1 Introduction

As demonstrated in Part I (published in SMPTE Journal 2009) , there are currently no plausible standards for defining sensitometric performance data (dynamic range and sensitivity) in digital motion picture cameras. However, for the development and manufacture of the Alexa camera system, a meaningful and easily reproducible metric was badly needed. The following article describes a process developed in Arnold and Richter's Image Analysis/QM department. During the development phase, this procedure served as for technological comparisons of professional still and motion picture cameras. Since the start of production in June 2010, this process forms part of the quality assurance procedures for every Alexa produced.

In principle, digital sensor data can be calculated by multiplying arbitrary amplifications, and therefore sensitivity, in the process chain. DSLR cameras impressively prove that sensitivity ranges from 100 – 100,000 ASA aren't uncommon. But because even the finest digital technology must obey the vile laws of physics, mathematical amplification (or reduction) has natural limits. The image quality in the form of the translatable dynamic range degrades because it's limited by noise in the dark areas and clipping in the light areas of the image.

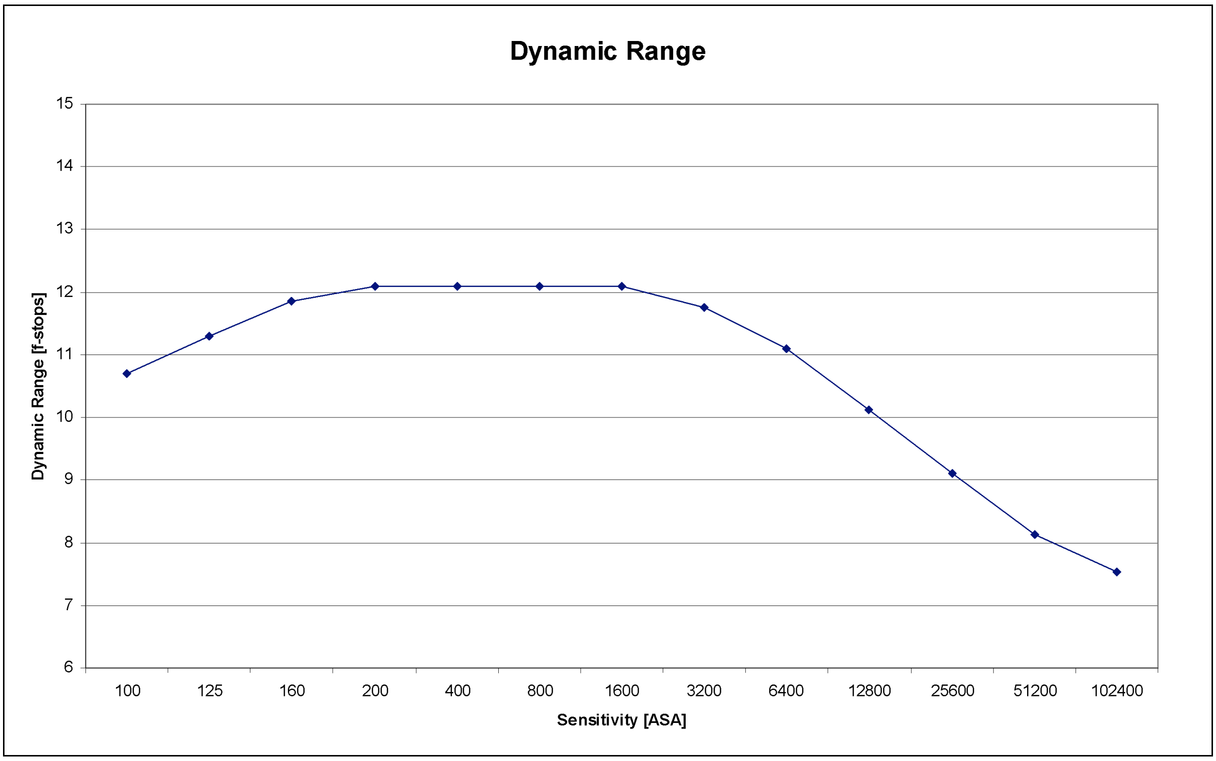


Figure 1: Dynamic range of a DSLR system

Figure 2: Loss of dynamic range in light areas of the image with low EI settings

The theory that the new measurement technology uses as its basis is very simple and can be summarized in 4 assumptions.

1. Trying to describe a digital camera system with a "native" sensitivity, as with the speed of an film emulsion, doesn't make sense. The adjustable EI value on the camera that can be measured with a light meter should, in future, be called the rating. It relates to the object brightness reached by the mapping point *M*. In digital cinematography this brightness corresponds with 40% signal in the luminance channel.

2. Sensitivity is no longer a value but the distance from the Mapping Point *M* in the direction of lower object brightness to the point *S (Threshold Value)*, the first point at which the digital signal is capable of conveying local information. This distance is given in apertures.
For the example in figure 3, the nomenclature would be:
"At EI400, the camera system has a sensitivity of 7.7 from the Mapping Point."

3. Dynamic range is the distance from the threshold value *S* to the clipping point *C* in f-stops.

4. The sensitometric characterization of a camera system is described by stating the area of maximum dynamic range.

$$EI160^{+5}_{-9} - EI1600^{+7}_{-7}$$

or explicitly as a rating

$$EI400^{+6,3}_{-7,7}$$

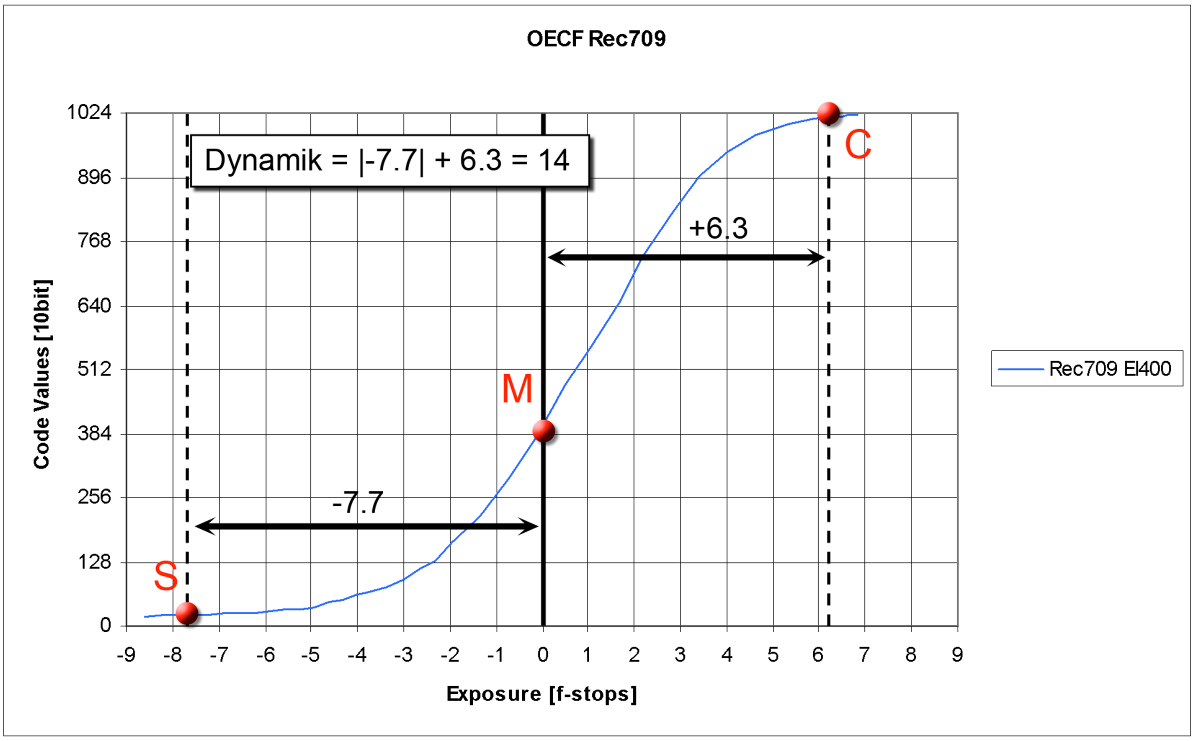


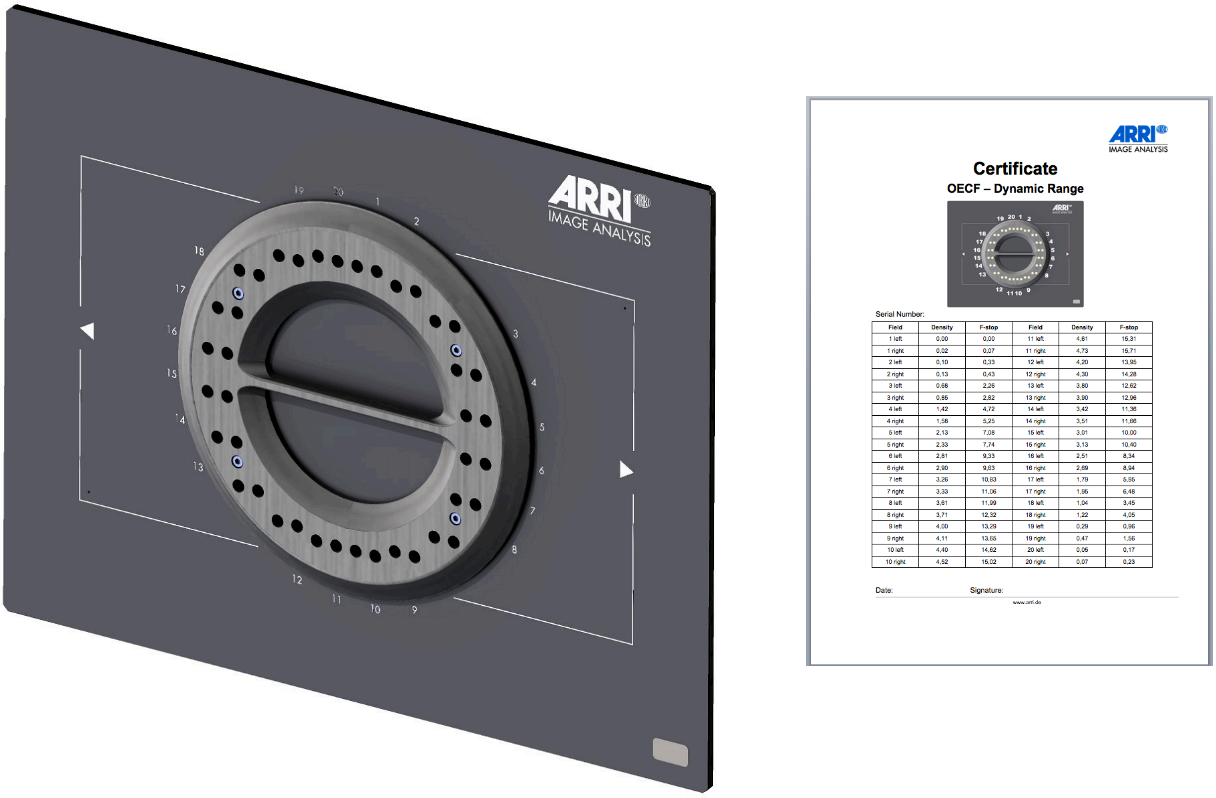
Figure 3: Threshold (Sensitivity Point) S Maping Poinz M and Clipping Point C in the OECF

2 Measurement set up

2.1 Test image requirements

Dynamic range and sensitivity should be measured in a single test image. With sequential attempts (multiple images with differing lighting levels), the possibility of a result being influenced by adaptive filters in the process chain can't be ruled out. Physiologically, the question of how much contrast can be transmitted in one image (simultaneous contrast) is more important than sequential contrast.

The test image should deliver at least 16 f-stops of dynamic range. This requirement could not be fulfilled with any standard test image and therefore the following procedure was developed.



ARRI
IMAGE ANALYSIS

Certificate

OECF – Dynamic Range

Serial Number:

Field	Density	F-stop	Field	Density	F-stop
1 left	0,00	0,00	11 left	4,61	15,31
1 right	0,02	0,07	11 right	4,73	15,71
2 left	0,10	0,33	12 left	4,20	13,95
2 right	0,13	0,43	12 right	4,30	14,28
3 left	0,68	2,26	13 left	3,80	12,62
3 right	0,85	2,82	13 right	3,90	12,96
4 left	1,42	4,72	14 left	3,42	11,36
4 right	1,58	5,25	14 right	3,51	11,66
5 left	2,13	7,08	15 left	3,01	10,00
5 right	2,33	7,74	15 right	3,13	10,40
6 left	2,81	9,33	16 left	2,51	8,34
6 right	2,90	9,63	16 right	2,69	8,94
7 left	3,26	10,83	17 left	1,79	5,95
7 right	3,33	11,06	17 right	1,95	6,48
8 left	3,61	11,99	18 left	1,04	3,45
8 right	3,71	12,32	18 right	1,22	4,05
9 left	4,00	13,29	19 left	0,29	0,96
9 right	4,11	13,65	19 right	0,47	1,56
10 left	4,40	14,62	20 left	0,05	0,17
10 right	4,52	15,02	20 right	0,07	0,23

Date: Signature:

www.arri.de

Figure 4: ARRI DRTC Dynamic range test chart with certificate

The set up uses a metal plate with 40 centrally arranged holes with a piece of B/W film under each one. This film is lit using an ARRILASER Film Recorder. Optical densities over 2.5 are reached by placing multiple strips of film over each other. Theoretically, these could be reached with a combination of ND filters but tests have shown that these have a very high IR transparency. Apart from that, they bleach faster than B/W material (archive film for color separations).

The test image is lit with a halogen lamp in an integrating sphere.

The optical density rating of the film strip in the test image is established using V-lambda (Dvis) and assumes the channel separated RGB interpretation of a camera also 'sees' a neutral scene brightness.

2.2 Test set up requirements

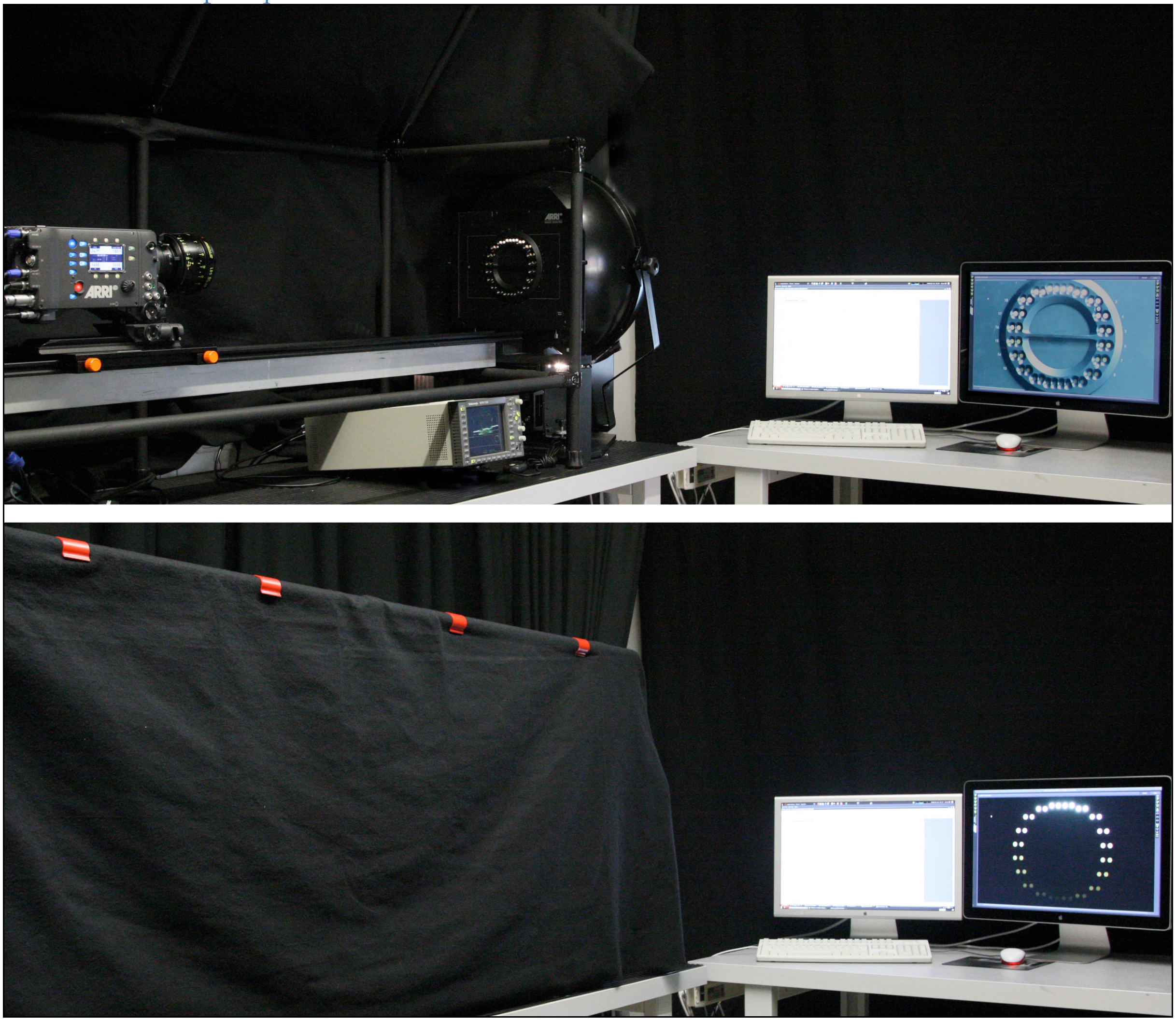


Figure 5: Reduction of scattered light during the test shot

The test set up should produce as little scattered light as possible!
With a lightest surface luminance of 800 cd/m2, a deviation of 0.8 cd/m2 in darker areas produces over 1 f-stop difference in dynamic range!

3 Determining sensitometric performance data

3.1 Adjusting the integrating sphere brightness

The adjustment of the integrating sphere is done with a spot photometer fitted with a closeup lens. The measurement is taken in Field 1 of the test image (highest transparency). The luminance to be adjusted measures 800 cd/m2. This value was determined experimentally and is suitable for a combination of ARRI test chart and camera systems with a sensitivity range of 100-2500 ASA.

3.2 Adjusting the optics

3.2.1.1 Lens

In order to conduct reproducible, comparable measurements, identical test conditions must, above all, be adhered to. Preferably using the same optics with the same aperture. The number, position, geometry and quality of each reflective surfaces influence the scattered light and therefore the dynamic range measured. Due to the size of the test image and the apertures, the use of a long focal length lens is recommended. With shorter focal lengths the larger field of view results in an adverse aperture shape over the measured field (the side of the lens barrel can be seen). 85mm provides a compromise between distance and field of view (with a sensor size equivalent to S35mm). It is taken with an aperture of T2.

3.3 Interpreting the data

3.3.1 Linearization of captured data for describing sensor characteristics

With pure sensor technology, it is essential to linearize all image data prior to analysis. Experience shows that a selectable camera mode marked 'linear' can't be trusted to actually show the raw linearized progression of the sensor characteristics.

In other words, during linearization, the digital luminance values (code values) obtained must be calculated back to the luminance of the scene because the actual characteristics aren't known. The luminance delta between the measurement fields (from the optical density measurement of the test image) can, however, be achieved by a mathematical linearization, i.e. through interpolation, with the formula $\Delta L = \Delta \exp osure$.

For the rest of the process, the specification of the 'raw' sensor data shouldn't be relevant.

In practice, it's the sensitometric specification of the complete camera system that is relevant. The image data are stated so that they are meaningful for the user. With professional digital motion picture cameras this generally means:

1. Rec 709 (with multiple sensitivities)
2. Log (with one or multiple sensitivities)
3. RAW (without LUT and matrixing)

3.3.2 Characteristics of captured data for specifying a camera system

3.3.3 OECF

The basis for all sensitometric data is the OECF, the opto-electronic conversion function. The HDSDI signal in 1920 x 1080, 10 bit dpx format is recorded by a frame grabber and loaded in the viewer of the analysis software. The OECF detection takes place automatically.

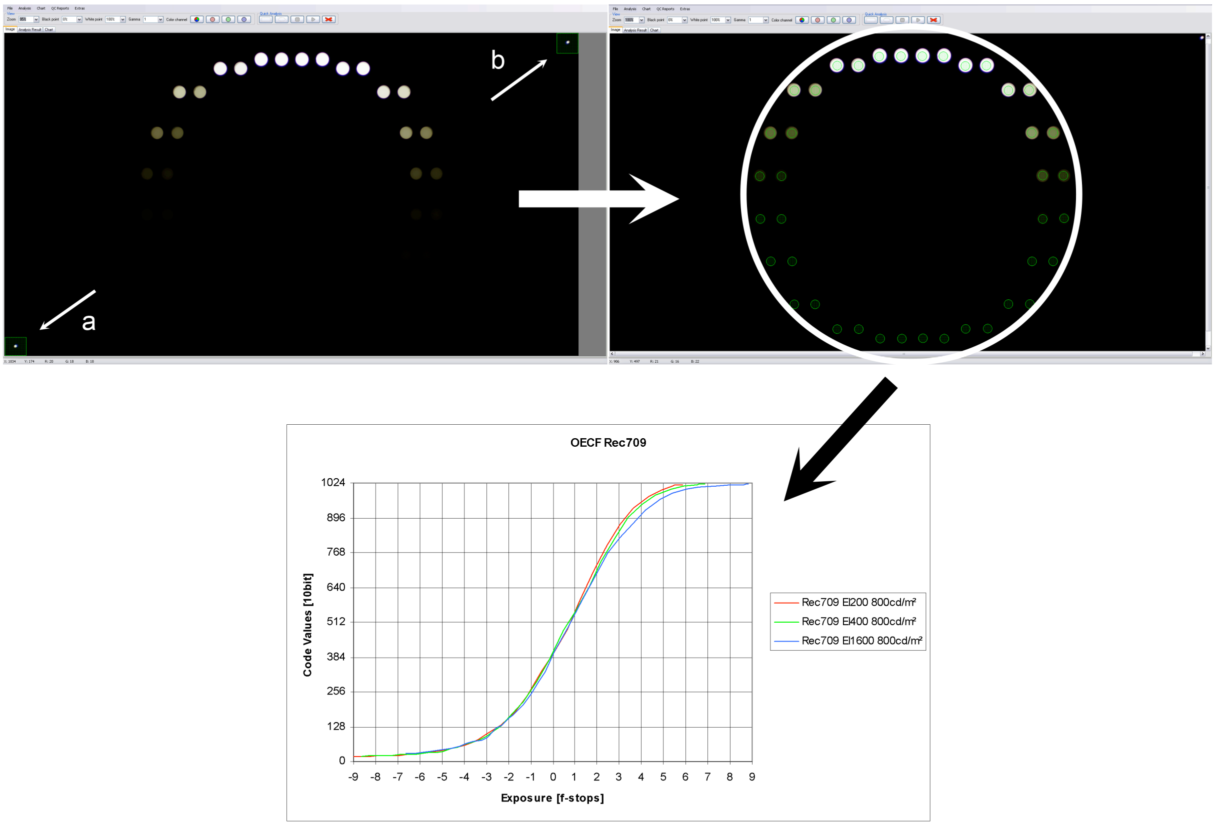


Figure 6: Automatic Analysis

The Software finds the control points a. and b. shown in Fig. 6. Starting from this position, each aperture in the image is automatically found and shown. The signal is calculated from the averaged RGB values of each field. The luminance value calculated from the RGB (0.21*r+0.72g+0.07*b) is shown against the optical densities in the test image converted by the sensor.

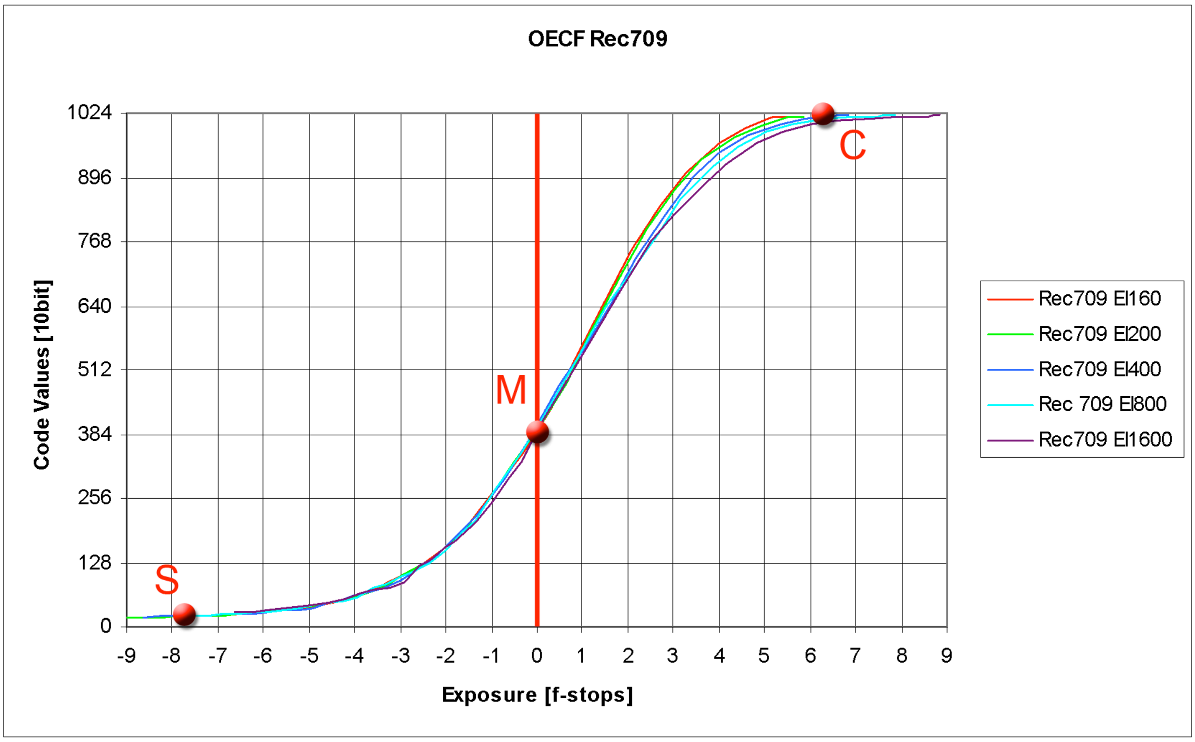


Figure 7: OECF Curves of various EI settings of a camera system.
Red marks the nominal exposure, 0

3.3.4 Nominal exposure and sensor exposure

The nominal exposure L_{nom} [cd/m2] of a neutral gray surface (18% gray) in the object space that results in a luminance signal level of 40% ,when exposed with a digital image sensor is calculated by the EI rating set on the camera [ASA, ISO or EI], exposure time t [sec] and the effective f-stop, Aeff [T-stop], as follows:

$$L_{nom} = \frac{14 \cdot A_{eff}^2}{EI \cdot t} \left[\frac{cd}{m^2} \right]$$

At the same time, the exposure time t [sec] of digital motion picture cameras with shutter apertures is calculated from the aperture angle of the shutter α [°] and the image frequency thus:

$$t = \frac{\alpha}{B \cdot 360°} [\mathrm{sec}]$$

As a result:

$$L_{nom} = \frac{14 \cdot A_{eff}^2 \cdot B \cdot 360}{EI \cdot \alpha} \left[\frac{cd}{m^2} \right]$$

Every additional test image luminance can be shown as sensor exposure relative to the nominal exposure:

$$Exposure_{1-40} = \log_2 \left(\frac{L_{nom}}{L_{1-40}} \right)$$

can be shown relative to the nominal exposure.[i]

* “historically,” with negative film, that was an optical density of 0.75 density levels above fog density.

3.3.5 Rating

The term sensitivity tells us straight away which measurement is meant, namely at which point a sensor (or camera system) converts light into a usable signal. This statement can’t be derived from the ASA or EI value.
The ASA value, which can, in practice, be obtained by a light meter, relates to the middle part of the characteristic (18% gray card). Now, it is being suggested that the EI value be kept, but to call it rating instead of sensitivity. This is a problem, but one that doesn’t exist in English-speaking countries because the term ‘sensitivity’ isn’t normally used there anyway. The correctness of the ratings used can be read directly from the OECF. If the nominal exposure (exposure 0) isn’t reaching 40% luminance, the offset can be read directly in f-stops.

3.3.6 SNR

As before, the question is still remainig how sensitive is a camera system or how much light do you need to get a usable signal . This can be answered measuring noise in each measurement field of the test image. Mathematically, this is the standard deviation.

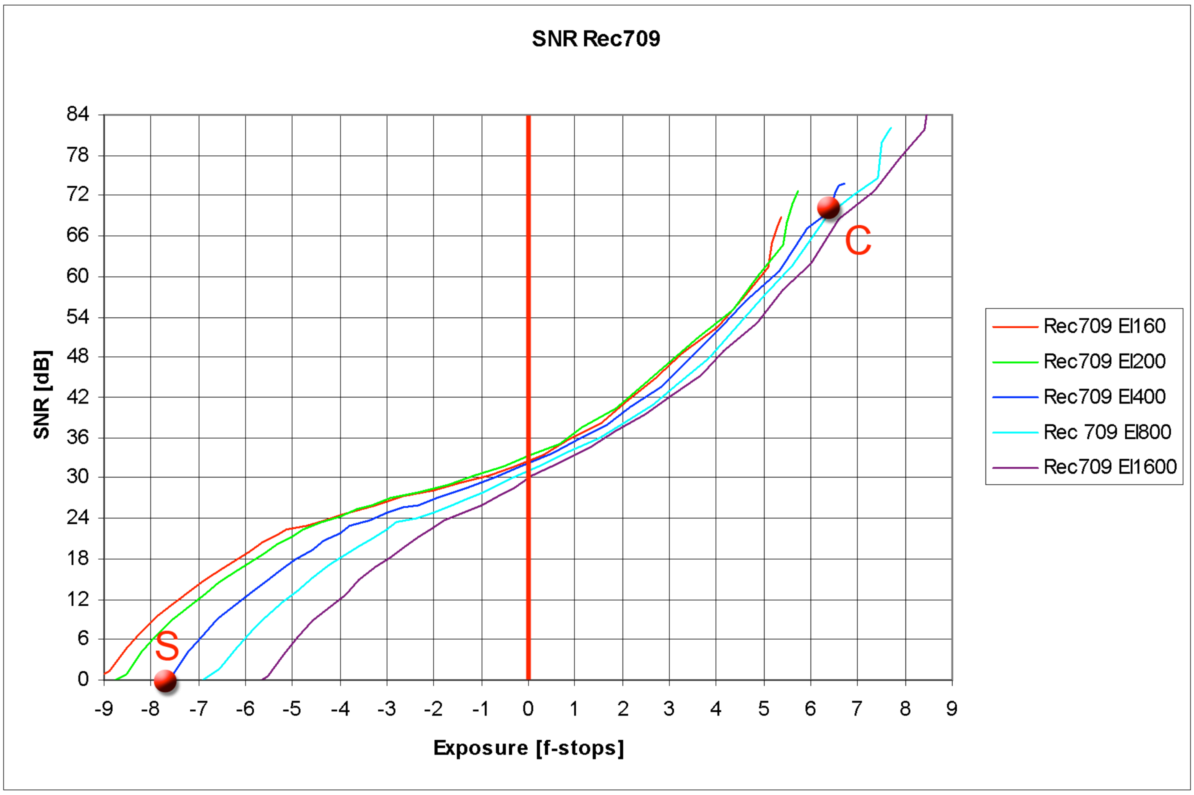


Figure 8: SNR Curves of a camera system at different EI settings.

By comparing noise and signal levels and showing these logarithmically, the signal to noise ratio can be obtained.

$$SNR[dB] = 20 * \log \frac{signal}{noise}$$

3.3.7 Sensitivity

The determination of the point S, at which the signal first conveys usable information is done by determining the signal to noise ratio, SNR. From the measured evaluation of sd signals, differentation of 10 dB are usable, 40dB are known as first excellent.[ii]

These values cannot be assigned in this way to an HD signal.

The higher spatial resolution of an HD signal provides a recognizable signal from as low as 0 dB.

Confirmation of this can be obtained with the help of the DRTC test image. (see Fig. 9). A raster whose spatial frequency is half the Nyquist frequency of an HD signal, is placed over the homogenous surface (This equates to 20 Lp/mm relative to the sensor size).

The signal can transmit recognizable spatial information up to half of the bandwidth limitation with a signal to noise ratio starting at 0 dB.

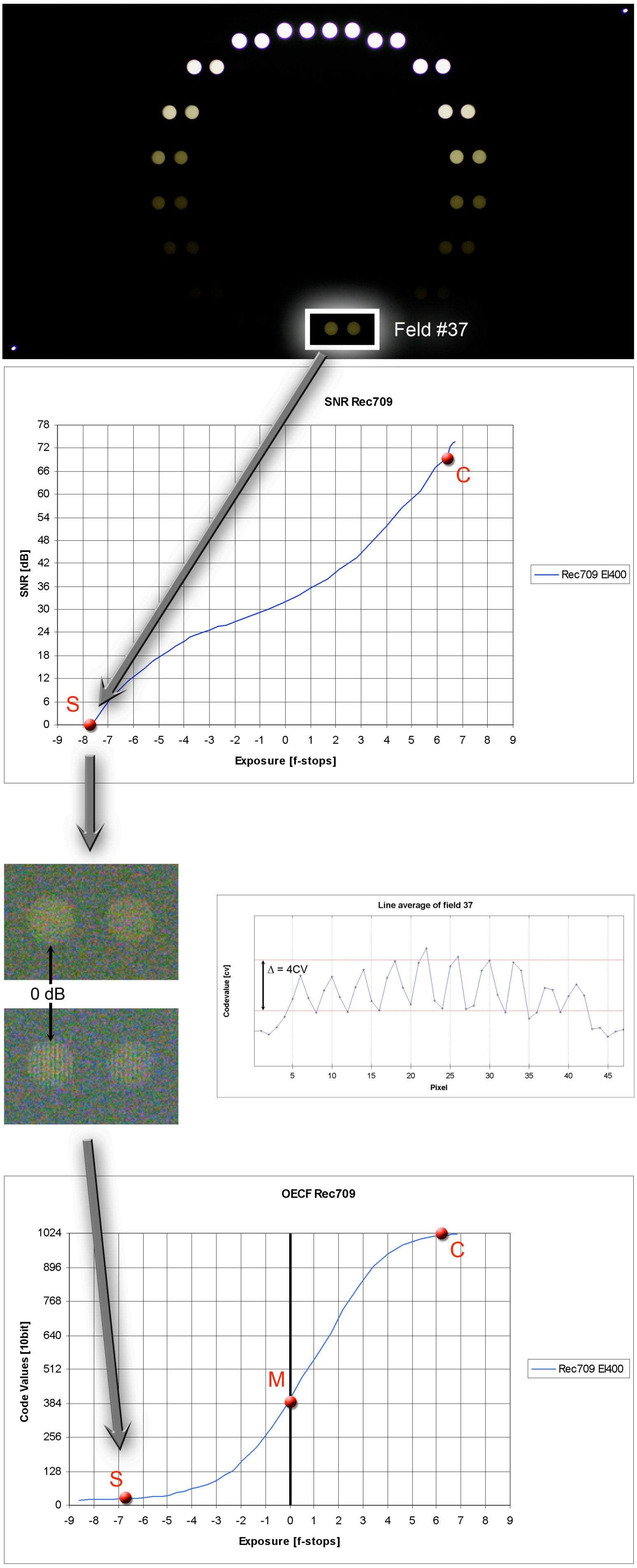


Figure 9: Establishing the threshold value S at EI400

3.3.8 Dynamic range

Once the ‘dark’ end of the usable signal has been defined by the sensitivity, the limitation in the bright part of the OECF is needed for the definition of the dynamic range.

This can be determined either by clipping, i.e. the point at which increasing luminance in the scene doesn’t lead to a rise in the signal or, on the other hand, by the signal to noise ratio.

If the clipping point C has been reached, the noise will be infinitely small and the rise in the SNR curve tilts to infinity.

The dynamic range can now be determined from the SNR curve in f-stops as the distance from the clipping point C to the sensitivity point S.

$$Dynamic\_Range = \overline{Exp(0)S} + \overline{Exp(0)C}$$

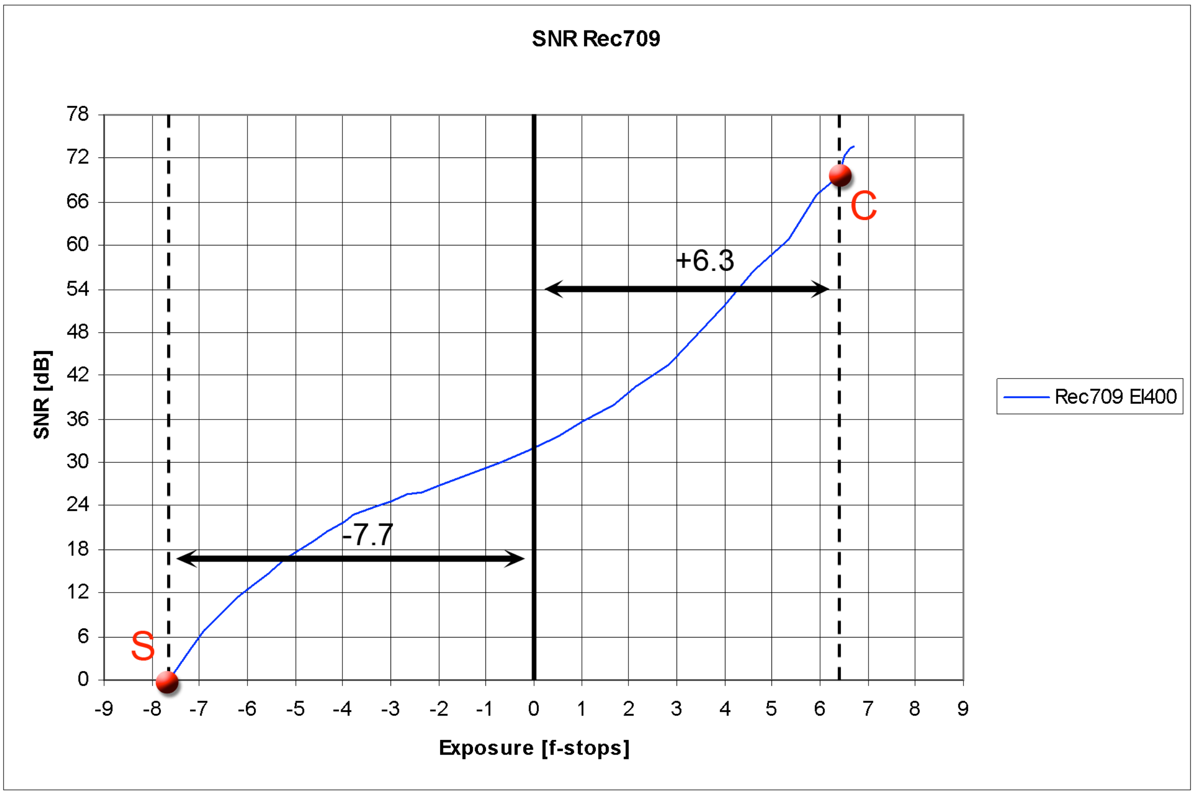


Figure 11: Sensitivity and dynamic range at EI400

According to this definition, the Alexa camera system provides a dynamic range of 14 f-stops. This range remains almost equally distributed from 160 – 1600 ASA.

$$\text{EI160}^{+5}_{-9} \mid \text{EI200}^{+5.3}_{-8.7} \mid \text{EI400}^{+6.3}_{-7.7} \mid \text{EI800}^{+7.4}_{-6.9} \mid \text{EI1600}^{+8.4}_{-5.6}$$

4 Conclusion

Of course, the objective evaluation of camera systems isn't just about contrast and sensitivity. Physiologically however, as hopefully conclusively proven in the preceding 4K+ series of articles, dynamic range is the decisive criterion.

Even though spatial and colorimetric aspects are very important, the all-round positive response to the outstanding image quality of the Alexa camera system has shown that ARRI's strategy of putting the emphasis on the sensor's sensitivity and dynamic range was the right one and that the fixation on megapixels is only half the battle.

Up to now, more than 300 Alexas have been measured using this method. The process has proved its worth and shown that it delivers reproducible and meaningful results. Test image, software and test procedures are available as products from ARRI. Currently, the EBU is testing the process and plans to adopt the procedure in the guidelines for calibrating broadcast cameras.

[ii]