Characterizing the Output of Photographic Flash Units

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ABSTRACT

We are often interested in quantifying the maximum "output" of a photographic flash unit. We often see descriptions in terms of *guide number*, *beam candlepower seconds* (BCPS), and *watt-seconds*. In this article we explain the different properties we may wish to describe and the various metrics and units that apply to them.

GENERAL

Introduction

A wide range of electronic flash units are used in different photographic applications. We are often interested in knowing, in a quantitative way, the maximum "output" of which they are capable, as this influences their suitability to produce proper exposure in different situations of distance to the subject, desirable aperture, and so forth.

There are in fact two major settings in which flash units are used, each suggesting a different property as the indicator of "output":

- Direct use, where the business end of the flash unit is aimed at the subject
- "Bounce" use, where the light from the flash unit is directed at a reflective surface, which could include a light-colored ceiling, an "umbrella" reflector, or other items.

SI units

In this article, we will regularly refer to "SI units". SI refers to the International System of Units[1], the so-called "modern metric system", the preferred system of units for physical quantities for use in technical and scientific work.

For historical and pragmatic reasons, other units are commonly used to quantify the properties we will be discussing. Those units, and their

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[1] The intitials "SI" come from its name in French, *Le **S**ystème **I**nternational d'Unités*.

relationships to the SI units, will be covered in each case after we have discussed the SI unit.

DIRECT FLASH

Luminous intensity

The fundamental property of interest in direct flash operation is the product of luminous intensity and the time duration of the flash burst.[2] This actually has no name in photometric terminology, other than “luminous intensity-time product”.

The modern preferred technical unit for this property is the derived SI compound unit *candela-second*. In actual practice, the older unit *candlepower-second* is often used. For all practical purposes, the units *candela* and *candlepower* are the same except for name, and thus so are the compound units *candela-second* and *candlepower-second*.

Even more commonly, the unit *beam candlepower-second* (BCPS) is stated. This is actually the same unit; the implications of the modifier “beam” will be discussed shortly.

More about luminous intensity

To avoid any misunderstandings, let me clarify some things about the property *luminous intensity*.

1. Strictly speaking, luminous intensity describes the amount of luminous flux per unit of solid angle in the emission, in a certain direction, from a *point source*; that is, a source whose dimensions are zero. Of course there is no such thing as a point source. From a practical standpoint, we can consider that the concept of luminous intensity can be applied to the emission from a source whose dimensions are “infinitesimal” compared to the distance at which we may be interested in the impact of its luminous intensity.

2. Luminous intensity does not involve distance from the source; it is a property of the emission from the source. What **does** vary with distance is, for any given luminous intensity, the illuminance caused on a surface by an emission of a given luminous intensity. For a true point source (the only thing that actually has a luminous

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[2] In fact, since the luminous intensity is not constant over the duration of the burst, the precise property is the integral of luminous intensity over time, but this is conceptually the same as the product of luminous intensity and burst time, and works in the same units.

intensity), that illuminance varies inversely with the square of the distance from the source (the famous "inverse square law").[3]

3. For an extended source (one of non-infinitesimal dimensions) whose dimensions are still small compared to the distance at which we may be interested in the impact of the source, we find that the source behaves very nearly like a point source, and so we may associate with its emission toward an object in a particular direction an *apparent luminous intensity*.

4. For such an extended source of area A and uniform luminance L, then at a distance that is substantial compared to the dimensions of the source, the illumination given by the source will be essentially that which would be given by a point source with luminous intensity $A \bullet L$. We may thus think of that luminous intensity as being the *apparent luminous intensity* of the source.

5. The luminous intensity-time product tells us nothing about the width of the beam.

The beam candlepower-second

Generally, the apparent luminous intensity of an extended source is denominated, in practical work, in the unit *beam candlepower*, and thus the luminous intensity-time product is denominated in the unit *beam candlepower second* (BCPS). The units are no different than the units of the same names not including the word "beam". The modifier "beam" in these unit names merely serves to:

1. Remind us that the apparent luminous intensity, rather than a true luminous intensity, is being spoken of (as the source is not a point source).

2. Suggest that the value given is the average value across our "beam" (rather than for a unique specific direction). (And we must decide how much of the beam "width" will be included.)

3. Avoid any misunderstanding between this unit and the different unit *spherical candlepower*, which is used to describe luminous flux, most commonly the total luminous output of a lamp. (The SI unit of luminous flux is the lumen; a luminous flux of 1.0 spherical candlepower corresponds to 4π [12.57] lumens.)

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[3] Note that the luminance also varies with the cosine of the angle at which the "beam" strikes the surface (measured with respect to a line perpendicular to the surface).

Guide number

Guide number is a special way to describe the luminous intensity-time product of a flash unit such that the basic photographic equation for "appropriate exposure" can be solved simply. If we know the guide number for a flash unit, then we divide that number by the distance from the flash to the subject and the result will be the f/number of the aperture that should yield "appropriate exposure".

The guide number, for any given luminous intensity-time product, will depend on the ISO sensitivity of the film or digital imaging system. It is common to state the guide number for a flash unit contingent on a sensitivity of ISO 100. For other ISO sensitivities, the guide number varies as the square root of the ISO number.

The dimensionality of the guide number is that of distance, and a guide number can be stated in different units, most commonly either feet or meters. One must be careful which unit is involved in a stated guide number before performing the determination of the appropriate aperture.

We often may wish to convert between luminous intensity-time product (perhaps stated in BCPS) and guide number (GN). However, the luminous intensity-time product is defined in terms of fundamental physical quantities, while guide number, like other "exposure equations", has "built in" a factor reflecting the manufacturer's view of the conditions for "proper exposure". Thus, there is not a unique conversion from BCPS to GN that can be firmly determined from physical principles.

However, a widely used relationship (used, for example, by Kodak in their film data sheets) is:

$$GN = \sqrt{\frac{BCPS \bullet ISO}{20}} \qquad (1)$$

where *GN* represents the guide number, in feet; *BCPS* is the luminous intensity-time product in beam candlepower-seconds; and *ISO* is the ISO sensitivity involved.

A further wrinkle in the matter of guide number is that many manufacturers measure the guide number of a flash unit in an environment with a 10-ft high light-colored ceiling, introducing into the measurement the effects of reflection of some light from that ceiling back toward the beam axis.

Note that guide number tells us nothing about the width of the beam, and beam width is not involved in the definition.

If we have a flash unit with a certain total luminous energy output (a property we have not yet discussed) and which has provision for changing the beam width (such as through a "zoom" head), then of course as we shift to a narrower beam, the luminous intensity-time product increases, and in turn so does the guide number.

INDIRECT FLASH

The luminous flux-time product

Almost any flash unit may be used in an indirect way, including the use of bounce operation off a ceiling or wall and the use of umbrella reflectors or various "light modifiers".

Because of the wide variation in effective beam width that may result from such operation, the luminous intensity-time product in any given direction varies widely, and in any case we are not simply interested in that quantity in a single direction (since a reflective path off the ceiling or whatever is often in play).

Partly for that reason, flash units specifically intended for such operation (such as "studio" flash units) are often not rated in terms of luminous intensity-time product (in BCPS) or in guide number. Rather, emphasis is placed on their total luminous energy output (often called the "luminous flux-time product"). This is of course the product of the total luminous flux output times the duration of the burst.[4] The SI unit is the compound unit *lumen-second* (lm-s).

We then must learn the pragmatic effect on illumination of the subject of the total luminous energy output combined with a particular "setup" (in terms of reflectors, bounce orientation, distance to the subject, and so forth). [5]

In reality, it is very difficult to predict the result, and thus in demanding work a flash meter is used, which directly measures the impact of a test flash burst at the location of the subject.

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[4] As before, the quantity of interest is actually the integral of total luminous flux output over time.

[5] The metric of this effect is the *luminance-time product*, and in SI terms it is denominated in the unit *lux-second*.

As mentioned above, the SI unit of luminous energy is the *lumen-second* (lm-s). An alternative is the *spherical candlepower-second* (a numerically different unit).

The stored energy metric ("watt seconds")

In actual practice, we rarely hear of the total output of a studio flash unit in terms of total luminous energy. Rather, a rather less explicit, implementation-based notation is used.

In a flash unit, one factor affecting total luminous energy output is the total quantity of electrical energy stored in the unit's flash capacitor and then delivered (in part) to the flash tube proper. The SI unit of energy (including electrical energy) is the joule, which is equivalent to the compound SI unit watt-second (W-s), and many studio flash units have a rating in terms of watt-seconds (less frequently expressed in joules, which is exactly equivalent).[6]

However, there is not a fixed relationship between the stored energy and the total luminous energy delivered by the flash, for these reasons:

1. The flash tube, even with the unit at "full output", does not draw all the stored energy out of the storage capacitor; as the voltage of the capacitor decreases during discharge, at a certain point the discharge in the flash tube is "extinguished", the luminous output ceases, and some charge is left in the capacitor. The extent of this phenomenon varies widely over different flash unit designs.

2. The flash tube in any case does not convert all the energy extracted from the storage capacitor into visible light. The fraction that is converted varies greatly over different flash unit designs.

Accordingly, two units having the same watt-second rating can deliver substantially different luminous energy levels. Some authorities have suggested that the conversion efficiencies of typical studio flash units fall in the range 15-50 lm-s per W-s (a variation of over 3:1!). Efficiencies on the order of 40 lm-s per W-s are common with modern units.

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[6] The energy stored in a capacitor is given by $E = \frac{1}{2} CV^2$, where E is the energy in joules, C is the capacitance in farads, and V is the voltage in volts.

In an attempt to deal with this, one flash unit manufacturer introduced a system in which the luminous energy output of their units was given an "effective watt-second" rating, which is based on a standardized conversion efficiency (a relatively low one, actually—apparently about 17.5 lm-s per W-s—one might cynically think this was so that the numbers stated would be nice and large, almost always larger than the watt-second value itself!).

Some photographers complain about this notation, characterizing it as a marketing trick intended to mislead users into thinking that a certain flash unit was more potent, compared to certain competitive models, than it is.[7] And they say, "this is not a true watt-second rating". Well, of course it isn't. But recall that we really **can't** compare luminous outputs based on the (true) watt-second rating—and we **can** do so based on effective watt-second ratings.

Of course, stating the actual property of interest, the luminous flux-time product, in lumen-seconds, would avoid that controversy altogether.

Many modern flash units have efficiencies about 2.5 times that contemplated by the "effective watt-second" convention. In other words, a unit with a stored energy of 500 watt-seconds (500 joules) may well have an effective watt-second rating of 1250.

In any case, regardless of the unit's efficiency, the total luminous energy output in lm-s is approximately 17.5 times the effective watt-second rating. Thus the unit in the example above can be expected to have a total luminous energy output of about 22,000 lm-s.

I discourage any effort to make conversions between watt-second (or even effective watt-second) ratings and total luminous energy, and discourage reliance on watt-second (or effective watt-second) ratings as an indication of the output capability of a flash unit. Hopefully, more flash unit manufacturers will come to express the output capabilities of the units on the basis of an actual metric for the property of interest, preferably stated in lumen-seconds.

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[7] The same objection was heard many years ago when "gain" antennas for radio broadcast stations came into use and the concept of *effective radiated power* was introduced to allow more meaningful comparison of the potency of station emissions than would be given by stating the actual transmitter power. ("They only have a 1000 W transmitter, but are claiming an output of 10,000 watts [that is, ERP].")

BACK TO DIRECT FLASH UNITS

We can estimate the total luminous energy output of a flash unit for which a luminous intensity-time product has been stated if we know the angular dimensions of the beam involved.

For example, suppose that for a particular flash unit, the stated dimensions of the beam (for a particular beamwidth setting) are 45° horizontally by 30.9° vertically[8]. The solid angle embraced by the beam would be about 0.42 sr (steradians).

If the luminous intensity-time product of that beam is known to be 5000 cd-s (candela-seconds), then the total luminous energy output will be the product of that and the solid angle embraced by the beam (0.42 sr). In this example, that would be 2100 lm-s (lumen-seconds).

Note that this evaluation assumes a sharply-defined beam of uniform luminous intensity, which of course rarely obtains.

If we do not have the rated luminous intensity-time product for a flash unit, but only the guide number, we can use the relationship given in equation 1 to convert with sufficient accuracy for most purposes. Solving that equation for the luminous intensity-time product (and adopting different symbols) we get:

$$IT = \frac{20G^2}{S} \qquad (2)$$

Where *IT* is the luminous intensity-time product in BCPS (or in candela-seconds, in fact), *G* is the guide number in feet, and *S* is the ISO sensitivity for which the guide number is given.

As an example, for a unit with a rated guide number of 55 meters (180 feet) at ISO 100 (for some particular beamwidth), *IT* would be about 6500 BCPS (6500 cd-s).

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[8] This would be a beam that illuminated a “3:2” area.