College of Optical Sciences
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Section 15

Telecentric Systems

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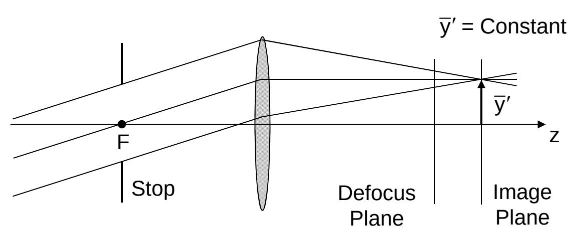
Image Space Telecentric

In a telecentric system, the EP and/or the XP are located at infinity. Telecentricity in object or image space requires that the chief ray be parallel to the axis in that space. As a consequence, the apparent system magnification is constant even if the object or image plane is displaced from its nominal position. The image will be blurred, but will have the correct size or magnification.

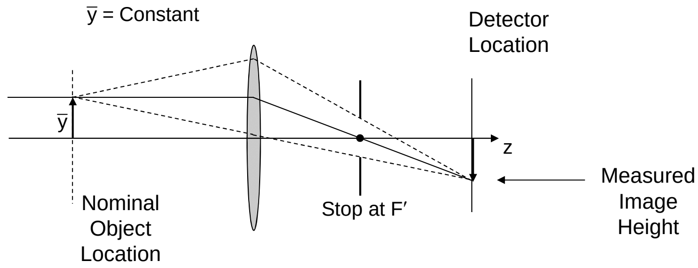
When the stop is located at the front focal plane of a focal system, the XP is at infinity, and the system is image-space telecentric. Defocus of the image plane or detector will not change the image height or magnification.



Object-Space Telecentric

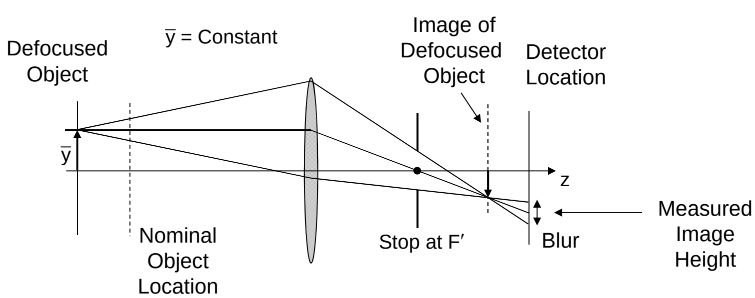
Placing the stop at the rear focal plane puts the EP at infinity and forms an object-space telecentric system. The system chief ray is parallel to the axis in object space.

The image plane or detector is located so that the nominal object position is in focus:



Object-Space Telecentric

When the object is displaced from the nominal object position, the location and size of the resulting image changes. The chief ray does not change, and the ray bundle remains centered on the chief ray. On the detector, a blur will be recorded, but the height of the centroid of this blur does not change from the original image height.



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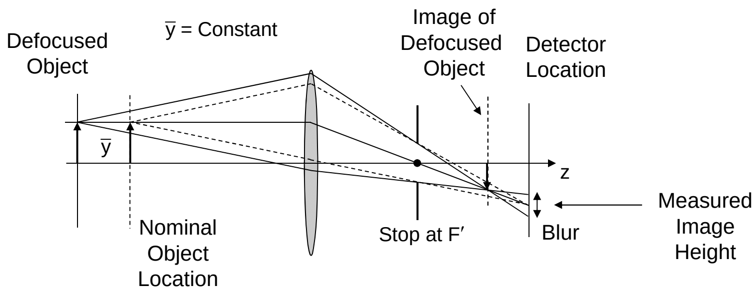
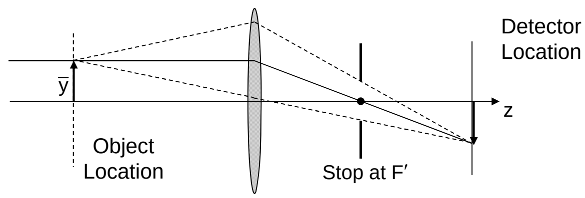
Object-Space Telecentric

In an object-space telecentric system, the measured image size is independent of the object location. The measured image will be blurred, but the centroid height of this blur does not change. The magnification of the recorded image of the object is fixed, and the correct object size can be determined.

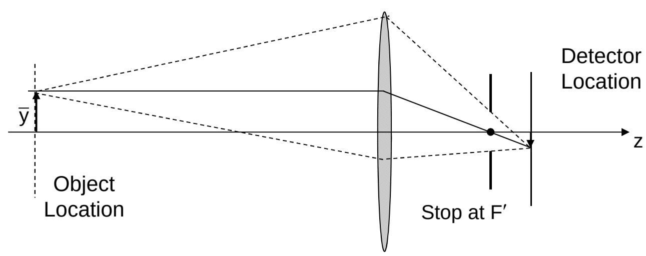


Object-Space Telecentric

Object-space telecentric systems are almost always used at close finite conjugates. The maximum object size is limited to approximately the radius of the objective lens due to vignetting considerations.

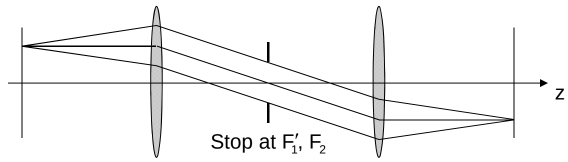


As the nominal object distance increases, the image and the detector move closer to the stop position. The required lens diameter increases.



Double Telecentric

An afocal system is made double telecentric by placing the system stop at the common focal point. The chief ray is parallel to the axis in object space and image space, and both the EP and the XP are located at infinity. All double telecentric systems must be afocal.



Since the ray bundle is centered on the chief ray, this condition guarantees that height of the blur forming the image is independent of axial object shifts or image plane shifts.

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Telecentric Systems

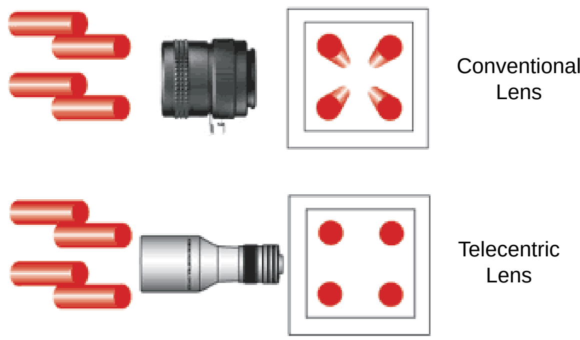
Telecentricity is an important feature of many optical metrology systems as the apparent size of an inspected object does not change with focus, object position, or object thickness. An example is the optical or projection comparator.

Microscope objectives are often designed to be telecentric in object space. The image size does not change with focus position. This prevents "zooming" of out-of-focus planes when focusing through a thick, transparent specimen, and different planes in the object are imaged at the same magnification.

Object-Space Telecentric
Schneider Optics

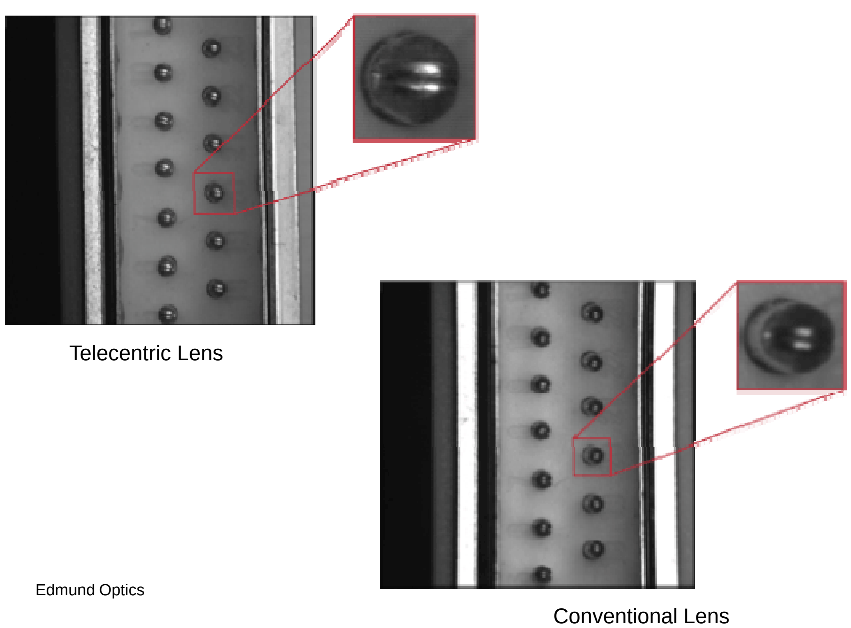
Double Telecentric
Navitar

<u>Telecentric Imaging</u>



sensorsmag.com

<u>Imaging Electronic Jumper Pins</u>



Edmund Optics

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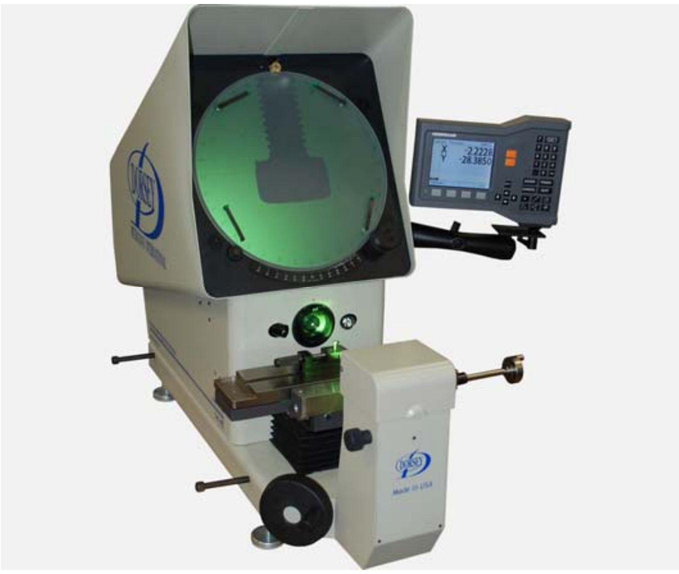
Projection or Optical Comparator



Dorsey Metrology

FOV and Telecentric Systems

Defining the angular FOV relative to the EP or the XP is impossible if the system is telecentric in that particular optical space because the respective pupil is at infinity. The object height or image height can, however, be used.

A second method for defining angular FOV is to measure the angular size of the object relative to the front nodal point *N*. This is useful because the angular sizes of the object and the image are equal when viewed from the respective nodal points. This definition of angular FOV fails for afocal systems which do not have nodal points. Double telecentric systems, being afocal, generally use the object height or the image height to define FOV.

The choice of using the EP or nodal point for angular FOV is of little consequence when the object is distant.

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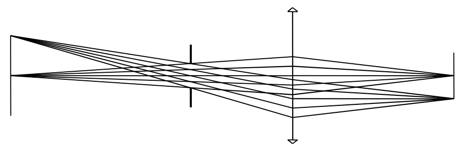
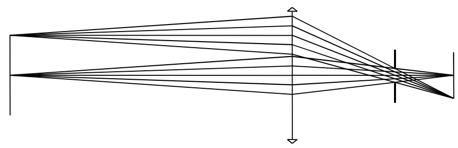
Telecentric Systems – Examples

Image Space Telecentric:



Object Space Telecentric:



Same f/$\#_W$

Defocused Object:

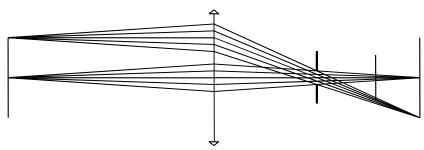
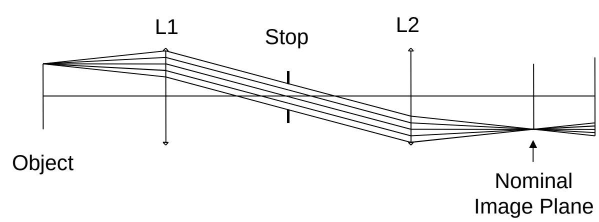


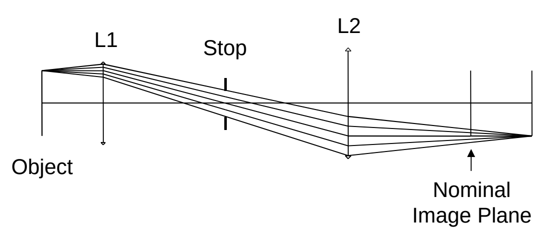
Image height at the nominal image plane is unchanged.

Double Telecentric Systems – Examples

Object in the front focal plane of L1:



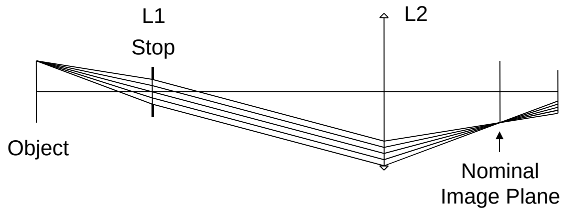
The object is shifted towards L1. The image at the nominal image plane is out of focus:



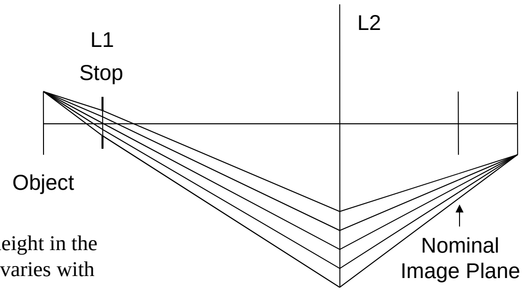
The apparent image height (although blurred) has remained constant.

Afocal System – Not Telecentric – Examples

Object in the front focal plane of L1:



The object is shifted towards L1. The image at the nominal image plane is out of focus:



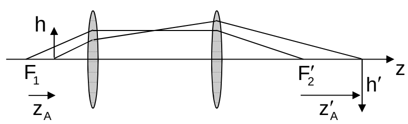
The apparent image height in the nominal image plane varies with object position.

Imaging With Afocal Systems

An afocal system consists of two focal systems sharing a common focal point. If the stop is located at this common focal point, the system is telecentric.

Because the magnification is constant, the cardinal points are not defined for an afocal system, and the Gaussian and Newtonian equations cannot be used to determine conjugate planes. However, any pair of conjugate planes coupled with the longitudinal magnification can be used. A convenient conjugate pair is the front focal point of the first system with the rear focal point of the second system.

Once a pair of conjugate planes is located, other pairs can be found using the longitudinal magnification. An axial shift in object space results in an image plane shift given by the longitudinal magnification times the object shift.



$$m = \frac{h'}{h} = -\frac{f_2}{f_1}$$

$$\bar{m} = m^2$$

$$z_A' = \bar{m} z_A$$

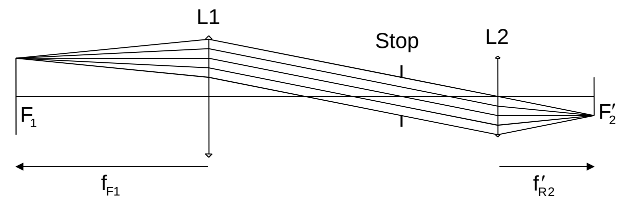
(in air)

Imaging With Afocal Systems – Examples

The following double telecentric system will be used for an example:

$m = -1/2$ $\quad f_1 = 100$ $\quad t = 150$

$\overline{m} = 1/4$ $\quad f_2 = 50$

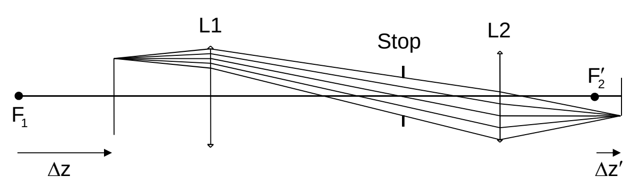


The front focal plane of the first element and the rear focal point of the second element will be used as the reference object and image positions. Object and image shifts will be measured relative to these initial conjugate locations.

Imaging With Afocal Systems – Examples

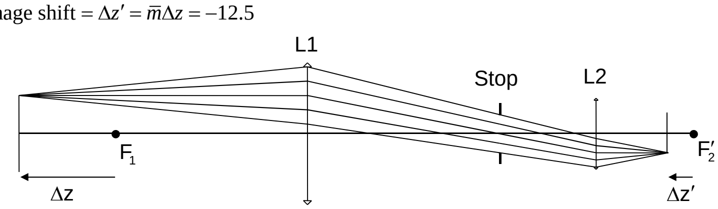
Object shift $= \Delta z = 50$

Image shift $= \Delta z' = \overline{m}\Delta z = 12.5$



Object shift $= \Delta z = -50$

Image shift $= \Delta z' = \overline{m}\Delta z = -12.5$



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Imaging With Afocal Systems – Examples

There are two other conjugate pairs that are easy to determine: either the object is located at the first lens, or the image is at the second lens.

Object shift $= \Delta z = 100$

Image shift $= \Delta z' = \bar{m}\Delta z = 25$

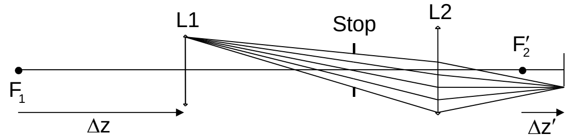
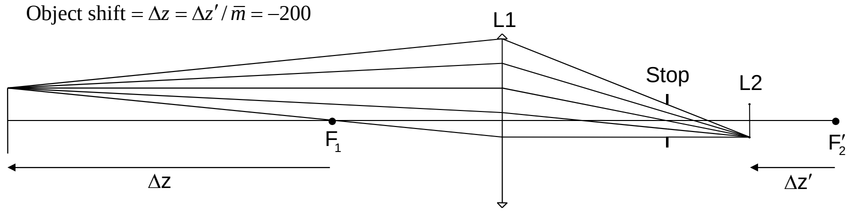


Image shift $= \Delta z' = -50$

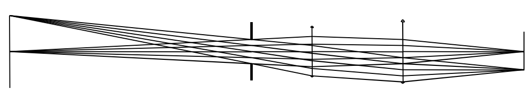
Object shift $= \Delta z = \Delta z' / \bar{m} = -200$



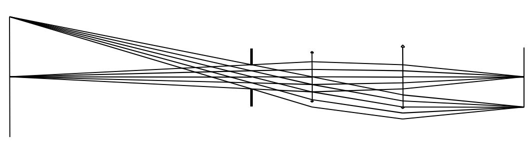
These two situations image as if the other lens was not present.

Vignetting Example – Object-Spave Telecentric Petzval Objective

Unvignetted:



Half Vignetted:



Fully Vignetted: