CASCADE LASER CORPORATION

Scanning Lenses (F-theta)
Product Information

Figure 1: *Scanning Lenses*

Standard features include:

- Air-spaced 3 or 4-element designs

- Transmission of > 90%

- F-Theta condition accuracy of better than 0.1%

A scanning (F-theta) lens supplies an image in accordance with the so-called F-theta condition (y' = f x θ) and, therefore, has a specially corrected distortion.

F-theta lenses are used in engraving and labeling systems, phototypesetting, image transfer and material processing, to read or write texts or image components with a laser beam. For instance, a laser beam bundle is directed by means of a movable mirror and focused by an F-theta lens. The object which is to be read or the material surface which is to be processed, is scanned in accordance with the scanning angle θ derived from the deflection (in a line or area).

Focusing in a plane despite swiveling of the mirror
The focusing of the beam and a variable beam deflection are necessary for the scanning. Focusing is achieved by means of a lens, and beam deflection is facilitated most simply by a movable mirror.
If the deflecting unit can be positioned in the beam path behind the lens (Figure 2), the lens only has to satisfy minimum demands with respect to the image angle: It may have a small diameter and must form a sharp image only in the paraxial zone. The positioning of the deflecting unit behind the lens, however, leads to a curved scanning path which lies in a circular arc around the turning axis of the deflecting unit.

This positioning is not suitable for the scanning of *flat surfaces*.

If the deflecting unit is positioned in the beam path in front of the lens (Figure 3), this results in a straight scanning path in a plane (image plane) perpendicular to the optical axis. In this case, strict demands are placed on the image angle of the lens, and moreover, other requirements must be met by the lens: It has to provide a large diameter, its entrance pupil must lie outside the lens at the point of deflection, it must be corrected for a fairly large

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image angle and must have a good flattening of the image field as well as a very special correction of distortion.

F-theta lenses need a special distortion

Normally, a lens is expected to be distortion-free in order that the image obtained is geometrically similar to the object. Freedom from distortion is obtained when the image height y' is proportional to the object height. With reference to the object angle θ, $y' = f \times \tan \theta$ applies. However, such a lens is not suitable for scanning. According to Figure 3 a linear relationship is required between the scanning angle theta and the image height y'.

To obtain this relationship, the lens has to have a negative (= a barrel-shaped) distortion defined by the formula $y' = f \times \theta$. F-theta lenses satisfy this so-called F-theta condition.

Identical angles have to be translated into identical scanning paths

Proportionality between the scanning angle θ and the image height y' ensures proportionality between the angular velocity of the deflecting system (e.g. of the mirror or polygon wheel) and the scanning speed in the image plane. This property is of special importance in those cases where the duration of exposure of the material surface to the beam is a factor (such as the exposure time of light sensitive film in phototype setting).

A deviation of the image formation geometry from the ideal position is called distortion in the case of ordinary lenses such as photographic lenses. F-theta lenses, however, must exhibit a well defined distortion in accordance with the F-theta condition.
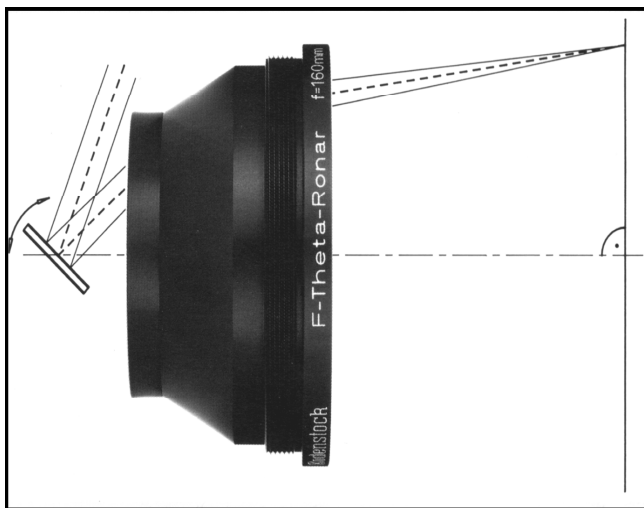

Figure 3: *If the deflection of the laser beam occurs in the beam path in front of the lens, the scanning path lies in a plane perpendicular to the optical axis of the lens. If the image height y' is to be proportional to the scanning angle theta, then y' = f x θ instead of y' = f x tanθ.*
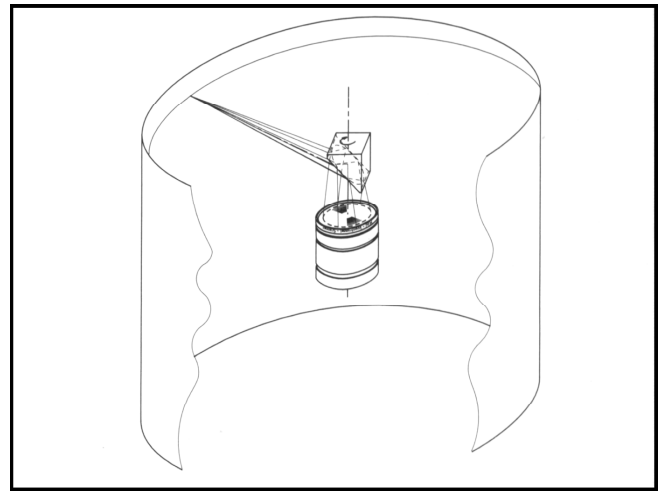

Figure 2: *If a laser beam focused by an ordinary lens is deflected in the beam path behind the lens, the scanning path produced takes the form of a circular arc.*

Cascade Laser Corporation can provide F-theta lenses that satisfy the F-theta requirements with an accuracy of better than 0.1%. (See footnote on Table 1, page 6)

A deviation from the F-theta condition manifests itself as...

...a deviation in position of a point on the scanning path from its ideal value,

...a scale change along the scanning path, and

...non-uniform scanning speed despite constant angular velocity of the deflecting system.

Which of these effects is the most serious, depends on the particular application. For customized F-theta lenses, it is possible to adapt the optimization to the application.

The entrance pupil lies outside the lens

Whereas the entrance pupil of ordinary lenses lies inside the particular lens, in the case of F-theta lenses it has to lie relatively far outside in the region of the location of the deflecting unit (e.g. at the galvo-mirror or at the active mirror surface of the polygon wheel). This is apparent in Figure 3 and Figure 5. Sufficient distance is necessary for the movement of the deflecting unit and for the entry of the beam bundle, especially when using a polygon wheel as the deflecting unit. A small distance, however, reduces the size and the cost of the F-theta lens. This should be taken into consideration in the design of the apparatus into which the F-theta lens is placed.

Utilization of the whole entrance beam diameter, where possible

Because of the optically advantageous properties of lasers (monochromaticity and coherence), it is possible to achieve diffraction-limited quality of the point image by using high-class F-theta lenses. In order to exploit this property in practice, the whole entrance pupil must be filled out by the entrance beam bundle evenly or in a gaussian form, depending on the application.

To satisfy this condition, the deflection unit(s) must be of sufficient size and, where necessary, e.g. in the use of a gas laser, a beam expander must be used to achieve the required expansion of the laser beam bundle.

Therefore, the table with the most important technical data of the standard-type F-theta lenses gives details of the recommended diameter of the entrance beam bundle and the position of the deflecting elements.

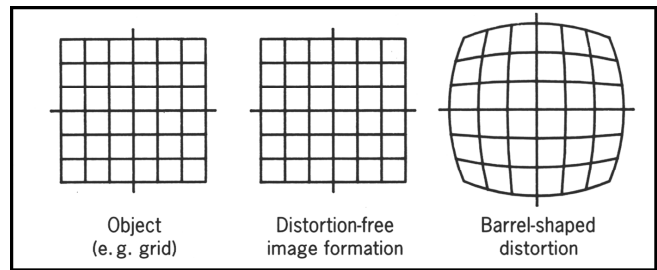This data sheet also shows the image point diameters where the intensity is reduced to $1/e^2$

Figure 4: *A lens satisfying the formula y' = f x tanθ yeilds a distortion-free image. In contrast, an F-theta lens must have an exactly defined negative (barrel-shaped) distortion, so that the image height y' is proportional to the scanning angle θ. Only then a uniform rotation of the deflecting unit is transformed into a uniform scanning movement.*

(y 13.5%) for both uniform and gaussian pupil illumination. The corresponding values of all these lenses also match the physical limits determined by diffraction.

If the entrance beam bundle fills out the pupil only partially or irregularly, then the point image diameter
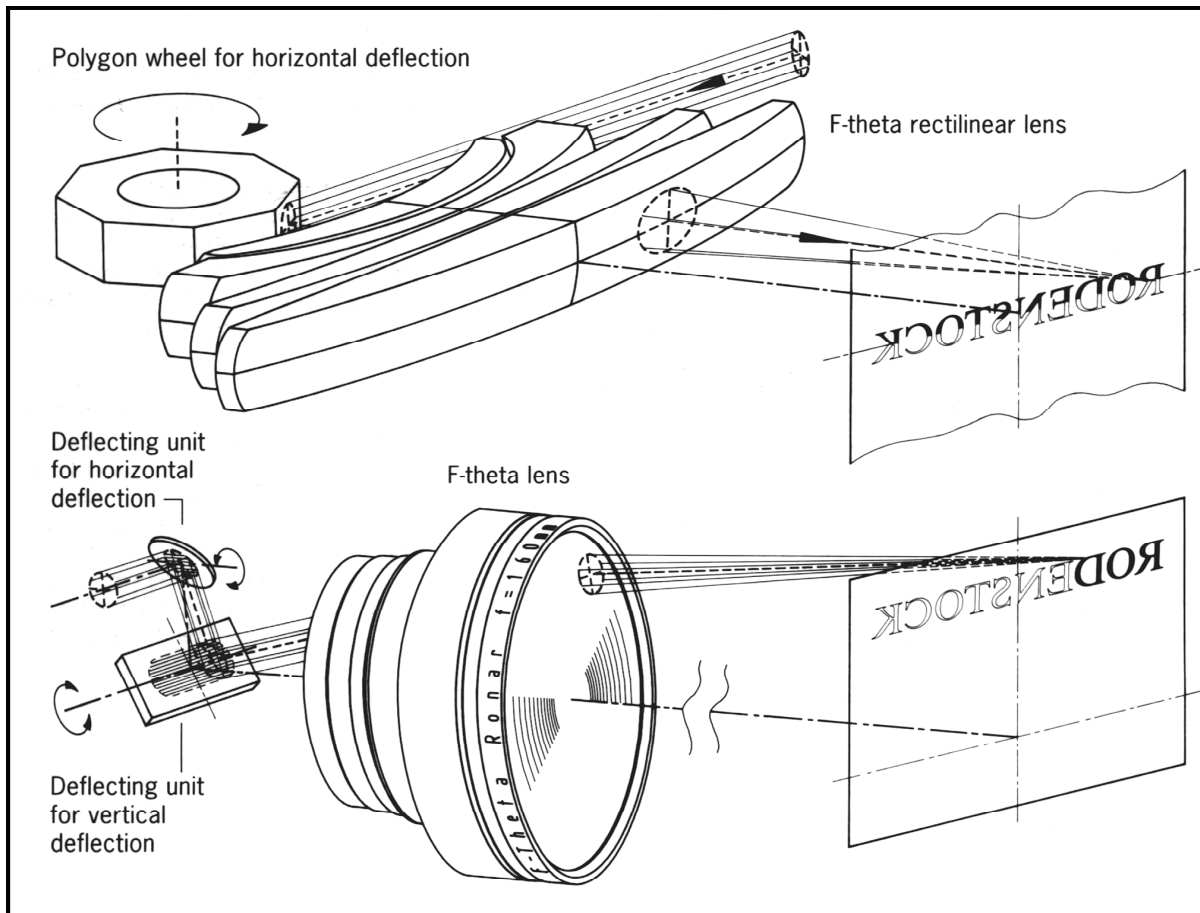

Figure 5, above: *If only one line is scanned, then only one deflecting unit is necessary, e.g. a polygon wheel. In this case the lens may also have a rectilinear form, which requires less space.*
Below: *An example for the use of an F-theta lens with beam deflection through two galvo-mirrors. This deflection system permits a rapid access to any image point in the scanning plane.*

is increased. At the same time the depth of focus is also increased, which is desirable in the scanning of non-flat surfaces (e.g. electric components on printed circuit boards).

A design with two deflecting mirrors requires an entrance pupil diameter that is markedly larger than the diameter of the entrance beam bundle. This ratio is approximately 1.4 to 1.8 in the case of our standard-type F-theta lenses.

If only one deflecting unit is used with such a lens, then the diameter or the entrance beam bundle may be correspondingly larger, whereby the resulting image point diameter is considerably reduced.

A special case: telecentric F-theta lenses
If a non-flat surface is scanned, and the beam hits the surface at an angle, there will be a deviation in the position compared to the projection of the respective point in the scanning plane. The extent of the deviation will be in proportion to the distance from the ideal scanning plane. This will result in a discrepancy of scale. This error is avoidable through use of a "telecentric" F-theta lens, which is distinguished from normal F-theta lenses in that the axis of the focused beam is perpendicular to the scanning path (Figure 6).

Telecentric F-theta lenses require very large lens diameters for long scanning paths (lens diameter ɣ 2y' + entrance beam diameter).

A large scanning angle has a number of advantages
The required scanning length can be achieved with a lens having a long focal length and a small scanning angle, or with a lens having a shorter focal length and a larger scanning angle. There are, however, a number of advantages of using a short focal length and a large scanning angle. There are, however, a number of advantages of using a short focal length and a large scanning angle which is typical for Cascade Laser Corporations' F-theta lenses.

- The short focal length associated with a large scanning angle allows a short construction of the total system and thus requires less space in the machine.

- With a shorter focal length and the same relative aperture, the lens and deflecting unit(s) are smaller, thereby reducing costs.

- Irregularities in the deflection movement, e.g. due to tolerances in the facet angles of the mirror polygon, have a less evident effect because of the short focal length.
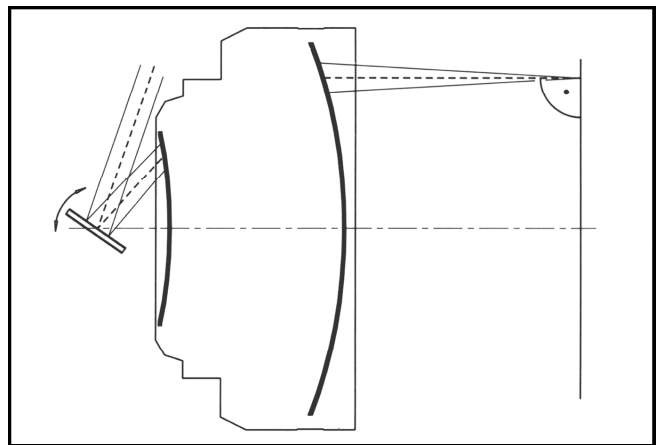
Cascade Laser Corporation is able to customize

Figure 6: *A telecentric F-theta lens differs from a normal F-theta lens in that the axis of the focused laser beam bundle is perpendicular to the scanning plane throughout.*

F-theta lenses for very different applications, so that comprehensive know-how is available to solve a large range of problems.

Customized solutions permit optimization
For example, extremely large scanning angles, achromatic F-theta lenses and telecentric F-theta lenses are possible. Cascade Laser Corporation is able to provide chromatic F-theta lenses for systems in which lasers of different wavelengths are used. The scanning angle was expanded in some other customized F-theta lenses to approximately +/- 70°.

An important feature is the availability of customized F-theta lenses in rectilinear form for scanning in a line (Figure 5, top). Because of their form, they take up less space. Their measurements may be further reduced, as the movement of the deflecting unit and the entry of the beam bundle (perhaps even outside the scanning angle plane!) afford more room. The entrance pupil can therefore be located closer to the lens. Due to a special assembly technology, Cascade Laser Corporation can manufacture rectilinear F-theta lenses with extremely high precision.

Furthermore, a customized construction permits the optimization of the performance to meet the particular requirements, e.g. a certain spot size and energy distribution, and takes into consideration the fitting conditions while minimizing the costs at the same time. This holds true especially for total systems, e.g. including light pens and beam expanders.

Serial production of standard-type F-theta Ronars
The table below contains the most important data for the serially produced standard-type F-theta lenses used primarily in material processing and labeling. They are suitable for scanning in a line
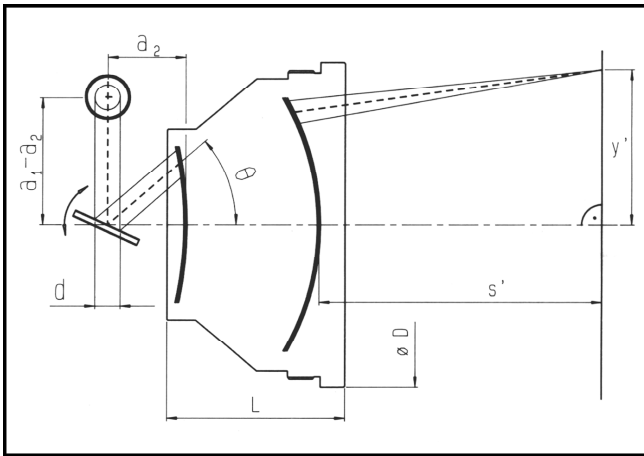
Figure 7: *Important dimensions of the F-theta Ronar (a_1/a_2 = distance to mirror 1/2, d = entrance beam diameter, D = lens diameter, s' = back focal length, θ = scanning angle, y' = image height).*

with one deflecting unit (in which case an entrance beam diameter of 1.4 to 1.8 times larger is possible, and the image point diameter becomes correspondingly smaller due to lower diffraction) and for surface scanning with two deflecting units (in which case the diagonal determines the maximum scan length).

Interchangeable protecting glasses for F-theta lenses

In material processing some material (metal, plastics, etc.) is burned away or vaporized by the laser beam. To prevent this from settling on the exit lens element, an interchangeable protecting glass is provided in most F-theta lenses (See chart).

Point images represent the very high image quality

The following point images are proof of the high image quality of our F-theta lenses throughout the entire scanning range. From the image center (0°) through to the corner (25°), the point images are almost identical.
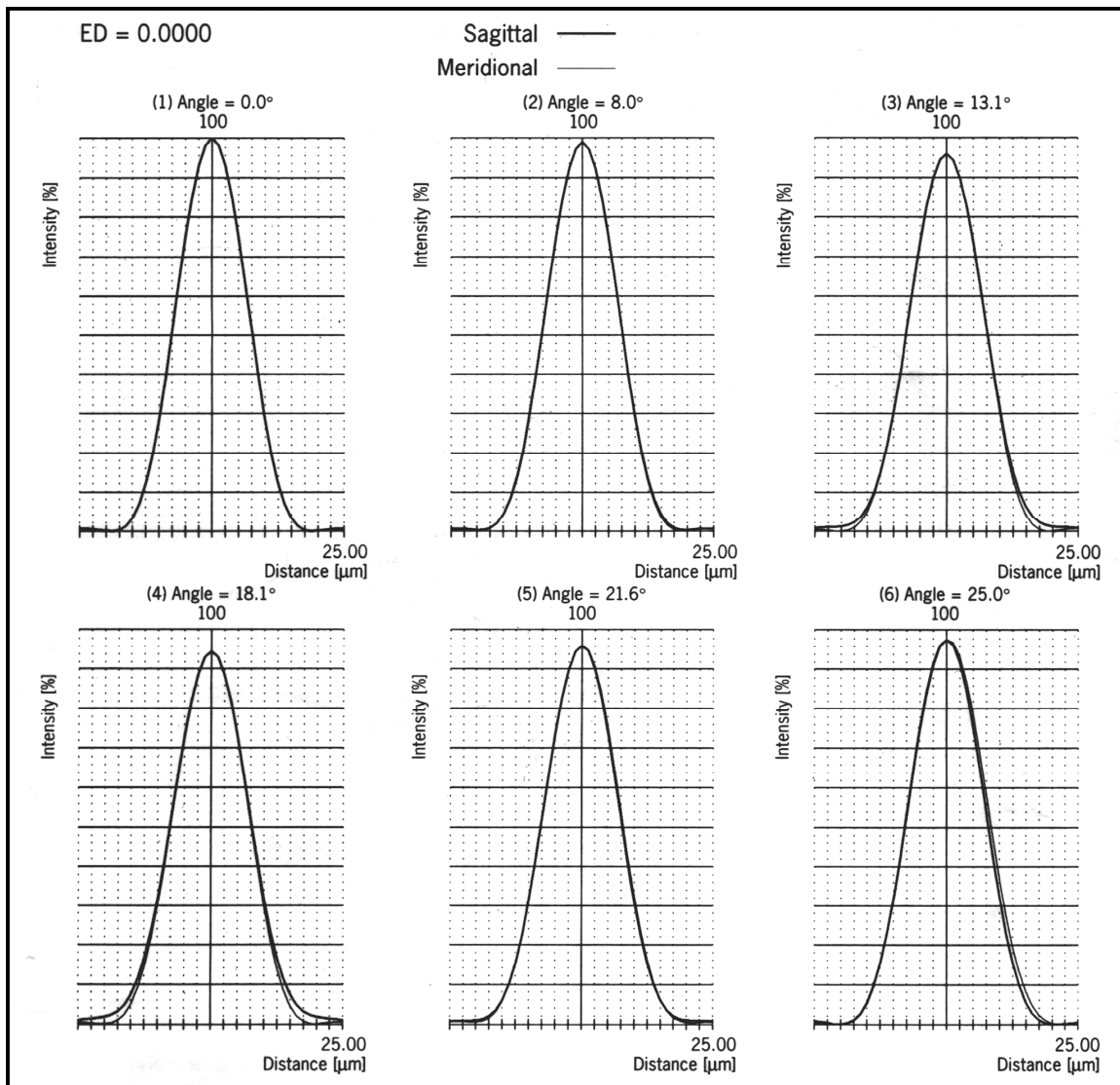

Figure 8: *Point image cross sections for six scanning angles from 0° to 25° in the case of gaussian pupil illumination limited to $1/e^2$ (Cascade Laser's F-theta Ronar 254 mm and laser wavelength 1064 nm).*

Nominal focal length	Effective focal length	Back focal length s' (from vertex of last lens element surface, at * from protecting glass)	Wavelength	Scanning length/diagonal 2y' max. in case of surface scanning	Total scanning angle theta max.	Entrance beam bundle diameter d	Image point diameter *** in the case of uniform pupil illumination	Image point diameter *** in the case of gaussian pupil illumination	Mirror distance a1/a2	Lens diameter D	Screw thread	Protecting glass (AR coated)	Order number
100 mm	94.0 mm	111.4 mm	532 nm **	82 mm	+/- 25 °	8 mm	10 mm	12 mm	28/12 mm	90 mm	M 85x1	yes	0599
100 mm	94.0 mm	111.4 mm	532 nm **	82 mm	+/- 25 °	8 mm	10 mm	12 mm	28/12 mm	80 mm	M 76x1	-	0599
100 mm	99.6 mm	118.4 mm	1064 nm **	87 mm	+/- 25 °	12 mm	14 mm	16 mm	28/12 mm	90 mm	M 85x1	yes	0599
100 mm	99.6 mm	118.4 mm	1064 nm **	87 mm	+/- 25 °	12 mm	14 mm	16 mm	28/12 mm	80 mm	M 76x1	-	0545
160 mm	159.6 mm	188.6 mm	532 nm **	140 mm	+/- 25 °	10 mm	14 mm	16 mm	28/12 mm	90 mm	M 85x1	yes	0599
160 mm	159.6 mm	188.6 mm	532 nm **	140 mm	+/- 25 °	10 mm	14 mm	16 mm	28/12 mm	80 mm	M 76x1	-	0545
160 mm	160.4 mm	189.7 mm	633 nm	140 mm	+/- 25 °	12 mm	14 mm	16 mm	28/12 mm	80 mm	M 76x1	-	0545
160 mm	160.1 mm	188.9 mm	1064 nm **	140 mm	+/- 25 °	12 mm	23 mm	26 mm	28/12 mm	90 mm	M 85x1	yes	0599
163 mm	163.1 mm	189.7 mm *	1064 nm **	162 mm	+/- 28.5 °	10 mm	28 mm	31 mm	37/24 mm	109 mm	M 76x1	yes	0500
254 mm	250.2 mm	291.4 mm*	532 nm **	218 mm	+/- 25 °	20 mm	11 mm	12 mm	46/24 mm	120 mm	M 85x1	yes	0545
254 mm	254.4 mm	299.1 mm *	1064 nm **	222 mm	+/- 25 °	20 mm	22 mm	25 mm	46/16 mm	120 mm	M 85x1	yes	0545
330 mm	-	393 mm	1064 nm ****	330 mm 307 mm 315 mm 289 mm	+/- 28.5 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 20 mm 15 mm 20 mm	-	40 mm 33 mm 40 mm 33 mm	33 33 42/24 47/17	120 mm	M 85x1	-	440
330 mm	-	390 mm *	1064 nm ****	330 mm 307 mm 315 mm 289 mm	+/- 28.5 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 20 mm 15 mm 20 mm	-	40 mm 33 mm 40 mm 33 mm	33 33 42/24 47/17	120 mm	M 85x1	ja	440
330 mm	-	386 mm	830 nm	324 mm 301 mm 309 mm 284 mm	+/- 28.5 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 18 mm 15 mm 15 mm	-	32 mm 27 mm 32 mm 27 mm	33 33 42/24 47/17	120 mm	M 85x1	-	440
330 mm	-	390 mm	532 nm	328 mm 305 mm 313 mm 288 mm	+/- 28.5 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	14 mm 18 mm 14 mm 18 mm	-	22 mm 19 mm 22 mm 19 mm	33 33 42/24 47/17	120 mm	M 85x1	-	440
330 mm	-	386.3 mm *	532 nm	328 mm 305 mm 313 mm 288 mm	+/- 28.5 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	14 mm 18 mm 14 mm 18 mm	-	22 mm 19 mm 22 mm 19 mm	33 33 42/24 46/17	120 mm	M 85x1	ja	440
420 mm	-	499.2 mm	1064 nm ****	412 mm 390 mm 401 mm 368 mm	+/- 28 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 20 mm 15 mm 20 mm	-	52 mm 40 mm 52 mm 40 mm	32 32 41/23 46/16	120 mm	M 85x1	-	440
420 mm	-	496.9 mm *	1064 nm ****	412 mm 390 mm 401 mm 368 mm	+/- 28 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 20 mm 15 mm 20 mm	-	52 mm 40 mm 52 mm 40 mm	32 32 41/23 46/16	120 mm	M 85x1	ja	440
420 mm	-	491.2 mm	830 nm	405 mm 383 mm 394 mm 362 mm	+/- 28 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 20 mm 15 mm 20 mm	-	40 mm 30 mm 40 mm 30 mm	32 32 41/23 46/16	120 mm	M 85x1	-	440
420 mm	-	497.1 mm	532 nm	411 mm 389 mm 400 mm 367 mm	+/- 28 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 18 mm 15 mm 18 mm	-	26 mm 22 mm 26 mm 22 mm	32 32 41/23 46/16	120 mm	M 85x1	-	440
420 mm	-	493.3 mm *	532 nm	411 mm 389 mm 400 mm 367 mm	+/- 28 ° +/- 26.5 ° +/- 27.2 ° +/- 25 °	15 mm 18 mm 15 mm 18 mm	-	26 mm 22 mm 26 mm 22 mm	32 32 41/23 46/16	120 mm	M 85x1	ja	440

Table 1 footnotes:

*)   Back focal length for protective glass.
**)   These lenses have an additional anti-reflective coating for the visual spectrum.
***)   The image point diameter in the case of uniform and gaussian pupil illumination is based on a decrease of intensity onto
       $1/e2$.
****) AR coating for 1064 nm + vis
a1:   distance between first deflection unit and vertex of first lens element surface
a2:   distance between second deflection unit and vertex of first lens element surface

F-theta condition is met by all listed models with an accuracy of better than 0.1%

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