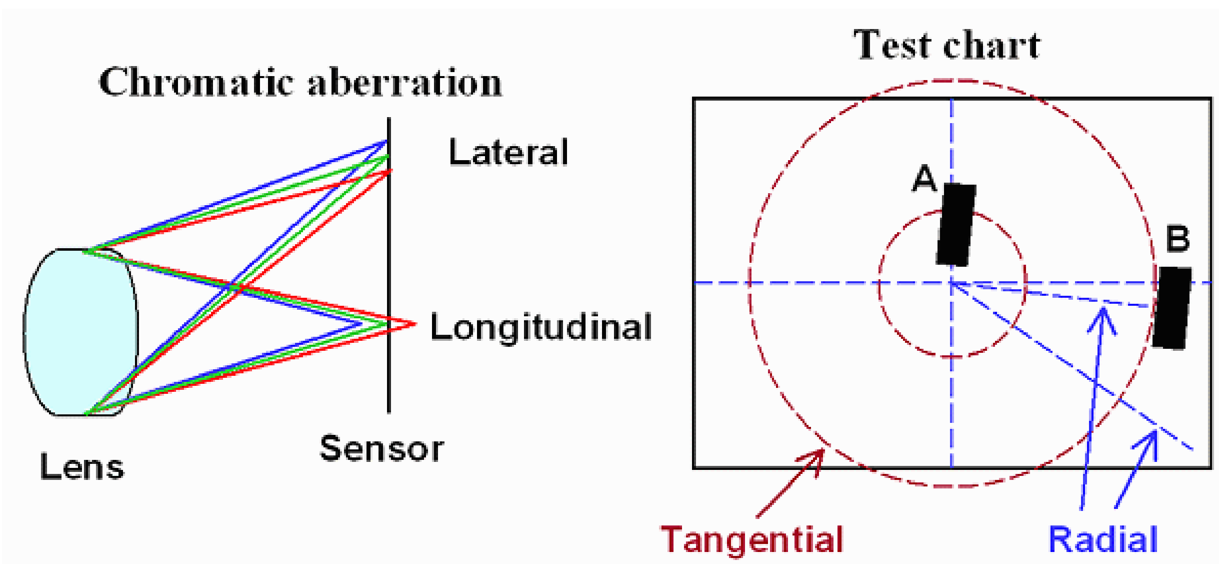
Chromatic Aberration AKA Color fringing

Introduction

Chromatic aberration (CA) is one of several aberrations that degrade lens performance. (Others include coma, astigmatism, and curvature of field.) It occurs because the index of refraction of glass varies with the wavelength of light, i.e., glass bends different colors by different amounts. This phenomenon is called ***dispersion***.

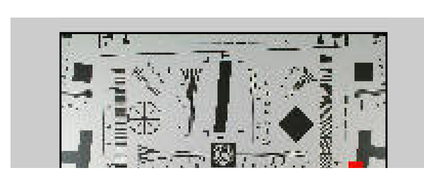
Minimizing chromatic aberration is one of the goals of lens design. It is accomplished by combining glass elements with different dispersion properties. But it remains a problem in several lens types, most notably ultrawide lenses, long telephoto lenses, and extreme zooms.



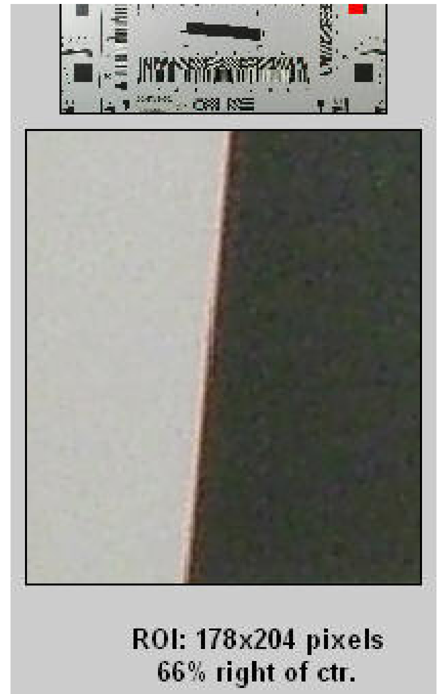
Lateral and Longitudinal CA; Tangential and radial lines

> ***Measurement tip*— Lateral chromatic aberration is best measured using a *tangential* edge near the side or corner of the image, for example, B on the left. It is not visible on radial edges such as A.**
>
> CA cannot be measured reliably if the center of the region of interest (ROI) is less than 30% of the distance from the center to the corners. In this case, the chart will be displayed in pale colors and CA in % will be omitted.

ROI for CA measurement



The two types of chromatic aberration are illustrated above.



Lateral chromatic aberration is best measured on a tangential edge near the sides or corners of an image. It's not visible on radial edges. Radial lines and tangential curves (which differ by 90 degrees) are shown in **burgundy** and **blue** on the right side of the above illustration. Because Imatest SFR requires edges to have an angle in the range of 3 to 7 degrees with respect to vertical and horizontal, only a limited number of locations in the ISO 12233 chart (on the right) are appropriate for measuring lateral CA. One is rectangle **B**,
above. SFR/SVG charts, which can be printed any size on high quality photographic inkjet printers, are much better for measuring CA.

The thumbnail on the right is from a 12 megapixel compact digital camera with fairly high chromatic aberration. The selected area is shown below. Red fringing, the result of lateral CA, is clearly visible. The black-to-white edge to the right side of this rectangle has equally vivid green fringing. Imatest analyzes the edge and produces a number that indicates the severity of the lateral chromatic aberration.

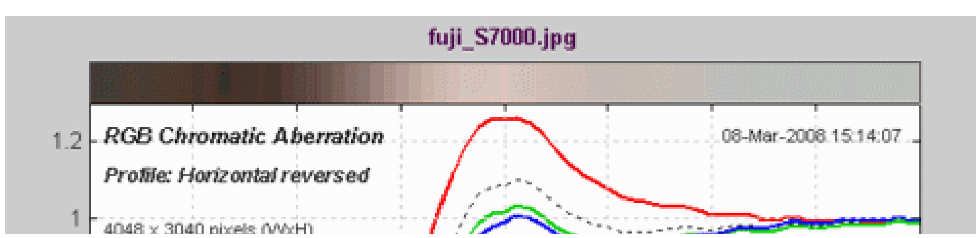
Imatest chromatic aberration measurement

The average transitions for the R, G, and B color channels, calculated by Imatest SFR for the above edge, are shown in the figure below. The edges have been normalized to have asymptotic limits of 0 and 1, i.e., they are dimensionless, approaching 0 and 1 at large distances from the transition center. Note that the three edges are not simply shifted, as you might expect if the focal lengths for the three colors were slightly different. They are distorted due to demosaicing (RAW conversion), as discussed below. When Bayer RAW images are analyzed, you do indeed see simple shifts.

The visibility of the chromatic aberration is proportional to the ***area*** between the edges with highes amplitude (in this case, **red**) and the lowest (in this case, **blue**). This area can be expressed by the following integral.

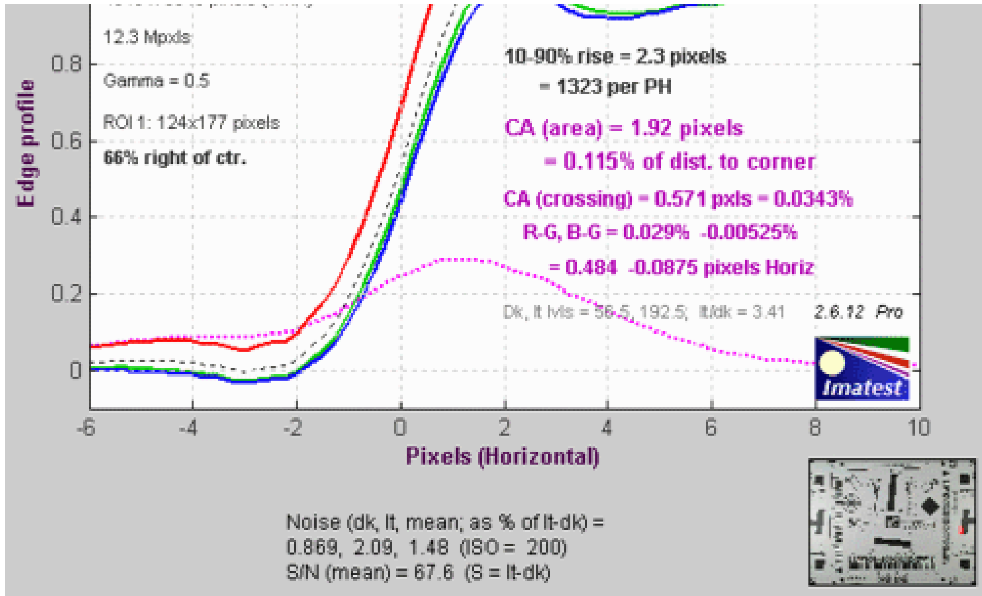
> $$CA\ (area) = \int [\ S_{max}(x) - S_{min}(x)\ ]\ dx$$

Chromatic Aberration figure (relatively high CA) (shown reversed: levels *always* increase from left to



right)

Since ***x*** has dimensions of distance in pixels and ***S*** is dimensionless, ***CA (area)*** has units of ***pixels*****—** units of distance even though it is an area. ***CA*** defined by this equation is called the area chromatic aberration. It is displayed in **magenta** in the figure on the right. **(CA (area) = 1.92 pixels**).



The distance between the crossings (the centers of the transitions) is also shown. It is less visually significant.

While area in pixels is a good measure of ***CA***, it has some shortcomings.

- It penalizes cameras with high pixel counts.
- The result depends on the measurement location. The chromatic aberration in most lenses is roughly proportional to the distance from the image center.

To deal with these issues Chromatic aberration is also measured in percentage of the distance from the image center to the corner (percentage of sensor diagonal/2) , corrected for the angle of the ROI with respect to the center. In the above example, CA (area) = 0.115% of the distance from the image center. The correction is described in the **green** box, below. This measurement gives the best overall results, since it's relatively independent of the measurement location and the number of pixels. A table below presents rough guidelines for the severity of CA. Measurements displayed on the right of the figure are summarized in the following table.

10-90% rise distance (original; uncorrected) in pixels and rises per picture height (PH).

CA (area): Chromatic aberration area in pixels. An indicator of the visibility of CA. The area between the channels with the highest and lowest levels. In units of pixels because the x-axis is in pixels and the y-axis is normalized to 1. Explained in the page on **Chromatic aberration**. Measured in along the axis indicated by ***Profile*** on the upper-left. **Meaning (now obsolete):** Under 0.5; insignificant. 0.5-1: minor; 1-1.5: moderate; 1.5 and over: serious.

CA (area) as a percentage of the distance to image center. A better indicator than pixels (above). Equal to 100 * (area between the channels with the highest and lowest levels) / (distance from center in pixels), corrected for the angle of the ROI. This number is relatively independent of the ROI because CA tends to be proportional to the distance from the image center. Explained in the page on **Chromatic aberration**. Measured along the radial line from the image center to the edge. **Meaning:** Under 0.04; insignificant. 0.04-0.08: minor; 0.08-0.15: moderate; over 0.15: serious.

CA (crossing). Chromatic aberration based on the most widely separated edge centers (positions where the edges cross 0.5). Tends to be less indicative of CA visibility than **CA (area)**. Measured two ways: (A) in pixels along the axis indicated by ***Profile*** in the upper left, and (B) in percentage of the distance from the image center to corner along the line from the image center.

R-G, B-G Red−Green and Blue −Green crossing shift expressed as percentage of the distance from the image center to corner, measured along the radial line from the image center. R-G is *r*(R)-*r*(G), where r is radius in percentage of difference to the corner..

R-G, B-G Red−Green and Blue −Green crossing shift expressed in pixels, measured along the axis indicated by ***Profile*** in the upper left. R-G is *x*(R)-*x*(G) for horizontal profiles or *y*(R)-*y*(G) for vertical profiles, where *x* and *y* are distances along the horizontal and vertical axes, respectively. **The sign may be different from the sign in the percentage measurement**, depending on the measurement quadrant.

Average pixel levels in the dark and light areas. Clipping can occur if they are too close to 0 or 255.

> ***Because Chromatic Aberration cannot be measured accurately near the image center, the chart is rendered in pale colors with the Region of Interest (ROI) is less than 30% of the distance from the center to the corner.***

Severity of chromatic aberration

Chromatic Aberration in percentage of distance from the image center	Severity

0-0.04	Insignificant
0.04-0.08	Low. Hard to see unless you look for it.
0.08-0.15	Moderate. Somewhat visible at high print magnifications.
over 0.15	Strong. Highly visible at high print magnifications.

Severity of chromatic aberration (old table)

Chromatic Aberration in pixels	**Severity**
0-0.5	Insignificant
0.5-1	Low. Not visible unless you look for it.
1-1.5	Moderate. Somewhat visible at high print magnifications.
over 1.5	Severe. Highly visible at high print magnifications.

Purple fringing
is ***not*** chromatic aberration, though it is often mistaken for it. It's a saturation phenomenon in the sensor, also known as "bloom," caused by the overflow of electrons from highly saturated pixel sites to nearby unsaturated sites. It tends to be worst in cameras with tiny pixels (e.g., 8+ megapixel compact digital cameras). It has everything to do with the sensor and nothing to do with the lens.

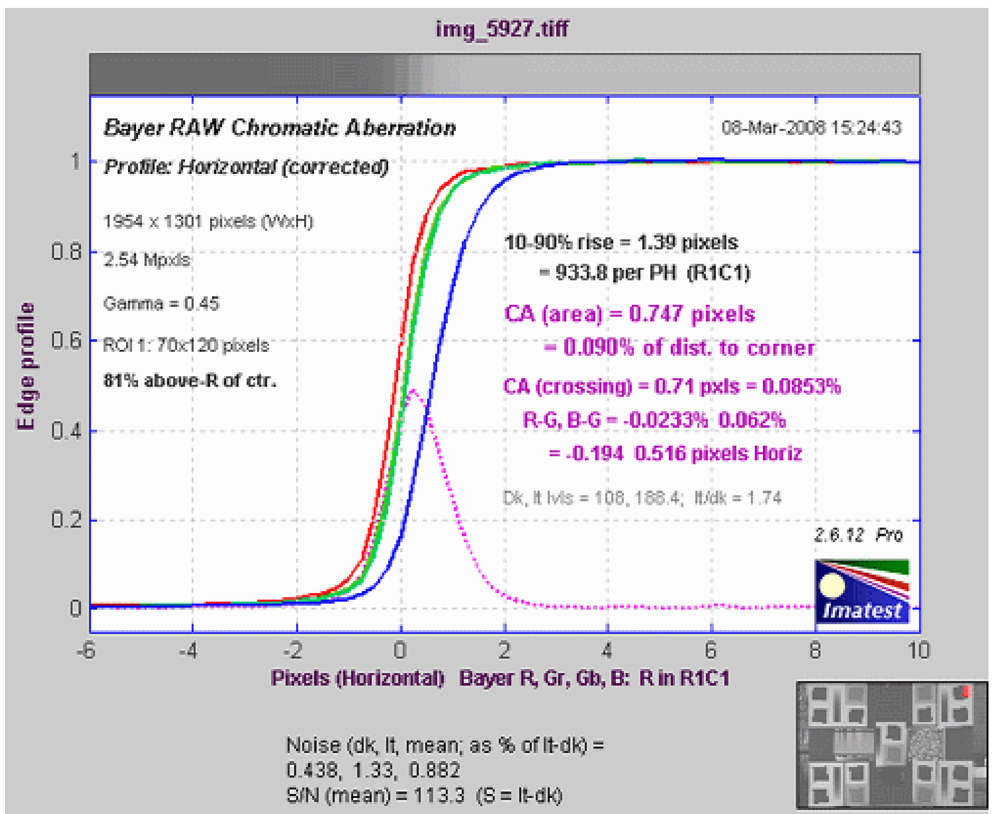
Demosaicing

Demosaicing is the process of converting Bayer RAW images, which have one color per pixel (RGRGRG…; GBGBGB…), to standard images, which have three colors per pixel. In the process of demosaicing, missing detail for each channel is inferred from detail in other channels. This is especially significant for **Red** and **Blue** pixels, which are half as common as **Green**. Demosaicing algorithms can be very mathematically sophisticated, but all of them can perform poorly in the presence of lateral CA, where detail is shifted from its expected location.

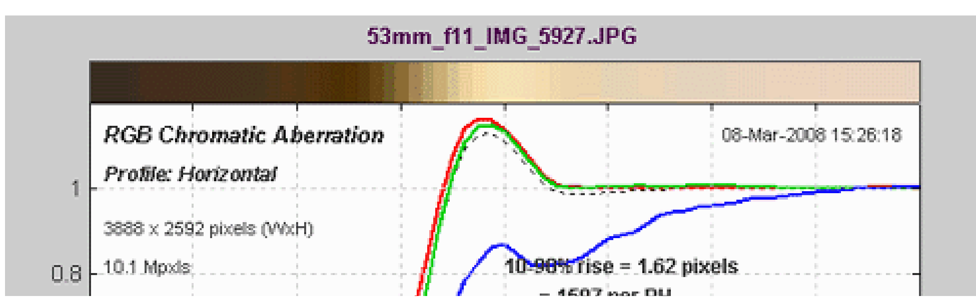
Demosaicing explains the shifted edges shown in the above example. Lateral CA cannot be reliably corrected after demosaicing, but it can be corrected to near-perfection prior to demosaicing. Correction coefficients can be calculated with Imatest Master, which can analyze Bayer RAW files created by converting manufacturer's Camera RAW files. Details are in the page on RAW files.

Here is an example illustrating the same region for a RAW and demosaiced file. Canon EOS-20D, 17-85mm IS lens, 53mm, f/11.

Chromatic aberration *before* demosaicing: easy to correct using a different magnification for each color ((1-0.00023)x for red; 1.000622x for blue; 1 for green).

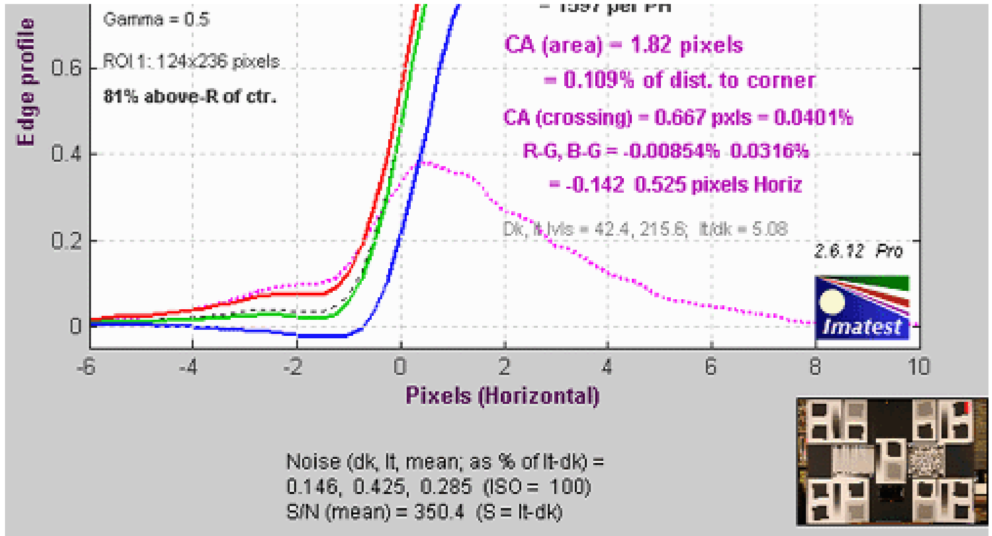


Chromatic aberration *after* demosaicing: difficult to correct.

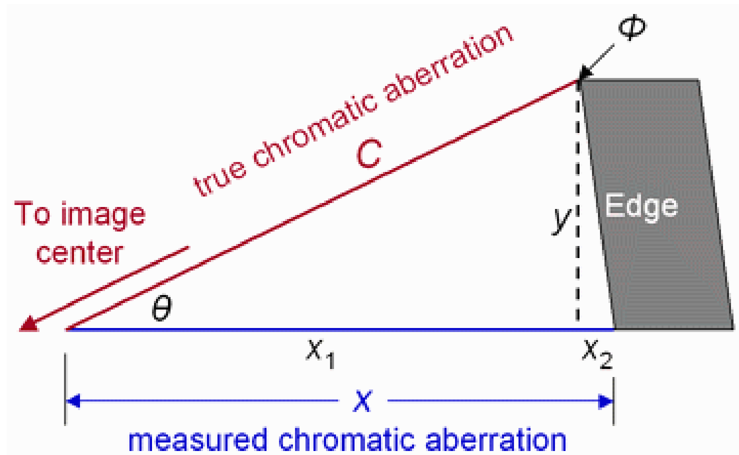


R-G and **B-G** are the CA correction coefficients. They are the spacing between the **Red** and **Green** and **Blue** and **Green** crossings, respectively, expressed as percentage of the center-to-corner distance. This mesurement is relatively independent of the location of the measurement.

Corrected chromatic aberration measurements



In *Imatest*, edge profiles are measured along horizontal or vertical lines. The blue line (x) on the right is an example. But chromatic aberration takes place along radial lines– lines from the center of the image to the region of measurement (shown in red on the right). Unless this line is vertical or horizontal, there will be a measurement error that must be corrected. The correction is illustrated on the right for a near-vertical edge, where the profile, and hence CA, is measured horizontally. In this illustration,



- $x = x_1 + x_2$ is the measured chromatic aberration, along a horizontal row of pixels.
- C = the true chromatic aberration, along the radial line (angle = Θ).
- Φ is the angle of the edge relative to vertical.

$x_1 = C \cos \Theta$; $y = C \sin \Theta$;

$x_2 = y \tan \Phi$ (x_2 may be negative if Φ is negative.)

$x = x_1 + x_2 = C \cos \Theta + y \tan \Phi = C (\cos \Theta + \sin \Theta \tan \Phi)$

$C = x / (\cos \Theta + \sin \Theta \tan \Phi)$