PERFORMANCE OF CANON Mk III FOCAL LENGTH EXTENDERS - Ian J. Wilson BSc(Hons), PhD(optics)

Auxiliary lenses used to multiply the focal length of a prime lens, called focal length extenders by Canon and teleconverters by Nikon, find a place in the kit of many bird photographers. Opinions on the usefulness of multipliers vary and there is little quantitative information available with which to make an objective assessment. There is a common belief that multipliers significantly degrade the image quality of the prime lens and cause unacceptable light loss which adversely affects the performance of the camera auto-focus. They also work better with some prime lens and camera body combinations than with others. On the positive side, they provide a convenient way of changing the effective focal length of a prime lens, are reasonably small and do not add a great deal to the overall length and weight, and are a relatively cheap way of getting more 'reach'. They also leave the minimum focal distance of the prime lens unaffected, which can be an advantage for close shots.

It is not easy to get answers to all the questions raised by the various claims and opinions about focal length multipliers. Nor is it easy to find published data or conduct the relevant tests and measurements needed to make an assessment. Nevertheless, it is not beyond the ability of photographers to make some measurements that will answer some important questions. For example, a great deal can be learned from taking pictures of a standard test chart.

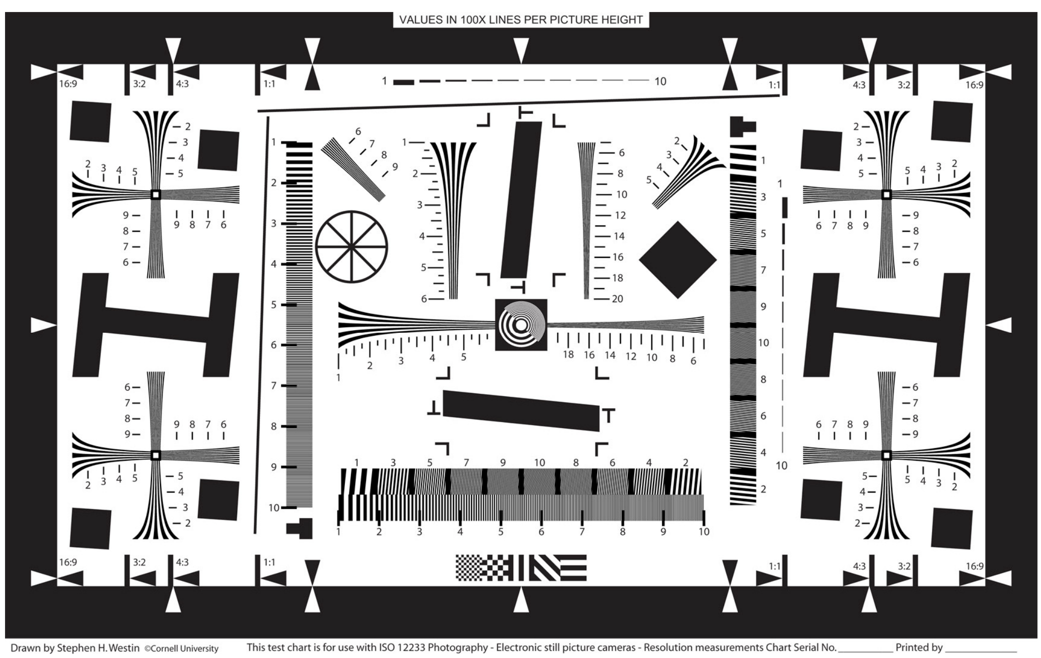

Fig. 1 ISO 12233 resolution test chart for testing electronic still picture cameras.

Resolution Testing

We use the test chart approved by the International Standards Organization – ISO 12233 Photography – Electronic still cameras – Resolution measurements (Fig. 1). It can be purchased from the International Standards Organization for 116 Swiss francs or Precision

Optical Imaging, Rochester NY, for US$135. Also, copies can be downloaded from the Cornell University website http://www.graphics.cornell.edu/~westin/misc/ISO_12233-reschart.pdf. It needs a high resolution A3 inkjet printer to make a full size print or it can be reduced and printed using an A4 printer. If using the latter, and you want calibrated rather than relative measurements, then the chart scale (scale factor) will need to be measured using, for example, an optical microscope with a micrometer driven specimen stage. The chart needs to be printed on good quality gloss photo paper and the printer needs to be able to print at least 1200 dpi. The quality of the print should be checked using a microscope to be sure there is no 'bleeding' of ink.

Tests conducted using the ISO 12233 protocol require light sources and calibration equipment not usually available to photographers. For example, it is essential that the test chart be uniformly illuminated with a source equivalent to sunlight. We use sunlight reflected off a mirror arranged so that the test chart is illuminated at near normal angle of incidence. The light is very uniform and of the right intensity for resolution testing using the lowest camera ISO setting. For testing at higher ISO values, the mirror can be replaced by a plain sheet of glass which reflects about one-tenth the amount of light. The distance between camera and the test chart is also important – for telephoto lenses a long test range is needed; we use an indoor range about 17 m long.

The camera system needs to be supported on a rigid mount such as a solid table with a wooden V-block under the lens barrel and another wooden block under the camera body. Fine adjustments to the inclination can be made by packing business cards under the lens. The area around the camera needs to be in low light to prevent leakage of light into the camera through the viewfinder eyepiece which may affect the exposure setting. Shots should be taken hands off using the 2 second or 10 second shutter timer and the lens image stabilizer should be turned off. Best results are obtained using the Live View Quick Mode electronic shutter in silent mode 1 – that is a bit of a mouth full so for the rest of this article we will call this 'LV silent mode'*. It uses the same auto-focus phase detection sensor that is used in viewfinder shooting. Vibrations from the standard mirror/shutter drive can seriously degrade resolution when using long focal length lenses, especially with the full-frame 5DIII. Mirror lock-up and the specially damped silent shutter on the 5DIII are only partly successful and not as effective as LV silent mode. The resolution in LV silent mode can be more than one-third better than that achieved with the standard shutter.

The normal camera sensitivity for resolution testing is ISO 100 as this is usually the baseline gain setting of the signal chain electronics. It is the ISO setting that has the least amount of noise and results in the best resolution and contrast in the recorded image. However, it may be more useful to do the testing with an ISO value more commonly used in the field. The standard test procedure is to set the camera ISO and take three shots for each aperture setting (f/No). The images are recorded in RAW and/or JPEG format. The pictures are then

---

* Live View has two other modes called AF Live and AF facial recognition, both of which use AF contrast detection for achieving focus. LV Quick Mode uses AF phase detection which achieves focus faster than the other two modes.

examined at 200% enlargement with the camera manufacturer's image viewing software using the default values for brightness, contrast, noise reduction, sharpness, and so on.

The ISO 12233 test chart has a number of scales and test patterns which, at first sight, can be a bit daunting but with a little familiarity, are easy to use. The most useful for our purposes are the grating panels, chirped gratings and the sets of converging line patterns. The patterns are arranged at right angles for testing the horizontal and vertical resolution and in the corners of the chart for testing off-axis performance. There are also patterns for measuring edge spread functions which can be used to determine resolution but this method need not concern us. We are only interested in measuring the finest detail recorded in the image using the gratings and converging line patterns. The scale factor, determined earlier, is used to calculate the finest detail resolved on the test chart. There may be slight differences between results obtained using the horizontal and vertical patterns and these two measurements should be averaged. Then the results from the three images taken at each f/No setting should be averaged to obtain the final value for the resolution limit. Near the resolution limit, coloured moiré bands (aliasing) will be noticed – these bands can be used to observe the effectiveness of the manufacturer's anti-aliasing filter.

Once the test setup is working properly, the first job should be to check that the auto-focus is accurate. This can be done by taking a picture of the test chart in LV silent mode with manual focus. The manual focus is achieved using the LV screen at maximum magnification and with the aid of a hand magnifying glass. This shot is then compared with one taken using AF in LV silent mode. In each case the 2 second or 10 second timer should be used. If the resolution of the AF shot is not as good as the MF shot, then fine adjustment of the AF point of focus may be required. Best results are obtained if this adjustment is done with the lens aperture closed down one or two stops.

After completing the preliminary tests and camera adjustments, the finest detail resolved on the test chart is measured for each f/No setting. The angle subtended by the finest lines that can be resolved is calculated using the formula: Angular resolution limit in radians = (Finest line spacing in mm) ÷ (Distance between camera and test chart in mm). This will be a very small angle and the unit of measurement is the radian. Note that π radians = 180°. In the image formed at the camera focal plane, the spacing of the finest lines will be given by: Image resolution limit in µm = 1000 × (Lens system focal length in mm) × (Angular resolution limit in radians). The unit of measurement in this case is the micrometre (µm) where 1 µm = 0.001 mm. All that remains to be done is to plot a graph of the image resolution limit versus f/No. The measurements, calculations and graph can be conveniently handled using the Excel software installed on most home computers. The results for the Canon 7D and 5DIII with 300 mm f/2.8 prime and 1.4× and 2× extenders are shown in Figs 2–3. The measured results were obtained from RAW picture files taken with the camera sensitivity set to ISO 500.

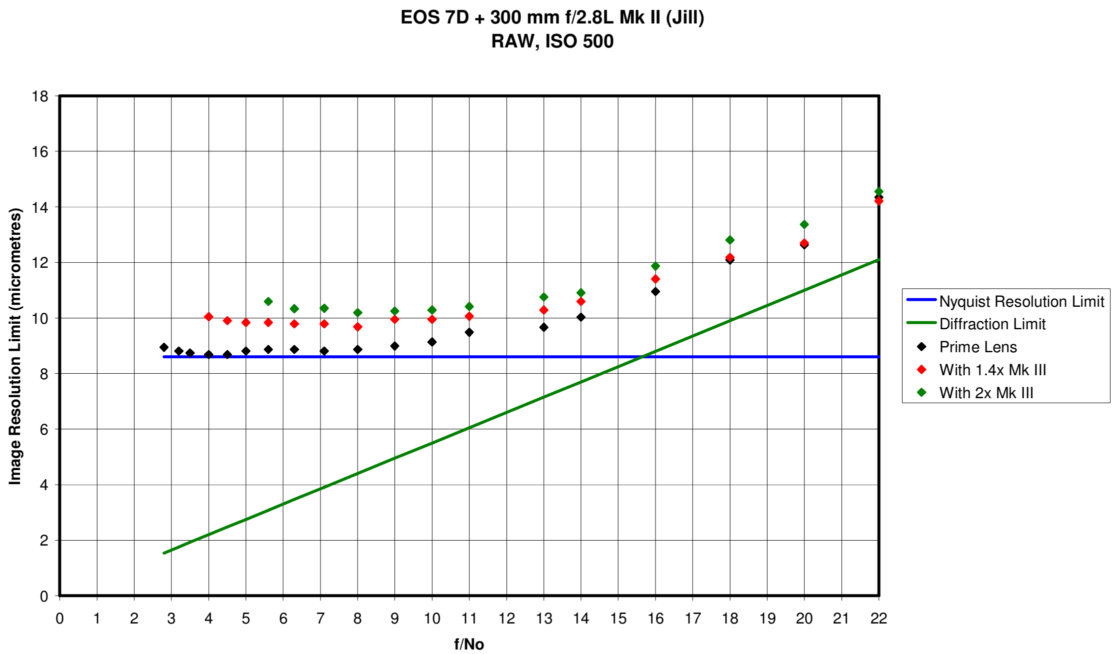

Fig. 2 Image resolution limit at ISO 500 for the 7D and 300 mm f/2.8L Mk II prime with Mk III extenders.

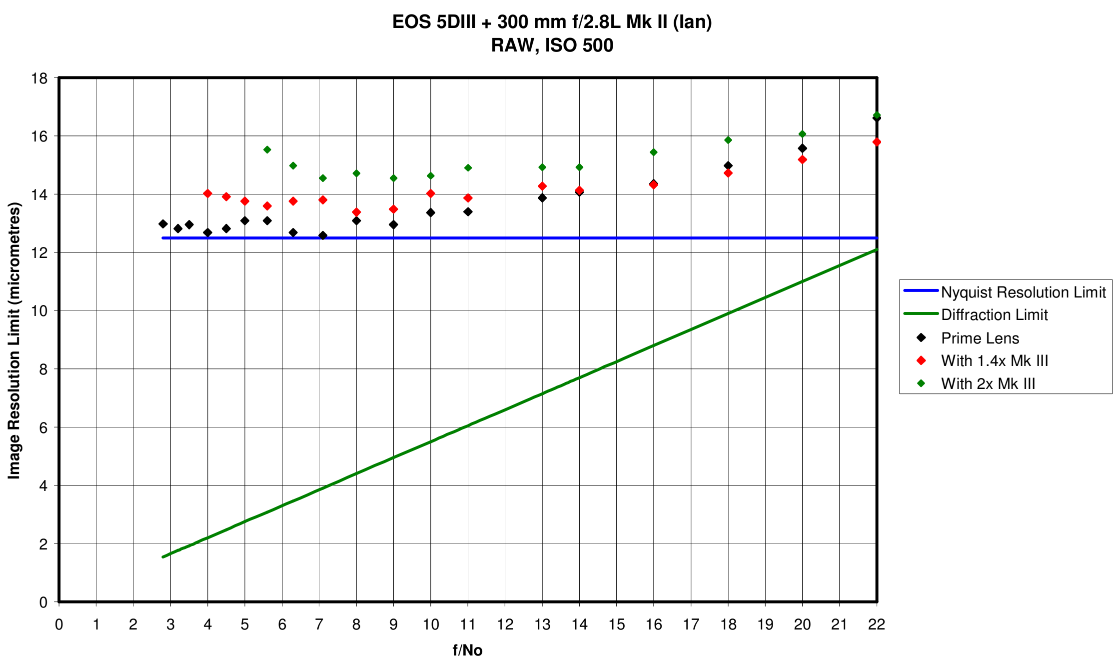

Fig. 3 Image resolution limit at ISO 500 for the 5DIII and 300 mm f/2.8L Mk II prime with Mk III extenders.

To put the results in context, we have included on the graphs the Nyquist resolution limit and the diffraction resolution limit. These are two fundamental limits to performance against which we can easily compare the measured results. The Nyquist resolution limit is the finest detail that can be faithfully resolved by the detector array and is twice the sampling interval of the pixels in the array. For example, the 7D, which has an array with pixels spaced 4.3 µm, has a Nyquist resolution limit of 2 × 4.3 = 8.6 µm and for the 5DIII the limit is 12.5 µm. The diffraction limit is caused by light which is diffracted from the ideal ray path by the edge of the aperture stop in the lens. This causes a tiny source of light, like a distant star, to appear larger than expected based on simple geometric ideas of imaging. If two tiny sources are moved close together there will be a point where they can no longer be resolved as two sources but will appear as one – this is the diffraction limit to resolution. The diffraction of light by an aperture depends on the wavelength of the light and the size of the aperture (f/No). For our purposes, we take the wavelength to be approximately 0.55 µm, corresponding to green light, about in the middle of the visible spectrum. The actual relationship is given by the formula: Diffraction limit in µm = (Wavelength in µm) × f/No. An alternative, less severe criterion, the Rayleigh resolution limit, is sometimes used. The Nyquist limit and diffraction limit are very useful for assessing how well a camera system is performing. The closer the measured results approach these fundamental limits, the better the performance.

Optics professionals usually prefer imaging system performance data to be presented as a function of spatial frequency. In the spatial frequency domain, the behaviour of optical systems can be analysed using the same kind of linear systems theory used to study the frequency response of electronic circuits. The spatial frequency of a grating or line pattern is a measure of the number of lines per unit of length (usually lines per mm). Taking the reciprocal of the resolution limit (changed from µm to mm) converts our data into spatial frequency units (lines/mm). The measured results in this form are shown in Figs 4–5. For each f/No, the measurements are the minimum resolvable contrast in the overall frequency response of the lens plus detector system. The overall frequency response is the lens frequency response, that is the modulation transfer function (MTF), multiplied by the frequency response of the anti-aliasing filter. The anti-aliasing filter behaves like a low pass filter that attenuates the high frequency detail capable of being imaged by the camera lens. The performance of the anti-aliasing filter depends on the detector array fill factor and some sophisticated thin film technology on the detector surface. The 5DIII has a greater fill factor than the 7D and this helps to make its anti-aliasing filter more effective and is said to be 'stronger'.

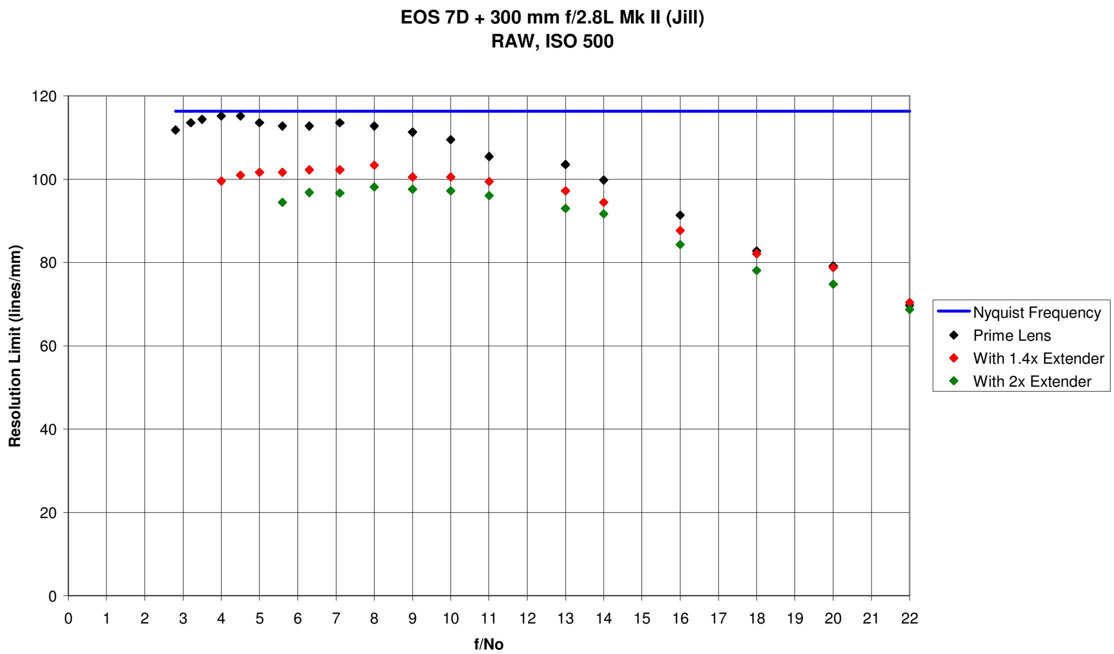

Fig. 4 Resolution limit in lines/mm derived from the data shown in Fig. 2.

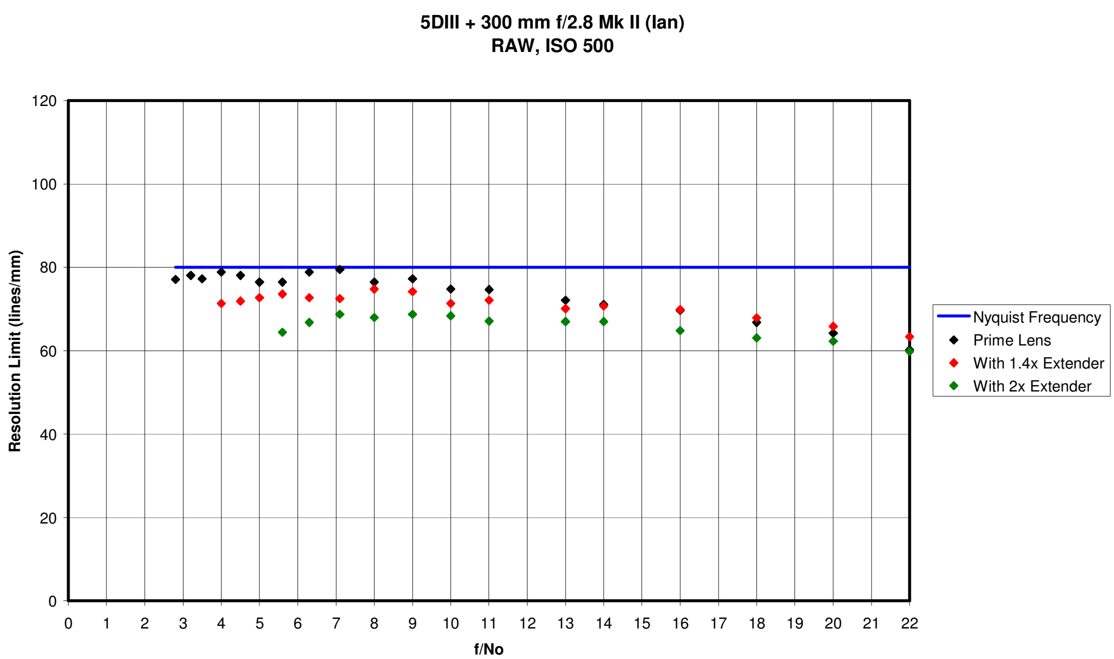

Fig. 5 Resolution limit in lines/mm derived from the data shown in Fig. 3.

Measured Results

As one would expect, the resolution limit measured for the prime lens without extenders, on both the 7D and 5DIII, is near the theoretical limit and therefore excellent. This is the kind of performance expected from well designed and manufactured prime lenses such as the 300 mm f/2.8, 400 mm f/2.8, 500 mm f/4 and 600 mm f/4 made by Canon and Nikon. Of more interest are the measurements for the prime lens with extenders. Looking at the results for the 7D, we can see a very good result using the 1.4× extender, about 85% of the Nyquist limit from f/4 to f/11. The performance using the 2× extender is also good, about 82% of the Nyquist limit from f/5.6 to f/11. We should note that this kind of performance is not easily achieved in the field as the camera will need to be mounted on a sturdy tripod and the LV silent mode must be used. If the standard shutter or mirror lock-up is used, the vibration degrades resolution by about 20% and is no better with the lens image stabilizer turned on. The 2× extender on the 7D is equivalent to putting an 872 mm lens on the 5DIII, making the 2× on the 7D particularly sensitive to vibrations and, therefore, not well suited for field use. With the 5DIII body, both extenders work well, each performing at better than 80% of the Nyquist limit through the useful operating range. LV silent mode is best but in the field we recommend the so-called silent shutter which degrades the resolution to a point intermediate between LV silent mode and the standard shutter. Mirror lock-up is no better than using the silent shutter and during testing, turning on the lens image stabilizer made little difference. However, in the field, the image stabilizer can be very effective for hand-held and monopod shooting and should always be used.

It is here worth noting that the 7D with 1.4× extender plus 300 mm prime and the 5DIII with 2× extender plus 300 mm prime are near enough identical from an optical point of view. The 7D has pixels spaced 4.3 µm and a 420 mm effective focal length lens while the 5DIII has pixels spaced 6.25 µm and a 600 mm effective focal length lens. When the f/No is the same for each system, one is just a scale version of the other. This means that the two systems should, ideally, have identical performance when used with the same f/No. In reality, there are differences, most notably in the extender designs, which result in different states of aberration correction and light transmission, in the anti-aliasing filter performance, and in the electrical properties of the detector arrays and associated signal chain electronics. Nevertheless, this similarity can still be observed in the resolution test results when the data is transformed to permit direct comparison of one system with the other. To do this the resolution data needs to be changed from linear measure (µm) to angular resolution measured in microradians (or any other angle measure). We already have the data in this form in the Excel spreadsheet so it is easy to produce a new graph as in Fig. 6. Examining the data in angle measure enables a direct comparison of the resolution independent of the range to the target. The angular resolution limit is also a convenient measure if we want to know the size of the tiny details that will be just resolved on the target at a certain range. Multiplying the angular resolution by the range gives the size of the smallest detail that can be resolved.

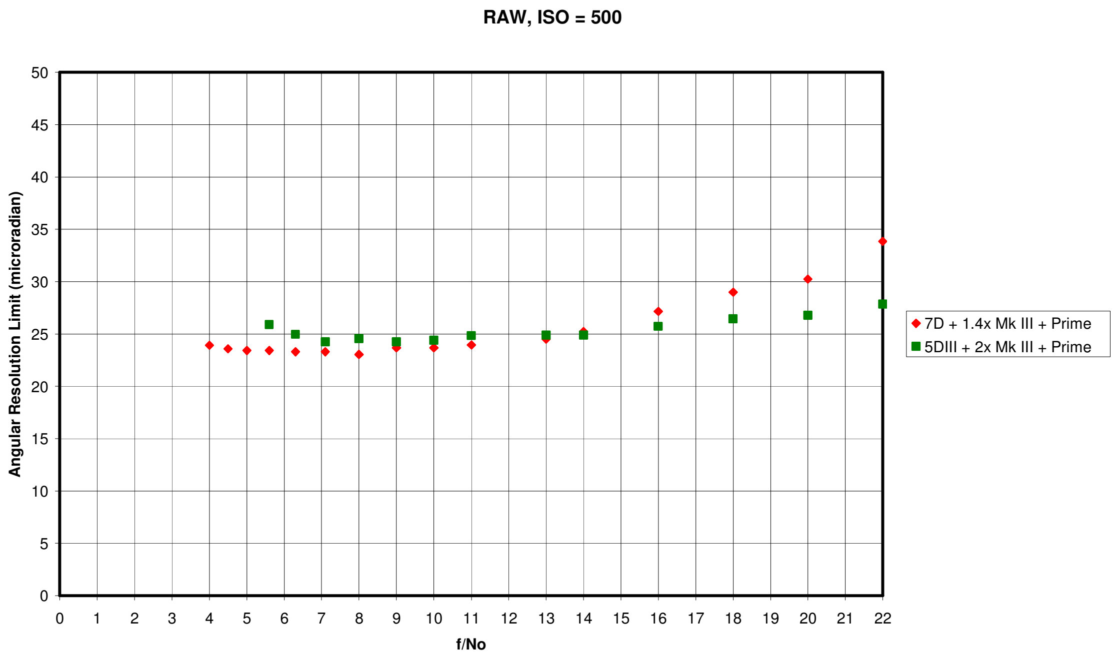

Fig. 6 Angular resolution limit for two optically equivalent Canon camera systems at ISO 500. As expected, the angular resolution limit is similar for both systems. For high ISO settings the 7D is adversely affected by noise and its performance becomes worse that the 5DIII system.

If the 7D with 1.4× extender plus 300 mm prime and the 5DIII with 2× extender plus 300 mm prime are roughly equivalent in performance, one may well ask why anyone would pay thousands of dollars more for the bigger and heavier system? To get to the bottom of this question we first need to further clarify what we mean by 'roughly equivalent'. In the field it means that if the two systems are side by side on the same bird, the target will be covered by the same number of pixels and when using the same f/No and ISO settings, the resulting exposure times will be similar. In good light, the ISO needed for correct exposure will be low, say ISO 200–400, and the resulting pictures will be almost identical in quality. This we have observed many times with Jill using the 7D with 1.4× extender on a 300 mm prime and me using the 5DIII with 2× extender on another 300 mm prime. However, the caveat here is 'good light'. In poor light, to get the correct exposure, the ISO and/or exposure time will need to increase. For hand-held shots or even tripod shots on a moving bird, there will be a limit to how much the exposure time can be increased before movement blur becomes a problem. For the camera systems we use, supported on monopods, the longest exposure time with a reasonable probability of producing a good picture is about 1/200 sec. If this is not enough, then the only remaining option is to push up the ISO and then the signal-to-noise performance becomes a critical issue. With the 7D, the maximum setting before noise becomes noticeable is about ISO 640. With its big brother, noise is under control until about ISO 1600. Another issue is the dynamic range of the detector system – as the ISO increases, the dynamic range begins to fall off. In practice this causes a loss of contrast. These two factors conflate and reduce the resolution as the ISO is increased. This is a major difference in the performance of the two camera systems – the 5DIII produces significantly better pictures in low light. It is a similar story for action shots – high ISO and shutter speed can be used to more effectively freeze motion using the 5DIII. It is a lot of extra money to pay for better low light performance and better pictures of birds in flight but some photographers think it is worth the cost.

Finally, a few observations on focal length extenders and their impact on the camera auto-focus. We did not feel it necessary to thoroughly investigate this issue because in the field we have not found it to be a problem. When using the 2× extender, the auto-focus is slower under all reasonable lighting conditions but not so slow as to cause concern. Using the 300 mm f/2.8 prime lens with 2× extender, the auto-focus operates with the aperture wide open, that is at f/5.6, in the instant before the aperture stop is automatically set for the shot. The prime lens has two restricted focal ranges, 2–6 m and 6 m – ∞, which are helpful in achieving rapid focus. In most situations there is enough light for the auto-focus to work properly up until about sunset. At sunset we usually take a minute to remove the extender and change over to the prime lens which will work through twilight and into the dark if torch-light is provided for finding focus.

Conclusions

The main objective of this study was to investigate the performance of the Canon Mk III extenders used with the 300 mm f/2.8 prime on the 7D and 5DIII camera bodies. The results show that the extenders work well and should be taken seriously. However, in order to realize their potential they need to be used with care and understanding. In particular, the accuracy of the camera AF needs to be checked and adjusted, if necessary, and shutter vibrations can noticeably degrade performance when using the 2x extender on both the 7D and 5DIII. Best results are obtained using the LV silent mode but this may not be practical in the field. The silent shutter on the 5DIII is helpful and goes some way to ameliorating the problem. It takes several times more energy to drive the 5DIII standard shutter than the smaller 7D shutter thereby making vibration less of an issue with the latter. Mirrorless cameras with electronic shutters should completely eliminate shutter vibration problems. In this regard, the Canon EOS M, to be released in October 2012, with APS-C detector array and adaptor for fitting Canon telephoto lenses, looks interesting, but surprisingly, it does not have a viewfinder.

The point of this article was not to compare the 7D and 5DIII but, rather, to investigate the performance of the focal length extenders. However, points of difference have emerged during our study which suggest that the 7D works best with the 1.4x extender and that the 5DIII can work well with either extender. They are both great cameras and should not be judged on shutter performance alone – in most situations they each take technically comparable still pictures, it is only in low light or high speed action that the 5DIII is clearly better. Value for money, the 7D is the winner but if you are into movie making, weddings or some other branches of photography, then you may well find good value in the 5DIII.

Acknowledgement

The writer thanks John Stirling for the great interest he has shown in the work and for many helpful suggestions during testing and in the preparation of the manuscript.