New Measures of the Sensitivity of a Digital Camera

Douglas A. Kerr, P.E.

Issue 2
August 30, 2007

ABSTRACT AND INTRODUCTION

CIPA, the technical association of the Japanese camera industry, introduced in 2006 two new measures of the "sensitivity" of a digital camera, recommended for use instead of the *ISO speed* rating to date used for the purpose. They are the *standard output sensitivity* (SOS) and *recommended exposure index* (REI). These new measures are also defined, as alternatives to the ISO speed, by the 2006 version of the relevant ISO standard itself. In this article, we discuss these two new measures and their significance. The article begins with background information on related topics encountered in the discussions. A summary is included.

SUMMARY

The *ISO speed* of a digital camera is a standardized measure of the "sensitivity" of the camera's imaging system. A principal use of this value is as the setting of the *exposure index* in a photographic exposure meter or automatic exposure control system, the parameter that allows the meter to scale its exposure recommendations to suit the sensitivity of the film or digital imaging system being used.

CIPA, the technical association of the Japanese camera industry, introduced in 2006 two new measures of the sensitivity of a digital camera, recommended for use instead of the ISO speed rating. They are *standard output sensitivity* (SOS) and *recommended exposure index* (REI). These new measures are also covered, as alternatives to ISO speed, by the 2006 version of the ISO standard itself.

Standard output sensitivity (SOS) is an objective measure defined in essentially the same fashion as ISO speed (for one of the two bases of ISO speed), but which normally will have a value about 0.71 of the ISO speed.

Recommended exposure index (REI) is the value the camera manufacturer recommends be used as the exposure index setting. It is not specified to be determined in any specific objective way, but may be chosen empirically to give what the manufacturer feels will be the best exposure results for most users in most cases.

BACKGROUND

Sensitivity

In a very nonspecific way, we can speak of the "sensitivity" of a type of photographic film or a particular digital camera imaging system as meaning (inversely) the level of *photometric exposure* [we'll define that shortly] required to cause a certain exposure result, defined in terms of some point on the overall range of response of the medium.

Over the years, considerable effort has been expended on establishing doctrines for quantifying this "sensitivity" in a consistent way for different types of film and, later, for digital imaging systems. Such a sensitivity rating is of use in several ways, prominently:

- It is a parameter needed by an exposure meter or automatic exposure system in order that it can scale its exposure recommendation process to suit the sensitivity of the particular medium in use.

- It allows us to broadly judge the suitability of the medium for such tasks as photography in low light conditions.

For a given distribution of scene luminance (brightness) and a particular lens aperture, a more sensitive medium will require a shorter exposure time ("faster" shutter speed) to produce an appropriate exposure result. As a result, it became common early on in the history of photographic technique to colloquially describe the sensitivity of a medium as its "speed". That term also became part of the formal name of certain standardized measures of sensitivity.

Here, I will continue to use "sensitivity" as the generic name for the property of interest, reserving "speed" for its use in the formal names of certain standard measures.

ASA speed for film

Over the years, work was done to develop, for various classes of film, standard definitions and procedures for the determination of sensitivity ratings that could be used as the exposure index in exposure metering with consistent results. In the U.S., these were initially promulgated (first in 1947) by the American Standards Association (ASA). In each case the sensitivity rating determined for a particular film type under the applicable ASA procedures was called the *ASA speed* of the film.

ISO speed for film

Eventually, this set of standards, and ones of similar purpose developed in other countries (in some cases before the ASA standard

emerged), were swept into standards of the International Organization for Standardization (ISO). The sensitivity ratings defined by these standards (generally numerically consistent with those under the ASA standards) are called the *ISO speed* of the film.

ISO speed for digital cameras

When digital photography emerged, there was a need to have a comparable scheme for rating the sensitivity of digital cameras. Such a scheme was developed, under objectives of practical consistency with the rating systems for film, and was promulgated in 1998 by international standard ISO 12232. As with film, a rating determined under the procedures of this standard is called the *ISO speed* of the camera. This standard was reissued, updated, in 2006.

Note that "ISO speed" is the full name of a specific technical measure, and is not properly applied to other ISO-defined measures of sensitivity ("speed") such as the new ones I will describe shortly.

Moving on

We will pick up the story after giving some background on an important collateral aspect of this topic: exposure metering

EXPOSURE METERING

General

Exposure metering is perhaps the most important use made of sensitivity ratings, and accordingly, exposure metering has always been the "elephant in the room" of the complex work on standard sensitivity ratings. In fact, the development of a doctrine for numerically rating the sensitivity of a film type or a digital camera is actually the development of a comprehensive concept of exposure metering and "exposure strategy".

Nevertheless, at the end of the day, the definitions of sensitivity ratings and the definitions of exposure meter behavior end up in different standards, symbiotically linked to the one another, with various explanations about the underlying premises of the whole scheme assigned to be revealed in one standard or the other based on jurisdictional considerations.

Basic exposure metering

The type of exposure metering that is directly contemplated in the standards for sensitivity rating, called "scene-average reflected light exposure metering", is very simple in concept. In it, the average luminance of the scene is measured. From that, along with knowledge of the sensitivity of the medium, the meter gives us a

choice of combinations of shutter speed and lens aperture that are "recommended" for use for the shot.

The exposure index

The parameter through which we tell the meter about the sensitivity of the medium is called the *exposure index*. It can be thought of as "what we tell the meter is the ISO speed of the medium".

Exposure index is not a property of a medium. We do of course typically set it to the ISO speed of the medium in use.

Exposure meter calibration

The specific linear relationship by which an exposure meter takes the measured average scene luminance and the user-set (or automatically-set) exposure index, and from these develops a recommended exposure ("exposure" here meaning a combination of shutter speed and lens aperture that will have a certain impact on the exposure process), is called the *calibration* of the meter.

Metering realities

Clearly, such a primitive approach to exposure control cannot produce a consistent result in terms of, for example, how scene objects of different reflectance get their values of photometric exposure on the medium. In any case, there is no consistent view among photographers as to what result in this regard is "ideal" even if we could consistently achieve it.

In modern times, the former part of this dilemma has been attacked by more sophisticated metering procedures in cameras, such as the "evaluative" or "matrix" metering systems. And the latter part of the dilemma is addressed by photographers using various techniques to make the result differ from that which would result from the normal operation of the metering system.

Nevertheless, the basic primitive metering scheme is the one contemplated in the work on the development of an integrated doctrine of sensitivity ratings and exposure meter calibration, and we assume this scheme here in our discussion of the implications of various sensitivity rating measures.

PHOTOMETRIC EXPOSURE

We will be speaking frequently of the physical property *photometric exposure*. This is basically defined as the product of the illuminance on the medium (at some point of interest in the image) and the period of time it persists (the exposure time, or shutter speed). The preferred unit is the lux-second.

The modern scientific symbol for photometric exposure is H.[1]

ISO standards for metering

Two international standards provide definitions of the operation of exposure metering systems, including their calibration. ISO 2720 applies to "free-standing" exposure meters. ISO 2721 applies to automatic exposure control systems, which are integrated exposure metering systems that automatically control aperture, shutter speed, or both in a camera.

ISO 2720

ISO 2720 describes the recommended calibration of the meter with an equation that includes a "reflected light exposure metering constant", *K*, whose value determines the calibration. The standard allows the manufacturer to choose the value of *K* it feels is desirable, over a modest range. Among other things, the value of *K* might be chosen:

- To best accommodate what the meter manufacturer feels is a reasonable expectation of the "transmission efficiency" of the lens, which affects the actual impact of any exposure meter calibration defined in this way.

- To invoke the meter manufacturer's view of the best "exposure strategy".

Note that the numerical value of K, for any given "choice", is dependent on the units used for luminance in the calibration equation.

ISO 2721

ISO 2721 prescribes a definite calibration for automatic exposure control systems (a special type of integrated exposure meter). In effect, that calibration involves a specific value of K (although the calibration is not defined in those terms).

Modern work on sensitivity rating generally assumes (without always saying so) that the calibration prescribed by ISO 2720 will pertain to the meter that will be involved in the use of the rating.

This calibration is defined by:

---

[1] It was at one time common to use the symbol E, as in the famous "D log E" curve portraying the response of negative monochrome film. However, E was formally adopted as the symbol for illuminance (a quantity also involved in the same area of work), so the alternate symbol H was adopted for photometric exposure.

$$H_{avg} = \frac{10}{S_{ei}} \text{ lux-sec} \qquad (1)$$

where H_{avg} is the average photometric exposure that will occur on the medium through the working of the exposure control system and S_{ei} is the setting of the exposure index. (I use the base symbol S because, until the latest developments in sensitivity rating, the normal thing would be for the exposure index to be set to the ISO speed of the medium, whose symbol is S.) Note that this value of H_{avg} will occur regardless of the average or range of the luminance of the scene.

ISO SPEED OF DIGITAL CAMERAS—THE PARTICULARS

ISO 12232 provides for a standardized measure of the sensitivity of a digital camera, called (as for film) the *ISO speed*.

Definition

The ISO speed to be stated for a particular digital camera[2] is the greater of two values, called S_{sat} (the "saturation-based" ISO speed) and S_{noise} (the "noise-based" ISO speed). There are practical impediments to the determination of S_{noise}, and great differences of opinion as to its significance, and as a result, the stated ISO speed is often just (by default) S_{sat}. We will only deal here with an ISO speed rating taken from S_{sat}.

S_{sat} is defined thus:

$$S_{sat} = \frac{78}{H_{sat}} \qquad (2)$$

where H_{sat} is the *saturation value* of photometric exposure for the camera, in lux-sec: the value that just produces the largest possible digital output.

Implications

If we assume that exposure is controlled by an automatic exposure system calibrated as prescribed in ISO 2721, whose exposure index is set to the (saturation-based) ISO speed of the camera, S_{sat}, then, as a result of the working of the automatic exposure system, the average photometric exposure on the sensor should be 0.128 H_{sat} (regardless of the average or range of the luminance of the scene).

---

[2] In a particular "sensitivity" mode, if it has more than one, which almost all digital cameras do, usually labeled with "ISO" values.

One consequence is:

- If we have a uniformly-illuminated scene with an average reflectance of 18% (often said to be a "typical" average scene reflectance), then a region in the scene whose reflectance is 100% (which we might expect would be the highest possible reflectance in a "natural" scene) will receive a photometric exposure on the sensor of 0.71 H_{sat} (that is, essentially "one half stop" below saturation).

This one-half stop "headroom" (borrowing the term used in audio recording) can be thought of as providing a "cushion" against the possibility of a high-reflectance region in the scene receiving a photometric exposure of greater than H_{sat} in cases where the actual average scene reflectance is somewhat less than 18%. (Such an occurrence would lead to "clipping of highlight detail".)

THE NEW MEASURES

In 2006, CIPA, the Camera & Imaging Products Association (Japan) issued a new standard (CIPA DC-004) covering the sensitivity of digital cameras. It defines two (new) measures of the sensitivity of a digital camera. These two measures are the *standard output sensitivity* (SOS) and the *recommended exposure index* (REI). The standard recommends only the use of these two measures for describing the sensitivity of digital cameras (rather than ISO speed).

Also in 2006, the ISO issued an updated version of its standard ISO 12232. This standard, as well as defining ISO speed, includes definitions of SOS and REI, consistent with the definitions in the CIPA standard. They are presented as alternative measures of sensitivity.

Standard output sensitivity

The standard output sensitivity (SOS) of a digital camera is based on the photometric exposure on the sensor required to produce a certain *reference digital representation*. The digital representation is to be observed in the pseudo-luminance (Y) component of a YCbCr encoded digital image in the sRGB color space (as found in an EXIF JPEG output file).[3]

The standard digital representation is 461/1000 of the full-scale digital value. In the 8-bit system of the EXIF JPEG file, the full-scale digital value of Y is 255, and thus the reference digital value is 118.

---

[3] Unfortunately, ISO 12232 neglects to mention this, making its definition of SOS meaningless. In the CIPA standard it is covered only in an annex.

Taking into account the standard nonlinear transfer function of the sRGB color space[4], we find that the photometric exposure, H_{SOS}, producing the reference digital output is given by:

$$H_{SOS} = 0.182\, H_{sat} \tag{3}$$

The definition of SOS (I_{SOS}) is given by the standard as:

$$I_{SOS} = \frac{10}{H_{SOS}} \tag{4}$$

Substituting for H_{SOS} from equation 3 we get:

$$I_{SOS} = \frac{54.9}{H_{sat}} \tag{5}$$

Comparing equations 5 and 2, we see that:

$$I_{SOS} = 0.704\, S_{sat} \tag{6}$$

In other words, the SOS value will consistently be 0.704 of the ISO speed (assuming again that the ISO speed is determined as S_{sat}).

Implications

If we assume that exposure is controlled by an automatic exposure system calibrated as prescribed in ISO 2721, and its exposure index is set to the SOS of the camera, I_{SOS}, then, as a result of the working of the automatic exposure system, the average photometric exposure on the sensor will be approximately 0.18 H_{sat} (regardless of the range or average of the luminance of the scene). One consequence is:

- If we have a uniformly-illuminated scene with an average reflectance of 18% (often said to be a "typical" average scene reflectance), then a region in the scene whose reflectance is 100% (which we might expect would be the highest possible reflectance in a "natural" scene) will receive a photometric exposure on the sensor of H_{sat} (that is, right at saturation).

Thus, compared to the use of the ISO speed as the exposure index, the use of SOS results in an exposure almost exactly one-half stop "hotter". In effect, the use of SOS "reclaims" the part of the available range of H that, under the classical ISO doctrine, is devoted to "headroom".

---

[4] This may not be precisely applicable, owing to "tonal curve processing" in the camera, but will serve for our purpose here.

So do we now have an increased hazard of overexposure of the highlights in scenes with a low average luminance? Yes.

Recommended exposure index

The recommended exposure index (REI) is a number arbitrarily chosen by a camera manufacturer that the manufacturer believes, if used as the exposure index for metering or automatic exposure control, will produce exposure results the user will like in a lot of cases (my wording). It is not determined under any standardized procedures.

The standards do give what looks like a "definition" of the value of REI (I_{REI}), but it is not derived from any property of the medium. It is:

$$I_{REI} = \frac{10}{H_m} \qquad (7)$$

where H_m is the average photometric exposure over the sensor the manufacturer would like to have happen as a result of the working of an automatic exposure system calibrated under ISO 2721. Of course H_m itself must be arbitrarily chosen. (Or perhaps it will emerge from a direct choice of I_{REI}!)

EXPRESSION OF THE NEW MEASURES

Insofar as the ISO standard is concerned (and certainly insofar as the CIPA standard is concerned), the measures SOS and REI are not forms, or variants, of the explicitly-defined measure *ISO speed*. They are separate measures, with their own complete names, "standard output sensitivity" and "recommended exposure index". Nevertheless, all three are "ISO measures".

Under the ISO standard, numerical values of these measures are to be stated this way:

ISO speed: "ISO xxx"

SOS: "ISO sss (SOS)"

REI: "ISO rrr (REI)"

where xxx, sss, and rrr represent the numerical value to be stated for the measure.

We should not see, in a product specification, anything like this:

"ISO speed: ISO 400 (SOS)"

More appropriate would be:

"Sensitivity: ISO 400 (SOS)"

However, we will probably see "incorrect" statements such as the former of these as manufacturers try to bridge the gap between the familiar notation and the new measures.

Note that a manufacturer may well wish to express both SOS and REI, with different values, for a camera. This could be seen thus:

"Sensitivity: ISO 400 (SOS), ISO 500 (REI)"

This would mean that the SOS, objectively determined under the CIPA/ISO procedures, is 400, but nevertheless, the manufacturer suggests that the user set the meter's exposure index to 500. In the case of an integrated automatic exposure system, this would probably mean that the exposure index value 500 will be internally fed to the metering algorithm.

Finally, the manufacturer is free to say:

"Sensitivity: ISO 400 (SOS, REI)"

This would mean, "the SOS of the camera is 400, and we recommend you set the exposure meter's exposure index to that value."

The CIPA standard recognizes these "ISO-oriented" expressions of sensitivity.

WHY THESE NEW MEASURES?

The real motivations for the introduction of these new measures are lost in the fog of war, but we can identify some considerations that were probably in the mix.

Why SOS?

The CIPA standard puts forth various points of rationale for the disability of SOS as an objective measure of sensitivity rather than ISO speed. some of which are hard to understand (or believe). But the following considerations may have been involved. The use of a consistent exposure metering calibration between the compared situations is assumed.

- By setting the meter's exposure index to SOS rather than ISO speed, better noise performance will be achieved for low-luminance portions of the scene. (The tradeoff, of course, is a greater possibility of loss of highlight detail through saturation.)

- Images taken with the exposure index set to SOS, "direct from the camera", without any postprocessing, displayed onscreen in a straightforward way, will appear "brighter" than images of the same scenes taken with the exposure index set to ISO speed. This could be seen as a marketing advantage among general public users. ("Wow! What kind of a camera did you take these with? I have to get one!")

Why REI?

Notwithstanding the thousands of man hours of excruciating sophistry, and hundreds of often ill-explained equations, in the work over the years on ASA speeds for film and their ISO successors, the "basic" type of reflected light metering that is the major user of the numerical results of this work remains largely an empirical process, where there isn't even a uniform accepted criterion by which we can judge "success". The REI definition is a candid address of this situation.

It avoids the hypocrisy, found in the recent practice of various digital camera manufacturers, of falsely stating the "ISO speed" of their cameras (that is, giving ratings that would not be the ones determined under the standard ISO procedures), in the interest of producing an exposure result situation the manufacturer believes would be "best for most users most of the time".

ADOPTION IN THE INDUSTRY

Canon

Canon, in its EOS digital SLR's prior to the EOS 400D (Digital Rebel XTi), has apparently always rated the various so-called "ISO speed" settings in its cameras at about 75% of what the ISO speed, determined under the procedures of ISO 12232, would be. (Canon has not said this, but it has been "reverse-engineered" by the author from information on the expected end-to-end behavior of the automatic exposure system of these cameras given by Canon.)

In effect, Canon has for some while in these cameras used very nearly what would now be described as the SOS value to rate the sensitivity modes (and as the exposure index input to the automatic exposure systems, which themselves apparently closely follow the ISO 2721 calibration).

Canon has now indicated that henceforth in EOS dSLR cameras they will designate these sensitivity settings with REI values.

Canon's latest EOS digital SLRs (as of this writing) are the EOS-1D Mark III, the EOS-1Ds Mark III, and the EOS 40D, which are the first models to which this new plan was applied. However, in some of the

early documents for these models, the sensitivity setting numbers are described (essentially) this way:

"ISO speed range: equivalent to ISO xxx-xxxx,[5] standard output sensitivity, recommended exposure index".

But in some later documents, they are described as:

"ISO speed range: ISO xxx-xxxx, recommended exposure index."

It may be that Canon, until the last minute, had planned to declare their ratings as both SOS and REI. Of course the use of the term "ISO speed" as part of that expression is in any case, technically, inappropriate—SOS and REI ratings are not forms or variants of "ISO speed". (Their numerical values, as mentioned earlier, are, however, properly stated with an "ISO" prefix.)

In any case, we do not know at this point what the actual ISO speed values are for the various "ISO" settings. My own suspicions is that the stated numbers are close to the *bona fide* SOS values (as seems to have been the case for earlier EOS cameras other than the 400D).

Other manufacturers

Several other digital camera manufacturers in their latest models (notably Pentax and Fujifilm) designate the different sensitivity settings in terms of SOS value. I don't currently know anything beyond that.

IMPACT ON PHOTOGRAPHERS

What will be the impact on photographers of the adoption of these new sensitivity ratings? It largely depends on what camera manufacturers do.

We could infer that this shift suggests that camera manufacturers will be moving to a "hotter" overall exposure result.

For example, suppose Excalibur (a fictional Japanese camera manufacturer), on their model 1000 had designated the sensitivity choices with *bona fide* ISO speed ratings (ones consistent with what we would get in a laboratory determination of ISO speed under the procedures of ISO 12232), but on their model 2000 designated these sensitivity choices with *bona fide* SOS values (ones consistent

---

[5] The significance of "equivalent to" is not known. It is perhaps a hangover from when ISO speeds were first established for digital cameras and were thought of as not being "real ISO speeds", on the (erroneous) premise that real ISO speeds only pertained to film.

with what we would get in a laboratory determination of SOS under the procedures of ISO 12232).

Suppose that when using a free-standing exposure meter with the Excalibur 1000, and setting the meter to the announced ISO speed, we have been getting exposure results we liked. Now if, with our new Excalibur 2000, we set the exposure index of this same meter to the announced SOS value, we will get "hotter" exposures than before.

But that will not necessarily be the case.

For example, it may be that Canon will still use the same numbers they used before for the corresponding sensitivity choices of their cameras (excluding the 400D). Previously they labeled the numbers "ISO speed", which was not correct. Now likely they label the same numbers "REI", which cannot be either correct nor incorrect (since this number is not objectively determined).

So, whatever metering result we got before with the inbuilt automatic exposure system, and whatever result we got with free-standing meters by setting their exposure index to the so-called "ISO speed" ratings of the camera, we'll still get the same result (unless Canon changes their "metering/exposure strategy", which is a wholly different matter than this change in notation).

And of course this is all hypothetical, since I don't know what Canon, or Excalibur, or any other manufacturer, is really doing.

So I'll watch Canon, and somebody else will have to watch Nikon, Pentax, and Fujifilm—and Excalibur.

WHAT ABOUT EXPOSURE METERS?

Will we see new models of free-standing exposure meters with an option to enter the exposure index in terms of SOS rather than ISO speed? Probably not. In effect, the meter manufacturers may say, "If a camera manufacturer wants to call for a hotter exposure than was anticipated by the ISO committees, it's not our job to negate that."

But it will be easy to correct exposure indexes to the new terms. Suppose we want to operate on a "by the book" basis (in a situation in which a genuine ISO speed into the meter presently works well). Then all we need to do is take 1.4 times the SOS rating and enter it as the ISO speed.

#