About the Contrast Range of Digital Photo Cameras

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Motivation

Digital photo cameras have a bad reputation regarding their contrast range. This reputation probably results from their nature to easily generate burned out highlights or coloured areas without any detail. This is caused by their transmission curve, i.e. the brightness value for each pixel in relation to the incoming light intensity. This curve ends relatively hard at it's upper end. This results in all picture areas with a brightness above a certain threshold becoming clear white or a totally saturated colour without any details. Picture processing cannot improve anything here because the information is lost irrecoverable.

Some photographers therefore claim that digital cameras cannot handle high subject contrasts and therefore are useless for serious photography. This article shall compare the actual capabilities of digital photo cameras with the performance of conventional slide and negative film. The reader may make up his own mind if he can be satisfied with these capabilities or if he prefers to stick to the established chemical photography.

Starting Point

Regarding the subject contrast which can be handled the classical (colour) negative film is the ideal instrument. With increasing exposure the negative film density increases and saturation is reached only very very slowly. This results in the capability to cope with enormous contrast ranges of up to 13 f-stops (further on referred to as EV = exposure value). Only very few scenes present such a huge contrast range. With a negative film you are well prepared to record details in all brightness ranges, from the darkest shadows up to the brightest highlights, assumed that the picture is exposed correctly. Underexposure leads to loss of detail in the shadows and thus must be avoided. Overexposure is relatively uncritical as there is a lot of headroom. Only the overall density of the negative is increased what leads to coarse grained (noisier) pictures. Fig.1 schematically shows the typical density or blackening curve of a negative film depending on the exposure (drawn curve).

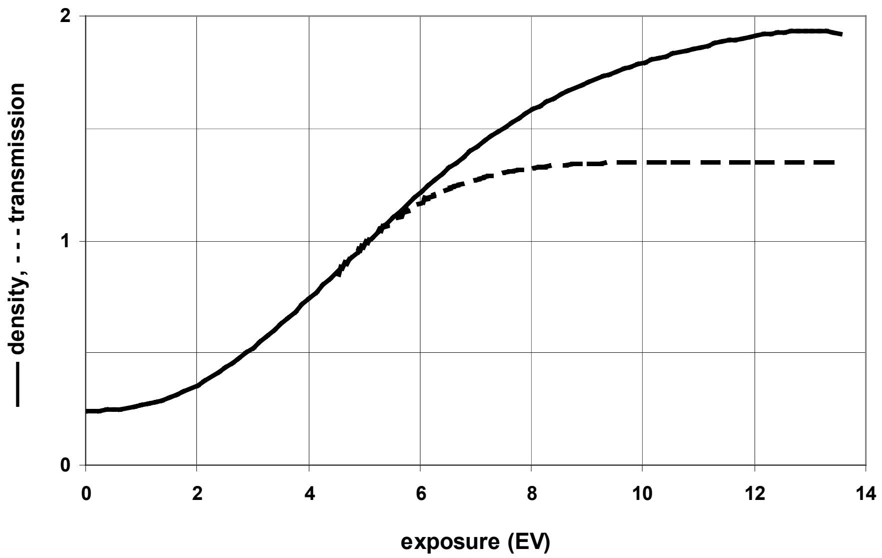


Fig.1: Density curve of negative film (——), transmission curve of slide film (- - -).

Within a certain range the darkening of the film can be influenced by the development process. This also effects the possible contrast range, but shall not be discussed here. Usually the approximately linear part of the transmission curve is used. It is located in the lower third of the curve. The lower end of the curve is called *sag* (here at about 1 EV). Below the curve meets the *fog* where no detail is recorded. The upper part above the linear range is called *shoulder*. The non-linear behaviour of negative film in the shoulder area is quite useful and is the source of the wide exposure margin of this film. You should not misinterpret this as a statement, that this wide contrast range can be transferred onto a photo print. In best case a photo print can display a contrast range of 1:60 which translates into approximately 6 f-stops. Compromise has to be made here. When processing high-contrast pictures a decision for details in the highlights or shadows is necessary. Classical darkroom techniques like dodging and burning can help to expand the usable contrast range when creating photo prints. Nevertheless, negative film holds enough information to offer these possibilities.

A slide film does not offer such reserves. It's typical contrast range is 5-6 EV. In the lights the transparency curves kinks relatively hard (Fig.1, dotted line). Subject details that are brighter than this kink point are lost irrecoverable when using slide film.

Digital photos show a quite similar curve form like slide film. Here we face three interesting questions:

1. Where is the kink point compared with slide and negative film?
2. Can the kink point be influenced comparable with variations in the development of chemical films?
3. Which impact do different sensor sizes have on the contrast range?

To anticipate the answers here:
1. It lies for digital photo cameras usually above the kink point of slide film, but below the horizontal part at the shoulder of negative film.
2. Yes.
3. Size matters.

The rest of this article deals with the exact position of the kink point, i.e. the actual contrast range of digital cameras and with the details around the answer on the other two questions.

Methods

The characteristics of slide and negative film are well known. Consequently this article deals with the investigation of the *usable* contrast range of digital photo cameras. What is claimed *usable* is subject to certain individual judgement and depends within some limits on the demand of the user. You can find more about this further below.

Cameras:
- *Canon EOS 20D*. This camera represents the modern single lens reflex (SLR) camera. I chose this camera because it showed a good contrast range in product tests and was praised for it's low noise levels. Sensitivity setting: 100 ISO, lens: Sigma 18-125 DC 3,5-5,6. This camera's sensor resolves 8.2 megapixels and measures 15x22.5 mm. Thus each sensor segment has a surface area of 41.1 μm^2.
- *Olympus C5060 WZ*. A good digital view finder camera with reasonable picture quality. Sensitivity: 100 ISO, resolution 5 megapixels, sensor size 7.18x5.32 mm. This results an a size of 7,6 μm^2 for each sensor element.
- *Minolta Dimage Xi*. This camera represents the ultra compact digital photo cameras. It's sensor measures only 5.27x3.96 mm. The resolution is 3.1 megapixels. Thus each sensor element has only 6.7 μm^2. This camera does not know a RAW mode, but offers only JPG and TIFF files. Sensitivity was 100 ISO.

Target: *IT 8.7 calibration chart by* Wolf Faust

Light source: Tungsten halide lamp, 50W, ~2800K

RAW data processing: *Canon Digital Photo Professional* for generating linear data sets, *Photoshop Camera RAW* for all other RAW processing steps.

Exposure series: As the target offers only a contrast range of 6.1 EV the presented contrast range had to be extended by series of over and under exposure. The neutral exposure was found with an 18% grey chart. Subsequently exposure series were taken from –6 to +9 f-stops. Together with the contrast range of the target this represents a contrast range of 21 EV. No commercially available transmission or reflection target offers such a wide contrast range. The photos were recorded in parallel as RAW and JPG files of the highest quality setting. The white balance for the JPG files was set manually to 2800K.

Measuring the target: The RAW files were converted into linear 16 bit TIFF files by using the Canon RAW converter. Subsequently the brightness values of all grey fields were measured in Photoshop's grey mode. The brightness values of all analysable shots were averaged for each grey field. Thus the relative brightness of all target fields were fixed under the given lighting conditions.

Evaluation of the brightness values: The JPG files were slightly corrected within Photoshop for their white balance and afterwards measured in grey mode. The RAW files were processed in Photoshop Camera RAW. The white balance was adjusted, all other settings were standard as following: brightness: 50, contrast +25, saturation: 0, shadows: 0, sharpening: 0, luminance smoothing: 0, colour smoothing: 25. Groups of 16 bit TIFF files were generated for all slides for the following Photoshop Camera RAW Exposure settings: -4, -2, 0, +2, +4 f-stops. Subsequently the files were measured in grey mode.
The measurements were linked to the target brightness values, corrected by the according over or under exposure. Further on the grey fields were analysed with the step chart analysis mode in Norman Koren's Imatest software in RGB mode for their individual noise components.

Results

The following diagrams show the pixel brightness values as a function of object brightness. Each diagram is shown with two scales: on the left is the double logarithmic diagram for close evaluation of the dark areas, right is the semi-logarithmic diagram for close evaluation of the light areas. The horizontal axis is scaled in EV and thus logarithmic per se. This corresponds with the viewing behaviour of the human eye. The position of the zero-point is arbitrary and without importance as we deal only with *differences* in brightness. OK, let's start with the Canon EOS 20D.

Camera JPG

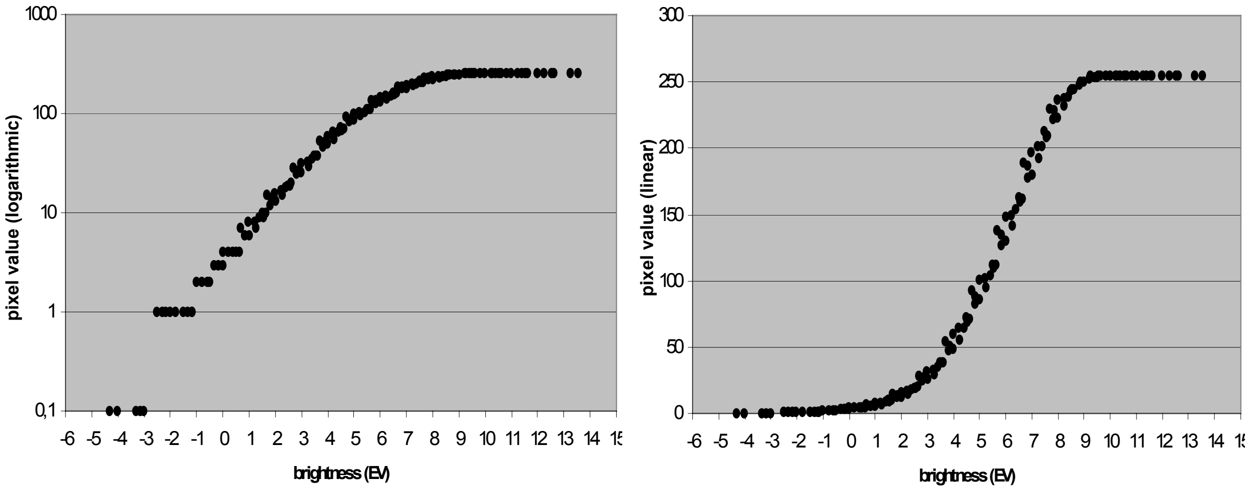


Fig.2: Transmission function for camera JPG (Canon EOS 20D)

The JPG files delivered by the camera show a transmission range from –3 EV to +9.5 EV (total 12.5 EV). This is the contrast range where differences in brightness are still recognised *metrological* and are translated into different pixel values. But this range cannot be used *photographically* as the details are covered in the dark picture areas by picture noise. The result is not good looking in these areas.

For a reasonable photographic usage a wider differentiation is needed between picture noise and picture detail. The technician calls this "signal-to-noise ratio". It is a subjective judgement where this border lies and it depends on the personal quality demands of the viewer. In order to evaluate this border as objectively as possible and to generate comparable results between different measurements I used the Imatest software to find the point where the RMS noise value exceeds 0.1 EV. This quality

threshold is thus set relatively high and corresponds with the criterion that is used in online publications like *Imaging Resource* (www.imaging-resource.com).
From this results a photographically usable contrast range for camera JPG files from +0.9 EV to +9,5 EV (total 8,6 EV). This value is also given in other publications on the EOS 20D. The curve slope is similar to slide film with extended contrast range. The curve runs into saturation quickly at it's upper end. This is clearly different from negative film which shows a further rise over several EVs.

Photoshop Camera RAW, ±0 f-stops (neutral setting)

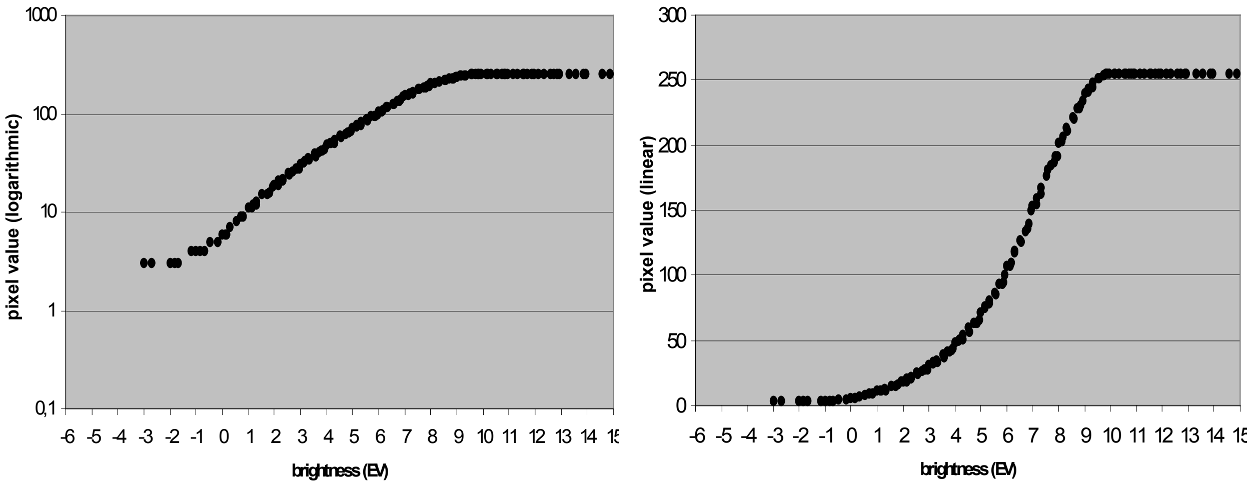


Fig.3: Transmission function for Photoshop Camera RAW (±0 f-stops, Canon EOS 20D)

Converting the camera's RAW data with Photoshop Camera RAW results in a slightly different picture. The curves is kinked a bit sharper than the JPG curve at the upper end. In the lower part it ends about one EV earlier. The total transmission range lies between -2 EV and +9.5 EV (11.5 EV). The photographically usable range lies between +1 EV and +9.5 EV (8.5 EV). This means that the Photoshop RAW converter transmits a slightly narrower contrast range than the camera JPG function. It limits the shadows earlier and cuts the lights a bit harder. Practically this difference should not be visible. But another factor is in favour of the RAW picture. The overall noise values are better than in the JPG picture. This may result from missing compression artefacts in the RAW files. The JPG picture shows RMS noise values for middle grey fields around 0.016 and 0.04 in the lower usable shadows. The RAW picture has noise values of 0.014 for middle grey and 0.028 for usable shadows. This means that the shadow areas which are particularly endangered by noise have almost only half the noise of the JPG files.

Photoshop Camera RAW, -2 f-stops Exposure Correction

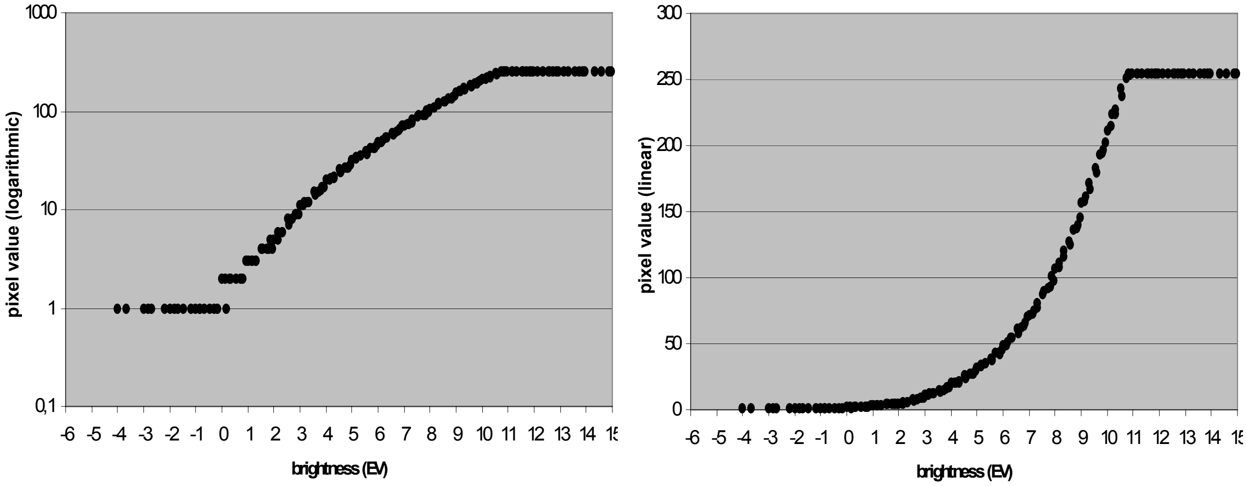


Fig.4: Transmission function for Photoshop Camera RAW, -2 f-stops exposure correction
(Canon EOS 20D)

Here comes the really exciting part. How much exposure margin is hidden in the RAW file? How much is Photoshop Camera RAW able to recover?

In the upper part the curves now kinks even sharper than the JPG curve, but it is shifted by at least 1.3 f-stops upwards. This does not come naturally, as the information must be actually contained in the RAW file, though the picture area is overexposed by 1.3 f-stops. The sensor does not saturate up to this point, but only the data processing for the JPG picture limits the transmission range at the upper end. As expected the lower end of the curve is shifted upwards by 2 f-stops. The total transmission range lies between 0 EV and +10.8 EV. The photographically usable range lies between +1.7 EV and +10.8 EV (9.1 EV).

The EOS 20D shows an exposure margin of 1.3 f-stops which can be used to rescue overexposed pictures.

Photoshop Camera RAW, -4 f-stops Exposure Correction

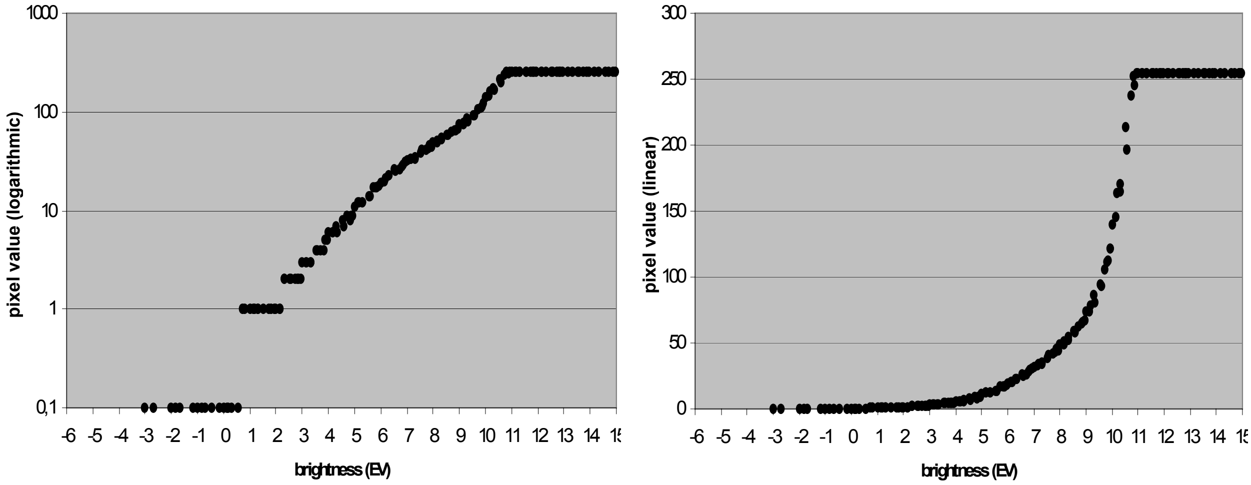


Fig.5: Transmission function for Photoshop Camera RAW, -4f-stops exposure correction
(Canon EOS 20D)

Excessive tuning at Photoshop-RAW's exposure correction obviously does not help. The upper end of the curve is pinned at 10.8 EV. Only the lower end is shifted upwards accordingly. But of interest is the behaviour of the curve in it's upper third. Here you can observe an effect which is described by Bruce Fraser in his excellent book *Camera RAW with Adobe Photoshop CS*. Different from what might be expected an extensive exposure correction towards smaller values does not result in a shift of the whole curve, what should result in white pixels becoming grey, but the white point remains where it is and only the transmission's curve upper part is bent downwards. This effect can be seen well when comparing the logarithmic diagrams 4 and 5. Besides that the exposure compensation in Photoshop Camera RAW does not give any advantage when going below -2 f-stops.

Photoshop Camera RAW, +4 f-stops Exposure Correction

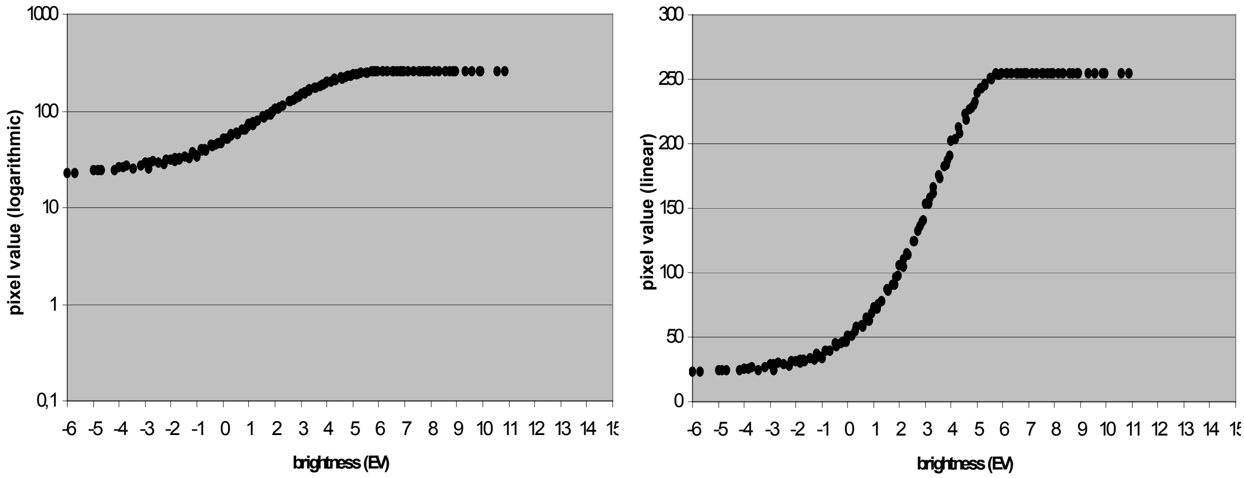
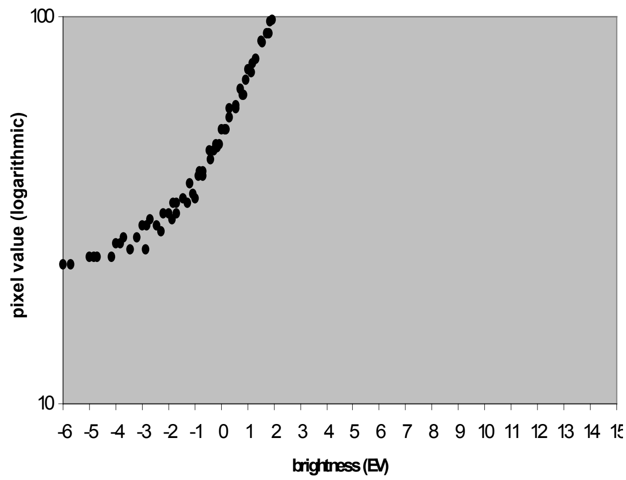


Fig.6: Transmission function for Photoshop Camera RAW, +4f-stops exposure correction (Canon EOS 20D)



Fix.7: Transmission function for Photoshop Camera RAW, +4f-stops exposure correction, detail (Canon EOS 20D)

Let's take a look if we can recover something from the RAW file at the lower end. Besides a rise of the curve's lower end up to values around 25 we can observe a shift down to –4 EV for the point where exposure differences still can be differentiated. Here the lower noise of the RAW file is advantageous. The photographically usable range ends at +0.9 EV. The upper end of the curve moves down to +5.8 EV. The total contrast range is 9.8 EV, the photographically usable range is 4.9 EV.

A positive exposure correction with Photoshop Camera RAW reveals one f-stop margin at the lower end of the brightness spectrum. This can be used to rescue underexposed pictures, but may be paid with higher noise in the shadows.

The contrast data for the Olympus C5060 WZ and the Minolta Dimage Xi were evaluated with the same methods and are shown in the following table.

Conclusion
Here one more time all measurement data for the contrast ranges.

contrast range	range total (EV)	total (EV)	photo-grafically usable range (EV)	photo-grafically usable (EV)	comment
negative film		13			very soft shoulder
slide film		5-6			hard shoulder
Canon 20D camera JPG	-3 – 9.5	12.5	0.9 – 9.5	8.6	soft shoulder, noisy shadows
Canon 20D PS-RAW ±0 f-stops	-2 – 9.5	11.5	1 – 9.5	8.5	hard shoulder
Canon 20D PS-RAW -2 f-stops	0 – 10.8	10.8	1.7 – 10.8	9.1	very hard shoulder
Canon 20D PS-RAW -4 f-stops	0.6 – 10.8	10.2	2.3 – 10.8	8.5	extreme hard shoulder, dimmed lights
Canon 20D PS-RAW +4 f-stops	-4 – 5.8	9.8	0.9 – 5.8	4.9	hard shoulder, low noise in the darkest shadows
Canon 20D sensor total (RAW file)	-4 – 10.8	14.8	0.9 – 10.8	9.9	total contrast range of the sensor
Olympus C5060 PS-RAW ±0 f-stops	-0.6 – 9.5	10.7	1.9 – 9.5	7.6	hard shoulder
Olympus C5060 sensor total (RAW file)	-2.4 – 10.5	12.9	1.9 – 10.5	8.6	total contrast range of the sensor
Minolta Dimage Xi JPG & TIFF	0.1 – 9.5	9.5	2.6 – 9.5	6.9	hard shoulder, no RAW mode available

Recently Fuji made an interesting step forward in this subject when presenting their Fujifilm FinePix S3 Pro digital SLR camera. This camera utilises their Super CCD SR sensor. This sensor has additional smaller sensor elements besides the normal, big sensor elements. Their purpose is to capture extended highlight details. This costs a bit of extra noise in the shadows (about 0,8 EV less usable shadow range compared to the EOS 20D), but offers in the highlights 3 EV extra margin in RAW mode and 2 EV extra margin with it's special "extended range JPG mode". This new technology goes significantly beyond previous sensors and defines the current state of the art in digital camera's contrast management. Canon could adapt it's own JPG algorithms in order to give access to the hidden 1.3 f-stops in an own "extended JPG mode".

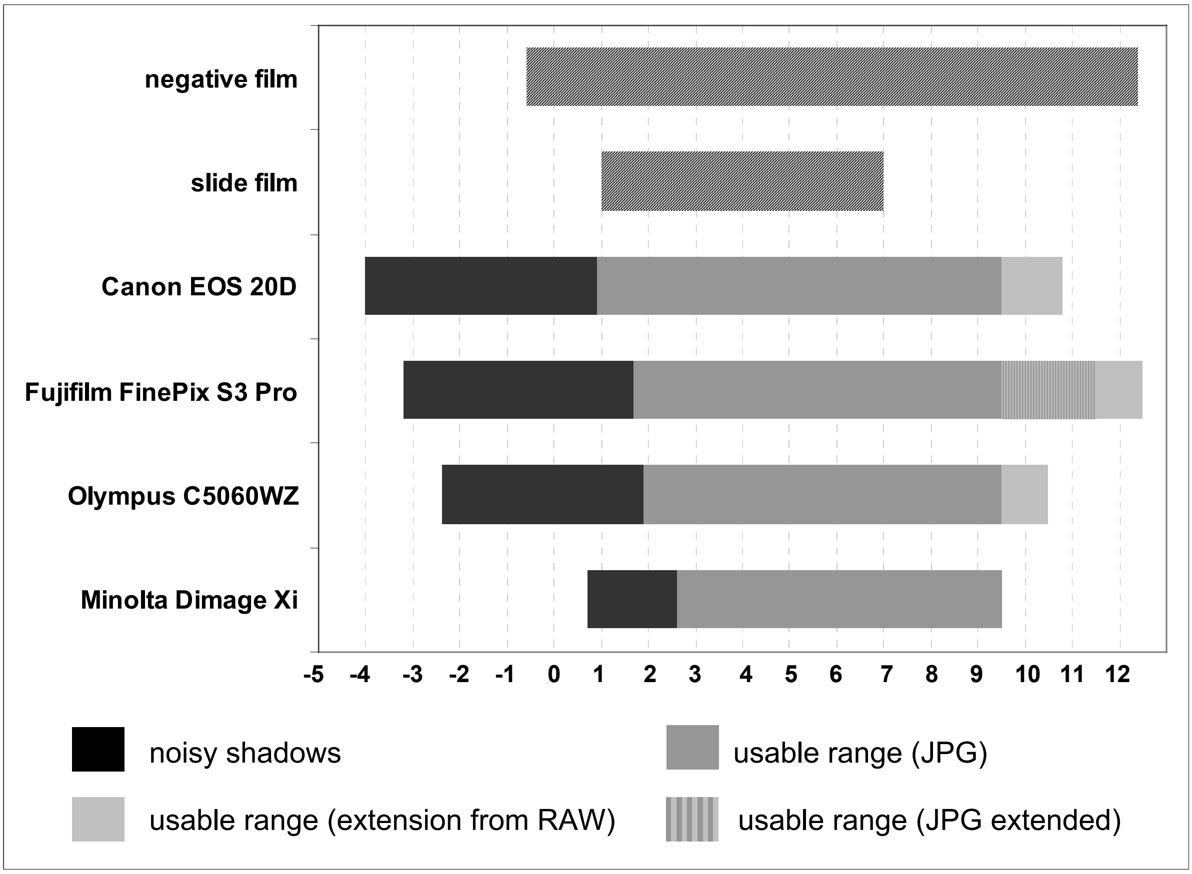


Fig. 8: Contrast range of different camera types

Summary

Modern digital photo cameras can deal with a contrast range of about 15 f-stops. This is quite comparable to negative film and far beyond the capabilities of slide film. This range can be made accessible by taking photos in RAW mode and subsequently processing them with the (Photoshop) RAW converter. Thus the RAW mode is correctly entitled the *negative of digital photography*. The photographically usable range for the **Canon EOS 20D** is 9.9 f-stops. **8.6 f-stops** of these are transferred into the **JPG file**. Fuji pushes the upper end of the usable contrast range even further with it's SR type CCD sensors.

The Olympus C5060 WZ shows in an uncorrected RAW 7.6 photographically f-stops. In the lower part the small sensor limits the usable range by more than one f-stop due to increased noise compared to the EOS 20D. In the upper part one f-stop can be recovered when using the RAW mode. The usable total contrast range for the **Olympus C5060 WZ** is **8.6 f-stops**. This is 1.3 f-stops below the Canon EOS 20D. Not a bad result when you take into account that each sensor element surface area is here less than 20% of the Canon EOS 20D.

The **Minolta Dimage Xi** naturally has a hard time with it's small sensor elements and the missing RAW mode. The usable contrast range in JPG and TIFF mode is **6.9 f-stops**. Possibly this value is even somehow improved by the camera's internal noise reduction algorithm. Due to the missing RAW mode this cannot be investigated and the sensor's actual contrast range remains unknown.

This investigation shows that modern digital cameras come close to chemical film regarding their contrast range and are far beyond slide film. This extra margin should be made accessible by consequent use of the RAW mode. Especially in situations where the white balance for a JPG picture cannot be adjusted perfectly (like in underwater photos, where strong shifts between the colour channels can extend to several f-stops) this margin is of great value. Bigger sensors offer bigger margins for overexposure and underexposure as well.

Compared to the JPG file the RAW file of the Canon EOS 20D contains 1.3 f-stops exposure margin at the upper end, the Fujifilm FinePix S3 Pro contains even 3 extra f-stops in it's RAW files. The lower end of the photographically usable range remains fixed despite all manipulation attempts. It is defined by the camera's sensor noise. If you are ready to accept some picture noise in the lowest shadows or if you are ready to take the effort of dampening this shadow noise in your picture processing software as much as 5 additional f-stops open up with (maybe partially usable) picture detail.