High Megapixel DSLR Opto-mechanical Limitations

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When Bob Young asked me to make a contribution to the newsletter on the subject of high megapixel DSLR performance, I was at first very reluctant to agree because he had in mind the 36 megapixel Nikon D800 with which I had no hands-on experience. However, in my discussion with Bob I came to realize that many of the performance limitations he was discovering with his new D800 were the same or similar to my experience with the 22 megapixel Canon 5D Mk III. I therefore agreed to write in general terms about some of the opto-mechanical issues likely to be encountered by users of full-frame, high megapixel cameras.

The main opto-mechanical subsystems in a modern DSLR are the mirror and shutter drive, the lens AF drive, and the lens aperture mechanism. Each of these has limitations which can impact on image quality, notably the sharpness. Mechanical vibration caused by the movement of the reflex mirror and shutter curtains has long been known to affect image quality. What is not so well known is the degree to which this is a problem and under what circumstances it is an issue. If it is an issue, what can be done to ameliorate the problem?

The amount of energy needed to drive the mirror and shutter curtains scales up roughly as the third power of the size of these two subassemblies. This means that the energy required to drive a full-frame camera mirror and shutter is 2–4 times as much as required to drive a 1.3–1.6 crop-factor camera. The corollary is that a full-frame camera needs to dissipate this much more energy than a cropped sensor camera. The energy is dissipated as heat, sound and vibration. Camera designers are well aware of the engineering issues and try to design mechanisms that are relatively quiet and dissipate the vibration load in a controlled way as heat. There are many trade-offs required, including cost, and consequently, the mechanisms are not perfect, especially for full-frame cameras.

Manufacturers have gone some way to addressing the problems by providing options such as ‘mirror lock-up’, ‘silent shutter’, and an electronic first curtain in Live View silent mode. Each of these options is helpful but has practical limitations. For example, when mirror lock-up is used, the mirror is out of the light path in the up position and through the lens viewing and AF is no longer available. The so called silent shutter is a quieter mode of operation using more damping and/or less energy but the downside is a slow frame rate when using continuous shooting. Live View uses the back screen with the optical viewfinder disabled and is really only practical if the camera has a remote shutter release, is on a tripod, and the bird is resting. There are occasions when this is practical and we have used Live View shooting to good effect when birds are at long range in situations where the slightest camera vibration might spoil resolution of fine detail.

The impact of vibrations depends on the size of the sensor pixels and the focal length of the camera lens. Cameras with small pixels are more likely to be affected than those with large pixels and long lenses are more likely to be affected than short lenses. Photographers using popular cropped sensor cameras with modest lenses are usually completely unaware of vibration problems. It is really only an issue for full-frame cameras and for telephoto lenses longer than about 300 mm focal length. To get a ‘feel’ for the magnitude of the problem, we have measured the resolution limit of a Canon 5DIII with 300 mm lens and 2x extender using the International Standards Organization digital camera resolution test chart. The lens was supported on a large, heavy V-block and the camera body was supported on a large parallel block. Thin strips of latex rubber were used between camera and supports to create a little mechanical compliance in the interface and increase the area of contact. The shutter was actuated using a remote release. Test shots were made using each of the options mentioned above and compared with the resolution achieved with the ‘standard’ shutter drive.

Because of the nature of the mirror movement and direction of travel of the shutter curtains (vertical), one would expect the main shock load to be in the vertical direction causing the resolution in this direction to be less than the horizontal resolution. The results are shown in Fig. 1 for resolution in both the vertical and horizontal direction. Slightly different results were achieved depending upon whether the lens image stabilizer was turned on or off and when the camera was mounted on a sturdy tripod. However, in all cases the same general trend was observed and the measurements show that vibration caused by the standard shutter had a significant negative impact on the resolution of fine detail. As expected, the best resolution, about 25 microradians, was achieved using the electronic first curtain in Live View silent mode. This can be compared with a theoretical best resolution of 21 microradians which could only be achieved with a perfect lens and an ideal anti-aliasing filter. In practice, the anti-aliasing filter begins to roll off the spatial frequency response before the Nyquist resolution limit is reached and at full aperture (f/5.6) there are residual lens aberrations which explains why the best resolution achieved using Live View was only 25 microradians. From f/7.1–f/10 the measured resolution limit was about 23 microradians, a good result.

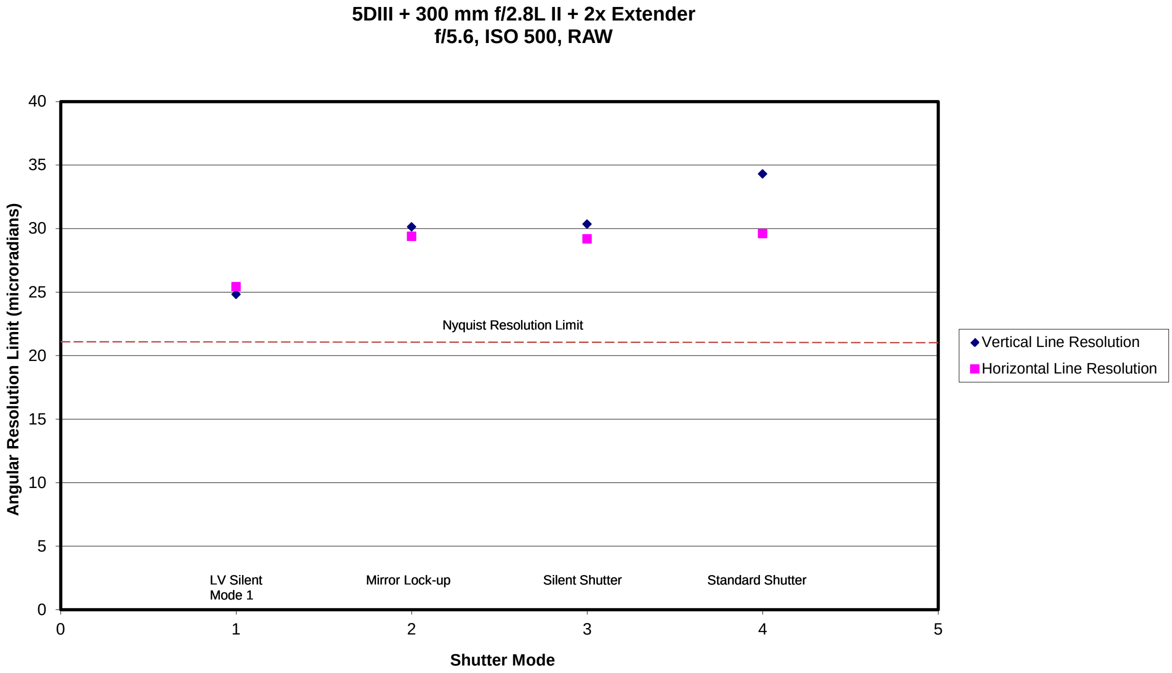

Fig. 1 Measured resolution limit using different mirror/shutter drive options. For reference, the theoretical best resolution, the Nyquist limit, is also shown.

At this point it is convenient to comment on the implications for high megapixel cameras. If the sensor in the 5DIII (6.25 μm pixels) was replaced by the sensor in the D800 (4.9 μm pixels), the Nyquist resolution limit in the above example would become 16.3 microradians. To get anywhere near this resolution in practice would require special techniques or a much better behaved mirror/shutter drive. The extent to which Nikon have managed to achieve this with the D800 is uncertain as I have been unable to find any measurements of the impact of the vibration load when using long lenses. While our measurements are for a particular camera and lens, we believe similar results will be observed for other full-frame–long lens combinations. We are fortified in this belief by the extraordinary measures taken by camera test engineers to eliminate vibrations when testing sensor resolution limits. They use mirror lock-up and 'bulb' to open the shutter and then illuminate the resolution test chart with a remote flash. Their use of flash exposure gives us a pointer to a technique for ameliorating the effects of vibration – more on this anon.

There are some other, simpler, ways of reducing the impact of vibrations. John Stirling, a retired engineer, prefers to hand-hold his camera, correctly reasoning that his body acts as a vibration damper. He has superb technique and regularly produces images of a very high standard. However, hand holding the camera has its limitations, especially when using large aperture long lenses and heavy camera bodies. Some people have developed effective techniques for lifting these systems for a quick burst then lowering them to the rest position. It is certainly not practical to hand-hold a large heavy combination for long and a support is inevitably required. Some photographers have found that vibration damping can be achieved by increasing the effective mass of their kit using a small bag of rice or similar, draped over the top of the lens barrel. Others advocate the use of a weight hanging from underneath their tripod head (engineers call this mass damping). Some tripods come with a special hook under the head making it easy to hang a small back-pack or a plastic supermarket bag containing a brick-size rock. The doyen of American bird photography, Arthur Morris, teaches students who attend his workshops an effective tripod technique that contains elements of a number of the simple ideas just mentioned. The Morris stance is illustrated in Fig. 2. The photographer rests his left arm on the top of the tripod, under the long lens, and his left hand provides support for the front of the lens. His face is pressed against the camera back with right hand gripping the camera body in the usual way. This stance is surprisingly effective in damping vibrations but takes a little practice. If you try this technique, the first thing you will notice is that the noise of the mirror/shutter mechanism sounds quieter, indicating that the vibration spectrum has been changed by the weight of the left arm and damping produced by the hands and face.

Fig. 2 Morris stance recommended for use with tripod-mounted long lenses.

The measures discussed above are all trying to dampen vibrations and are more or less effective but not perfect solutions to the problem. The perfect solution, using flash exposure, has been mentioned but it is not practical for bird photography. However, a variation of this flash technique can be very effective and practical in a range of situations. I have in mind the high-speed flash techniques that I talked about at the Ingham *Photography in the Bush* conference and published in the December 2013 issue of our newsletter. The idea is that if the flash pulse is very short, say 1/5000 sec, then the exposure will be over and done with before the vibration waves propagating through the camera and lens have time to spoil the image quality. It goes without saying that, with such a short effective exposure time, movement blur from other sources will also be a non-issue. For best results, multiple synchronized flashes should be used in a kind of ‘outdoor studio’ setting such as at a bird-bath, water-hole, or other situations where the presence of birds is predictable. Images recorded under these conditions are essentially free of vibration and movement blur with the resolution limited by diffraction, residual lens aberrations and the sensor. The image quality can be stunning making the set-up well worth the effort.

Opportunistic bird photography is also possible with high-speed flash if the ambient light level is low such as early or late in the day, on overcast days, and in shady situations. A Better Beamer is essential and a powerful flash unit is an advantage so that the flash provides the main light exposing the scene. Under these conditions, provided the bird is closer than about 7.5 m, the effective exposure time can be very short, with the same benefits as in the outdoor studio set-up.

It will not have escaped the notice of some readers that the mechanical vibrations that limit the resolution of a camera act like a low pass filter. This is similar to the effect produced by the anti-aliasing filter, also known as an optical low-pass filter, and tempts one to speculate that manufacturers who are now omitting AA filters from their cameras are doing so in the knowledge that mechanical vibrations are doing the work for them. Indeed, in a bizarre development, the recently released Pentax K-3 uses its sensor-shift technology to vibrate the sensor array to produce the effect of an AA filter and Nikon have patented a device that achieves the same thing but in a different manner. In the future, full-frame mirrorless cameras may be part of the answer. We already have the 24 megapixel, full-frame, mirrorless, Sony Alpha 7 with electronic first curtain shutter. Its sibling, the Sony Alpha 7R has 36 megapixels and no anti-aliasing filter but, curiously, it also has no electronic first curtain option, which is a pity. Further down the track one can foresee all-electronic shutters, perhaps using thin film optical transmission switches. With no moving parts, cameras of the future should make the vibration problems of today a distant memory.