Lateral Chromatic Aberration Compensation Function:

In JAI color line scan cameras (3CCD/4CCD/3CMOS/4CMOS), sensors and prisms are precisely fabricated. On the other hand, the lens mounts of the cameras use industry standards, meaning a variety of lenses of varying quality can be attached.

Each lens will have some degree of lateral chromatic aberration – defined as an inability to focus all color wavelengths to the same convergence point(s) along the sensor plane. In other words, the red, green, blue, and NIR waves associated with a given point on the target image may be focused to different pixels on the camera's imager. The result of this is typically soft edges with color fringes on objects in the field of view. In a line scan camera, this will be most prominent on edges that are perpendicular to the sensor's plane (see Figure 1).

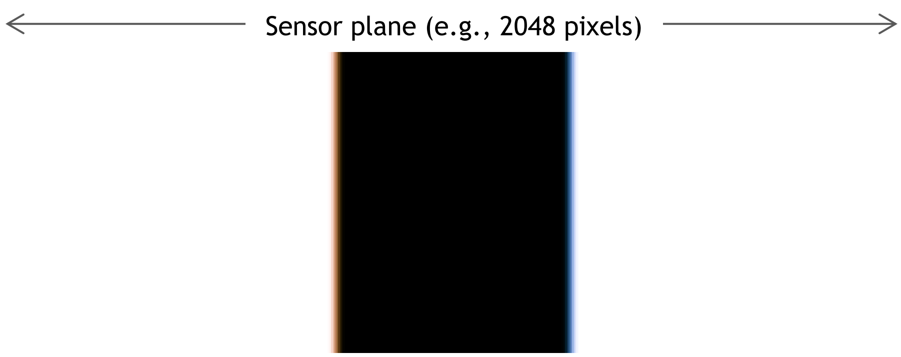


Figure 1 – Color fringes caused by lateral chromatic aberration

To compensate for the lateral chromatic aberration characteristics of a particular lens, JAI prism line scan cameras support a Lateral Chromatic Aberration Compensation function.

This document provides a description of how to execute Lateral Chromatic Aberration Compensation. It uses for its example:

Camera: JAI LQ-201CL (4-channel line scan camera with 2048 pixels per line)
Lens: BlueVision BV-L1035-F

1. Preparation

To compensate lateral chromatic aberration, each channel output (R/G/B/NIR) needs to be checked visually, with the desired adjustments entered into the Lateral Chromatic Aberration Compensation form. Therefore, a kind of test chart (see example in Figure 9) or measurement scale is needed. As noted above, a series of high contrast lines oriented perpendicular to the line sensor's plane will make it easier to see any chromatic aberrations that exist.

You will also need a tool that allows you to view the output of each channel on a line profile graph, preferably with the pixel index in the horizontal direction and the pixel intensity (pixel value) in the vertical direction. Most of the image capture software packages provided by frame grabber manufacturers have such a tool included for viewing this type of multi-channel histogram.

Lastly, to check actual lateral chromatic aberration efficiently, equivalent output levels are preferable from all channels in the camera. To achieve this, white balancing and flat shading correction should be executed before performing Lateral Chromatic Aberration Compensation.

2. Flat Shading Correction:
An example of setting the camera and light source for flat shading correction is shown in Figure 2.

For lens aperture and focus, the same settings that are anticipated for the actual use case are preferable. The light source should be flat and uniform. Figure 3 shows the label from the light source used in this document.

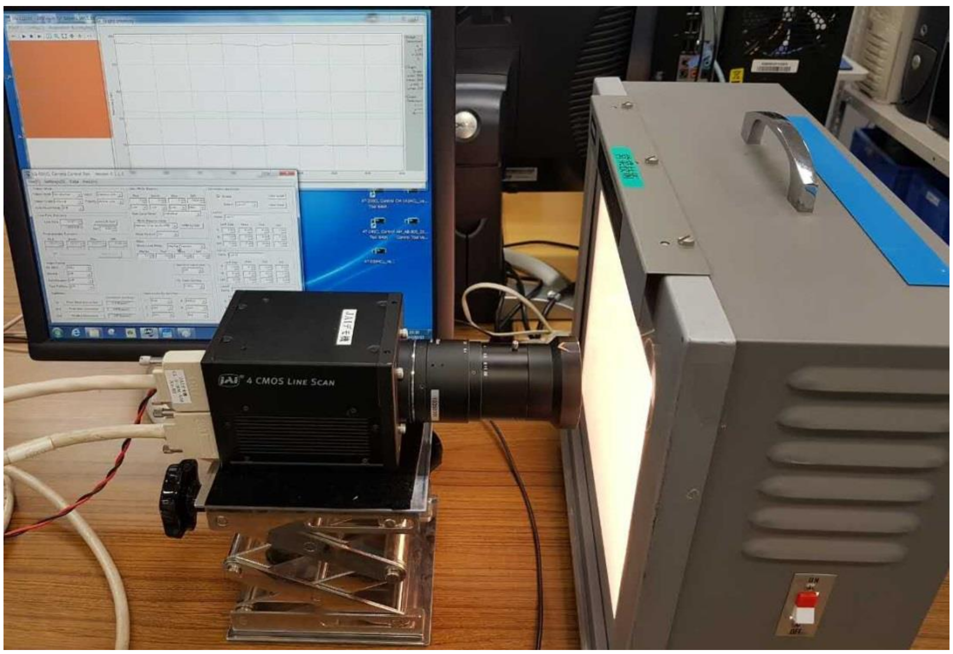


Figure 2 – Camera and light source

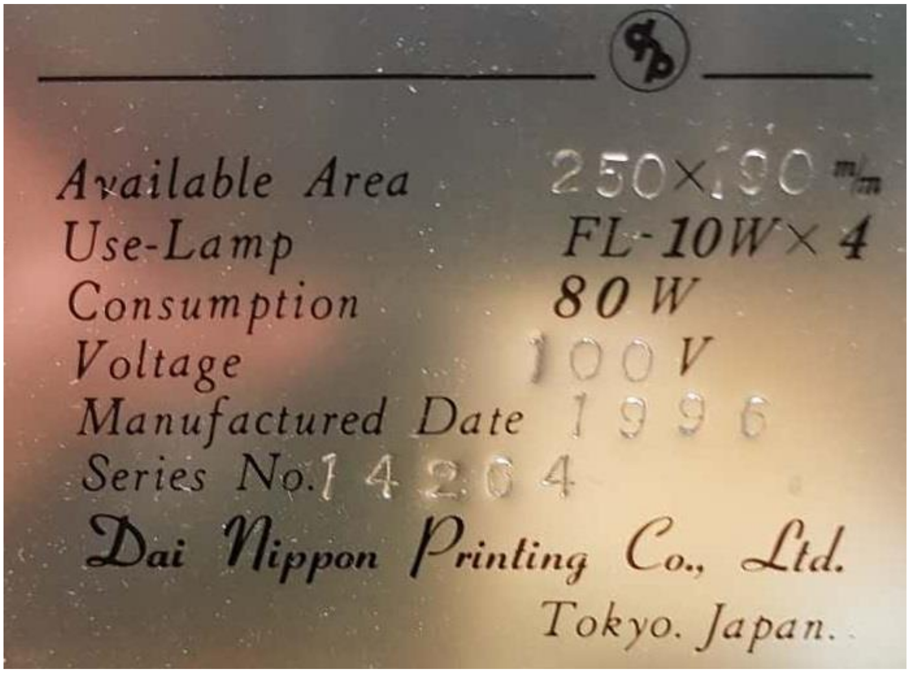


Figure 3 – Light source label

Start by using your line profile tool to check the horizontal brightness as shown in Figure 4. Use a uniform target that provides a light intensity below saturation. Notice how the center parts of our lines are brighter than the right/left sides due to the lens characteristics (roll-off).

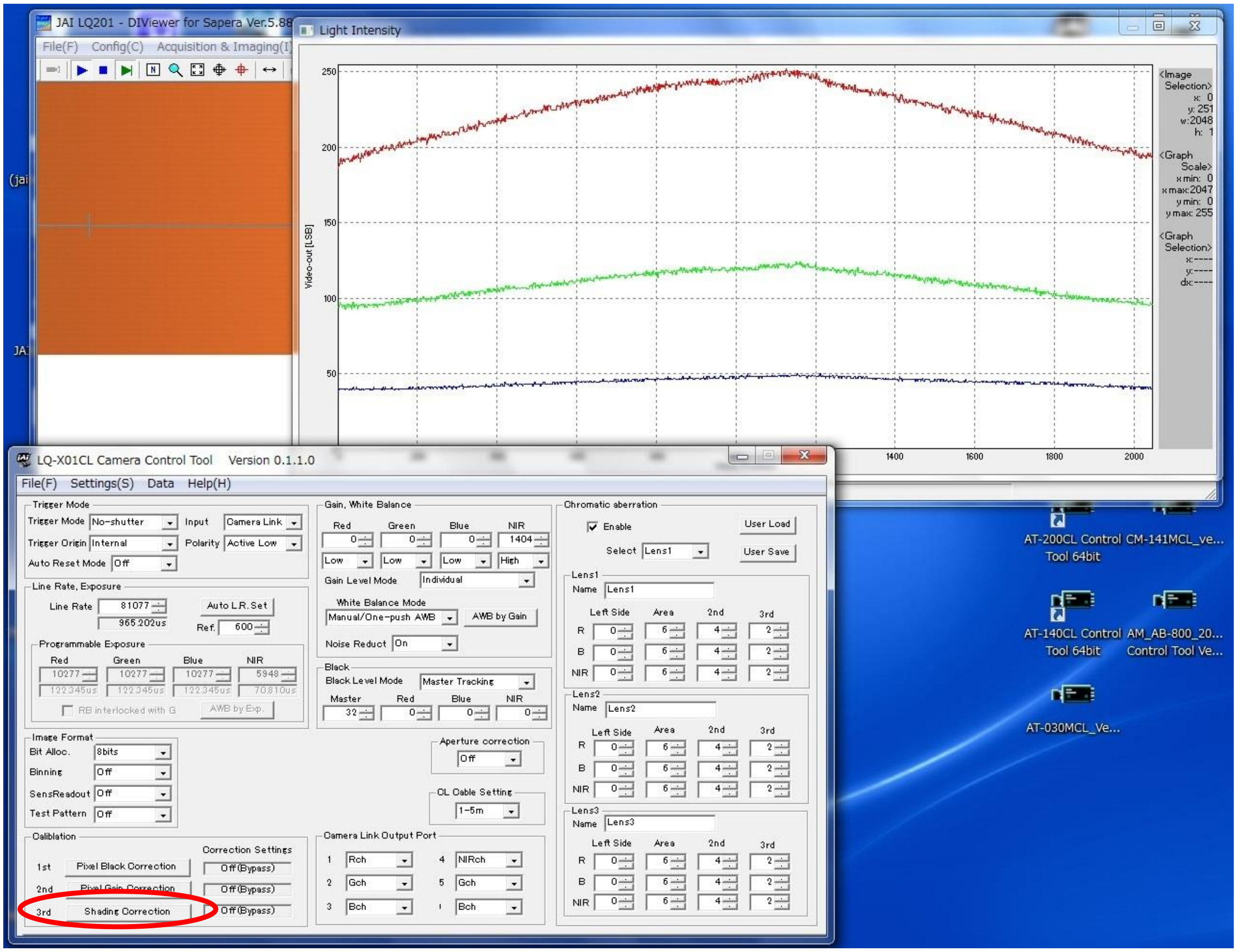


Figure 5 – Shading correction needed

To correct the output level to be flat, open the camera control tool and click the “Shading Correction” button. Depending on which camera model you are using, the button may be located in a different part of the control tool window. For the LQ-201CL, which we have used for this example, the button is in the lower left corner of the control tool. In the pop-up window that appears, select “User” and click the “Flat Shading” button. After a while, the output of each channel becomes flat as shown in Figure 6.

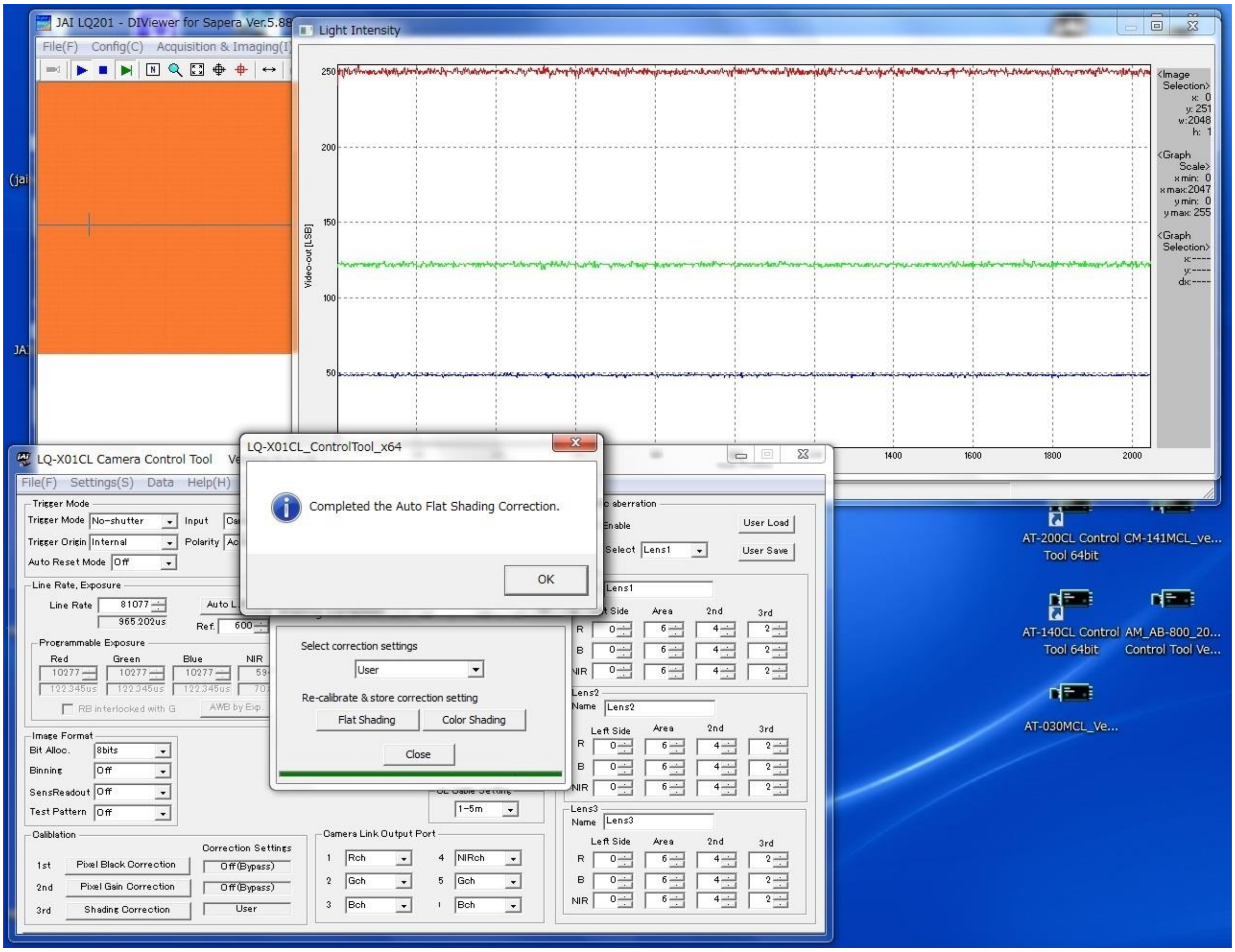


Figure 6 – Shading correction completed

3. White Balance

To execute a white balance, the settings on the camera and light source should be the same as those used for flat shading correction. This time, in the camera control tool, click the “AWB By Gain” button. In the LQ-200CL’s control tool, this button is in the upper center section (see Figure 7). After a while, the “Completed” dialog appears.

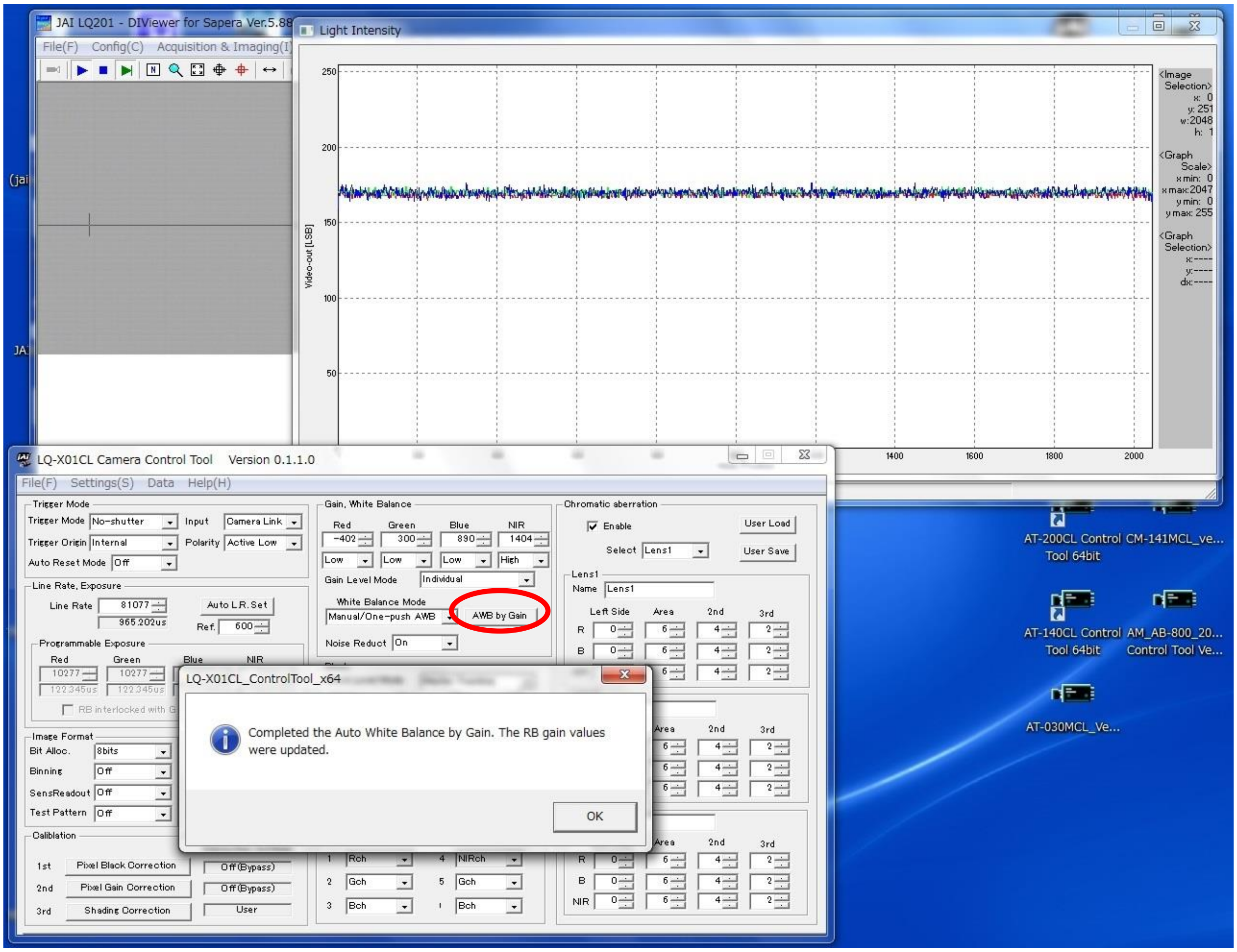


Figure 7 – White balancing completed

Note: In white balancing, the master gain is the green channel (G-ch): Red and blue channels (R-ch and B-ch) are adjusted to match the green channel. In the case of G-ch's gain being 0, white balance sometimes fails because the amount of positive or negative gain that needs to be applied to the other channels might exceed the camera's allowable range. In this case, changing G-ch's gain to a more appropriate value is needed.

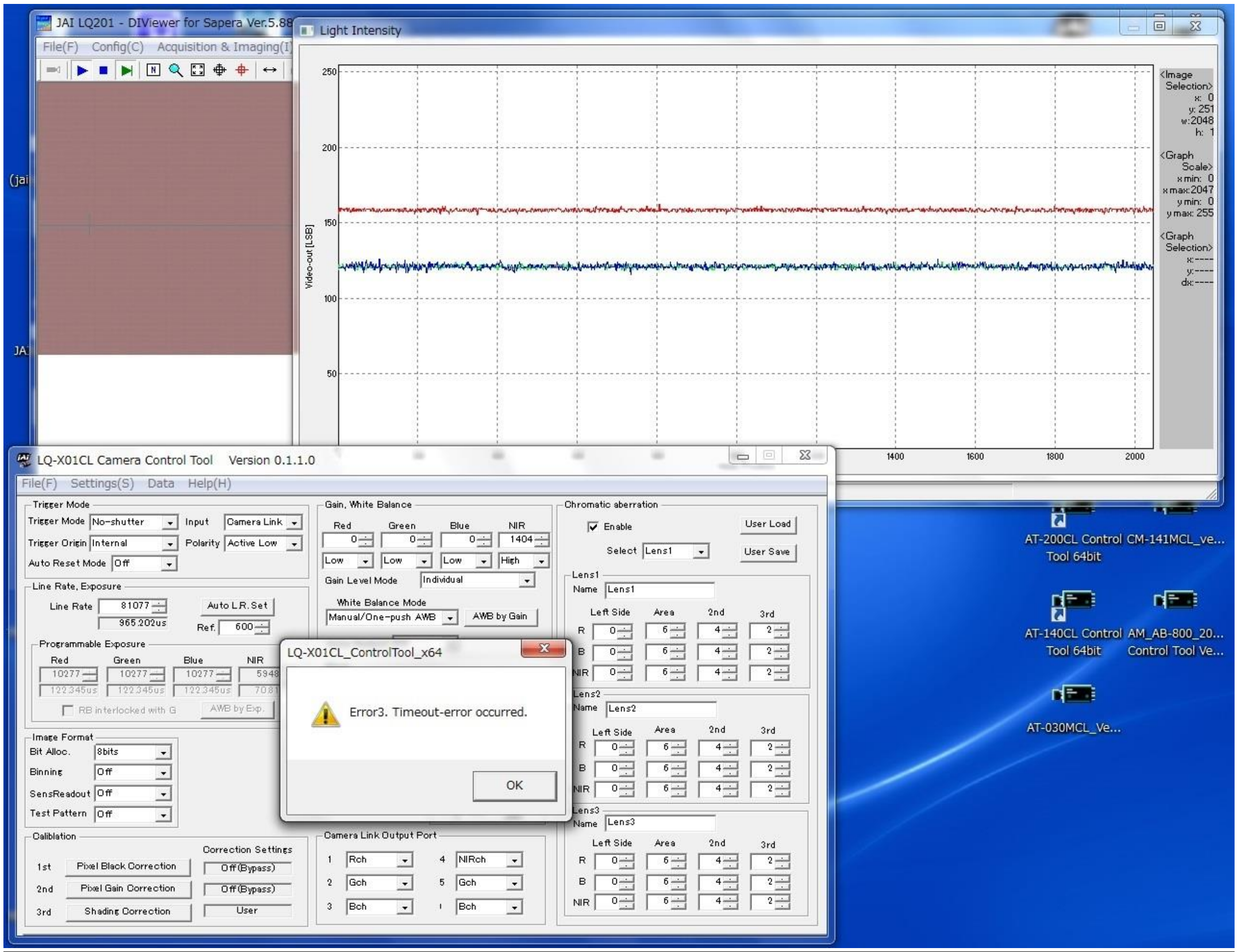


Figure 8 – White balancing error

Shown above is an example where a white balancing error has occurred. The green channel's (G-ch) gain was set to 0 and white balancing resulted in the R-ch's gain being pushed all the way to -402 before the error occurred. Since -402 is the minimum gain value allowed in the LQ-201CL, it is likely that reaching this point before white balance was achieved is the reason for the timeout error.

After changing G-ch's gain to 300, the R-ch was able to reach a balance point without exceeding the allowable gain value. Thus, the white balance succeeded when it was rerun.

4. Lateral chromatic aberration compensation:

Now that the channels have been normalized for lens shading and white balance, it is time to check for lateral chromatic aberration.

This requires a kind of test chart such as that shown in Figure 9. The vertical white/black alternating lines will create peaks and valleys in the intensity graph, which will make it easier to judge the focal point for each of the camera's 4 channels. You can easily make such a chart, if needed, using PowerPoint or similar software. The alternating lines should span the full field of view of the camera/lens combination being calibrated so that the full imager can be calibrated under stable (unchanging) conditions.

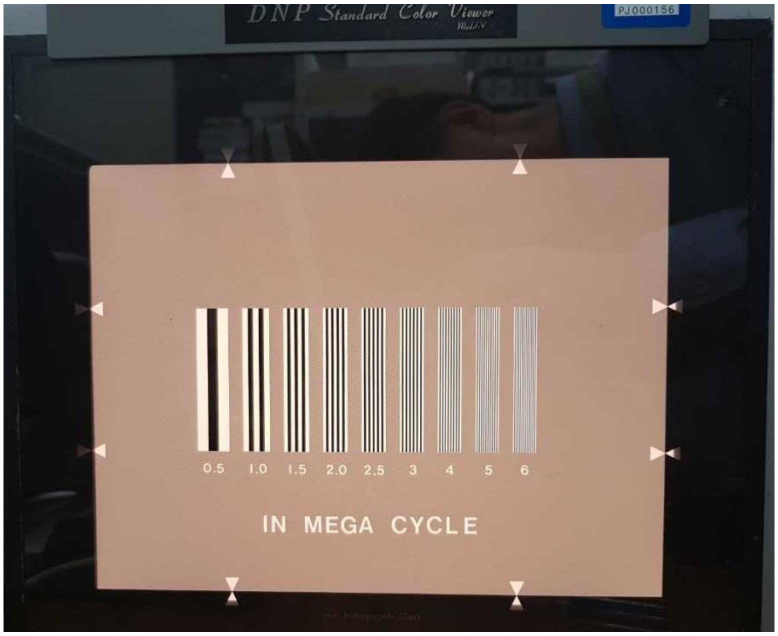
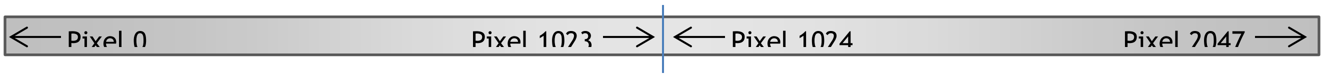


Figure 9 – Test chart

Figure 10 – Overview of setup

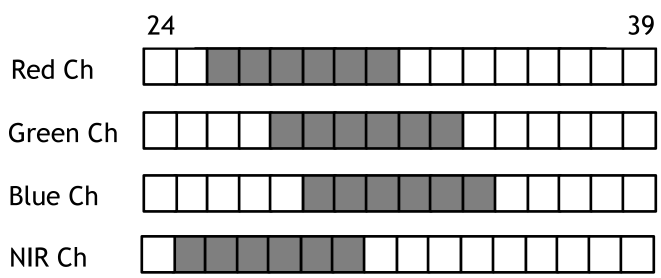
4.1 Concept overview

Before beginning, it is helpful to have a graphical representation of how lateral chromatic aberration is manifested. Figure 11 is a simplified representation of one of the line sensors used in our camera. In this case, it has 2048 pixels running from pixel 0 on the left edge to pixel 2047 on the right edge.



Although the sensors for each channel are precisely aligned with respect to the optical path through the prism, the characteristics of the lens causes the actual focal point of each channel to shift slightly relative to each other. As was the case with shading, this shift is greatest at the outer edges of the sensor.

Thus, if we enlarged our sensor graphic to show a magnified view of a section of 16 pixels where a particular "line" from our target is being focused, we might see the following:



As you can see, the same six-pixel-wide line on the target is shifted laterally depending on the channel. The result will be the colored "fringe" shown in Figure 1. Also note that this section of pixels is from near the left edge of the sensor (pixels 24-39). Typically, if we looked at the right edge of the sensor, we would see a mirror image of this. That would mean the Red channel and NIR channel would be shifted to the right (relative to Green) while the Blue channel would be shifted to the left.

But if we looked at a similar line in a section of pixels near the center of the imager, we might see the following:

Clearly, this is what we want. But if we want to maintain the same edge sharpness and color fidelity at the edges of our field of view as in the center, we will need to carefully apply some lateral shifts to the channels to make this happen.

As noted in Section 1, our process will utilize line profile graphs to visualize the pixel shifts and to confirm the effects of our compensation adjustments.

4.2 Compensation process

JAI's multi-imager line scan cameras utilize a sophisticated set of filter coefficients to compensate for the lateral shifts described above. A default set of coefficients is provided at the JAI factory as a starting point. Users can then adjust the default set based on the specific lens they are using.

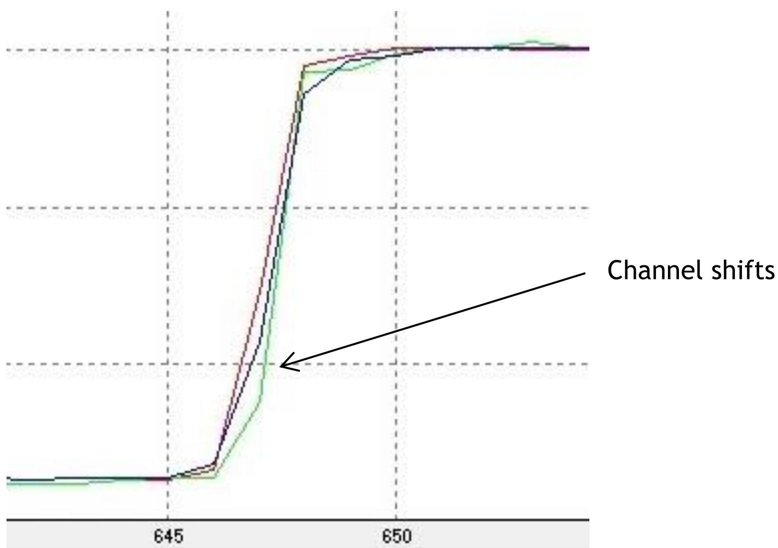
The process for utilizing JAI's Lateral Chromatic Aberration Compensation function is as follows:

Step 1 Divide the whole line into 16 equal areas. In this case, that means each area will be 128 pixels wide (2048/16 = 128). We assume that the area in the center of the sensor will require no compensation and that any aberrations will be roughly symmetrical (mirrored) in the lateral direction. Therefore, we number our areas from 1 to 8, starting at the left and right edges and working to the center as shown below.

1	2	3	4	5	6	7	8	8	7	6	5	4	3	2	1

Step 2 Use our setup in Figure 10 to image a set of vertical lines across the width of the sensor (or at least one half of the sensor).

Step 3 We will then use our line profile graph to analyze the peaks and valleys resulting from the alternating white and black lines on our target. If the rising and falling edges are perfectly aligned all the way to the edges of the sensor, then no compensation will be needed.



Step 4 If we see shifts occurring between the different channels, then we will enter the appropriate data about the shifts into the Chromatic aberration section of the control tool

Step 5 The Lateral Chromatic Aberration Compensation function will use the data to remove the aberrations associated with the specific lens being used. This data can be saved in a User Data set for recall anytime that specific lens is used. Up to 3 different lenses can have compensation data saved in a User Data set.

4.3 Executing the process

As noted in Step 1, we have defined 8 possible areas on each half of the sensor where Lateral Chromatic Aberration Compensation may be needed. With our test chart being captured by the camera (Step 2) we can now begin our analysis.

The first thing to do is to determine how many of our 8 areas will require some amount of compensation. We can assume that the center areas need no compensation (if there are problems in the center, then most likely the lens is damaged or of very low quality and must be repaired or replaced). However, if we wanted to verify this, we could look at our line profile graphs somewhere within area #8, which spans pixels from 896-1023. Figure 11 shows a section of our line profiles taken from the left edge of Area #8 and extending into Area #7. The peaks represent white lines on our target chart.

The top graph shows that the RGB channels are all properly aligned as expected. The bottom graph shows that the NIR wavelengths are also being focused at the same points on the sensor.

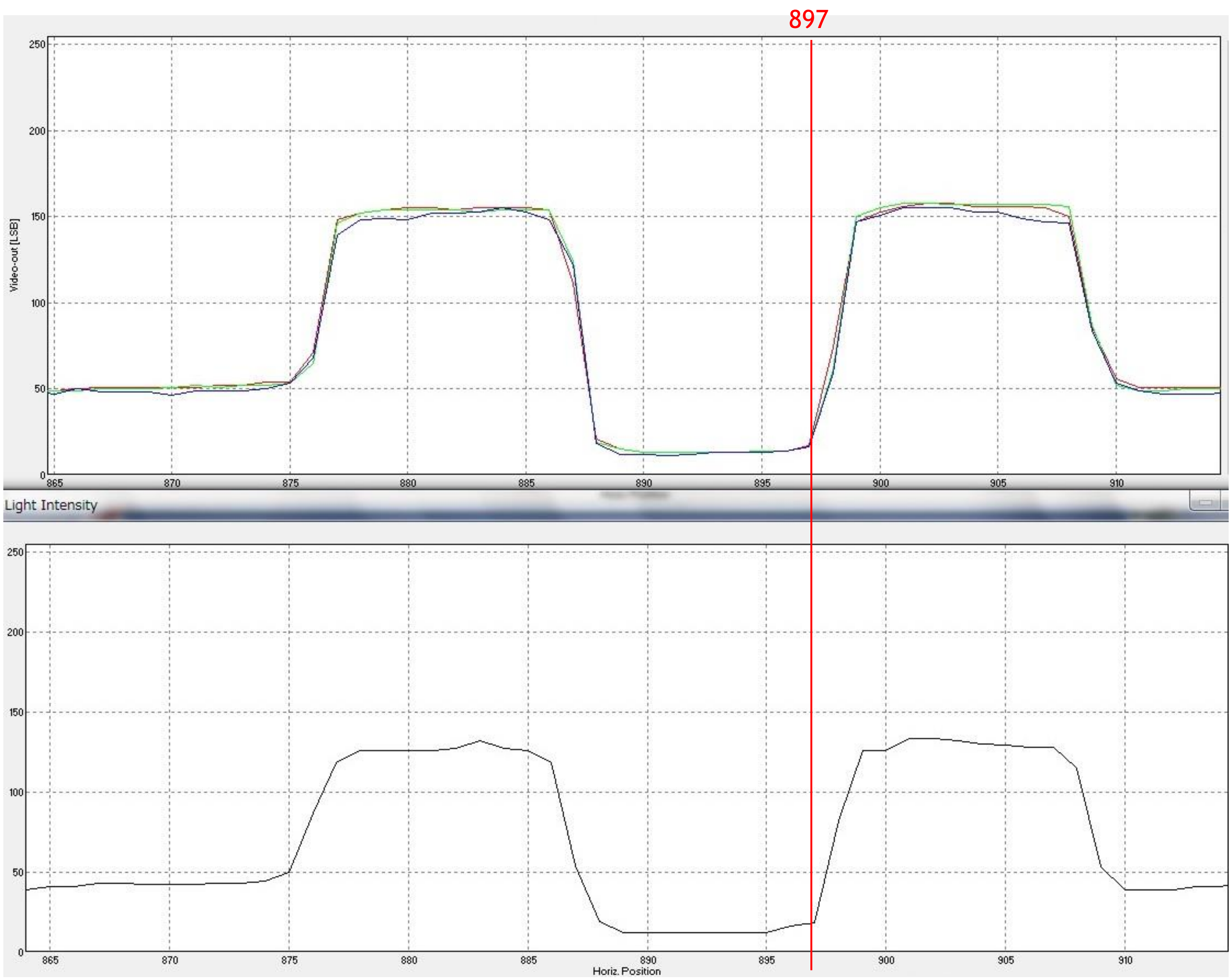


Figure 11 – Alignment in Areas #7 and #8

Now we can begin working outwards towards the left edge of the sensor. In Figure 12, we are looking at an area spanning parts of Area #5 (512-639) and Area #6 (640-767). Here we can see that the RGB lines still show good alignment. But the NIR line (bottom graph) is shifted to the left by 1 pixel at the left edge of Area #6.

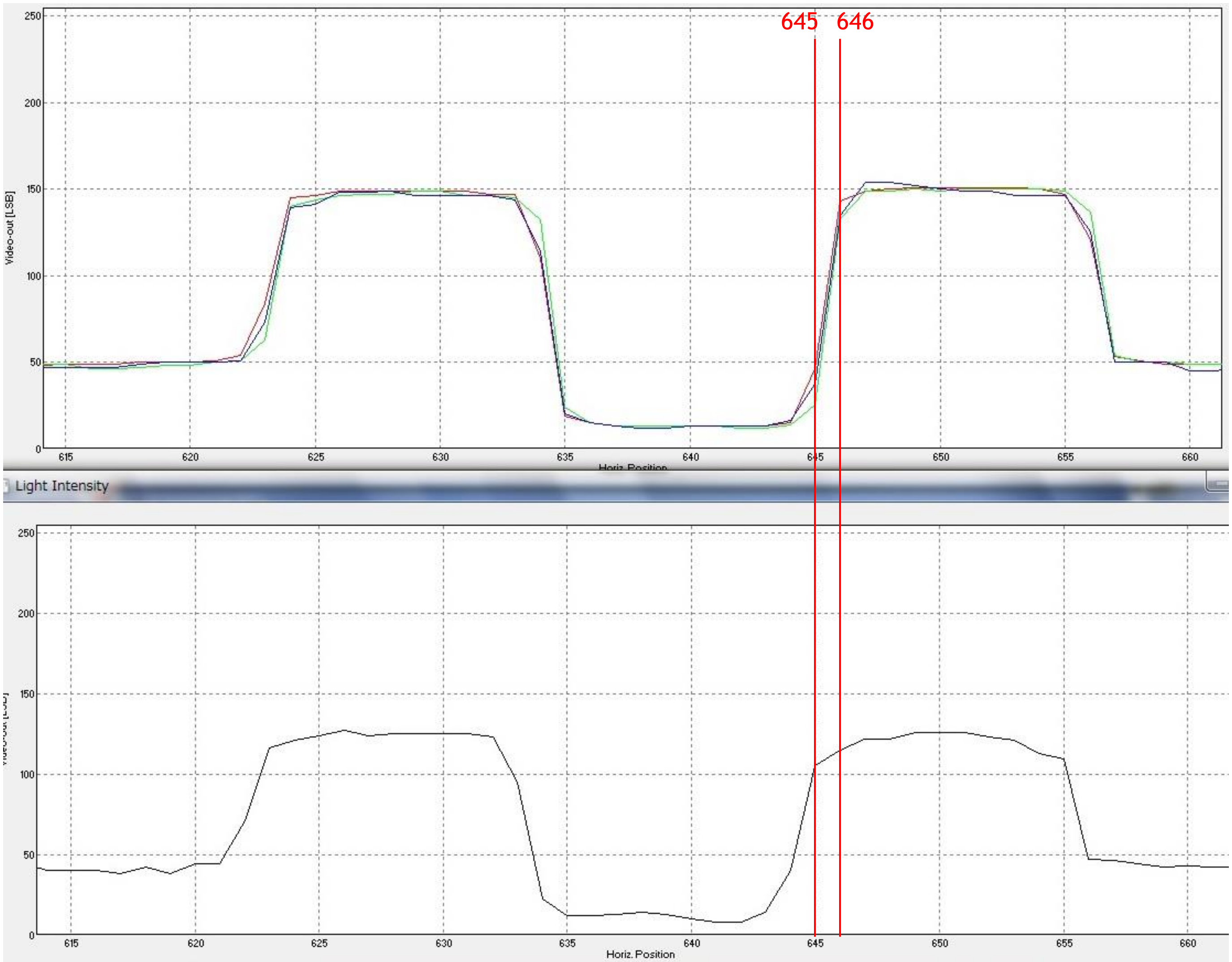


Figure 12 – NIR shifted left in Area #6

We can enter this information into the Lateral Chromatic Aberration Compensation form (Figure 13), which is located at the right side of the LQ-201CL control tool.

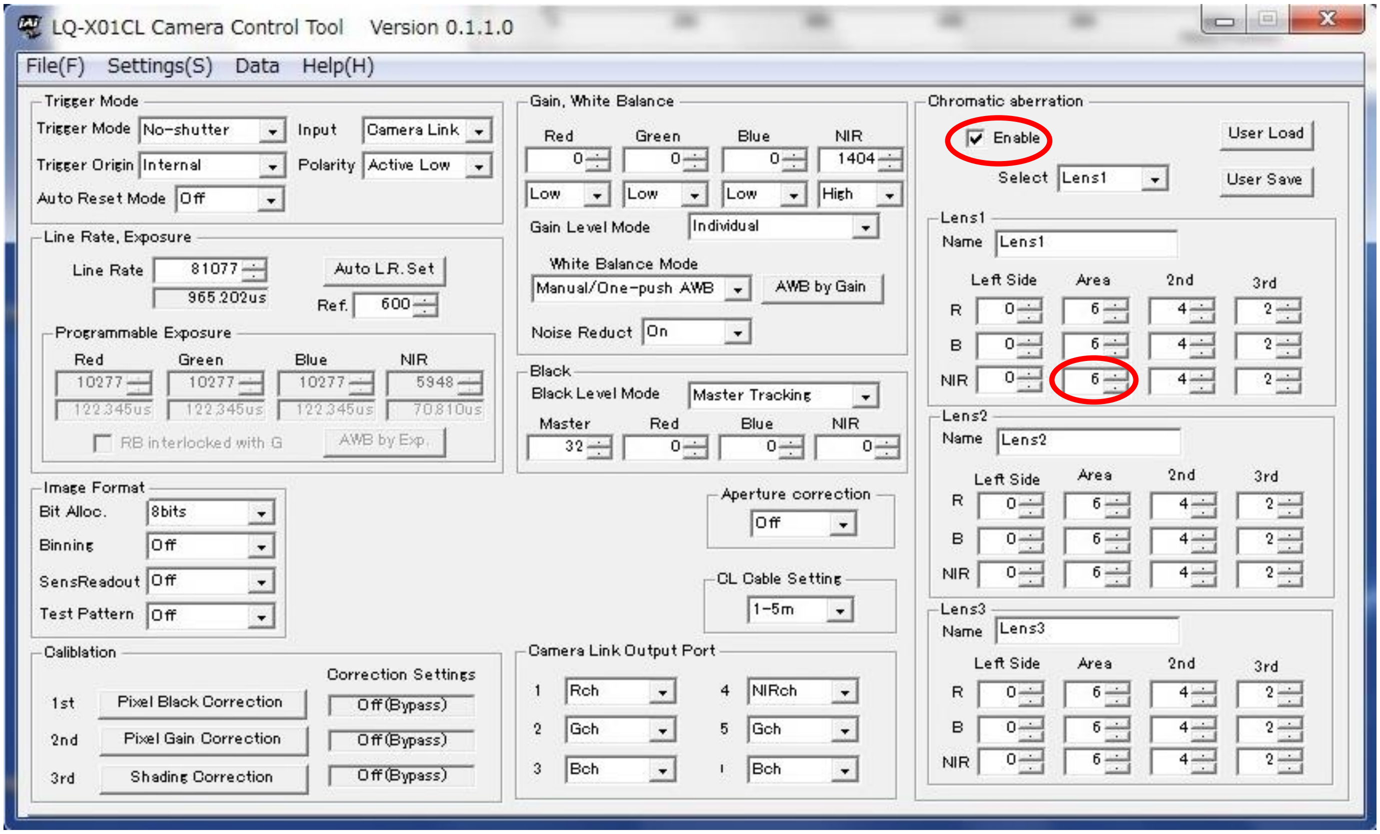


Figure 13 – Chromatic aberration form with default Area set

First, tick the "Enable" box to enable the form and turn on the chromatic aberration function. As noted, you can set compensation data for up to three different lenses. We will leave the Select box set to Lens1 and will enter our data in the Lens1 section below. The second column, which is labeled "Area", is for setting how many areas will require some lateral compensation. The default value is 6. Our analysis in Figure 12 shows that the NIR channel does indeed need to be compensated starting in Area #6, so we can leave the default value here. Since the RGB channels are still aligned, we will probably need to change their default values, but we can leave them as is for now.

Now we continue outward to see where any lateral shifts might start for the Red or Blue channels. In Figure 14, we can analyze portions of Area #3 (256-383) and Area #4 (384-511).

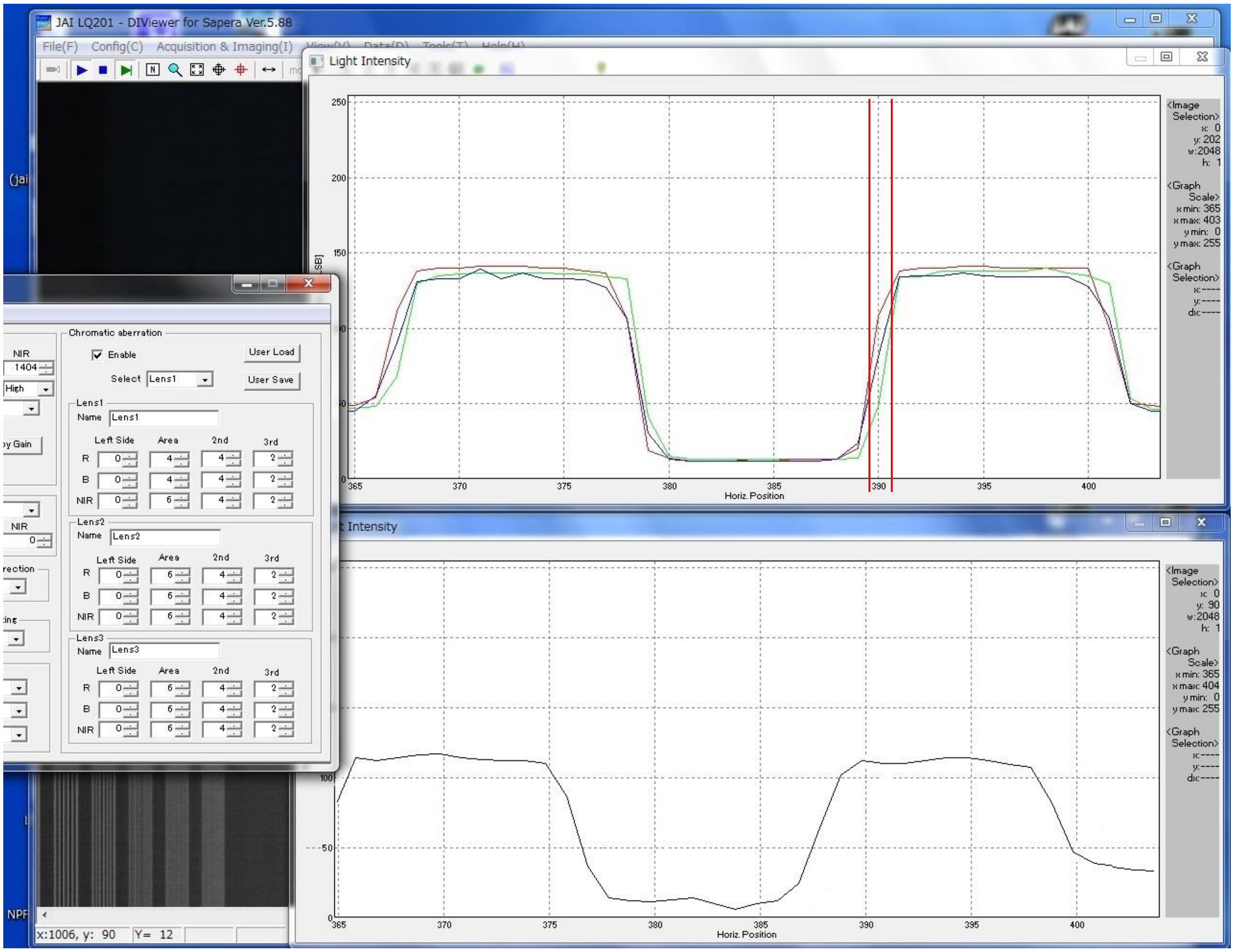


Figure 14 – R/B shift begins in Area #4

Here we can see that both the Red and Blue channels are beginning to show a 1-pixel shift to the left of the Green channel at around 390, which is the left edge of Area #4.

Based on this, we can change the Area value for R and B to “4” in the Chromatic aberration form as shown in Figure 15 on the next page. Since the shift amount for the Blue channel is not quite a full pixel, we could also choose to enter a “3” for its Area value, meaning no adjustment except for the last 3 areas. Note that this would make the value in “Area” less than the value in “2nd”. If this happens, we should temporarily change the value in “2nd” to match “Area” (we’ll explain why later). However, for this example, we are going to change both the R and B values to 4.

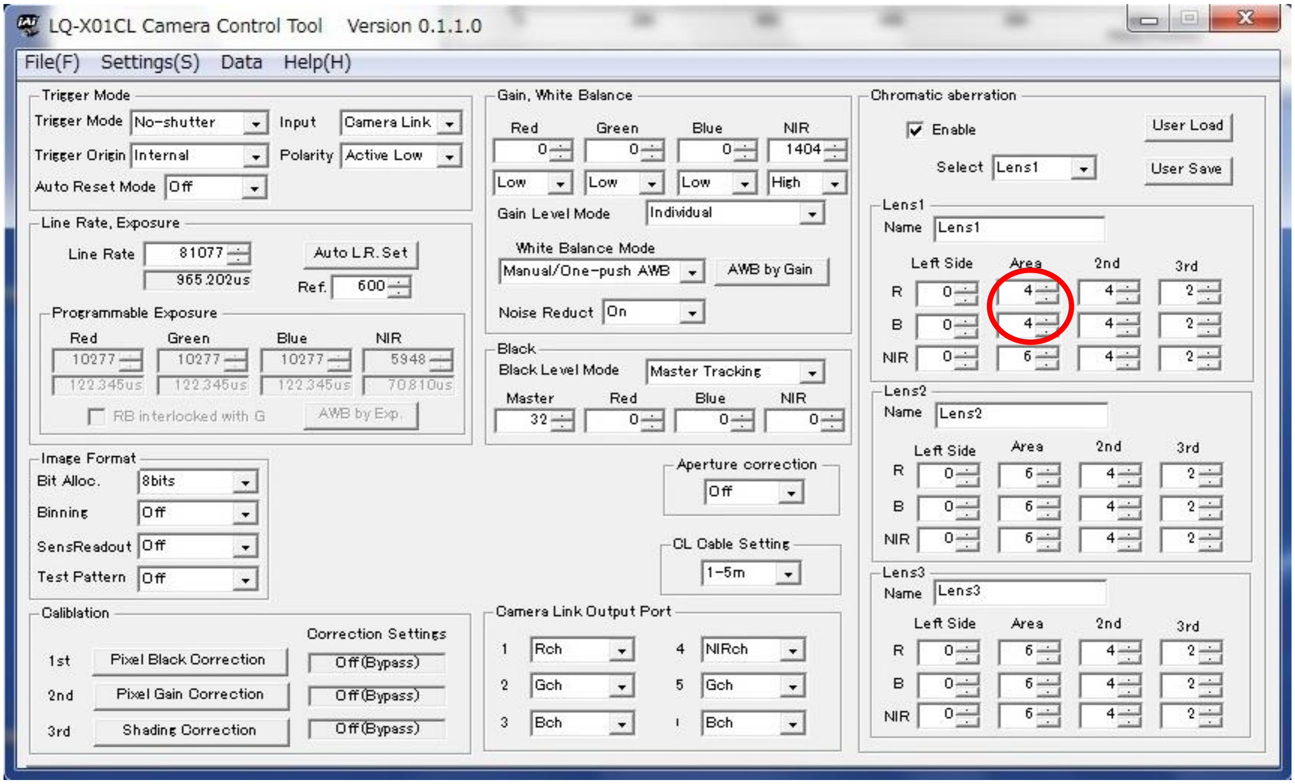


Figure 15 – Setting the "Area" value for R/B channels

Now that we have found the starting point for all the channels and entered it in the Area column, we can determine the maximum amount of lateral compensation that is needed at the outermost area on the sensor (Area #1). We can do that by looking at our line profile graph in the area closest to the edge of the sensor. This is where the aberration will typically be greatest. So that means looking in Area 1 on the left half of the sensor, which ranges from pixel 0 to pixel 127.

We do this in Figure 16. Note that the grid scale for these graphs is 10 pixels per vertical line instead of 5 in the earlier graphs. We observe that the Blue channel is still shifted one pixel to the left of the Green channel, but the Red channel is now two pixels to the left and the NIR channel is approximately 3 pixels to the left. Fortunately, the Lateral Chromatic Aberration Compensation function has a maximum compensation range of ±3 pixels.

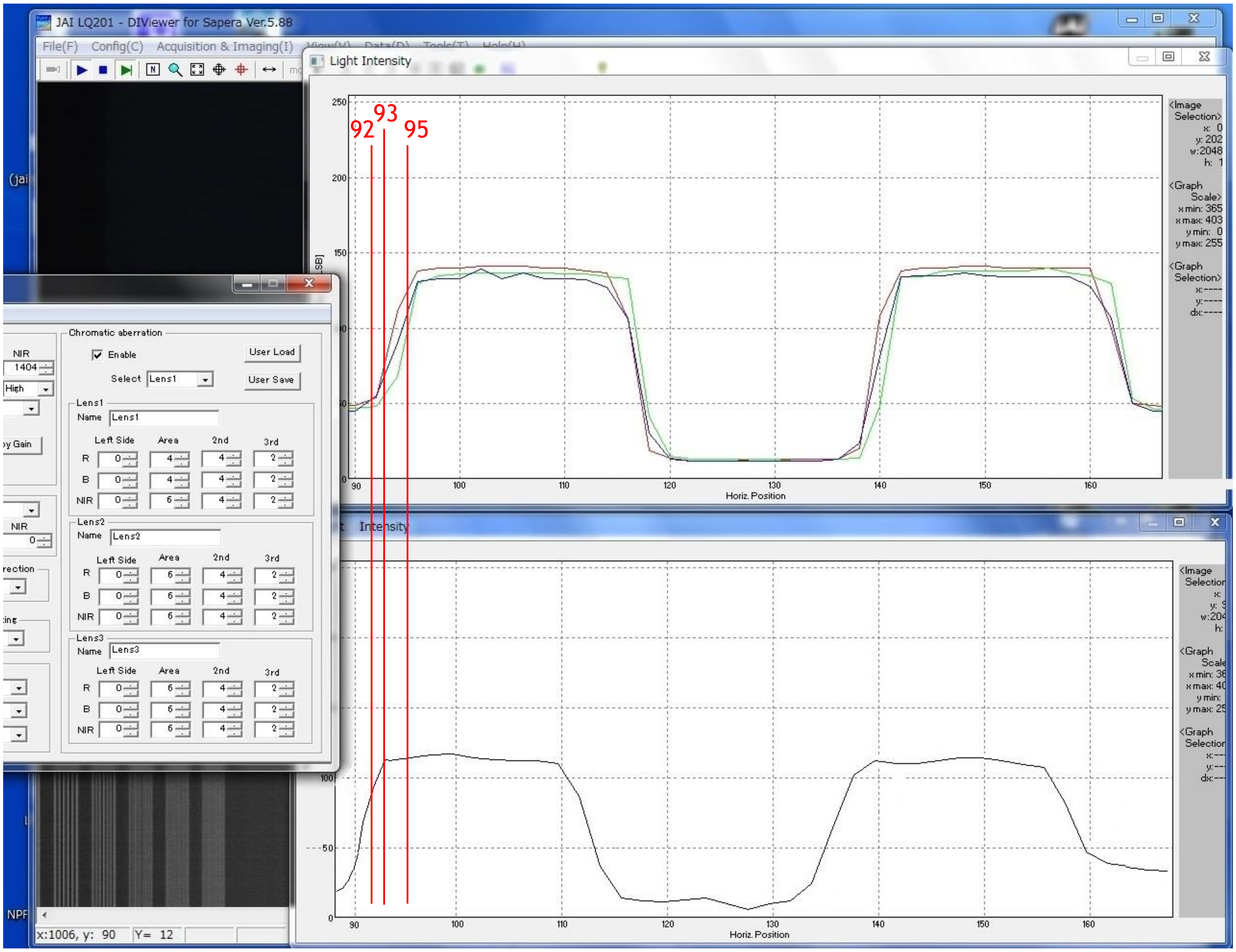


Figure 16 – Maximum shifts in outermost area (Area #1)

We can now use the form to enter our maximum shifts for each channel in the column labeled "Left Side." This can be thought of as answering the question: "At the left edge of the sensor (i.e., Area #1) how many pixels should a channel be shifted relative to the Green channel and in which direction, positive or negative?

Since all channels are shifted to the left of the Green channel, these will be entered as positive values, i.e., "adding" to the pixel numbers, thereby moving the shifted lines towards the center of the imager. If the any of the channels showed a shift to the right of the Green channel, we would use a negative value to move them towards the outside of the sensor.

Figure 17 shows the values entered in the form. We have entered 2 for Red, 1 for Blue, and 3 for the NIR channel.

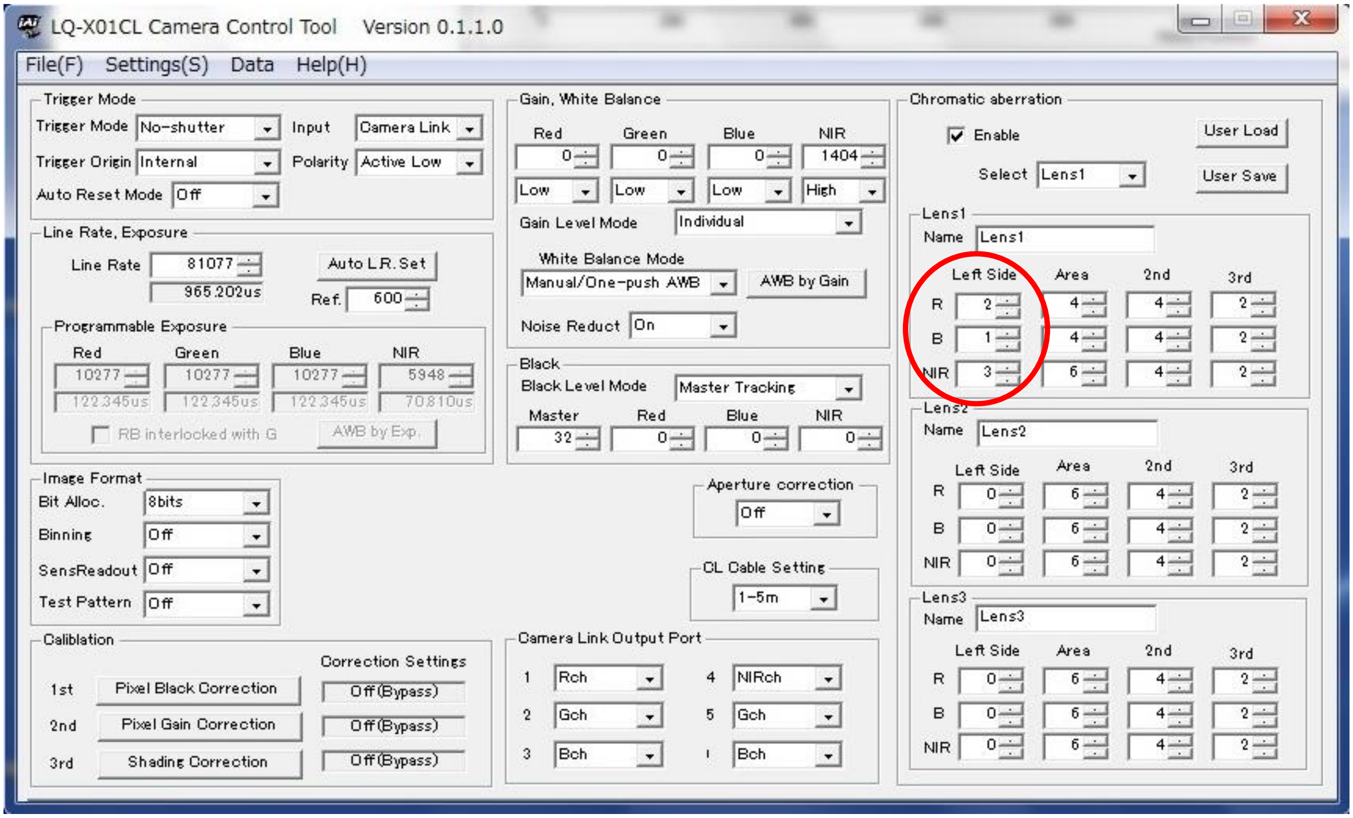


Figure 17 – Maximum compensation values entered in "Left Side" fields

Note that all of our analysis and form entry has been done while the camera is running. So, when we enter values in the "Left Side" fields, the compensation is immediately performed and we can observe the changes in our line profile graphs. Figure 18 shows the changes in Areas #1 and #2.

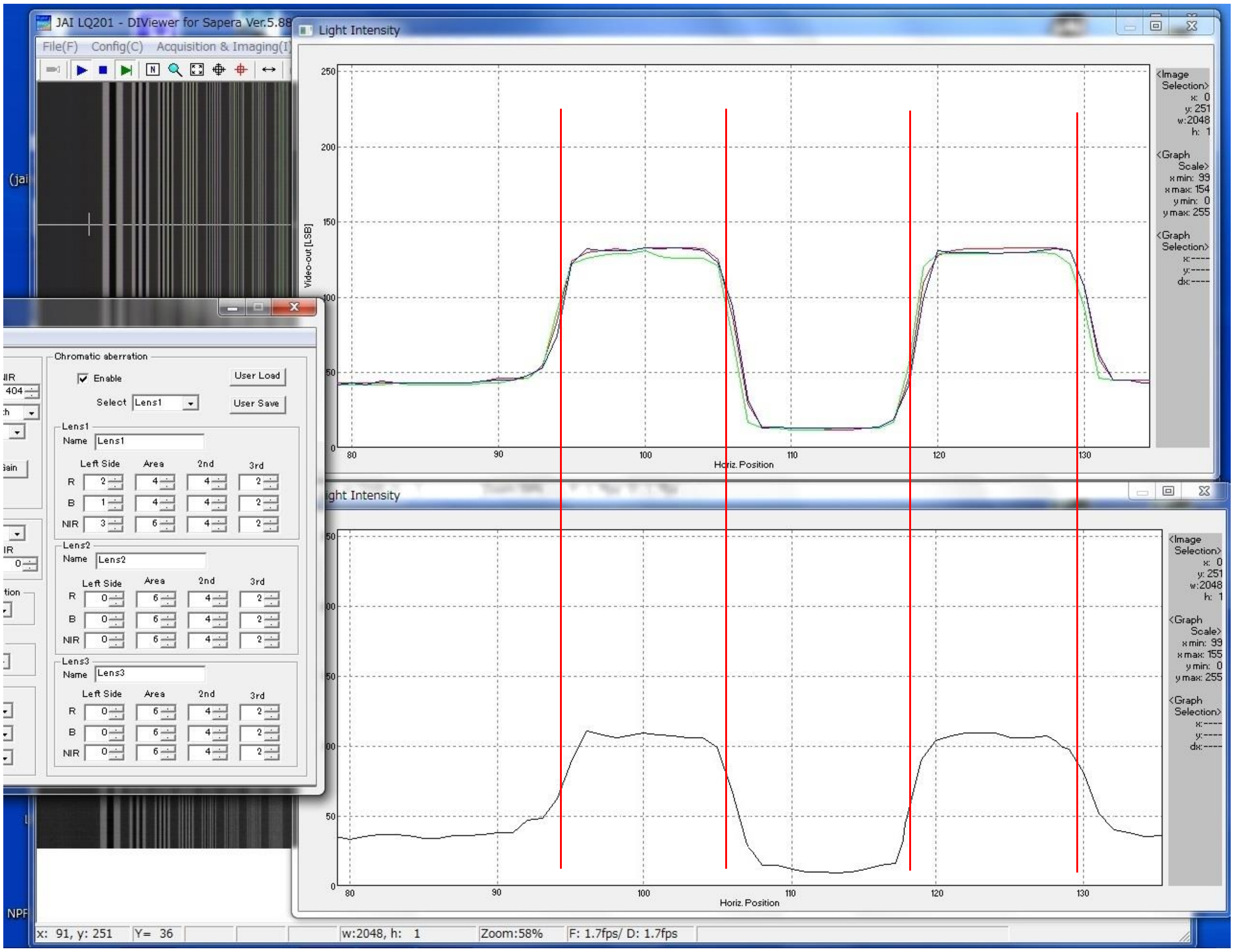


Figure 18 – Left side alignment

With the “Left Side” compensation applied, we can see that our Red and Blue channels are now well-aligned with our Green channel. Likewise, the NIR channel has been shifted back into alignment.

Our final step involves smoothing the transitions for each channel from the outermost area to the center of the imager (Area #8) where no compensation has been applied. Remember that we used the column labeled “Area” to mark where the first sign of a lateral shift occurred. In other words, this is where we would like to shift from one pixel of compensation to zero pixels of compensation in the middle.

However, if we consider our NIR channel, we have just finished applying the maximum left side compensation of three pixels in order to achieve proper alignment in Area #1. Our goal then, is to get from this three-pixel shift down to a one pixel shift in Area #6, otherwise we will find that our waveforms have been “overshifted” as we move towards the center and are now out of alignment in the other direction.

To do this, we will use the fields labeled “2nd” and “3rd”. In “3rd”, we can enter the number of the area where we want to transition from a 3-pixel shift to a 2-pixel shift. This field is only used when the “Left Side” value is 3 or -3, otherwise it is ignored. Likewise, in the field labeled “2nd”, we can enter the number of the area where we want to transition from a 2-pixel shift to a 1-pixel shift. It is used when the "Left Side" value is 2, 3, -2, or -3, otherwise it is ignored.

Since the NIR channel has been set to 3, we will use both fields. To determine the best area numbers to enter in these fields, we can once again analyze our waveforms looking for shifts, however in practice, it is usually much faster to simply evenly space the vales between the "Left Side" and the "Area" values and only adjust if we are not happy with the result. Therefore, for the NIR channel, we will set "3rd" to 2 and "2nd" to 4. Since these are the default values, we do not have to change them. Our Chromatic aberration form remains as shown in Figure 19.

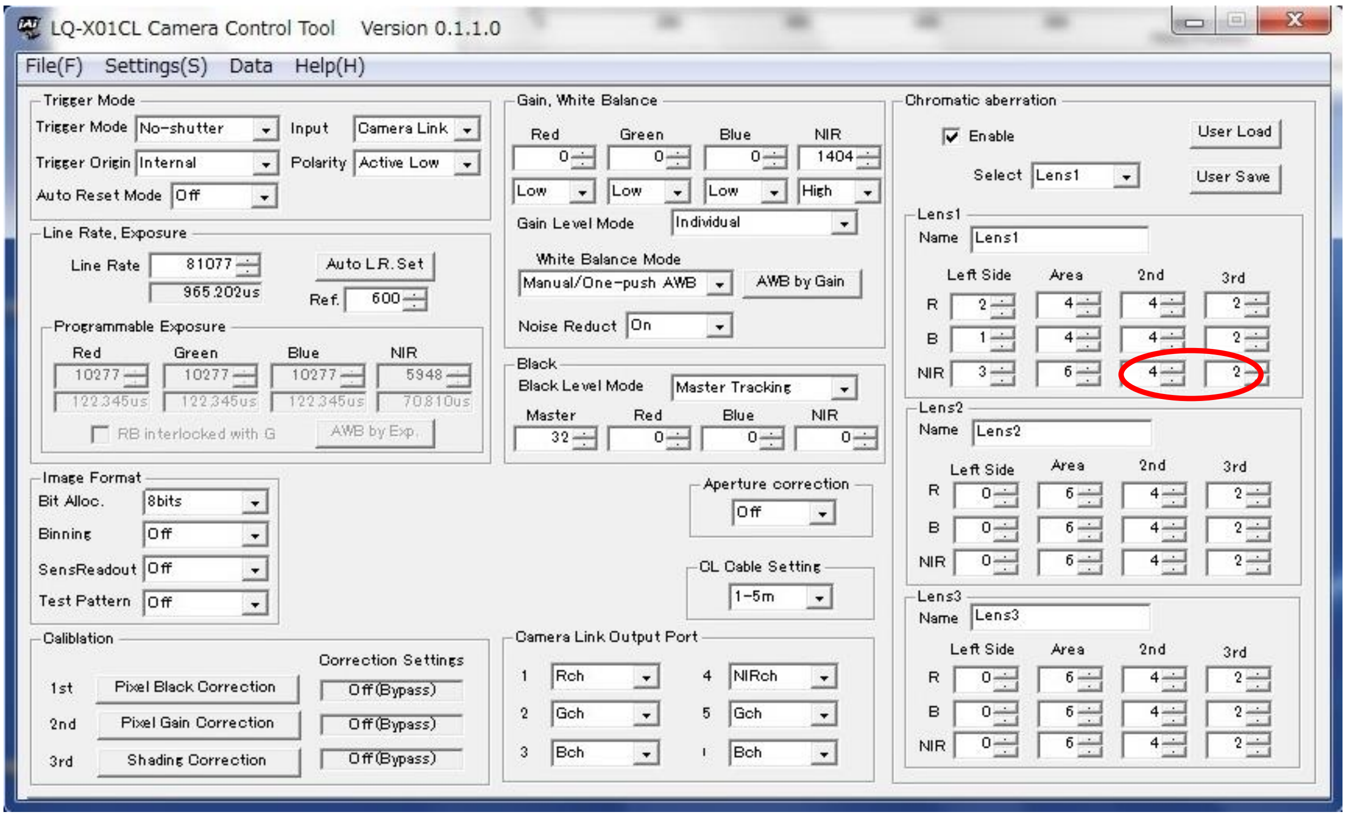


Figure 19 – Transition values for NIR channel

We can visualize the effect of our compensation on the NIR channel in Figure 20 below. At the outer edge of the sensor (Area #1) we apply a 3-pixel shift towards the center (+3). This becomes a 2-pixel shift after Area #2, a 1-pixel shift after Area #4, and a 0-pixel shift after Area #6. This is mirrored on the right half of the sensor.

Area	#1	#2	#3	#4	#5	#6	#7	#8	#8	#7	#6	#5	#4	#3	#2	#1
Shift	3 px →	3 px →	2 px →	2 px →	1 px →	1 px →	0 px	0 px	0 px	0 px	1 px ←	1 px ←	2 px ←	2 px ←	3 px ←	3 px ←

Figure 20 – Effect of compensation on NIR channel

Our Red channel has a maximum two-pixel shift applied at the left edge of the sensor and a defined compensation area starting at Area #4. We can use the "2nd" field to indicate where the transition from the 2-

pixel shift to a 1-pixel shift occurs. As with the NIR channel, we can start by placing this point midway between the outer edge and Area #4, then adjust if we are not happy with the results. Therefore, for the Red channel, we change the value in “2nd” to 2 as shown in Figure 21. We do not need to change the value in “3rd” since it will be ignored by the compensation function.

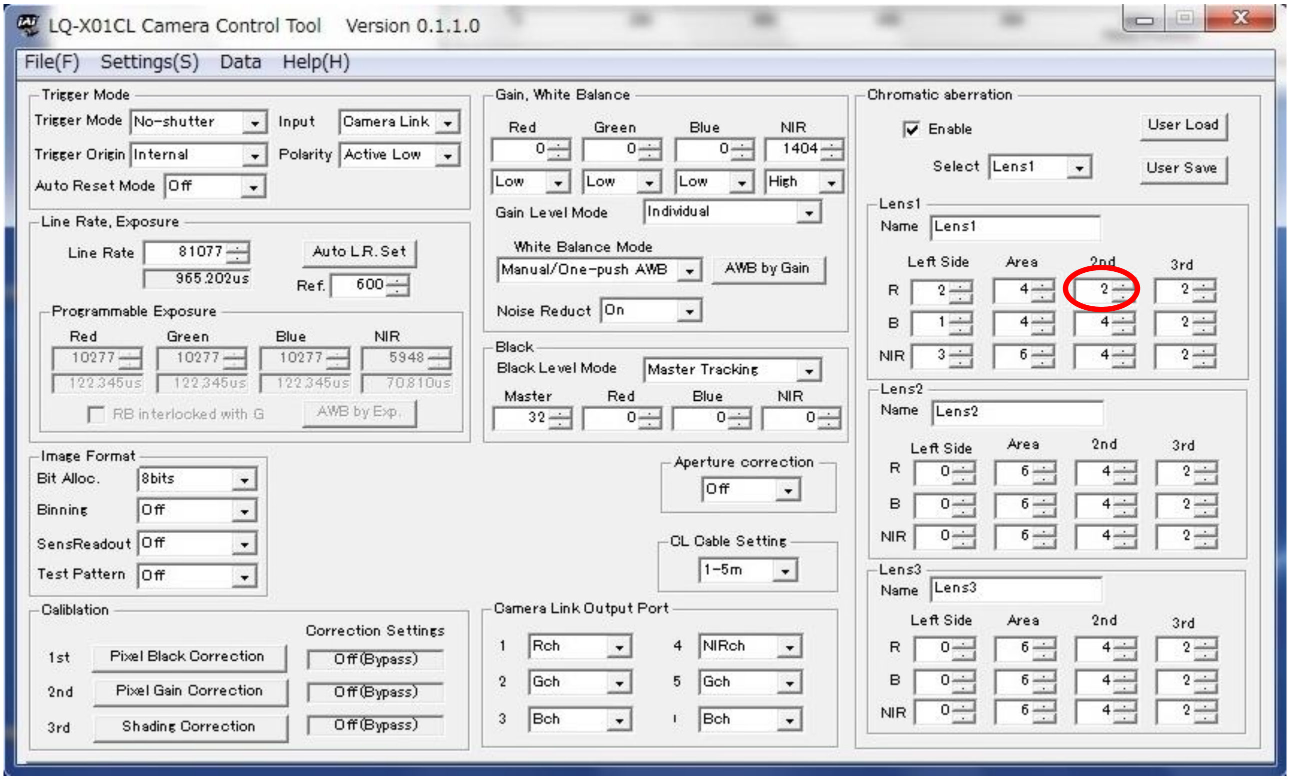


Figure 21 – Red channel transition settings

Since our Blue channel only requires one pixel of compensation at the Left Side, no further adjustments are needed on this channel. The compensation will shift one pixel to the right at the left edge of the sensor and will transition to no compensation as it moves from Area #4 to Area #5, approximately half way to the center of the imager.

We can quickly check several places on our line profile graphs to make sure that the compensation is having the desired effect. Figure 22 shows the boundary between Area #3 and Area #4. We can see that all channels are aligned properly. We can check a few other points and if the results are similar, then we can consider our analysis complete.

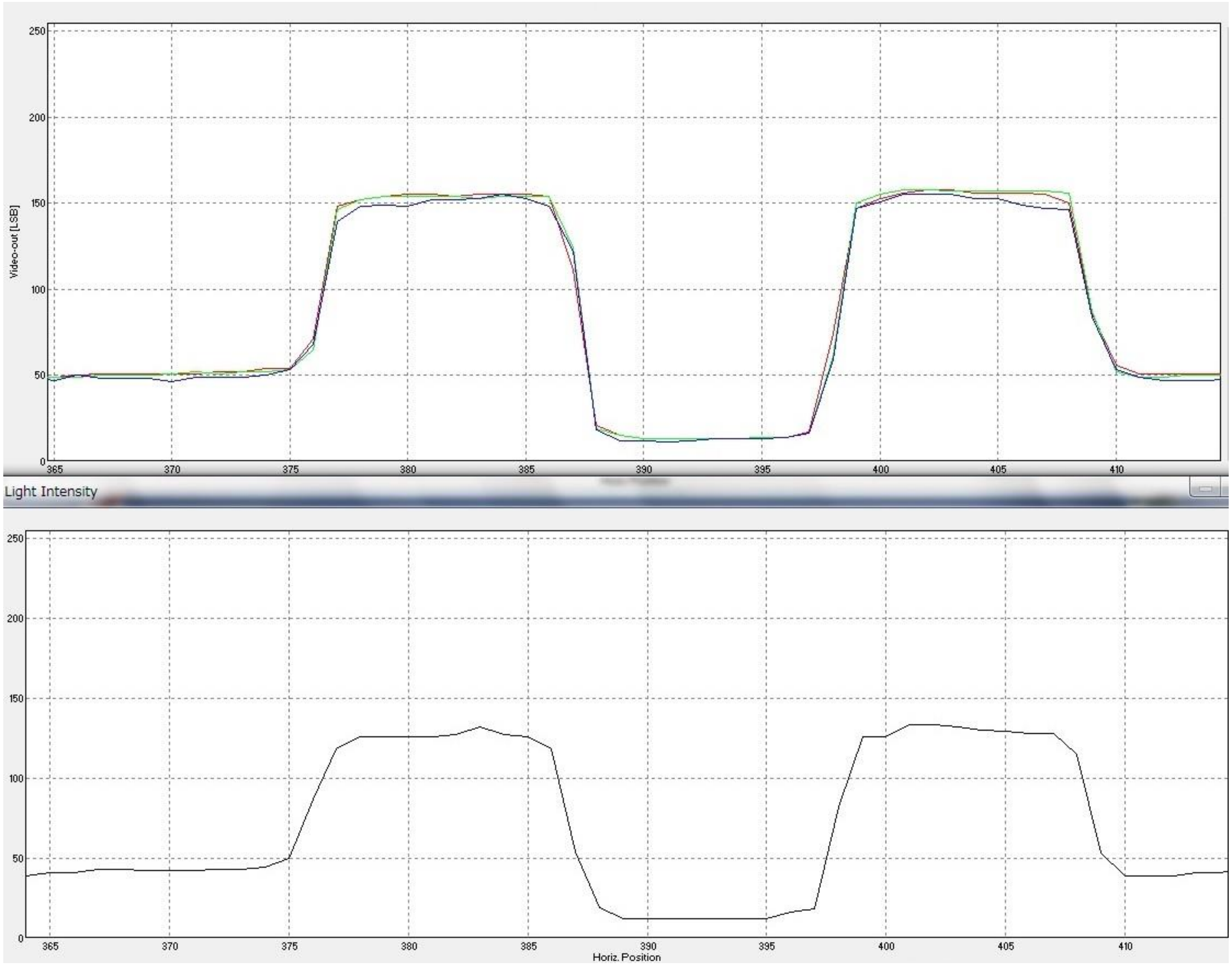


Figure 22 – Waveforms aligned from position 365 to 410

4.4 Last step – saving the compensation

Once we have made the proper adjustments, we should save our results.

Note: the "User Load" and "User Save" buttons are for saving a user-calculated set of compensation coefficients. They do NOT save the current settings in a User Data set. Refer to your camera's manual for instructions on saving a User Set. In most cameras, save options can be found under the "Settings" menu in the control tool or by using the ASCII command "SA".

In the Chromatic aberration form, we can leave the name field as "Lens1" or we can change the name to our specific lens model. This will be retained as part of our User Data set.

End.

Revision History

Revision	Date	Changes
1	2017/2/28	New release