Correlating Digital Imager Sensitivity to Traditional ISO Film Speed

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Abstract

Light sensitivity is one of the most important parameters of an imaging system. Regardless of post processing routines, a low signal to noise ratio (SNR) at the imager will undoubtedly lead to a degraded image.

When using traditional film based cameras target scene illumination is used to specify film type and shutter speed settings. In digital imaging systems sensitivity settings are adjusted automatically or manually by controlling the gain and exposure of the detector. Amplifier compensation can only be used to a certain extent before noise begins to noticeably affect image quality. It is at this defined image SNR that the sensitivity of a digital camera is stated.

In order to compare digital imagers with their film based counterparts it is necessary to relate digital data to common ISO film speed ratings. By taking a series of measurements at calibrated light levels an SNR plot versus luminance can be created for the sensor under test. From this plot the luminance required to achieve the desired SNR is then used in conjunction with sensor integration time and lens f-number to calculate the estimated corresponding ISO film speed.

The goal of this work-in-progress paper is to provide a repeatable characterization method for evaluating sensitivity of a digital imager and to establish a quick reference to the ISO film speed equivalent.

Introduction

The behavior of film is well documented. ISO Film speed ratings have been used for many years as a light sensitivity specification for traditional film based cameras. With the advent of digital imagers that rival performance of their film based counterparts and often provide a much broader feature set, it has become necessary to accurately correlate their operational parameters.

In a traditional camera the target scene is used to specify a particular film and shutter speed. For a digital imager the film is replaced by a sensor with variable gain which is set in conjunction with exposure time to establish sensitivity. By manipulating these two settings digital cameras can successfully acquire images over a very broad range of light, eliminating the need to change out specific film for each target scene. In order to establish sensitivity performance image quality is quantified by calculating signal to noise ratio (SNR).

To characterize SNR for a particular camera it is necessary to process various images captured over the full luminance range of the imager. One of the best sources of the required uniform diffuse light is a calibrated variable luminance visible light integrating sphere. In addition to the light source, target and optics are also required to complete the test setup. Image interrogation is completed on a per pixel basis, most likely with the aid of a separate software application. This test setup can be compiled from individual components or can merely be comprised of an off the shelf system such as the Electro Optical Industries VIP100.

Test Setup

The VIP100 is a twelve inch (304.8 mm) integrating sphere with a two inch (50.8 mm) output port which feeds a filter/target dark-box and a set of relay optics. See Figure 1. The laptop PC has a frame grabber interface and is loaded with the EO TestLab Suite software package. The unit under test (UUT) mounts to the relay optics using a standard F-Mount.

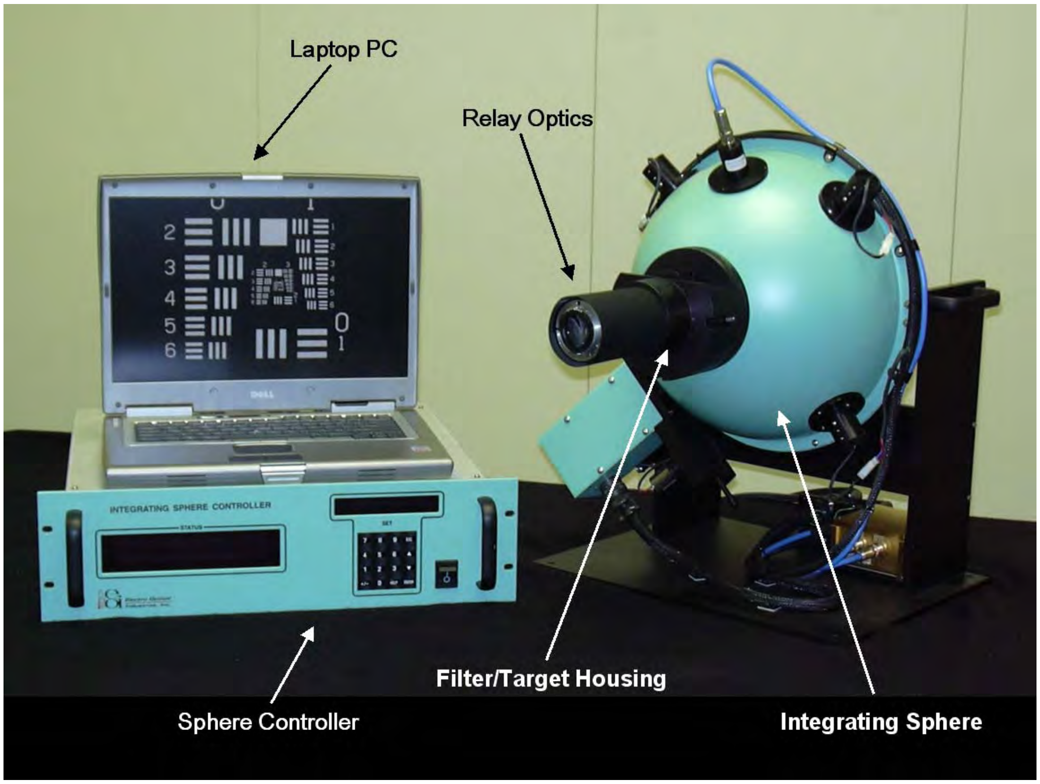

Figure 1. VIP100 Test Setup

Luminance is controlled either directly through the front panel of the VIP100 rack-mount controller or remotely via IEEE-488.2 from EO TestLab Suite. The range of the VIP100 is approximately 5 ft-L (17 cd/m^2) to 20,000 ft-L (68,517 cd/m^2). Optional neutral density filters can be installed for extended low light testing.

Data Acquisition

Testing is conducted using an ultra low reflectance etched metal knife edge or “half-moon” target. Various images of the target are captured over the operating luminance range of the imager. A minimum of 5 data points is required in the luminance/SNR region of interest.

All frames are analyzed individually by EO TestLab to determine SNR. The signal area is defined as a 100x100 pixel area within the light section of the half-moon. The background is a 100x100 pixel area within the dark section. See Figure 2. Average signal level and background levels are calculated by first fitting a second-order polynomial to each sample data line, subtracting this function from each line to remove any trends, then finding the mean of these lines. The difference between signal and background values is the signal value. The square root of the sum of variances from the background region is the RMS noise. All calculations are completed automatically using EO TestLab once relevant areas of interest are defined. See Figures 3 and 4.

Some imaging systems clamp the background to a uniform black when subjected to a high contrast image such as the knife edge target. In this situation the classical SNR calculation results in an undefined value. For these cases noise is instead derived from the variance in the signal as opposed to variance in the background.

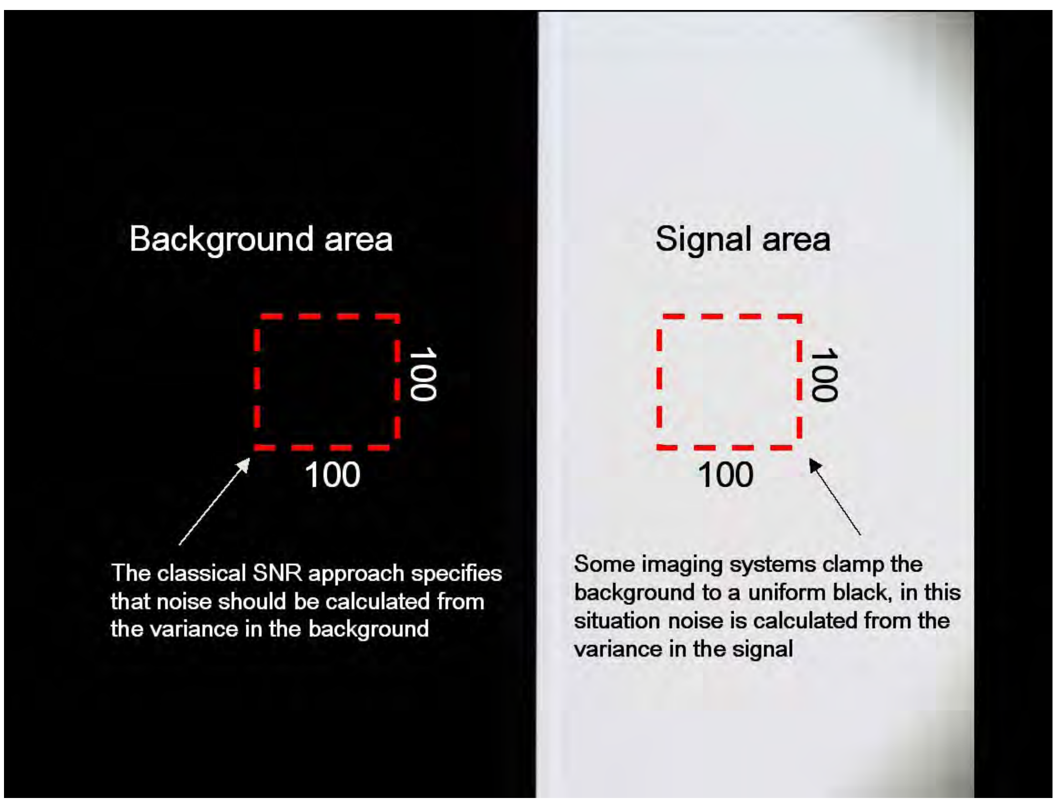

Figure 2. Test Image

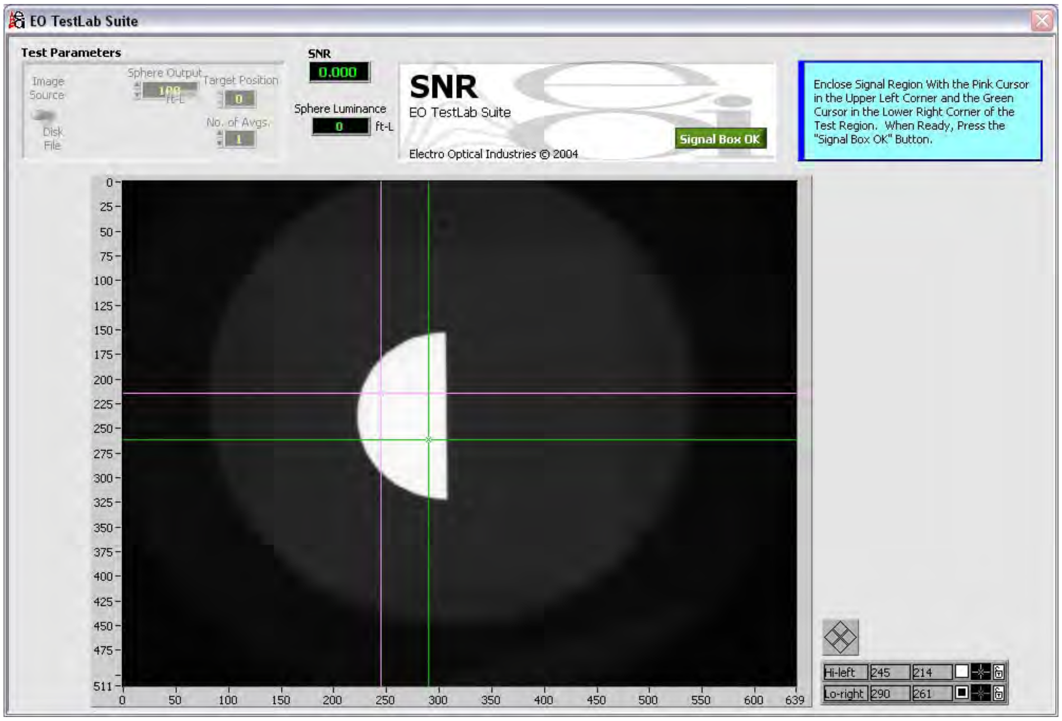

Figure 3. EO TestLab SNR Area of Interest Definition

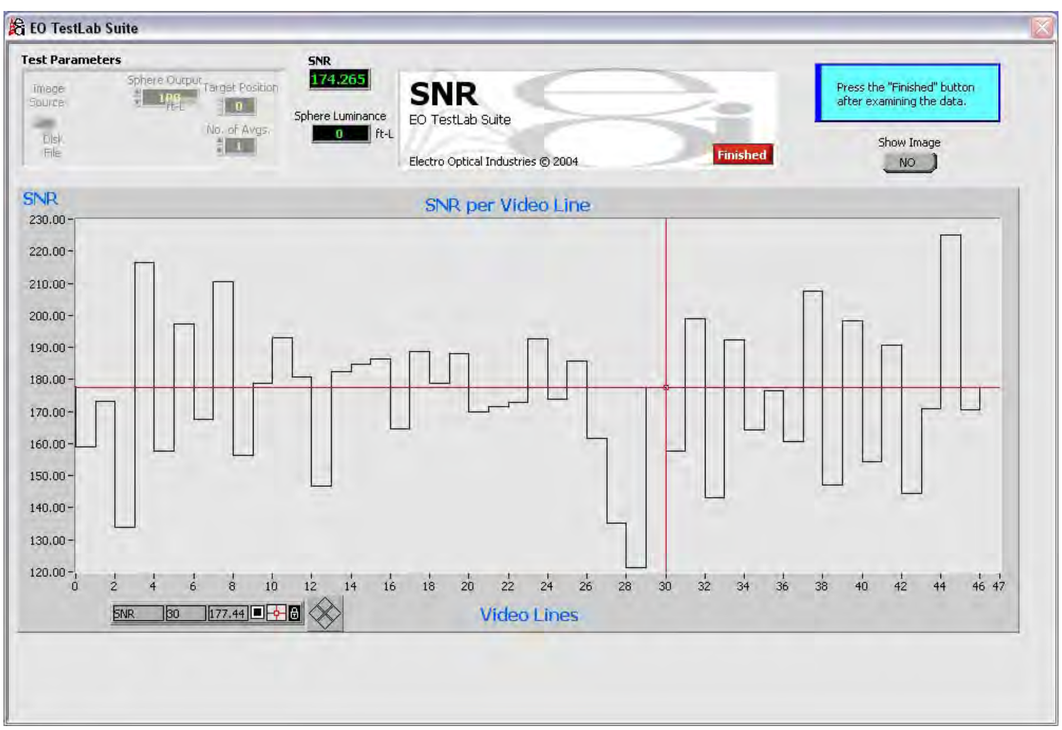

Figure 4. EO TestLab SNR Results

All sampled data is plotted as luminance versus SNR. See Figure 5.
A multi-order polynomial trend line is best-fit to the data to facilitate the defined acceptable image SNR corresponding luminance to be graphically interpolated.

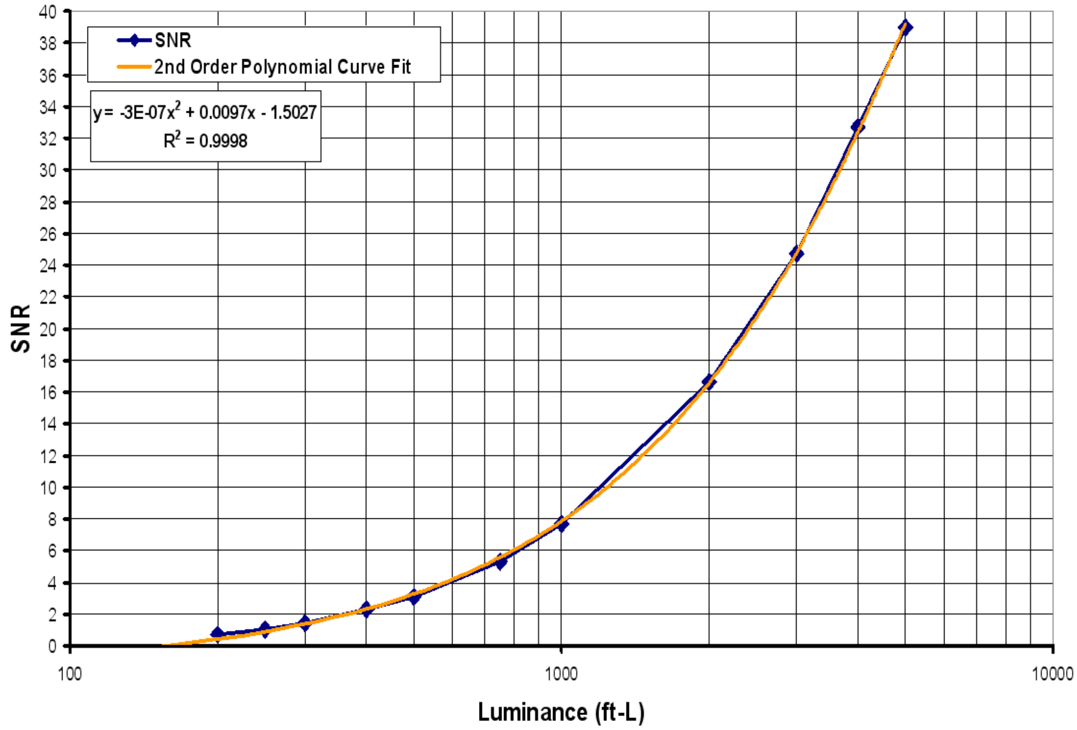

Figure 5. Signal to Noise Ratio Plot

Sensitivity Correlation Conversions

An SNR of 40 is defined as an "excellent" image and an SNR of 10 is defined as an "acceptable" image per ISO 12232. Depending on the application either value may provide more relevant sensitivity data. For this discussion we will assume that an "acceptable" image is sufficient, and thus an SNR point of 10 will yield the sensitivity of the camera.

The interpolated luminance at an SNR of 10 is then read from the plot and used to calculate the Recommended Exposure Index, Equation 1 below, which was derived from ISO 12232.

$$REI = 4.5\left[\frac{(f/\#)^2}{(L_{SNR(10)})(t)}\right] \qquad (1)$$

Where…

REI	=	*Recommended Exposure Index*
$f/\#$	=	*Effective f-number*
$L_{SNR(10)}$	=	*Luminance (ft-L) @ SNR = 10*
t	=	*Sensor integration time (seconds)*

Given the following assumptions:

a) Focal plane flare exposure (lux-seconds) is much less then the focal plane exposure (general, lux-seconds)
b) Transmission of lens is 90%
c) Image point is 10% off axis
d) Vignetting factor is 0.98

Flare exposure is caused by scattered peripheral light that becomes incident on the focal plane. A poorly designed or damaged lens assembly or improperly blacked camera body can each contribute to flare exposure. The fixed lens transmission, image point, and vignetting factor are all general assumptions made of a typical optical system and are used to simplify Equation 1 by consolidating these variables into the constant value of 4.5. If a more precise calculation is required, refer to Annex B of ISO 12232.

References

ISO 12232: 1997 *Photography – Electronic Still Picture Cameras – Determining ISO Speed*

Rather than reporting digital camera sensitivity in terms of quantum efficiency of the sensor, such as volts per incident photon, Recommended Exposure Index (REI) is used instead to relate measured sensitivity in terms of ISO film speed. Table 1, which was compiled from ISO 12232 speed latitude information, is used in conjunction with the calculated REI to determine the ISO film speed equivalent of the digital imager.

Table 1. REI to ISO Film Speed Correlation

REI ≥	REI <	ISO
4	5	**4**
5	6	**5**
6	8	**6**
8	10	**8**
10	12	**10**
12	16	**12**
16	20	**16**
20	25	**20**
25	32	**25**
32	40	**32**
40	50	**40**
50	64	**50**

REI ≥	REI <	ISO
64	80	**64**
80	100	**80**
100	125	**100**
125	160	**125**
160	200	**160**
200	250	**200**
250	320	**250**
320	400	**320**
400	500	**400**
500	640	**500**
640	800	**640**
800	1000	**800**

REI ≥	REI <	ISO
1000	1250	**1000**
1250	1600	**1250**
1600	2000	**1600**
2000	2500	**2000**
2500	3200	**2500**
3200	4000	**3200**
4000	5000	**4000**
5000	6400	**5000**
6400	8000	**6400**
8000	10000	**8000**
10000	12500	**10000**

References

ISO 12232: 1997 *Photography – Electronic Still Picture Cameras – Determining ISO Speed*