Permanently IR-modified Canon Rebel XT. Stitched panorama, 260Mpixel

Digital Infrared Photography
Part Two

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THE ISSUE OF CORRECT FOCUSING

Hot spots and focusing are the two challenging problems in IR digital photography. Without returning to the issue of focusing, let us just remind ourselves that a camera will be optimized for one or two lenses, others will suffer from some degree of front- or back-focus and/or from hot spots. Note that also those lenses — like the ones in Canon's L series — that do have a red sign on the barrel for focus correction in the IR range do so for some specific wavelength: in the case of Canon around 800nm. This choice is obviously not an accident: most commercial IR films tend to be sensitive around this wavelength and lose their sensitivity shortly afterwards. This is not true though with CMOS sensors, that can go down as far as 1300nm. Some erratic behavior when using these lenses with an IR-modified DSLR is to be expected even though they sport the classical red dot or red line on the focusing ring.

The bottom line for the photographer is the correct focusing is a mix of science, magic, and luck. However, when all three work together an IR-modified DSLR becomes an intoxicating tool for the creative photographer. Let us remember that we can now take *hand-held pictures at f/8 or f/11 with EV8 and 200ISO.* Once we operate at these apertures the focus shift becomes less of a problem, especially with moderate wide angles. Sure, if one wants to use a tele lens wide open using AF even an aperture of f/8 cannot hide back - of front - focus problems in the IR domain.

To get some basic understanding of how bad the problem of focusing is in real life situations we have carried out extensive experiments using our IR-modified Rebel XT. We have tested both Canon and Nikon lenses. The Canon lenses have been the following ones:

- 16-35mm f/2.8 L USM – This lens has a red '16' sign on the barrel to be used to correct the focus when shooting IR. We have been unable to learn whether, by writing '16' on the barrel, Canon does not recommend the use of the lens in IR for other than the 16mm focal length, whether other focal lengths should be corrected using the same sign, whether other

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focal lengths need no correction, whether ...

- 70-200mm f/2.8 L IS USM – Here the situation is even more complicated. The lens features to signs: a red '70' and a red '100' on the focusing ring. What to do when shooting with other focal lengths is not clear.
- 400mm f/5.6 L USM – This lens has a red sign to correct on the focusing ring.
- Macro 100mm f/2.8 USM – We wanted to see whether the macro design had some peculiarities.
- 50mm f/1.4 USM - Classical lens design, classical focal length.

We have also analyzed how our Rebel XT behaved with some manual focus Nikon lenses (AIS) via a Nikon-to-Canon mount adapter. The Nikon lenses have been the following:

- Nikkor 85mm f/1.4 AIS – This lens has a red dot on the focusing ring, like most Nikon AIS lenses. This is a very fast lens with a truly shallow depth of field at f/1.4 (a little less than an inch when the subject is seven feet away).
- Nikkor 105mm f/2.5 AIS - A well corrected, compact lens.
- Nikkor 135mm f/2.8 AIS – A classical tele lens in the Nikon AIS family.
- Nikkor 55mm f/1.2 AI – A 'difficult' lens with some historical significance.
- Nikkor 500mm f/8 Mirror – A specific chapter is dedicated to this lens.

In what follows we will show only the results of the first two Nikon lenses and of the first three Canon lenses, to spare the reader for a flood of pictures. We have a table at the end that summarizes the results for all the lenses, though.

The first two Canon lenses in the list above are known in the internet community as lenses that should be avoided when shooting IR because of hot spots. We can confirm this, although it is not true that hot spots are present all the time. The same observation can be made for the Nikkor 85/1.4.

We have used a home made setting to assess focusing issues (see picture below). Although is far from being sophisticated it does serve our goals rather effectively. A series of ten columns made of Lego bricks have been aligned from left to right. In one setting each column is 40mm (about 1 ½ inches) behind the next one; in a second setting this distance is 24mm (almost one inch). Each column has a paper strip glued on it that says 'Canon' and is numbered from 1 to 10.

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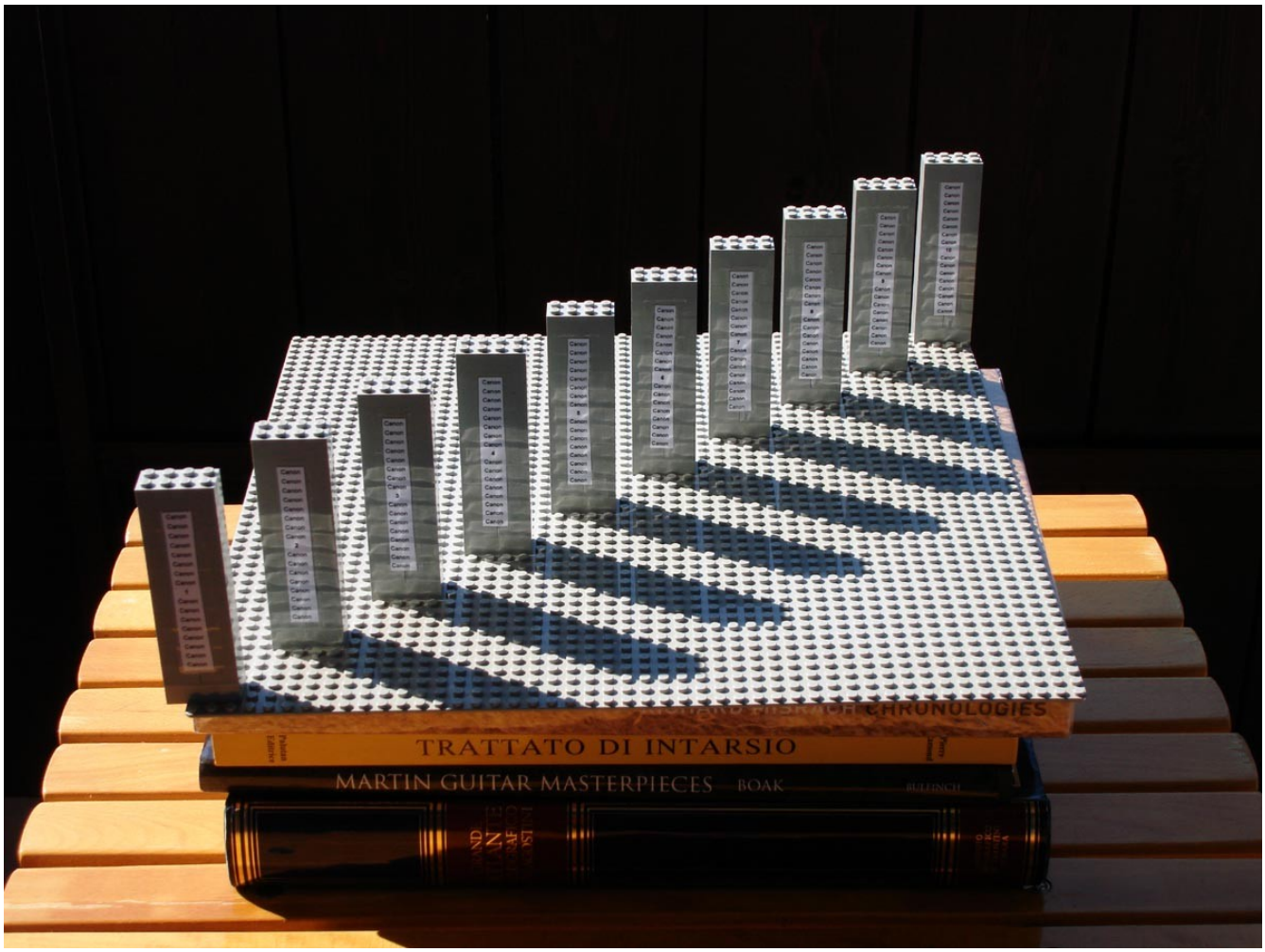


The set-up used to assess the focusing issues with our IR-modified Rebel XT and both Nikon and Canon lenses. Ten columns of Lego bricks, numbered from 1 to 10 are placed in a skewed fashion. Column N is 40mm(in one setting) or 24mm (in another setting) behind column N-1. This picture shows the setting where a column is 40mm behind the previous one (from left to right).

All the pictures have been taken at ISO 100, the camera (or the lens, in the case of the 70-200 zoom or the 400mm tele) was on the tripod, the mirror was raised before shooting and the place of the sensor be made as parallel as possible to the fronts of the ten columns. *In all pictures we have focused (either manually or through the AF) on the column labeled '5', i.e., the one in the middle.*

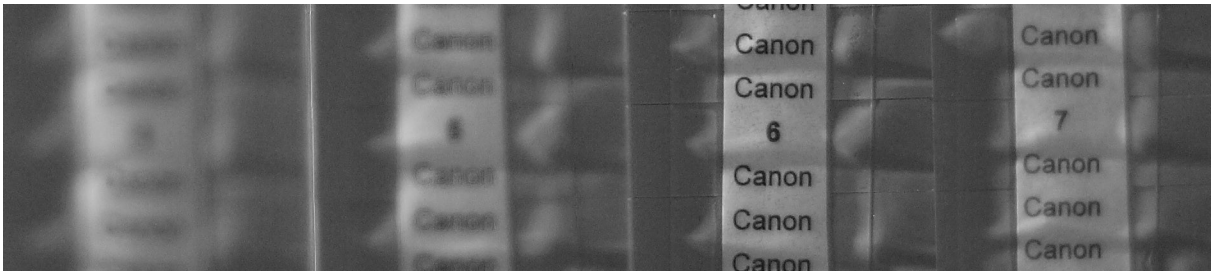
TWO NIKON LENSES

The 85mm lens has been chosen to amplify any possible focusing problem. The Nikkor 105mm has been chosen because one of the authors uses it as his main lens for very large panoramas that are stitched together. It was absolutely crucial that the IR-modified Rebel XT worked flawlessly with this lens.

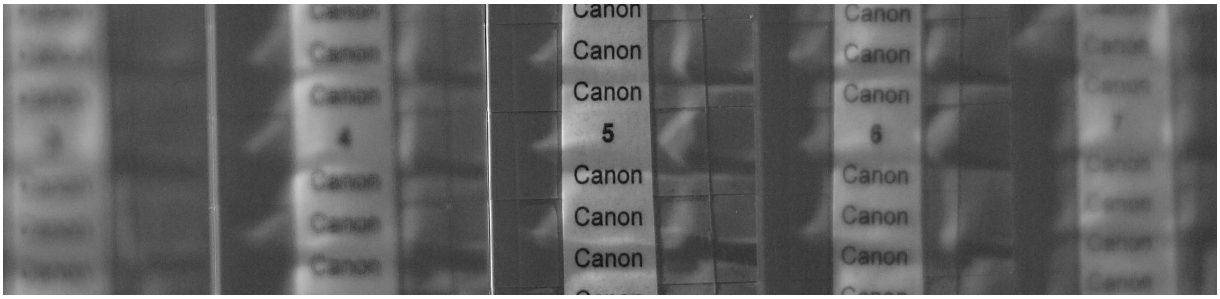
Nikkor 85/1.4

We have taken to pictures of the set-up from 1m and 5m. Aperture was 1.4. In both cases we have focused manually first and then compensated by aligning the distance with the red dot on the focusing ring. Before doing so, however, we have checked that the measured distance

(from the sensor plane to column 5) and the one on the focusing ring coincided perfectly: this was indeed the case. The two pictures from 1m are shown below. First the one without IR compensation:

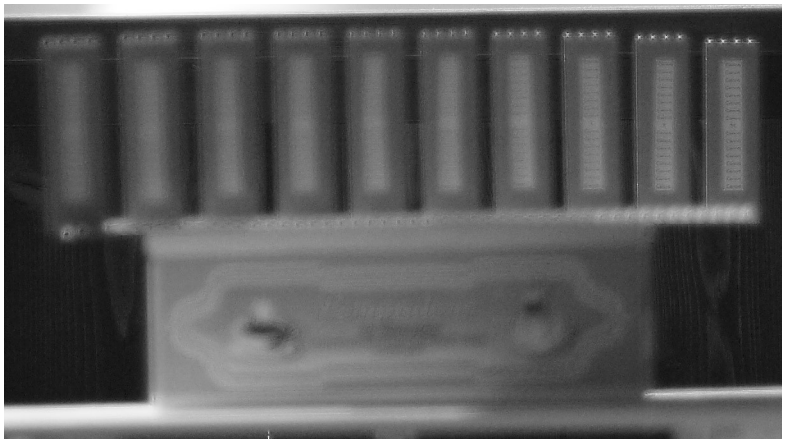


Then the one with IR compensation:



As one can notice the focusing accuracy is outstanding, a textbook behavior. Without compensation column 6 was in focus, an error of about 24mm. Once the IR compensation is applied column 5 snaps into focus. As a reminder, the depth of field of an 85mm lens at f/1.4 from 1m and a CoC of 0.019 is less than 10mm.

The depth of field with the same parameters but at a distance of 5m is 180mm. These are the two images taken from 5m. First, the one without IR compensation:



Then the one with IR compensation:

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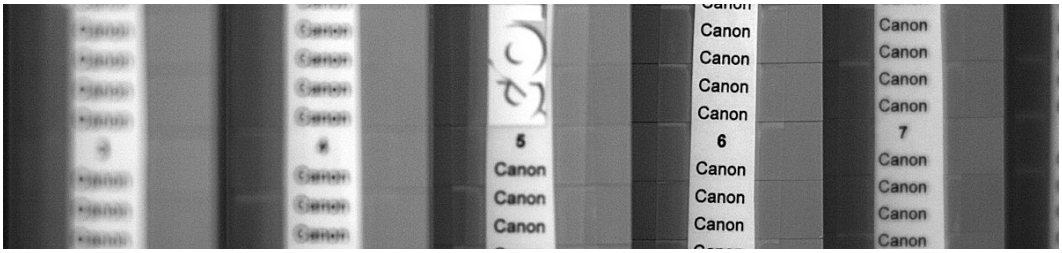
The results speak for themselves.

Conclusion: the Nikkor 85mm/1.4 AIS, or at least the sample we have tested, is perfectly capable of delivering correct focusing when used with a Rebel XT modified as we have explained in this article.

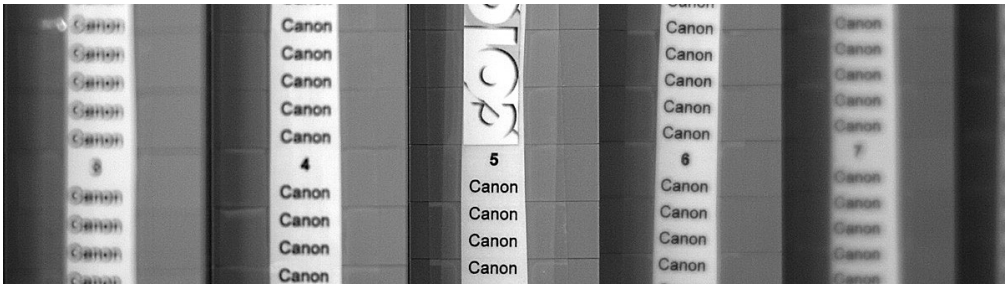
Nikkor 105/2.5

We have taken two pictures from 1.5m and 5m, at full aperture in both cases, i.e., f/2.5. Once again we have focused manually, taken the pictures, then applied a compensation to the focusing by aligning the red dot to the distance on the focusing ring. As we did with the 85mm/1.4 we have checked that the measured distance from the sensor plane to column 5 corresponded *perfectly* to the value displayed on the focusing ring of the lens, and this was indeed the case. Again, the columns in the set-up are 24mm one behind the other.

We show now the two pictures taken from 1.5m. The depth of field here for a CoC of 0.019 is about 20mm (distance: 1.5m; aperture: f/2.5). First, the picture without IR compensation:



Then the one with IR compensation:



Again, a textbook behavior. Without compensation column 6 shows much better focus than column 5 while once IR compensation is applied column 5 snaps into focus.

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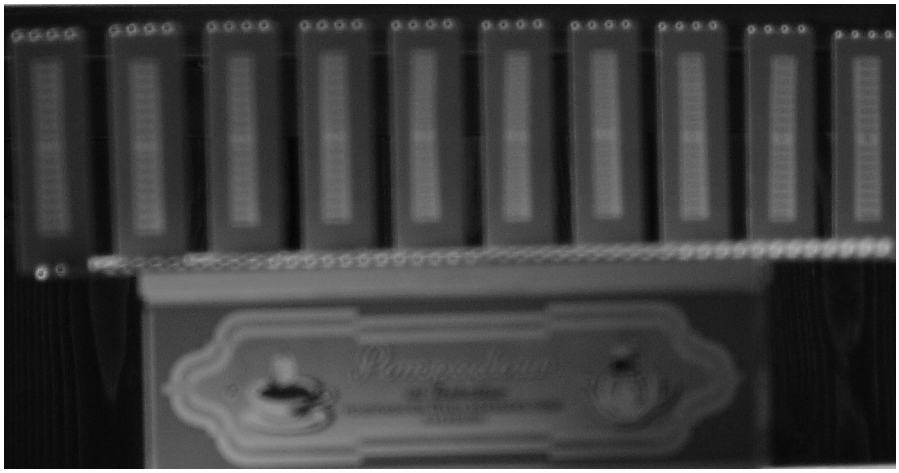
We now show the two pictures taken from 5m. The depth of field is now 220mm. This is the picture without IR compensation:



This is the picture with IR compensation:

The results overlaps those obtained with the 85mm[1].

Conclusion: the Nikkor 105mm/2.5, or at lest the sample we have used in our tests, is a very well behaved tool for IR photography using the DSLR camera and internal filter described in this article.

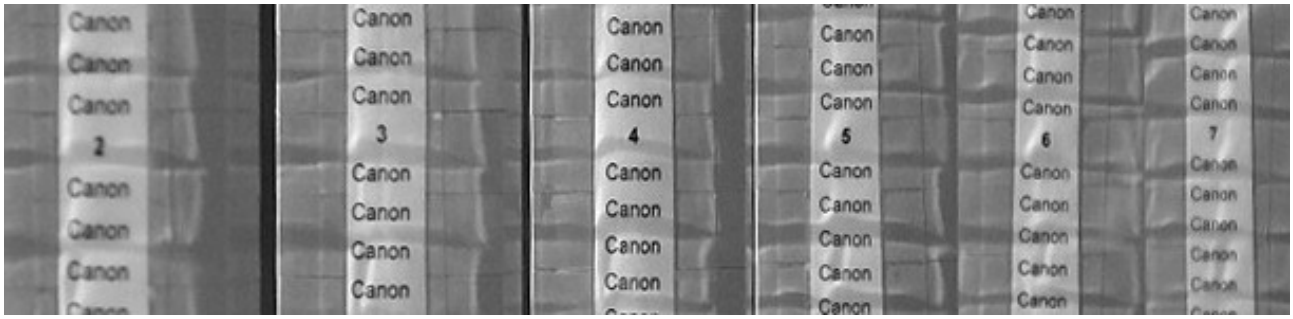
THREE CANON LENSES

In this case the situation gets more complicated because of the presence of the autofocus. Therefore, we have three and not two experiments to carry out for each lens and for each distance. In the tests with AF the rule is to proceed with caution; in fact, a lens could suffer from front- or back-focus issues in visible light and when exercised in the IR domain end up producing fals positives or false negatives! This is why we are not going to claim that "the AF of lens XYZ works correctly (or doesn't) in IR photography." The only thing we can claim is that the sample that we have tested is more or less well-behaved. We hope that this exercises will help the interested reader in being alert as to the traps or pitfalls of this type of photography (i.e., IR photography with a permanently modified DSLR).

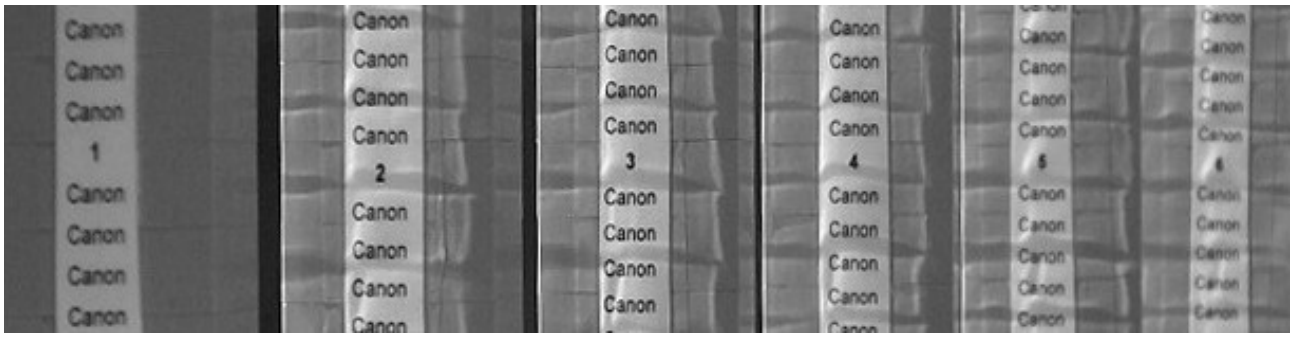
Canon Zoom 16-35/2.8 USM L

[1] This 105mm lens has been extensively used for months after these tests in IR photography and has been truly stretched: it never failed to deliver superb results: no hot spots, spot-on focus all the time.

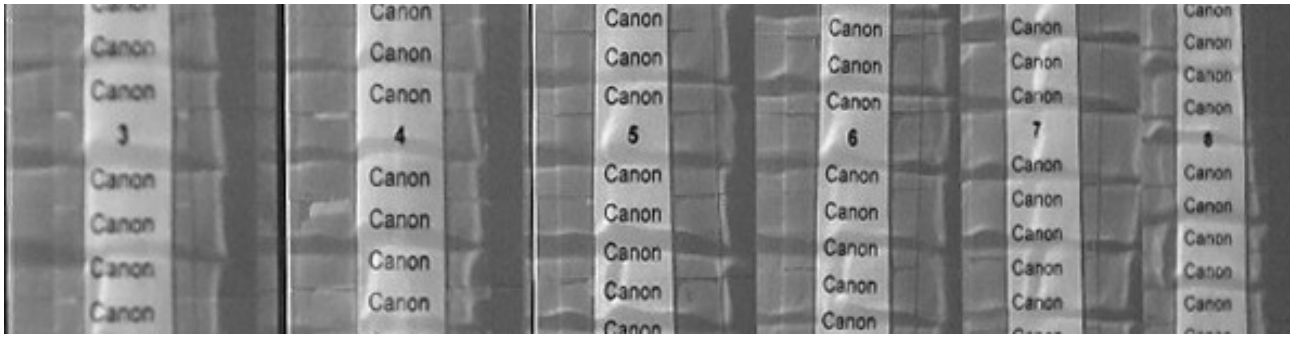
We have taken two images of the set-up both wide open (f/2.8). One with a focal length of 16mm, 50cm away from column 5, the other with a focal length of 35mm, 1m away from column 5. In the first image the depth of field for the usual CoC is about 110mm. Columns are 24mm one behind the other. This is the picture without IR compensation, followed by the one with manual IR compensation, followed by the one using the AF (on column 5).



Canon 16-35/2.8 L USM @ 16mm:manual, without compensation



Canon 16-35/2.8 L USM @ 16mm: Manual, with IR compensation

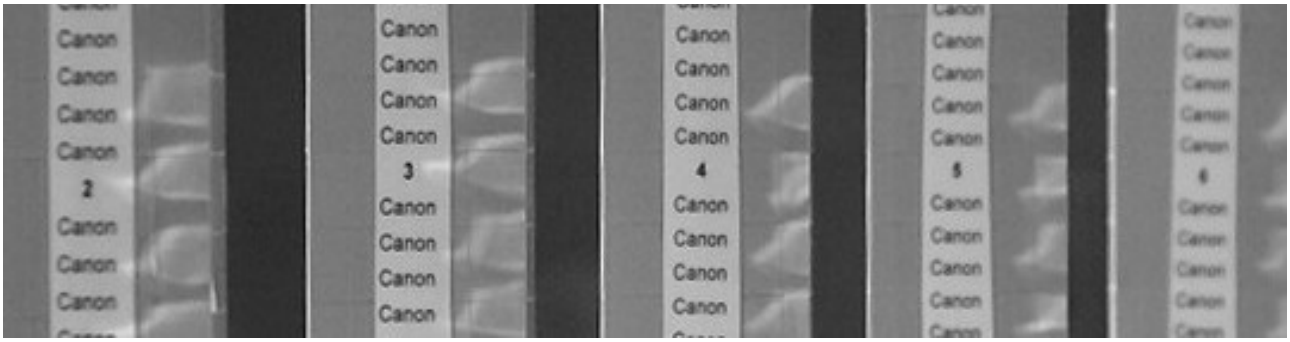


Canon 16-35/2.8 L USM @ 16mm: Autofocus 'ON'

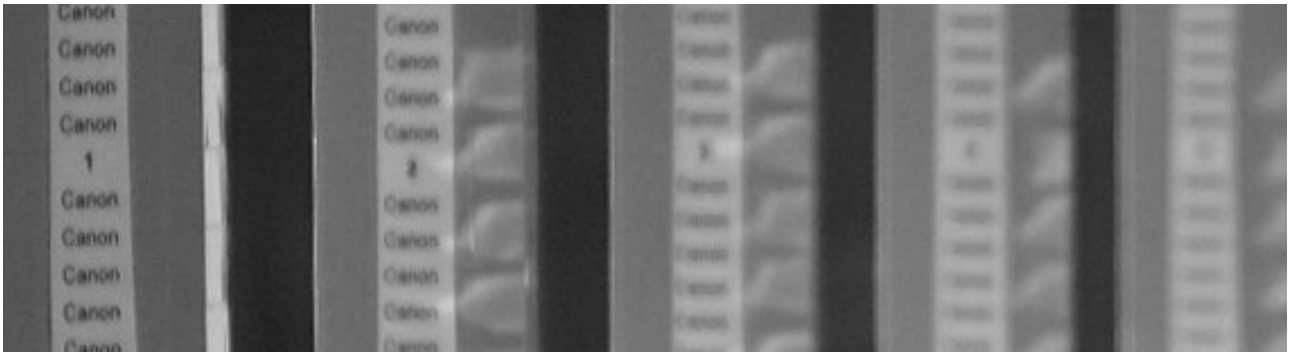
A qualitative analysis of the three pictures seems to show that column 5 is never perfectly in focus, although the AF does not grossly misbehave, and that the IR compensation does not certainly improve the situation, on the contrary. The lens has been tested in visible light to see if it suffered from front- or back-focus problems but its behavior has been exemplary. A possible explanation goes back to the issue already discussed above that Canon optimized the IR compensation for an 800nm wavelength, and here we have components that go well beyond 1000nm. Having said this, given the substantial depth of field when closed down to

f/5.6 or f/8, the lens can be safely used at 16mm in practical situations, especially in landscapes.

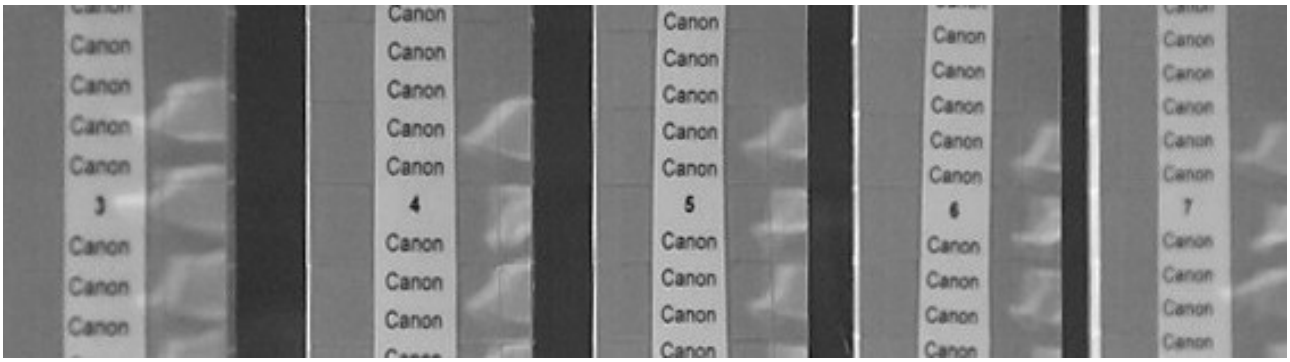
Let us analyze now the lens at 35mm with the set up 1m away from the sensor plane. The depth of field is about 90mm. We should not be surprised if the lens exhibited some strange behavior because of the red '16' marked on the barrel. Given that nowhere can be found what to do at 35mm we have rotated the barrel to align the distance with the '16' sign. Let us see what happened.



Canon 16-35/2.8 L USM @ 35mm:manual, without compensation



Canon 16-35/2.8 L USM @ 35mm: manual, with IR compensation



Canon 16-35/2.8 L USM @ 35mm:autofocus 'ON'

The conclusion is rather straightforward: with this lens, or at least with our sample, the best approach is to let the AF do its job. It may not be able to deliver an ultra-sharp image, but it seems to deliver the *best possible focusing.* A third test carried out focusing the lens at infinity has reinforced these conclusions. Its major drawback remains the propensity to generate hot spots.

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Canon Zoom 70-200mm/2.8 USM L IS

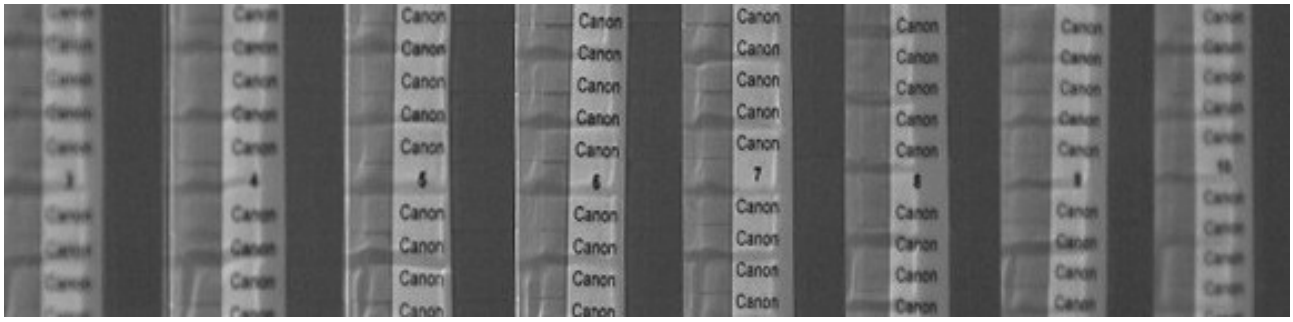
All pictures have been taken using a tripod, so we have turned off the image stabilizer. All images have been taken wide open, i.e., at f/2.8.

We have taken four images, two at a 70mm focal length and two at 200mm. The set-up has been placed at a distance of 1.5m and 5m. The depth of field for a CoC of 0.019 is shown in the table below (in mm).

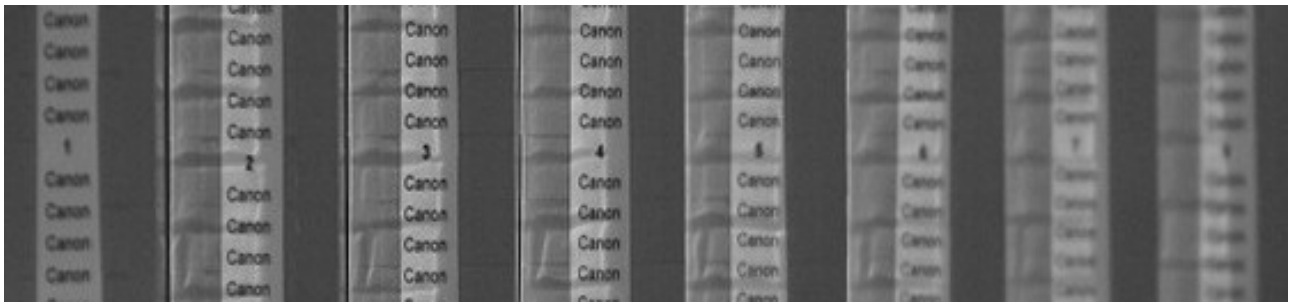
	70mm	200mm
1.5m	*40*	*7*
5m	*550*	*60*

This lens features two signs on the barrel; one reads '70', the other '100'. We have used the first one to compensate when shooting with a focal length of 70mm, the second one when shooting with a focal length of 200mm. As in the case of the 16-35mm when we shot at 35mm, we realize that this latter compensation is at least quite debatable.

First image taken at 70mm from a distance of 1.5m



Canon 70-200mm/2.8 L IS USM @ 70mm: manual focus, without IR compensation, set-up distant 1.5m



Canon 70-200mm/2.8 L IS USM @ 70mm: manual focus with IR compensation, set-up distant 1.5m

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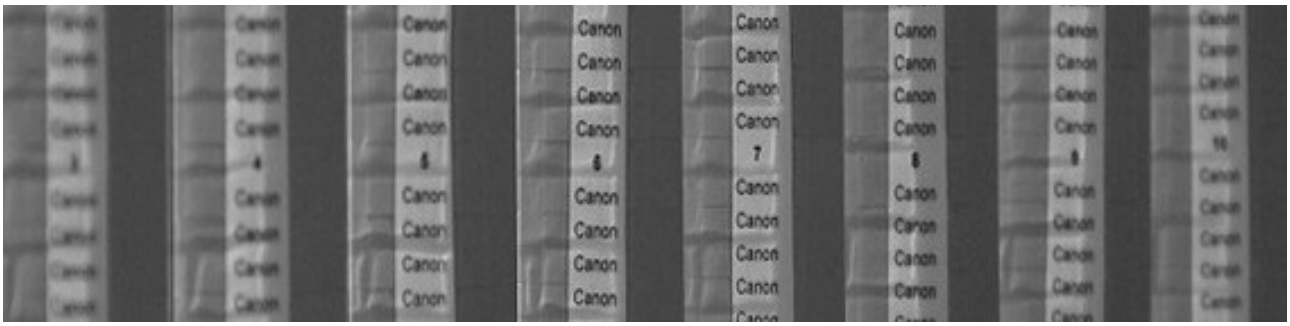
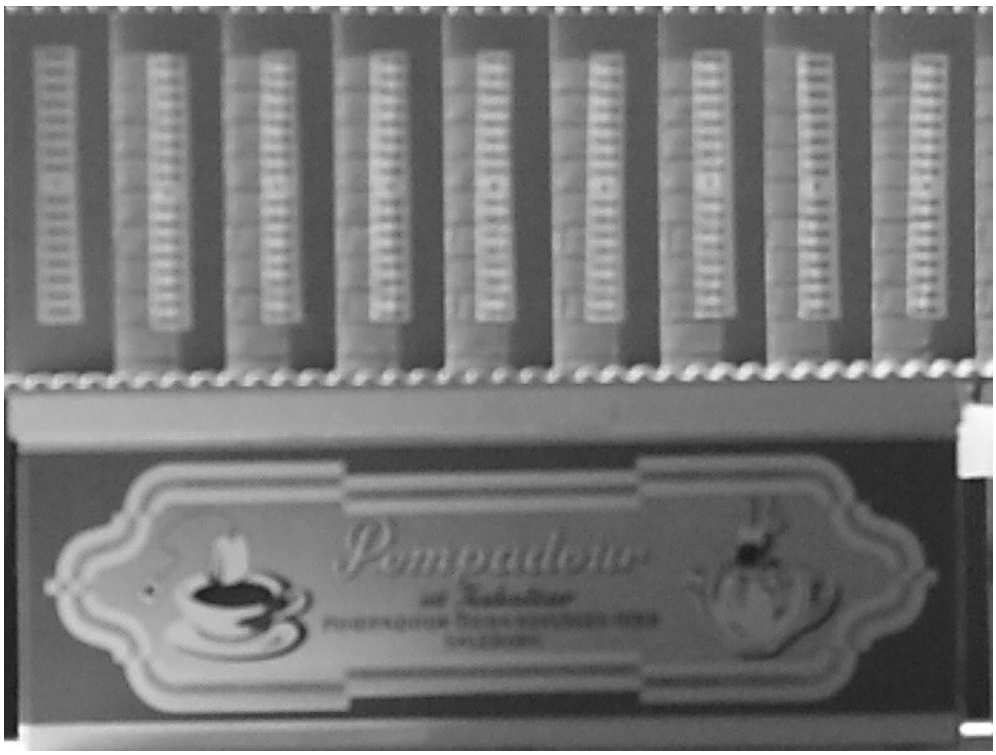


Canon 70-200mm/2.8 L IS USM @ 70mm: autofocus 'ON', set-up distant 1.5m

Second image: 70mm focal length, set-up from a distance of 5m.



Canon 70-200mm/2.8 L IS USM @ 70mm: manual focus, without IR compensation, , set-up distant 5m

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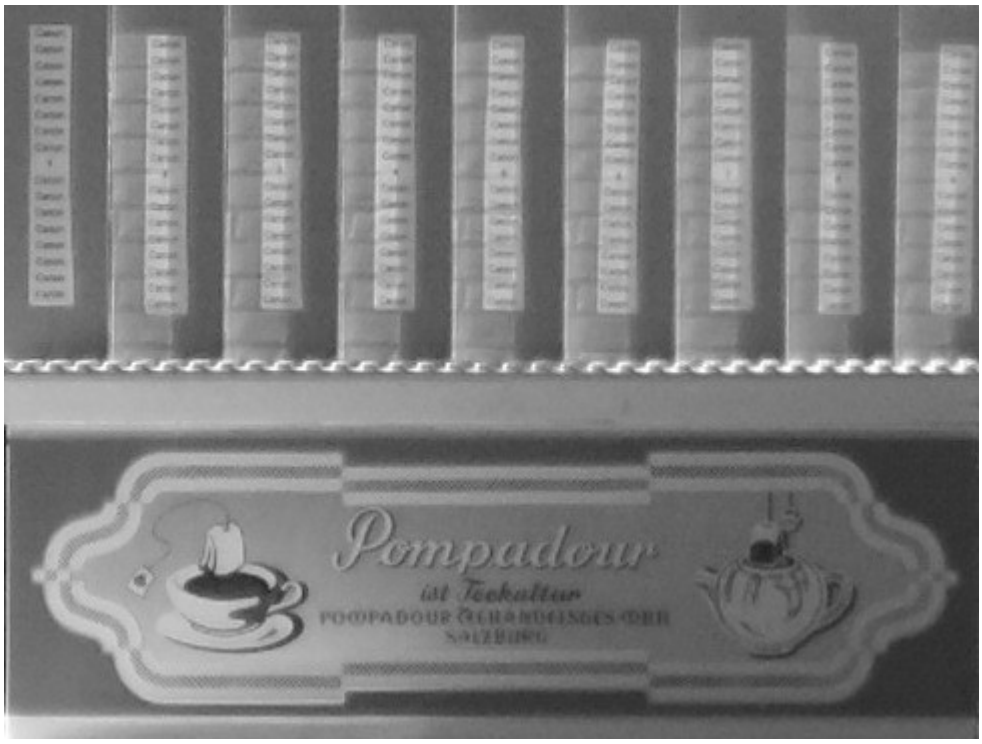

Canon 70-200mm/2.8 L IS USM @ 70mm: manual focus, with IR compensation, , set-up distant 5m

Canon 70-200mm/2.8 L IS USM @ 70mm: autofocus 'ON'

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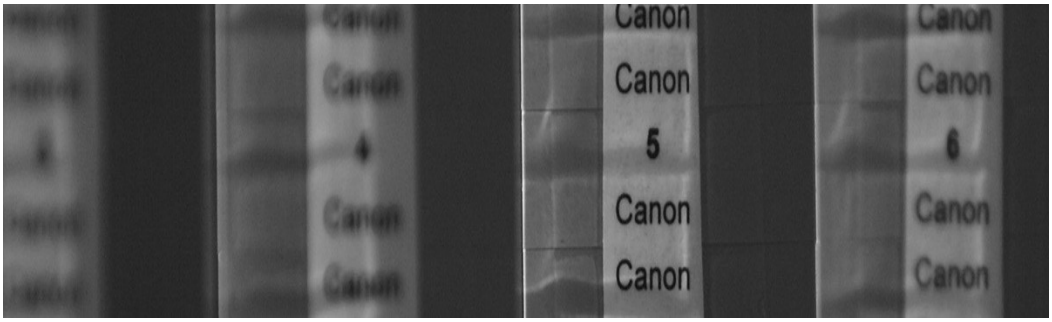
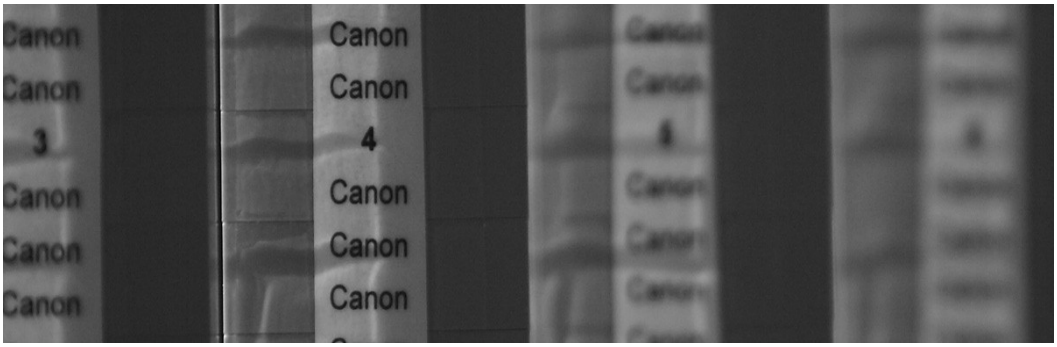
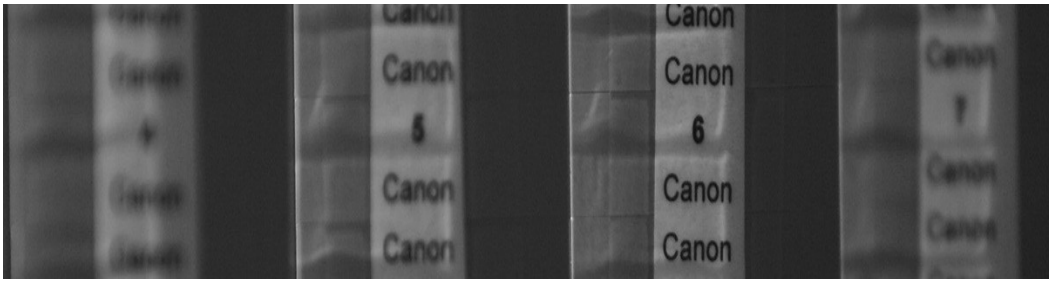
Third image: 200mm a 1.5m.



Canon 70-200mm/2.8 L IS USM @ 200mm: manual focus without IR compensation, set-up distant 1.5m



Canon 70-200mm/2.8 L IS USM @ 200mm: manual focus with IR compensation, set-up distant 1.5m



Canon 70-200mm/2.8 L IS USM @ 200mm: autofocus 'ON', set-up distant 1.5m

Fourth image: 200mm at 5m

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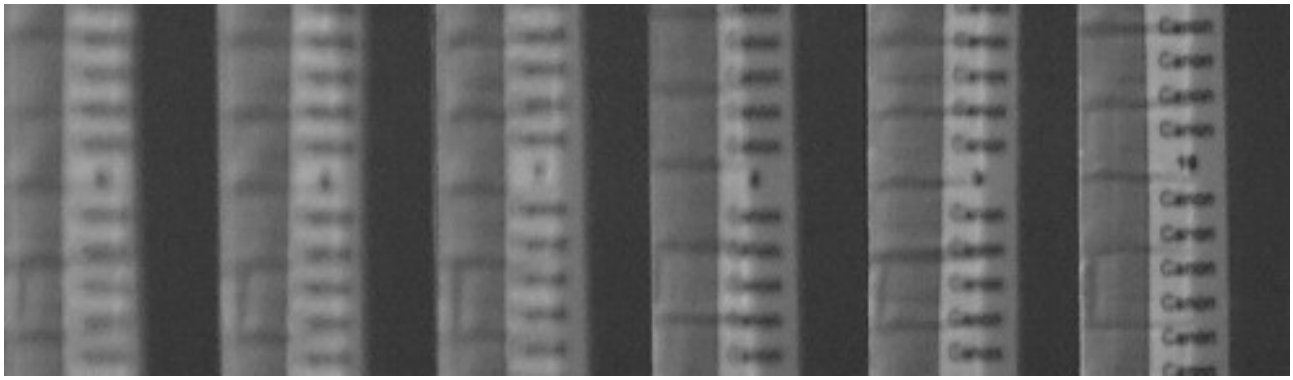
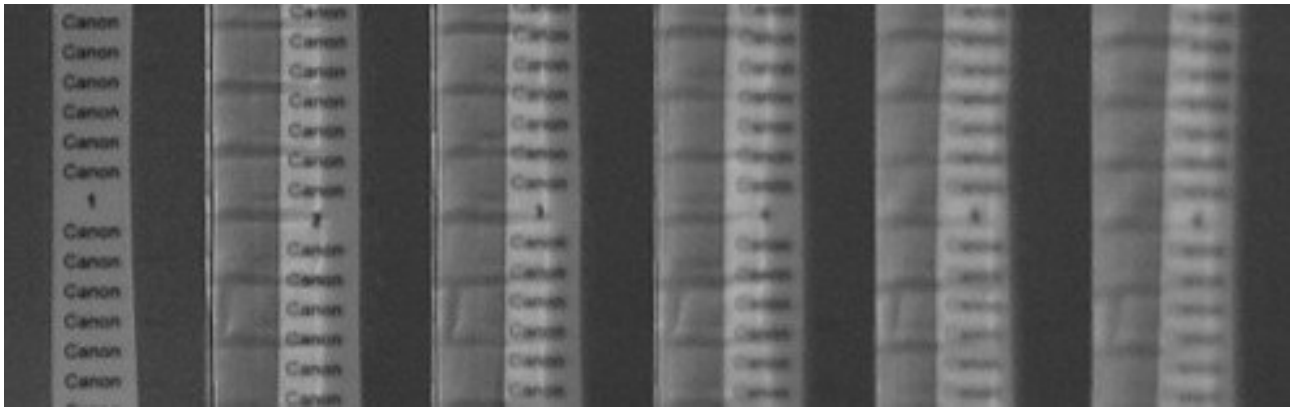
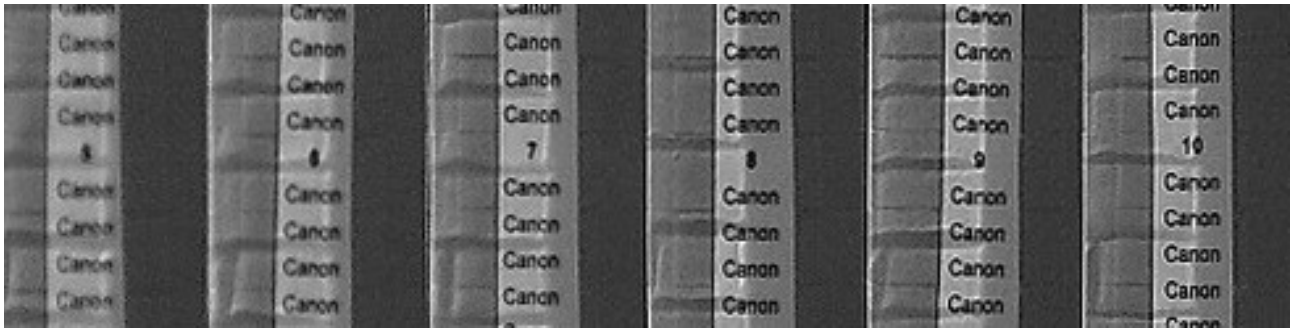


Canon 70-200mm/2.8 L IS USM @ 200mm: manual focus without IR compensation, set-up distant 5m



Canon 70-200mm/2.8 L IS USM @ 200mm: manual focus with IR compensation, set-up distant 5m



Canon 70-200mm/2.8 L IS USM @ 200mm: autofocus 'ON', set-up distant 5m

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It is quite difficult to draw a conclusion because the tests go pretty much all over the places. We have checked the lens for AF problems in visible light and, within the limitations of our set-up, we have found no front- or back-focus. The IR compensation has been correct @70mm and wrong @200mm, but this was expected: the lens does not have any sign on the barrel for IR compensation @ 200mm, so this may in fact be the problem. In the general the AF has shown an acceptable behaviour.

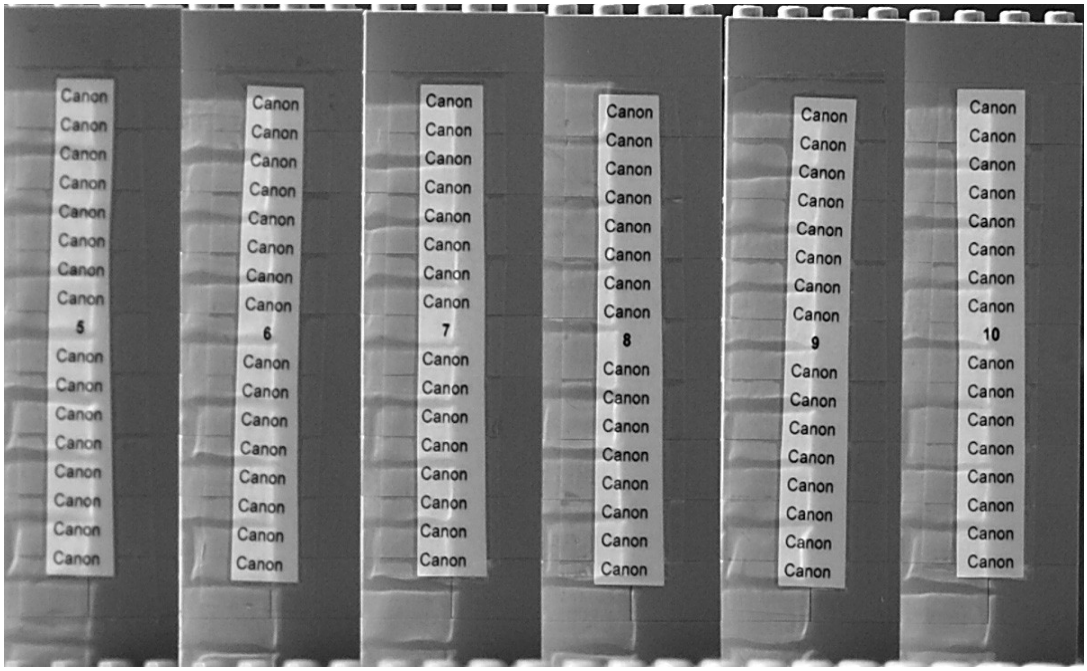
We have then carried out some further tests at infinity that have confirmed the findings of the tests above. The IR compensation worsens the situation, the manual focus with no compensation is borderline but mediocre in general, the AF cannot be relied upon.

Conclusion. The sample we have tested here is not recommended for IR photography. Once again, we are left wondering what is the meaning of not putting a '200' red mark on the barrel and whether the lens is in fact optimized for a wavelength of 800nm and here we are exercising the sample up to 1300nm.

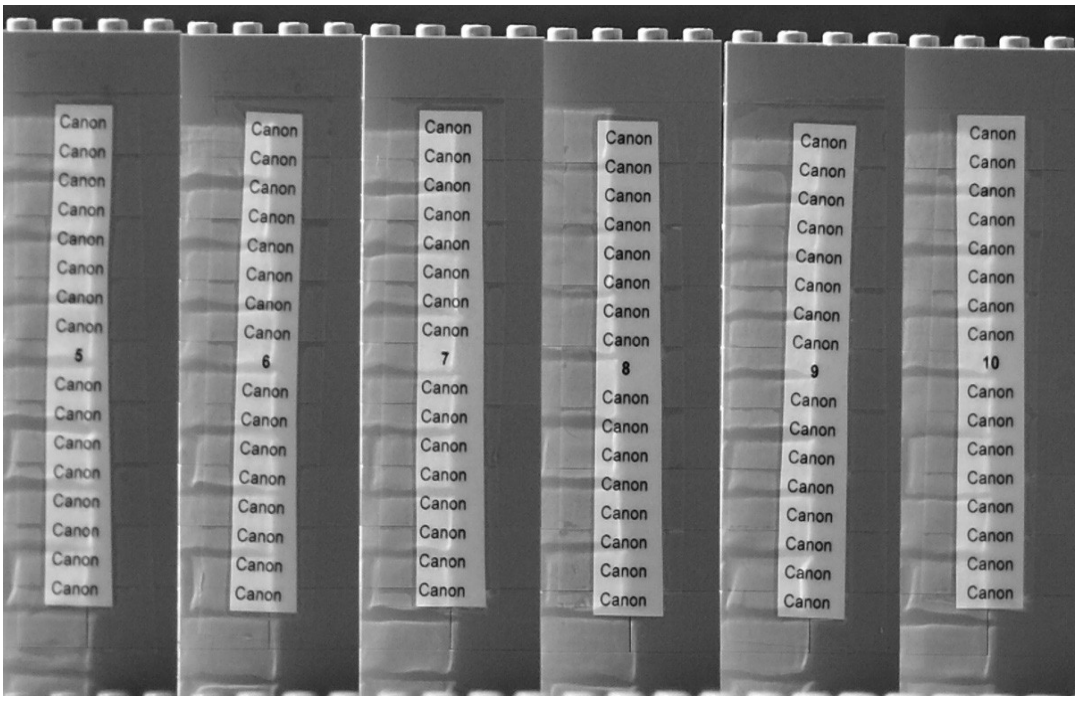
Canon 400mm/5.6 USM L

We have taken one picture from 7m with the lens wide open. Columns were 24mm one behind the previous one. The depth of field of 60mm.

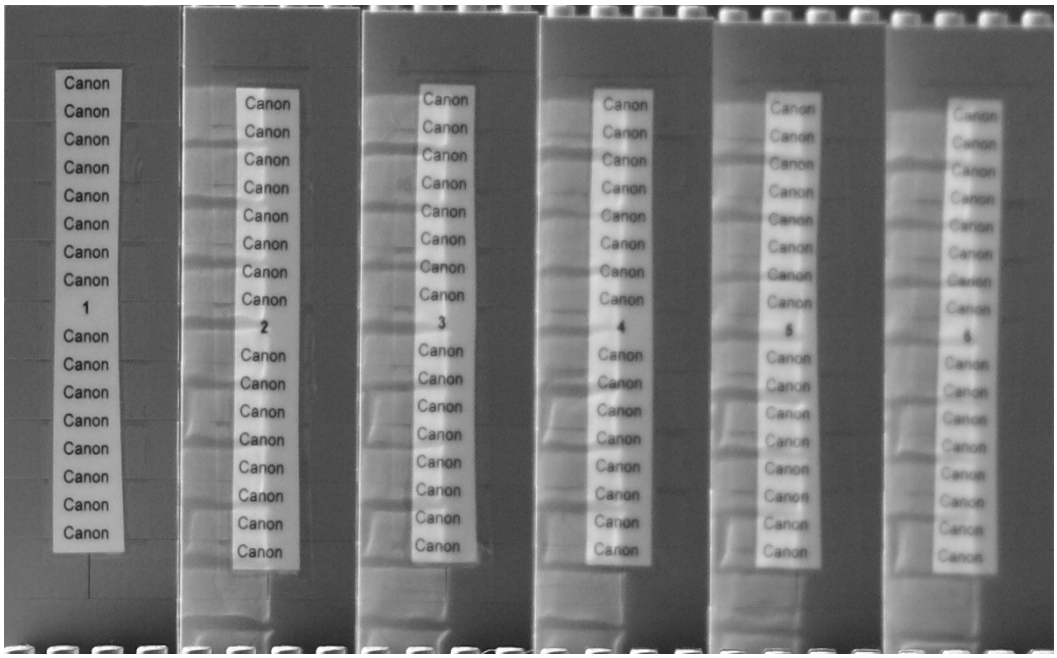
These are the three pictures:



Canon 400mm/5.6 L USM: manual focus, without IR compensation, set-up distant 7m



Canon 400mm/5.6 L USM: manual focus with IR compensation, set-up distant 7m



Canon 400mm/5.6 L USM: autofocus 'ON', set-up distant 7m

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The AF grossly failed and therefore we decided to check its performance in visible light. We have taken a picture of the same set-up and we include below a 100% crop. The lens operates perfectly in visible light. We assume that with lens we are using the AF outside its design envelope.

Conclusion. We do not recommend to use this sample with our IR-modified Rebel XT.

IR AND MIRROR LENSES

During one of our readings we have stumbled on the following sentence: *"Catadioptric lenses may be achromatic into the near IR, depending on the design, and visual focusing is correct for IR use."*[2] We immediately checked our Nikkor Mirror 500mm/8 and there is in fact no sign on the barrel for IR compensation. We then put the lens on the IR-modified Canon Rebel XT, focus at the minimum distance of 4m (the depth of field is a very shallow 20mm) and checked whether this was indeed the case. Well ... it was.

A picture taken with the Nikkor Mirror of two leaves taken at a distance of 4.5m and in full sunlight is shown below. A 100% crop shows the perfect focus of the subject.

[2] Applied Photographic Optics by Sidney F. Ray, Focal Press, 2002, p.424.

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Nikkor Mirror 500mm/8. Subject at 4.5m. focusing in visible light without IR compensation. Catadioptric lenses often need no IR compensation as they are achromatic into the near IR range by design.

SUMMING UP

The table shown below sums up all the results obtained. The minus sign means 'front focus' while the plus sign means 'back focus.' Each one of the five Canon lenses we have tested — all of them of the last generation and three of them of the top 'L' series — has its own specific optical design and behaves in the near IR range rather differently. The calibration of the optical path to make sure that the AF with lens X works correctly does not guarantee *at all* that the AF will behave correctly with lens Y. Moreover, let us not forget that some of these lenses suffer from hot spots in a relatively hard to predict way. Our intuition tells us that in general the faster a lens is the more likely it will exhibit hots spots.

The table below shows in the last column a general assessment of the lens. This assessment is more forgiving than what the raw numbers may suggest because we take into account issues such as the increased dept of field by closing down the lens in practical, real life situations. It is clearly a judgment call: some readers may agree, others may not. Finally, we have indicated with (hs) those lenses that tend to suffer from hot spots, and with (hs+) those that can be used only with extreme caution because their tendency to suffer from hot spots is more the norm then the exception.

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Lens	f	Dist. (mm)	DoF (mm)	MF No Comp.	MF IR Comp.	AF	OK ?
Nikon 55mm/1.2 AiS (hs+)	1.2	1000	15	Bad	40	-	No
Nikon 55mm/1.2 AiS (hs+)	1.2	3000	136	40	0	-	Yes
Nikon 85mm f/1.4 AiS (hs)	1.4	1000	7	24	0	-	Yes
Nikon 85mm f/1.4 AiS (hs)	1.4	5000	184	Bad	0	-	Yes

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Nikon 105mm f/2.5 AiS	2.5	1000	9	24	0	-	Yes
Nikon 105mm f/2.5 AiS	2.5	1200	12	24	0	-	Yes
Nikon 105mm f/2.5 AiS	2.5	1500	19	12	-24	-	Yes
Nikon 105mm f/2.5 AiS	2.5	2000	34	108	-24	-	Yes
Nikon 105mm f/2.5 AiS	2.5	3000	78	Bad	-24	-	Yes
Nikon 105mm f/2.5 AiS	2.5	5000	216	Bad	0	-	Yes
Nikon 135mm f2.8 AiS	2.8	2000	23	80	20	-	Yes
Nikon 500mm f/8.0 MF Catadiottrico	8	4000	19	0	0	-	Yes
Canon EOS AF 100mm2.8 Macro	2.8	2000	43	80	-	80	No
Canon Zoom 16-35/2.8 USM L @ 16mm (hs+)	2.8	500	105	-24	-48	0	Yes
Canon Zoom 16-35/2.8 USM L @ 35mm (hs+)	2.8	1000	87	-32	-48	0	Yes
Canon Zoom 70-200mm/2.8 USM L IS @ 70mm	2.8	1500	49	24	-36	36	Yes
Canon Zoom 70-200mm/2.8 USM L IS @ 70mm	2.8	5000	544	Bad	Bad	Bad	No
Canon Zoom 70-200mm/2.8 USM L IS @ 200mm	2.8	1500	6	0	-24	24	Yes
Canon Zoom 70-200mm/2.8 USM L IS @ 200mm	2.8	5000	67	Bad	-120	72	?
Canon 400mm/5.4 USM L	5.6	7000	65	96	Bad	60	?
Canon 50mm/1.4 (hs)	1.4	1470	46	Bad	Bad	24	Yes

CONCLUSIONS

When we speak about uncertainty in focusing we refer to data obtained through tests; at any rate we should not forget that the autofocus has some latitude in performance in visible light as well, being influenced by its own design (closed loop, open loop) the manufacturing tolerances of the lenses and the bodies, drift issues, quality control, and so on.

In real life people do not take pictures of funny columns made out of Lego bricks with the lens wide open. The data shall be interpreted therefore neither as an 'anything goes' nor as an 'impossible to use.' The relationship among the depth of field, the accuracy in focusing, the increased diffraction when closing down the lens and working in the near IR range, should be carefully considered.

If there is a recommendation at the end of this article is that who wants to modify a DSLR permanently for near IR photography should ask herself or himself what kind of IR photography she or he wants to make and select a couple of lenses that will become the only one to be used. At this point, and after making sure that there is no hot spot issue that cannot be predicted with good confidence, it is possible to modify the camera in such a way that it will be well behaved with the selected lenses in the near IR range.

In spite of all good news we should not also forget that the lenses we use are conventional lenses with some degree of correction that make them *usable* in the near IR range. These are not specialized tools for IR imaging. This means that, in spite of all our effort for achieving precise focusing, avoiding hot spots, etc some *residual aberrations may still be there and create some 'haze' effect.*

Digital photography has created some renewed interest in IR photography. We do not know if this is a short-lived fad or it will indeed open up the door for some new interesting artistic

development. Permanently IR-modified DSLRs allow the general public for the first time in the history of photography to take pictures in the near IR range with exposure times of 1/1000s in full sunlight. This is not history repeating itself, it is *new*. The capability of IR to go through air pollution may become an important feature as well (we all hope that this prediction will turn out to be completely wrong, needless to say).

Even the 'false color' methodology (see the picture below), somewhat reminiscent of hand-painted monochrome IR prints of the past, can be utilized creatively in interesting ways, as long as one does not exaggerate with the 'psychedelic' look that becomes boring very fast.

Permanently IR-modified Canon Rebel XT. 'False color' stitched panorama.

Alternatively, one can go back to the old paradigms of the early nineteen century, as the picture of the Palace of Fine Arts in San Francisco demonstrates.

The Palace of Fine Arts in San Francisco. Canon 1DsMkII with IR filter.

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