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Technical Note

Understanding Dynamic Range—The Numbers Game

There is a fair amount of confusion in the reporting of dynamic range of beam profilers. The purpose of this technical note is to explain some of the terminology used in the discussion of this parameter by both Photon and our competitors.

Definition

Dynamic Range is the ratio of the largest measurable signal to the smallest measurable signal. The smallest measurable signal is typically defined as that equal to the noise level, or alternatively the "Noise Equivalent Exposure" or that point where the signal-to-noise ratio (SNR) is 1. To measure a beam profile we should have a SNR of at least 10 to obtain a minimally useful result. It requires a SNR of about 100:1 to achieve 2% accuracy in beam size measurements from the beam profile. Dynamic range is a key specification of beam profilers and is determined from the level of digitization of the detector signal. However, this seemingly straightforward specification is not standardized, and different approaches exist.

Units

Dynamic range can be express as a ratio; for example, 1000:1, or it can be expressed in decibels of either power or voltage.

Power Decibels:

$$dB_{power} = 10\log\left(\frac{P_2}{P_1}\right) = 30dB_{power}$$

Voltage Decibels:

$$dB_{volts} = 20\log\left(\frac{V_2}{V_1}\right) = 60dB_{volts}$$

Example:

Consider a CCD or CMOS array used for beam profiling. Assume there are two levels of beam power: 1mW and 10mW. The attenuation is set so that the 1mW power signal on the array is 25.5 counts and at the 10mW level the signal is 255 counts. In terms of the relative dB for the two levels dB_{power} is 10dB, but dB_{volts} is 20dB. Since we know that the power changed by 10dB, which is the more appropriate measurement? Which one sounds more impressive?

Our instrument specifications are given in Optical Power (dB_{power}). Our competitors often use Voltage (dB_{volts}), which is misleading. Optical power is the quantity that is of interest in beam profiling and indicates the actual capability of the profiler in terms of the laser power that is being measured.

Example:

Consider an 8-bit CCD camera, such as the Model 2320. The digitization range of the framegrabber is from 0 to 2^8-1 counts, or 0-255 counts. Expressed in dB_{power} this is 24dB. Expressed in dB_{volts} this becomes the much more impressive, but misleading 48dB. The lesson here is to be sure you understand the units when comparing the dynamic range of a system expressed in dB.

Mode Field Diameter Example:

The fiber optic parameter Mode Field Diameter (MFD) is defined by a standard TIA/EIA Fiber Optic Test Procedure (FOTP) that requires a dynamic range of at least 50dB. The Photon LD8900HDR was designed for this protocol and provides a minimum of 64dB for a 0dBm (1mW) source into a single mode fiber. One of our competitors jumped onto the MFD bandwagon with a camera solution, erroneously assuming that the specification was in dB_{volts}, and advertised that they could also measure MFD. This was not the case: the equivalent *voltage* specification for MFD is in excess of 100dB, which would require a camera that could digitize the signal into 16.5 bits. This camera was something that they did not, in fact, have in their product line.

Digitization Dynamic Range vs. Measurement Signal Dynamic Range

Consider the Model 2320 with an 8-bit digitizer. The camera itself is a COHU array with a specified dynamic range of 150:1. This is actually less than the range of the framegrabber, so when we say that the dynamic range is 24dB, we are really talking about the digitizer. The 150:1 range of the array relates to the Noise Equivalent Exposure, and results in a dB_{power} of 21.76dB. However in reality we need a minimum SNR of 10:1 to provide a usable beam measurement. This leads to an actual useful dynamic range for the array of only 15:1 or 11.76dB.

Instantaneous (single measurement) vs. Total Achievable Dynamic Range

We can now separate the dynamic range of the instrument in to two parts: one is the instantaneous or single measurement capability. This is the digitization dynamic range minus any noise levels. The second is the total achievable range capability including the digitization range and any extensions to the range achieved using gain and exposure controls and external attenuation, such as ND filters.

LD8900HDR Example:

With the Photon LD8900 HDR the digitization dynamic range is 24dB, and the electronic gain ranges up to 139dB (this is an electronic specification, therefore is measured correctly using dB_{volts}). Therefore, the total optical dynamic range is 24+(139/2) or $93.5dB_{power}$. For the silicon version of the HDR the gain goes up to 159dB, giving a total range of $103.5dB_{power}$.

USBeamPro Example:

The digitization dynamic range of the USBeamPro is 30.1dB (10-bit). The exposure control ranges from 10µsec to 30msec, giving another factor of 1000, or 30dB. The ATP-SM has and optical density of 1.7 to 7.4 for and additional range of 5.01×10^5, or 57dB. Add another high power attenuator with and OD of 2.3 and we can add another 23dB. The total measurement dynamic range is therefore 140.1dB.

Although theoretically one could continue to add 2.3OD attenuators to this and increase the dynamic range *ad infinitum,* there is a practical limit. At 140.1dB we would have the dynamic range to measure a beam with a power density of $8x10^8$ W/cm^2. This is a beam that is 800 MW/cm^2, which is several orders of magnitude above a laser power that anyone could ever practically measure.