Veiling glare and Dynamic Range measurement from two images

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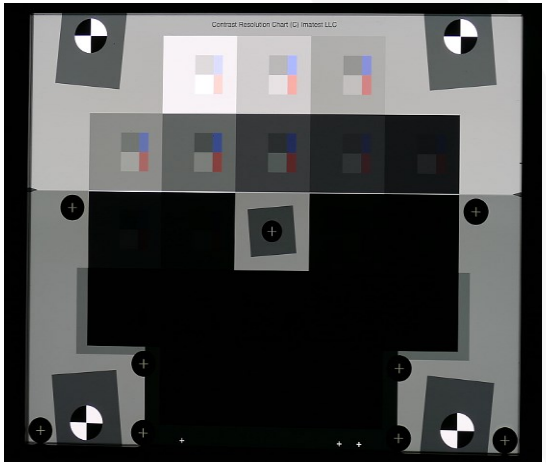
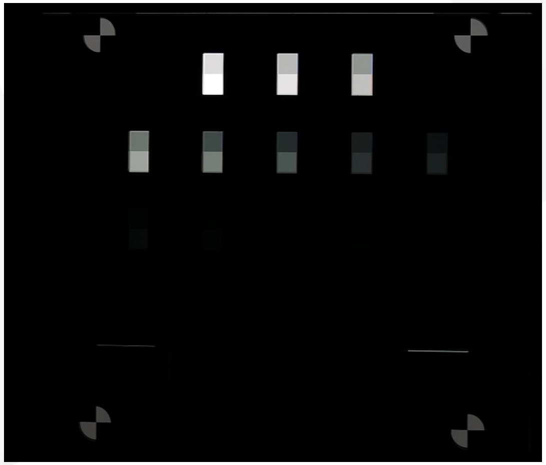
Stray light (veiling glare) degrades image quality by fogging important details in darker areas, but it can be challenging to measure.

We present a technique that uses *two* images of the Contrast Resolution chart, taken without and with a mask, to obtain

- **A measurement of veiling glare**
- **insight into its effect on camera performance, especially the visibility of objects in darker areas**
- ***two* DR measurements**





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Veiling glare

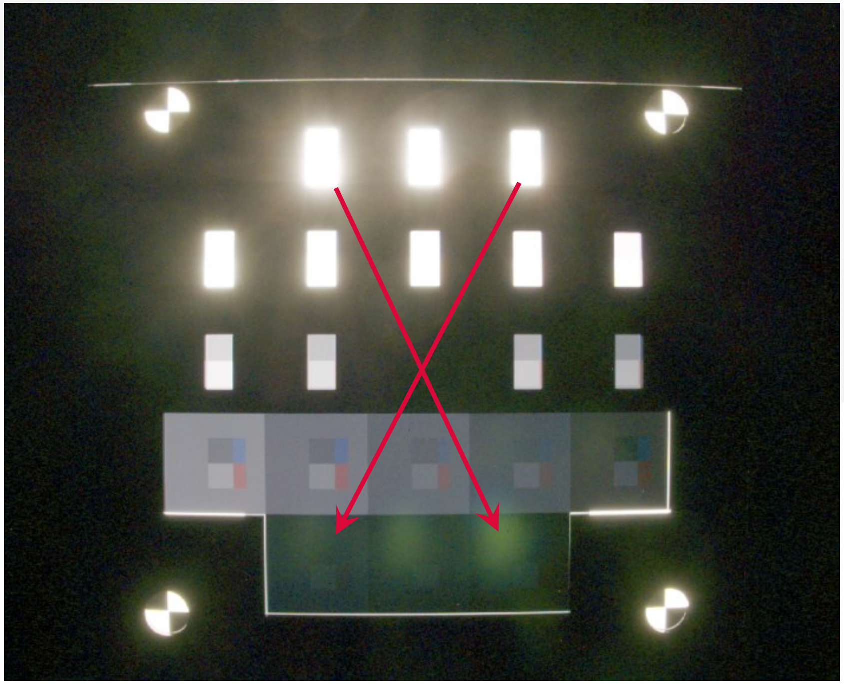
Veiling glare is stray light from bright regions inside or outside an image that can fog the entire image or portions of the image.

It can be messy because it can appear as "ghost" images, which are badly behaved, and very different for different lenses!

It tends to radiate from bright light sources, decreasing with distance.

When it appears as ghost images, it's often called "flare light".

VG can misleadingly improve Dynamic Range measurements even though it degrades the true DR.

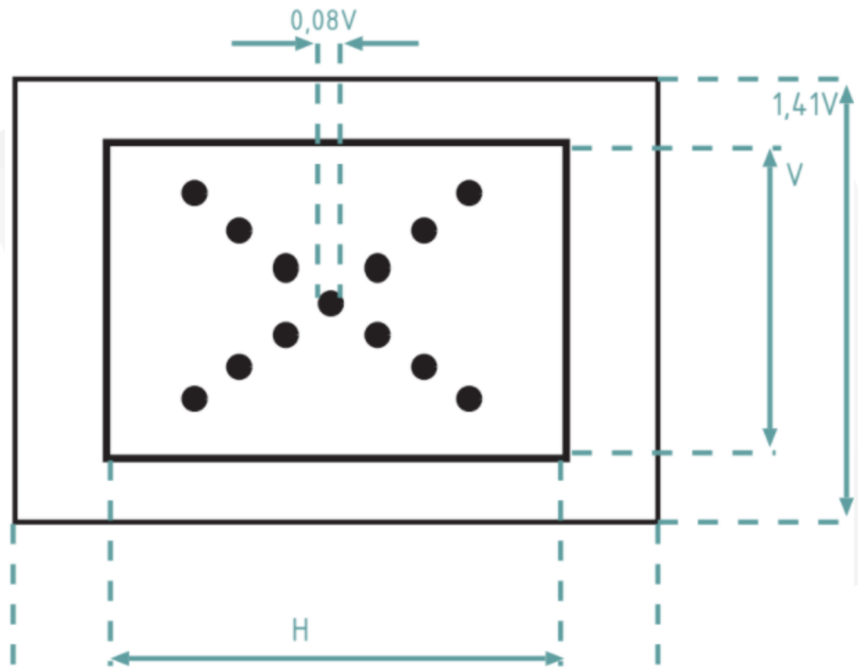


Exaggerated veiling glare from an overexposed and lightened masked image. Some ghosting is visible.
(not the same image analyzed below)

ISO 18844
(older veiling glare measurement)

ISO 18844 is a popular standard for measuring veiling glare. Targets consist of white fields with several black cavities.

The pixel level is measured inside each black cavity, corrected for gamma encoding (if any), then compared with the surrounding white areas.



Deficiencies with this technique

- **Only short-distance veiling glare is measured. Longer-distance veiling glare, for example, the effect of headlights on shadow areas at some distance, is not accounted for.**
- **There is no good way to relate ISO 18844 measurements to actual image degradation (reduction of dynamic range, fogging in shadows, etc.).**

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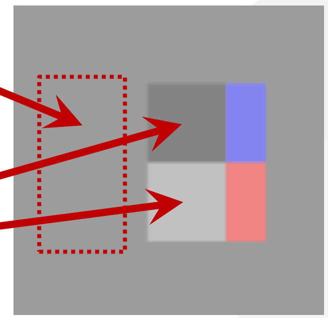
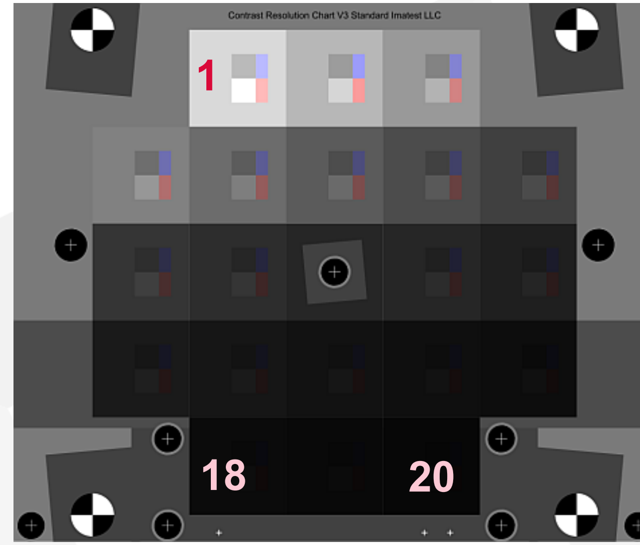
Contrast Resolution chart

The Contrast Resolution chart is a trans-missive chart designed to measure dynamic range from

(1) standard grayscale regions

(2) The difference between adjacent small patches where Δ(optical density) = 0.3 (2:1 contrast). Reduces false signal readings from offsets, veiling glare, local tone mapping, and deviations from linearity.





Large patches have density increments of 5 dB.

The mean of the patches in the bottom row (18-20) is used to measure veiling glare, much of which radiates from bright patches in the top row. The mean chart density of this row is 90 dB below patch 1 ($3.16 \times 10^{-5} \times$ patch 1)

Dynamic Range
standard measurement

Dynamic range (DR) **is defined as the range of exposures where an image has good SNR (Signal-to-Noise Ratio) and good image contrast.**

Signal s **= pixel level (from large patches)**

Image contrast c **is the slope of log(*s*).**

$$c = \frac{d(\log(s))}{d(\log \text{exposure})} \geq 0.075c_{max}$$

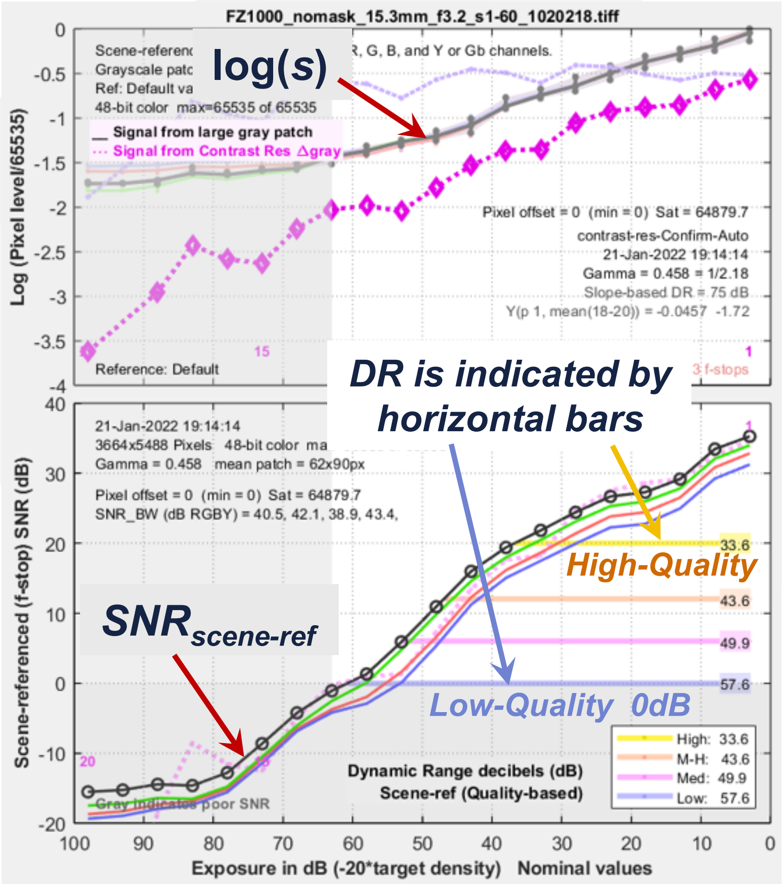
to be inside the Dynamic Range.

Contrast is usually lower in dark regions due to veiling glare

Scene-referenced SNR**, which backs out the effects of *c*, is used for standard DR.**

$$N_{scene-ref} = \frac{N_{pixel}}{d(s)/d(exposure)}$$

$$SNR_{scene-ref} = \frac{s}{N_{scene-ref}}$$



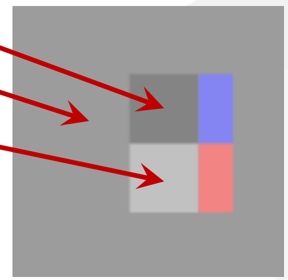
Contrast Resolution Dynamic Range DR_{CR}

DR_{CR}* is based on the difference signal Δ*s*, *which correlates with the visibility of low-contrast objects in a scene.

Contrast Resolution signal

$$\Delta s = pixel\ level_{light} - pixel\ level_{dark}$$

dark
middle
light



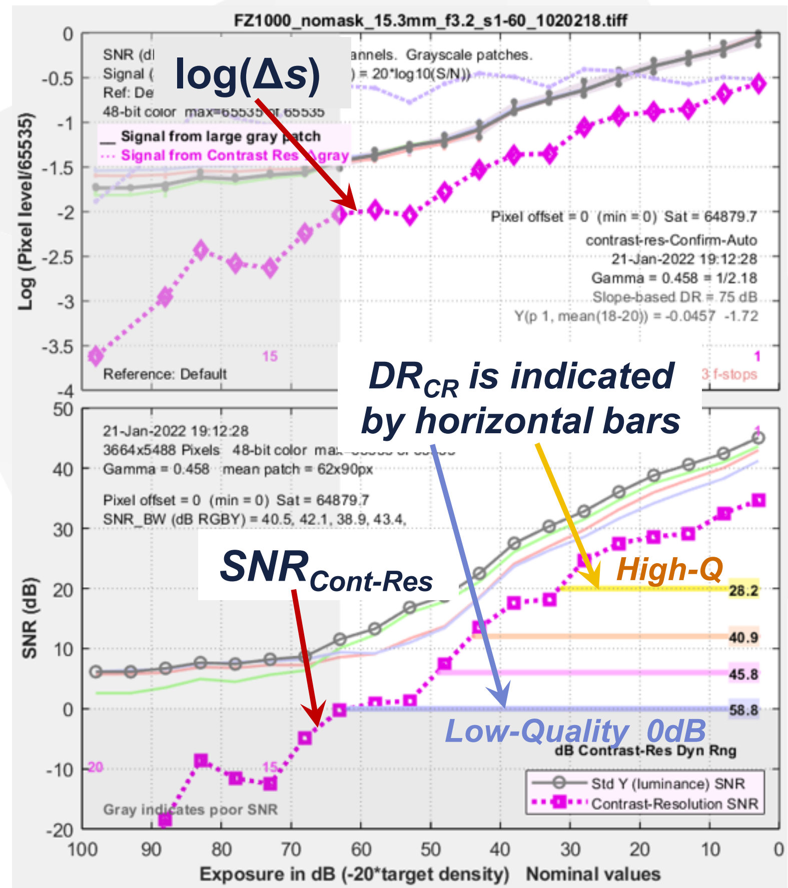
Contrast Resolution SNR

is used for DR_{CR} calculation.

$$SNR_{CR} = \frac{\Delta s}{N_{middle}}$$

***DR_{CR}* is shown as horizontal bars: 28.2 dB for high quality (*SNR_{CR}* = 20 dB), etc.**

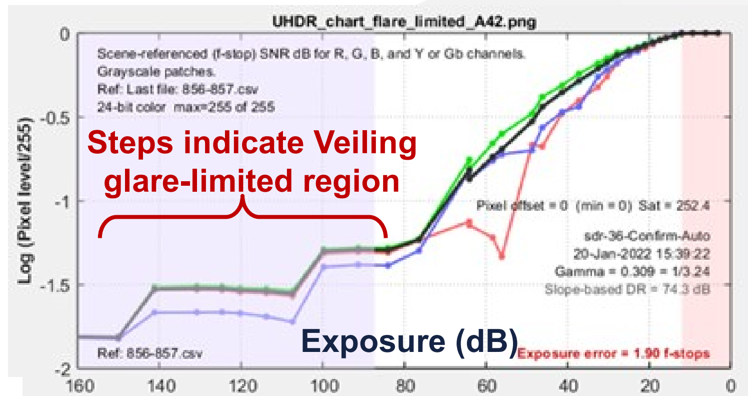
***DR_{CR}* is often similar to standard Dynamic Range, but more accurate for tone-mapped images and highly robust.**



Dynamic Range limitations

Dynamic Range can be limited by Signal-to-Noise Ratio (SNR), veiling glare, or a combination of the two. Typical cases:

- **SNR-limited in DSLR/mirrorless cameras with linear sensors and high quality lenses.**
- **Veiling Glare-limited in cameras with HDR sensors that outperform lenses. Shadow regions may be fogged.**



Response beyond 80 dB is from stray light from top of image.

HDR sensors (which are Veiling Glare-limited) are increasingly used in the automotive industry.

Apology: Because of time & resource limitations, we don't have a good example of a veiling glare-limited camera with an HDR sensor.

Signal-to-Noise Ratio (SNR)
appearance

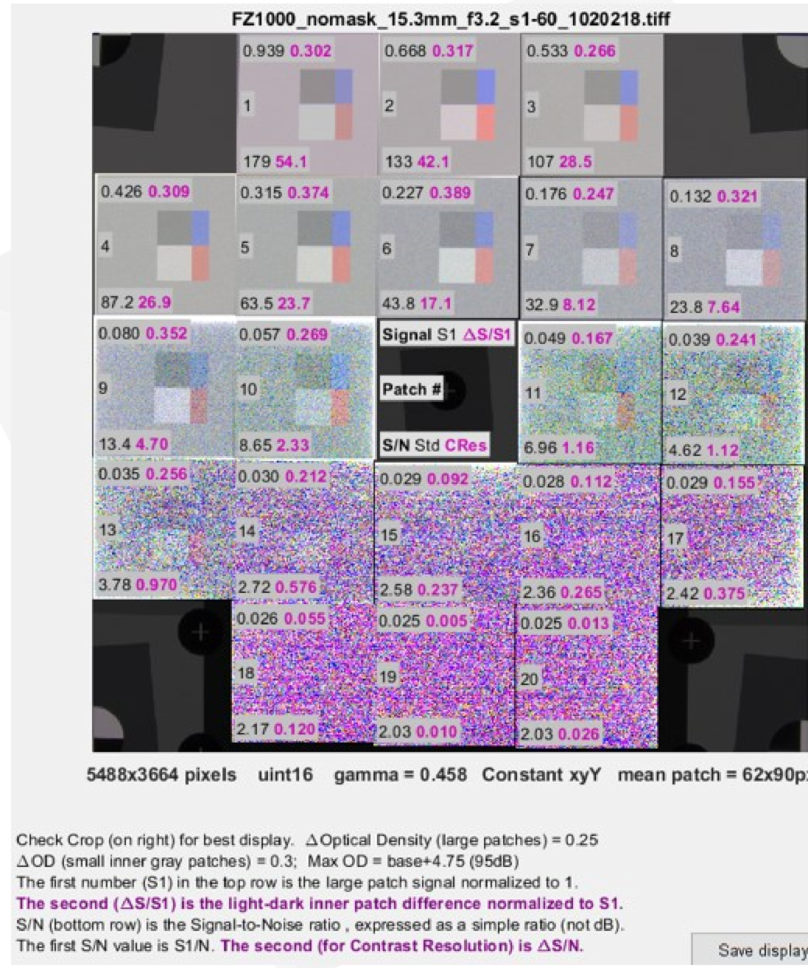
Contrast-Resolution chart with large patches displayed at the same luminance levels (*Y* from xyY).

Visibility of features declines where S/N (SNR) and contrast are low.

SNR(standard) **and *SNR$_{CR}$* (ratio; not dB) are based on *s* and *Δs*:**

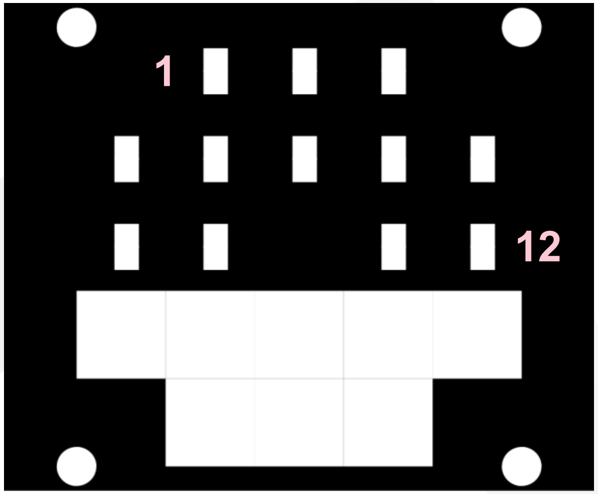
When SNR is too low,
the image is lost in noise.

When contrast is too low,
"there's no there there".

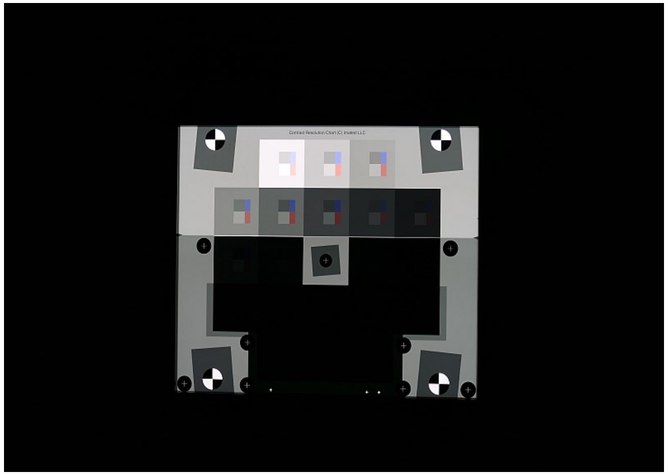


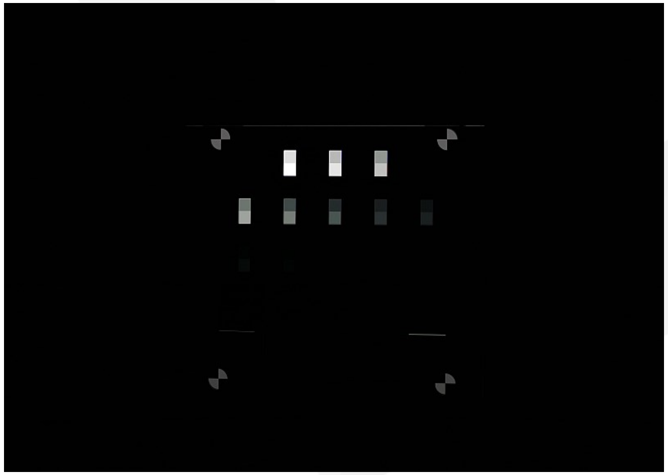
Veiling glare from two images

Veiling glare and its effects can be measured from *two* images taken under identical conditions (manual exposure) without and with an acrylic mask that covers 86% of the lighter patches (1-12), placed immediately in front of the chart.



Raw images from a superzoom camera with a 1" sensor were converted to 16-bit TIFFs. JPEGs were inadequate for this calculation.

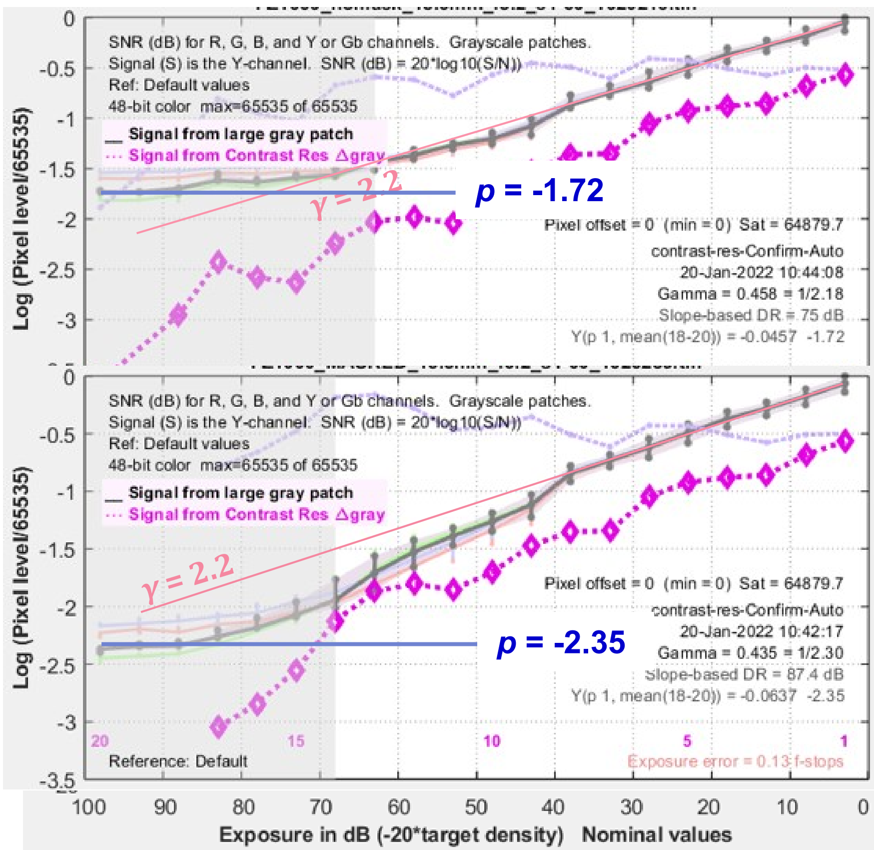


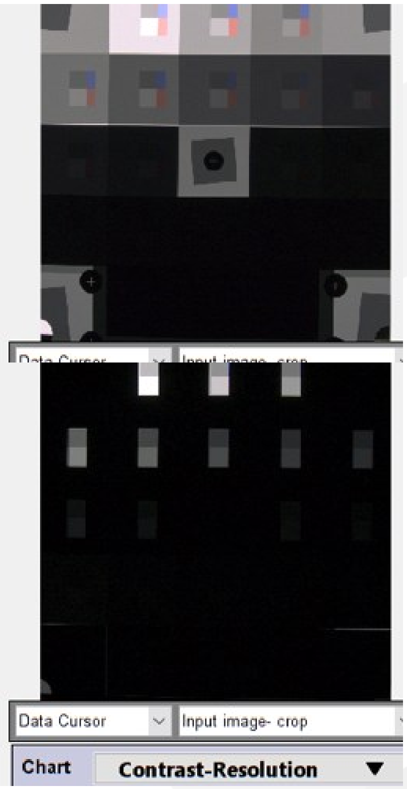


(unmasked, masked images shown uncropped)

Tonal response measurements
without and with mask

log(s)





***p* is log pixel level**

No mask

Patches 1, *m*(18-20)
p = -.046, -1.72

Δp_{nomask} = -1.67

Masked

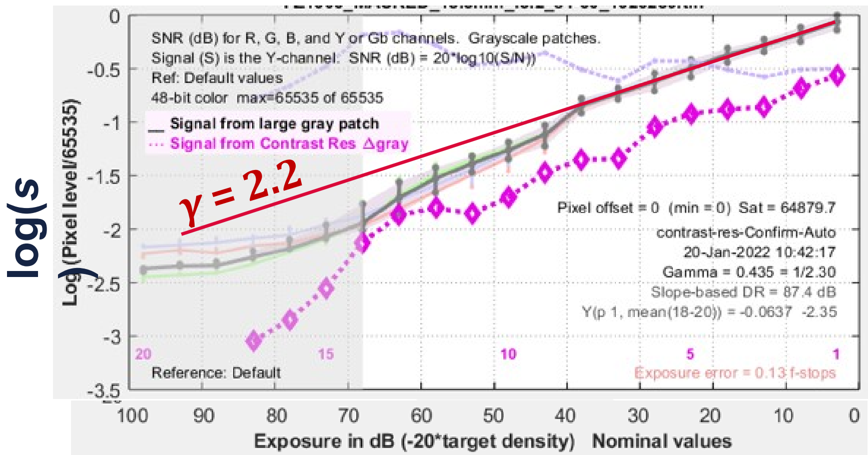
Patches 1, *m*(18-20)
p = -0.64, -2.35

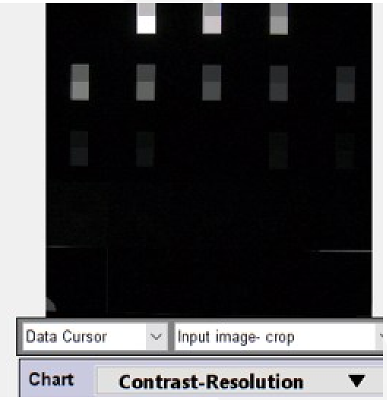
Δp_{masked} = -2.29

Δp is the difference in log(*pixel level*) between patch 1 and the mean *m* of patches 18-20 (bottom row). The next slide has an approximate equation for the illumination levels.

Linearity failure

Systems we've tested are not as linear as we expected: either due to the sensor, the image processing, or the chart calibration.





Nonlinearity manifests as response *below* the red line (for a linear system with encoding gamma $\gamma = 1/2.2$ (Adobe RGB)). Stray light would cause response to be *above* the red line.

Because of the nonlinearity, the linear Veiling Glare equation is *approximate*.

$$\Delta VG = 10^{(\Delta p_{nomask}/\gamma_{enc})} - 10^{(\Delta p_{masked}/\gamma_{enc})}$$

For the above example, $\Delta VG = 10^{(-1.67\times 2.2)} - 10^{(-2.29\times 2.2)} = 2.022\text{e-}4 = -73.9\ \text{dB}$

ΔVG is not an absolute number because the masked image has some veiling glare.

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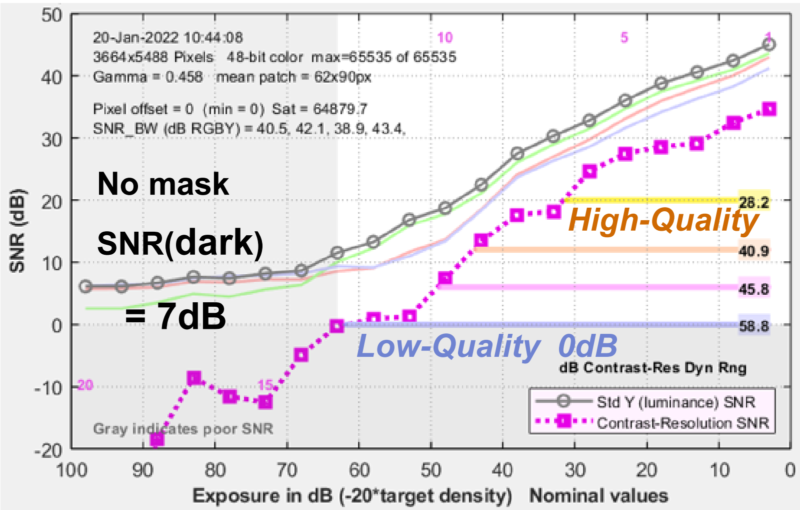
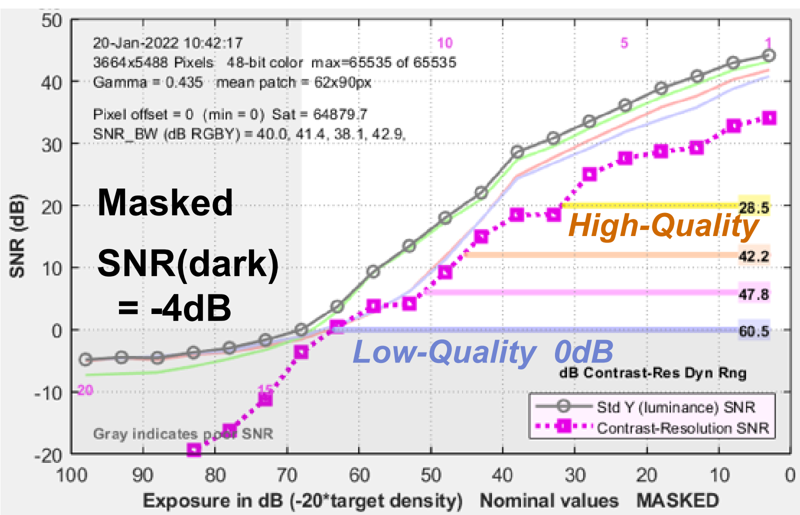
Dynamic Range measurements

without and with mask





Standard SNR (gray) in dark regions is 7dB with no mask and -4dB with the mask. This difference is an artifact of veiling glare — Standard SNR is *not* used for DR calculations.

Contrast Resolution DR (from the difference image; magenta line) is only slightly better for the masked image.

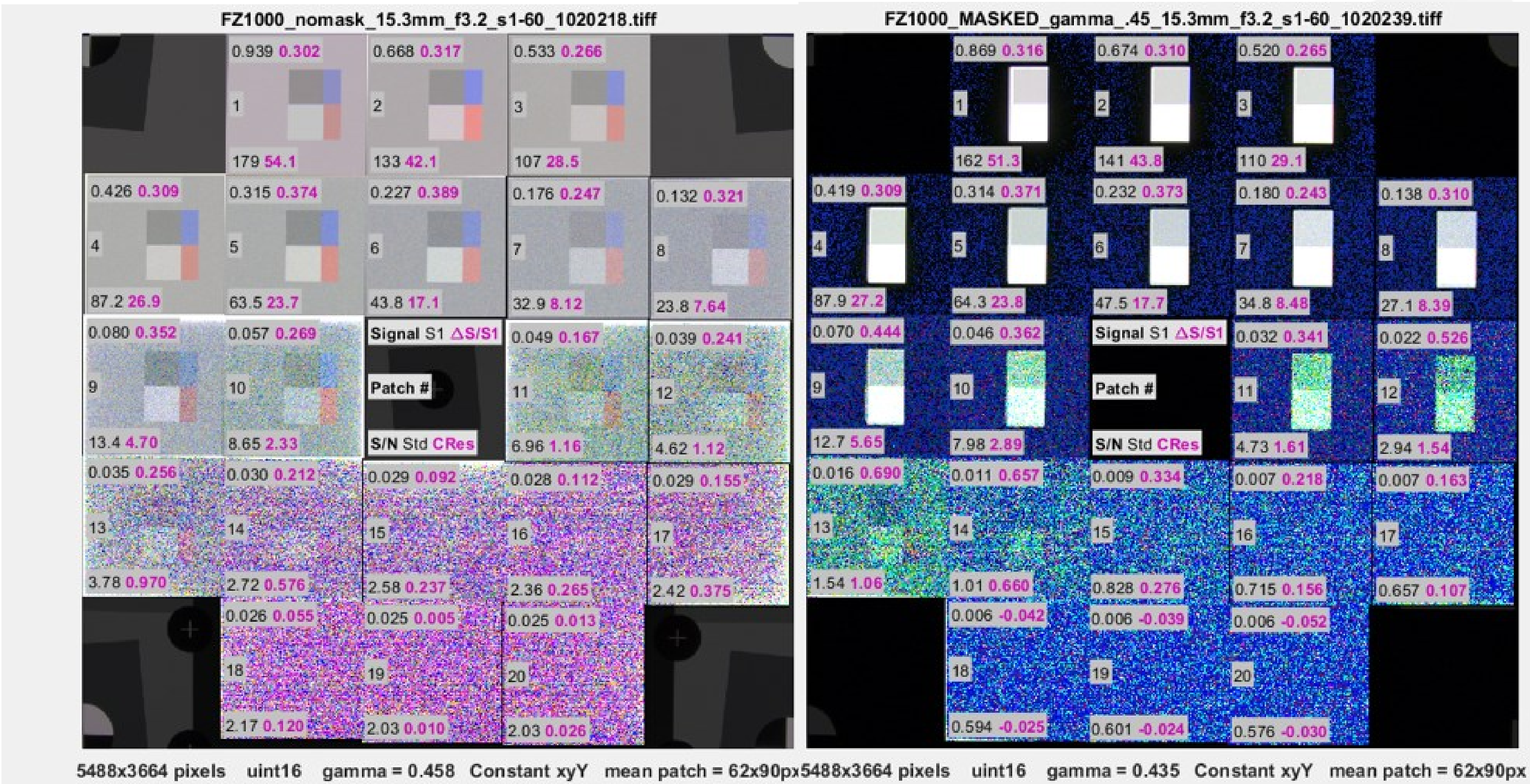
Standard DR was nearly identical.

This camera is SNR-limited.

We expect a larger difference for automotive cameras with HDR sensors, which are likely to be Veiling Glare-limited.

Equal *Y* (Luminance) image comparisons

Unmasked | **Masked**



Check Crop (on right) for best display. ΔOptical Density (large patches) = 0.25
ΔOD (small inner gray patches) = 0.3; Max OD = base+4.75 (95dB)
The first number (S1) in the top row is the large patch signal normalized to 1.
The second (ΔS/S1) is the light-dark inner patch difference normalized to S1.
S/N (bottom row) is the Signal-to-Noise ratio , expressed as a simple ratio (not dB).
The first S/N value is S1/N. **The second (for Contrast Resolution) is ΔS/N.**

Performance is similar. Contrast is reasonably good in patches 13, 14. Noise-limited.

We expect different behavior with HDR sensors.

Summary — Methods of comparing the two images

We have shown three methods for comparing Veiling Glare in unmasked and masked images.

1. **Compare the mean of the log(*pixel level*)) of patches on the bottom row. It's higher for the unmasked image. An approximate linear difference, *VG*, can be calculated.**
2. **Compare the Contrast Resolution Dynamic range (DR_{CR}); we expect larger differences for cameras with HDR sensors.**
3. **Observe the image, processed so all patches have the same luminance (*Y*). Results similar to 2.**

For veiling glare-limited cameras, veiling glare measurements are highly sensitive to chart design, framing, and illumination outside the chart,

Standardization of measurements is extremely important.

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Summary 2

This work was motivated by a concern that

- A major factor limiting automotive camera performance is stray light (veiling glare), which it can obscure important detail in shadow areas, especially in night scenes with bright lights.
- The automotive industry is not paying enough attention the effects of stray light and how best to measure it.

Important questions that I would like to see answered.

How much dynamic range is needed in automotive cameras?

Do we need detail to be visible in light sources as well as shadows?

Could it be better to minimize veiling glare than to maximize dynamic range (i.e., do lenses need more attention)?

TO DO

Measure more cameras with HDR sensors.

Improve stray light/veiling glare measurements to correlate better with camera performance.

Photograph charts under more challenging conditions — with additional bright light sources outside the chart area to simulate worst-case automotive scenarios.

Design additional test charts (we’re exploring a new chart technology; not ready for prime time.)

Continue educating engineers so they understand that camera Dynamic Range, measured from images taken with lenses, can never approach the numbers in HDR sensor specifications. This is a constant challenge.

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