you expose the frame and accumulate charge, you also accumulate noise. This is called shot noise. The more charge you accumulate during the frame exposure, the more shot noise you will have.

You should now know the main sources of noise in a high-speed video. This allows us to take the next step and discuss the trade-offs that come with using gain to boost camera sensitivity. And, we’ll cover that topic in the next article.

Topic # 5

SNR and Dynamic Range

Signal-to-noise ratio (SNR) and dynamic range are two ways of specifying image quality. In general, the higher they are the nicer the image will look. And, perhaps more importantly, the higher they are the better the “data” you have in the image. If you are making scientific measurements based on
the brightness of a pixel, or tracking particles using particle image velocimetry (PIV) or a similar technique, the quality of the data in the image is critical. If you need to match images from two or more cameras for 3D modeling, you want the data to be as good as possible, for example.

**Signal-to-Noise ratio (SNR)** is the ratio of the signal in electrons (e-) to the total temporal noise at any charge level.

I’ve been told that people generally stop reading articles the first time a formula appears. Even my early reviewers of this article stopped reading at this point since I included a formula! Still, I’m going to stick some formulas in here, but please don’t stop reading because of them. Just skip them.

For best image quality, it usually makes sense to set the camera up to use its full range. So, there will usually be parts of the image that are dark and parts that are bright. It is useful then, when specifying SNR, to calculate the SNR at saturation (or full-well capacity).

**The formula for SNR is:**

\[ SNR = \frac{\text{Total Signal}}{\text{Total Noise}} \]

For best image quality, it usually makes sense to set the camera up to use its full range. So, there will usually be parts of the image that are dark and parts that are bright. It is useful then, when specifying SNR, to calculate the SNR at saturation (or full-well capacity).

**SNR = \frac{FWC}{\text{Total Noise at FWC}}**

The total noise is the sum of two RMS values, one for the readout noise and one for the shot noise. If I remember correctly, to sum two RMS values, you first square them then add them together then take their square root.

**So the equation for the SNR at saturation is:**

\[ SNR = \frac{FWC}{\sqrt{\text{Shot Noise}^2 + \text{Readout Noise}^2}} \]

An interesting factoid here: the maximum theoretical SNR would come at saturation with no readout noise and would be equal to: \( \sqrt{FWC} \)

Remember in part #3 of this discussion we found that when you used gain to boost ISO you were effectively decreasing the FWC? We can now see the effects of that on SNR.

What does all this mean? When you boost gain, you decrease SNR. This means there is less separation between the signal and the noise in an image and there will likely be more visible temporal noise in the image.

**Dynamic Range (DR)** is the range of values from the darkest to the brightest image that a sensor can provide. Often expressed in decibels (dB) or f-stops (stops). It is a function of the full-well capacity and readout noise. If two cameras have the same readout noise, the camera with the greater FWC will have the greater DR.

It seems like this range should be infinite—that there should be an infinite number of values of “brightness” between black and white. But, the first limitation on that is the number of electrons in the FWC. Even with each added electron creating a new value, the number of values would then be limited to the number of electrons at FWC. But, we then use A/D converters to quantize that range of values into discreet digital number representations. So two charge values that are close together may get quantized into the same value during the analog to digital conversion. Meaning, the most values we can have on a perfect sensor is \( 2^n \), where “n” is the bit-depth of the A/D. (Here come some more formulas you can skip.)

**The formula for dynamic range expressed in dB is:**

\[ DR = 20 \cdot \log_{10}(\frac{FWC}{\text{Readout Noise}}) \]

And, the equation expressed in f-stops is:

\[ DR = \log_{10}(\frac{FWC}{\text{Readout Noise}}) \]

Perhaps some examples would be useful here. Let’s look at the Phantom Miro 310 camera. It has a FWC of 26,300 e- and, typically, 29 e- of readout noise. The shot noise at FWC would be \( \frac{\sqrt{FWC}}{2} \), or 162 e-. (You should at least look at the answer to these next few formulas.)

**So the SNR at full charge would be:**

\[ SNR = \frac{26,300}{\sqrt{162^2 + 29^2}} \]

Or,

\[ SNR = 160 \]
Boosting Sensitivity

That is pretty good considering for a high resolution digital still camera an SNR of > 40 is often considered acceptable.

The DR in dB would be:

\[ DR = 20 \cdot \log_{10}\left( \frac{26,300}{29} \right) \]

Or,

\[ DR = 59 \text{ dB} \]

(I’m rounding these numbers off for simplicity).

The above are all calculated with a gain of 1. Let’s boost the gain to 2 and see what happens. Boosting the gain to 2 simply reduces the FWC used in the formulas from 26,300 to 13,150.

The resulting SNR (at saturation) is 80. The DR is 53 dB or 8.82 stops. So, we halved the signal-to-noise ratio and decreased our dynamic range by 1 stop. Not too bad, we still have an acceptable image and have boosted the native ISO from 6,400 (native ISO for a monochrome camera under daylight illumination) to 12,800. However, this would be expressed as an Exposure Index (EI) of 16,000 to conform to one of the standard ISO values.

That is probably enough for today’s article. Just remember, you can boost sensitivity by adding gain. Adding gain effectively reduces the full-well-capacity of the sensor. Reducing the FWC means you have a lower signal-to-noise ratio and dynamic range. Reducing SNR and DR is okay, up to the point it starts to affect your experiment by either creating an overly noisy image or decreasing the data set available for data analysis.

Topic #6

Let’s Pause and Recap What We’ve Learned

We’ve covered a lot of ground and I think now is a good time to summarize what we’ve learned:

Important point #1: Even ISO values that conform to ISO 12232 cannot be compared directly as these values are likely “rounded up” from some lower native value. The specification was not created with the goal of comparing cameras. Rather, the specification was created to allow photographers a way of judging/calculating appropriate lighting and exposure to mimic the behavior of a film camera and prevent saturation (that’s explains the “round up”). The ISO specification simply tells you the maximum possible value of the camera’s sensitivity—the actual value can be, and probably is, less. Two cameras with different actual sensitivity values could have the same ISO specification. The best way to compare to cameras is in a side-by-side comparison using identical setups for each camera.

- An ISO rating is commonly used to specify a camera’s light sensitivity.
- ISO ratings are determined by following the measurement and specification methodology outlined in ISO 12232:2006 (which I’ll call just 12232 from here on).
- A camera’s ISO specification is not necessarily an exact representation of the camera’s native sensitivity since the method allows for “rounding up” the measured value to a standard value.

Important point #2: Tungsten ISO specs are valid under the ISO 12232 methodology. However, the measurement method artificially limits the measured value for monochrome cameras. So, while we still use the standard’s methodology at Vision Research, we do not use the prescribed IR cut filter
The application of gain has the effect of decreasing the total number of electrons a photosite (pixel) can hold before saturation (called the full-well capacity).

Important point #4: Nothing is free. While gain can be used to boost sensitivity, the result is a decrease in achievable SNR and DR yielding lower quality images, possibly with visible temporal noise.

- There are two “kinds” of noise in a sensor: fixed noise and temporal noise.
- All camera vendors work hard to minimize fixed noise and the best way to compare cameras is in a side-by-side evaluation under identical setups.
- Temporal noise is noise that is not fixed and changes over time. And, there are two types of temporal noise that most affect the images from a high-speed digital camera: readout (or dark) noise and shot noise.
- Readout noise is the noise present in a perfectly dark image at the start of the exposure time. It can be affected by sensor and camera design.
- Shot noise is the noise that accumulates during the exposure time and is a function of the number of photons collected.
- The amount of temporal noise in an image determines its visual quality as well as the usefulness of the image in quantitative/analytical measurement techniques.
- Image quality is often specified with Signal-to-Noise Ratio (SNR) and/or Dynamic Range (DR). Maximum achievable SNR and DR are functions of full-well capacity and one or both noise sources.
- As full-well capacity decreases, maximum SNR and DR will also decrease yielding a lower quality image.

Now, let’s look at some examples using hypothetical cameras.

Here are the specs for two cameras that have the same resolution, speed, minimum exposure times, etc.

Camera A: ISO 20000 D Mono
Camera B: ISO 10000 D Mono
Boosting Sensitivity

That’s it. That’s all the information you have. Two, otherwise identical cameras but one has an ISO spec of 20,000 and the other of 10,000.

**Which is the better camera?**

I hope you scratched your head before answering. If you are considering sensitivity specifications, and only sensitivity specifications, Camera A appears to be the “better” camera. It seems to be twice as sensitive.

Now, what if I told you that the ISO measurements, before rounding up, were 16,300 and 9810 respectively? Camera A is still more sensitive by this unadjusted measure, not by twice but by 60%. Not even a full stop.

What if I told you that the FWC for Camera A is 16,000 e- and for Camera B it is 26,500 e-?

I’d hope you would then ask for one more key specification: What is the readout noise? Because, with readout noise, you can now apply the formulas from part 5 of this series and determine maximum signal-to-noise ratio and dynamic range! (Don’t worry, I’m not going to make you do this.)

Let’s say both cameras, since they are using the same CMOS sensor technology, have a readout noise of 25 e-.

Now, armed with those additional specs, which is the “better” camera?

Here is a table of all the relevant information:

<table>
<thead>
<tr>
<th>Gain</th>
<th>Measured Sensitivity</th>
<th>ISO Spec</th>
<th>FWC</th>
<th>Read-out Noise</th>
<th>Shot Noise</th>
<th>SNR</th>
<th>DR (dB)</th>
<th>DR (Stops)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>16300</td>
<td>20000</td>
<td>16000</td>
<td>25</td>
<td>126</td>
<td>124</td>
<td>56</td>
</tr>
<tr>
<td>B</td>
<td>1</td>
<td>9810</td>
<td>10000</td>
<td>26500</td>
<td>25</td>
<td>163</td>
<td>161</td>
<td>61</td>
</tr>
</tbody>
</table>

On paper, Camera A appears twice as sensitive. In a side-by-side comparison, it would be 60% more sensitive, less than one stop. However, Camera B has a higher SNR and has 0.7 stops more dynamic range. Which is the “better” camera?

Let’s add a little gain to Camera B.

<table>
<thead>
<tr>
<th>Gain</th>
<th>Measured Sensitivity</th>
<th>ISO Spec</th>
<th>FWC</th>
<th>Read-out Noise</th>
<th>Shot Noise</th>
<th>SNR</th>
<th>DR (dB)</th>
<th>DR (Stops)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>1</td>
<td>16300</td>
<td>20000</td>
<td>16000</td>
<td>25</td>
<td>126</td>
<td>124</td>
<td>56</td>
</tr>
<tr>
<td>B</td>
<td>1.7</td>
<td>16677</td>
<td>20000</td>
<td>15588</td>
<td>25</td>
<td>125</td>
<td>122</td>
<td>56</td>
</tr>
</tbody>
</table>

A gain of 1.7 raises the measured sensitivity of Camera B from 9810 to 16,677, which we can round up to 20,000 as the valid ISO specification. This effectively reduces the FWC to 15,588 e-, pretty close to the 16,000 e- of Camera A. And, now the SNR and DR values are identical (to the precision we are calculating).

If I can non-destructively raise the ISO of Camera B to equal Camera A, and still have the same SNR and DR values as Camera A, which is the “better” camera?

I say “non-destructively” because if I add the gain using image processing tools applied to the original raw data, I achieve not only a camera output equivalent to Camera A, but if needed I can always go back to the raw data from Camera B, apply a different set of image processing values and regain the higher original maximum SNR and DR!

This technique of adding gain to change the effective ISO is a common feature of modern DSLR cameras. An adjusted sensitivity rating is called an Exposure Index or EI, and we’ll talk more about that in a subsequent article.
**Topic #7**

**How to Add (Linear) Gain using PCC**

We've discussed using gain to boost sensitivity and the trade-offs that come with that technique. Now, let's briefly look at how to add gain using PCC.

There is a set of tools called Image Tools available by clicking on the “painter’s palette” in the top toolbar of PCC.

Image Tools gives you a lot of control over how your image appears. However, all adjustments made here are non-destructive. They control how the image appears but they do not change any of the raw data. The controls you see will be a little different between a monochrome camera and a color camera.

Adjustments made in image tools are applied to the raw data and “baked into” any file you create when you choose to convert the raw images to some other format such as ProRes or h.264. But, even then you have the original raw cine file available if you want to go back to the raw data or make different adjustments.

I’m not going to go into all the adjustments available. Let’s just focus on two things: the histogram view of the image data, and the linear Gain adjustment. Here is how it looks on a monochrome camera.
In this example, the gain is set to “2”. You can make the gain adjustment by typing the desired value in the text box. Or, you can use your mouse to drag the slider.

The histogram shows the distribution of all available digital number values of pixels in the currently visible frame of the cine file. Remember, for a 12-bit camera, we can have 4096 different values ranging from 0 (totally black) to 4095 (just at the point of saturation).

This is useful because as you add gain, you’ll “spread” these values out over the full range and you will see some values approaching saturation. The histogram helps you know when you’ve boosted gain too much and driven some values to saturation. On the other hand, spreading the values out over the full range helps you to achieve greater apparent sensitivity.

Here is an example from a color camera:

![Histogram Example](image)

In this case, the gain is set to “3” and you can see that the values are pretty well spread out over the full range.