how many bits is enough?

Choosing the correct digitization for a beam profiler depends on the application.

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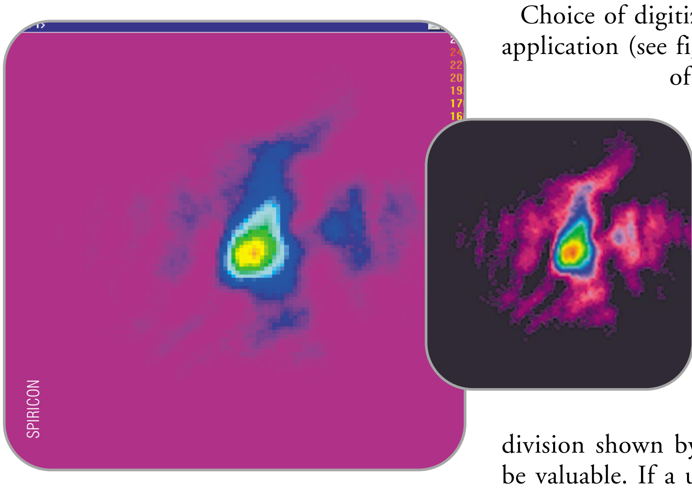
The width of a laser beam, W_0, is one of its most critical parameters. The beamwidth is typically determined by capturing an image of the beam with a CCD camera and digitizing it for measurement with a computer (see ***oe****magazine,* March 2002, page 48). Properly characterizing the low-level energy in the wings of the beam is critical to accurate beamwidth measurements.

The ability to measure this energy with camera systems is compromised by camera DC drift and camera random noise. DC drift is a change in the overall camera baseline, typically related to camera warm-up. Random noise is the electronic noise the camera produces when no energy is falling on the detector array. Both DC drift and random noise can disguise the low-level light energy in the wings of the beam by either increasing the DC level and creating an apparently larger beam or suppressing the wings below the digitizer zero to create an apparently smaller beam. For digitizer systems in which the components of random noise are truncated at zero, the positive components integrate to provide the effect of a net positive DC baseline.



Beam profiles taken using the same camera with an 8-bit digitizer (left) and a 12-bit digitizer (right) show the difference the correct digitizer makes.

The choice of digitizer accuracy can be critical in determining the correct DC baseline and properly treating random noise to obtain an accurate beamwidth measurement. Random camera noise, captured by the digitizer, is an essential ingredient in determining the camera baseline level. The noise is typically Gaussian and is both positive and negative about a mean or average level. Digitization affects how this noise is quantified: An 8-bit digitizer yields 256 discrete signal levels, a 12-bit digitizer provides 4096 levels, and a 14-bit digitizer provides 16,384 levels.

A standard CCD camera usually exhibits a dynamic range of about 54 dB RMS or a signal-to-noise ratio (SNR) of about 500 to 1. The 3σ peak-to-peak noise is six times greater, however, which gives a peak-to-peak SNR of only 83 to 1. When an 8-bit digitizer (256 counts) is used with this type of camera, the digitized noise is $N = 256/83$, or about three counts peak-to-peak. By taking a long-term average of these three counts of noise, it is possible to determine an accurate DC baseline.

New, low-noise cameras typically boast dynamic ranges of 70 dB, or RMS SNRs of about 3150 to 1 (525 to 1 peak-to-peak). In the case of an 8-bit digitizer, then, $N = 0.5$ counts. In such a case, the minimum signal level of the camera is below the threshold of the digitizer so that the digitizer is unable to detect the zero level. Essentially, the system loses its ability to determine the camera DC baseline. On the other hand, the same camera used with a 12-bit digitizer would produce about eight counts of noise, which would be about right for finding the zero baseline.

Choice of digitizer should also be driven by application (see figure). A camera with 54 dB of dynamic range used with a 12-bit digitizer would produce about 50 counts of peak-to-peak noise, which would be more noise than necessary to correctly determine the zero-signal baseline. However, if the user is averaging or summing to pull weak signals out of noise, then the finer noise division shown by the 12-bit digitizer would be valuable. If a user were to choose a 14-bit digitizer, a camera with a dynamic range of more than 80 dB (one part in 10,000 RMS, or 1667 to 1 peak-to-peak) would be needed to produce 10 counts of noise and allow them to take advantage of the increased capability of the digitizer. Few cameras used in beam diagnostics come close to this specification.

As lower-noise cameras are developed for more-demanding applications, the use of 10- or 12-bit digitizers can allow users to take advantage of the superior camera performance. Without the proper algorithms, however, inaccurate beamwidth calculations can still be made.

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