Pulsed Lasers With Rolling Shutter

Introduction

Capturing pulsed lasers normally requires a synchronous shutter which opens and closes on all pixels simultaneously. This is called a global shutter and is preferably triggered to coincide with the laser pulse. DataRay offers several global shutter cameras, which are always the preferred choice for pulsed lasers. However, if you have a rolling shutter CMOS such as the BladeCam2-HR or BladeCam2-XHR you can still capture pulsed lasers in many cases.

A camera with a rolling shutter sensor has each line in the frame open at a different time, stay open for the duration of the exposure and then close. The white block in the two frames on the left in Figure 1 illustrates this open period of the electronic shutter ”rolling” down the frame. This is not an issue for stable CW beams, but can cause problems with moving or pulsed beams.

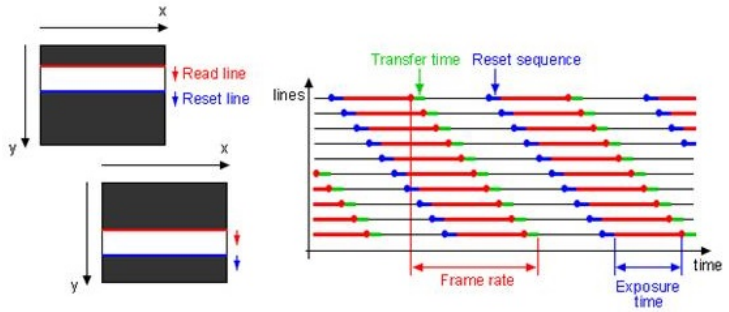


Figure 1: Rolling shutter diagram

Pulse capture ***may*** be achieved with a rolling shutter CMOS camera if:

- **Everything is perfectly timed.** The size of beam and the duration of the Exposure, the PRR (Pulse Repetition Rate), the pulsewidth (pw) and the pulse timing are all perfectly synced such that the beam is measured without any rolling shutter artifacts.
- **It is measured with pulse averaging.** The exposure time adequately averages a number of pulses, most commonly true at a high pulse repetition rate (**PRR**).

These two cases are discussed in detail below.

1) **Everything is perfectly timed.**

   If both of the following occur, a single full pulse image may occasionally be captured:

   (a) The laser fires off during the exposure time.

   (b) The pulse sits completely within the open frame.

   When the above conditions are true, you may occasionally capture a full pulse image. It is also possible to capture partial pulses. Examples of various measurements and methods are below.

- **2 Hz Pulse Repetition Rate**
  - **Auto-Exposure**
    The Image Buffer sequence in Figure 2 shows 21 captures out of 64 frames–but they are overexposed. This is because most frames have no images so the auto-exposure auto-adjusts to the default max limit of 100 ms, over-exposing the pulses that are captured.

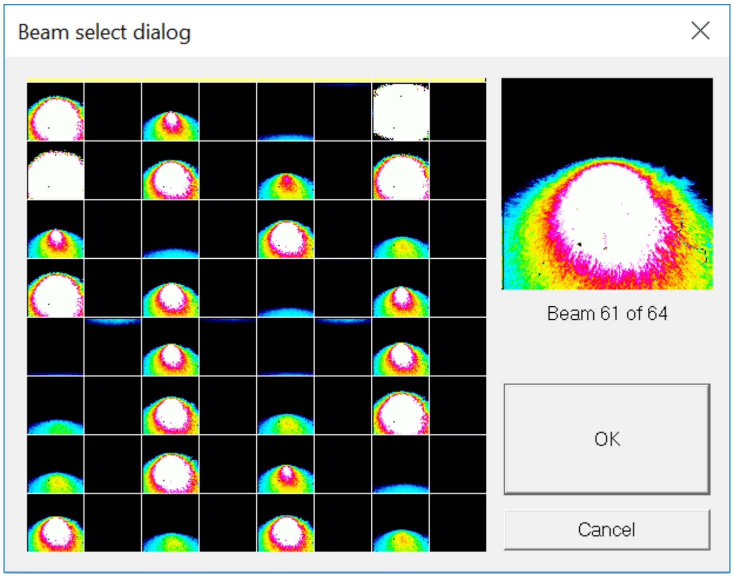


Figure 2: 2 Hz PRR, 100 ms pulse width, Auto-Exposure

The beam select dialog is accessed from the toolbar in the DataRay software. The arrow buttons in the toolbar can also be used to cycle through the data buffer while the camera is stopped.

Since these pulses were long (10's of ms), disabling auto-exposure and reducing the exposure time can capture partial pulses without saturating the sensor as shown in Figure 3.

  - **Reducing exposure time to prevent saturation by capturing partial pulses**
    Figure 3 shows that reducing the exposure time can capture partial pulses without saturating the sensor. But the capture rate can be very poor, and partial pulses might not be the desired measurement–sometimes capturing full pulses is required. At an exposure of 1.3 ms, the camera only captured 12 complete images in 64 frames as well as some chopped images. Also, because the exposure time is 1/10 of the pulse width, none of the captured pulses are full pulses.

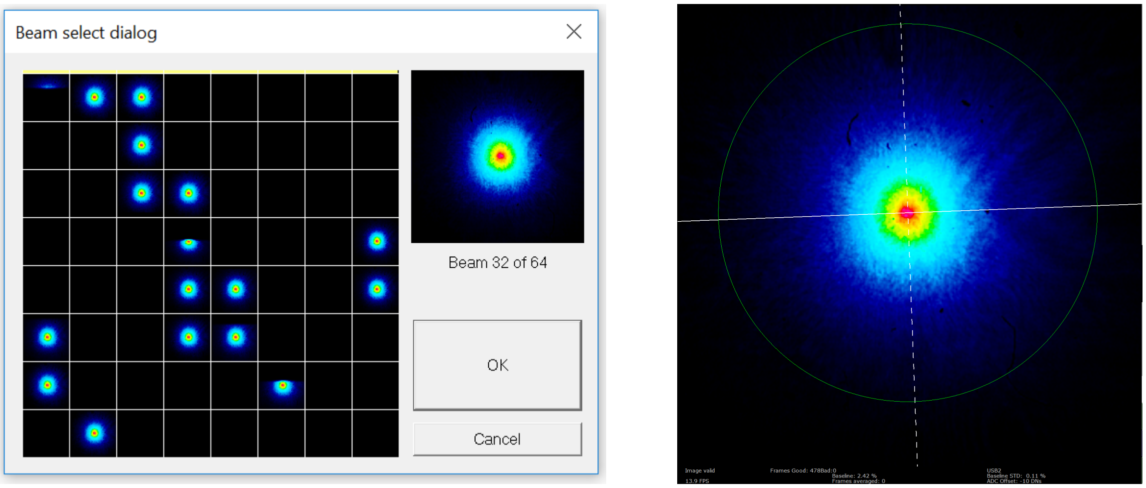
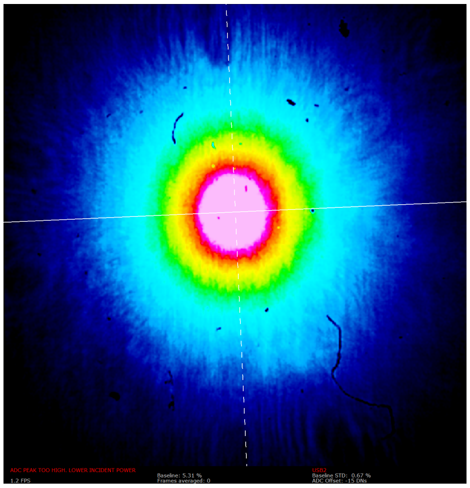
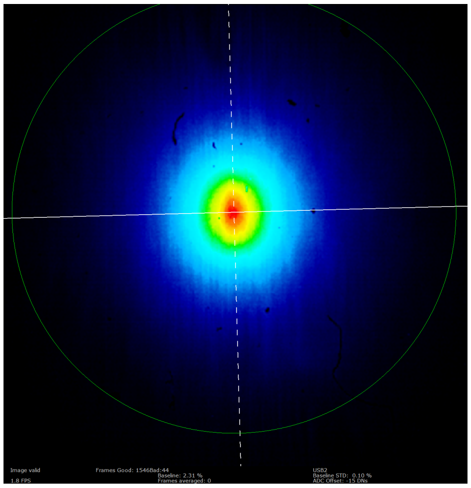


Figure 3: 2 Hz PRR, 100 ms pw, 1.3 ms Exposure time

- **Capturing full pulses by setting exposure time to 1/PRR and lowering pulse energy**
  To ensure full pulses are captured, the exposure time should be set to 1/PRR. For the 2 Hz pulse, this requires an exposure time of 500 ms. If a full pulse over-saturates the detector as shown in Figure 4a, then the pulse energy must be decreased by either adjusting the laser or adjusting the attenuation. Figure 4b shows the same measurement after decreasing the laser pulse energy on the detector.



(a) 2 Hz PRR, 100 ms pw, 500 ms Exposure time, Over-saturated Image

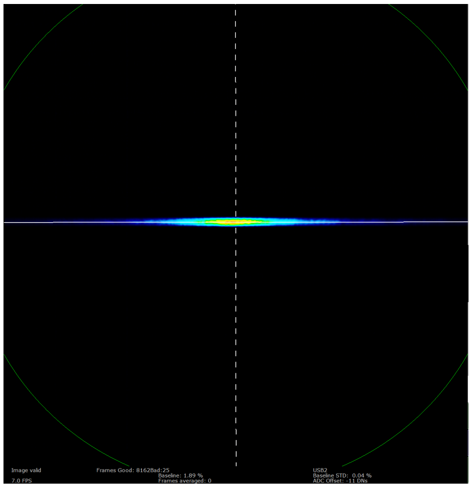


(b) 2 Hz PRR, 100 ms pw, 500 ms Exposure time, Valid image of the full pulse

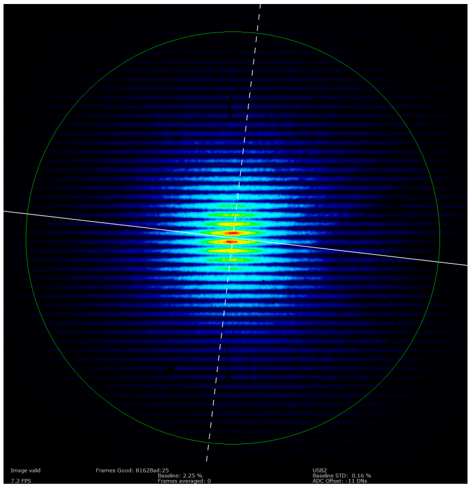
Figure 4: These images are taken after setting the exposure time to 1/PRR. The image on the left is over-saturated by the full pulse. The pulse energy on the detector was then lowered for the second image where the full pulse is measured without saturation.

- **Higher Pulse Repetition Rates**

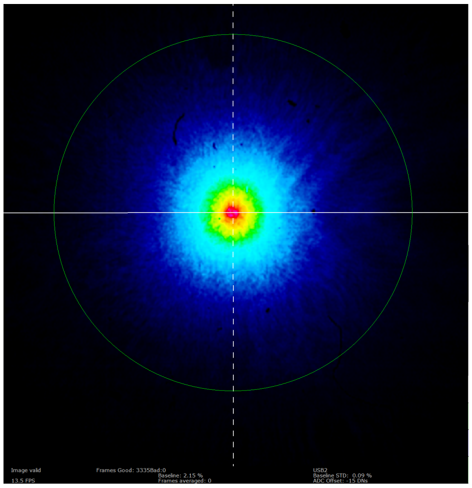
Figure 5 show how higher repetition rates can provide more complete images even at short exposure times. The exposure time can be set to 1/PRR for full pulses, or ideally longer to average several full pulses as discussed in the next section.



(a) 5 Hz PRR, 1 ms pw, 1.3 ms Exposure time



(b) 500 Hz PRR, 1 ms pw, 1.3 ms Exposure time



(c) 1kHz PRR, 1 ms pw, 1.3 ms Exposure time

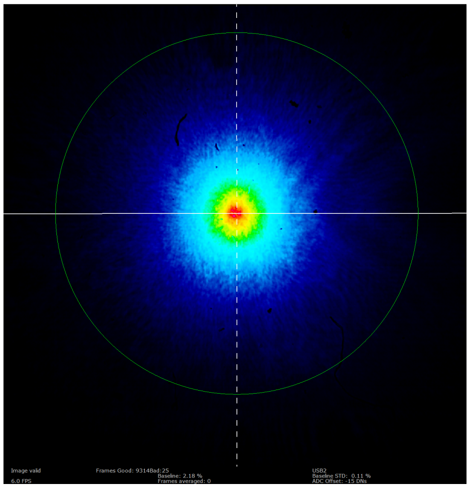
Figure 5: Higher PRR values result in more complete images, even at short exposure times.

2) **Pulse Averaging**

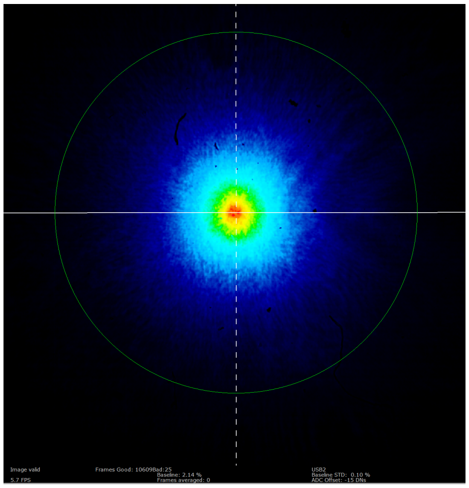
If your repetition rate is high and you do not need to capture individual pulses, then averaging is often the most useful method to eliminate rolling shutter artifacts.

- **500 Hz Pulse Repetition Rate**
  At a PRR of 500 Hz, an exposure of 39.7 ms will average approximately 20 pulses. With the frame averaging feature in the DataRay software set to **Average 10**, an effective average of 200 pulses is achieved. Figure 6a shows the results of pulse averaging the 500 Hz PRR beam. This provides a valid image and is a substantial improvement over the 500 Hz beam measured at a 1.3 ms exposure time without averaging in Figure 5b.
- **2 kHz Pulse Repetition Rate**

At higher PRR values, each exposure can contain a greater number of pulses. This allows for sufficient pulse averaging even when **No Averaging** is selected in the Dataray software. Figure 6b demonstrates the result.



(a) 500 Hz PRR, 0.1 ms pw, 39.7 ms Exposure time, **Average 10**, effectively averages 200 pulses



(b) 2 kHz PRR, 60 s pw, 49.7 ms Exposure time, **No Averaging**, effectively averages 100 pulses

Figure 6: The image on the left shows the result of a 200 pulse average using both exposure and frame averaging. The image on the right shows the result of a 100 pulse average using only exposure time averaging without additional frame averaging.