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EP 1566681 A1 **US 20140016210 A1**
US 20130022345 A1 **US 20130010370 A**

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INT CL **G02B**
Other: **Online: Epodoc, TXTE, WPI**

(54) Title of the Invention: **Anamorphic objective lens**
Abstract Title: **Anamorphic objective lens with three lens groups**

(57) An anamorphic objective lens comprising along an optical axis and in order from an object space S1 to an image space S30: a first spherical lens group G1; an anamorphic lens group G2; and a second spherical lens group G3. The objective lens further comprises an optical stop S22 located along the optical axis. The optical stop/ aperture may be located between the anamorphic lens group and the second spherical lens group, within the second spherical lens group or on the opposite side of the second spherical lens group from the anamorphic lens group. The focus can be adjusted by moving lens 2. The surfaces of the lens elements in the anamorphic group may be spherical, cylindrical or planar. The objective lens may be configured to provide an image of out of focus objects close to the optical axis with an elliptical bokeh shape.

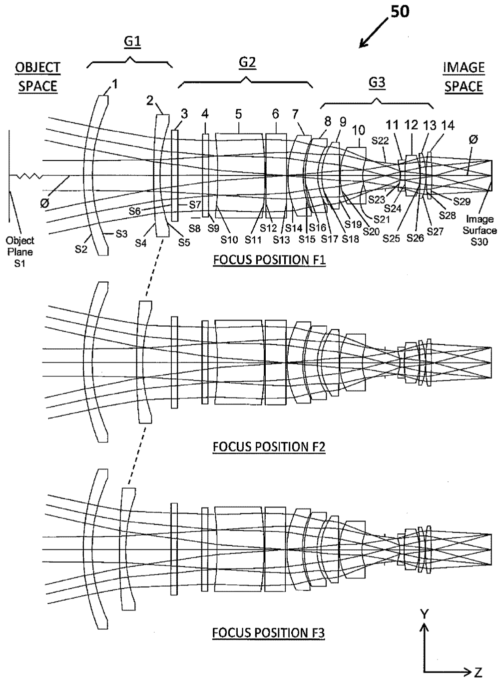


FIG. 1

GB 2513993 A

At least some of the priority details shown above were added after the date of filing of the application.

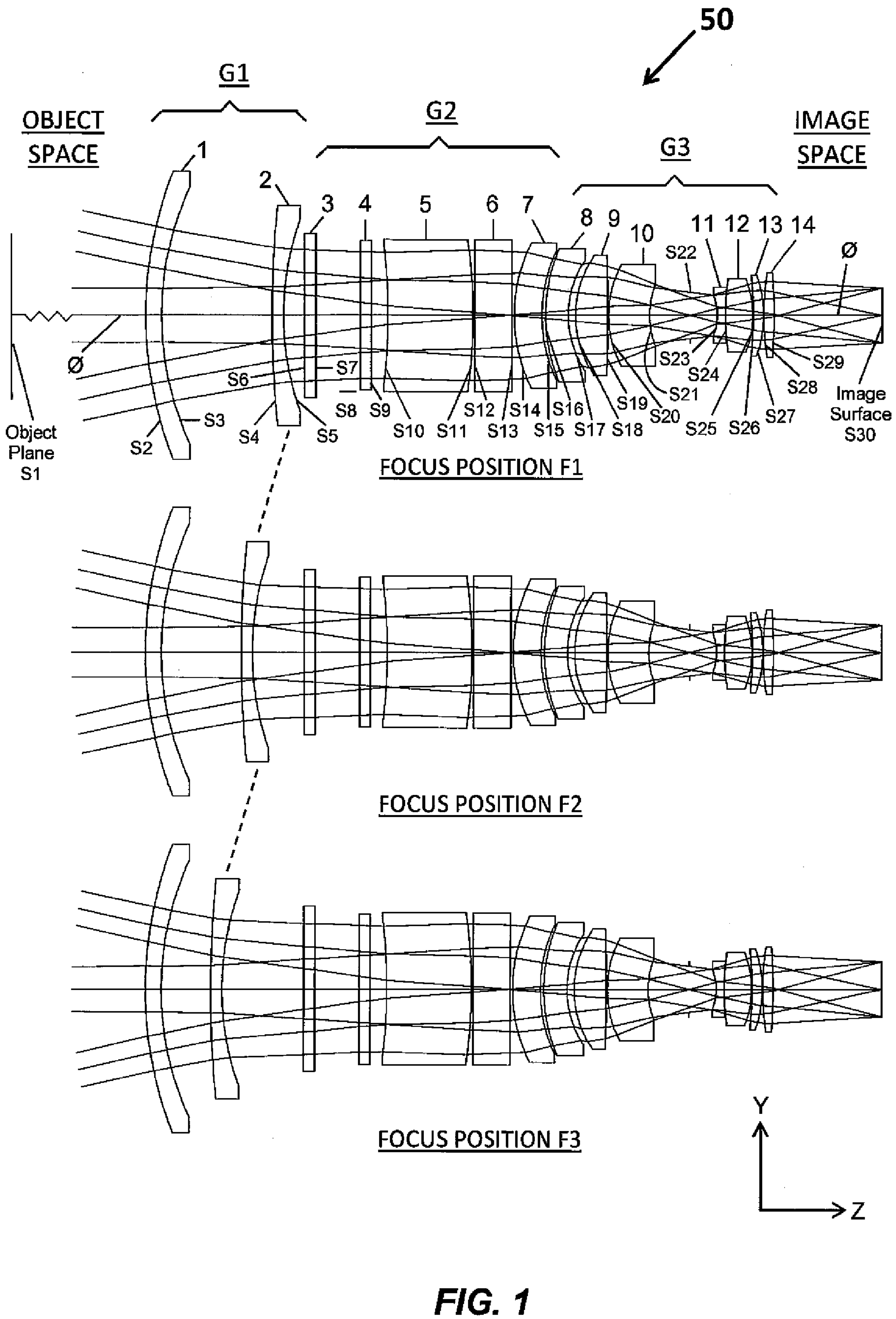

50
G1
G2
G3
OBJECT SPACE
IMAGE SPACE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Ø
S22
Ø
S6
S7
S8
S9
S10
S11
S12
S13
S14
S15
S16
S17
S18
S19
S20
S21
S23
S24
S25
S26
S27
S28
S29
Object Plane S1
S2
S3
S4
S5
Image Surface S30
FOCUS POSITION F1
FOCUS POSITION F2
FOCUS POSITION F3
Y
Z

FIG. 1

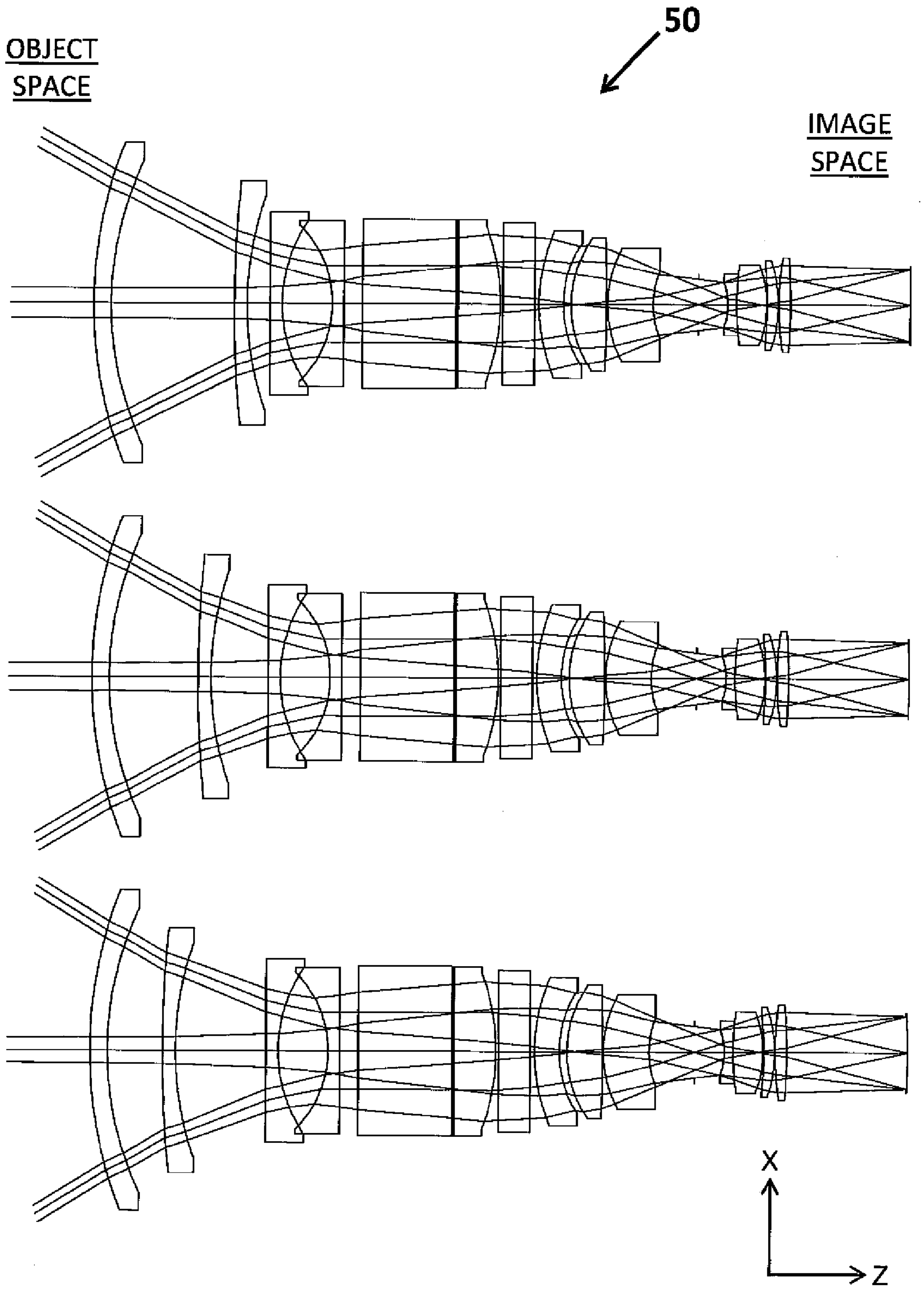


FIG. 2

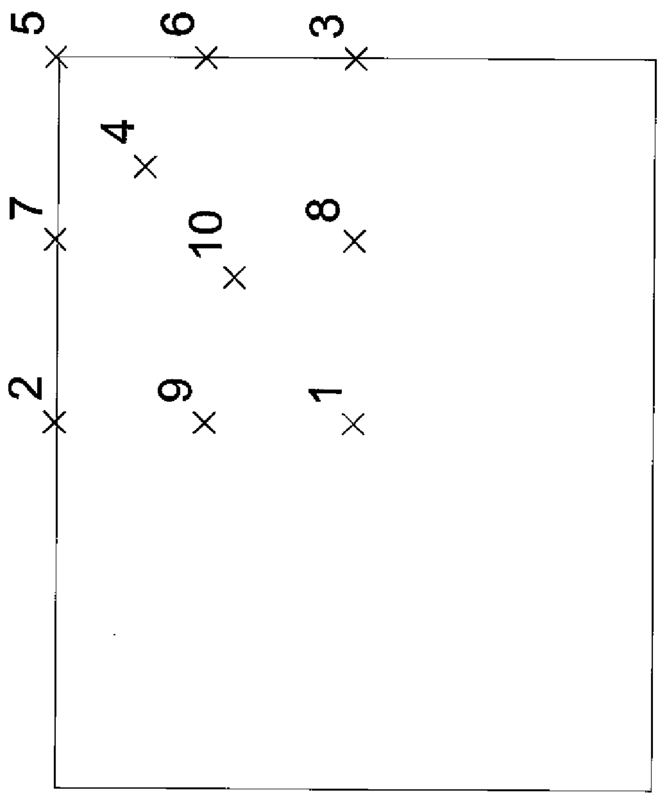
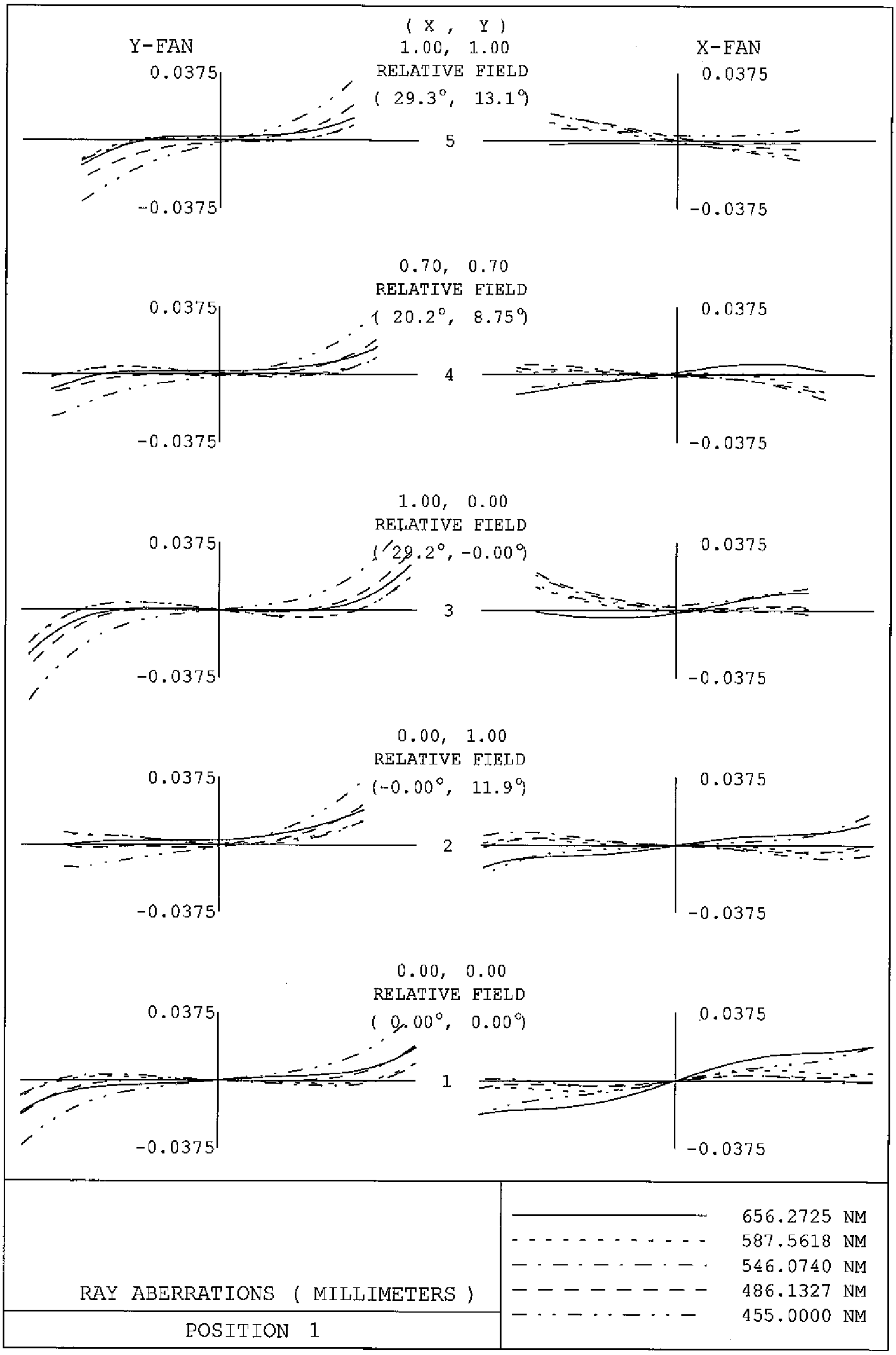


FIG. 3



(X , Y)
Y-FAN
X-FAN
1.00, 1.00
RELATIVE FIELD
(29.3°, 13.1°)
0.0375
-0.0375
5
0.70, 0.70
RELATIVE FIELD
(20.2°, 8.75°)
4
1.00, 0.00
RELATIVE FIELD
(29.2°, -0.00°)
3
0.00, 1.00
RELATIVE FIELD
(-0.00°, 11.9°)
2
0.00, 0.00
RELATIVE FIELD
(0.00°, 0.00°)
1
656.2725 NM
587.5618 NM
546.0740 NM
486.1327 NM
455.0000 NM
RAY ABERRATIONS (MILLIMETERS)
POSITION 1

FIG. 4

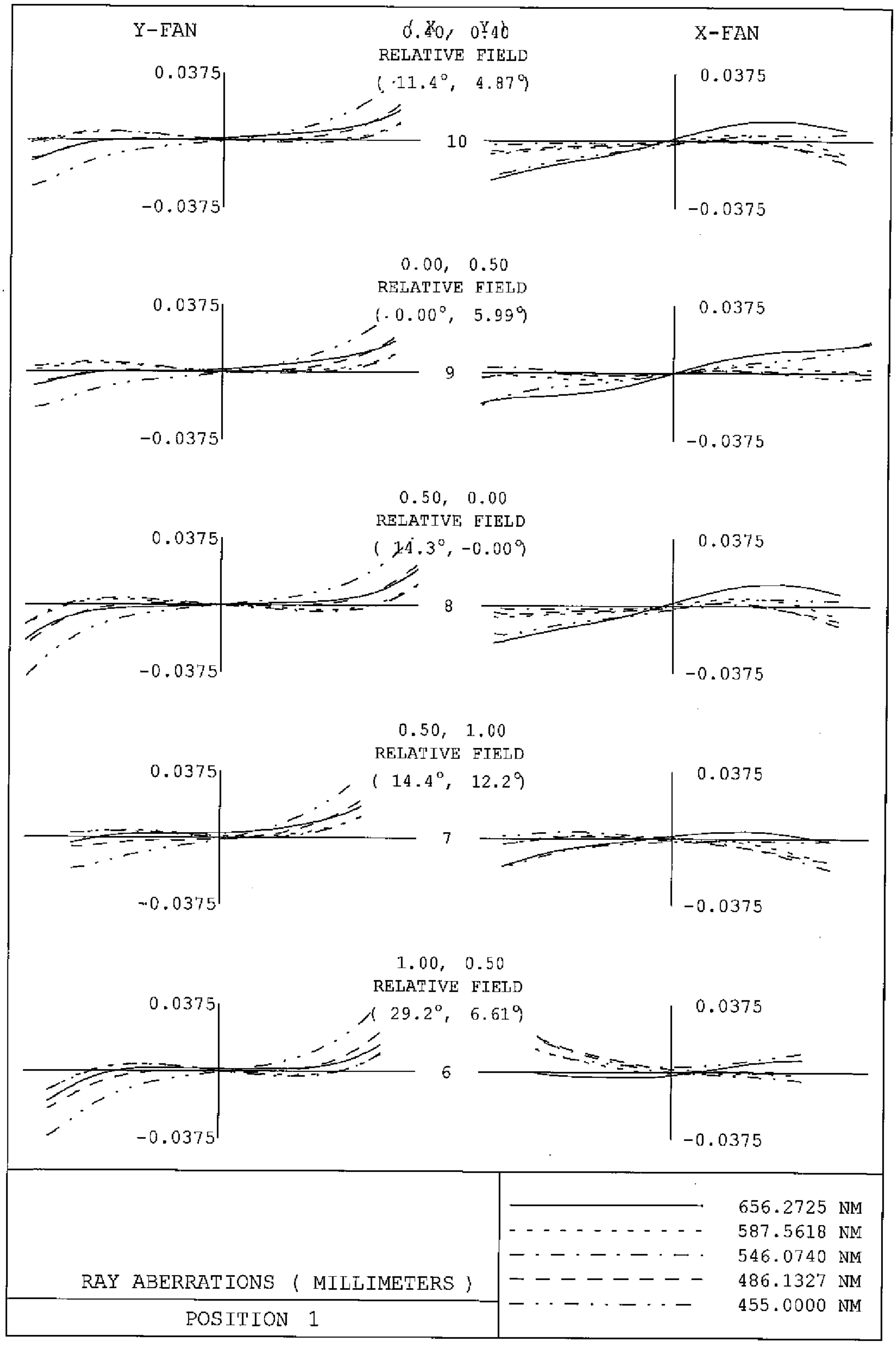

Y-FAN
X-FAN
RELATIVE FIELD
(11.4°, 4.87°)
0.0375
-0.0375
10
0.00, 0.50
RELATIVE FIELD
(0.00°, 5.99°)
9
0.50, 0.00
RELATIVE FIELD
(14.3°, -0.00°)
8
0.50, 1.00
RELATIVE FIELD
(14.4°, 12.2°)
7
1.00, 0.50
RELATIVE FIELD
(29.2°, 6.61°)
6
656.2725 NM
587.5618 NM
546.0740 NM
486.1327 NM
455.0000 NM
RAY ABERRATIONS (MILLIMETERS)
POSITION 1

FIG. 5

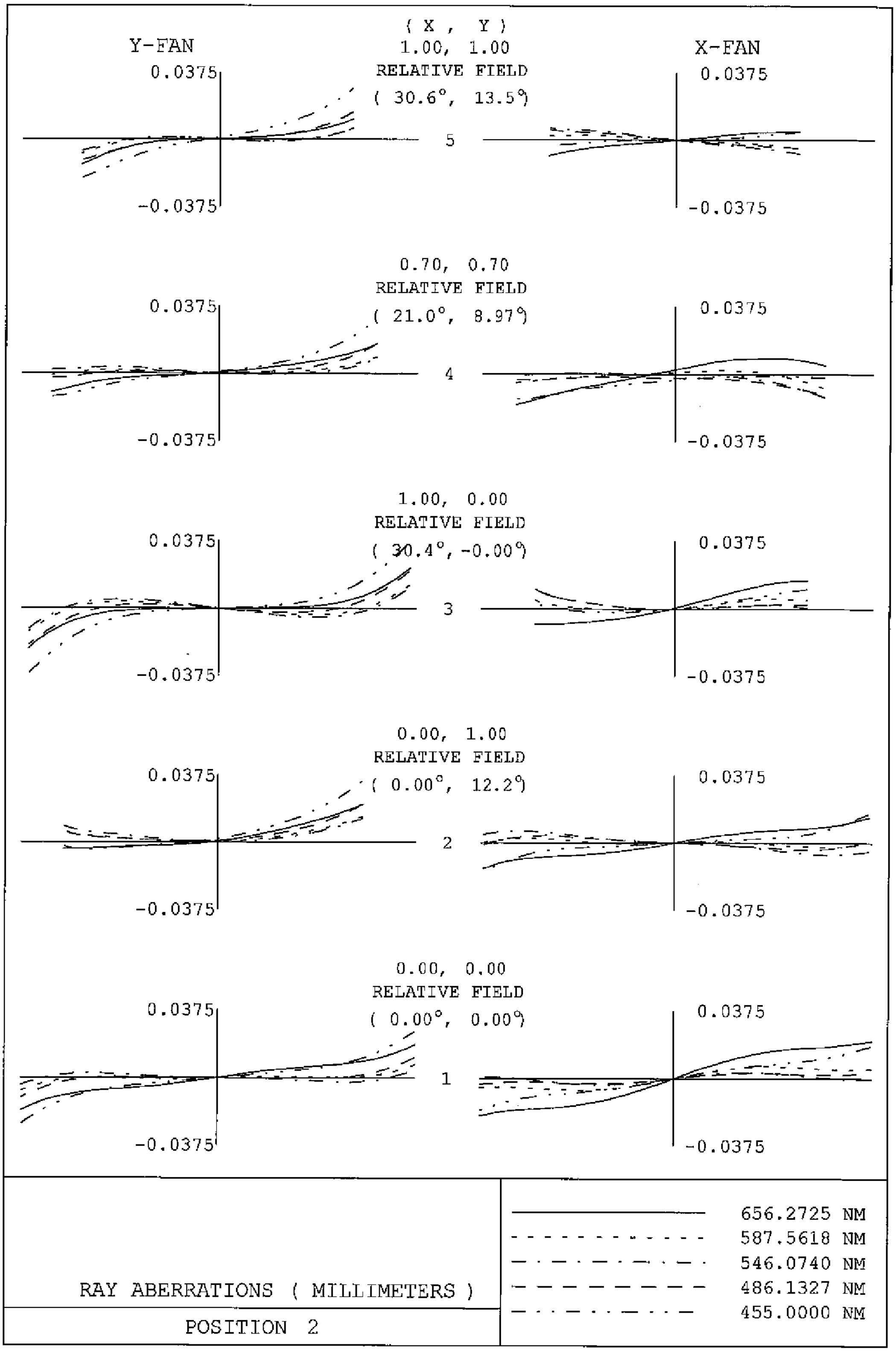

(X , Y)
Y-FAN
1.00, 1.00
RELATIVE FIELD
(30.6°, 13.5°)
X-FAN
0.0375
-0.0375
5
0.70, 0.70
RELATIVE FIELD
(21.0°, 8.97°)
4
1.00, 0.00
RELATIVE FIELD
(30.4°, -0.00°)
3
0.00, 1.00
RELATIVE FIELD
(0.00°, 12.2°)
2
0.00, 0.00
RELATIVE FIELD
(0.00°, 0.00°)
1
RAY ABERRATIONS (MILLIMETERS)
POSITION 2
656.2725 NM
587.5618 NM
546.0740 NM
486.1327 NM
455.0000 NM

FIG. 6

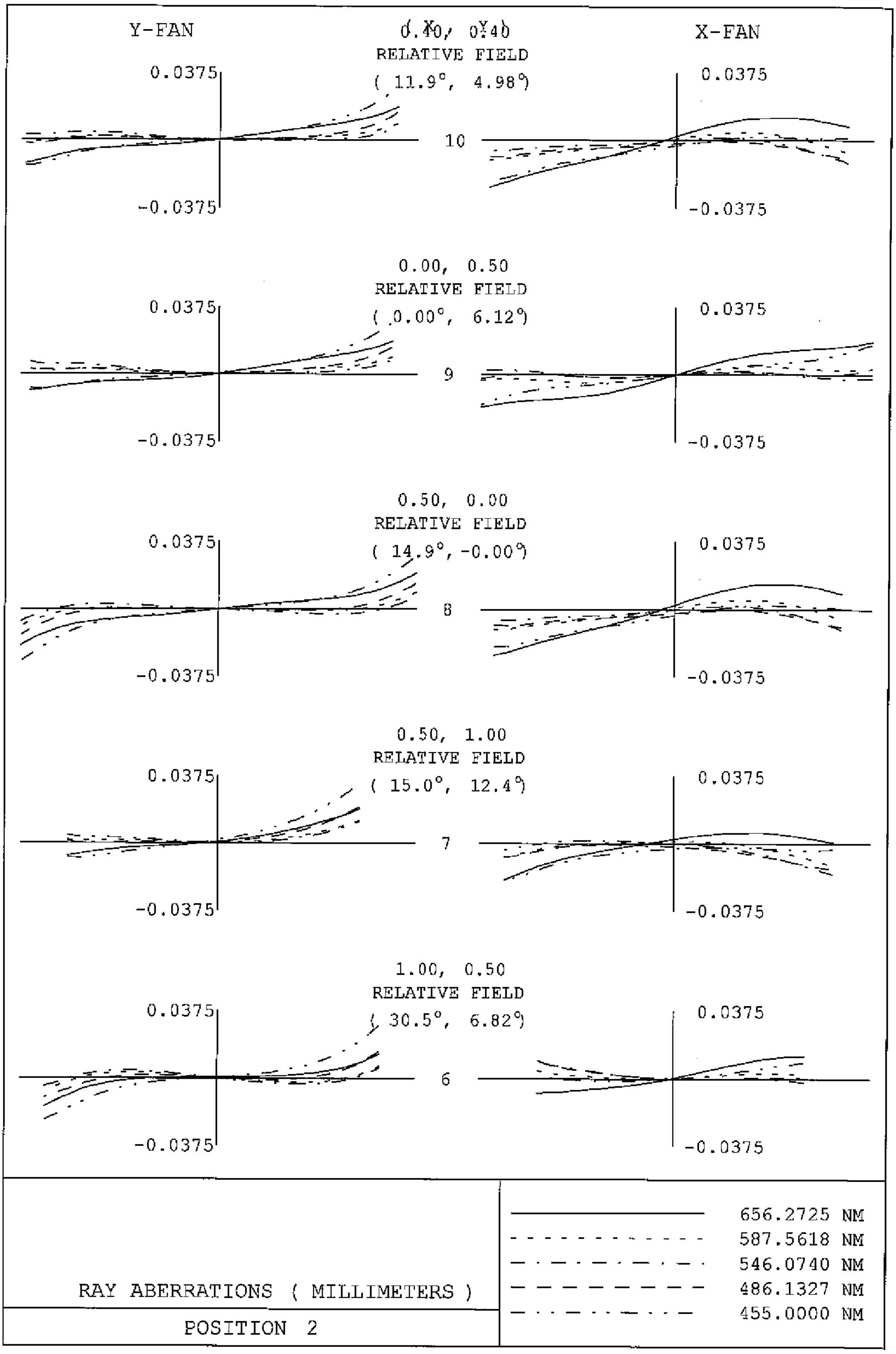
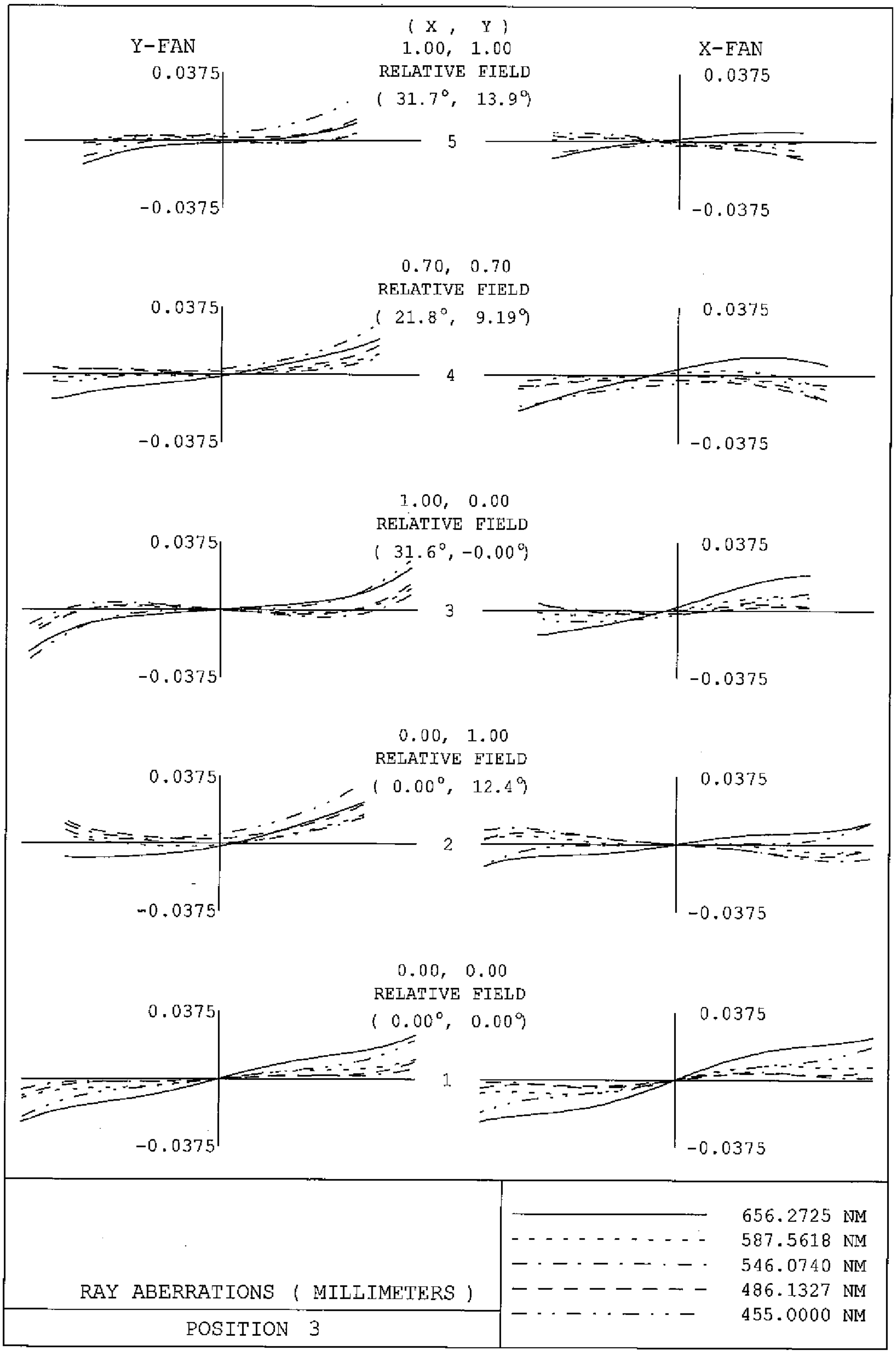

Y-FAN
0.00, 0.40
RELATIVE FIELD
(11.9°, 4.98°)
X-FAN
0.0375
-0.0375
10
0.00, 0.50
RELATIVE FIELD
(0.00°, 6.12°)
9
0.50, 0.00
RELATIVE FIELD
(14.9°, -0.00°)
8
0.50, 1.00
RELATIVE FIELD
(15.0°, 12.4°)
7
1.00, 0.50
RELATIVE FIELD
(30.5°, 6.82°)
6
656.2725 NM
587.5618 NM
546.0740 NM
486.1327 NM
455.0000 NM
RAY ABERRATIONS (MILLIMETERS)
POSITION 2

FIG. 7



Y-FAN
(X , Y)
1.00, 1.00
RELATIVE FIELD
(31.7°, 13.9°)
X-FAN
0.0375
-0.0375
5
0.70, 0.70
RELATIVE FIELD
(21.8°, 9.19°)
4
1.00, 0.00
RELATIVE FIELD
(31.6°, -0.00°)
3
0.00, 1.00
RELATIVE FIELD
(0.00°, 12.4°)
2
0.00, 0.00
RELATIVE FIELD
(0.00°, 0.00°)
1
656.2725 NM
587.5618 NM
546.0740 NM
486.1327 NM
455.0000 NM
RAY ABERRATIONS (MILLIMETERS)
POSITION 3

FIG. 8

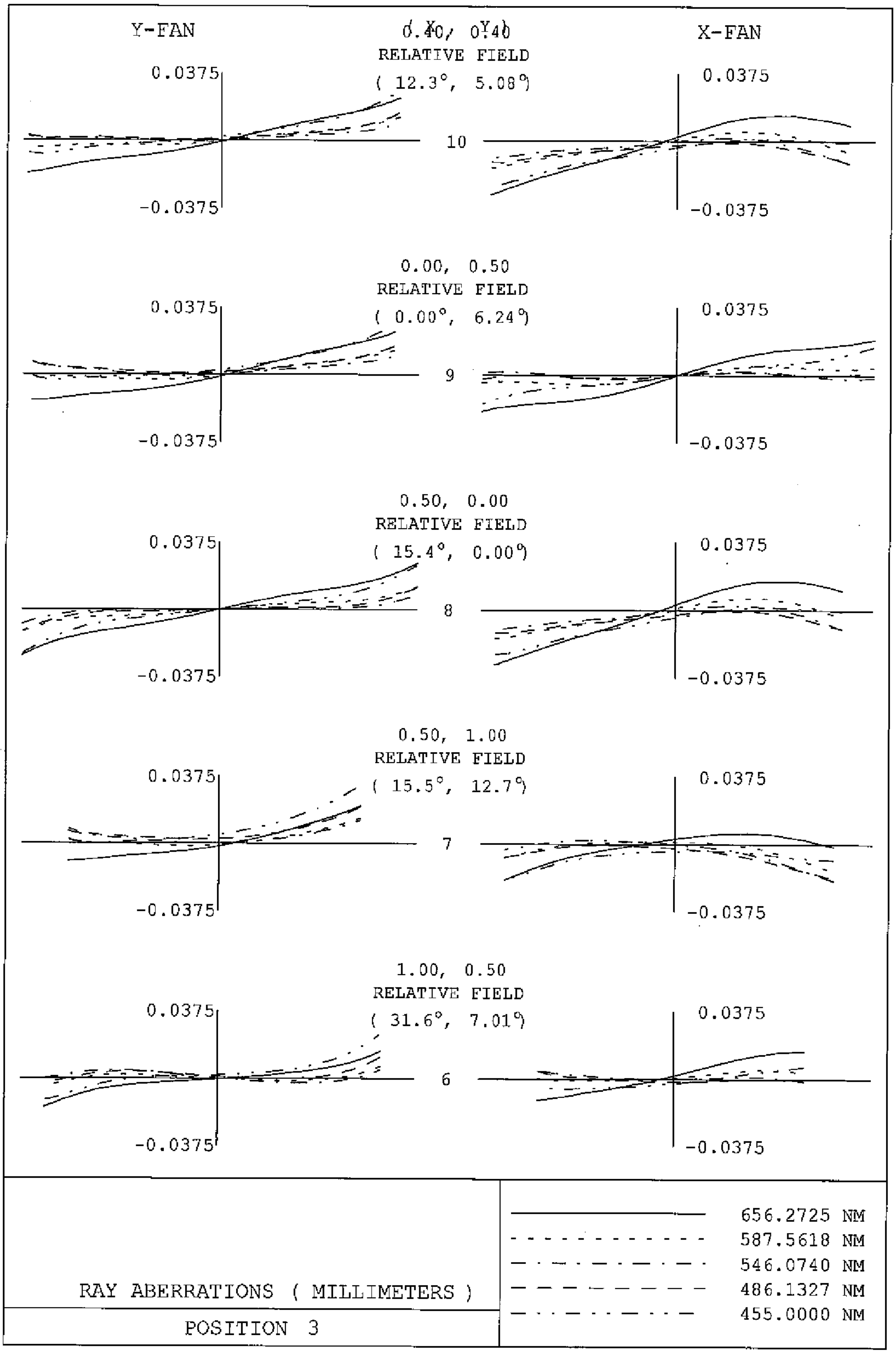
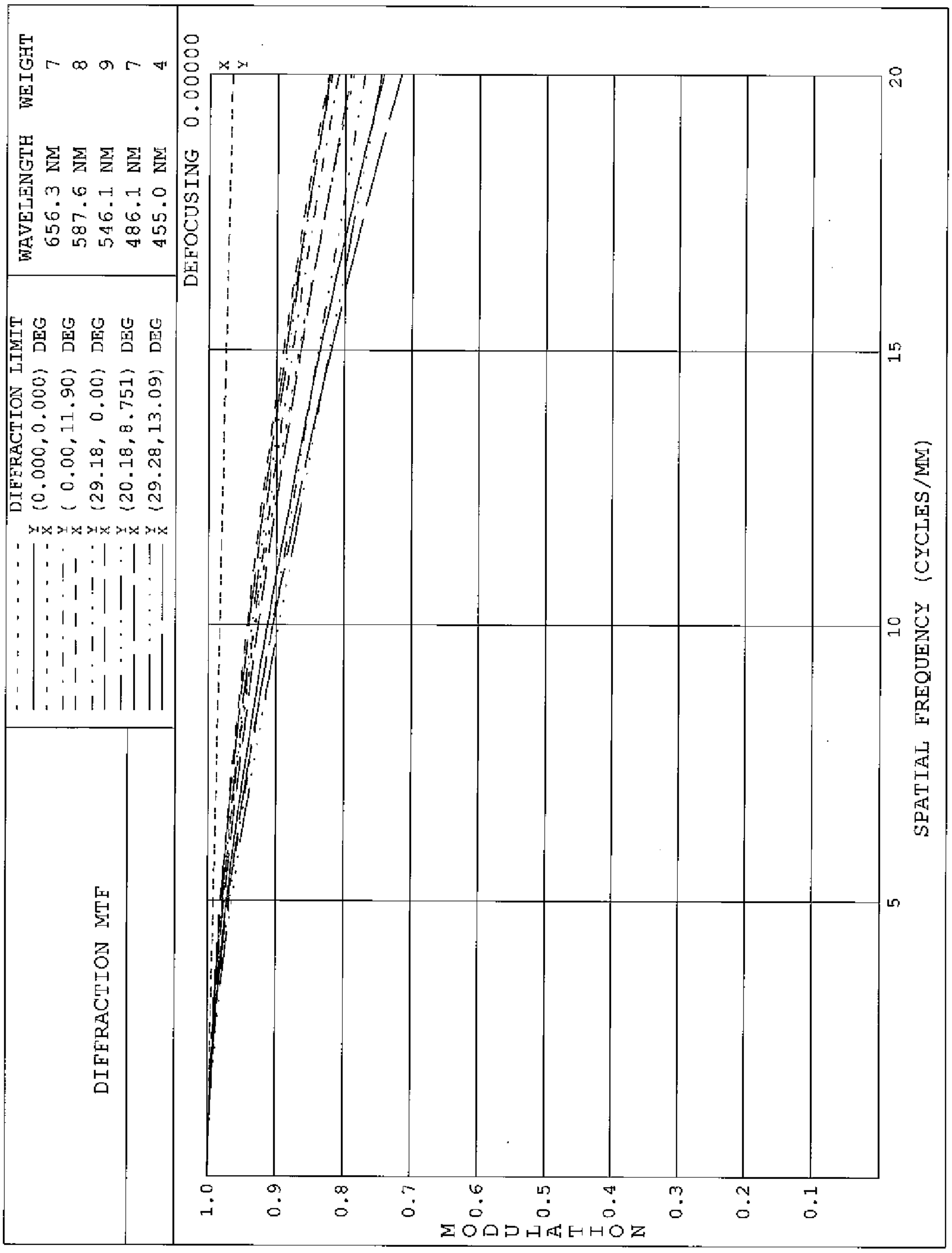

Y-FAN
0.40, 0.40
RELATIVE FIELD
(12.3°, 5.08°)
X-FAN
0.0375
-0.0375
10
0.00, 0.50
RELATIVE FIELD
(0.00°, 6.24°)
9
0.50, 0.00
RELATIVE FIELD
(15.4°, 0.00°)
8
0.50, 1.00
RELATIVE FIELD
(15.5°, 12.7°)
7
1.00, 0.50
RELATIVE FIELD
(31.6°, 7.01°)
6
RAY ABERRATIONS (MILLIMETERS)
POSITION 3
656.2725 NM
587.5618 NM
546.0740 NM
486.1327 NM
455.0000 NM

FIG. 9


DIFFRACTION MTF
DIFFRACTION LIMIT
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(0.00,11.90) DEG
(29.18, 0.00) DEG
(20.18,8.751) DEG
(29.28,13.09) DEG
WAVELENGTH WEIGHT
656.3 NM 7
587.6 NM 8
546.1 NM 9
486.1 NM 7
455.0 NM 4
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
5
10
15
20
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 10

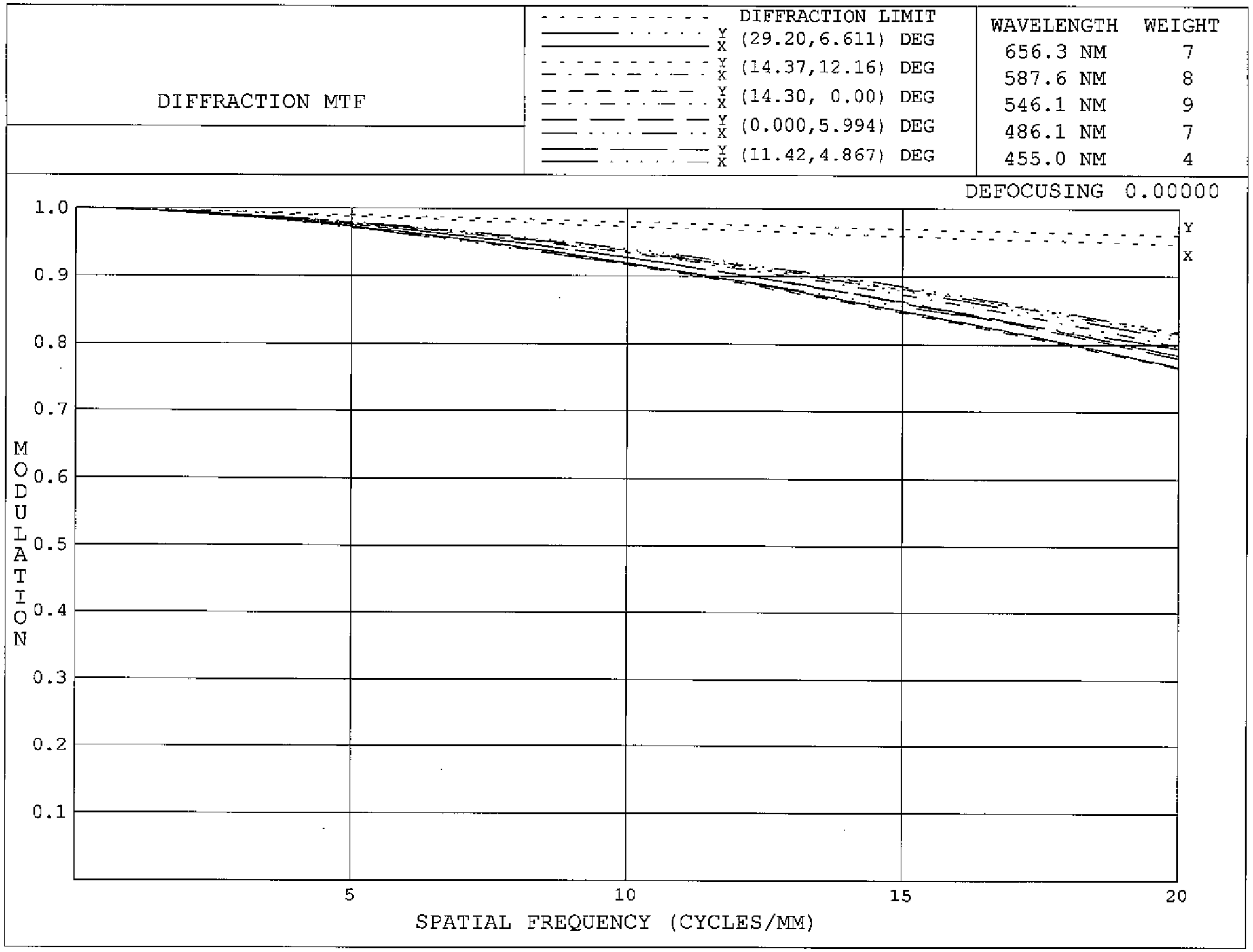

DIFFRACTION MTF
DIFFRACTION LIMIT
Y X (29.20,6.611) DEG
Y X (14.37,12.16) DEG
Y X (14.30, 0.00) DEG
Y X (0.000,5.994) DEG
Y X (11.42,4.867) DEG
WAVELENGTH WEIGHT
656.3 NM 7
587.6 NM 8
546.1 NM 9
486.1 NM 7
455.0 NM 4
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Y
X
5
10
15
20
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 11

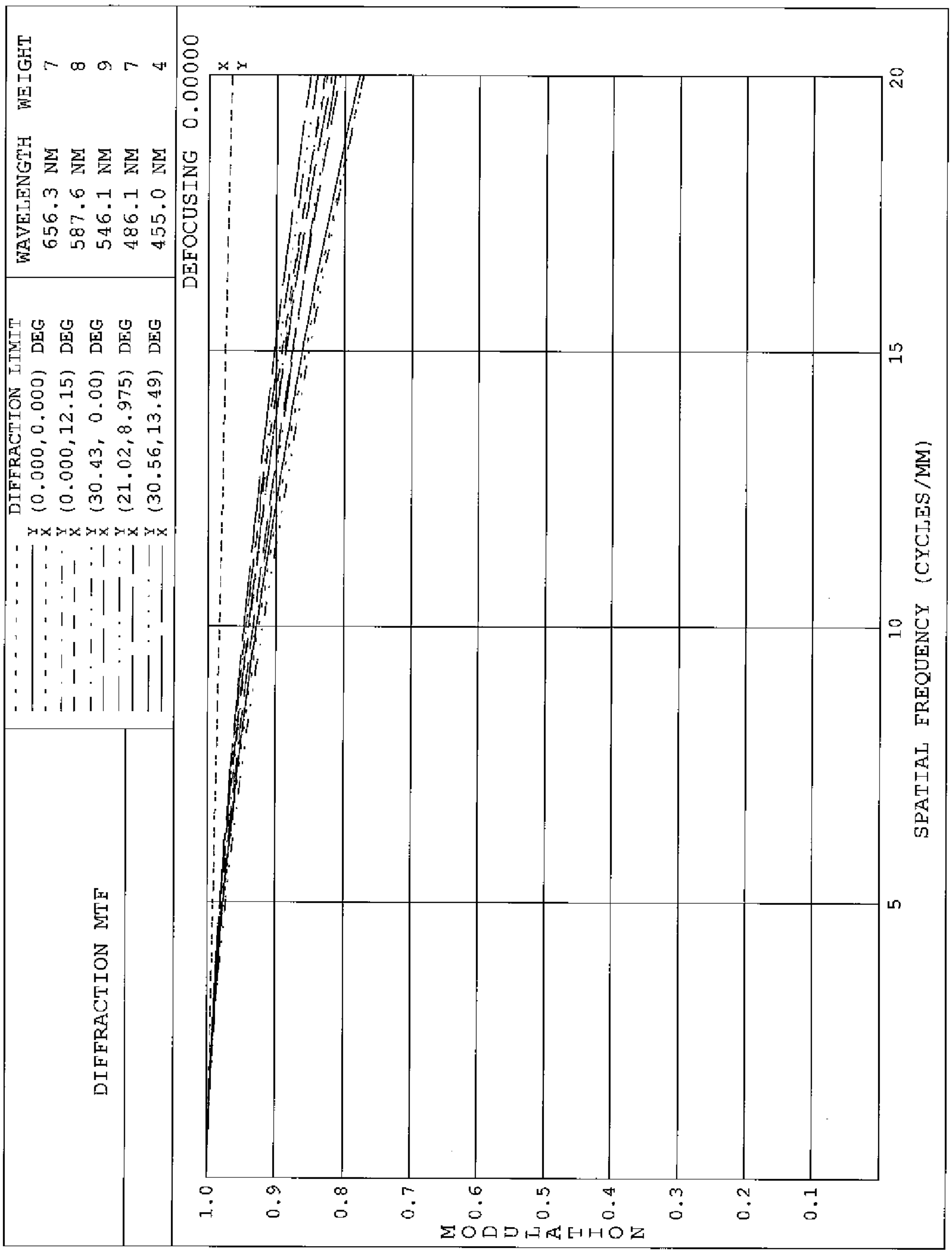
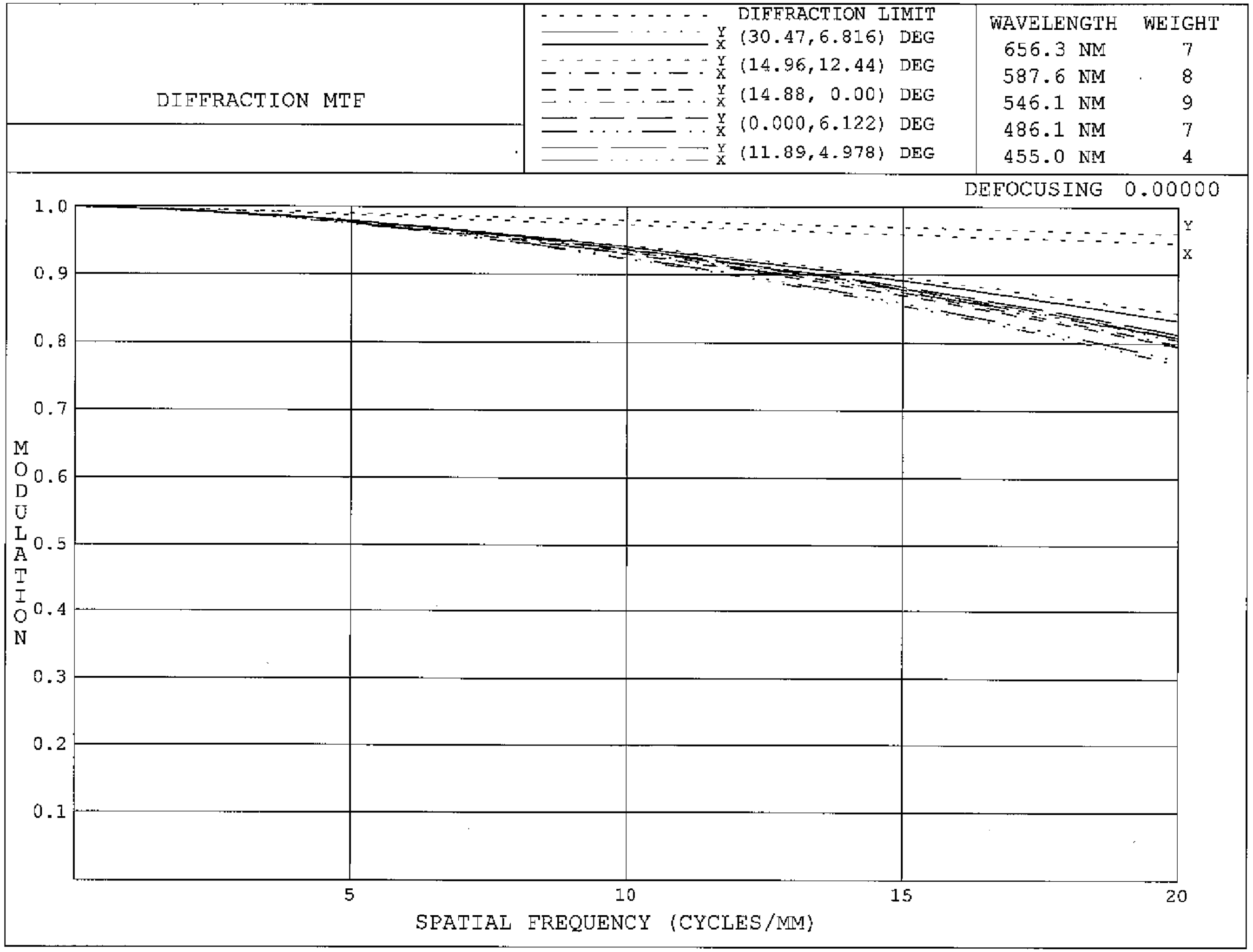

DIFFRACTION MTF
DIFFRACTION LIMIT
X Y (0.000,0.000) DEG
X Y (0.000,12.15) DEG
X Y (30.43, 0.00) DEG
X Y (21.02,8.975) DEG
X Y (30.56,13.49) DEG
WAVELENGTH WEIGHT
656.3 NM 7
587.6 NM 8
546.1 NM 9
486.1 NM 7
455.0 NM 4
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
5
10
15
20
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 12



DIFFRACTION MTF
DIFFRACTION LIMIT
Y X (30.47,6.816) DEG
Y X (14.96,12.44) DEG
Y X (14.88, 0.00) DEG
Y X (0.000,6.122) DEG
Y X (11.89,4.978) DEG
WAVELENGTH WEIGHT
656.3 NM 7
587.6 NM 8
546.1 NM 9
486.1 NM 7
455.0 NM 4
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
Y
X
5
10
15
20
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 13

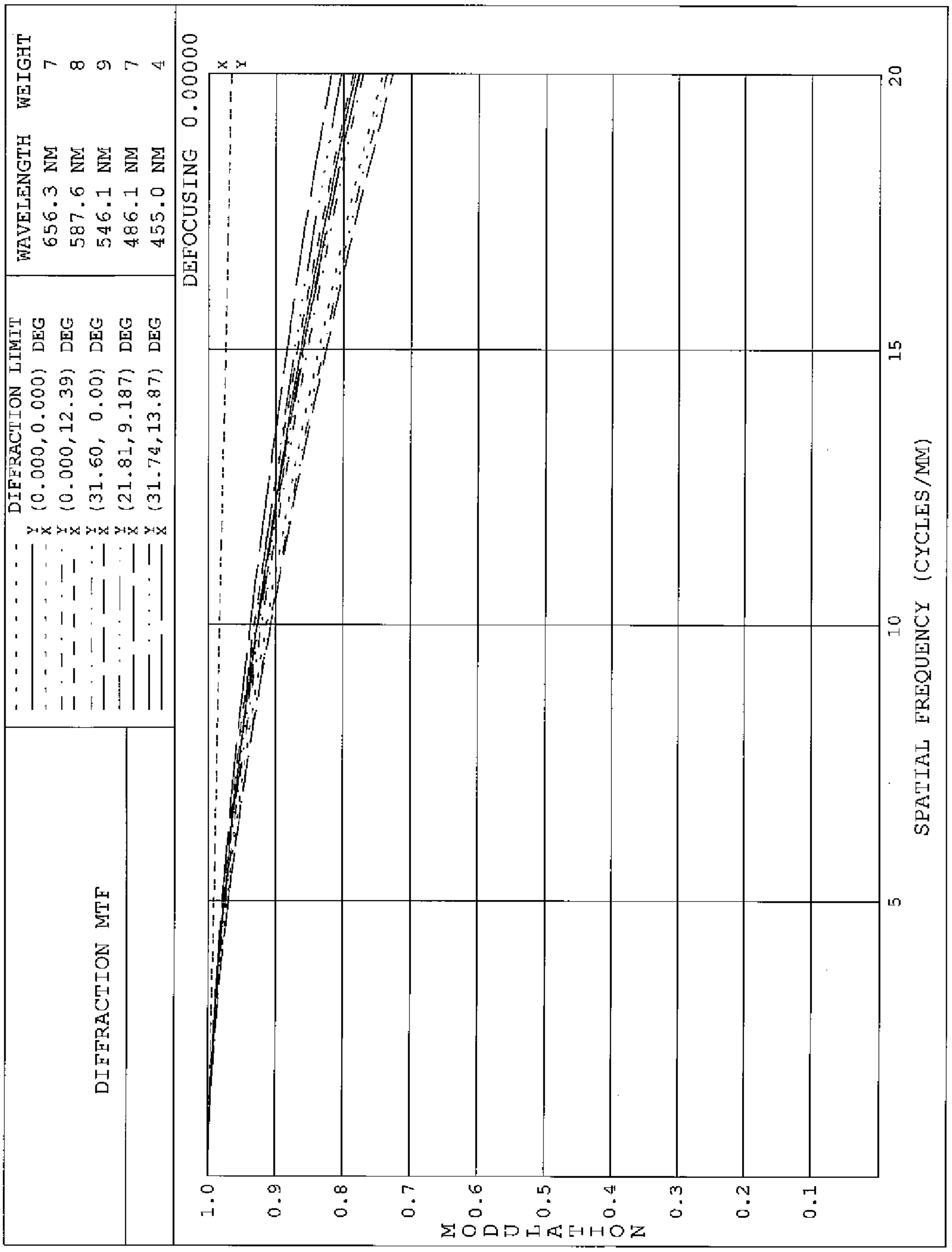

DIFFRACTION MTF
DIFFRACTION LIMIT
(0.000,0.000) DEG
(0.000,12.39) DEG
(31.60, 0.00) DEG
(21.81,9.187) DEG
(31.74,13.87) DEG
WAVELENGTH WEIGHT
656.3 NM 7
587.6 NM 8
546.1 NM 9
486.1 NM 7
455.0 NM 4
DEFOCUSING 0.00000
MODULATION
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
5
10
15
20
SPATIAL FREQUENCY (CYCLES/MM)

FIG. 14

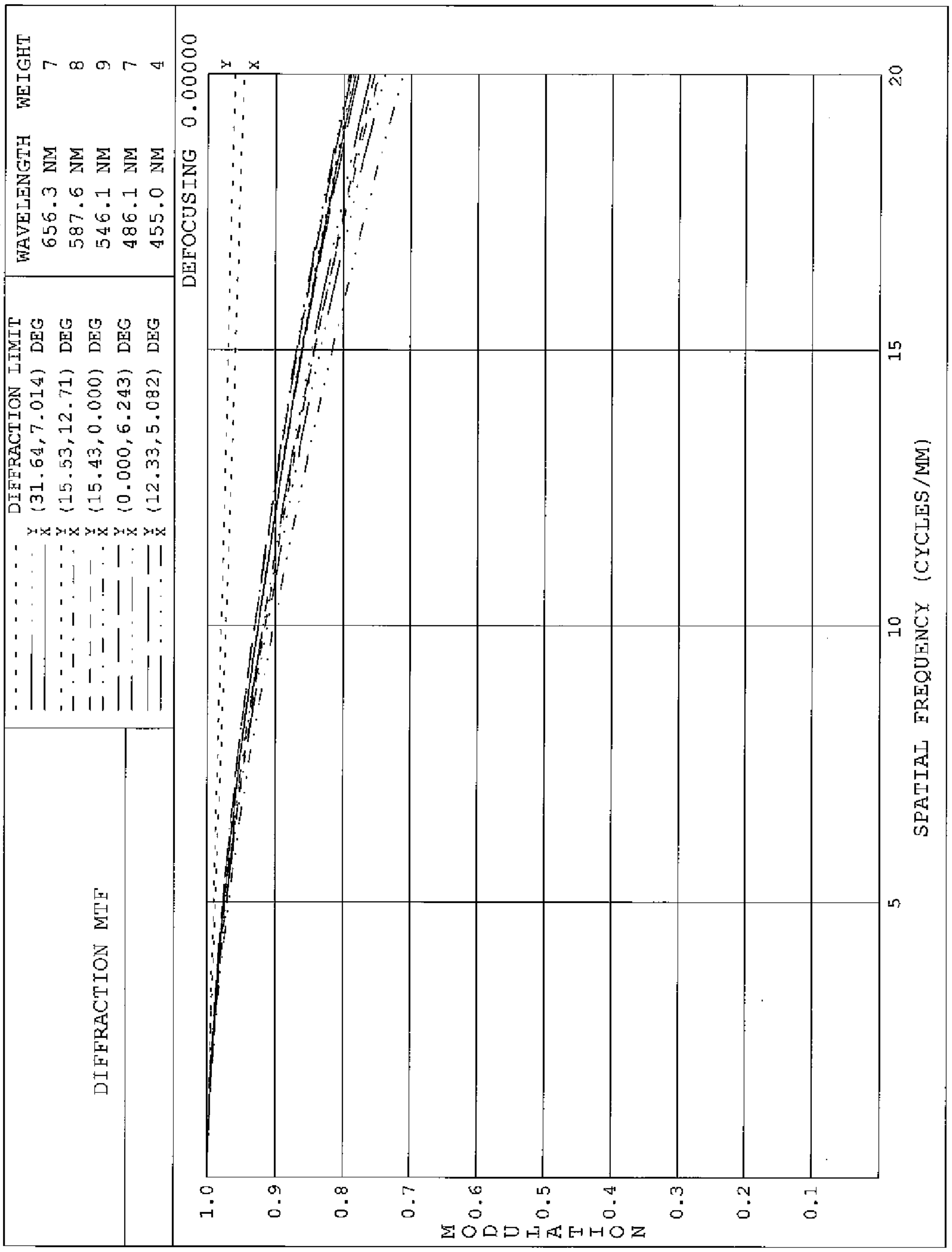

DIFFRACTION MTF
DIFFRACTION LIMIT
(31.64,7.014) DEG
(15.53,12.71) DEG
(15.43,0.000) DEG
(0.000,6.243) DEG
(12.33,5.082) DEG
WAVELENGTH WEIGHT
656.3 NM 7
587.6 NM 8
546.1 NM 9
486.1 NM 7
455.0 NM 4
DEFOCUSING 0.00000
MODULATION
SPATIAL FREQUENCY (CYCLES/MM)
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
5
10
15
20

FIG. 15

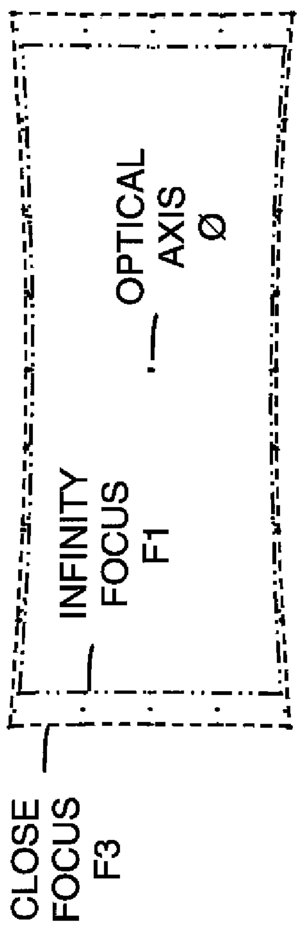


FIG. 16

TABLE 1

Optical Prescription

Item	Group	Surface No.	Surface Shape[1]	Focus Position	Separation (mm)	Y Radius of Curvature (mm)	X Radius of Curvature (mm)	Material Type	Material Code	Material Name[2]	Material Supplier[3]	Aperture[4,5] Half Diameter (mm)
Object Plane		S1	Plano	F1	999999.000	Flat	Flat	Air				
				F2	1588.000							
				F3	740.000							
1	G1	S2	Sph.	All	5.200	126.302	126.302	Glass	713539	S-LAL8	OHARA	44.81
		S3	Sph.	F1	36.814	97.245	97.245	Air				41.68
				F2	26.599							
				F3	16.553							
2	G1	S4	Sph.	All	3.800	353.064	353.064	Glass	734515	S-LAL59	OHARA	33.93
		S5	Sph.	F1	6.883	92.759	92.759	Air				31.40
				F2	17.097							
				F3	27.144							
3	G2	S6	Plano	All	3.500	Flat	Flat	Glass	516641	S-BSL7	OHARA	25.26
		S7	X Cyl.	All	14.839	Flat	42.117	Air				24.37
4	G2	S8	X Cyl.	All	3.450	Flat	-32.150	Glass	497816	S-FPL51	OHARA	22.90
		S9	Plano	All	5.746	Flat	Flat	Air				22.76
5	G2	S10	Y Cyl.	All	27.940	-173.155	Flat	Glass	847238	SF57	SCHOTT	22.59
		S11	Y Cyl.	All	0.630	-162.219	Flat	Air				23.30
6	G2	S12	Plano	All	12.510	Flat	Flat	Glass	678553	S-LAL12	OHARA	23.21
		S13	X Cyl.	All	0.653	Flat	-61.868	Air				22.89
7	G2	S14	Y Cyl.	All	9.576	50.915	Flat	Glass	883408	S-LAH58	OHARA	22.28
		S15	Y Cyl.	All	1.260	46.847	Flat	Air				20.82
8	G3	S16	Sph.	All	7.688	53.607	53.607	Glass	847238	SF57	SCHOTT	20.27
		S17	Sph.	All	2.459	31.937	31.937	Air				17.95
9	G3	S18	Sph.	All	10.712	33.809	33.809	Glass	713539	S-LAL8	OHARA	18.17
		S19	Sph.	All	0.250	-417.944	-417.944	Air				17.14
10	G3	S20	Sph.	All	13.716	34.017	34.017	Glass	805255	ZF7LHT	CDGM	15.42
		S21	Sph.	All	13.684	26.110	26.110	Air				10.05
Stop		S22	Plano	All	8.868	Flat	Flat	Air				7.51
11	G3	S23	Sph.	All	2.640	-18.475	-18.475	Glass	805255	ZF7LHT	CDGM	6.73
12	G3	S24	Sph.	All	8.997	82.967	82.967	Glass	649530	S-BSM71	OHARA	8.20
		S25	Sph.	All	0.140	-31.527	-31.527	Air				10.85
13	G3	S26	Sph.	All	3.432	-121.596	-121.596	Glass	835427	HZLAF55A	CDGM	11.49
		S27	Sph.	All	0.100	-38.403	-38.403	Air				12.03
14	G3	S28	Sph.	All	3.447	84.972	84.972	Glass	835427	HZLAF55A	CDGM	12.67
		S29	Sph.	All	36.067	-179.044	-179.044	Air				13.20
Image Surface		S30	X & Y Cyl.	F1		-969.559	-1399.906	Air				
			X & Y Cyl.	F2		-932.314	-317.163					
			X & Y Cyl.	F3		-2149.64	-213.21					

Notes:-

1. In the Surface Shape column the image surface is not flat to simulate equivalent curved object surfaces through focus distance positions F1, F2 and F3.
2. In the Material Name column the trade name of the lens material used is given.
3. In the Material Supplier column a manufacturer name is given although there may be alternative manufacturers.
4. The data given in the Aperture Half Diameter column is for circular apertures.
5. The data given in the Aperture Half Diameter column for surface numbers 21, 23 and 29 are vignetting field stop apertures.

TABLE 2

Focal Length, Anamorphic Squeeze and Illumination

Focus Position	Paraxial Effective Focal Length Y Direction (mm)	Paraxial Effective Focal Length X Direction (mm)	Anamorphic Squeeeze Ratio[1]	Relative Illumination[2] (%)
F1	42.47	21.47	1.978	45.1
F2	41.13	20.59	1.998	45.2
F3	39.94	19.81	2.016	45.2

Notes:-

1. Based on paraxial focal length in Y direction divided by paraxial focal length in X direction.
2. At maximum radial image distance from the optical axis which is at the corner of the image.

ANAMORPHIC OBJECTIVE LENS

FIELD OF THE INVENTION

[0001] The present invention relates to anamorphic objective lenses, and more particularly to anamorphic objective lenses for cinema cameras.

BACKGROUND OF THE INVENTION

[0002] Contemporary anamorphic objective lenses (which are compound lenses commonly referred to as anamorphic “objective lenses”) normally have an optical axis and are commonly based on a front anamorphic lens group having cylindrical refractive surfaces that are aligned (e.g. X cylinder refractive optical surfaces) and a rear spherical lens group with an optical stop that is either in the rear spherical lens group or between the rear spherical lens group and the front anamorphic lens group that may be in the form of a variable aperture diameter iris or diaphragm.

[0003] This anamorphic objective lens arrangement produces images having numerous residual optical aberrations and characteristics, some of which are desired by cinematographers because they produce an artistic look that is different from spherical objective lenses.

[0004] Many of the less desired residual optical aberrations and characteristics of this arrangement were accepted by cinematographers with film based cameras but, with the advent and adoption of electronic sensor based digital cameras, some of them have become less acceptable. In particular the amount of residual chromatic aberration has become less tolerable, whereas some field curvature combined with some residual astigmatism is still acceptable.

[0005] Specific anamorphic objective lens characteristics of this arrangement such as the oval or elliptically shaped of out of focus objects, commonly referred to as the “bokeh” (as compared to the circular bokeh shape produce by spherical objective lenses, e.g. non-anamorphic objective lenses) is preferred because of the distinctive artistic look produced. Another characteristic that is desired, because of the distinctive artistic look produced, is the depth of field being different in the vertical azimuth direction of the field versus the horizontal azimuth direction of the field. In the case of an anamorphic objective lens that squeezes the horizontal field of view by substantially two times as compared to the vertical field of view, the depth of field in the horizontal azimuth direction of the field is substantially two times greater than the depth of field in the vertical azimuth direction of the field.

[0006] Improving the optical aberrations and characteristics of anamorphic objective lenses of this arrangement may involve increasing optical surface shape complexity and hence manufacturing cost including adding aspherical surfaces (i.e. having continuous rotational symmetry about the optical axis, also known as circular symmetry) and free-form shaped optical surfaces (e.g. having two-fold mirror symmetry).

[0007] Thus, to address the artistic need of cinematographers and maximize the imaging potential of both film and digital cameras a cost effective anamorphic objective lens arrangement with a suitable blend of residual optical aberration correction and characteristics needs to be achieved.

SUMMARY OF THE INVENTION

[0008] According to an aspect of the invention, there is provided an anamorphic objective lens comprising along an optical axis and in order from an object space to an image space: a first spherical lens group; an anamorphic lens group; and a second spherical lens group, wherein the objective lens further comprises an optical stop located along the optical axis in a position selected from the group consisting of the following locations: between the anamorphic lens group and the second spherical lens group; within the second spherical lens group; and on the opposite side of the second spherical lens group from the anamorphic lens group.

[0009] The anamorphic lens group may have at least one cylindrical surface orientated in a first direction and at least one cylindrical surface orientated in a direction substantially perpendicular to the first direction (where the orientation of a cylindrical surface is defined such that a cylindrical surface orientated in the X direction curves in the XZ plane and is planar in the YZ plane, and a cylindrical surface orientated in the Y direction curves in the YZ plane and is planar in the XZ plane). The anamorphic lens group may have at least one cylindrical surface in a first direction and at least a second cylindrical surface in a substantially perpendicular direction to the first direction to enable a high degree of aberration correction over the whole image, whereby the residual longitudinal chromatic aberration and the residual lateral chromatic aberration are substantially reduced.

[0010] The anamorphic lens group may comprise at least a first cylindrical surface that is orientated in a first direction and is located between second and third cylindrical surfaces orientated in a direction substantially perpendicular to the first direction. The cylindrical surfaces may be consecutive surfaces or maybe separated by other non-cylindrical surfaces. The cylindrical surfaces may be on different lens elements of the anamorphic group, or two of the cylindrical surfaces may be provided on the same lens element.

[0011] The first spherical lens group may be a negatively powered (-) spherical lens group. The provision of the negatively powered spherical lens on the object side of the anamorphic lens group enables the anamorphic lens group to be designed to provide enhanced optical performance.

[0012] The second spherical lens group may be a positively powered (+) spherical lens group. The positively powered spherical lens focuses the image to the image surface. The provision of the positively powered spherical lens on the image side of the anamorphic lens group enables the anamorphic lens group to be designed to provide enhanced optical performance.

[0013] The optical stop may be located within the second spherical lens group.

[0014] The first spherical lens group may be configured to provide focusing. The provision of focusing by the first spherical lens group, on the object side of the anamorphic lens group, enables the use of an anamorphic group that provide enhanced optical performance.

[0015] The first spherical lens group may comprise two lens elements, one of which is axially moveable relative to the other. The negatively powered first spherical lens group may provide focusing by movement of at least one of the lens elements contained therein and so the anamorphic objective lens may exhibit low breathing in the focus range.

[0016] The anamorphic group may comprise lens elements only having surfaces selected from the group consisting of: spherical, cylindrical and plano (e.g. planar) surfaces.

[0017] The anamorphic objective lens may have an image surface, and be configured to transmit radiation from the second spherical lens group to a sensor at the image surface, in which the radiation is angled to the optical axis by less than 10 degrees. The second spherical lens group, adjacent the image space, delivers the radiation passing through the optical system on to the image sensor with nearly telecentric light paths and suitably high relative illumination, thereby increasing the efficiency of many electronic sensors.

[0018] The anamorphic lens group may have focal lengths in the X and Y directions which differ by a ratio of substantially two. The anamorphic lens group may provide a squeeze of the field of view so that the focal lengths in the X and Y directions are different by a ratio of about two times, which is common for traditional anamorphic optical systems.

[0019] The anamorphic objective lens may have a focal length within the range of from 25mm to 135mm.

[0020] The anamorphic objective lens may be configured to provide an image of out of focus objects close to the optical axis with an elliptical bokeh shape.

[0021] The anamorphic objective lens may provide different depths of field in the vertical and horizontal azimuth directions of the field of view.

[0022] The optical stop may have a full aperture of f/2.0 to f/2.8.

[0023] The lens groups may be fabricated of lens elements made of glass.

[0024] The first and second spherical lens groups may consist of lens elements with surface shapes that are continuously rotationally symmetrical about the optical axis.

[0025] The first and second spherical lens groups may consist of lens elements with surface shapes selected from the group consisting of spherical and plano surfaces.

[0026] The anamorphic lens group may comprise a lens element with a surface shape that is not continuously rotationally symmetrical about the optical axis (i.e. is not circularly symmetric).

[0027] The anamorphic objective lens may be configured to operate over a waveband of 455-656nm.

[0028] The anamorphic lens group may comprise five cylindrically surfaced lens elements with the following lens surface shapes: four Y cylindrical surfaces, three X cylindrical surfaces and three plano surfaces.

[0029] The first spherical lens group may comprise two lens elements, one of which is axially moveable relative to the other.

[0030] The second spherical lens group may comprise seven lens elements.

[0031] At least one field stop may be located on the object space side of the optical stop.

[0032] At least one field stop may be located on the image side of the optical stop.

BRIEF DESCRIPTION OF THE DRAWINGS

[0033] Embodiments of the anamorphic objective lens of the invention are further described hereinafter with reference to the accompanying drawings, in which:

[0034] FIG. 1 shows three lens plots in the YZ elevation (side view) on an optical axis Ø where the Y direction focal length is 42.47mm with three fields shown at zero, top and bottom of the field of view, and the top to bottom diagrams showing far, intermediate and close focus distance arrangements.

[0035] FIG. 2 shows three lens plots in the XZ elevation (plan view) on an optical axis Ø, corresponding with the respective lens plots in Figure 1, where the X direction focal length is 21.47mm with three fields shown at zero, top and bottom of the field of view, and the top to bottom diagrams showing far, intermediate and close focus distance arrangements.

[0036] FIG. 3 is an image plot for the image points used in the transverse ray aberration (TRA) and diffraction based modulation transfer function (MTF) plots in Figures 4-15.

[0037] FIG. 4-9 are transverse ray aberration (TRA) plots at far, intermediate and close focus distances with five fields shown in each Figure and 10 fields spread across the image for each focus distance.

[0038] FIG. 10-15 are diffraction based modulation transfer function (MTF) plots at far, intermediate and close focus distances with five fields shown in each Figure and 10 fields spread across the image for each focus distance.

[0039] FIG. 16 is a field plot of the field of view covered at far, intermediate and close focus distances.

[0040] The information shown in Figures 1-16 was generated by CodeV® optical design software, which is commercially available from Synopsis Optical Research Associates, Inc., Pasadena, California, USA.

DETAILED DESCRIPTION OF THE INVENTION

[0041] The invention relates to anamorphic objective lenses, and in particular to a range of different focal length anamorphic objective lenses covering at least a focal length range from 25mm to 135mm and providing low residual chromatic aberration, a traditional oval bokeh shape and different depths of field in the vertical and horizontal azimuth directions of the field.

[0042] The term “lens group” as used in connection with the anamorphic objective lens disclosed herein means one or more individual lens elements.

[0043] An “optical stop” S22 (also known as an “aperture stop”) is the opening that determines the cone angle of a bundle of rays that come to a focus, on the optical axis Ø, in the image surface S30. A “field stop”, as the term is used herein, is a stop (i.e. opening) provided in a location along the optical axis Ø to vignette (i.e. trim) the rim rays (also known as meridional rays, which are typically the rays in the upper and lower, left and right extremities of each beam converging at locations on the image surface) of the radiation beams received at the image surface.

[0044] The terms “negative power” and “positive power”, in describing a lens group, respectively refer to lens groups (each of one or more lens elements) that have an overall divergent or convergent focusing effect, i.e. they would respectively spread a collimated axial beam away from the optical axis Ø or focus a collimated axial field beam to the optical axis. However, it will be appreciated that in the case of a lens group comprising more than one lens element (i.e. a compound lens), some of the lens elements may have an optical power that is opposite to the collective power of the respective lens group.

[0045] The term "spherical", in describing a lens group, refers to a group of lens elements in which the optical surface shapes of the lens elements all have circular symmetry (i.e. are continuously rotationally symmetrical) about the optical axis Ø, e.g. a spherical or plano surface. In contrast, in the "anamorphic lens group", at least one lens element surface has a shape that does not have circular symmetry (i.e. is not continuously rotationally symmetrical) about the optical axis Ø, for example having at least one cylindrical surface.

[0046] In the example of an anamorphic objective lens 50 provided herein, the front lens group G1 is negatively powered and the rear lens group G3 is positively powered, and they have been paired with an anamorphic lens group G2 to work in unison and match the preferred optical interface characteristics of sensors at the image surface S30, where near telecentric radiation beams approach the sensor.

[0047] The example embodiment discussed below is a medium fast full aperture anamorphic objective lens (i.e. the optical stop has a full aperture of f/2.0 to f/2.8) having a field of view of approximately 56° horizontally (conventionally the direction of the wider field of view is referred to as being the horizontal direction) and 62° diagonally (i.e. it is a moderately wide angle field of view, being broader than a "normal lens" that has an angle of view of about 45° diagonally, similar to that of the human eye, and narrower than a conventional wide angle lens), which is of the fixed focal length (prime) type.

[0048] In the example embodiment, all of the lens elements are made from glasses, and further details are provided in Table 1.

[0049] In the aforementioned optical example, the anamorphic objective lens provides low breathing and near telecentric radiation output at the sensor, as well as enhanced image quality resolution and contrast, high relative illumination for low shading and efficient optical throughput at the sensor. In particular, the anamorphic objective lens is configured to transmit near telecentric radiation from the positively powered spherical lens group (i.e. second spherical lens group) to the image sensor at the image surface, having an angle to the optical axis of less than about 10 degrees. The near telecentric radiation provides enhanced efficiency of light collection in the case of a digital image sensor having a surface provided with micro-lenses, which have an efficiency that is beam angle dependent and conventionally optimized for radiation received perpendicular to the sensor.

[0050] The novel configuration of having a negatively powered spherical lens group G1 and an anamorphic lens group G2 that is followed by a positively powered spherical lens group G3, with an optical stop S22 within or directly to one side of the positively powered spherical lens group (i.e. between the anamorphic lens group and the positively powered spherical lens group or on the opposite side from the anamorphic lens group) provides good overall optical performance at a moderate manufacturing cost. The anamorphic objective lens may still produce some residual distortion, astigmatism and field curvature aberrations, but those aberrations, to a tolerable extent, contribute to the anamorphic look as desired by many cinematographers. In particular, the anamorphic objective lens of the invention provides the optical characteristic of an elliptical bokeh (elliptically shaped of out of focus objects) in the image formed at the image surface. Further, the anamorphic objective lens provides reduced residual chromatic aberration. The design enables the use of lens elements in the anamorphic lens group G2 that are small in diameter, relative to the lens elements of the negatively powered spherical lens group G1, which particularly reduces the cost of the components and assembly during manufacturing. The provision of focusing by the first spherical lens group G1, on the object side of the anamorphic lens group G2, enables the anamorphic lens group to be designed to provide enhanced optical performance. The provision of the positively powered spherical lens group G3 on the image side of the anamorphic lens group G2 enables the anamorphic lens group to be designed to provide enhanced optical performance. In addition, a balanced blend of the afore-described lens characteristics may aid in cost reduction of manufacture. With the advent and adoption of digital cameras employing electronic sensors a large back focal length which was once required for film cameras having a reflex mirror may be less necessary but is still provided for in the novel anamorphic objective lens.

[0051] The example embodiment disclosed operates with an optical stop set at an aperture of f/2.4 and over a waveband of 455-656nm and this waveband is what was used in the Transverse Ray Aberration (TRA) plots in Figures 4-9 and in the diffraction based modulation transfer function (MTF) plots in Figures 10-15 (as indicated in their respective keys). A faster or slower aperture may be required and an extended waveband may be required. The aperture may be increased or reduced and the waveband expanded or contracted and the optical designs re-optimized to maximize image quality over such apertures and wavebands without departing from the invention. Also, during such re-optimization alternate glass types (i.e. alternate to those listed in

Table 1) may be used without departing from the spirit and scope of the disclosure. Furthermore, more complex optical surface shapes such as aspherical and free-form surfaces may be provided on the surface of one or more lens elements of the anamorphic objective lens for expanded performance, but at the likely effect of increased manufacturing cost.

[0052] Figures 1 – 16 relate to an example embodiment in which the focal length in the Y and X directions are 42.47mm and 21.47mm, the overall length is 245mm from the first refractive surface vertex of the anamorphic objective lens facing object space (i.e. the intersection of the optical axis Ø with surface S2) to the image vertex (i.e. the intersection of the optical axis Ø with the image surface, surface S30), the front diameter clear aperture (i.e. the beam width at surface S2) is 89.61mm, the back focal length from the rear refractive surface vertex (i.e. the intersection of the optical axis Ø with surface S29) to the image vertex is 36.07mm, and the close focus distance from the object to the image is 985.00mm. The focal lengths of the lens groups are: -130.62mm, -132.23mm and 133.86mm for the far, intermediate and close focus distances of the negatively powered spherical lens group G1; 1032.81mm in the Y direction and -140.60mm in the X direction of the anamorphic lens group G2; and, 66.75mm for the positively powered spherical lens group G3.

[0053] The lens elements 3-7 of the anamorphic lens group G2 each have at least one cylindrical surface. As least one of the lens elements 3-7 has a cylindrical surface orientated in a direction that is substantially perpendicular (i.e. “crossed”) to the orientation of the cylindrical surface of another lens element (e.g. a lens element has a cylindrical surface orientated in the X direction and another has a cylindrical surface orientated in the Y direction). Further, the lens elements 3-7 of the anamorphic group are preferably arranged in an intermixed arrangement such that at least one lens element having a cylindrical surface orientated in a first direction is located between lens elements having a cylindrical surface orientated in a second, substantially perpendicular direction. In the illustrated embodiment, the anamorphic group G2 has five lens elements 3-7, and in order from an object space to an image space, the lens elements have focal lengths of: -81.27mm (in X direction), -64.50mm (in X direction), 1379.50mm (in Y direction), 90.87mm (in X direction) and 6151.28mm (in Y direction). It is to be understood that the focal lengths of the five anamorphic lens elements in the complementary respective X and Y directions are substantially large and hence have little optical power. The nominal image size is 8.91mm vertical half height and 10.65mm horizontal half width.

[0054] In the illustrated embodiment the lens elements of the anamorphic lens group each have one cylindrical and one circularly symmetric surface (e.g. a plano surface) or two cylindrical surfaces that are aligned in the same direction (e.g. lens element 7). However, alternatively, one or more lens elements of the anamorphic lens group may each have two cylindrical refractive surfaces orientated in substantially perpendicular directions, for example being formed by X and Y cylindrical surfaces or Y and X cylindrical surfaces. In this case, the intermixed arrangement may be formed by providing an arrangement of lens elements in which at least a first cylindrical surface orientated in a first direction is located between second and third cylindrical surfaces orientated in a direction substantially perpendicular to the first direction (i.e. crossed cylindrical surfaces may be provided on a single lens element). An arrangement with crossed cylindrical surfaces on a single lens element may improve the imaging characteristics but likely at the effect of additional manufacturing cost.

[0055] The use of cylindrical surfaces arranged in substantially perpendicular directions improves imaging performance (in particular enabling the provision of a better balance of aberrations) than for an anamorphic lens group with only cylindrical surfaces aligned in a single direction. Further, the intermixed arrangement of differently orientated cylindrical surfaces (whether on different lens elements, as in the illustrated embodiment, or having crossed cylindrical surfaces on one or more single elements) provides more degrees of freedom in designing the anamorphic lens group, enabling an enhanced balance of lower residual aberrations over the whole of the field of view of the anamorphic objective lens.

[0056] The lens system of the anamorphic objective lens 50 comprises a total of fourteen lens elements with twelve singlets and one doublet. The negatively powered spherical lens group G1 contains two lens elements with one element (lens element 2) axially movable for focusing at different distances in object space. The anamorphic group G2 contains five cylindrically surfaced lens elements with four Y cylinders, three X cylinders and 3 plano surface shapes. The positively powered spherical lens group G3 contains seven lens elements. The optical stop S22 lies within the positively powered spherical lens group G3. In this example embodiment the near telecentric radiation output has an angle to the optical axis Ø of about 7.8 degrees at the focus positions illustrated in each of Figures 1 and 2 at the peripheries of the image.

[0057] Optical prescription Table 1 is set forth below in the Appendix and describes a select example of the embodiment of the anamorphic objective lens disclosed herein.

[0058] Table 2 contains focal length, anamorphic squeeze and illumination data. In Table 2, it is shown that the relative illumination is above 40%, which is sufficiently high for low shading across the field of view when an anamorphic objective lens is used in combination with an electronic sensor at the image surface, such as when the anamorphic objective lens constitutes part of a digital camera. In contrast, conventional anamorphic lenses may have a relative illumination that decreases at the corners to less than 25%. The enhanced relative illumination of the anamorphic objective lens of the present invention is possible due to the optimization of the anamorphic lens group, that is enabled by the use of the first and second spherical lens groups, arranged on either side of the anamorphic group.

[0059] In Figures 4-9, the transverse ray aberration (TRA) performance for the example embodiment is shown with minimized residual astigmatic, longitudinal and lateral chromatic aberrations on curved image surfaces to approximately emulate curved object surfaces. Figures 4 and 5 show transverse ray aberration plots at a far focus distance, Figures 6 and 7 show transverse ray aberration plots at an intermediate focus distance, and Figures 8 and 9 show transverse ray aberration plots at a close focus distance.

[0060] In Figures 10-15, the polychromatic diffraction based modulation transfer function (MTF) performance at a spatial frequency of 20 cycles/mm is shown for the example embodiment to be greater than 70% at all field positions at the far and close focus distances, and greater than 75% for all axial field positions at an intermediate focus distance. Figures 10 and 11 show MTF at a far focus distance, Figures 12 and 13 show MTF at an intermediate focus distance, and Figures 14 and 15 show MTF at a close focus distance.

[0061] In Figure 16, the periphery of the field of view at far, intermediate and close focus distances is shown on a plane in object space located at substantially 3.66m from the image surface. The variation in the field of view size is mainly dependent on variations through focus in the anamorphic squeeze ratio, distortion in X and Y directions, and focus breathing caused by change in the X and Y focal lengths.

[0062] In addition to the optical stop S22 indicated in Table 1 and Figures 1 and 2 of the exemplary embodiment, field stops may also be provided. The field stops may be located anywhere within the lens system of the anamorphic objective lens 50. Their purpose is to vignette the radiation and they may be circular, elliptical, oval, rectangular, or even rectangular with radius corners. In particular, the field stops may particularly improve image quality by vignetting off-axis radiation away from the optical stop, thereby removing unnecessary radiation that could cause increased residual aberrations. Although not separately indicated in Figures 1 and 2, field stops are provided on surfaces 21, 23 and 29, of the illustrated embodiment, as referenced in Table 1.

[0063] Although the present invention has been fully described in connection with an embodiment thereof with reference to the accompanying drawings and data listing, it is to be noted that various changes and modifications including smaller and larger focal lengths, smaller and larger anamorphic squeeze ratios, smaller and larger full aperture f/numbers, smaller and larger image sizes, smaller and larger wavebands, etc. (e.g., 435 nm to 656 nm) may be made, as will be apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the present invention as defined by the appended claims.

CLAIMS

1. An anamorphic objective lens comprising along an optical axis and in order from an object space to an image space:

a first spherical lens group;

an anamorphic lens group; and

a second spherical lens group,

wherein the objective lens further comprises an optical stop located along the optical axis in a position selected from the group consisting of the following locations:

between the anamorphic lens group and the second spherical lens group;

within the second spherical lens group; and

on the opposite side of the second spherical lens group from the anamorphic lens group.

2. The anamorphic objective lens of claim 1 wherein the anamorphic lens group has at least one cylindrical surface orientated in a first direction and at least one cylindrical surface orientated in a direction substantially perpendicular to the first direction.

3. The anamorphic objective lens of claim 2 wherein the anamorphic lens group comprises at least a first cylindrical surface that is orientated in a first direction and is located between second and third cylindrical surfaces orientated in a direction substantially perpendicular to the first direction.

4. The anamorphic objective lens of any one of claims 1, 2 or 3, wherein the first spherical lens group is a negatively powered (-) spherical lens group.

5. The anamorphic objective lens of any preceding claim, wherein the second spherical lens group is a positively powered (+) spherical lens group.

6. The anamorphic objective lens of any preceding claim, wherein the optical stop is located within the second spherical lens group.

7. The anamorphic objective lens of any preceding claim, wherein the first spherical lens group is configured to provide focusing.

8. The anamorphic objective lens of any preceding claim wherein the first spherical lens group comprises two lens elements, one of which is axially moveable relative to the other.

9. The anamorphic objective lens of any preceding claim, wherein the anamorphic group comprises lens elements only having surfaces selected from the group consisting of: spherical, cylindrical and plano surfaces.

10. The anamorphic objective lens of any preceding claim having an image surface, and configured to transmit radiation from the second spherical lens group to a sensor at the image surface, in which the radiation is angled to the optical axis by less than 10 degrees .

11. The anamorphic objective lens of any preceding claim wherein the anamorphic lens group has focal lengths in the X and Y directions which differ by a ratio of substantially two.

12. The anamorphic objective lens of any preceding claim having a focal length within the range of from 25mm to 135mm.

13. The anamorphic objective lens of any preceding claim configured to provide an image of out of focus objects close to the optical axis with an elliptical bokeh shape.

14. The anamorphic objective lens of any preceding claim providing different depths of field in the vertical and horizontal azimuth directions of the field of view.

15. The anamorphic objective lens of any preceding claim wherein the optical stop has a full aperture of f/2.0 to f/2.8.

16. The anamorphic objective lens of any preceding claim wherein the lens groups are fabricated of lens elements made of glass.

17. The anamorphic objective lens of any preceding claim wherein the first and second spherical lens groups consist of lens elements with surface shapes that are continuously rotationally symmetrical about the optical axis.

18. The anamorphic objective lens of claim 17, wherein the first and second spherical lens groups consist of lens elements with surface shapes selected from the group consisting of spherical and plano surfaces.

19. The anamorphic objective lens of any preceding claim wherein the anamorphic lens group comprises a lens element with a surface shape that is not continuously rotationally symmetrical about the optical axis.

20. The anamorphic objective lens of any preceding claim which is configured to operate over a waveband of 455-656nm.

21. The anamorphic objective lens of any preceding claim wherein the anamorphic lens group comprises five cylindrically surfaced lens elements with the following lens surface shapes: four Y cylindrical surfaces, three X cylindrical surfaces and three plano surfaces.

22. The anamorphic objective lens of any preceding claim wherein the second spherical lens group comprises seven lens elements.

23. The anamorphic objective lens of any preceding claim wherein at least one field stop is located on the object space side of the optical stop.

24. The anamorphic objective lens of any preceding claim wherein at least one field stop is located on the image side of the optical stop.

Intellectual Property Office

Application No:	GB1405804.4	**Examiner:**	Mr Conal Clynch
Claims searched:	1-24	**Date of search:**	2 September 2014

Patents Act 1977: Search Report under Section 17

Documents considered to be relevant:

Category	Relevant to claims	Identity of document and passage or figure of particular relevance
X	1 & 4-5 at least	US2013/022345 A1 (DODOC AURELIAN) see the figures and paragraphs 70-77 especially
A	_	EP1566681 A1 (CANON KK)
A,E	_	US2014/016210 A1 (VALLES NAVARRO ALFREDO)
A	_	US2013/010370 A (SEIKO EPSON CORP)

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G02B

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Online: Epodoc, TXTE, WPI

International Classification:

Subclass	Subgroup	Valid From
G02B	0013/08	01/01/2006