# What is Telecentricity?

**By Jim Michalski**

Telecentricity is a special property of certain multi-element lens designs in which the chief rays for all points across the object or image are collimated. For example, telecentricity occurs when the chief rays are parallel to the optical axis, in object and/or image space. Another way of describing telecentricity is to state that the entrance pupil and/or exit pupil of the system is located at infinity (see Figures A and B).

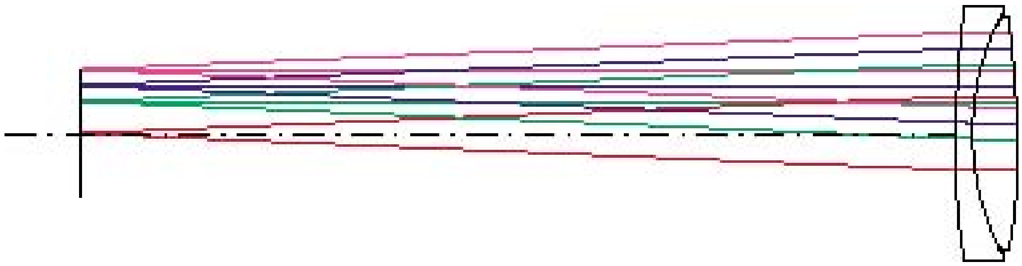


Figure A

*Telecentric lens drawing showing discrete object points being imaged.*

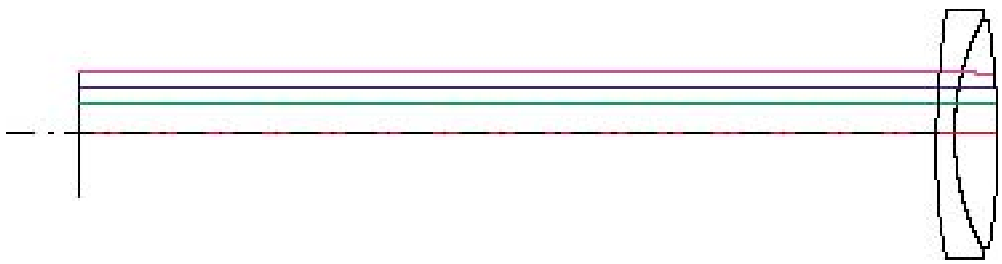
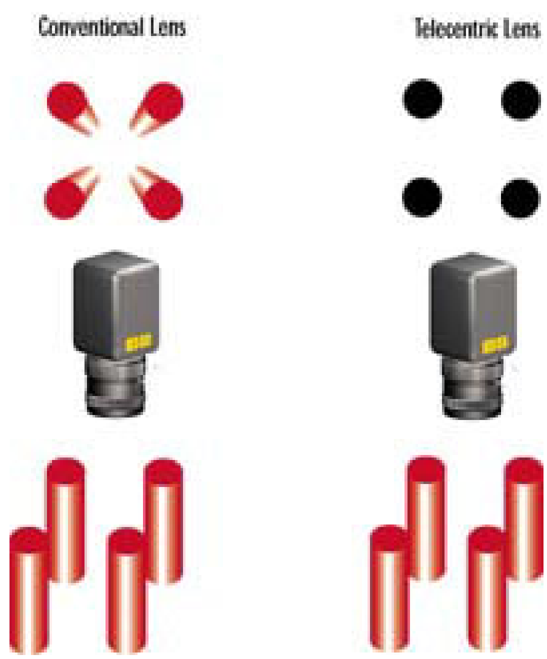


Figure B

*Telecentric lens drawing showing chief rays for each object point. Note that the chief rays are parallel to the optical axis.*

**ADVANTAGES**




This definition of telecentricity leads to a number of questions. Why is telecentricity desirable? What are its advantages, disadvantages, and limitations? For many applications, telecentricity is desirable because it provides nearly constant magnification over a range of working distances, virtually eliminating perspective angle error. This means that object movement does not affect image magnification.

In a system with **object**

**space telecentricity**, movement of the object toward or away from the lens will not result in the image getting bigger or smaller, and an object which has depth or extent along the optical axis will not appear as if it is tilted. For example, a cylindrical object whose cylindrical axis is parallel to the optical axis will appear to be circular in the image plane of a telecentric lens. In a non-telecentric lens this same object will look like the Leaning Tower of Pisa; the top of the object will appear to be elliptical, not circular, and the side walls will be visible (see Figure C).

Figure C:
*Non-telecentric, Telecentric*
*Imaging results at the image plane of a telecentric and non-telecentric lens system. Notice the telecentric system eliminates perspective distortion.*

In systems with **image space telecentricity**, image plane movements to focus or intentionally defocus the system will not change the image size. This property is fundamental to today's microlithography industry where tolerances on feature size are routinely below a tenth of a micron. An additional advantage of image space telecentricity is that it can lead to extremely uniform image plane illumination. The normal **cos$^4$q falloff** in image plane illumination from the optical axis to the edge of the field is removed, since all chief rays have an angle of θ ° with respect to the image plane.

**DISADVANTAGES**
There are a number of qualities inherent in telecentric lenses which may be considered disadvantages. First, the optical elements in the region of telecentricity (image side or object side) tend to grow in size. In the case of a doubly telecentric design (telecentric in

both object and image space), both the front and rearmost lens groups need to be bigger than the object and image respectively. Thus, a one hundred millimeter object or image height will require a lens of significantly larger aperture diameter to provide an unvignetted field of view along with mechanical mounting and retention features. This is illustrated in Diagram 1 and 3 (see below).

The graphics below (Figures 1-3) depict examples of both telecentric and non-telecentric lenses designed by Edmund Optics. These examples include 0.5X relay lenses (both telecentric and non-telecentric) along with a doubly telecentric 0.25X reduction camera lens for microlithographic use operating at the ArF laser line (0.193 microns).

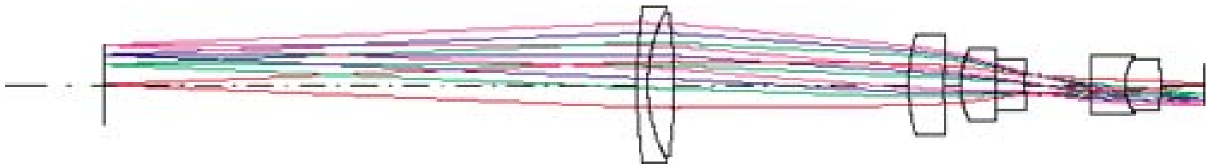


Diagram 1

*Y-Z profile drawing of a 0.5X telecentric lens (telecentric on object side)*

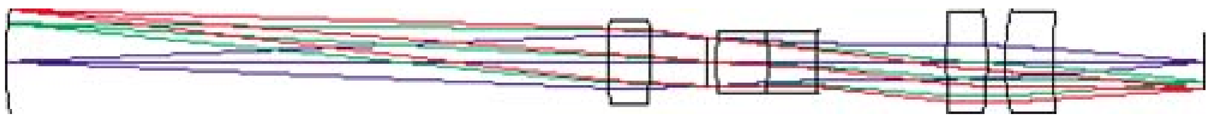


Diagram 2

*Y-Z profile drawing of a 0.5X non-telecentric lens*

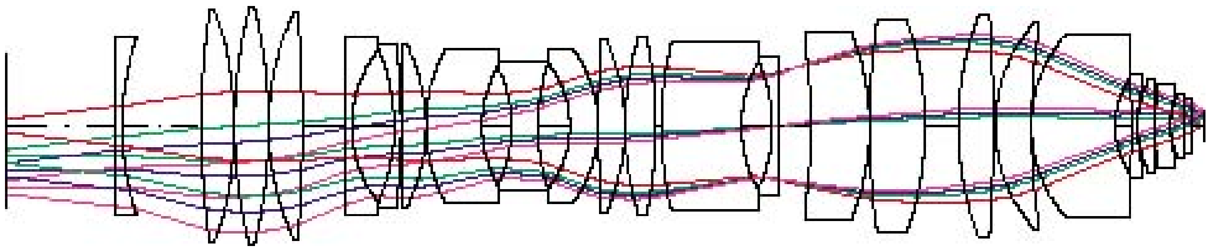


Diagram 3

*Doubly telecentric 0.25X reduction camera lens for microlithographic use operating at the ArF laser line (0.193 microns)*

Diagram 1 is a Y-Z profile drawing of a 0.5X telecentric lens and Diagram 2 is a Y-Z profile drawing of a 0.5X non-telecentric lens. It is important to note that both lenses have the same lateral magnification (0.5X), object working distance (125mm), object height (semi-diameter = 11.0mm), and the same working F/# (F/6). The front lens group of the telecentric lens has a diameter of approximately 40mm while that of the non-telecentric lens has a diameter of less than 20mm - a factor of more than two times smaller.

A second disadvantage of telecentric designs is that they tend to be more complex than non-telecentric designs. This is illustrated by the difference in element count within the two designs shown in Diagram 1 and 2. The telecentric design has seven elements while the non-telecentric design is comprised of only five. It should be pointed out that the non-telecentric lens in Diagram 2 can easily be made to perform at F/6 (it was originally designed to work at F/2) with only four elements, three less than the telecentric lens.

As with many other subjects, there is a common misconception concerning depth of field and telecentricity. The misconception about telecentric lenses is that they have a larger depth of field than ordinary lenses.

Realistically, telecentricity does not imply large depth of field, which is only dependent on F-number and resolution. With telecentric lenses, objects still blur farther away from best focus, but they blur symmetrically, which can be used to one's advantage. As long as the object's features are within the telecentric working distance, the magnification will not change. In other words, features closer to the lens do not appear larger than those furthest away.

**APPLICATION USES**

There are a variety of applications that depend upon, or can benefit from, the use of telecentric optics. These applications include CCD based measurement systems, metrology equipment, and microlithographic camera systems.

CCD based measurement systems can be used to measure the spacing and/or size of a number of objects on an electrical or mechanical component. The precise measurements of objects or features, or their separations, is accomplished through the use of measurement software. This type of software uses centroiding algorithms in the calculations of object separation and size. A telecentric lens is ideal for this application because extended objects will appear symmetrical, whereas the image from a non-telecentric optic will be elliptical (see Figure D). The improvement in measurement accuracy resulting from the use of a telecentric lens can often mean the difference between success or failure.

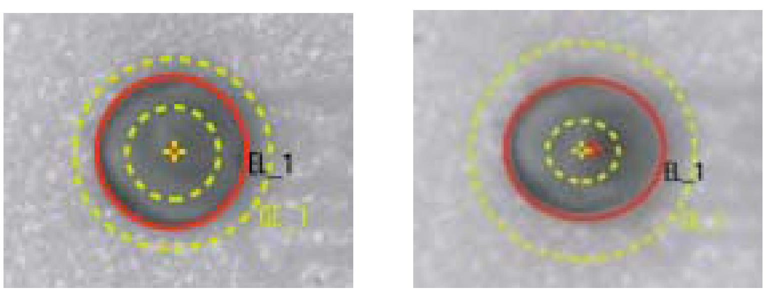



Figure D

Telecentric, Non-telecentric

*Extended objects will appear symmetrical in a telecentric optic, whereas the image from a non-telecentric optic will be elliptical.*

Many metrology systems also depend upon telecentric optics. A profile projector is one example of such a system. The profile projector is used to measure an object, or a feature within an object by projecting an image of the area under test onto a screen. This projected image is then either compared to a "gold standard" reference at the proper magnification, or it is measured directly and its dimensions compared to the nominal designed part. This type of measurement absolutely requires that magnification does not change with object position. If not telecentric, this type of instrument would give a different measurement result each time the working distance to the object was changed. This is obviously not desirable in an instrument designed to provide absolute measurements.

Microlithographic camera systems also depend upon the property of telecentricity in their application. These lens systems are often doubly telecentric-telecentric in both image and object space. These lens systems, which can cost in excess of hundreds of thousands of dollars, are used in the manufacture of integrated circuits (IC's). The wafers or chips upon which the IC's are fabricated go through many imaging operations, which create the surface features on the wafer. These features are routinely sub-micron in size and getting smaller with every new generation of microlithographic equipment. The size of these features, along with their absolute locations, must be controlled to small fractions of a micron. This problem is exacerbated by the overlay necessary when numerous resist exposures and etches are required in the IC production process. Maintaining a constant magnification through the use of telecentric optics is crucial in this whole process.

**SUMMARY**

In summary, this article has defined the difference between telecentric and non-telecentric optics. It has also presented some of the benefits, liabilities and limitations of telecentric optical systems. In addition, a number of applications and sample designs have been presented. If you have any questions or a need for further discussion, please feel free to contact our Applications Engineering department at (800) 363-1992 or techsup@edmundoptics.com.

***Jim Michalski*** *joined Edmund Optics in May 1999 as our Chief Scientist after working in the defense industry for 13 years. He has a BS in Optical Engineering from the University of Rochester and is working on his MS in Optical Engineering from the University of Arizona. Jim has 20 years of lens design experience working in the UV, visible, NIR, 3-5 micron and 7-12 micron spectral ranges.*