

Tutorial: Understanding Dynamic Range...The Numbers Game

There is a fair amount of confusion caused by the reporting of dynamic range of beam profilers. The purpose of this applications note is to explain some of the terminology used in the discussion of this parameter by both Ophir-Spiricon and other suppliers of beam profilers.

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 more like SNR of 100:1 to achieve the 2% accuracy. However, in instrument specifications Ophir and its competitors use the Digitization Dynamic Range. The discussion below will follow this approach.

Units

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

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

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

Therefore, if the 1000:1 ratio is of two laser power levels, the dB dynamic range would be:

$$dB_{power} = 10 \log \left(\frac{1000}{1} \right) = 30 dB_{power}$$

However, if the ratio is of a voltage, such as when discussing the gain within an instrument amplifier circuit, then the dB dynamic range would be:

$$dB_{volts} = 20 \log \left(\frac{1000}{1} \right) = 60 dB_{volts}$$

Example

Consider a typical 12-bit CCD camera, such as the BeamGage SP-620, or the 12-bit NanoScan. The digitization range of the computer interface is from 0 to $2^{12}-1$ counts, or 0-4095 counts. Expressed in dB_{power} this is 36dB. Expressed in dB_{volts} this becomes the much more impressive 72dB. The lesson here is to be sure you understand the units when comparing the dynamic range of a system expressed in dB.

Digitization Dynamic Range versus Measurement Signal Dynamic Range

Consider the 12-bit SP-620 again. The camera itself is a CCD array with a specified dynamic range of 880:1. This is actually less than the digitizer's range, so when we say that the dynamic range is 64dB, we are really talking about the digitizer. The 880:1 range of the array relates to the Noise Equivalent Exposure, and results in a dB_{power} of 29.44 dB.

Instantaneous (single measurement) versus Total Achievable Dynamic Range

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

For the above mentioned SP-620 with the BeamGage software package, the exposure and gain controls add an additional 72 dB_{volts} , 36 dB_{power} . This gives a

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total dynamic range per frame of around $65\text{dB}_{\text{power}}$. However, by adding attenuation to this, we can extend the dynamic range to an almost limitless level.

NanoScan Example

The digitization dynamic range of the NanoScan is $36\text{dB}_{\text{power}}$ (12-bit). The amplifier circuits provide an automatic gain range of around $85\text{dB}_{\text{volts}}^i$, therefore, the total measurement dynamic range can then be claimed to be $78.5\text{dB}_{\text{power}}$. ($36+(85/2)$). This can be seen in the operating space charts of the various NanoScan models that show around seven (7) orders of magnitude.

Conclusion

It is important to understand what units are being used when comparing the dynamic range of different instruments. Most CCD systems report dynamic range in dB_{volts} . NanoScan and Goniometric Radiometers report their dynamic ranges in dB_{power} . Both are valid, but if you want to understand how the dynamic range will affect your laser beam measurements, dB_{power} will provide a more realistic value of the response of the sensor to varying laser power levels.

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ⁱ This varies slightly depending on the type of detector (e.g., the silicon detector has a gain range of $103\text{dB}_{\text{volts}}$, the pyroelectric 85dB)



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