How to select the Right Lens

High image quality is synonymous with low aberrations. As a result, designers often utilize two or more lens elements in order to obtain higher image quality compared to a single lens solution. Many factors contribute to selecting the right lens for an application: type of source, space constraints, cost, etc.

Figures 6a - 6e compare a variety of lens systems for a relay lens, or 1:1 imaging, application. In this specific example, outlined in the following series of comparisons, it is easy to see how image quality is affected by the inherent geometry and optical properties of the lenses chosen.

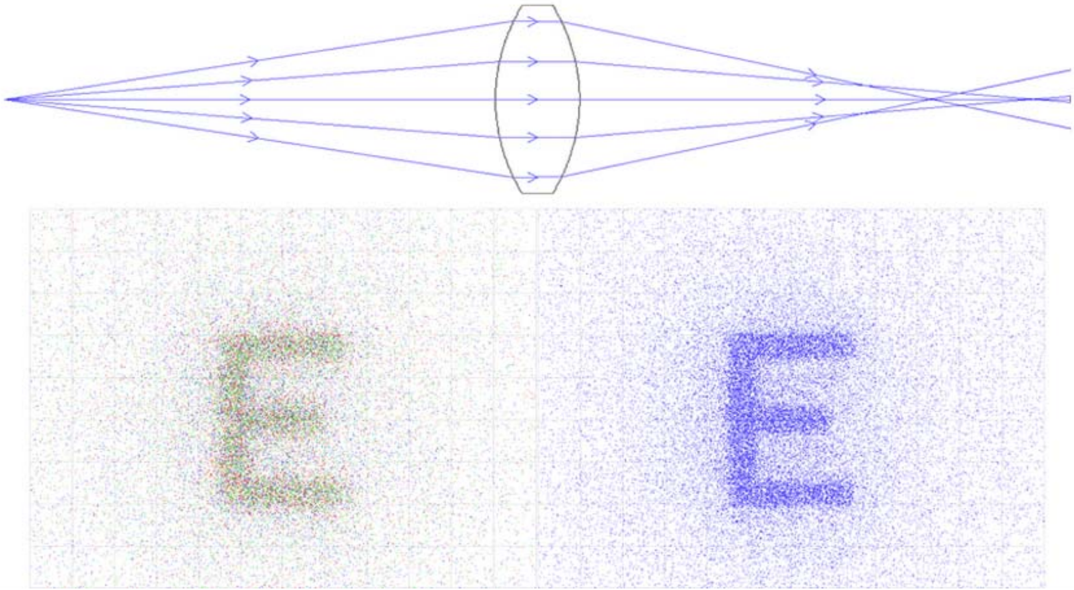

Figure 1a: DCX Lens Relay System: 25mm EFL x 20mm Entrance Pupil Diameter (Left is Color and Right is Monochromatic)

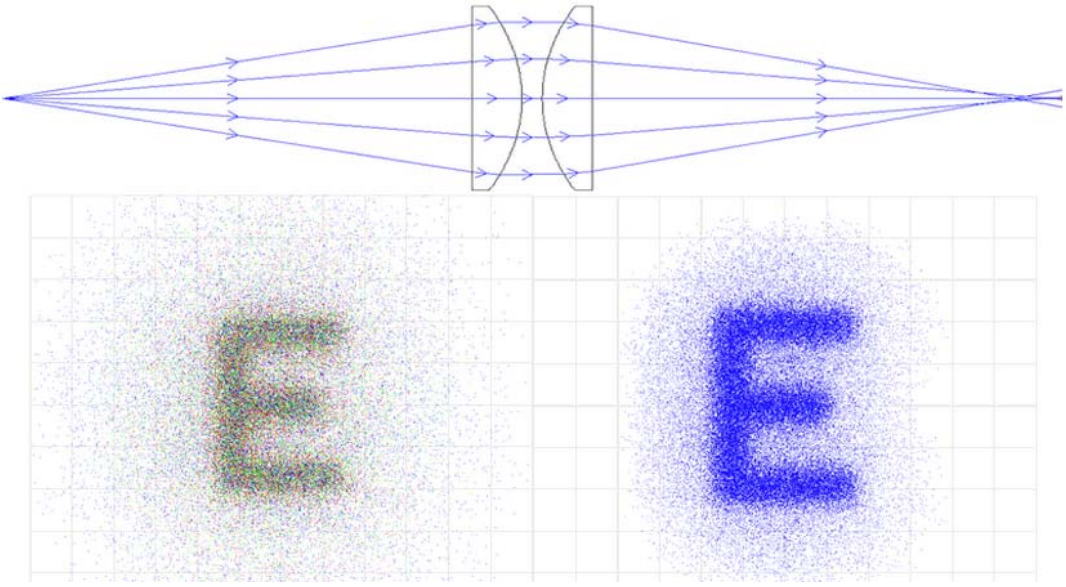

Figure 1b: PCX Lens Relay System: 50mm EFL x 20mm Entrance Pupil Diameter (Left is Color and Right is Monochromatic)

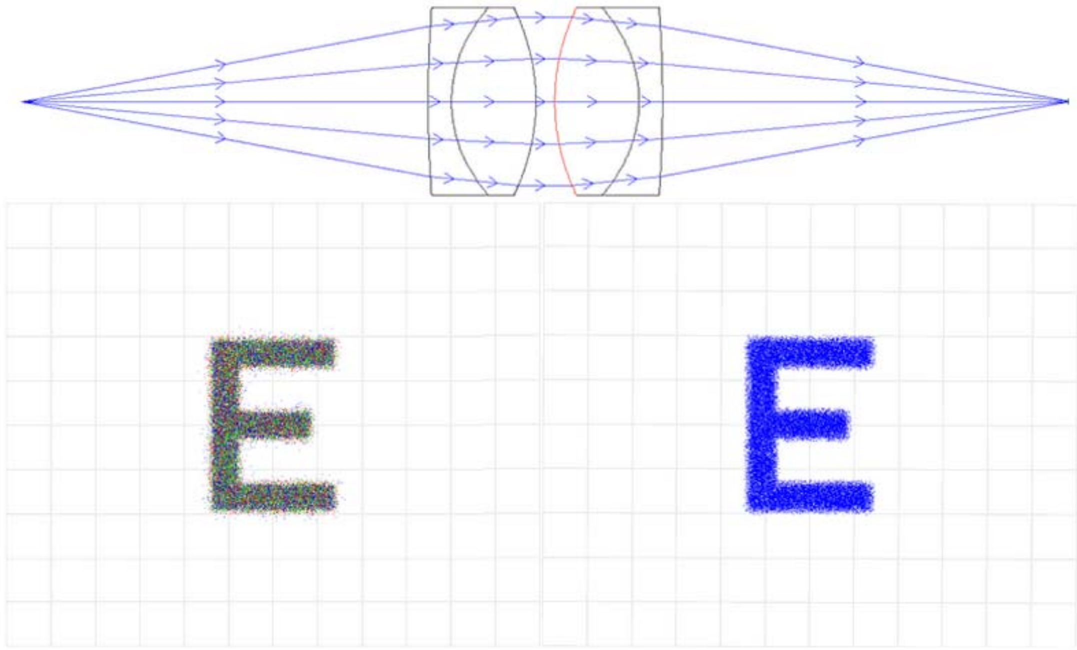

Figure 1c: Achromatic Lens Relay System: 50mm EFL x 20mm Entrance Pupil Diameter (Left is Color and Right is Monochromatic)

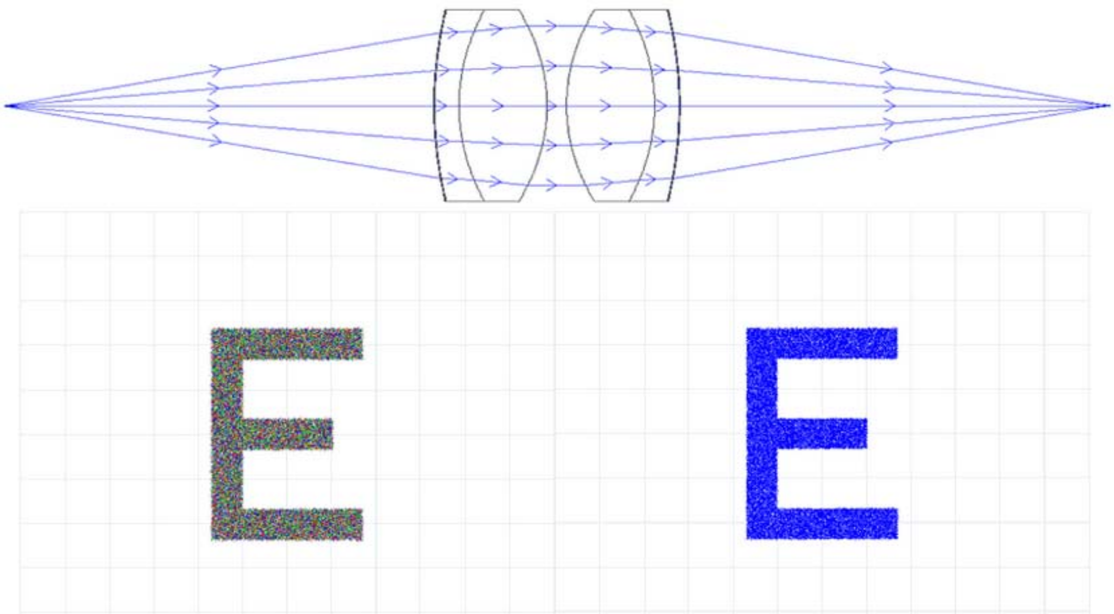

Figure 1d: Aspherized Achromatic Lens Relay System: 50mm EFL x 50mm Entrance Pupil Diameter (Left is Color and Right is Monochromatic)

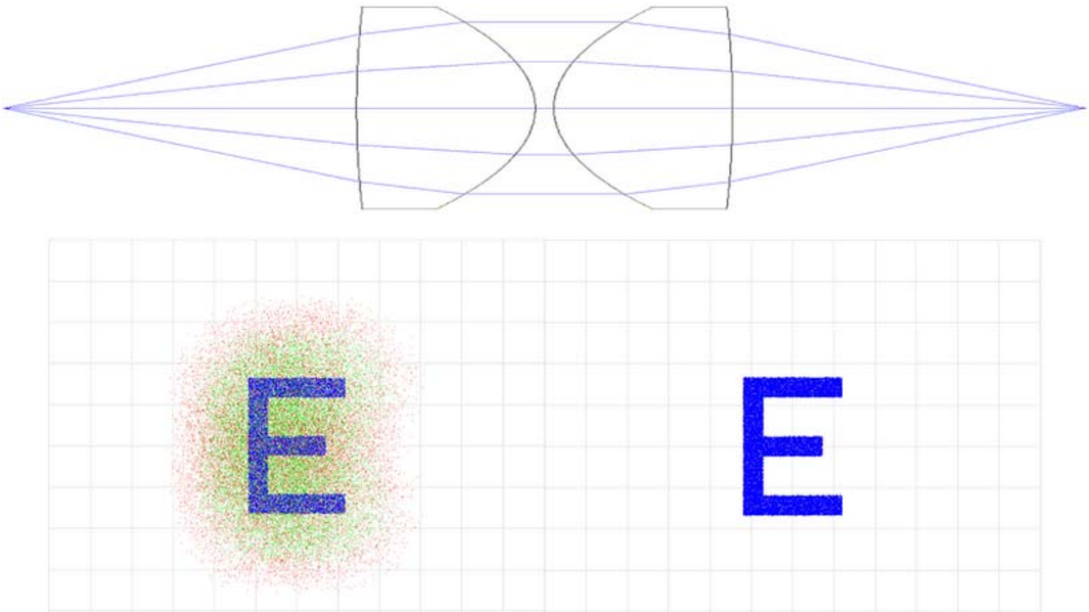

Figure 1e: Aspheric Lens Relay System: 50mm EFL x 40mm Entrance Pupil Diameter (Left is Color and Right is Monochromatic)

Application Example: Single Element Lens System

A double-convex (DCX) lens is regarded as the best single element for 1:1 imaging because of its symmetrical shape, as both sides of the lens have equal power, instead of one side bending rays more than the other, such as a plano-convex (PCX) lens. Since the lens system is made of just one lens, the aperture stop is essentially the lens, which allows for the reduction of many aberrations. For these reasons, a DCX lens is preferable to a single PCX lens for 1:1 imaging. However, it is important to keep in mind that at a low f/#, there is still significant spherical aberration and coma. These aberrations are caused by the Shape Factor (S) of the single lens:

$$S = \frac{R_2 + R_1}{R_2 - R_1} \quad (2.1)$$

where R_1 and $_2$ are the radii of each surface of the lens.

For applications that only need one lens, with the object or source at infinity, a better shape factor can be found, to reduce whichever aberration is most detrimental to the system. For example, to reduce spherical aberration, the ideal shape factor can be calculated by:

$$S = -\frac{2(n^2-1)}{n+2}p \quad (2.2)$$

$$S = \frac{R_1+R_2}{R_2-R_1} \quad (2.3)$$

$$p = \frac{z'+z}{z'-z} \quad (2.4)$$

Where n is the Index of Refraction of the Glass Substrate, p is the Position Factor, z is Object Distance (measured to be a negative value), and z' is Image Distance (measured to be a positive value).

To reduce coma for an object at infinity, the Shape Factor can be calculated by:

$$S = -\frac{(2n^2-n-1)}{n+1}p \quad (2.5)$$

For glass that has an index of 1.5 (N-BK7 is 1.517), with an object at infinity, a Shape Factor of about 0.8 will balance the corrections of both coma and spherical aberrations.

Application Example: Double Element Lens System

In order to improve the system, a single DCX lens could be replaced with two equal PCX lenses each with a focal length twice that of the DCX, with an aperture stop in the center. Doing so splits the power of each surface of the lenses, as the focal length is inversely proportional to power. Since each lens has less power, there is less spherical aberration created in the system. By using two lenses, the powers of each surface add, which allows for the same overall focal length, but less spherical aberration. Since the diameter also has remained the same, the f/# did not change between using a single DCX or two PCX lenses, but the spherical aberration is decreased, even if the f/# is large.

The convex surfaces are nearly in contact, with the aperture stop located between them. Better image quality is achieved by orienting the convex surfaces towards the longest conjugate distance.

Application Example: Achromatic Lens System

Another option is to use two achromatic lenses, or achromats. An achromatic lens consists of two optical components cemented together, usually a positive low-index (crown) element and a negative high-index (flint) element. Using achromats improves polychromatic (white light, multiple wavelength) imaging as well as reduces spherical aberration and coma. If both lenses are achromats with convex surfaces facing each other, a far superior imaging system is obtained, as many aberrations are significantly reduced compared to the same

system with single lenses (either DCX or two PCXs). While spherical aberration is negligible at large apertures or high f/#s, chromatic aberration is greatly reduced with the use of achromats. Many relay lens systems on the market utilize this type of four element configuration.

Unlike PCX, DCX and achromatic lenses, which are made from portions of a sphere, an aspheric lens is one that has a curvature other than that of a sphere or cylinder, usually made from portions of a hyperbola or parabola. The key concept of aspheric lenses, or aspheres, is that the radius of curvature varies radially from the optical axis of the lens. As a result, aspheric lenses easily correct spherical aberration, and are great for correcting off-axis aberrations.

Aspheric lenses are used in many systems, as one aspheric lens can replace two or more spherical lenses, thereby reducing space and costs within a system.

Type of Lens System	**Spherical Aberration**	**Chromatic Aberration**
DCX Singlet	High	High
2 PCX	Medium	High
2 Achromats	Low	Negligible
2 Aspherized Achromats	Negligible	Negligible