

Information-based Dynamic Range

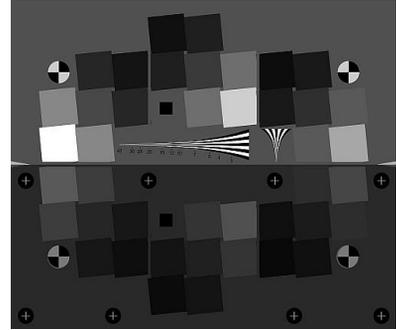
Measuring camera performance over a wide range of illumination from a single image

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Electronic Imaging, Burlingame, CA, March, 2026

Information capacity C is a fundamental metric of image quality combining sharpness (MTF/SFR), noise (or SNR), and contrast.

We present the new InfoDR chart that can measure C_4 — the information capacity of 4:1 contrast objects measured from a 4:1 slanted edge — over a wide range of exposure from a single image.

This cannot be done with current test charts.



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Information-based Dynamic Range: Contents

Brief review of information theory and C_4 information capacity

Description of traditional test charts, and why a new chart is needed to measure C_4 over a wide range of exposure.

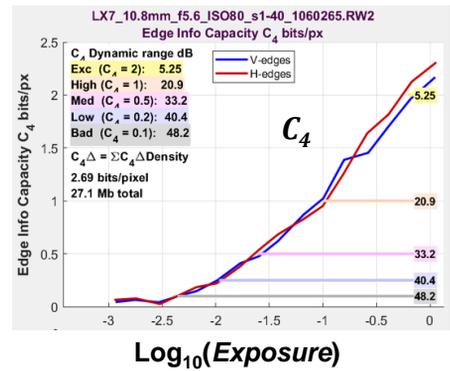
Design of the new InfoDR test chart

Light measurement

Running the InfoDR chart analysis

Key result: C_4 as a function of exposure

Examples from several cameras.



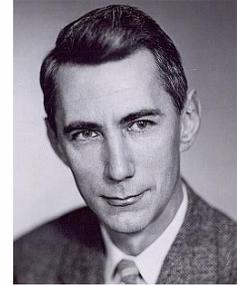
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Review of Information theory & metrics

Developed by Claude Shannon at Bell Labs in 1948-9.

Information is the amount by which the outcome of a measurement or event reduces uncertainty. Classic example: The result of a “fair” coin flip ($P(head) = P(tail) = 0.5$) has one bit of information. Lower for a biased flip.



Widely used in electronic communications, where channels are characterized by information capacity C in bits/second, which is the maximum amount of information a channel can transmit without error.

Images are communication channels where C has units of bits/pixel.

Imatest has developed a method to conveniently calculate C by measuring signal power, $S(f)$, and noise power, $N(f)$, at the same slanted-edge location.

C_4 is the amount of information a 4:1 object can convey. C_{max} — the maximum information the image can convey is calculated using extrapolation — not valid for HDR sensors and not useful for characterizing performance as a function of illumination.

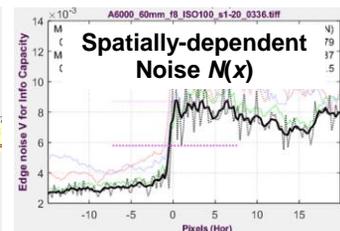
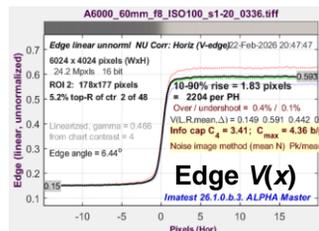
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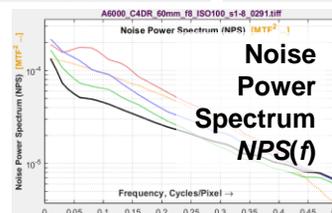
Information calculations

Two tricks are used to measure signal S and noise N or NPS at the same location from the widely-used slanted-edge pattern.

1. Spatially-dependent noise $N(x)$ from the sum the squares of each slanted-edge scan line.



2. Noise image from “inverse binning” the ROI & subtracting the original noisy ROI. Convert the 2D noise spectrum, into 1D, $NPS(f)$.



The new metrics are the basis of the proposed ISO 23654 standard.

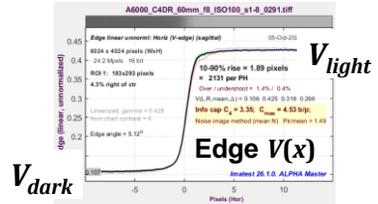
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Shannon-Hartley equation for C_4

4:1 contrast edges are specified by ISO 12233 and widely used for practical measurements.

$S(f) = ((V_{light} - V_{dark}) SFR(f))^2 / 12$ is the mean signal power derived from the edge, $V(x)$: includes sharpness ($SFR(f)$).



$$C_4 = \int_0^W \log_2 \left(1 + \frac{S(f)}{NPS(f)} \right) df$$

C_4 is the amount of information that can be conveyed in a 4:1 contrast edge.

W is always the Nyquist frequency, 0.5 Cycles/Pixel.

$NPS(f)$ is the Noise Power Spectrum, from the noise image

C_4 is a **complete** pixel-level performance metric that combines **partial** metrics: Signal amplitude, sharpness, and Noise.

Notes on information capacity and C_4

Information capacity C is (relatively) unaffected by *reversible* image processing (linear with no response nulls for $f < f_{Nyquist}$). Image processing, especially sharpening, cannot increase C .

C_4 — the information capacity of a 4:1 object — varies with exposure. 4:1 contrast is a good compromise, typical of many real-world objects of interest. Camera is quasi-linear: can calculate C for other contrast ratios.



- > 10:1 is susceptible to saturation;
- ≤ 2:1 has poor SNR.

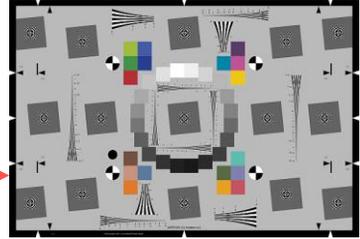
The signal used to calculate SNR is the difference between mean Digital Numbers of light – dark patches. Responds correctly to stray light.

Additional metrics derived from C_4 : NEQ (Noise Equivalent Quanta), SNR_i (ideal observer SNR, which quantifies object detectability). contrast

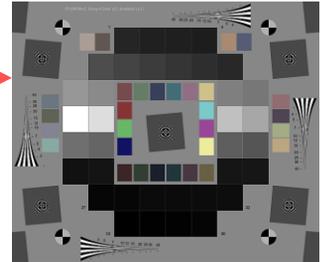
Spatial vs. tonal detail

Two types of chart are currently in widespread use.

Charts with high spatial detail Sharpness and C_4 — the information capacity of 4:1 contrast objects measured from widely-used 4:1 edges — can be measured at only one illumination level. →

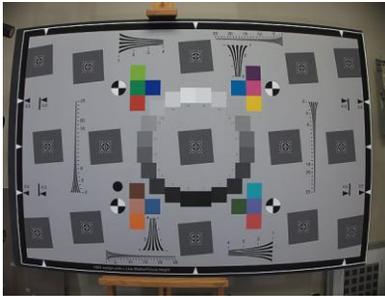


Charts with high tonal detail Traditional Dynamic Range based on Signal-to-Noise Ratio (SNR), but not C_4 , can be measured from flat patches on High Dynamic Range (HDR) test charts, usually near the center of the image. →



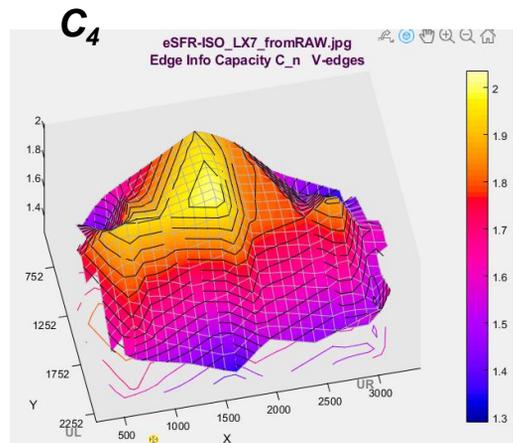
We introduce a new chart can be used to measure C_4 over a wide exposure range from a single image.

Calculating C_4 from charts with *spatial* detail

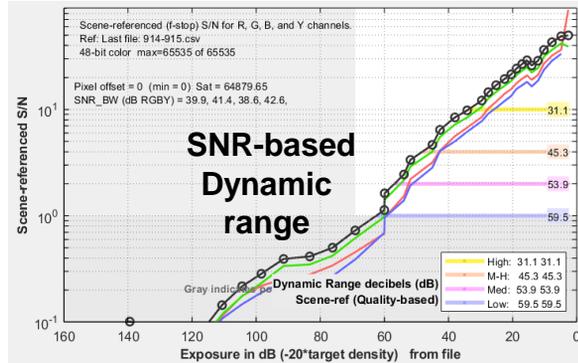
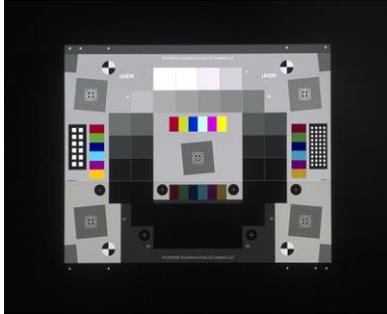


Several charts (Checkerboard, eSFR, SFRplus) can calculate C_4 with good spatial detail, but only for one set of tones (one exposure).

Multiple exposures are required for tonal detail or low light performance.



Traditional Dynamic Range: SNR measured from charts with good tonal detail, near center of the image



Signal-to-Noise Ratio (SNR) vs. exposure showing Dynamic range. Excellent tonal detail, but SNR is a *partial* metric that doesn't fully characterize performance.

Measuring C_4 over a wide tonal range (range of exposures) would be a much better indicator of performance.

The Information-based Dynamic Range (InfoDR) test chart: building blocks

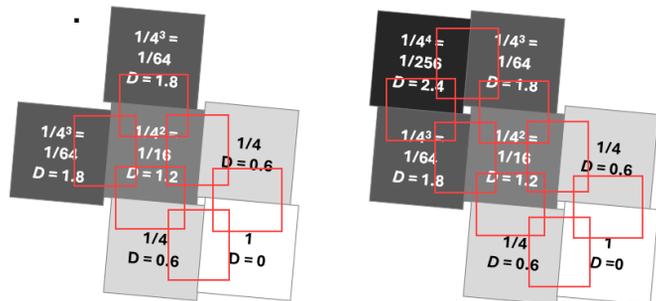
The InfoDR chart contains

a large number near-vertical and near-horizontal 4:1 contrast (Δ Density = Δ D = 0.6) slanted edges in a compact arrangement so SFR doesn't vary by much in the active area.

Mean density steps smaller than 0.6 (Δ D = 0.15, 0.2, or 0.3) in the final chart, where neighboring groups of patches are offset.

Basic building blocks (patch groups)

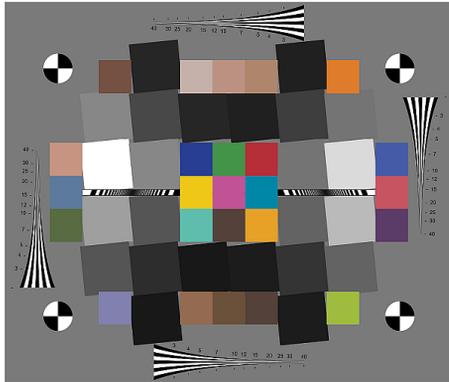
Each square differs from its neighbors by Δ D = 0.6 (4:1 contrast). Groups of {1,2,1,2} patches of the same Density.



Constructing the InfoDR test chart

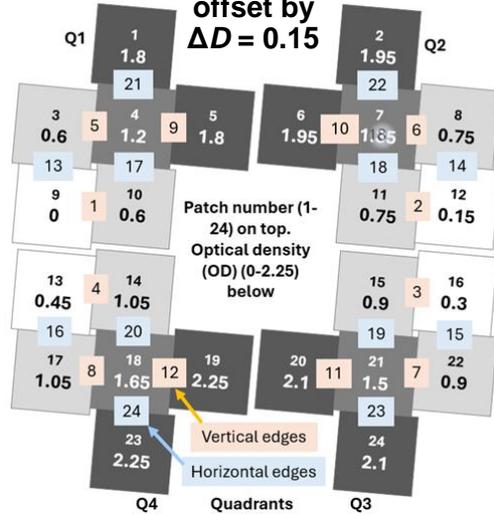
Four groups of squares are combined for the final (reflective) chart design.

Each group is offset from its neighbors by $\Delta D = 0.15$.



Final design

Schematic: 4 groups, each offset by $\Delta D = 0.15$



Two-layer film InfoDR test chart

for Dynamic Range measurements

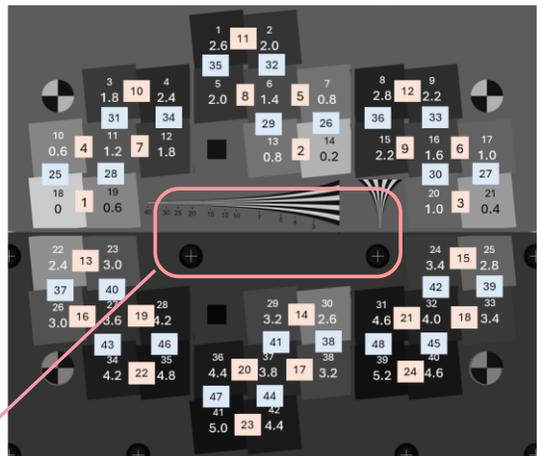
Schematic: 6 groups offset by $\Delta D = 0.20$, showing near V & H edge ROIs

Six groups of squares; each offset from its neighbors by $\Delta D = 0.20$. 2nd layer with $D = 2.4$ on bottom.

42 patches; $D_{max} = 5.2$ (104 dB);

48 (V & H) edges; Edge D -range = 4.6 (92 dB).

Patches analyzed sequentially from light to dark: last good MTF is kept when SNR becomes too low to measure MTF.

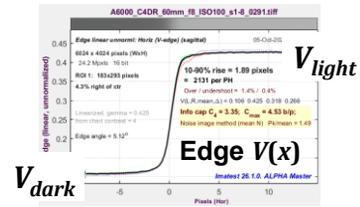


V2 (modified) design leaves open space near the chart center where reflections are worst.

Edge contrast adjustment for calculating C_4

4:1 contrast is the nominal value for calculating C_4 .

But transmissive film charts can vary enough so that individually-measured reference files are supplied with each chart. Contrast can differ from 4:1.



The edge density increment is $\Delta D_i = D_j - D_k$ for adjacent patches j and k . Contrast ratio is $10^{\Delta D_i}$.

To correctly calculate C_4 for each edge i , replace $\Delta V_i = (V_{light} - V_{dark})$ with

$$\Delta V_{i-corrected} = \Delta V_i \cdot 10^{(\text{mean}(\Delta D) - \Delta D_i)}$$

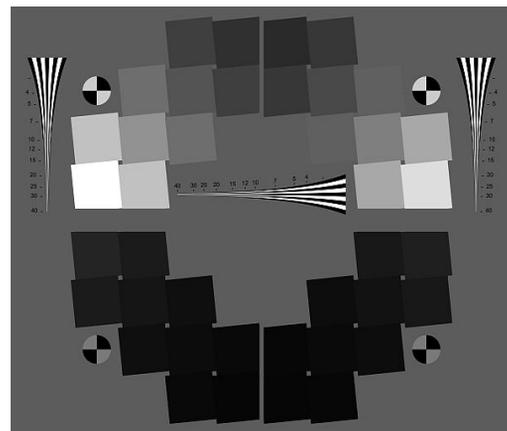
Where $\text{mean}(\Delta D) \cong 0.6$.

Alternative InfoDR (C_2) test chart (design – not yet built)

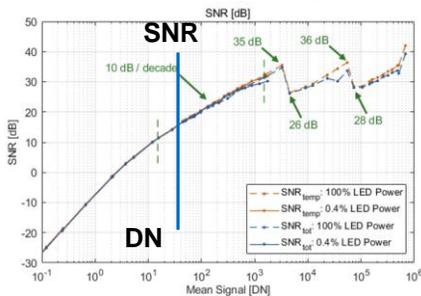
For examining anomalies near steps in HDR sensor behavior

Measures C_2 over a wide tonal range: 75 dB in steps of 3 dB (0.15 OD) (not quite HDR).

Same analysis as C_4 charts, but may require several image captures.



Suggested by Uwe Artmann



Using the InfoDR test chart

The active area of the chart are should **NOT** fill the frame — it should be near the center, where SFR is relatively consistent. 600 vertical pixels are sufficient.

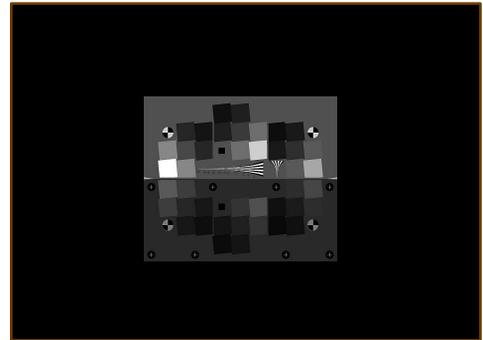
The chart **must** be in good focus (unlike traditional SNR-based DR measurements).

Measure and enter the lightbox luminance in candelas/meter², lens aperture A (f-number) and shutter speed t (seconds) to get absolute light level readings.

Photograph the chart in a dark environment.

Save raw files (if possible) and convert to RGB with minimal processing.

Enter the (individually-measured) density reference file into the program.



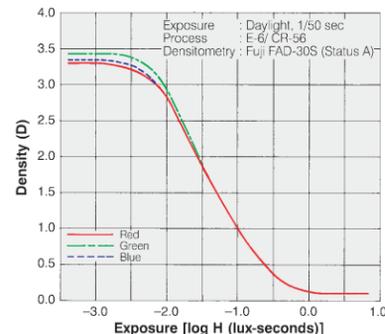
Light measurement

Use a luminance meter pointed at the lightbox to measure lightbox luminance, L_{source} in cd/m².

Patch luminance is $L_{patch} = L_{source} 10^{-D_{patch}}$, where D_{patch} is the patch density from the density reference file.

The x-axis selections for the C_4 plot:

- three *relative* measurements: \log_{10} exposure (-Density), Exposure dB, and F-stops (EV) and
- three *absolute* measurements: Luminance cd/m² @ patch (L_{patch}), $H = \text{Exposure in Lux-sec @ sensor}$, and $\log_{10}(H)$, where $H \cong 0.65 L t / A^2$ from ISO 12232:2019, Annex B.



Film characteristic curve with x-axis, Exposure [$\log_{10} H$ (lux-seconds)]

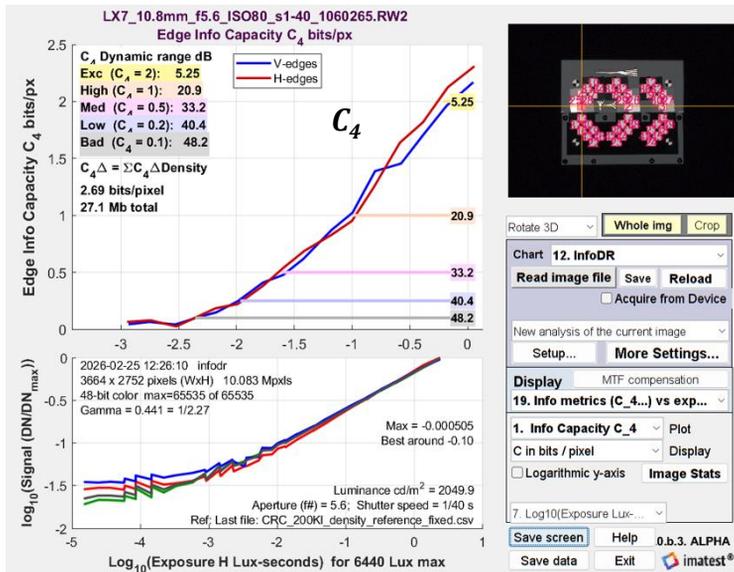
C₄ vs. Exposure (log₁₀(H)): the key InfoDR result

Upper

C₄ plot, showing Dynamic Range and a new heuristic figure of merit, C₄Δ

Lower

OECF (tonal response): Log(DN) vs. exposure

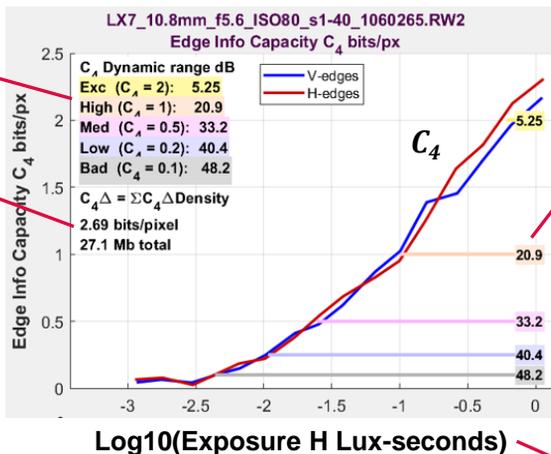


C₄ vs. Exposure (log₁₀(H))

The C₄ curve (similar for Vertical and Horizontal edges) is the best metric of pixel-level performance, especially at low light levels.

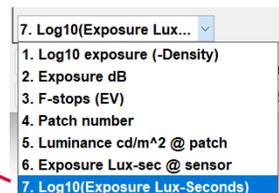
Dynamic Range values

Preliminary heuristic Figure of Merit: C₄Δ is the area under the C₄ curve, where the x-axis has log₁₀ units (same as Optical Density)



Dynamic Range bars and values:

Excellent (C₄ = 2 b/p) through Bad (C₄ = 0.1 b/p)



Tonal response ($\log_{10}(DN/DN_{max})$ vs. Exposure)

Tonal response is calculated from patches. Also available with traditional Dynamic Range measurements.

Bumps from stray light (?)

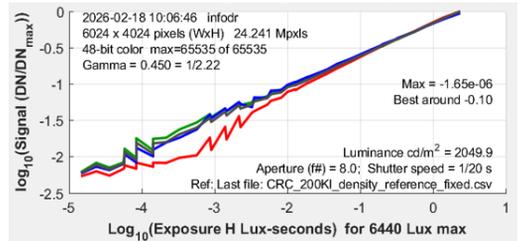
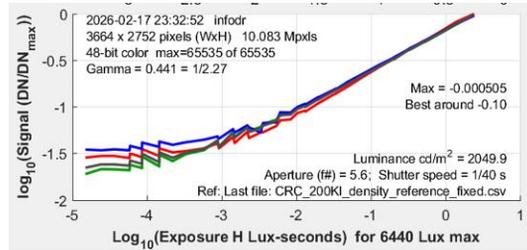
For raw-converted files with a straight gamma curve (Adobe RGB, *not* sRGB, which has a linear section),

$$D_{min} = \min(\log_{10}(DN/DN_{max}))$$

is a meaningful metric for veiling glare from stray light.

Upper: compact camera with 3:1 zoom lens. $D_{min} \cong 1.6$

Lower: APS-C camera with prime macro lens. $D_{min} = 2.2$



$\log_{10}(\text{Exposure } H \text{ Lux-seconds})$

Results: Compact 3:1 zoom camera

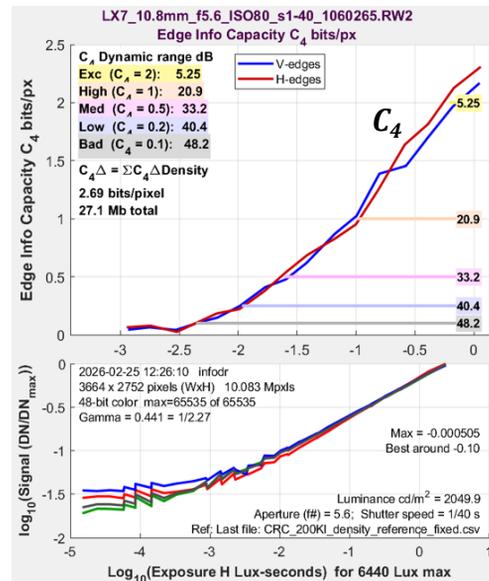
Compact camera with Leica-branded 3:1 zoom, f/5.6, 2.14 μm pixels, 10 Mp

$$C_4\Delta = 2.74 \text{ bits/px} = 27.6 \text{ Mb total}$$

High, Low DR (dB) = 21.3, 39.7 dB

$$D_{min} = -1.6 \text{ average}$$

Note that although the plot has the same shape as the previous camera, the x and y-axis scales are different.



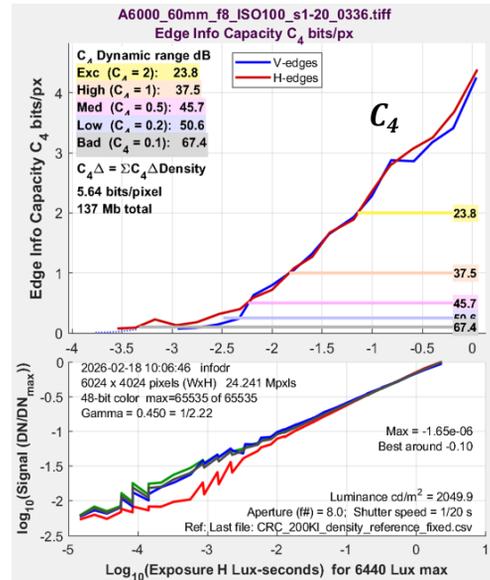
Results: APS-C camera with prime macro lens

APS-C camera with Canon 60mm
f/2.8 prime macro, f/8, 3.88 μm pixels,
24 Mp

$C_4\Delta = 5.64$ bits/px = 137 Mb total

High, Low DR (dB) = 23.8, 45.7 dB

$D_{min} = -2.2$ (excellent)



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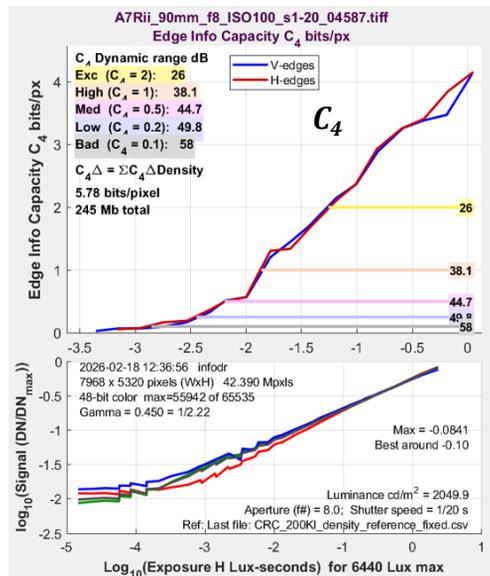
Results: Full-frame camera with prime macro lens

Premium full-frame camera with
Sony 90mm f/2.8 prime macro, f/8,
3.88 μm pixels, 42.4 Mp

$C_4\Delta = 5.78$ bits/px = 245 Mb total

High, Low DR (dB) = 26, 49.8 dB

$D_{min} = -2$ (very good)



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Results: Pixel 8 Pro camera phone

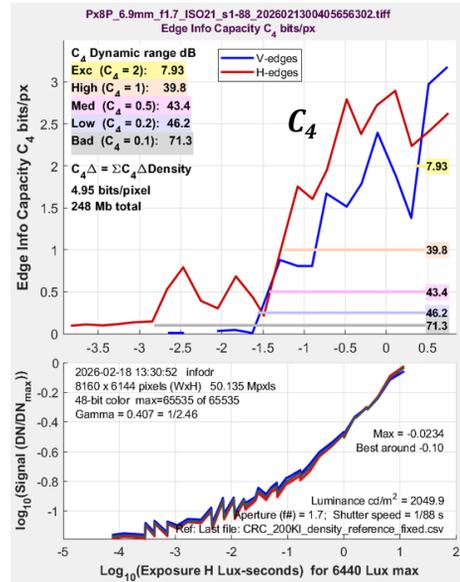
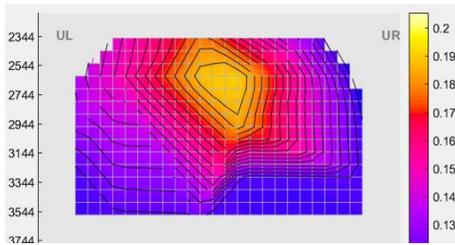
Pixel 8 Pro camera, 1.2 μm pixels, 50 Mp

$C_4\Delta = 4.95$ bits/px = 248 Mb total

High, Low DR (dB) = 39.8, 46.2 dB

$D_{min} = -1.2$ (issues with stray light)

The rough C_4 response was caused by SFR falloff from the image center.



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Results: iPhone 15

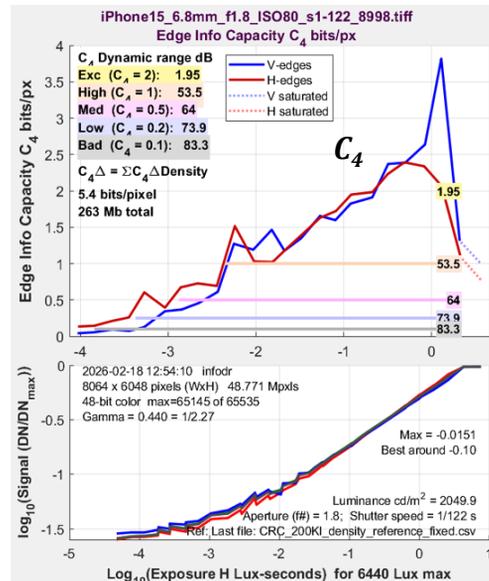
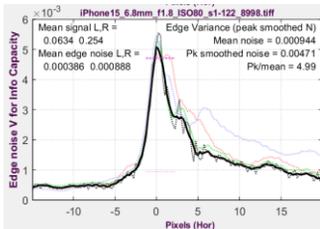
Camera phone, f/1.8 1.22 μm pixels, 48.8 Mp

$C_4\Delta = 5.4$ bits/px = 263 Mb total

High, Low DR (dB) = 53.6, 73.9 dB

$D_{min} = -1.6$

There appeared to be noise reduction in the raw images, evidenced by the peak in the spatial noise — not seen in other raw images. Even with noise derived from peak, performance was outstanding.



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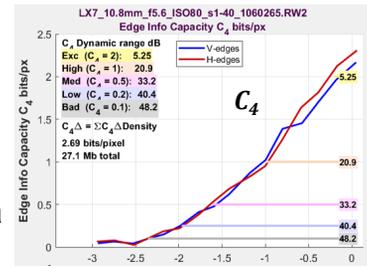
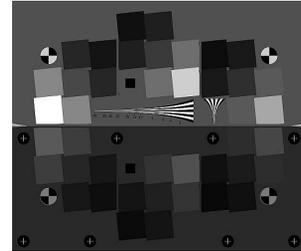
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Summary

We have developed the new InfoDR test chart with a compact design that measures C_4 information capacity (for 4:1 contrast objects) over a wide range of exposures.

- measures low light performance
- more meaningful results than standard Dynamic Range measurements.

Although It has excellent *tonal* detail (Δ Density = 0.2 = 4 dB over a 92 dB range), a chart with more *spatial* detail, such as Checkerboard, eSFR, or SFRplus, should be also be measured for a more complete camera characterization.



Key result: C_4 vs. Exposure H

Thank you.

Contact norman@imatest.com.

Documentation is linked from

image information metrics



InfoDR



Please visit the Imatest booth. I'm happy to answer questions.



www.imatest.com/solutions/image-information-metrics/
www.imatest.com/support/docs/26-1/infodr-instructions-part-1/